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AN EMSIAN-EIFELIAN CALCITURBIDITE SEQUENCE AND THE POSSIBLE CORRELATABLE PATTERN OF THE BASAL CHOTEČ EVENT IN WESTERN OSSA-MORENA ZONE, PORTUGAL (ODIVELAS LIMESTONE)

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(3 figures, 3 plates, 1 table)

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ABSTRACT. An Emsian-Eifelian carbonate-volcaniclastic sequence in south-western Ossa-Morena Zone (Portugal) was studied in terms of reef fauna, conodont biostratigraphy, macro- and micro-facies and magnetic susceptibility stratigraphy. The results point to a bracketing between the *Po. patulus* and *T. australis* conodont biozones (uppermost Emsian – middle-late Eifelian). The field data, facies analysis and reef fauna indicate that the sequence is composed entirely of calciturbidite and debris-flow deposits (intercalated with hemipelagic tuffites) related to a (up-slope) reefal system resting on top of volcanic buildings within a large volcanic complex. The purity of the limestones does not seem to be generally influenced by volcanic contributions. Although with some uncertainties, the first part of the section seems to show pre-, syn- and post-Basal Choteč Event (BCE) beds as recorded by significant shifts in lithofacies and magnetic susceptibility signal. A tentative interregional correlation with magnetic susceptibility curves is suggested with sections in Morocco, Nevada (USA) and Uzbekistan.

KEYWORDS: Stratigraphy, sedimentology, magnetic susceptibility, Emsian-Eifelian boundary, Basal Choteč Event, Odivelas Limestone, SW Ossa-Morena Zone.

1. Introduction

The Ossa-Morena Zone (OMZ) is one of the geotectonic units of the southern sector of the Iberian Massif (Lötze, 1945; Julivert & Martínez, 1983, see Fig. 1A). The OMZ is composed by several domains or units which have complex tectonic settings (Fig. 1A). These domains were defined according to their stratigraphic, metamorphic and magmatic characteristics, but the division present here (Fig. 1A) is not consensual (e.g. Oliveira et al., 1991; Robardet & Gutiérrez-Marco, 1990, 2004). The south-western border of the OMZ is associated with a remnant ophiolitic complex (Beja-Acebuches Ophiolitic Complex (BAOC), Fonseca & Ribeiro, 1993; Fonseca et al., 1999; Figueiras et al. 2002; Mateus et al., 1999; Ribeiro et al., 2007; 2009) and a highly deformed exotic terrane of oceanic nature ("Pulo do Lobo" Accretionary Terrane (PLAT)). The BAOC and PLAT accreted to the OMZ before the Middle/Upper Devonian times (Fonseca & Ribeiro, 1993; Fonseca et al., 1999; Ribeiro et al., 2009). The BAOC separates the OMZ and the South-Portuguese Zone (SPZ). Within the westernmost domain of the OMZ (Beja-Aracena Massif, Fig. 1A) vast areas, especially to the West, are covered by suites of volcanic and plutonic, mafic to felsic igneous rocks. The ages of these rocks are highly variable, ranging at least from the Emsian to the Pennsylvanian (see Jesus et al., 2003, 2007 and Mateus et al., 2001 for the discussion of the ages and magmatic evolution of the area). This group of igneous rocks constitutes the Beja Igneous Massif (BIC). Palaeozoic sedimentary rocks are scarce within the BIC.

Lower and Middle Devonian sediments are known from other domains of the Ossa-Morena Zone, but their intercorrelation is difficult to establish due to the strong deformation (and frequently metamorphism) in most areas. Consequently the regional palaeogeography is essentially unknown. Middle Devonian sedimentary rocks have long been considered to be generally absent in the OMZ probably due to a generalized uplift of the area during this time period (e.g. Robardet & Gutiérrez-Marco, 1990, 2004; Oliveira et al. 1991).

In a recent paper Machado et al. (2009) re-analysed a Late Eifelian-Early Givetian reef system within the mafic

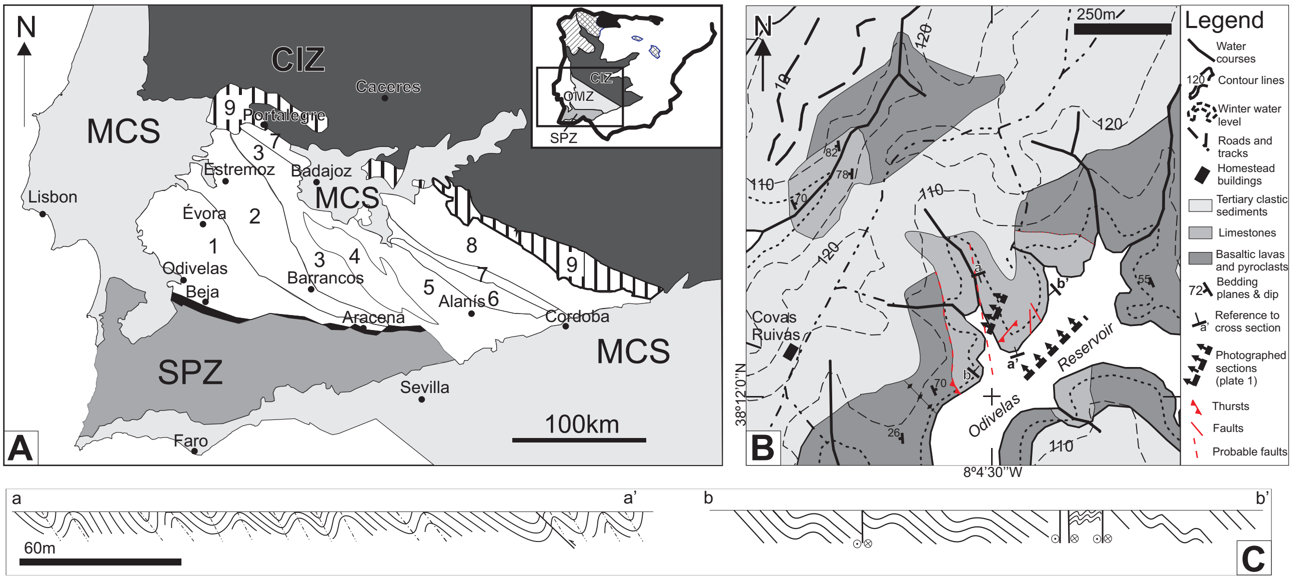

Figure 1. A - Geological sketch of southern Iberian Peninsula (adapted from Robardet & Gutiérrez-Marco, 2004); CIZ: Central Iberian Zone (9 - Los Pedroches batolith and other granitoids); SPZ: South Portuguese Zone (Beja-Acebuches Ophiolitic complex in black); MCS: Meso-Cenozoic sediments; Ossa-Morena Units or domains (in white): 1 - Beja Aracena Massif; 2 – Barrancos-Hinojales Domain (also referred to as Estremoz-Barrancos unit or domain); 3 – Alter-do-Chão – Elvas Domain; 4 – Olivenza-Monesterio Antiform; 5 – Zafra – Córdoba – Alanís Domain; 6 – Sierra Albarrana Domain; 7 – Córdoba – Badajoz shear zone (milonitic zone); 8 – Obejo-Valsequillo-Puebla de la Reina Unit; B - local geological map of the Covas Ruivas locality. C – Schematic structural cross-sections from lines aa' and bb' indicated in B.

volcanics of the Beja Igneous Complex (BIC) (Beja-Aracena Massif), western Ossa-Morena Zone (Odivelas Limestone). The association of reef fauna and the facies of the limestones were indicative of a Late Eifelian-Early Givetian age and correlatable with the Rhenish facies of similar age found elsewhere in Europe (Machado et al., 2009). The data collected suggested a close palaeogeographical relation between the limestones and the surrounding volcanics, probably with a volcanic building supporting a bioherm-biostromal system in the shallower areas, surrounded by calciturbidite-type sedimentation on the flanks of the building.

Several other limestone occurrences within the BIC and further N and NW were briefly noted and correlated with the Odivelas Limestone in several papers (van den Boogaard, 1973: Pedreira de Engenharia Eifelian calciturbidites and Andrade et al., 1976; Andrade, 1983: Odivelas reservoir area). Other rare and dispersed limestone occurrences along the contact between the Ossa-Morena and South Portuguese Zones (e.g. Caerinha, Monte da Pena) were reported by Pereira & Oliveira (2006) and Oliveira et al. (2006). These are usually heavily deformed, silicified and frequently contain or are associated with Fe-Cu oxides ores (Relvas, 1987; Oliveira et al., 2006). All of these occurrences have so far remained a mystery in regard to their age. Recent findings of rare and poorly preserved crinoid columnal sections attributable to the *Cupressocrinites* and *Gasterocoma* genera suggest a middle Devonian age for some of these limestone outcrops and are thus tentatively correlatable with the Odivelas Limestone.

The Basal Choteč Event (BCE) is regarded as a global bioevent which corresponds to a transgressive pulse within a series of moderate to strongly manifested fluctuations of sea level closely above the Emsian-Eifelian boundary. In carbonate slope conditions, these environmental changes are often (but not always) manifested by the presence of "blackish" suboxic sediments and reduced carbonate accumulation rate, typically with an overlying series of rapidly accumulated coarse litho- and bioclastic calciturbidites (e.g. Berkyová et al., 2008; Chlupáč & Kukal, 1986). This event was originally defined in the Barrandian area (Chlupáč & Kukal, 1986) and has been reported from many other basins world wide (Berkyová et al., 2008) e.g. in Southern Europe, North Africa, North America (Appalachians), South America and Asia (Siberian Platform, Ural Mountains). In MS-GRS records (Koptikova et al. 2007), the BCE usually corresponds to a zone with low amplitude MS records, whereas the immediately overlying intervals show broadly oscillatory patterns, and the BCE level is typically followed by the shift of Th/U ratio and uranium concentration peak (burial of organic matter, hiatuses). The glaciogenic origin of a sea level fall and subsequent sea level rise around and after the BCE, respectively, was proposed according to oxygen isotope trends (Elrick et al., 2009).

Here we report a reassessment of one of the localities mentioned in Andrade et al. (1976) and Andrade (1983), Covas Ruivas, in the northern banks of the Odivelas reservoir (Ferreira do Alentejo County, Beja district). We present a coupled litho(bio)facies – conodont – magnetic susceptibility stratigraphy analysis and discuss the possible record of the BCE in this section. The correlation of the studied outcrop with magnetic susceptibility and biostratigraphy with other time-equivalent sections around the World is also discussed. The bio- and litho-facies analysis and the data from reef fauna provide important information for the local and regional palaeogeography and also for regional and global palaeobiogeography.

The locality described in this work is particularly relevant for several reasons: the scarcity of Middle Devonian sedimentary rocks in the Ossa-Morena Zone and surrounding geotectonic units; the general poor availability of continuous sections (due to poor exposure and/or to strong deformation) in Southern Iberia and the fact that few of the known localities are properly described. The inter-regional correlation potential of the section adds relevance to its study.

2. Local Geological setting and previous work

The Covas Ruivas site is within the Beja Aracena Massif (Fig. 1A). The limestones are capped by volcanic rocks belonging to the older volcanic rocks of the BIC (Oliveira et al., 1991). Volcanic rocks have a porphyritic texture, with plagioclase phenocrysts, and more rarely, clinopyroxenes changed and transformed to epidote, still with some chlorite and calcite (Santos et al., 1990). A typical mineral paragenesis of low-grade metamorphism (green schists facies), with chlorite + actinolite + epidote (in occurrence order) is observed.

Andrade et al. (1976) grouped these volcanic rocks in the Peroguarda Complex, and named them Rebolado Basalts. This author described the rocks as (meta)basalts that range from pyroclastic to effusive rocks. Santos et al. (1990), states that the Rebolado Basalts (referred as OD-6 unit) consist of basic to intermediate volcanites.

The limestones are bounded by two major faults that connect the volcanic rocks with the limestones. Internally the limestone body presents folding (Figs 1B-1C), which is attributed to regional variscan deformation and so there is some uncertainty on the existence of small repetitions and/or gaps in the section.

The name of the locality – Covas Ruivas – derives from the name given to a local farm house referred in topographic maps of the 1950's and 1960's used in Andrade et al. (1976) and Andrade (1983). The site is composed by extensive and continuous natural outcrops and a several small abandoned quarries (central limestone area in Fig. 1B, Pl. 1). Limestones are over- and underlain by fine tuffites that grade to coarser pyroclastic "true volcanic" deposits and basaltic lava flows. Tertiary deposits cover discordantly the whole area so that outcrops of older rocks are restricted to valleys and low land zones.

The section is divided into 3 parts by observational gaps which can represent a few meters of missing or repeated sequence. The 3 parts are labelled, from base to top, as A, B and C (Fig. 2).

3. Materials and Methods

The Covas Ruivas site was logged and the limestone beds sampled for magnetic susceptibility and conodont analyses. Lithology, fossil content and relevant sedimentary structures are described. Additional samples of the limestones and interbedded tuffites were taken for thin-sectioning, palynology processing and XRD analyses.

3.1 Conodonts

33 limestone samples weighting between 1,5kg and 4kg were collected in regular intervals. Limestones composed of sand-sized particles were preferably chosen, which normally corresponded to the base of beds. Each sample was washed with running water and brush and crushed to pieces of about 4 cm in diameter. Dissolution was done using 10 % acetic acid in ca. 20 L plastic buckets in laboratories in Aveiro University and in Prague (Institute of Geology, Academy of Sciences). The acid was replaced when reaction halted and the < 1 mm undissolved residue separated. The residue was further sieved to discard the < 125 μm fraction. After drying, the residue was observed under a binocular microscope and conodont elements picked into a cell. The dissolution of some samples resulted in a large amount of residue. In these cases heavy liquid and magnetic separation were performed. Selected conodont elements were observed and photographed by SEM CAMECA SX 100 at the Institute of Geology of the Academy of Sciences of the Czech Republic (see Pl. 2).

3.2 Reef fauna

One thick limestone bed between 58 and 61,5 m (Fig. 2; Pl. 3) was particularly rich in macroscopic (up to a few centimetres) bioclasts of corals, stromatoporoids and crinoids. Weathered surfaces revealing fossils were photographed and floats deriving from this bed were sampled for thin section analysis.

3.3 Thin sections, XRD, TOC and palynology analysis

Conodont samples were thin-sectioned for semi-quantitative petrographic description. Additional samples closely below and above the Emsian-Eifelian boundary were thin-sectioned and described. Besides standard petrographic characterization, the proportions of selected components were quantified. Counting of particles (> 100 µm) along successive, randomly chosen, lines on thin sections was performed. Particles were grouped according to their origin: reef and platform derived (crinoid skeletal remains, bryozoa, corals, stromatoporoids, etc.); pelagic origin (tentaculites and radiolarians); peloids; intraclasts; volcanic grains; other non-carbonate grains (micas, quartz, feldspars, etc.) and pyrite and oxides (mostly diagenetic). These groups were assembled in bar charts and plotted on Fig. 2. This method overestimates the purity of limestones as it does not consider smaller non-carbonate particles. Roughly the same samples were processed for determination of total organic and inorganic carbon concentrations in rocks (TOC, TIC) in the Infra-Red Laboratory of the Institute of Geology SAS, Banská Bystrica, Slovakia. The results are plotted in Fig. 2.

Tuffite and limestone samples were crushed and sieved to obtain the smaller than 63 μm fraction. A small amount was placed over a glass slide and homogenized by mixing with distilled water and was left to dry. The X-ray

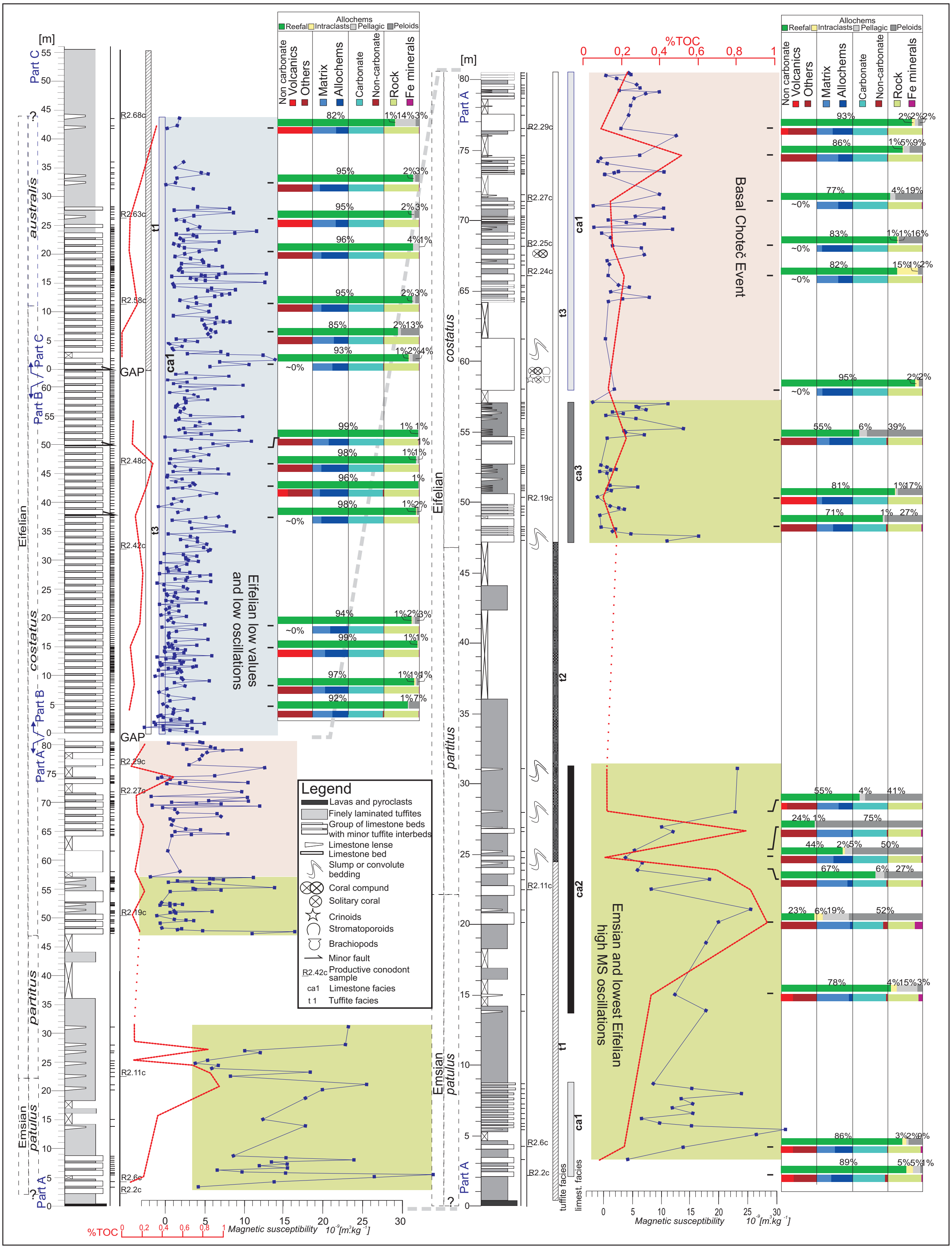

Figure 2. Lithological column of the Covas Ruivas site. On the left a simplified column of the whole sequence (Parts A, B and C) with the indication of productive conodont samples; "tuffite" and limestone facies; corresponding MS signal, TOC curve and quantification of main components (based on thin sections). On the right side a detailed column of the first part of the sequence (part A) with the same data plus macroscopically recognizable bioclasts and relevant sedimentary structures. Note that particles counted on thin sections are all greater than 100µm (with some tolerance on peloids) and thus the purity of limestones is most likely overestimated as it does not take into account smaller particles. GAP indicates division of parts A, B and C of the section where a few meters of may be repeated or missing.

diffraction pattern was recorded with a copper anode X-ray tube (Cu-Kα radiation) using a Philips PW1710, powder diffractometer and X´Pert software PC-APD 3.6 at the Tropical Research Institute (IICT) Department of Natural Sciences(DCN) / Global Development (DES) in Lisbon. Six samples of dark grey tuffites were also processed for palynology using standard HCl + HF attacks.

3.4 Magnetic susceptibility

The top of each calciturbidite bed was preferably sampled avoiding the overlying tuffite bed. Each calciturbidite bed was considered to be a single turbidity event and thus quasi-instantaneous. Several beds were sampled at different levels and the resulting MS values varied very little (< 2.10^{-9} [$m^3.kg^{-1}$]) within a single bed, even for thicker (> 2 m) beds. This method resulted in a sampling spacing dependant on the thicknesses of each limestone bed and tuffite interbed. In practice the spacing varies between 10 cm and ca. 50 cm. At the base and top of the sequence, tuffites are dominant over the limestones (mostly lenses) and the spacing between two samples can reach several meters (Fig. 2). All samples were measured using a Kappabridge KLY-2 (Agico s.r.o.) at the Rock Magnetism Laboratory of the Instituto D. Luiz (Faculty of Sciences of the University of Lisbon).

4. Results

4.1 Litho- and bio-facies and TOC

The Covas Ruivas II site has a long exposure of mildly deformed volcanic rocks, mostly coarse pyroclastic deposits and subordinate basaltic lava flows (Pl. 1B). Rare black chert beds up to ca. 2 m thick occur within the finer pyroclastic material. The sequence fines up to silt-sized, very finely laminated tuffs/tuffites where the first limestone beds appear. The term tuffite is used here in a broad sense. It refers to the rocks usually forming thin laminated beds, which have, invariably, a large proportion of volcanic-derived material (Pl. 1C; Pl. 1E). These seem to be, in most instances, hemipelagites.

All limestone beds have visible recrystalization, observed both macroscopically and in thin sections (the detail of some grains is frequently obliterated). We describe and categorize the bio- and litho-facies as observed macroscopically and in thin sections. Facies codes are ca1, ca2, … for limestones and t1, t2, … for tuffites. The data is summarized in Table 1.

The first 5 m of sequence (Section part A) are within the *patulus* Zone and are characterized by continuous beds of wackestones and grainstones with very abundant crinoidal fragments (lithofacies ca1). These are interbedded with finely laminated tuffites which are dominant over the limestones (lithofacies t1). The following 42 m (5 to 47 m) correspond to the *patulus* and *partitus* Zones. The limestone beds become generally thinner, laterally discontinuous and rarer (lithofacies ca2) (Pl. 1D). Between 20 and 27 m, there are thicker, laterally continuous limestone beds, but these have the same characteristics as the limestone lenses just above and below. In the same interval and up to 31 m, there are several limestone beds and lenses with convolute bedding. One of these beds has abundant friable green shally clasts up to 2 cm in diameter. XRD analysis of these clasts show a composition dominated by calcite, but with relevant amounts of feldspars (ca. 15 %), quartz (ca. 5 %), clay minerals (illite, chlorite and smectite) and small amounts of Fe oxides. We interpret these clasts as weathered tuffs/tuffites resting on the marine floor that were eroded during a particularly energetic turbidity event.

Between 25 and 47 m the interbeded tuffites become dominant over the limestones. The tuffites become progressively darker with dark grey and black chert and cherty laminae (and radiolarians) increasing in proportion (lithofacies t2). The large gaps between 35 and 47 m correspond to a part of the section covered by rubble derived solely from dark grey and black cherty tuffites with rare outcrops. This part of the section is very probably a continuous sequence of cherty tuffites (lithofacies t2) which erode and disaggregate more easily than limestone beds.

Above these initial 47 m and up to 81 m, in the basal *costatus* Zone, the tuffites become suddenly subordinate in relation to the limestones and the section becomes carbonate rich (up to 80 %) with few cherty mm lenses (lithofacies t3).

Between 47 and 57 m limestone beds characteristically have a coarser massive base and fine up to a finely laminated top with silt sized grains (Pl. 1I). Synsedimentary deformation features such as small scale slumping and more commonly convolute bedding are observable occasionally throughout this part of the sequence (lower *costatus* Zone) (Pl. 1H). Most of beds have a significant amount of peloids (up to 40 %) (lithofacies ca3).

Above 57 m and to the top of part A of the section (80 m) all limestone beds can be classified as belonging to facies ca1, with a variable but generally decreasing proportion of peloids and pelagic grains (Pl. 1F). Within this interval the thick coarse breccia bed (57 to 61.5 m) allows a closer description of the bio- and lithoclastic material and its characteristics. The debris is highly polydisperse and contains fragments from millimetre size up to several centimetres size. Variable alterations are indicative of an extensive mixing of the material delivered with the ‘coral breccia’. Fresh or slightly reworked crinoidal debris are relatively common, from about 5 to 40 vol. % of the rock, and crinoidal pluricolumnals are also present. Brachiopods, bryozoans, ostracods, foraminifers, algae and other shell/skeleton forming organisms are also observed, but they never represent the dominant rock components. The coarsest ‘breccia’ types have the lowest contents of crinoids, and amount of sediment matrix is reduced in general, so that the large clasts have mostly stylolitic, pressure solution contacts. Intraclasts are also highly diversified. The spectrum of their compositions encompasses the rock types from partly cemented grainstones of platform and upper slope environments to compacted calcisiltites and muds of slope

Name	Texture	Mesoscale features	Main bioclasts	Distribution	Interpretation
ca1	Wst - gst abundant bioclasts.	Laterally thin (<30 cm) continuous beds, coarse-grained (sand) bases.	Crinoidal fragments (up to 90 %). Rare tentaculites, ostracods, bryozoans, corals.	> 0 to 5 m of part A (lower *patulus* zone) > 58 m of part A to top of part C (*costatus* zone).	High-energy calciturbidites and rare debris flow deposits.
ca2	Calcimudstones with abundant peloids (up to 75 %). Occasional mixing of coarser carbonate grains.	Frequently laterally discontinuous. Fine lamination. Very fine grained with occasional mixing of coarser carbonate grains and possibly highly altered volcanic material. Common convolute bedding.	Crinoidal fragments ca. 25 %, rare foram/algae, tentaculites and radiolarians.	> 14 to 31 m of part A (upper *patulus* and lower *partitus* zones).	Reworked (?) organic-rich hemipelagic sediments and rare calciturbidites.
ca3	Wst - gst with significant proportion of peloids. Frequent presence of calcimudstone clasts.	Variable bed thickness (from 10 cm to 4 m). Convolute bedding. Coarse- to very coarse-grained bases (sand to cobble-sized grains).	Crinoidal fragments (up to 80 %). Frequent corals, stromatoporoids, crinoids, bryozoans, algae.	> 47 to 57 m of part A (basal *costatus* zone).	Low density calciturbidites with reworked material.
t1	Cryptocrystalline texture, fine micas and other silicate grains. Rare carbonate-rich laminae.	Fine lamination. Brown, slightly coarser laminae and dark grey finer laminae	Rare tentaculites and radiolarians.	> 0 to 24 m of part A (*patulus* and lowermost *partitus* zones) and 55m of part C (uppermost *costatus* and *australis* zones).	Hemipelagic deposits mainly of volcanic-derived material.
t2	Cryptocrystalline texture, fine micas and other silicate grains. Significant amount of organic matter. Often cherty.	Dark grey and black, with mm- to cm-thick chert or cherty lenses, often with py. Fine lamination.	Radiolarians and tentaculites are common, may form thin radiolarite.	> 24m to 47m of part A (*patulus* zone).	Hemipelagic siliceous ooze
t3	Microcrystalline with very small carbonate grains (up to 80 %) and quartz and micas grains. Carbonate-rich laminae alternate with siliceous laminae or mix of silicate grains.	Grey, pink coloured. Silt-sized (silt to fine sand). Fine lamination.	Tentaculites, radiolarians and ostracod shells common is some siliceous and carbonate laminae. Dark grey organic tissues.	> 47 m to 81m of part A and 0 to 60m of part B of the section (*costatus* zone).	Hemipelagic deposits and reworked (?) siliceous and calcareous ooze.

Table 1. Caption - Summarized main characteristics of the limestone (ca) and tuffite (t) lithofacies and their distribution. Py. is Pyrite.

(e.g. Pl. 3D), as marked by sponge spiculae, styliolinid and rare cephalopod shells. The intraclasts of lithified limestones contain a variety of rocks types, which are ranging from coarse and well-washed grainstones to medium- to fine grained, well-sorted grainstones containing unaltered bioclasts together with micritized chips and peloids, both in roughly equal amounts. Besides the grainstones and packstones of reef and upper slope environments, the basal parts of the channelized breccia flow sediments and coarse calciturbidites also contain blackish intraclasts of hemipelagic calcimudstones (rarely wackestones-packstones), which have angular to subrounded shapes and cm sizes. These were presumably reworked from older parts of the sequence (*patulus* and *partitus* zones?), and may originate from deeply dissected slopes (similarly as in the case of the younger Kačák Event and its post-event breccia flows (e.g. Hladil, 1993).

The coral and stromatoporoid skeletons are fragmentary, broken into mm to dm sized parts; complete coral colonies are almost absent. Some skeletons have a fresh appearance and were filled by cements after their breccia- or turbulent flow redeposition into a deeper water environments, but many of them do not. In the latter, the silicification/desilicification and dolomitization/dedolomitization spots together with micritized rims and bands are commonly observed, and these altered spots in skeletons (partly also in early cements) were cut by abraded/crushed surfaces. Further, these surfaces were often micritized or coated by cryptalgal structures, and sometimes repeatedly. The intensity of this early change varies depending upon time of exposure and burial in the original sediment, differently on specimens or sides of the clasts. This type of alteration resembles the shoals with coral gravel on repeatedly abraded islands in Eastern Moravia (Hladil et al., 1994; Bosák et al., 2002).

Parts B and C of the sequence (within the *costatus* Zone) (Pl. 1K) are generally monotonous in terms of facies, bioclast content, thicknesses, proportion of tuffites/ limestones, etc. and very similar to the upper 24 m (57 to 81 m) of part A of the sequence (lower *costatus* Zone) and can be generally included in the limestone facies ca1 (more rarely ca3) and tuffite facies t3 (Pl. 1G, Pl. 1H).

The top of the sequence (part C), starting near the base of the *australis* Zone (Pl. 1K), is marked by an increase of the thickness and relative abundance of the tuffite beds. Limestone beds become rarer and laterally discontinuous, but are still grainstones/wackstones with abundant crinoid fragments – limestone facies ca1 and more rarely ca3. The composition of the tuffites becomes more siliceous, with quartz dominating (up to 90 %) and very small amounts of calcite, feldspars and micas. Organic matter is present in minor amounts and its composition and maturity remains the same as for the rest of the sequence – tuffite facies t1.

Results from TIC/TOC analysis show an inverse proportional relation between organic and inorganic carbon content for all the analyzed samples. The higher TOC values are associated with lithofacies ca2, coherent with the darker colour and higher organic matter content observed in thin sections. There is, nevertheless, a sharp drop in TOC within this interval (ca. 15 to 31 m of part A) at 24.5 m. This drop is mimicked by the MS signal and the same roughly parallel curve is observed in the remaining section, with few, but noteworthy exceptions. After the sharp drop at 24.5 m there is sharp increase and a second sharp drop and the TOC values seem to remain low, contrary to the high MS values for the same interval (28-31 m). The gap above and significantly different sampling intervals preclude further correlations. The MS values at the base of the *costatus* zone (47-48 m of part A) are not mimicked by the TOC curve. An inverse correlation is observed in the topmost part of the sequence (*australis* zone – part C) with a general decrease of the MS values and a general increase of TOC values.

4.2 Conodonts

31 of the 33 samples collected and processed provided more than one hundred, mainly platform conodont elements. Only a few samples, however, provided well preserved specimens for identification and documentation including stratigraphically significant taxa regarding the current zonal concept. The CAI is estimated to be between 4 and 5 corresponding to ca. 300ºC, coherent with the results obtained from the maturation of the organic matter.

There are several problems with taxonomical delimitation in the *Polygnathus* stock just around the Emsian-Eifelian boundary. These are mostly expressed by difficulties in identification of taxa in the critical (boundary-defining) part of the *Polygnathus costatus* lineage (*Po. cost. patulus – Po. cost. partitus – Po. cost. costatus*). The lineage suffers from lack of pronounced morphological change that would clearly characterize the succession of taxa whose stratigraphic ranges largely overlap (see Klapper et al., 1978; Berkyová, 2009). The zonally diagnostic taxa are also accompanied by a great number of morphologically variable forms appearing in short time-spans that preclude clear identification of the conodont indexes. In spite of these problems the platform conodont elements obtained from samples from Covas Ruivas, enabled to observe a moderate morphological progress in the *costatus* lineage and compare it successfully with the material figured from type localities in New York and the Barrandian. Some associated taxa (e.g. "*Pandorinellina*" cf. *expansa* Uyeno & Mason, 1975 and *Polygnathus* aff. *P. trigonicus* Bischoff & Ziegler, 1957) provided further biostratigraphical control. Many determinations out of 31 selected and photographed platform elements were left in open nomenclature due to breakage or uncertainties regarding some morphological features.

The age of this sequence of the Odivelas Limestone is most probably latest Emsian to middle-late Eifelian (*patulus – australis* Zones). The clear morphology of *Polygnathus serotinus* Telford, 1975 found in two samples would point to an "earlier" late Emsian age, but in regard of stratigraphic precision, there is a certain limitation due to its overlap with the stratigraphic range of all three problematic members of the *costatus* lineage (the Emsian "*patulus*" and the Eifelian "*partitus*" and "*costatus*" taxa). However the faunal succession in the Covas Ruivas locality indicates a high probability of late Emsian age of the lower part of the section (part A) (there are no associated "*partitus*" and "*costatus*" in samples with *P. patulus*). The Emsian-Eifelian boundary is probably at the level of sample R2.11c (22 m) or closely below this level. The precision is affected by the density of successful conodont samples (see Fig. 2). Sample R2.19c (50 m) is already within the *costatus* Zone. The base of this zone is however obscured by the underlying gap.

The record of *Polygnathus* aff. *P. cooperi cooperi* Klapper et al., 1978 and *Icriodus* cf. *beckmanni sinuatus* Klapper et al., 1978 (i.e., typical taxa for the *serotinus* Zone) in sample R2.48c which is already deep within the *costatus* Zone might be caused by repetition in the section or reworking, although there is no colour change or wear out of the respective specimens, neither significant faults, nor any other suggestion of repetition of the sequence in that part of the section (samples below and above are well within the *costatus* Zone).

An important guiding conodont – *Tortodus kockelianus australis* Jackson, 1970 appears in sample R2.58c. It is associated with typically middle-late Eifelian – early Givetian taxa as *Polygnathus eiflius* Bischoff & Ziegler, 1957, *Polygnathus* cf. *pseudofoliatus* Wittekindt, 1966 and *Polygnathus* aff. *ansatus* Ziegler & Klapper, 1976. Due to stratigraphical overlap of *T. k. australis* Jackson, 1970 with subsequent zonal indexes and the above mentioned associated taxa (although some were left in open nomenclature) that are characterized by a rather long range, an earliest Givetian age of the last sample R2.68c (top of part C) cannot be excluded.

4.3 Reef fauna

The exact determination of coral and stromatoporoid fauna is complicated by several factors related to the mode of preservation. First of all it is almost impossible to achieve the precise orientation of the sections, and it is due to strong fragmentation of colonies, as well as to the growth distortion within the small fragments and, occasionally, also to deformation (compaction or shear deformation). In addition, the early diagenetic changes caused that a significant part of original microstructures was changed or erased completely. Although many significant features in morphologies and microarchitecture of the skeletons remain, all the determinations had to be classified as being uncertain, at about a 60 to 80 % level of reliability, so that the taxa in the approximate lists of faunas, as follows, must be used with question marks. In spite of this unavoidable degree of uncertainty, the rough outlines of the studied coral and stromatoporoid assemblages are remarkably wide:

Tetracorals: *Disphyllum* sp., *Grypophyllum* sp., *Neospongophyllum* sp., *Parasociophyllum isactis* Frech, 1886, *Petronella* sp., *Pseudamplexus* sp., *Solipetra* sp., *Spinophyllum* sp., *Stringophyllum* sp., *Syringaxon* sp., and about 7 other, undetermined taxa (17 together).

Tabulate corals: *Alveolitella* sp., *Alveolites edwardsi* Lecompte, 1939, *A. nalivkini* Sokolov, 1952, *Axuolites* sp., *Bainbridgia* sp., *Caliapora* (*Luciaella*) sp., *Caliapora venusta* Yanet, 1972, *Celechopora* sp., *Celechopora devonica* Schlüter, 1885, *Cladopora* sp., *Coenites* sp., *Dualipora* sp., *Hillaepora circulipora* Kayser, 1879, *Hillaepora* sp., *Lecomptia* sp., *Microalveolites* sp., *Planocoenites* sp., *Platyaxum* sp., *Remesia* sp., *Roemerolites* sp., *Scoliopora cruciformis* Yanet, 1959, *Scoliopora serpentina* Yanet, 1972, *Spongioalveolites* sp., *Squameoalveolites fornicatus* Schlüter, 1889, *Squameoalveolites robustus* Pradáčová, 1938, *Squameoalveolites* sp., *Striatopora* sp., *Striatopora* ex gr. *zeaporoides* Dubatolov, 1963 , *Taouzia* sp., *Thamnopora* sp., and about 3 other, undetermined taxa (33 together).

Heliolitids: *Heliolites barrandei* Penecke, 1887, *H. porosus bilsteinensis* Iven, 1980, *H. porosus intermedius* Le Maître, 1947, *H. porosus porosus* Goldfuss, 1826, *Heliolites* sp., *H. vulgaris* Tchernyshev, 1951, and 2 problematic forms (8 together).

Rhapidoporids ('chaetetids'): *Rhapidopora crinalis* Schlüter, 1880, *Rhapidopora* sp., and 2 undetermined, possible rhapidoporid taxa (4 together).

Stromatoporoids: *Actinostroma perspicuum* Nicholson, 1886, *Actinostroma* sp., *Amphipora* sp., *Atelodictyon* sp., *Atopostroma* sp., *Bifariostroma* sp., *Clavidictyon* sp., *Dendrostroma* sp., *Ferestromatopora* sp., *Habrostroma* sp., *Hermatoporella* sp., *Hermatostroma* sp., *Hermatostromella* sp., *Labechia* sp., *Parallelopora* sp., *Plectostroma* sp., *Pseudoactinodictyon* sp., *Salairella* sp., *Stachyodes* (*Sphaerostroma*) sp., *Stachyodes* (*Stachyodes*) sp., *Stictostroma* sp., *Stromatopora* sp., *Syringostromella* sp., *Trupetostroma* sp., and about 7 difficultly classifiable taxa (31 together).

The majority of above listed genera and possible species have European and territorially widespread Asian terrane records. Many of them also reach to north American realm (e.g., *Grypophyllum*) (Pl. 3G) or, on the other hand, are linked even to Australian basins (e.g., *Pseudamplexus*). Some taxa may be considered as being mostly the representatives of typically peri-Laurussian and Rhenish faunas (e.g., *Alveolites edwardsi*) (Pl. 3B), but some taxa which are regularly connected with the peri-Gondwanan areas are also involved (e.g., *Taouzia* –an Ibarmaghian marker, Plusquellec & Hladil, 2001) (Pl. 3H). The markers of the types as represented by *Bainbrigia-Dualipora* association or numerous forms of *Heliolites* (Pl. 2F) are indicative of settlements coming with open-ocean migration routes (Tourneur, 1991), because these markers primarily contribute to coral colonizations on off-shore volcanic mounds, elsewhere (Hladil, 1993). The stratigraphic significance of this faunal assemblage is only modest. It must be noted that the precise biostratigraphic correlation based on corals and stromatoporoids is basically impossible due to absence of specialized studies on coral assemblages which are strictly related to this BCE time window in particular. On the other hand, the prevailing 'Middle Devonian' character of the faunas puts significant constraints on any stratigraphically deeper recycling of older Emsian coral-stromatoporoid limestones.

4.4 Magnetic susceptibility stratigraphy

Hypothetically the volcanic-sedimentary setting of this section could preclude the application of magnetic susceptibility stratigraphy to it. The MS values are generally very low, indicative that the volcanic-derived admixture is very low and probably negligible (opposed to the carbonate-rich interbedded tuffites that had MS values one or two orders of magnitude higher). The insoluble residues from acetic acid and also hydrochloric acid show extremely rare particles that could have a volcanic origin (< 1 mm, black rounded microgranular particles) but again the samples where these particles are slightly more common do not correspond to higher MS values. Pyrite is present, although rare, in samples with greater amount of organic matter. However, the proportion of this non-volcanic accessory material is known only approximately as it was estimated from the counts of diagenetically affected mineral aggregates and grains of 100 μm and larger sizes. We cannot exclude the possibility that extremely fine volcanic-derived material (ashes), which are difficult to observe or detect, could affect the MS signal. There is an evident absence of terrigenous clastics in this facies association in general.

There seems to be no relation between the amount of non-carbonate material (volcanic or non-volcanic) with the MS values in this section (compare MS values to proportions of carbonate and non-carbonate particles in Fig. 2). The sensitivity of magnetic rock properties to background sedimentation components together with prevailingly low magnetism of volcanic admixtures in these limestones suggest that there is a good opportunity to trace general MS stratigraphic patterns which are not fully masked by noise from local volcanic and sedimentary regimes. These conclusions corroborate the observed similarities with inter-regionally juxtaposed MS stratigraphic curves (see below).

The upper Emsian and the lowest Eifelian MS records (part A) show an alternation of periods with high amplitude oscillations with highly oscillating intervals (between 0–10 and 20–30 m), and the mean MS values are visibly elevated ($14.25 x 10^{-9}$ and $11.8 x 10^{-9}$ $m^3.kg^{-1}$ respectively, contrasting with an overall section average of $3.57 x 10^{-9}$ $m^3.kg^{-1}$). Koptikova et al. (2007, 2008) described a coherent pattern of low MS values in different sections (Nevada – Lone Mountain section and Barrandian area – Na Škrábku Quarry, Prastav Quarry Červený lom Quarry), occurring just before the BCE. In the Covas Ruivas section, this decrease was not observed but could correspond to the major gap in part A (Fig. 2 and Fig. 3, 36-47 m), as well as to the first sets of calciclastic (skeletal, lithoclastic and peloidal), rhythmically arranged beds above this lacuna. An abrupt positive shift on MS values which ends the interval with low values occurs within these calciclastic series (around 47 m). This shift is continued by irregularly structured patterns with high mean MS values (47–57 m). Above, a markedly developed decrease of MS values (from $11.17 x 10^{-9}$ to $-1.9 x 10^{-9}$ $m^3.kg^{-1}$around 58 m) is observed, which might be considered as the starting of the BCE. However this interval of low MS values is not as significant as the pre-BCE low. Also the amplitudes of oscillations in this interval are higher than during the former low (68–80 m of part A).

5. Discussions and conclusions

Conodont data point to a limestone deposition which can be most probably bracketed between the *patulus* and the *australis* Zones (latest Emsian – middle-late Eifelian). These results also indicate that there are no relevant gaps or repetitions within the sequence due to faulting. The volcanic activity of this part of the BIC occurred before and after this time span as can be seen by the field stratigraphical relation. Volcanic activity in the immediate vicinity of the sedimentation area must have stopped to allow the development of the reef system and was probably extremely reduced in the region, as this was probably not an isolated reef (see below).

The close palaeogeographical relation between the volcanic buildings of the oldest part of the Beja Igneous Complex and the limestone deposition is inferred by the gradual passage at the base and top of the section to tuffs/tuffites and by the existence of interbedded hemipelagites with a significant volcaniclastic component.

The general abundance of reef- (or platform-) derived bioclasts indicates that sedimentation took place in a peri-reefal environment. The coarser, usually massive base and the finer laminated top (and the intermediate cross bedded interval occasionally seen) suggest a low density calciturbidite type of sedimentation. Convolute bedding and slump structures are further indications of sedimentation on a slope. The fact that most beds show relatively fine grained and well sorted material (silt-sand, rarely coarser) indicates a considerable transport distance, implying that the deposition area is not in the close vicinity of a bioherm/biostrome. The intercalation of tuffites with hemipelagic characteristics constrain the sedimentation setting to the base of slope where basinal sedimentation is recorded between turbidity current events.

The reef fauna diversity is quite unusual when compared with Middle Devonian faunas which are known from analogous tectonosedimentary settings, e.g., from the basalt heights of Horní Benešov, Moravia (Galle et al., 1995), Maly Bozkow, Central Sudetes (Hladil et al., 1999), or Ještěd Ridge, western Sudetes (Chlupáč & Hladil, 1992). The number of taxa for corals and stromatoporoids is about three times smaller at the localities which are used for comparison. However, a higher diversity was reported in the studies on corals and stromatoporoids of NW Sauerland (May, 1987, 1993). This unusually large spectrum of corals and stromatoporoids in Early Eifelian 'breccia' must be related to sources in complex, large and long-term surviving reefs, because only the large and complex platforms and reefs may provide numerous possible guilds and environments which do not represent only ephemeral or short-term colonizations. In addition, the faunal remains found in the 'breccia' bed are characteristic of various types of settings (calm water, inner backreef colonizers (e.g., *Amphipora*) to high energy water conditions of outer lagoon or reef-front (e.g. *Stachyodes*) or open-ocean colonizers (e.g., *Bainbridgia*, partly heliolitids) (Pl. 3A). Such a diversity and overlapping complexity of faunas can be either explained by possible existence of a really large volcanic complex, or may suggest a possible juxtaposition of such a volcanic complex with some large crustal block beneath or in neighbourhood. However, the latter possibility seems to be constrained by lack of detrital quartz in these sedimentary rocks.

The wide and complex palaeogeographical relationships of these faunas suggest that connection of this area with open ocean territories was good. A continuous, strong and diverse colonization flux of coral and stromatoporoid planulae and larvae was, most likely, an unavoidable precondition for the development of these high-diversity faunas.

The MS signal does not seem to be related to the amount of observed non-carbonate material and there is no evidence of relevant detritism – no quartz or other minerals associated with siliclastic input were observed. Thus a scenario where the major part of this impurity was delivered by atmospheric transport seems likely (see also Hladil et al., this volume; Koptikova et al., this volume). Possible delivery of dust into the basin waters is almost regularly connected to enrichment of these marine areas in dissolved Fe-bearing solute species, and consequently, the fertilised aquatic conditions and also (bio)precipitation of highly magnetic phases may follow (Jickells, et al. 2005; Kaspari et al., 2009).

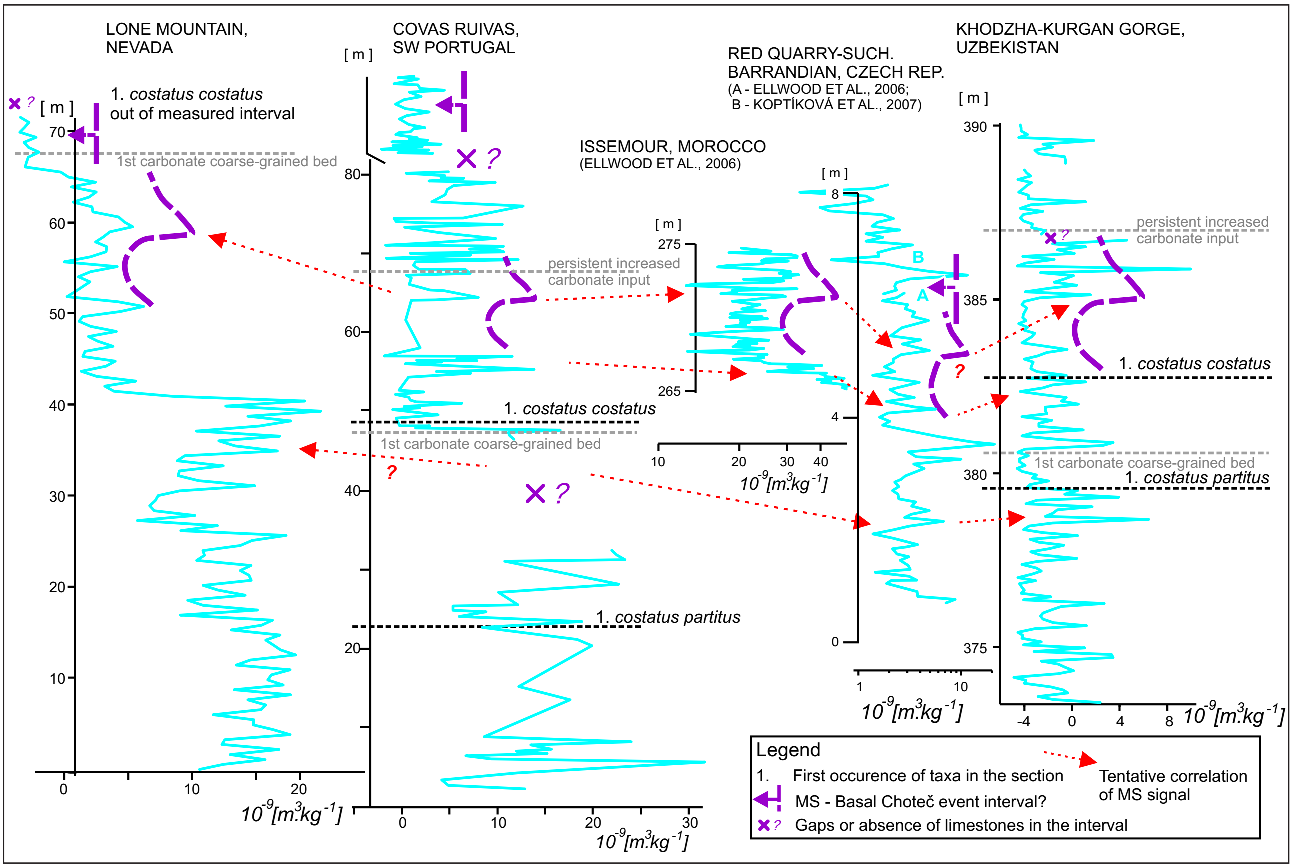

Figure 3. Tentative correlation of the MS curve from Covas Ruivas section with other MS curves from Lone Mountain, Nevada, USA (Elrick & Hinnov, 1996, Klapper & Johnson, 1975 and unpublished data); Issemour, Morocco (Ellwood et al., 2006) and Khodzha-Kurgan Gorge, Uzbekistan (unpublished data) and the Red Quarry in the Barrandian, Czech Republic (Elwood et al., 2006; Koptikova et al., 2007).

The intensity of magnetic signal is contrasting to small amounts of impurity in limestone and, therefore, is almost certainly associated with hematite or magnetite (Hladil et al., 2006).

In spite of a considerable uncertainty in conodont based correlation, which is highly indicative of stratigraphic levels but not describing them in detail, the arrangements of MS stratigraphic patterns in the section suggest the possibility for interregional comparison, even with distant places like Nevada, Uzbekistan or Morocco (Fig. 3) (see also for long distance correlations of Devonian sections Boulvain et al., this volume).

It is interesting to note that the onset of syn- to post-BCE calciclastites is a very important lithological marker inter-regionally (Koptikova et al., 2007; 2008), and the development of pre-BCE MS low with rapidly evolving spikes on MS curves within these calciclastites is a potentially applicable marker, at least for part of the Emsian-Eifelian sections and lithologies. The prospective application of these tentatively defined patterns and MS curve alignments seems to be strengthened by the common occurrence of MS oscillatory and stepwise decrease which occurs still within the levels with *Po. costatus costatus*. (Koptikova et al., 2007; 2008) The deposition of coarse bioclastic and intraclastic, calciturbidites just after a pronounced period of deposition of low-carbonated hemipelagites is indicative of the record of the BCE in this section (Berkyová et al., 2008; Elrick et al., 2009). The richly bioclastic beds occur exclusively in the coral breccia interval, (between 58 and 61 m), and may relate to a typical, early *costatus*-Zone facies change (syn- to post-BCE calciclastites).

The TOC curve roughly follows the overall trends which are seen in the MS curves which can be explained by the increased organic productivity (and consequent organic matter accumulation) induced by an increased delivery of dust (Kawahata et al., 2000). In detail there are many differences between the two curves. However, these differences can also be caused by natural variability of rock compositions or occurrence of inhomogenities. This variability must be considered between samples which are cm apart or even two parts of a sample with ~20-40 g. Considering the significant degree of similarity between TOC and MS, but an obvious dissimilarity between these two parameters and the amount of volcanic-derived impurities in the limestones (Fig. 2), one can infer that the burial of organic matter (or also increased primary productivity in open sea) was particularly linked to increased contents of non-volcanic clayey/silty components. The process when increased transport of aerosol with mineral dust into the oceans (MS on paramagnetic and ferri-/ferromagnetic minerals) causes increased organic productivity and organic carbon burial (MS on diagenetic Fe-mineral phases) would be relevant to this case (e.g. Kawahata et al., 2000; Saltzman, 2005).

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7. References

ANDRADE, A.A.S., 1983. Contribution à l'analyse de la suture hercynienne de Beja (Portugal): perspectives métallogéniques. Laboratoire de Métallogénie I Nancy, Institut National Polytechnique de Lorraine. *PhD thesis*: 137pp.

ANDRADE, A.A.S., PINTO, A.F.F. & CONDE, L.E.N., 1976. Sur la géologie du Massif de Beja: Observations sur la Transversale d' Odivelas. *Comunicações dos Serviços Geológicos de Portugal*, 60: 171–202.

VAN DEN BOOGAARD, M., 1973. Conodont faunas from Portugal and Southwestern Spain. Part 1: A Middle Devonian fauna from near Montemor-o-Novo. *Scripta Geologica,* 13: 1-11.

BERKYOVÁ, S., 2009. Lower-Middle Devonian (upper Emsian-Eifelian, *serotinus-kockelianus* zones) conodont faunas from the Prague Basin, the Czech Republic. *Bulletin of Geosciences*, 84: 667–686.

BERKYOVÁ, S., FRÝDA, J. & KOPTÍKOVÁ, L., 2008. Environmental and biotic changes close to the Emsian/Eifelian boundary in the Prague Basin, Czech Republic: paleontological, geochemical and sedimentological approach. *In* Kim, A.I., Salimova, F.A. & Meshchankina, N.A. (eds) *International Conference Global Aligments of Lower Devonian Carbonate and Clastic Sequences, SDS/IGCP Project 499 joint field meeting, 25.8.-3.9.2008, State Committee of the Republic of Uzbekistan on Geology and Resources & Kitab State Geological Reserve, Contributions*, *Taskhent-Novosibirsk*: 18-19.

BOSÁK, P., MYLROIE, J.E., HLADIL, J., CAREW, J.L. & SLAVÍK, L., 2002. Blow Hole Cave: An unroofed cave on San Salvador Island, the Bahamas, and its importance for detection of paleokarst caves on fossil carbonate platforms. *Acta Carsologica*, 31, 3: 51-74.

BOULVAIN, F., DA SILVA, A.-C., HLADIL, J., GERSL, M., KOPTIKOVA, L. & SCHNABL, P., 2010. Magnetic susceptibility correlation of km-thick Eifelian–Frasnian sections (Ardennes and Moravia). *Geologica Belgica*, this volume.

CHLUPÁČ, I. & HLADIL, J., 1992. New Devonian occurrences in the Jested Mts., North Bohemia. *Journal of the Czech Geological Society*, 37(3): 185-191.

CHLUPÁČ, I. & KUKAL, Z., 1986. Reflection of possible global Devonian events in the Barrandian area, C.S.S.R. *In* Walliser, O.H. (ed.), Global Bio-events. *Lecture Notes in Earth Sciences*, Springer-Verlag, Berlin, 8: 169-179.

ELRICK, M. & HINNOV, L. A., 1996. Millennial-scale climate origins for stratification in Cambrian and Devonian deep-water rhythmites, western USA. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 123: 353-372.

ELRICK, M., BERKYOVÁ, S., KLAPPER, G., SHARP, Z., JOACHIMSKI, M. & FRÝDA, J., 2009. Stratigraphic and oxygen isotope evidence for My-scale glaciation driving eustasy in the Early-Middle Devonian greenhouse world. *Palaeogeography, Palaeoclimatology, Palaeoecology,* 276: 170-181.

ELLWOOD, B.B., GARCIA-ALCALDE, J.L., EL HASSANI, A., HLADIL, J., SOTO, F.M., TRUYÓLS-MASSONI, M., WEDDIGE, K. & KOPTIKOVA, L., 2006. Stratigraphy of the Middle Devonian Boundary: Formal Definition of the Susceptibility Magnetostratotype in Germany with comparisons to Sections in the Czech Republic, Morocco and Spain. *Tectonophysics*, 418: 31-49.

FIGUEIRAS, J., MATEUS, A., GONÇALVES, M., WAERENBORG, J. & FONSECA, P.E., 2002. Geodynamic evolution of the South Variscan Iberian Suture as recorded by mineral transformations. *Geodinamica Acta*, 15/1: 45–61.

FONSECA, P. & RIBEIRO, A., 1993. Tectonics of the Beja-Acebuches Ophiolite: a major suture in the Iberian Variscan Foldbelt. *Geologische Rundschau*, 82: 440–447.

FONSECA, P., MUNHÁ, J., PEDRO, J., ROSAS, F., MOITA, P., ARAÚJO, A. & LEAL, N., 1999. Variscan ophiolites and high-pressure metamorphism in Southern Iberia. *Ofioliti,* 24/2: 259–268.

GALLE, A., HLADIL, J. & ISAACSON, P. E., 1995. Middle Devonian biogeography of closing South Laurussia to North Gondwana Variscides; examples from the Bohemian Massif, Czech Republic, with emphasis on Horni Benešov. *Palaios*, 10: 221-239.

HLADIL, J., 1993. Tabulatomorphs and stromatoporoids below and above the upper boundary of the Acanthopyge Limestone, Eifelian - Givetian transitional interval, Central Bohemia. *Věstník Českého geologického ústavu*, 68/2: 27-42.

HLADIL, J., CEJCHAN, P., BABEK, O., KOPTIKOVA, L., NAVRATIL, T. & KUBINOVA, P., 2010. Dust – a geology-orientated attempt to reappraise the natural components, amounts, inputs to sediment, and importance for correlation purposes. *Geologica Belgica*, this volume.

HLADIL, J., GERŠL, M., STRNAD, L., FRÁNA, J., LANGROVÁ, A. & SPIŠIAK, J., 2006. Stratigraphic variation of complex impurities in platform limestones and possible significance of atmospheric dust: a study with emphasis on gamma-ray spectrometry and magnetic susceptibility outcrop logging (Eifelian-Frasnian, Moravia, Czech Rep.). *International Journal of Earth Sciences*, 95/4: 703-723.

HLADIL, J. HELEŠICOVÁ, K., HRUBANOVÁ, J., MÜLLER, P. & UREŠ, M., 1994. Devonian island elevations under the scope - Central Europe, basement of the Carpathian Mountains in Moravia. *Jahrbuch der Geologischen Bundesanstalt in Wien*, 136/4: 741-750.

HLADIL, J., MAZUR, S., GALLE, A. & EBERT, J.R., 1999. Revised age of the Maly Bozkow limestone in the Klodzko metamorphic unit, early Givetian, late Middle Devonian; implications for the geology of the Sudetes, SW Poland. *Neues Jahrbuch fur Geologie und Palaontologie*, *Abhandlungen*, 211: 329-353.

JICKELLS, T.D. et al., 2005. Global Iron connections between desert dust, ocean biogeochemistry and climate. *Science*, 308: 67-71.

JESUS, A., MATEUS, A., WAERENBORGH, J., FIGUEIRAS, J., ALVES, L.C. & OLIVEIRA, V., 2003. Hypogene titanian, vanadian maghemite in reworked oxide cumulates in the Beja layered gabbro complex, Odivelas, southeastern Portugal. *Canadian. Mineralogist*. 41/5: 1105–1124.

JESUS, A., MUNHÁ, J., MATEUS, A., TASSINARI, C. & NUTMAN, A., 2007. The Beja layered gabbroic sequence (Ossa-Morena Zone, Southern Portugal): geochronology and geodynamic implications. *Geodinamica Acta*, 20/3:139–157.

JULIVERT, M. & MARTÍNEZ, F., 1983. Estructura de conjunto y visión global de la Cordillera Herciniana. *Libro Jubilar J. M. Rios*. *Geología de España*, 1: 607-630.

KASPARI, S., MAYEWSKI, P. A., HANDLEY, M., KANG, S., HOU, S., SNEED. S., MAASCH, K. & QIN, D. 2009. A High-Resolution Record of Atmospheric Dust Composition and Variability since a.d. 1650 from a Mount Everest Ice Core. *Journal of Climate*, 22: 3910-3925.

KAWAHATA, H., OKAMOTO, T., MATSUMOTO, E. & UJIIE, H., 2000. Fluctuations of eolian flux and ocean productivity in the mid-latitude north Pacific during the last 200 kyr. *Quaternary Science Reviews*, 19: 1279-1291.

KLAPPER, G. & JOHNSON, D. B., 1975. Sequence in conodont genus Polygnathus in Lower Devonian at Lone Mountain, Nevada. *Geologica et Palaeontologica*, 9: 65-83.

KLAPPER, G., ZIEGLER, W. & MASHKOVA, T. V., 1978. Conodonts and correlation of Lower Middle-Devonian boundary beds in the Barrandian area of Czechoslovakia. *Geologica et Palaeontologica,* 12: 102-116.

KOPTÍKOVÁ, L., BERKYOVÁ, S., HLADIL, J., SLAVÍK, L., SCHNABL, P., FRÁNA, J. & BÖHMOVÁ, V., 2008. Long-distance correlation of Basal Chotec Event sections using magnetic susceptibility (Barrandian –vs– Nevada) and lateral and vertical variations in fine-grained non-carbonate mineral phases. *In* Kim, A.I., Salimova, F.A. & Meshchankina, N.A. (eds): *International Conference Global Aligments of Lower Devonian Carbonate and Clastic Sequences, SDS/IGCP Project 499 joint field meeting, 25.8. - 3.9. 2008, State Committee of the Republic of Uzbekistan on Geology and Resources, Kitab State Geological Reserve, Contributions*: 60-62.

KOPTÍKOVÁ, L., HLADIL, J., SLAVÍK, L., ČEJCHAN, P. & BÁBEK, O., 2010. Fine-grained non-carbonate particles embedded in neritic to pelagic limestones (Lochkovian to Emsian, Prague synform, Czech Republic): composition, provenance and links to magnetic susceptibility and gamma-ray logs. *Geologica Belgica*, this volume.

KOPTÍKOVÁ, L., HLADIL, J., SLAVÍK, L., & FRÁNA, J., 2007. The precise position and structure of the Basal Choteč Event: lithological, MS-and-GRS and geochemical characterisation of the Emsian-Eifelian carbonate stratal successions in the Prague Syncline (Tepla-Barrandian unit, central Europe). *In* Over, D. & Morrow, J. (eds): *Subcommission on Devonian Stratigraphy and IGCP 499 Devonian Land Sea Interaction, Eureka, NV, 2007, San Diego State University & SUNY-Geneseo, Eureka, September 9-18. SDS & IGCP 499 Eureka NV 2007 Program and Abstracts, Geneseo*: 55-57.

LÖTZE, F., 1945. Zur Gliederung der Varisziden in der Iberischen Meseta. *Geotektonische Forschungen* 6: 78–92.

MACHADO, G., HLADIL, J., KOPTÍKOVÁ, L., FONSECA, P. E., ROCHA, F. T. & GALLE, A., 2009. The Odivelas Limestone: evidence for a Middle Devonian reef system in western Ossa-Morena Zone (Portugal). *Geologica Carpathica*, 60/2: 121-137.

MATEUS, A., FIGUEIRAS J., GONÇALVES M. & FONSECA P.E., 1999. Evolving fluid circulation within the Beja-Acebuches Variscan Ophiolite Complex (SE, Portugal). *Ofioliti* 24/2: 269–282.

MATEUS, A., JESUS A.P., OLIVEIRA V., GONÇALVES M.A. & ROSA C., 2001. Vanadiferous iron-titanium ores in Gabbroic Series of the Beja Igneous Complex (Odivelas, Portugal); remarks on their possible economic interest. *Estudos Notas e Trabalhos do Instituto Geológico e Mineiro,* 43: 3–16.

MAY, A., 1987. Der Massenkalk (Devon) nördlich von Brilon (Sauerland). *Geologie und Paläontologie in Westfalen*, 10: 51-84.

MAY, A., 1993. Korallen aus dem höheren Eifelium und unteren Givetium (Devon) des nordwestlichen Sauerlandes (Rheinisches Schiefergebirge). Teil I: Tabulate Korallen. *Palaeontographica, Abt. A*, 227: 87-224.

OLIVEIRA, J. T., OLIVEIRA, V. & PIÇARRA, J. M., 1991. Traços gerais da evolução tectono-estratigráfica da Zona de Ossa-Morena, em Portugal: síntese critica do estado actual dos conhecimentos. *Comunicações dos Serviços Geológicos de Portugal*, 77: 3-26.

OLIVEIRA J.T., RELVAS J.M.R.S., PEREIRA Z., MUNHÁ J.M., MATOS J.X., BARRIGA F.J.A.S. & ROSA C.J., 2006. O complexo Vulcano-sedimentar de Toca da Moura-Cabrela (Zona de Ossa-Morena); Evolução tectono-estratigráfica e mineralizações associadas. *In* Dias R., Araújo A., Terrinha P. & Kullberg J.C. (eds) *Geologia de Portugal*: 1–13.

PEREIRA, Z. & OLIVEIRA, J. T., 2006: Palynostratigraphy of the Toca da Moura and Cabrela Complexes, Ossa Morena Zone, Portugal. Geodynamic implications. *Review Paleobotany and Palynology*, 139/1-4: 227–240.

PLUSQUELLEC, Y. & HLADIL, J., 2001. Tabulate corals of Ibarmaghian affinities in the Upper Emsian of Bohemia. *Geologica et Palaeontologica*, 35: 31-51.

RELVAS, J., 1987. Alteração hidrotermal na área da Mina da Caeirinha (Santa Susana): perspectiva metalogenética. *Unpublished BsC thesis*. *Universidade de Lisboa*: 254p.

RIBEIRO, A., MUNHÁ, J., DIAS, R., MATEUS, A., PEREIRA, E., RIBEIRO, M.L., FONSECA, P. E., ARAÚJO, A., OLIVEIRA, J. T., ROMÃO, J., CHAMINÉ, H., COKE, C. & PEDRO, J. C., 2007. Geodynamic evolution of the SW Europe Variscides. *Tectonics*, 26: TC6009.

RIBEIRO, A., MUNHÁ, J., FONSECA, P.E., ARAÚJO, A., PEDRO, J., MATEUS, A., TASSINARI, C., MACHADO, G. & JESUS, A., 2009. Variscan Ophiolite Belts in the Ossa-Morena Zone (Southwest Iberia): geological characterization and geodynamic significance. IGCP Project 497, Ocean Rheic Special Volume, *Gondwana Research*, 17: 408-421.

ROBARDET, M. & GUTIÉRREZ-MARCO, J.C., 1990. Passive margin phase (Ordovician-Silurian-Devonian). *In* Dallmeyer R.D. and Martínez García E. (eds) *Pre-Mesozoic Geology of Iberia*. Springer Verlag: 249–251.

ROBARDET M. & GUTIÉRREZ-MARCO J. C., 2004. The Ordovician, Silurian and Devonian sedimentary rocks of the Ossa-Morena Zone (SW Iberian Peninsula, Spain). *Journal of Iberian Geology*, 30: 73-92.

SALTZMAN, M.R., 2005. Phosphorus, nitrogen, and the redox evolution of the Paleozoic oceans. *Geology*, 33: 573–576.

SANTOS, J.F., ANDRADE, A.S. & MUNHÁ, J.M., 1990. Magmatismo Orogénico Varisco no limite meridional da Zona de Ossa-Morena. *Comunicações dos Serviços Geológicos de Portugal*, 76: 91-124.

TOURNEUR, F., 1991. The *Bainbridgia – Dualipora* association (Cnidaria, Tabulata): palaeogeographical and palaeoecological implications. *Hydrobiologia*, 216/217: 419-425.

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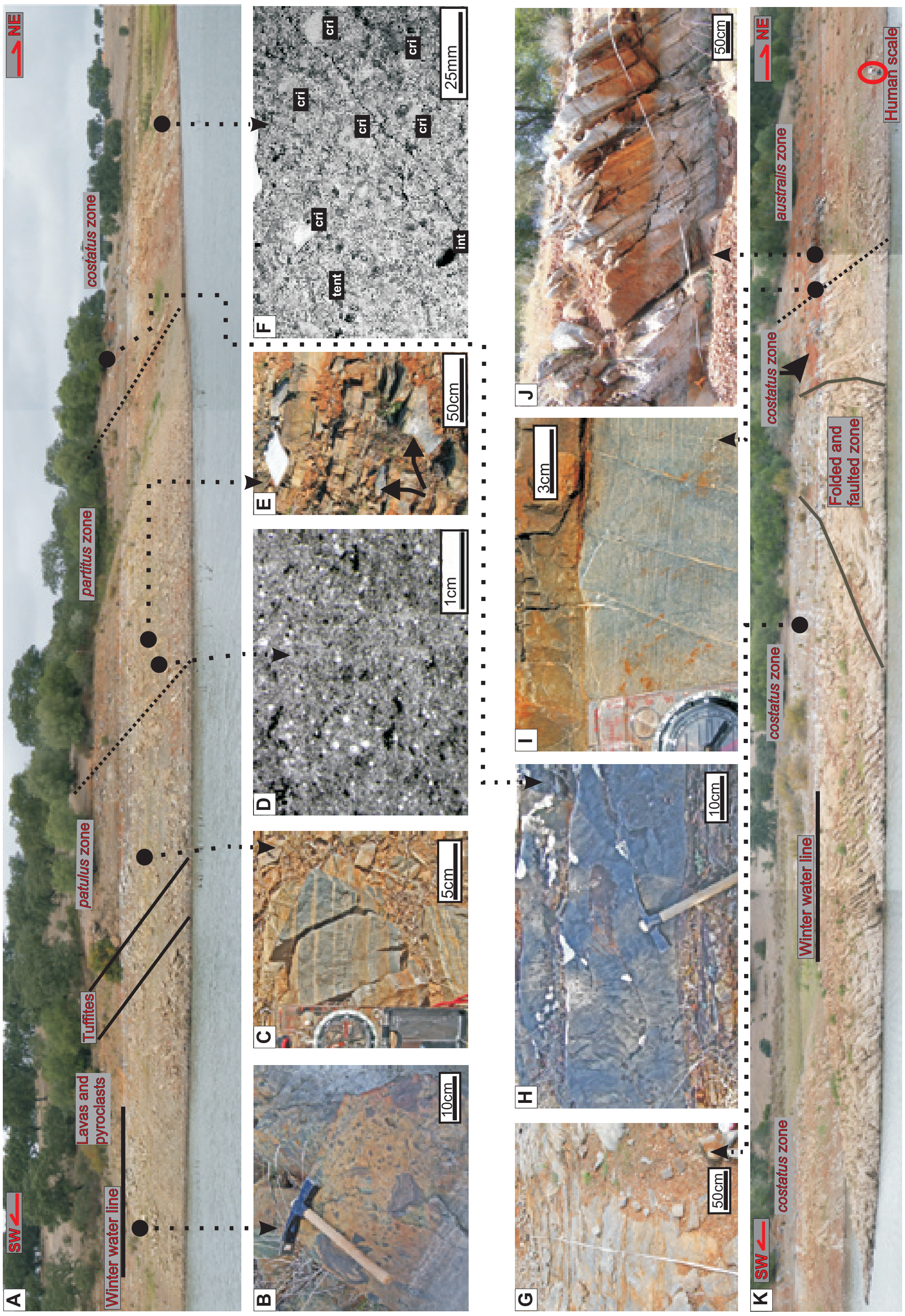

Plate 1. Field and microscopic images of the Covas Ruivas II locality
A – Panorama of part A of the section (0-80m) with the approximate extension of the conodont biozones.
B – Detail of a coarse pyroclastic deposit a few meters below the first limestone beds.
C – Hand specimen scale image of a finely laminated tuffite (facies t1) in the *patulus* zone where the limestones are subordinate to tuffites. Note the dark grey organic mater-rich laminae alternating with the coarser and lighter laminae.
D – Microscopic image (white transmitted light) of limestone facies ca1 in basal *partitus* zone. Note the (locally) common radiolarians and peloids.
E – Limestone lense (arrows) interbeded with finely laminated tuffites within the lower *partitus* zone.
F – Microscopic image (white transmitted light) of a grainstone belonging to facies ca1 within *costatus* zone. Note the abundant crinoid skeletal elements (cri) and the rare intraclasts (int) and tentaculites (tent).
G – General appearance of the section within the *costatus* zone (part B). Note the thicker limestone beds (grainstones) and the subordinate, much thinner, interbeded tuffites.
H – Slumped bed in lower *costatus* zone. The slump "head" contains reworked material from both tuffite and limestone beds.
I – Small scale trough cross-bedding at the top of a limestone bed, overlaid by a tuffite bed.
J – General appearance of the section in lower *australis* zone (part C). Note the thicker limestone beds and the subordinate tuffites, as in most of the *costatus* zone below. Compare with G.
K – Panorama of parts B and C of the section, separated by a faulted zone. The approximate extension of the conodont biozones is shown. The first part of the section is seen in the background in the upper left.

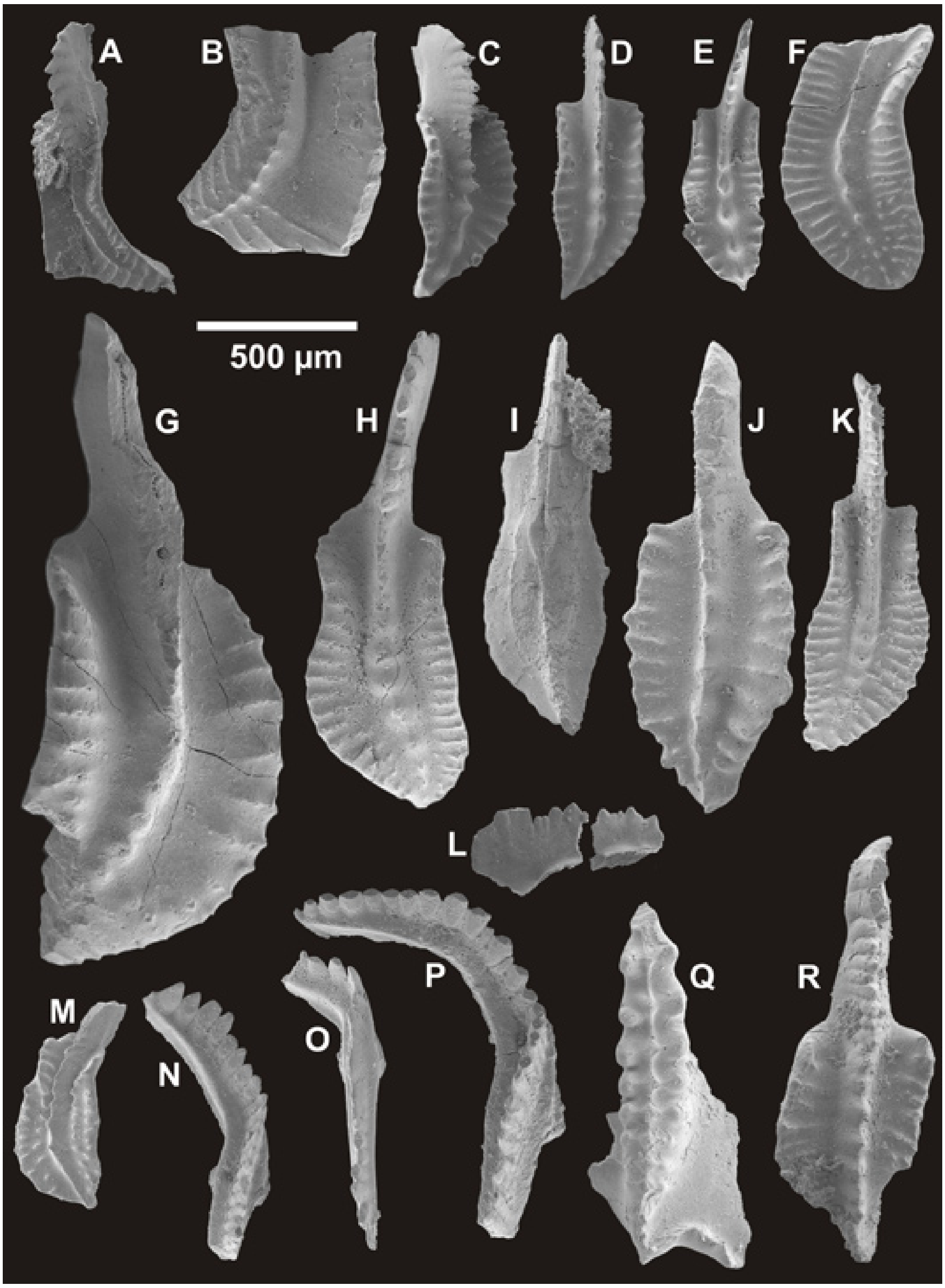

Plate 2. Selected conodont specimens from Covas Ruivas site (SEM images, all specimens are the same scale, corresponding to the 500μm scale bar on the plate) Figured conodont specimens and additional material are stored on one slide at the Museu Geológico of the Portuguese Geological Survey, inventory number 25927.

A to B – *Polygnathus serotinus* Telford, 1975; A - sample R2.2c, upper view; B - R2.6c, upper view of broken specimen

C to D – *Polygnathus costatus patulus* Klapper 1971; both specimens from sample R2.2c, upper view

E – *Polygnathus costatus* cf. *partitus* Klapper, Ziegler & Mashkova 1978; sample R2.11c, upper view

F to G – *Polygnathus* cf. *costatus costatus* Klapper 1971; F - broken specimen from sample R2.27c, G - incomplete specimen from sample R2.19c, upper view

H to I – *Polygnathus costatus costatus* Klapper 1971; H - sample R2.27c, upper view, I - sample R2.42c, lower view

J – *Polygnathus* aff. *P. trigonicus* Bischoff & Ziegler 1957, sample R2.42c, upper view

K – *Polygnathus* aff. *P. cooperi cooperi* Klapper et al. 1978, sample R2.48c, upper view

L – *Pandorinellina* cf. *expansa* Uyeno & Mason 1975, broken specimen from sample R2.2c, lateral view

M – *Polygnathus eiflius* Bischoff & Ziegler 1957, sample R2.58c, upper view

N to P – *Tortodus kockelianus australis* (Jackson 1970) (in Pedder, Jackson & Ellenor, 1970); N - sample R2.68c, upper view; O - sample R2.58c, upper view; P - sample R2.68c, upper view of deformed specimen, all specimens incomplete

Q – *Icriodus* cf. *beckmanni sinuatus* Klapper, Ziegler & Mashkova 1978, incomplete specimen from sample R2.48c, upper view

R – *Polygnathus* aff. *ansatus* Ziegler & Klapper 1976, sample R2.68c, upper view

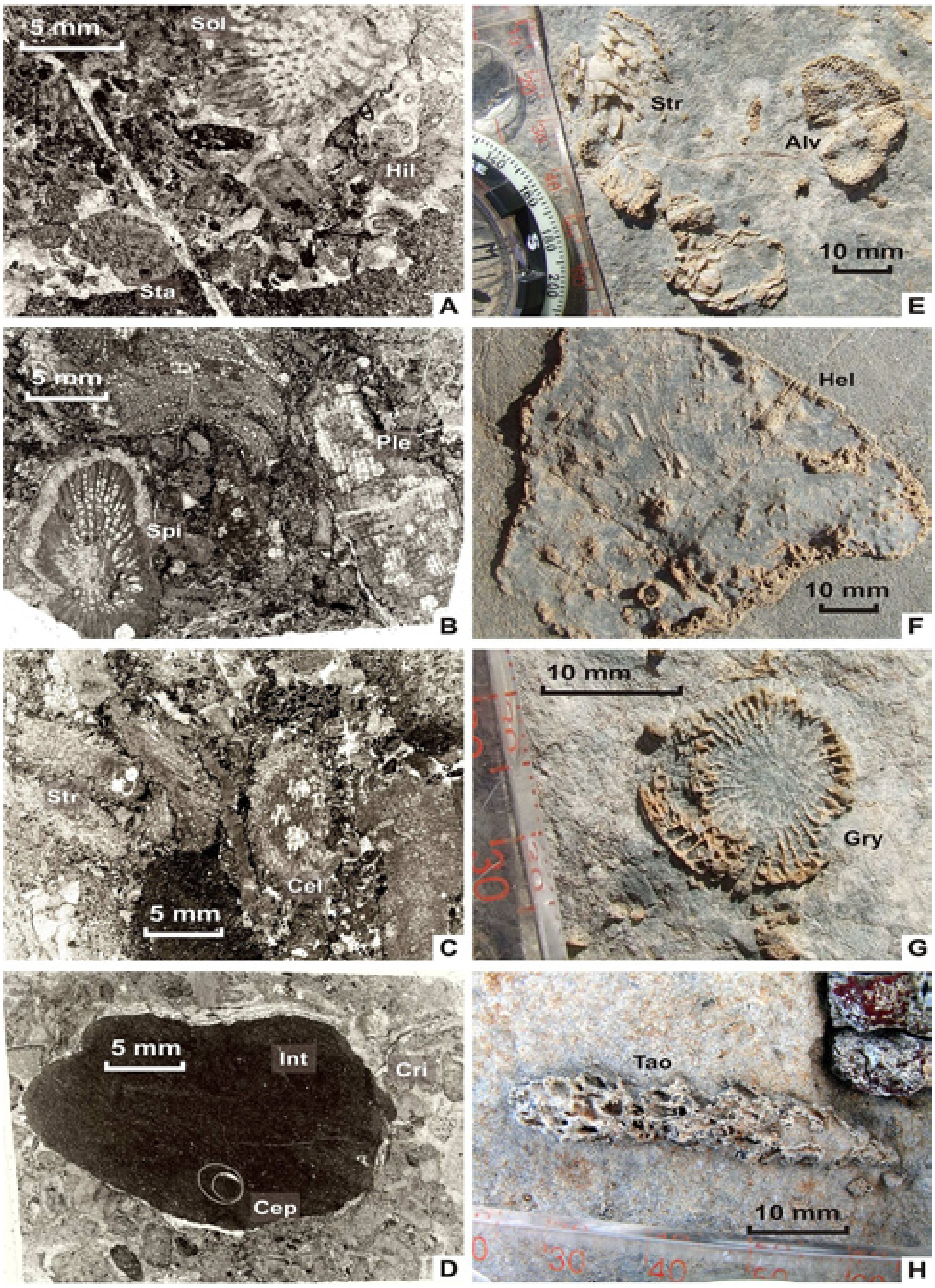

Plate 3. Selected thin section and natural weathering images of the fauna from the breccia bed at 58-61,5m of the Covas Ruivas site.
A to D – Microscopic views, thin sections, transmitted white light, photographs by J. Hladil.
A – Diversified coral and stromatoporoid bioclasts, all being altered to various degrees; crinoid columnals and ostracods are scattered in this material. 'Sol' - rugose coral *Solipetra*; 'Hil' - tabulate coral *Hillaepora*; Sta - stromatoporoid *Stachyodes*. Erosional contact with an interleaving bed of finer calciturbidite is seen at the base (above the lower edge of the picture).
B – A part of rock, where fragments of stromatoporoids prevail, occurring together with *Rhapidopora*, *Hillaepora* and amphiporids. 'Spi' - rugose coral *Spinophyllum*, 'Ple' - stromatoporoid *Plectostroma*. Note the early diagenetic, silicified and partly desilicified patches in cemented skeleton of *Plectostroma*.
C – Densely packed coral detritus is mixed with originally semi-lithified intraclasts of different compositions: from grainstones (upper right corner) to dark grey calcisiltites (lower part of this picture). 'Cel '- tabulate coral *Celechopora*, 'Str' - tabulate coral *Striatopora*.
D – Coarse grained calciturbidite with crinoidal debris contains a medium large, sub-rounded intraclast of calcisiltitic-mud sedimentary rock. This intraclast has evidently a deeper and pelagic environmental affinity when compared with shallow water debris of reef builders also found in the 'breccia' bed. 'Int' – intraclast; 'Cep' - two small cephalopod shells, with telescopic insertion of one shell into another.
E to H – Macroscopic views. Natural weathering of these rocks has very selective effect on altered and 'fresh', pure calcite bioclasts; i.e., the most of 'fresh' bioclasts are not so nicely seen in the relief. Photographs taken directly in field, by G. Machado.
E – Str - rugose coral, possibly *Stringophyllum* (or *Neostringophyllum*?), Alv - *Alveolites edwardsi*. Note that the slightly visible skeleton structures (in grey colour hues, just above the alveolitid colony as marked) may suggest a presence of a 'fresh' heliolitid skeletal fragment.
F – A medium large fragment of a colony of *Heliolites porosus* is embedded mostly in fine grained calciturbiditic grainstone. The weathering-resistant margins typically contain increased amounts of silica and dolomite.
G – Gry - rugose coral *Grypophyllum*. This coral is embedded in diversified detritus of millimetre sized clasts of pure calcite compositions, where only few crinoid ossicles are selectively weathered and have positive relief and brownish colour hues (because of slight dolomite and silica contents; mix of differently altered clasts from different parts of the reef and slope areas).
H – A partly abraded branch of tabulate coral *Taouzia*, marked as Tao in the picture. This coral is present in the layers where also intraclasts richer in original clayey and silica components occur; see the fractured intraclast in the upper right corner of the picture, for example.