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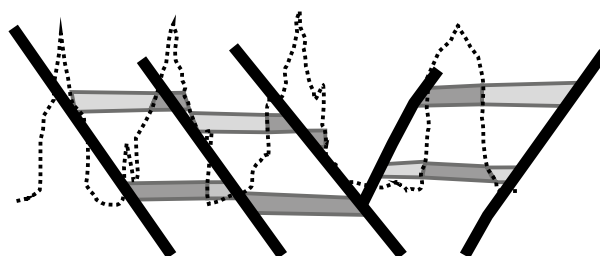
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Lower-Middle Devonian limestones of the SW border of the Ossa-Morena Zone; from local to global paleogeographic scale

Calizas del Devónico inferior a medio del suroeste de la zona de Ossa-Morena; de la escala paleogeográfica local a global

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Abstract: *The record of Lower and Middle Devonian sedimentation in the SW border of the Iberian Massif is scarce. The scattered presence of uppermost Lower Devonian to Middle Devonian limestones in the SW margin of the Ossa-Morena Zone sheds light on the local and regional paleogeography and allows to clarify geodynamic models for the northern Gondwana realm during the Devonian. The several studied localities show the presence of isolated reef structures and spatially associated calciturbidites, interpreted as a result of the erosion of the reef buildings. Coeval volcanic rocks suggest reef development was supported by volcanic edifices, but in other instances basement highs may have supported the reef structures. Two global events, the basal Choteč and the Kačák, are recorded in these limestones, providing a better understanding of the paleogeographical extent of these events and their lithological, stratigraphical and paleoecological expression.*

Keywords: *Early-Middle Devonian, Limestones, Ossa-Morena Zone, Biotic Crisis, Paleogeography*

Resumen: El registro sedimentario del Devónico Inferior y Medio en el borde suroeste del Macizo Iberico es escaso. La presencia dispersa de calizas de la parte superior del Devónico inferior y medio en el margen SW de la Zona de Ossa-Morena arroja luz sobre la paleogeografía local y regional y permite aclarar los modelos geodinámicos para el dominio norte de Gondwana durante el Devónico. Las diversas localidades estudiadas muestran la presencia de estructuras aisladas de arrecifes y calciturbiditas asociadas espacialmente, interpretadas como resultado de la erosión de los arrecifes. Las rocas volcánicas coetáneas sugieren que el desarrollo de los arrecifes se produjo sobre edificios volcánicos, pero en otros casos, los altos del basamento también pueden servir de base para el desarrollo de las estructuras de arrecifes. Dos eventos globales, el Choteč basal y el Kačák, se registran en estas calizas, proporcionando una mejor comprensión de la extensión paleogeográfica de estos eventos, su expresión litológica, estratigráfica y paleoecológica.

Palabras clave: Devónico Inferior-Medio, Calizas, Zona Ossa-Morena, Crisis Biótica, Paleogeografía

INTRODUCTION

The Devonian period is characterized by several biotic crisis events, when compared to other Phanerozoic periods, generally associated with global mass extinctions in both marine and terrestrial realms (e.g. Bábek et al., 2018; Machado et al., 2020). These biotic crisis events are generally preserved in the geological record, as the result of several causes which includes environmental and biological/ecological changes (Bábek et al., 2018). The recognition of those events is crucial to the reconstitution of local and global paleoecology, paleoenvironment and paleogeography of the Devonian period.

The present paper focuses on the stratigraphic characterization of the Lower-Middle Devonian limestones of the SW border of the Ossa-Morena Zone (OMZ), emphasizing the significance of carbonate sedimentation along the SW domains of the Iberian Massif and framing it in the

geodynamic evolution and paleogeography of the northern edge of the Gondwana landmass.

GEOLOGICAL SETTING

The Devonian sedimentation of the OMZ is fragmentary; the Lower Devonian succession is dominated by siliciclastic rocks, while the Middle and Upper Devonian is considered absent (Robardet and Gutiérrez-Marco, 2004; Oliveira et al., 2019). However, along the SW border of the OMZ, Lower and Middle Devonian limestones were identified (e.g. Oliveira et al., 2019). Those rocks are associated either with volcanic rocks (Rebolado Basalts, coeval of Devonian limestones; Moreira et al., 2010) or with a Mississippian flysch succession, although the geometrical relation between both units allows conflicting interpretations (Oliveira et al., 2019 and references therein): the limestones were considered olistoliths or tectonically imbricated

within the Mississippian siliciclastic rocks, although some are covered by the carboniferous succession, and that contact is marked by a polygenic conglomerate which outlines an unconformity. Nevertheless, it is important to emphasize that Devonian limestones are scarce and the most common feature of the OMZ is the absence of the Middle and Upper Devonian successions.

DEVONIAN LIMESTONES OF THE SW BORDER OF THE OSSA-MORENA ZONE

As mentioned, the SW OMZ limestones are scarce and disperse (Oliveira et al., 2019) and two formations are well-defined, described below.

- Odivelas Limestone

This formation was initially defined in the Cortes section (Conde and Andrade, 1974), with a second section in the same area (Covas Ruivas). The limestones from the Cortes section was considered as Middle-Upper Devonian based on the macrofauna association, namely brachypods, bryozoans, conodonts and trilobites (Conde and Andrade, 1974). The authors also describe the presence of crinoids, stromatoporoids and coral faunas. Machado et al. (2009), with new sampling, identified several genera and species of rugose and tabulate corals, brachiopods, crinoids and stromatoporoids, preserving bioherm/ biostromal facies. In this section, beyond the reefal facies, coeval peri-reefal bioclastic calciturbidites were also identified (Machado et al., 2009), containing abundant crinoids and minor amounts of tentaculitids, sponge spicules and ostracods (Machado et al., 2020), occasionally with black chert nodules. The new biostratigraphic assessment indicates a Late Eifelian-Early Givetian age, recently supported by conodont data in calciturbidites (Fig.1; *hemiansatus* biozone; Machado et al., 2020).

The Covas Ruivas section is a 200 m thick succession with Emsian-Eifelian age (Fig.1; *patulus* to *australis* zones; Machado et al., 2010). This succession is mainly composed of bioclastic dark calciturbidites, ranging from coarse-grained sand to shale, interspersed with hemipelagic tuffites. The bioclasts are dominated by crinoids, with small amounts of tentaculites, ostracods, bryozoans, stromatoporoids and corals (Machado et al., 2010). Several evidences of syn-sedimentary deformation (e.g. convolute bedding or slumps) were identified.

The low $^{87}\text{Sr}/^{86}\text{Sr}$ values of both sections are correlatable with the seawater signature during the uppermost Lower-Middle Devonian for both sections (Moreira et al., 2019).

- Pedreira da Engenharia Limestone

The first biostratigraphic study of this formation was done by Boogaard (1972), which indicated a Middle Devonian age to this succession; new data specifies an Early-Middle Eifelian age (Fig.1; *costatus* to *australis* zones; Silvério et al., 2019). The 30 m thick succession is composed of dark-grey calciturbidites, with centimeter to decimeter beds, with grain-size ranging from fine-grained sand to shale (Silvério et al., 2019), also showing evidences of syn-se-

dimentary deformation. Crinoids, ostracodes, radiolarians and abundant dactyloconarids were also identified in the calciturbidites.

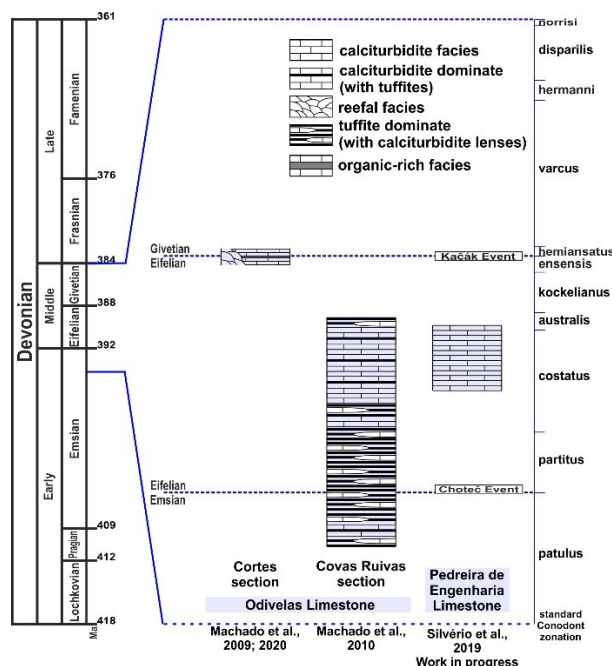


FIGURE 1. Schematic stratigraphic sections at the Odivelas and Pedreira da Engenharia Limestone, with indication of conodont biozones and the identified major biotic crisis events.

LOCAL PALEOGEOGRAPHY

The described successions emphasize the association between the reefal and calciturbidite facies in the Cortes section, contrary to the other sections. The fossiliferous content of the Cortes section indicates a well-developed reef system, with significant diversity of reefal faunas (crinoids, corals and stromatoporoids). The calciturbidites include frequent fragments of crinoids and common coarse-grained calciturbidites, which seems to indicate the proximal nature of these deposits.

In the Covas Ruivas section, there is an association between volcanic-derived tuffites with calciturbidites. The abundance of reefal-derived bioclasts, namely crinoids, stromatoporoids and corals (Machado et al., 2010) seems to indicate that sedimentation also took place in a peri-reefal environment. Furthermore, the coarser-grained, usually massive, base and thinner-laminated top suggest a low density calciturbidite type of sedimentation, with significant instability during sedimentation, as proved by abundant syn-sedimentary deformation structures. The relative abundance of fine-grained calciturbidites (Machado et al., 2010) indicates a considerable transport distance, implying that the deposition area is not in the close vicinity of a bioherm/biostrome (possibly at the base of the slope), which is in accordance to their association with hemipelagic tuffites.

The depositional environment of Pedreira da Engenharia calciturbidites is quite similar to those described to Covas Ruivas section. The significant amounts of dactyloconarids

rid specimens (Silvério et al., 2019) and the clear dominance of fine-grained calciturbidites, seems to record a distal depositional environment (possibly base of slope) of low-density carbonate turbidites deriving from a reef area (Silvério et al., 2019).

The Devonian carbonate sedimentation can be interpreted as peri-reefal calciturbidites, associated to a reefal system (only preserved in Cortes section) developed near the SW border of the OMZ. The presence of coeval extrusive volcanic rocks (Rebolado Basalts) in the Covas Ruivas section (Moreira et al., 2010) indicates that the reef systems, or part of them, were developed around the top of volcanic edifices, possibly forming atoll-like structures, near the sea surface allowing the colonization and development of reef building taxa. These environmental conditions allow the erosion/dismantlement of reef systems, developed on the flanks of the volcanic edifices, along their edges, generating coeval peri-reefal sedimentation represented by the calciturbidite successions, with occasional debris-flow breccias (Machado et al., 2010), which extend at least to the base of the slope. The presence of syn-sedimentary deformation in the calciturbidite succession is also in accordance with the proposed depositional environment and local paleogeography and can be explained either by the topographic slope or by the contemporaneous volcanic and/or tectonic activity. It is not excluded that some of these reefal structures could be developed in basement highs, as there is no direct evidence for coeval volcanic rocks in the Pedreira de Engenharia section (Oliveira et al., 2019).

HOW GLOBAL EVENTS ARE REGISTERED

Four major global extinction events are well-documented in Gondwana, but also in Baltica and Laurentia, during the Lower to Middle Devonian, namely: the Lochkovian/Praagian Event, the Daleje Event, the Basal Choteč (jugleri) Event, and the Kačák (otomari) Event (Bábek et al., 2018 and references therein). Among these Lower-Middle Devonian prominent events, two events are preserved in the SW of the OMZ, both in Odivelas Limestones sections (Fig. 1): the Choteč and the Kačák events (Machado et al., 2009; 2010; 2020).

In the Covas Ruivas section, the magnetic susceptibility and lithological record of the basal part of this section is consistent with the Basal Choteč Event (Machado et al., 2010). This global transgressive event is located just above the Emsian-Eifelian boundary (Fig. 1; Machado et al., 2010; Koptiková, 2011), being materialized by suboxic-deposited organic-rich sediments and low carbonate sedimentation rates, followed by coarse bioclastic calciturbidites and debris-flow carbonate breccias. This lithological succession closely matches the one described in the Covas Ruivas section from upper partitus to costatus conodont zones.

In summary, the magnetic susceptibility record, the described lithological succession and the obtained ages are consistent with the Basal Choteč Event of other localities around the world (Fig. 2; see Machado et al. 2010 and references therein for details).

The Cortes calciturbidites succession seems to be consistent with the record of the Kačák Event. This event is characterized by a hypoxic-anoxic depositional setting, recorded in a 2m thick calciturbidite section with condensed stratigraphy.

The Cortes dark organic-rich calciturbidites, with chert nodules, present low magnetic susceptibility magnitudes and the pattern is tentatively correlatable to the end-Eifelian record of the Moravian Karst section (Czech Republic), where the Kačák Event is well-constrained (see Machado et al. 2009 and references therein for details); the conodont ages confirms the Emsian-Givetian age for this succession (Machado et al., 2020). Recent data also indicates an anomalous abundance of putative fungal hyphae and prasinophycean algae in the same section (Machado et al., 2020). Similar stratigraphic record was described in other Devonian biotic crisis (e.g. Brocke et al. 2016) and the abundance of these organic particles was interpreted as related with both marine and terrestrial crisis during the Kačák event (Machado et al., 2020). Similar uppermost Eifelian – lowermost Givetian successions characterized by high marine organic productivity, evidenced by dark organic matter-rich limestones or shales within coarser and lighter limestones sections have been described previously for the Kačák Event, which was interpreted as a global scale transgressive episode (see Machado et al. 2020 and references therein for details).

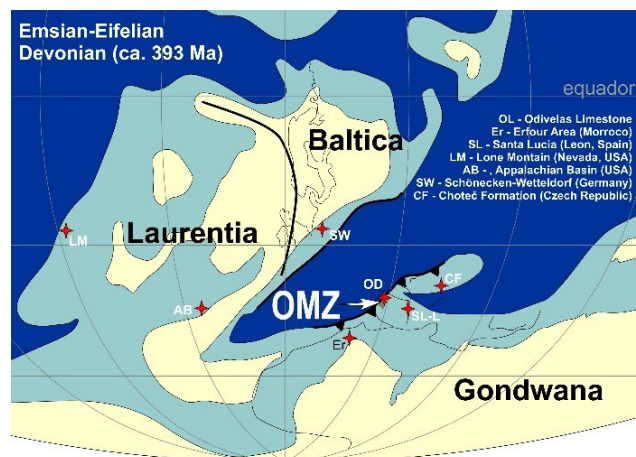


FIGURE 2. Location of Eifelian-Emsian successions where Basal Choteč Event was identified (locations adapted from Ellwood et al., 2006; Machado et al., 2010; Brucke et al., 2016; paleogeographic map adapted from Scotese, 2014; Dias et al., 2016).

THE NORTH GONDWANA PALEOGEOGRAPHY

During uppermost Lower to Middle Devonian, the northern realm of the Gondwana was characterized by extensive epicontinental seas, developed in low to middle latitudes (Fig. 2), associated with particular paleoclimatic conditions, such as high insolation levels and high temperatures.

Several authors point to the beginning of subduction of Variscan Ocean(s) along the northern margin of Gond-

wana during the Lower-Middle Devonian (e.g. Moreira et al., 2014; Dias et al., 2016; Oliveira et al., 2019) and in the SW branch of the Iberian Massif, namely in the OMZ, the subduction process generates a volcanic arc and sea-floor elevations (basement highs) during the deformation process. This local paleogeographical setting and the paleoclimatic conditions may have favoured the development of reef fauna, with generation of atoll-like structures, and associated calciturbidite successions. The crustal uplift of the OMZ during the Middle Devonian (Moreira et al. 2014) explains the absence of sedimentation and the Odivelas and Pedreira de Engenharia Limestone, among other limestones occurrences in the SW of OMZ, can be interpreted as isolated reefs, not larger than a few km across, explaining their scarce and disperse nature. The presence of land-derived particles (filaments) in Cortes section is in agreement with this interpretation, implying the relative proximity of land (possibly a volcanic-arc island) during Givetian times.

In the Odivelas Limestone, the reef fauna is particularly diversified, containing organic elements which are typical of the Peri-Laurussian realm, but also Peri-Gondwana ones (Machado et al. 2009; 2010). This data indicates a proximity between both realms during the Middle Devonian, consistent with Variscan Ocean(s) subduction during Devonian times.

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