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Article

Stratigraphic succession, facies and depositional environment of Emsian reefal carbonates in the Ossa-Morena Zone (SW Spain)

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With 6 figures

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Abstract: The Devonian succession between the Guadiana and Guadalquivir valleys in the Obejo-Valsequillo Domain comprises more than 600 m of shale and sandstone with some interbedded limestone and marl. The most complete reefal sequences of the region are exposed in the Guadámez-2 section, which is located on the western bank of the Guadámez River, near Zalamea de la Serena. It consists mainly of shale and calcareous shale in its lower part and shaly, skeletal and reefal limestone in its upper part. Conodont and brachiopod data indicate that this section spans the interval from the Lochkovian to at least the upper Emsian. Eight microfacies types have been identified in the calcareous facies: A, brachiopod-echinoderm wackestone/packstone; B1, echinoderm grainstone; B2, echinoderm-bryozoan grainstone/packstone; C, echinoderm packstone; D, tabulate coral rudstone; E, brachiopod wackestone/packstone; F, brachiopod grainstone/packstone; and G, stromatoporoid and tabulate coral boundstone/rudstone. Microfacies A, B1, C, E and F represent a sequence of environments from middle platform (A) to tidal flat (F), including shoals (B1) and shallow platform facies. Microfacies B2, D and G represent the development of patch-reefs superimposed on the shoals.

Key words: Lower Devonian, Emsian, Spain, microfacies, facies, reefs, carbonates, paleoenvironments.

1. Introduction

Devonian rocks crop out at Sierra Morena in Southwestern Spain, along 200 km from Cáceres in the Northwest to Córdoba in the Southeast, near the Guadalquivir Valley (Fig. 1). They cover a part of the Obejo-Valsequillo-Puebla de la Reina Domain that is located in the controversial area of contact between Ossa-Morena and Centro-Iberian zones (Lotze 1945). For detailed discussions about this matter see Dallmeyer & Martínez-García (1990), Quesada (2006), and Ribeiro et al. (2007). The Devonian succession in that area comprises more than 600 m of shale and sandstone with some interbedded limestone and marl. In spite of the presence of abundant fossils in the limestone, palaeontological studies are very scarce.

The oldest references (Herranz 1970 and Llopis-Lladó et al. 1970) are devoted to the Devonian regional stratigraphy. Both papers indicated the pre-

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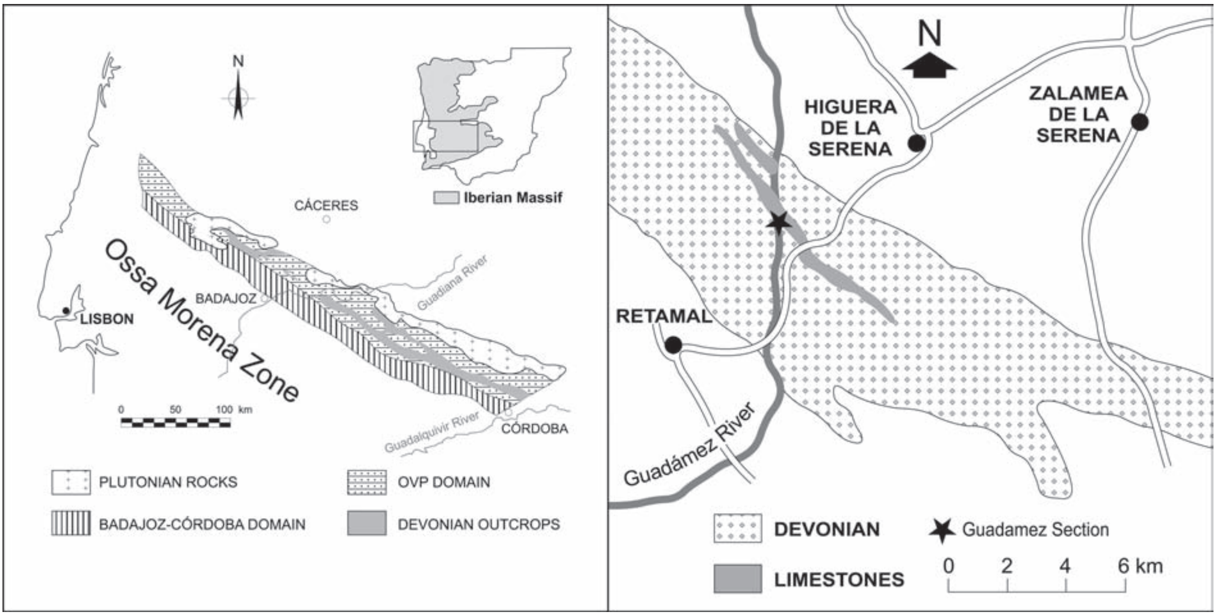

Fig. 1. Location map of the Guadámez 2 outcrop.

sence of coral facies and abundant brachiopods. They assigned an Emsian age to the limestone. Rodríguez (1978) analysed the stratigraphy of limestone in several outcrops and described some rugose corals from Chamorra, Guadámez and Peñón Cortado sections. Rodríguez & Soto (1979) described some additional corals, mainly from the Arroyo del Pozo del Rincón locality. After the new coral identifications, the age of this locality was regarded as Givetian. Herranz (1984) described the general stratigraphy of the Devonian in the northern area (between Hornachos and Mérida). Moreno-Eiris et al. (1995) described some localities for a field trip during the VII Fossil Cnidaria symposium, but they did not add any new data on the visited localities. May (1999) described some stromatoporoids collected during that field trip.

Recently, Liao et al. (2003) identified Lochkovian/Pragian conodont assemblages from the Arroyo del Pozo del Rincón section, showing the existence of an important discontinuity in the limestone succession at that locality. This study prompted a group of palaeontologists from the universities of Valencia, León and Madrid to initiate a more detailed study of the main Devonian outcrops in Sierra Morena (Research Project BTE 2003-2065). Our research-team has studied some of the most interesting outcrops in the north-western area during the last 3 years. The most complete successions containing reefal facies are located in four sections, named Guadámez-2, Peñón Cortado, Zújar and Arroyo del Pozo del Rincón. To date, this project has produced several papers that provide additional information on stromatoporoids (May 2004, 2006, 2007), tabulate corals (Fernández-Martínez 2005), conodonts, brachiopods, ostracods, fishes and more precise age determination (Valenzuela et al. 2006a, b), and also about the structure and stratigraphy of the Devonian outcrops (Pardo & Valenzuela 2006).

The main aims of this paper are: 1) to describe the stratigraphical succession at Guadámez-2 section; 2) to describe the facies from that succession with special emphasis on reefal facies; and 3) to analyse the environment in which the deposition of reefal rocks took place. This section is especially interesting because it shows the best natural Devonian outcrop in the region and because the main reefal development there took place during the Emsian. Most other sections (Zújar, Arroyo del Lobo, Peñón Cortado) show Pragian reefal development and scarce bioconstruction processes during the Emsian, but reefal development is conspicuous in Guadámez-2. Being a single section, our reconstruction is limited and we do not try to establish a general model for the Devonian sedimentation of the area, but to identify the processes that allowed a reefal development in a mainly silici-

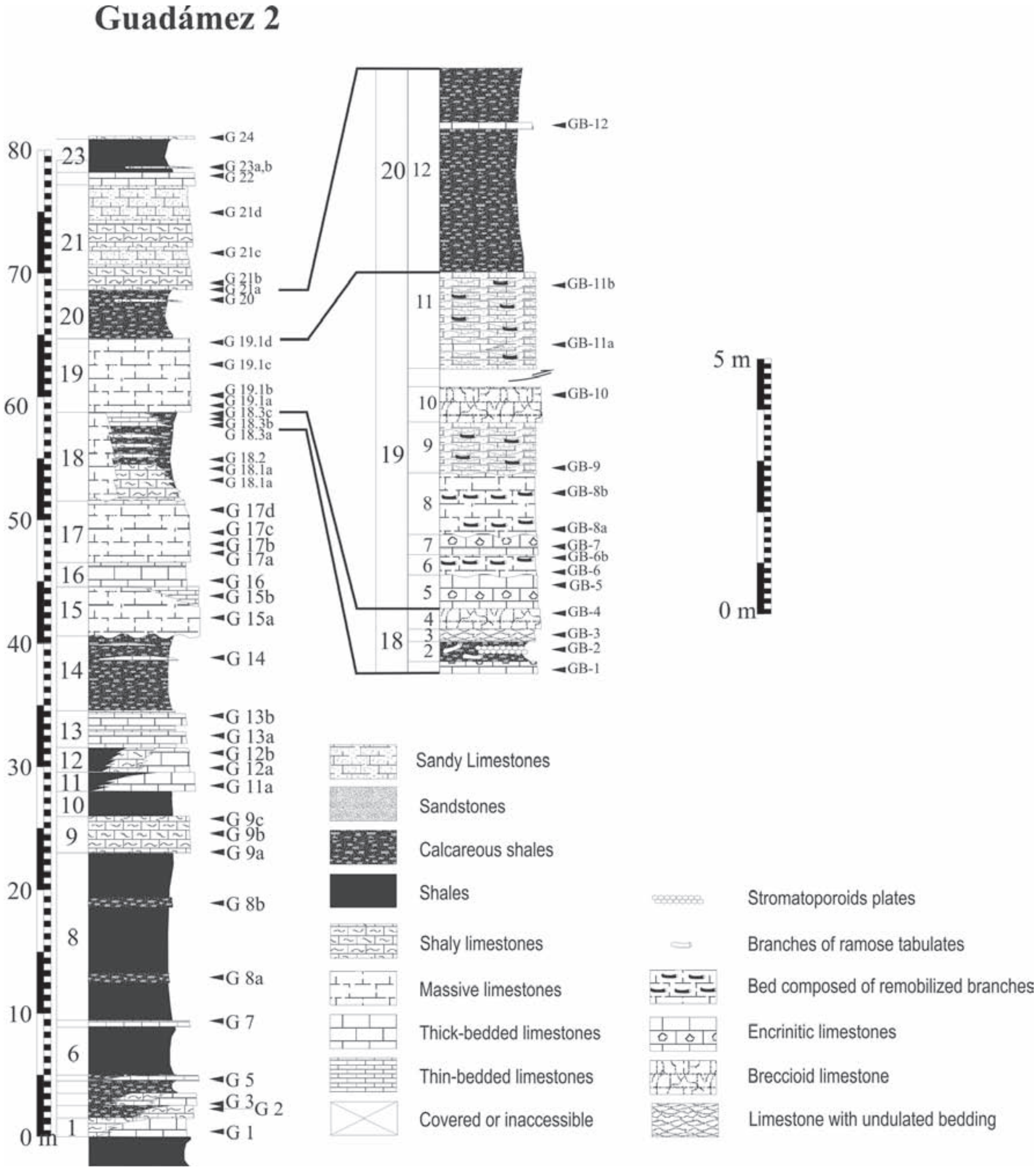

Fig. 2. Stratigraphical sections at Guadámez 2 outcrop.

clastic basin. A general model for the Devonian limestone sedimentation in the Obejo-Valsequillo Domain will be established when the study of all other sections (Peñón Cortado, Arroyo del Lobo and Zújar) will be completed.

2. Geographical and geological setting

The Guadámez 2 outcrop is located at the western bank of the Guadámez River, 2 km to the northwest of km 12 of the road from Campillo de Llerena to Higuera de la Serena, in the Badajoz Province (Fig. 1).

Devonian limestone crops out along a northwest-southeast strip of 6 km in that area and crosses the Guadámez River valley. Two main sections were studied there by Rodríguez (1978) who named them Guadámez-1 and Guadámez-2. The Guadámez-1 section is exposed in some old quarries, but it is discontinuous and facies are very monotonous, consisting only of calcareous shale and echinoderm limestone, and lacking the reefal facies that are exposed in Guadámez-2. Although we studied this section for comparison to Guadámez-2, it did not provide any valuable information.

Rodríguez (1978) summarily described the Guadámez-2 section and cited the presence of rugose and tabulate corals, brachiopods, bryozoans and echinoderms, among others. He regarded a part of the succession as being a "Tabulate/stromatoporoid bioherm".

2.1. General description of the Guadámez-2 section

The Guadámez-2 section is composed of 82 metres of shales, calcareous shales, limestones and shaly limestones, with some beds of sandstones (Figs. 2-3); massive bioclastic and reefal limestone are conspicuous in the middle upper part of the section. It can be divided into four parts.

Part I. Units 1-8. The succession begins with shales, marly and sandy shales with interbedded lenses of well bedded limestones, 5 to 50 cm thick, with irregular bases and conspicuous variations in thickness (Fig. 3a). The limestone beds show microfacies A (see below). The siliciclastic rocks are mainly monotonous sequences of lutites and limolites containing low percentages of marl and thin beds of quartz sandstones (2-5 mm, rarely up to 10 cm in thickness) that show cross lamination. Quartz grains are angular and always very small (< 0.5 mm). The upper units of this part show levels with some broken branches of *Parastriatopora* ex gr *floralis-annulata*. Based on the conodont record, part I is Lochkovian in age because of the presence of *Icriodus lotzei* (unit 4), *Icriodus fallax* and *Icriodus* ex. gr. *angustoides* (unit 8) (Valenzuela et al. 2006a, b; Pardo & Valenzuela 2006).

Part II. Units 9-18.3a. Part II is composed of 34 m of limestone, and calcareous shales (Fig. 3a, b). Calcareous shales show increasing quantity of marl and sandstones are reduced to small lenses 1-2 cm in thickness having low lateral continuity. The most conspicuous lithology are massive limestone beds, 1 to 7 m thick, with erosive bases, convex upper surfaces and cross stratification (units 9, 11, 13 15, and 17). They show microfacies B1. The interbedded calcareous shales show microfacies C (Units 12, 14, 16, 18-1, and 18-3). Good outcrops of this lithology occur only close to the Guadámez River where they yielded common brachiopods (*Pleurochonetes* sp., *Euryspirifer* cf. *pellicoi, Hysterolites* sp., *Leptostrophia* sp., *Meganteris* sp., *Brachyspirifer* sp., *Xana* sp., Strophomenidina indet., Athyrididae indet.), branched tabulates (*Coenites* sp., *Cladopora* sp., *Thamnopora* sp.) and scarce rugose corals. Part II is Pragian to Emsian in age, based on the presence of *Icriodus angustoides angustoides* (units 9-15) and *Icriodus celtibericus* (unit 17a) (Vaalenzuela et al. 2006a, b; Pardo & Valenzuela 2006).

Part III. Units 18.3b and 19. Part III comprises 8 m of massive limestone with high percentages of fossils of reef building organisms, interbedded with shaly limestones and calcareous shales containing common fragments of brachiopods (Fig. 3c). Sandstones are totally absent in this part of the section. Beds show undulate stratification. This part represents partly a bioconstruction; a detailed section has been measured in this part (GB), about 50 metres southwards of the main section, where the bioconstruction reaches its maximum development. Microfacies represented in this part are B2, D and G. The most conspicuous macrofossils are crinoids and brachiopods (*Uncinulus* cf. *pila, Brachyspirifer* sp., *Oligoptycherhynchus* gr. *pareti, Plicostropheodonta* sp., Athyrididae indet.). The age of part III is Emsian (Valenzuela et al. 2006a, b; Pardo & Valenzuela 2006).

Part IV. Units 20 to 24. Part IV consists of 16 m of calcareous shales, shaly and sandy limestones, thick-bedded limestone and shales corresponding to

Fig. 3. Guadámez 2 column and field aspects of selected levels. a) View of the upper part of unit 8 and units 9 to 13. b) View of the units 15 to 17. c) View of the upper part of unit 19. d) View of unit 20.

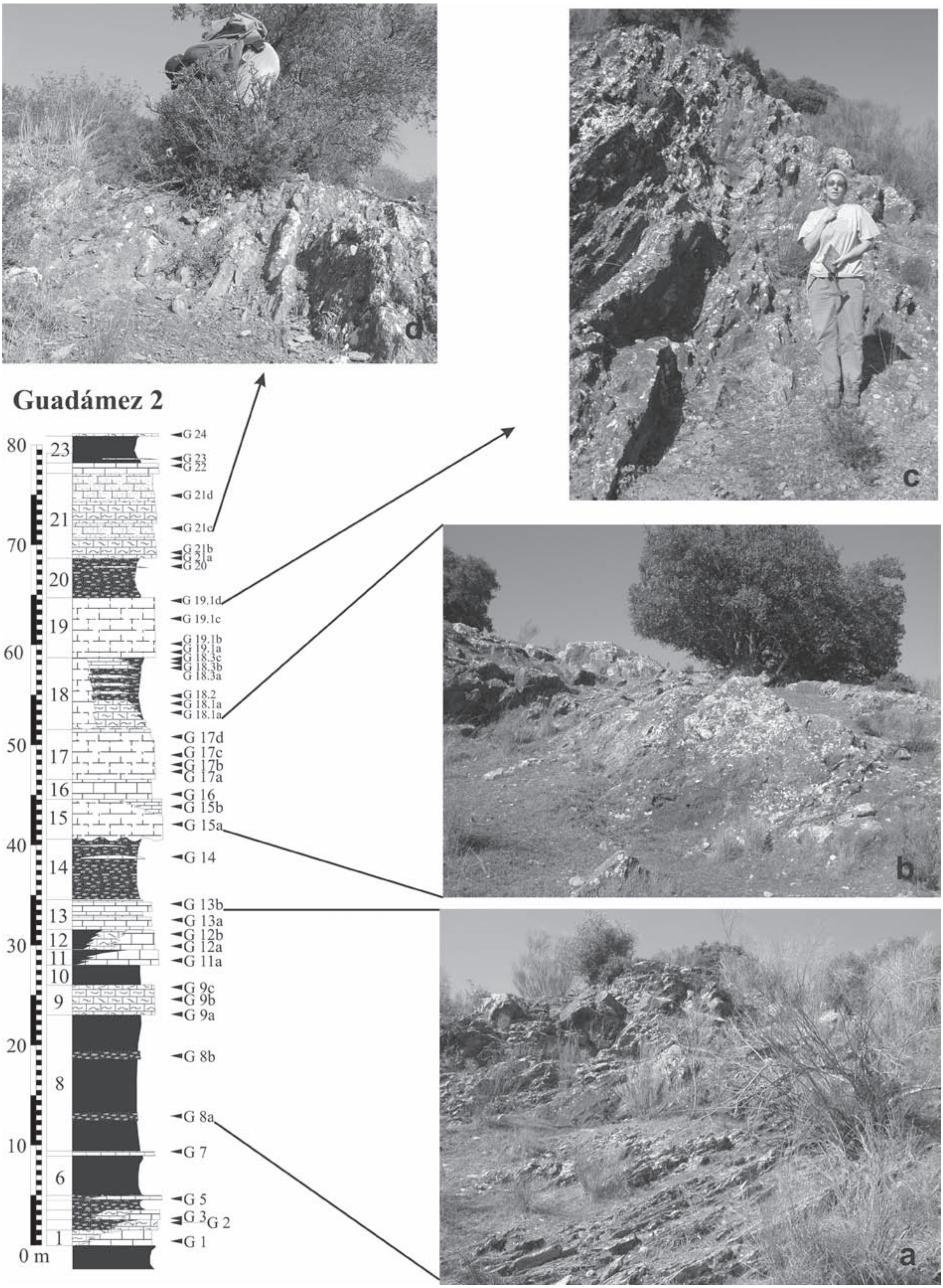

Fig. 3 (Legend see p. 72)

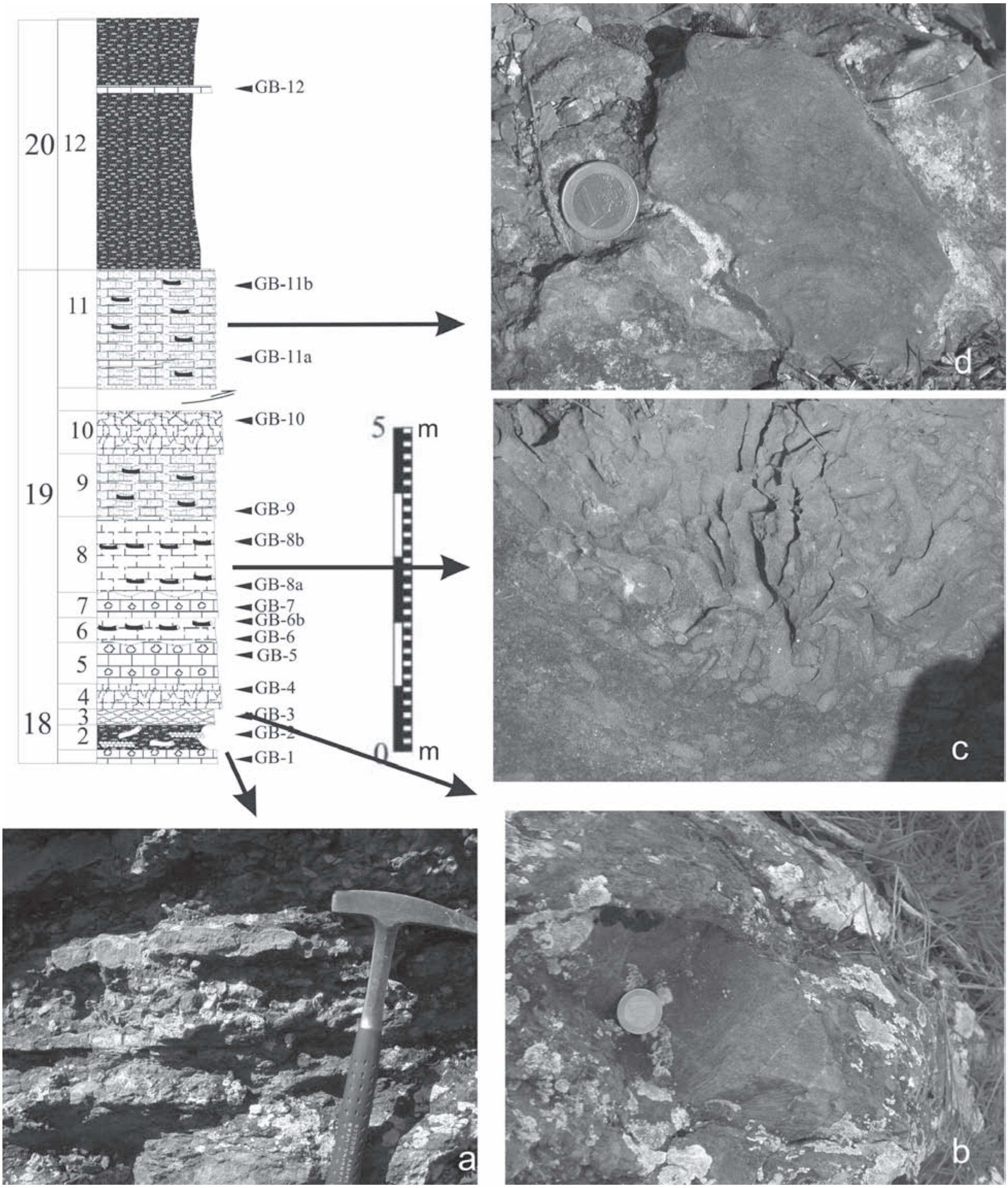

Fig. 4. Details of reefal facies. a) Unit GB-2; masses of branching tabulates encrusted by laminar and tabular bryozoans and stromatoporoids. (*Pseudotrupetostroma anacontentoae* May, 2007) b) Unit GB-4; rudstone of massive tabulates and stromatoporoids. c) Unit GB-8; branching tabulates in growth position. d) Unit GB-11. Rudstone of stromatoporoids.

microfacies E and F (Fig. 3d). No individual beds of sandstones have been recorded, but quartz grains are abundant in many beds having the same features as in Part I. Quantity of quartz increase and thick sequences of thick grained sandstones showing cross stratification occur two meters above the last limestones beds. The lower part, composed of 3.5 m of calcareous shales, is very rich in brachiopods (*Brachyspirifer* sp., *Iridistrophia* sp. *Plicostropheodonta* sp., *Plebejochonetes* sp.). This part is Upper Emsian in age based on the presence of Icriodus corniger ancestralis (unit 22) and *Icriodus corniger* cf. *leptus* (unit 24) (Valenzuela et al. 2006a, b; Pardo & Valenzuela 2006).

3. Description of bioconstructed units

As explained above, units 18.3b to 19 are composed of reefal limestone. A detailed section has been measured close to the Guadámez River, about 50 m southwards from the main section. This section has been divided into 12 units (GB-1 to GB-12; Fig. 2).

Some metres below the main reefal episode, at the base of the unit 18.3 (bed 18.3a), we observed a small lens about 10 cm thick, composed of branching tabulate corals and showing common epizoans (encrusting bryozoans and stromatoporoids, *Girvanella, Rothpletzella*, etc.). Auloporoids occur in the marly matrix present around the lens.

GB-1: (15-20 cm). Echinoderm packstone, Facies C.

GB-2: (40 cm). Marly limestone mainly composed of broken ramose tabulate corals (Thamnopora spp.) that lie parallel to the strata surface and are covered by encrusting stromatoporoids and more rarely by bryozoans, and alveolitids (Alveolites sp.), Facies D (Fig. 4a).

GB-3: (25 cm, highly variable). Nodular limestone composed of laminar and tabular stromatoporoids and branching (*Thamnopora* spp.), tabular and low domal massive tabulate corals (*Squameofavosites* sp.), Facies G.

GB-4: (40-45 cm). Massive limestone composed mainly of branching (*Thamnopora* spp., *Coenites* sp.) laminar (*Alveolites* sp.) and massive (*Squameofavosites* sp.) tabulate corals and stromatoporoids. Skeletons are commonly broken and removed, Facies G (Fig. 4b).

GB-5: (75 cm). Echinoderm grainstone, Facies B2.

GB-6: (40 cm). Massive limestone with abundant branching tabulate corals (*Thamnopora* sp.), Facies D, locally B2.

GB-7: (40 cm). Echinoderm grainstone, Facies B2.

GB-8: (120 cm). Massive limestone composed of branching tabulate corals (*Thamnopora* sp.) that in some instances are in growth position, showing a bafflestone structure, Facies D (Fig. 4c). Breccioid limestone composed of fragments of corals and stromatoporoids (Facies G) occur between the bafflestone layers.

GB-9: (100 cm). Marly limestone with long, bifurcated, not eroded branches that show a random distribution, Facies D.

GB-10: (70 cm). Massive limestone composed of massive favositids (*Favosites* spp.), heliolitids (*Heliolites* sp.) and stromatoporoids (Fig. 4d). They are mainly broken and removed, but occasionally in growth position, Facies G.

GB-11: (70 cm). Limestone with undulated stratification composed of branching (*Thamnopora* spp.) and massive tabulates (*Favosites* spp., *Squameofavosites* sp., *Alveolites* sp., *Heliolites* sp.) and stromatoporoids, Facies G.

GB-12: Sandy and shaly limestone, Facies E.

4. Facies analysis

Diverse facies have been identified in the Guadámez 2 Section. Some of them correspond to siliciclastic rocks: siltstones (shales) and sandstones. Our study has been focused on the calcareous facies that show characteristic microfacies; we distinguished seven facies that have been labelled with letters A-G.

Facies A: Brachiopod-echinoderm wackestone/packstone

Occurrence: Units G-1, 2, 3, 5, 7, 8a, b (Fig. 2).

Field observations: Thin to middle thick beds (5-50 cm) of marly limestone, with flat base and top, but showing lateral variation in thickness. They are interbedded with marly limolites and lutites.

Microfacies description: Wackestone and less commonly packstone mainly composed of brachiopods (5-20%) and echinoderms (1-10%). Less common components are bryozoans, trilobites, ostracods and rare tabulates (fragments of parastriatoporid branches and michelinids), rugosans (*Adradosia* sp.) and fish scales. Percentage of angular quartz grains is usually lower than 10 %, but in

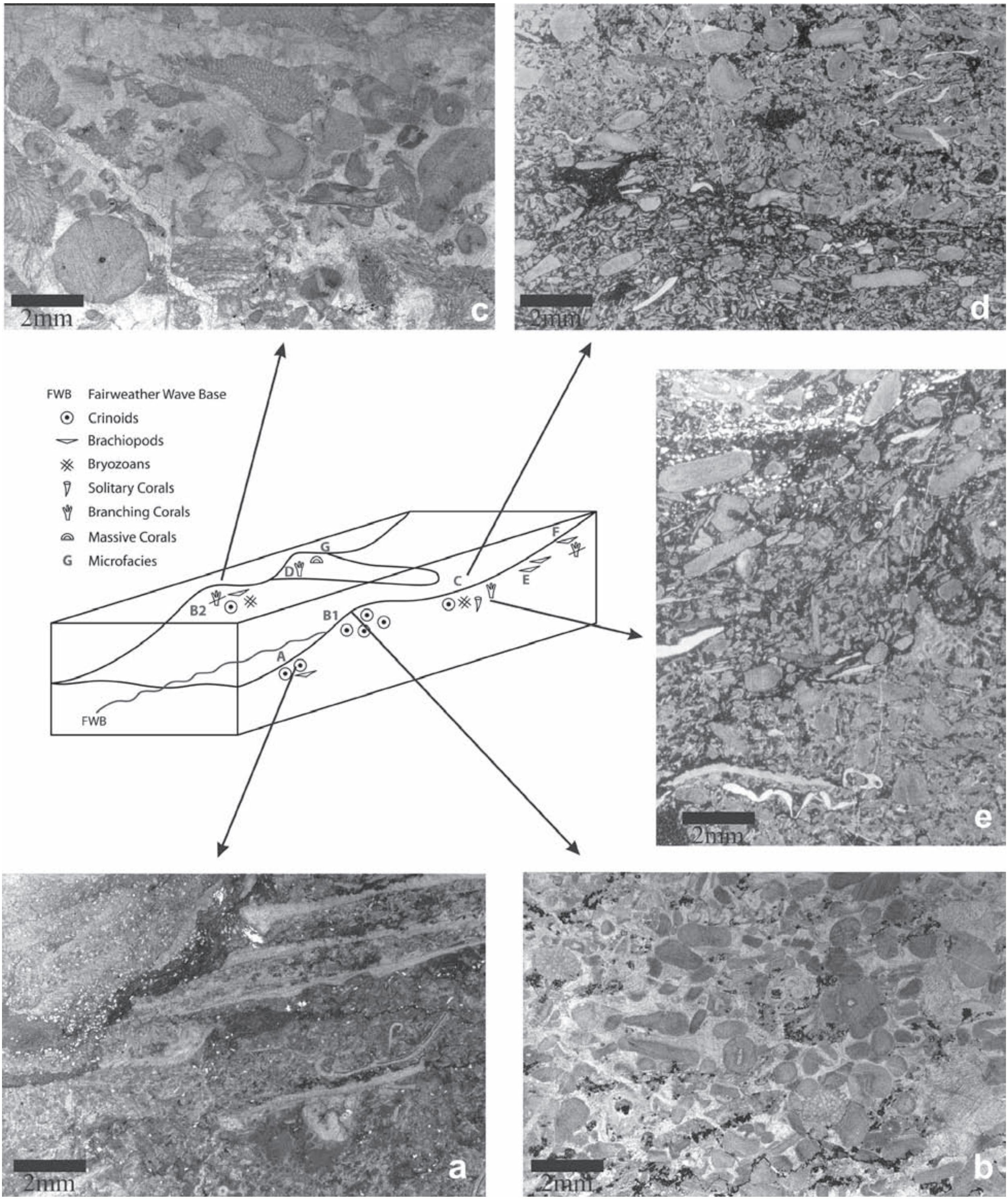

Fig. 5. Microfacies A-C. a) G-4, microfacies A, brachiopod-echinoderm wackestone; b) G-17, microfacies B1, echinoderm grainstone; c) GB-1, microfacies B2, echinoderm-bryozoan grainstone; d) G-16, microfacies C, echinoderm packstone; e) G-18a, microfacies C, echinoderm packstone.

some samples it reaches up to 35 % (G-7). Peloids rarely occur. Spectrum of fossil components is middle/high and only brachiopods and echinoderms are abundant (Fig. 5a). This microfacies shows a low degree of grain selection and an intense bioturbation that notably modifies the original texture of the rock. In preserved zones, the elongated clasts are parallel to the stratification, beds thus showing flat or slightly oblique lamination. Packstone layers show higher disorder of clasts than wackestone layers. Bioclasts are strongly fragmented and disarticulated. Beds with low bioturbation show lower fragmentation but also high disarticulation. Occasionally, geopetal infillings in brachiopods that are parallel to the strata surfaces, indicate that they were not reworked alter burial (G-2).

Environment: Presence of high levels of fragmentation and disarticulation indicates that the environment suffered moderate to high degrees of energy; fragmentation is partly due to bioturbation (Sepkoski et. al. 1991), but disarticulation is mainly due to the original water movement, because even beds with low level of bioturbation show mostly disarticulated bioclasts. Energy was, however, fluctuating, because all samples show high percentage of micrite, which indicates long quiescent periods (Flügel 2004). Abundance and diversity of bioclasts and presence of stenohaline organisms (brachiopods, corals, echinoderms) show that salinity was normal marine. By similar reasons we assume that oxygenation was high (aerobic zone). Presence of brachiopods with spines and echinoderms with rootlets indicate a firm substrate (Racki & Balinski (1981). Hard substrate impedes the use of such systems of attachment and soft substrate made them useless.

All these environmental factors are typical of shallow platform, located below the fair weather wave base, but above the storm wave base (Fig. 5). Fragmentation, disarticulation and disorder of clasts were produced during the storm periods (Seilacher & Aigner 1991).

Facies B1: Echinoderm grainstone

Occurrence: Units G-9a, b, c, 11a, 13a, b, 15a, 15b and 17a, b, c, d.

Field observations: Massive limestone beds, 1 to 7 metres thick showing erosive bases, undulated upper surfaces and cross stratification at metric scale. They are interbeded with marly limestone of facies C and show conspicuous lateral variation of thickness.

Microfacies description: Echinoderm grainstone (passing to packstone in some zones). Echinoderm percentage reaches up to 40 % of the rock, but usually varies between 15 and 30 %. Brachiopod percentage is usually lower than 10 %, but it reaches 25 % in G-9A. Less common components are bryozoans, trilobites, ostracods and molluscs. Corals are rare in this microfacies (Fig. 5b). Clasts size varies between 0.1 mm and 5 cm.

Bioclast packing degree is high; sparite varies between 30 and 40 %. Disarticulation and fragmentation level is very high; on the contrary, degree of grain-selection is low. Distribution of clasts is chaotic at the base (G-17a), but ordered in oblique layers at upper parts of each bed (G-17d). Dolomitisation and recrystallisation are conspicuous in units 9, 15 and 17.

Environment: Presence of high levels of fragmentation and disarticulation indicates moderate to high energy. Absence of micrite shows that this high energy was constant. Sedimentation at the base of each bed was quick, which is proved by chaotic distribution of bioclasts, but it progressively diminished because upper parts of beds show some order in the clasts that produced oblique stratification. As in previous microfacies, the abundance of stenohaline organisms points to a normal marine salinity and high diversity indicates high oxygenation. Substrate was probably composed of mobile sands (Copper 1992).

All these factors plus the presence of erosive bases and cross stratification define carbonate sand shoals (Lerat et al. 2000). Most bioclasts deposited there originated in crinoidal prairies located in shallow platform seaward from the shoals (Fig. 5). Crinoids should be transported from somewhat deeper waters by waves (Aigner 1985; Potter & Pettijohn 1977; Ruhrman 1971a, b).

Facies B2: Echinoderm-bryozoan grainstone/packstone

Occurrence: Units G-19-1a and 1b.

This facies occurs in units GB-5, 6b and 7 of the detailed section. It corresponds to the basal part of bioconstructed limestone beds.

Field observations: Massive to well bedded limestones that laterally pass to bioconstructed facies D. Similar features to facies B1, but lower in thickness.

Microfacies description: Grainstone with zones of packstone at the top. Echinoderm fragments percentage varies between 20 and 35 %. Bryozoans reach in some zones similar percentages (15-20 %). Tabulate coral and brachiopod fragments are also common. Subordinate components are trilobites, ostracods, molluscs, algae and cyanobacteria (*Rothpletzella, Girvanella*) (Fig. 5c). Main differences to microfacies B1 are high percentages of bryozoans and tabulate corals and the presence of algae and cyanobacteria. Clasts size varies between 0.1 mm and 5 cm.

Environment: Most inferences made for facies B1 are also valid here; consequently the sedimentary environment was a calcareous shoal (Fig. 5). The higher percentages in reef building organisms may be due to the proximity of reefal structures.

Facies C: Echinoderm packstone

Occurrence: Units G-12a, b, 14, 16, 18-1a, 18-1b and 18-3a. It is also present in the detailed section, unit GB-1.

Field observations: Well bedded marly limestone usually covered except in the proximity of the river Guadámez. Erosive bases and amalgamation of beds are common. They are interbedded with massive limestone of facies B1.

Microfacies description: Packstone having echinoderm plates as main component; usually from 10 % to 30 % of the rock, up to 40 % in G-16 (Fig. 5d, e). Brachiopods are also common reaching about 10 %. Minor components are bryozoans, trilobites, ostracods, dacryoconarids, gastropods, rugosans and tabulates. Some algae and cyanobacteria (*Rothpletzella, Girvanella*) occur locally. Small (0.05-0.2 mm) spherical peloids are common, some clay (up to 10 %) and very tiny quartz grains (< 3 %) have been recorded in some beds. Micrite percentage is usually about 40 %.

Fragmentation and disarticulation are high, but brachiopods and corals show low fragmentation at the top of some beds. Bioclasts commonly lie with their longest axis parallel to the strata surface. Bioturbation is moderate but very variable.

Environment: Presence of high levels of fragmentation and disarticulation indicates that degree of energy was high during long periods. However, abundance of micrite and low fragmentation at the top of beds indicate that they alternated with calm phases. Abundance and diversity of clasts indicate a normal marine salinity. Presence of moderate bioturbation and echinoderms, with rootlets mark a firm substrate (Copper 1992), but abundance of bioclasts allowed the fixation of bryozoans and corals that needed hard bases for their attachment.

These environmental factors show a shallow platform affected frequently by waves (Catalov 1972; Skupin 1973; Ruhrmann 1971a, b). Nevertheless, typical features of storms, such as high disorganization of the clasts and amalgamation of beds have been observed (Aigner 1985; Hubmann 1999); the physical relationships with grainstones of facies B1 indicate that such a platform would be partly protected by shoals (Fig. 5).

Facies D: Tabulate coral rudstone

Occurrence: Units G-18-3b, 18-3c, 19-1c and 19-1d in the main section, and, GB-2, 6a, 8a, 8b and 9 in the detailed section (Fig. 2), represent this microfacies. It is interbedded with facies B2, but not directly related to facies C, restricted to the lower levels of Part III.

Field observations: Massive to well-bedded limestone showing large fragments (up to 10 cm in length) of building organisms skeletons, mainly ramose tabulate coral colonies, that are commonly encrusted by bryozoans and stromatoporoids (Fig. 4a). Locally ramose tabulates occur in growth position (Fig. 4c).

Microfacies description: Tabulate coral rudstone that locally presents a lower density of bioclasts (floatstone) and shows many encrusted layers (laminar stromatoporoids, bryozoans, cyanobacteria and algae). Tabulates reach percentages of 30 %; they include fragments of thamnoporoids and branching alveolitids with their longest axis parallel to the stratification (Fig. 6a). Bryozoans and stromatoporoids are also common (mostly encrusting ones, sometimes present as fragments). Echinoderms, brachiopods, gastropods, trilobites, ostracods, algae, cyanobacteria and rugosans occur, too. Spaces between clasts are occupied usually by micrite, but some zones (G-19.-1d) show moderate percentage of sparite.

Spectrum and abundance of bioclasts is high (up to 20 different components in a single thin section). No grain selection has been observed, but long clasts are parallel to the stratification. The degree of fragmentation and disarticulation is high.

Environment: Fragmentation of branching tabulates indicates high energy, but dominance of micrite indicates that the high level of energy was not constant. Encrustations by stromatoporoids and bryozoans (and less frequently by algae and cyanobacteria) probably occurred during calm phases (Kershaw & Brunton 1998). Presence of those encrustations as well as large fragments of colonies and more rarely colonies in growth position indicate that transport was short or absent and fragmentation took place in the same area where the corals grew (Rodríguez 2005). Presence of algae and cyanobacteria shows a very shallow environment (Liebau 1980). The substrate was hard, appropriate for the attachment of diverse colonial organisms (Brett 1988).

All features prove the development of a bioconstruction in an unstable environment where destructive processes were also important. It was probably a patch reef in initial stage of development, affected by periodical storms (Fig. 6) (Pohler et al. 2007).

Facies E: Brachiopod wackestone/packstone

Occurrence: Units G-20, 23, and GB-11b.

Field observations: Shaly and sandy, well-bedded limestones rich in brachiopods in beds 10 to 30 cm in thickness. Low-angle cross stratification.

Microfacies description: Wackestones and packstones with high percentages of quartz grains (15-35 %) and micrite (35-55 %). It could be also regarded as hybrid sandstone (Fig. 6b). Brachiopods reach 25 % to 35 % of the rock. There are small percentages of tabulates, echinoderms, bryozoans, dacryoconarids and gastropods. The latter reach significant percentage in G-23 (15 %). Most bioclasts are quite large, reaching up to 2 cm in length. On the contrary, quartz grains are very small, never reaching more than 0.1 mm in diameter. Small irregular oncoids occur in GB-11b. They are nucleated on brachiopod fragments.

None of the thin sections shows high diversity and only brachiopods are abundant. Bioclasts are always oriented parallel to the stratification, but concavity is either upwards or downwards. Fragmentation and disarticulation are moderate to low. Grain selection is also low, but quartz

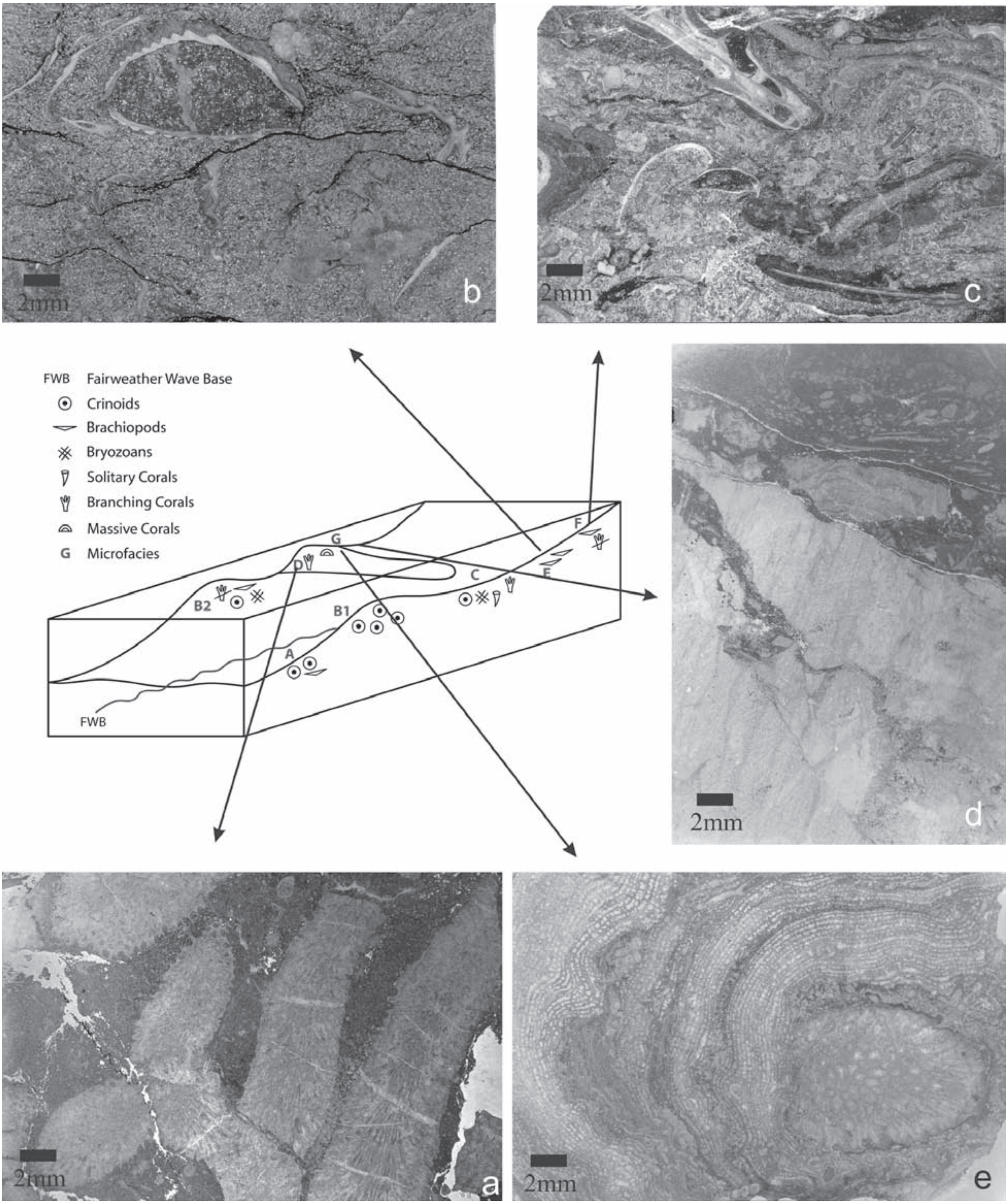

Fig. 6. Microfacies D-G. a) GB-2, microfacies D, tabulate coral rudstone; b) G-23, microfacies E, brachiopod wackestone-packstone; c) G-24, microfacies F, brachiopod grainstone/packstone; d) GB-4, microfacies G, stromatoporoid/tabulate coral boundstone; e) GB-4, microfacies G, stromatoporoid/tabulate coral boundstone, with *Stromatoporella* ex gr. *granulata* (NICHOLSON, 1873).

grains show size homogeneity, showing that they are inherited from other environments.

Environment: Low level of fragmentation and disarticulation indicates a low degree of energy, which is confirmed by high percentage of micrite and bioclasts having stable position. Dominance of brachiopods (that are mostly stenohaline, Fürsich & Hurst 1980; Racki 1986) indicates normal marine salinity. High percentage of inherited quartz indicates close relationship to continental environment.

These features show a protected (but not restricted) very shallow platform. Protection was probably provided by shoals (facies B) and patch reefs (microfacies D and G). This environment was most time below fair weather wave base, but probably close to it (Preat & Mamet 1989) (Fig. 6).

Facies F: Brachiopod grainstone/packstone

Occurrence: Units G-21a, b, c, d, 22, and 24.

Field observations: Well-bedded limestones rich in brachiopods. Irregular lower and upper surfaces and locally cross stratification.

Microfacies description: Similar to microfacies E, composed mainly of brachiopods (25-40 %), but percentage of quartz and clay is lower and micrite is almost absent (Fig. 6c). Fragments of tabulate corals, echinoderms, bryozoans, dacryoconarids, ostracods, gastropods and small percentages of peloids also occur. Some grains show superficial micritization.

Diversity is somewhat higher than in microfacies E and only brachiopods are abundant. Bioclasts lie parallel or slightly oblique to the strata surfaces, producing planar to low-angle cross lamination. Degree of fragmentation and disarticulation is somewhat higher than in microfacies E, but many brachiopod shells are complete or almost complete.

Environment: Low degree of fragmentation indicates that energy was not high; however, low quantity of micrite shows that the level of energy was not low and that this level of moderate energy was persistent. Thus, the sedimentary environment suffered constant waves of low intensity. Oxygenation was consequently high and salinity normal marine (abundance and diversity of brachiopods; Racki 1986).

These features point to a typical quiescent tidal flat environment, protected by shoals and patch reefs (Fig. 6). Tabulate coral fragments could be transported from those patches (Preat & Kasimi 1985).

Facies G: Stromatoporoid and tabulate coral boundstone/rudstone

Occurrence: Units GB-3, 4, 10, and 11a.

Field observations: Massive limestone showing large blocks of frame building organisms' skeletons that reach up to 0.5 metres in diameter (Fig. 4b). Some areas show stromatoporoids and massive tabulates in growth position (Fig. 4d). It corresponds to the maximum development of bioconstructions, in which massive and tabular colonial organisms (stromatoporoids, tabulates) dominated.

Microfacies description: Stromatoporoid and massive tabulate framestones/bindstones (Fig. 6e) are interbedded with branches of ramose tabulates and bryozoans and with encrusting bryozoans. Sediment in the spaces between colonies is a packstone with fragments of the same components plus echinodermal plates.

Upper zones of stromatoporoids and massive tabulates are usually broken and the general degree of fragmentation is very high. Distribution of bioclasts is chaotic and diversity is lower than in previously described microfacies types (Fig. 6d).

Environment: Maximum development of patch reefs having a rigid structure with optimal development for domal massive organisms (Fig. 6). The structure of the reefal facies shows that reefs were small and lack complex structure. They were probably patch reefs developed in the proximity of the echinoderm shoals. The Facies G represents domination of reef community by massive tabulate corals and stromatoporoids (Fernández et al. 2006; Kershaw & Brunton 1998; Pohler et al. 2007).

5. Discussion

Development of a calcareous platform in the studied area took place in an environment dominated by siliciclastic sedimentation during the Lower Devonian. The siliciclastic influence is always present, but during the Lochkovian (part I), activity of organisms, mainly echinoderms and brachiopods, produced calcareous sedimentation in a shallow marine environment (microfacies A, C). Such organic activity increased at the beginning of the Pragian, producing a shallow carbonate platform.

During the Pragian (part II), the succession of Guadámez-2 shows deposits produced by accumulation of skeletal fragments of the mentioned organisms in moderate-energy environments (microfacies C) and high-energy environments (microfacies B1). Most probable distribution of these deposits is shown in the schematic drawing of figures 5-6. The diversity increases in that period and some other organisms such as dacryoconarids, bryozoans and tabulate corals became important components of he communities.

During the Emsian (parts III and IV), the Guadámez-2 succession shows two important changes in the sedimentary processes. First, the development of bioclastic shoals (microfacies B2) and second, the installation of reefal patches on protected zones of the shoals (microfacies D). These deposits show up to three phases of construction and destruction (microfacies D and G) that will be described in detail in a future paper (Fernández-Martínez et al. in prep.). Microfacies D represents colonization of the environment by an assemblage dominated by ramose tabulate corals where laminar bryozoans and stromatoporoids are also abundant. Microfacies G represents boundstones to rudstones composed mainly of massive stromatoporoids and tabulate corals.

Reefal development was terminated by an influx of siliciclastic sediments (part IV, upper Emsian in age), and subsequent settlement of a tidal flat inhabited by a rich brachiopod fauna registered in microfacies A and F. The schemes of Figs. 5-6 show a probable distribution of the Lower Devonian shallow platform at Guadámez area.

Reefal setting of Guadámez-2 is rather similar to that observed in the Cantabrian Mountains (NW Spain) where the Silurian siliciclastic sedimentation was replaced by a shallow carbonate platform at the beginning of the Pragian. In the Cantabrian Mountains an important reefal episode took place during the late Emsian. It consists of biostromes and small bioherms developed as patch reefs (Mendez-Bedia et al. 1994) and probably related to bioclastic bars. They are mainly built by tabulate corals and stromatoporoids with a minor participation of rugose corals. Most of the coral and stromatoporoid genera recorded in Guadámez-2 section occur in the Cantabrian reefs which show a higher taxonomic diversity. Apart from this difference, reefal facies, cyclicity and general evolution are similar in both regions.

Emsian reefs in Europe and North Africa usually grew under quiet environments. These are the cases of the Emsian reefs of the Graz area (Austria) which are *Amphipora* mounds (Hubmann 2006; Hubmann et al. 2007) and of the Emsian mud mounds of Morocco (Brachert et al. 1992).

On the contrary, some reefs similar to this studied in the Guadámez-2 section are known in several European regions: Lochkovian and Pragian reefs from the Carnic Alps (Kreutzer 1990; Hubmann et al. 2003), Pragian Koneprusy Limestone from Bohemia (Flajs & Hüssner 1996) and Eifelian from the Eifel region (Mabille et al. 2008), among others.

6. Conclusions

The Guadámez-2 section shows the development of carbonate sedimentation from Lochkovian to Emsian in a general background dominated by siliciclastic sedimentation. Eight carbonate microfacies have been identified. They represent a sequence of environments from middle platform (A) to tidal flat (F), including shoals (B1) and shallow platform microfacies (C, E). Microfacies B2, D and G represent the development of patch-reefs superimposed on the shoals.

Reefal episodes occurred during the Emsian and comprise several development intervals. Each bioconstruction episode develops on skeletal limestone dominated by echinoderm plates. Bioconstructions show two main microfacies: microfacies D represents colonization of the environment by an assemblage dominated by ramose tabulates where laminar bryozoans and stromatoporoids are also abundant. Facies G represents boundstone to rudstone composed mainly of massive stromatoporoids and tabulates. Reefal development was terminated by an influx of siliciclastic sediments and subsequent establishment of a rich brachiopod fauna.

The importance of these reefal episodes rests on the rarity of reefal episodes in the Emsian from Europe. Similar models of patch-reefs mainly composed of ramose tabulate corals, massive stromatoporids and tabulate corals and laminar stromatoporoids developed on crinoidal shoals have been only described in the Emsian from Cantabrian Mountains and in the Pragian from Carnic Alps.

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