Revista de la Sociedad Geológica de España 27 (1)

ISSN (versión impresa): 0214-2708
ISSN (Internet): 2255-1379

THE PENNSYLVANIAN MICROBIAL-DOMINATED CARBONATE PLATFORM OF THE EL SUEVE MASSIF: CONTRIBUTION TO THE RECONSTRUCTION OF THE VARISCAN FORELAND BASIN OF THE CANTABRIAN ZONE (N SPAIN)

La plataforma carbonatada Pensilvánica del macizo de El Sueve: contribución a la reconstrucción de la cuenca varisca de antepaís de la Zona Cantábrica (N de España)

Juan Ramón Bahamonde[1], Lucía Martín[1,2] y Luis Pedro Fernández[1]

[1] Departamento de Geología, Universidad de Oviedo, 33005-Oviedo, Spain.
jrbaham@geol.uniovi.es, UO156117@uniovi.es
[2]Current address: Geoalcali, S.L., 31002-Pamplona, Spain.
lpedro@geol.uniovi.es

Abstract: *The Pennsylvanian carbonate systems of the Cantabrian Zone are characterized by microbial carbonates, and a flat-topped and steep-margined platform geometry. These systems have been exhaustively investigated from a sedimentological point of view in the Sierra del Cuera area and the Picos de Europa Province, but their NW prolongation in the El Sueve massif, has been overlooked so far. The main aim of this work is to study the El Sueve outcrops, applying the knowledge obtained in the previous studies. The main interest of the El Sueve outcrops concerns the depositional fabrics and facies of the microbial carbonates, the lateral extent and variability of microbial-dominated carbonate systems in the foreland basin of the Cantabrian Zone and the basin palaeogeography during Bashkirian times. The 925 m-thick studied succession shows the superposition of the three stratigraphic domains of a microbial-dominated carbonate platform: basin floor/toe of slope, depositional slope and platform top. This carbonate system was probably connected with other coeval carbonates (Valdeteja Fm.) exposed both to the West (Sobia and Aramo Units) and to the East (Cuera and Picos de Europa), forming a large scale calcareous domain defining a strong longitudinal (oriented N-S, parallel to the orogen) asymmetry of the Cantabrian foreland basin during the Bashkirian.*

Keywords*: Cantabrian Zone, Pennsylvanian, carbonate platform, microbial carbonates, El Sueve.*

Resumen: *La sucesión carbonatada Bashkiriense (Fm. Valdeteja, Carbonífero Superior) que aflora en el macizo de El Sueve está constituida, de muro a techo, por tres dominios estratigráficos: 1) 150 m de calizas mudstone microlaminadas (facies tipo Barcaliente), que incluyen algunos niveles centimétricos gradados bioclásticos (calciturbiditas) y escasos niveles de ortobrechas calcáreas en la parte superior; 2) 500 m de calizas masivas micríticas ricas en cemento marino, interpretadas como carbonatos bioconstruidos de origen microbial; y 3) 275 m de alternancias de calizas granosoportadas compuestas por bioclastos, granos recubiertos y ooides, y acumulaciones de algas calcáreas de tipo bereséllidas. Estos tres dominios han sido interpretados, respectivamente, como los cinturones de facies de cuenca/base de talud, talud bioconstruido y techo de una plataforma carbonatada de márgenes elevados. La sucesión estudiada es comparable a la descrita en la parte central de la Unidad de los Picos de Europa, donde grandes masas de carbonatos microbiales crecieron directamente sobre el techo de la Fm. Barcaliente (Serpukhoviense superior-Bashkiriense basal); y diferiría de las sucesiones clinoformales que caracterizan la progradación del sistema carbonatado en sus zonas externas (como las del Cuera o las Llacerias), donde acumulaciones potentes de brechas del talud inferior de la plataforma se disponen entre el techo de la Fm. Barcaliente y las bioconstrucciones microbiales del talud superior. Este estudio con-*

firma la existencia de una plataforma carbonatada en los sectores septentrionales de la Cuenca Carbonífera Central Asturiana que se acuñaría hacia el S, donde se acumularon potentes sucesiones siliciclásticas. Este sistema carbonatado pudo estar conectado con los que afloran en el área del Cuera (al E) y en las de las Unidades de la Sobia-Aramo (al O), constituyendo así un gran dominio carbonatado que se extendería por los sectores septentrionales de la cuenca varisca de antepaís de la Zona Cantábrica. Este hecho implicaría la existencia de una fuerte asimetría en la cuenca sedimentaria en dirección N-S, paralelamente al frente orogénico, lo cual sería un rasgo peculiar en este tipo de cuencas. Durante la transición del Bashkiriense al Moscoviense, la porción de dicho dominio carbonatado que aflora en el área de El Sueve fue fosilizada por las cuñas prodeltaicas que progradaban desde sectores más proximales de la cuenca (al O).

***Palabras clave**: Zona Cantábrica, Pensilvánico, plataforma carbonatada, carbonatos microbiales, El Sueve.*

Bahamonde, J.R., Martín, L. y Fernández, L.P. (2014): The Pennsylvanian microbial-dominated carbonate platform of the El Sueve massif: contribution to the reconstruction of the variscan foreland basin of the Cantabrian Zone (N Spain). *Revista de la Sociedad Geológica de España*, 27(1): 47-62.

Carbonate precipitation induced by photosynthetic cyanobacteria and heterotrophic bacteria, living in symbiosis with siliceous sponges, were passively responsible (with the contribution of bryozoans, echinoderms, foraminifers and algae) for the accumulation of carbonate successions in the Upper Palaeozoic (Wood, 1999).

The variscan foreland basin of the Cantabrian Zone (CZ) developed on the continental margin of Gondwana, located at palaeoequatorial latitudes on the eastern coast of Pangea (Fig. 1A). A significant peculiarity of this marine basin was the prolific production of microbial carbonates, which took place coevally with a high siliciclastic input from the uplifting orogen and was attributed by Della Porta (2003) to a reduced connection between the basin and the open ocean, due to a complex palaeogeography. Confined basins may possess organic-rich dysoxic basin floors with more alkaline and warmer water than open oceanic realms, which gave rise to optimal environmental conditions for fostering microbial and algal carbonate factories. Examples of restricted basins with a high production of microbial carbonates have been reported from the Proterozoic (Grotzinger and Knoll, 1995) to Miocene (Messinian crisis in the Mediterranean, Braga et al., 1995) with many examples from the Middle Devonian to the Late Permian and Triassic (Della Porta, 2003). In foreland basins, carbonate systems typically nucleate on the distal, cratonward side showing homoclinal ramp profiles (Dorobeck, 1995; Bosence, 2005). But in the Cantabrian Zone, the prolific precipitation of microbial carbonates during the Carboniferous allowed the development of flat-topped carbonate platforms both in the low subsiding distal sectors (Cuera/Picos de Europa platform, Bahamonde et al*.,* 1997, 2004, 2007; Della Porta et al*.,* 2002a, 2002b, 2003, 2004, 2005; Kenter et al*.,* 2003, 2005), and in relatively proximal (foredeep) depositional settings (Escalada Fm, Bahamonde et al., in press), and even carbonate ramps on the wedge-top depozone (Puentellés Fm, Merino-Tomé et al*.,* 2007).

The Carboniferous carbonate succession that overlies the Barcaliente Fm. (Serpukhovian-early Bashkirian) has been exhaustively studied in the Sierra del Cuera area and the Picos de Europa Province, in the NE of the Cantabrian Zone (CZ), but the coeval carbonate rocks cropping out in the El Sueve massif (Bashkirian, Lower Pennsylvanian, Valdeteja Fm.) have not been studied yet from a sedimentological point of view. The main aim of this study is to apply the knowledge derived from the above mentioned studies to the Bashkirian carbonates of the El Sueve massif. A second objective is to cast some light on the Bashkirian palaeogeography of the Variscan foreland basin of the CZ. Excluding the complex Pisuerga-Carrión Unit, the foreland basin of the CZ developed a strongly asymmetric depositional profile in a transversal cross section (Colmenero et al*.,* 2002; Fernández et al*.*, 2004).

This study is mainly based on outcrop observations, including data from petrographic studies of thin sections. Two stratigraphic sections (Picu Pienzu and Majada de Espineres; see below) have been logged, totalling more than 1500 m.

The stages and substages of the East European (Russian) time scale are adopted for global terminology. Absolute ages are from Davydov et al. (2012).

Geological setting

The Cantabrian Zone (CZ), the most external unit in the NE corner of the Iberian Massif, comprises a thick Palaeozoic succession, which ranges from Cambrian to Carboniferous, and is affected by a Variscan thin-skinned deformation style accompanied of a very low to absent metamorphic degree (Julivert, 1971; Pérez-Estaún et al*.*, 1988). The foreland basin of the CZ, resulting from the continental collision of Gondwana and Laurentia during late Devonian-Carboniferous times (Martínez-Catalán et al*.*, 1999; Matte, 2001), developed on the continental margin of Gondwana in the eastern coast of Pangea at palaeoequatorial latitudes (Fig. 1A). The Carboniferous sedimentary infill of the basin comprises: 1) a 300 m-thick laterally continuous ensemble of Mississippian-lowest Pennsylvanian strata, including the condensed deposits of the Baleas, Vegamián and Alba Formations (Tournaisian to early Serpukhovian) and the calci-mudstones of the Barcaliente Fm. (late Serpukhovian-early Bashkirian); 2) an up to 6,000 m thick ensemble of Pennsylvanian (Bashkirian-Moscovian) siliciclastic-dominated foredeep successions, with subor-

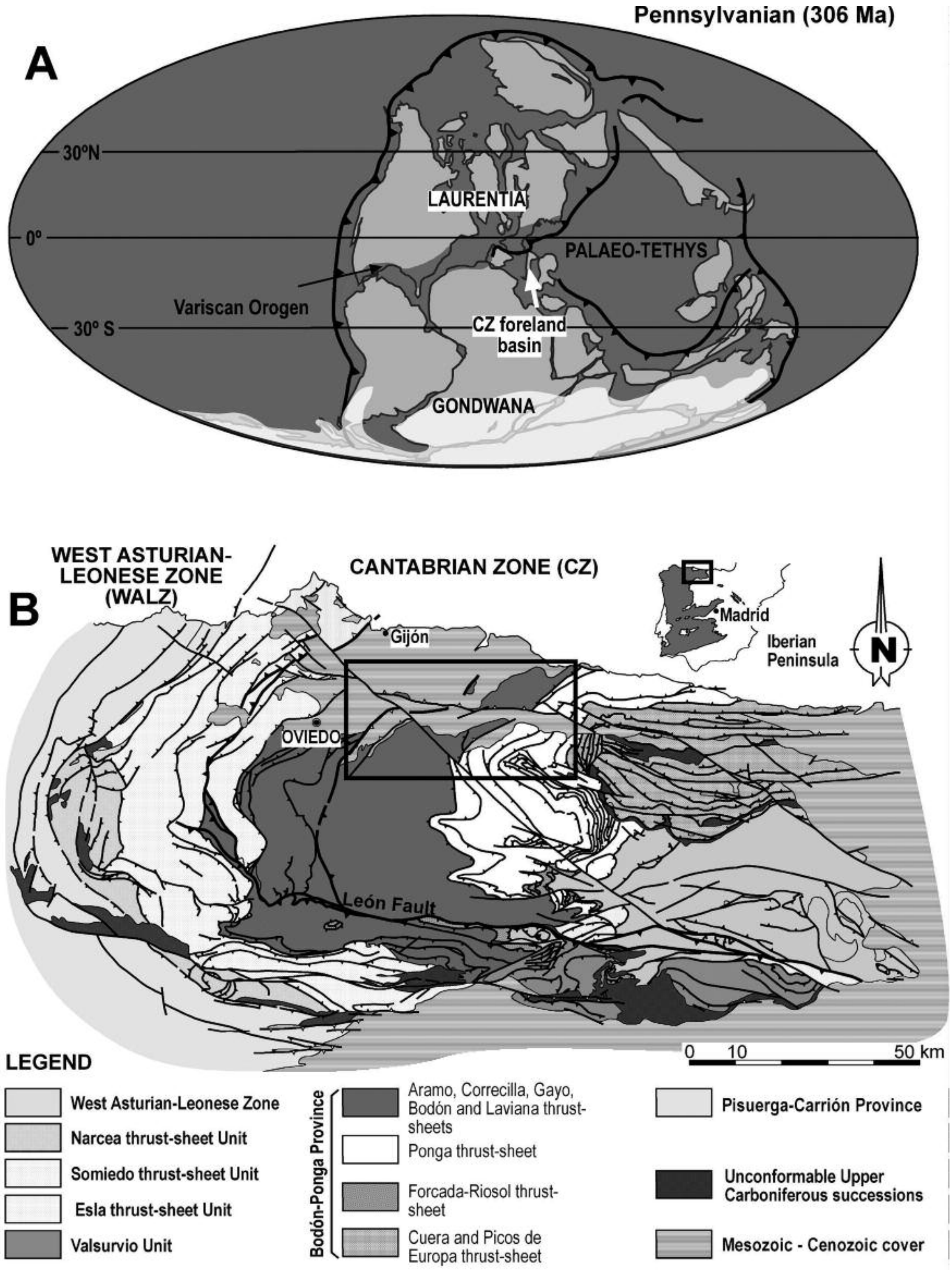

Fig. 1.- A) Palaeogeography of Pangea during Pennsylvanian times (modified from Golonka et al., 1994) showing the location of the Variscan orogen and the inferred position of the Cantabrian Zone foreland basin (CZ). B) Schematic geological map of the Cantabrian Zone showing its main constituent units (based on Julivert, 1971; Pérez-Estaún et al., 1988; and Alonso et al., 2009), and the location of the El Sueve massif. Boxed area shows the location of Figure 2.

dinate carbonate units; and 3) a Pennsylvanian (Bashkirian-Moscovian) microbial-boundstone-dominated high-relief carbonate platform (Cuera/Picos de Europa platform), developed on the craton-ward margin of the basin and buried by the youngest progradational siliciclastic wedges in the late Moscovian (Bahamonde et al., 1997). Additionally, other carbonate systems accumulated during Bashkirian times (Valdeteja Fm.) in others sectors of the basin.

As a result of the thin-skinned Variscan tectonics, the Palaeozoic successions of the CZ form an imbricate system of thrust sheets (Julivert, 1971; Marcos and Pulgar, 1982; Pérez-Estaún et al., 1988; Alonso et al., 2009). On the basis of the tectono-stratigraphic features, the CZ was subdivided into several provinces and units (Julivert, 1971; Pérez-Estaún et al., 1988), which recently have been grouped into three main units: Somiedo, Bodón-Ponga and Pisuerga-Carrión (Alonso et al., 2009; Fig. 1B).

The study area is located in the NNE–SSW-oriented El Sueve calcareous massif and represents the NE prolongation of the Central Asturian Coalfield (Bodón-Ponga Unit of Alonso et al., 2009) in the Laviana thrust sheet (Figs. 1B and 2). In the El Sueve area, a Lower Palaeozoic-Carboniferous succession is tilted with an overall dip of 70º to the NW. The Carboniferous strata begin with a very thick Pennsylvanian carbonate package, made up of the Barcaliente (late Serpukhovian-early Bashkirian) and Valdeteja (Bashkirian) Fms, which is overlain by the Lena Group, a lower Moscovian siliciclastic succession with some carbonate units, mainly in its lower part (Fig. 3). To the NE and SW of the El Sueve area, the palaeozoic succession is bound by alpine WNW-ESE trending faults (Figs. 2 and 4). In the N, in the NNE block of the Gobiendes Fault, the El Sueve Palaeozoic succession crops out patchily, being mostly buried by a thick unconformable Permian cover. In the NNE block of the Gobiendes Fault, the Pennsylvanian carbonate succession is apparently thinner than in the SSE block due to tectonic duplication by thrusts in the latter (Fig. 4). To the SSW of the southern bounding faults, the El Sueve succession is also buried by a Permian-Mesozoic cover, beyond which, further SSW, it lies the Central Asturian Coalfield (Fig. 2).

Stratigraphy of the Valdeteja Fm (Bashkirian) in the El Sueve massif

On the basis of the two studied sections (Picu Pienzu and Majada de Espineres, Fig. 4), a thickness of 925 m is estimated for the Valdeteja Fm of the El Sueve massif. In the succession of this formation, three stratal domains, corresponding to basin-floor/toe-of slope, depositional slope and platform-top facies, have been distinguished (Figs. 4 and 5). From base to top, these are: a) a ~150 m-thick interval transitional between the Barcaliente and Valdeteja Fms and composed of Barcaliente-like, well-bedded and dark lime mudstones, which include some cm-thick graded skeletal beds, cm-thick bands with scattered siliceous tests of uncertain organisms, and several metre-scale breccia beds in the upper part; b) a ~500 m-thick interval made of

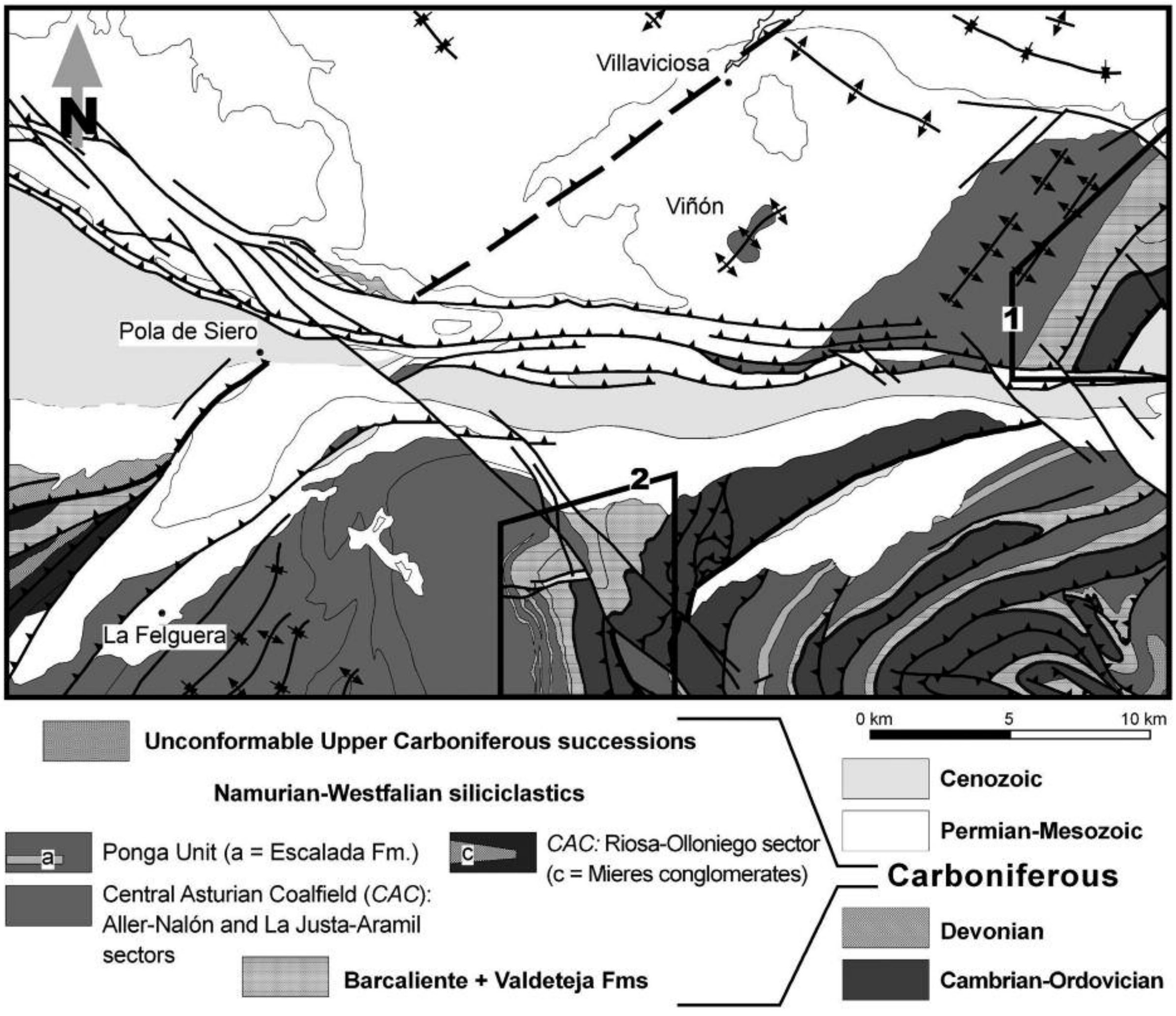

Fig.- 2.- Geological map of the NE sector of the Central Asturian Coalfield (see Fig. 1B for location), showing the distribution of the Barcaliente and Valdeteja Fms in the areas of El Sueve (1) and El Condado (2) where the Valdeteja Fm pinches out (modified from Pérez-Estaún et al., 1989).

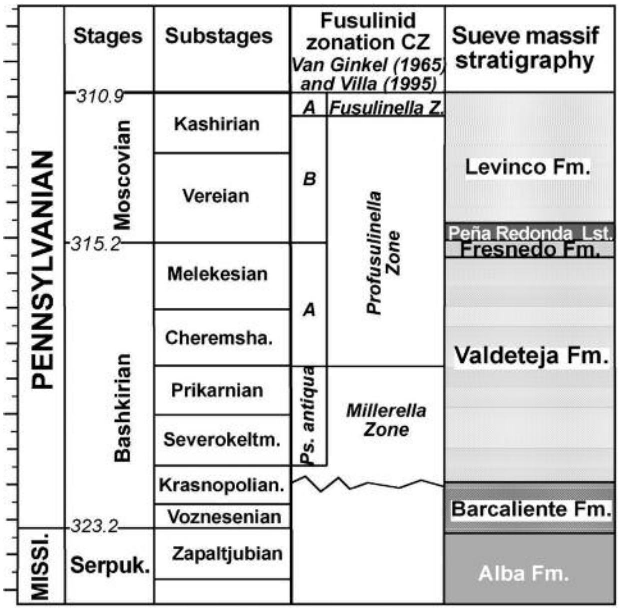

Fig. 3.- Chronostratigraphic chart of the Bashkirian-Moscovian (after Davydov et al., 2012) showing the stratigraphic units of the El Sueve area (dating after Villa, 1995).

massive boundstones showing clotted/peloidal micrite masses, micro-laminated rims of dense micrite, usually interpreted as microbial carbonates, and early marine cements (radiaxial-fibrous and botryoidal); and c) a ~275 m-thick interval comprising moderately- to well-bedded skeletal, coated-grain and ooidal grainstones, and green-algal (dasycladacean) boundstones.

Microfacies, facies and facies associations

The textures observed in the El Sueve outcrops, where stratal patterns are only partially visible, were compared with those described in the Cuera (Della Porta et al., 2002b, 2003) and Picos de Europa (Bahamonde et al*.,* 2000, 2007) outcrops, where complete depositional profiles of the carbonate system are exposed. The results indicate that the three stratal intervals described in the El Sueve succession (Figs. 4 and 5) accumulated respectively, in a) deep-water marine basin-floor and toe-of-slope, b) depositional slope and c) shallow-water platform-top environments. The vertical arrangement of these deposits reflects the progradation of the carbonate system.

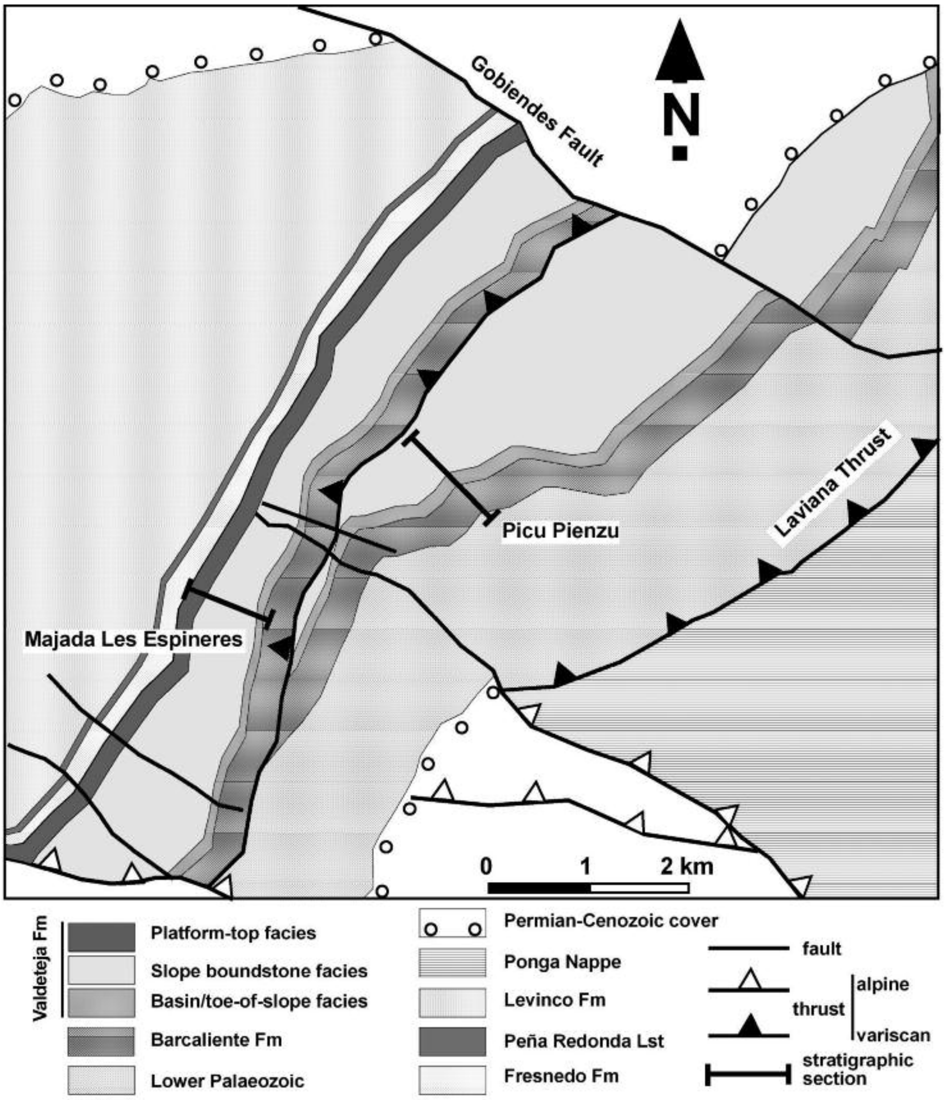

Fig. 4.- Detailed geological map of the El Sueve area (modified from Merino et al*.,* 2011), showing the location of the two studied sections.

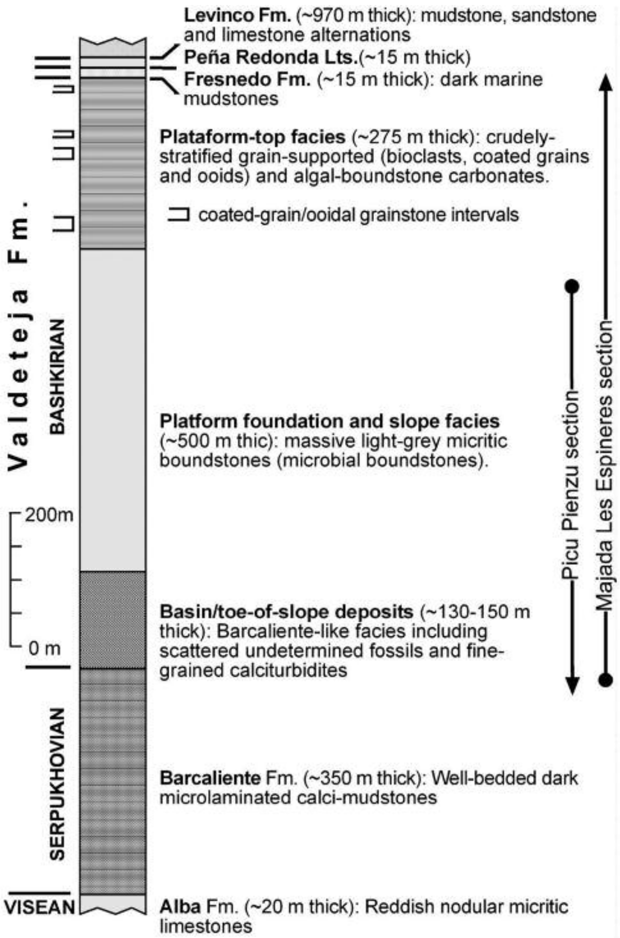

Fig. 5.- Synthetic stratigraphic log of the Bashkirian succession in the El Sueve area, showing the three stratal domains defined in the Valdeteja Fm.

The Cuera/Picos de Europa carbonate system, which might form one single or several buildings, is characterized by: a) abundant in-situ bio-mediated calcium carbonate (microbial carbonate), and b) a flat-topped and high-relief platform geometry with steep depositional slopes. These features define this carbonate system as a microbial boundstone-dominated and flat-topped carbonate platform. This research states that the Valdeteja Fm. (Bashkirian) in the El Sueve area exhibits stratigraphic and sedimentological features characteristic of this type of carbonate system.

A. Basin-floor/toe-of-slope facies association

The basin/toe-of-slope deposits form a well-stratified, ~150 m-thick interval, which directly overlies the dark and micro-laminated lime mudstones, almost barren of skeletal fragments, of the Barcaliente Fm. Most of the basin/toe-of-slope interval consists of Barcaliente–like limestone beds but with a significantly higher biota content. Skeletal grains occur scattered or forming thin graded beds. These deposits are interpreted as basin-floor deposits. The upper part of this interval is a few meters-thick and consists of matrix-free calcareous breccias, graded skeletal grain- to packstones and siliceous sponge spicule accumulations. Locally, chert nodules, slumps, load cast and fluid-deformation structures have been recognized. These deposits are interpreted as toe-of-slope facies.

A.1.- Laminated lime mudstones.- They consist of alternating, dark and light bands, up to 1 cm in thickness, composed of neomorphic microsparite (Fig. 6A). They contain skeletal grains of unknown affinities, either scattered or forming graded units, (Fig. 6A and C). These skeletal particles are ~1 mm in diameter spheres composed of diagenetic quartz crystals that obliterated the original microstructure and composition (Fig. 6B).

A.2.- Siliceous sponge spicule accumulations.- These are bioturbated skeletal packstones, in which monoaxon siliceous sponge spicules are the main skeletal component (Fig. 6D-E). Other fine-grained bioclasts, such as echinoderms, brachiopods, foraminifers, ostracods, rugose corals, bryozoans and calcispheres, have been scarcely observed.

A.3.- Graded skeletal grain- to packstones.- They form cm- thick fine-grained graded beds with a sharp base (Fig. 6C). Grains include bioclasts and rare intraclasts, ooids and peloids. The most common bioclasts are echinoderms (forming sometimes mono-specific intervals of rudstones) and foraminifers. Brachiopods, gastropods, ostracods, rugose corals, bryozoans, calcareous sponges, algal fragments and calcispheres are less abundant. Bioturbation is restricted to the upper part of these beds and to the bedding surfaces.

A.4.- Matrix-free calcareous breccias.- They form decimetre-thick beds that occur scarcely in the uppermost part of the basin/toe-of-slope interval. They are made of poorly-sorted, intraformational microbial-boundstone-derived lithoclasts. Clasts are tightly packed, showing sutured contacts.

Interpretation.- The finely laminated structure and the scarcity of bioturbation and faunal content point to deposition of facies *A.1* in an overall restricted environment (cf. Bottjer and Savrda, 1993). Nevertheless, restriction was not as severe as during the deposition of the underlying Barcaliente Fm as witnessed by the intercalated fossiliferous layers. Geometrical relationships and strata patterns show that similar deposits in the Sierra del Cuera area were deposited in a basin floor several hundred metres in depth (Bahamonde et al., 2004).

Sediments rich in siliceous sponge spicules (spiculites, facies *A.2*) have been classically interpreted as deposited in basinal settings adjacent to carbonate platform areas (SMF 18 of Wilson, 1975; Yurewicz, 1977). They would record settling from suspensions of sponge spicules re-

Fig. 6.- Basin-floor deposits. A) Hand sample of laminated calci-mudstone showing undetermined siliceous shells concentrated in bands (facies *A.1*). B) Microphotographs of the previous sample showing the spheres made of neomorphic quartz crystals embedded in microsparite. C) Hand sample of dark laminated mudstones (Barcaliente-like facies) with two beds of graded calciturbidites (cal; facies *A.3*) made of skeletal grain- to packstones. D-E) Microphotographs of fine-grained siliceous sponge accumulations (facies *A.2*), including siliceous sponge spicules (sp) and echinoderm fragments (ech).

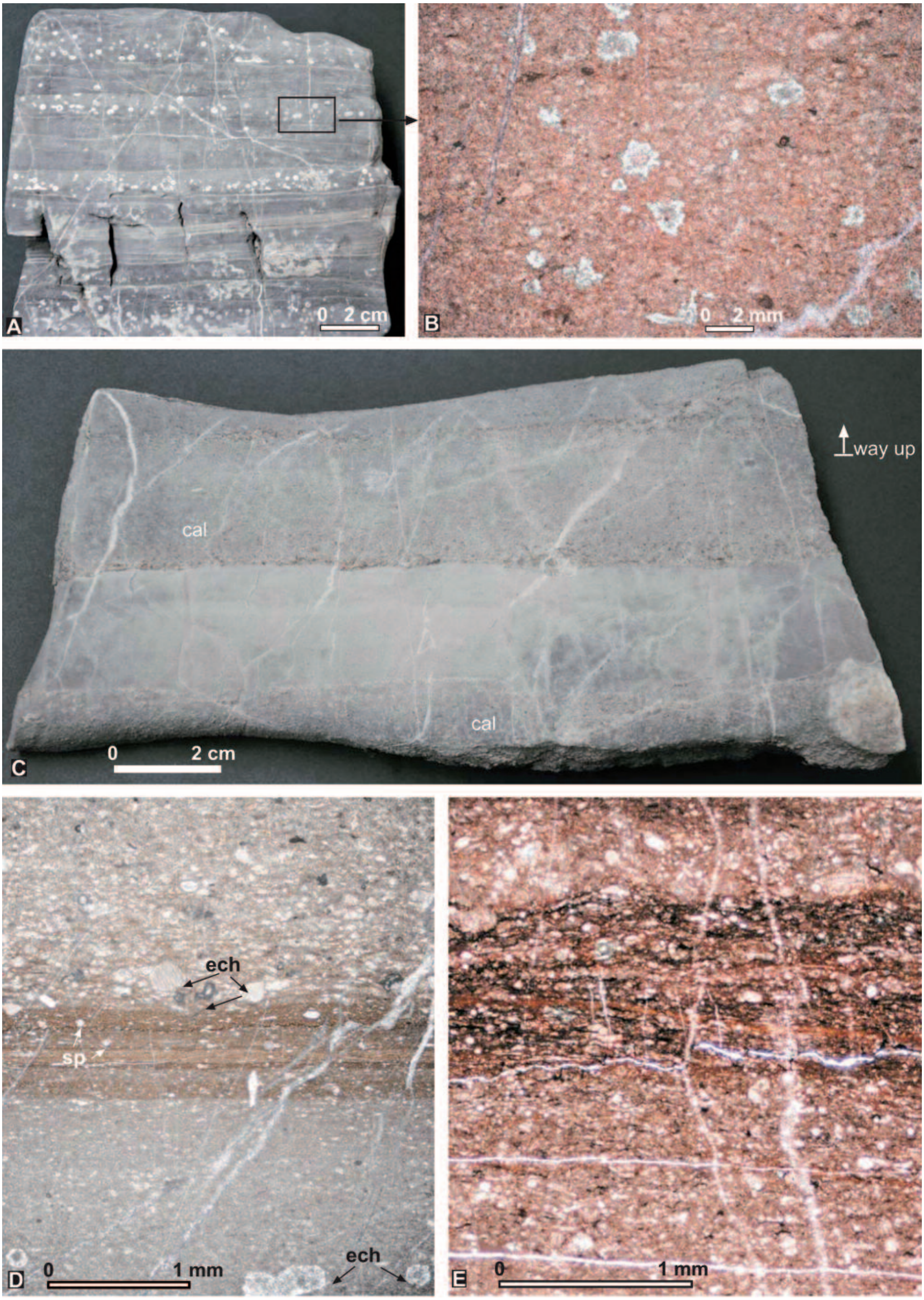

Figura 6

leased from degrading siliceous sponge bodies. In the Cuera/Picos de Europa carbonate platform, this facies is diagnostic of the basin-floor/toe-of-slope setting and records stages of no sediment-shedding from the platform top to the basin (Kenter et al., 2002; Della Porta et al., 2003, among others). Silica preservation is indicative of low alkalinity, low temperature ambient water, which typifies usually the basin floor. On the contrary, the dissolution of biogenic silica is attributed to warmer, more alkaline waters, associated with high rates of carbonate precipitation in shallower settings (Arp et al., 2003).

Deposits similar to the grain- to packstone and rudstone beds (facies *A.3*) have classically been interpreted as calciturbidites resulting from storm-triggered, low- and high-density turbidity currents (Harris, 1994; Reijmer et al., 1991; see also Bouma, 1967; Middleton and Hampton, 1973). Crinoid beds would derive from the reworking and re-sedimentation during storm events of crinoidal bars developed below the fair-weather wave base in the outer platform (Della Porta et al., 2004). It is a characteristic toe-of-slope deposit in the Cuera/Picos de Europa carbonate platform (Bahamonde et al., 2004 and 2007).

Intraformational, matrix-free breccia beds (facies *A.4*) are interpreted as gravitational, rock-fall or avalanche deposits resulting from the collapse of boundstones with a depositional topography (see Della Porta et al., 2003, Bahamonde et al., 2004).

B. Depositional slope facies association

This impressively massive stratigraphic domain represents the actual carbonate factory of the carbonate platform, reaching ~500 m in thickness (Figs. 4 and 5). The rocks are mainly composed of lime mudstone (clotted micrite) and of early marine cements. The latter occur filling a high volume of primary porosity developed in the former. According to the depositional fabrics, two facies have been differentiated, both interpreted as biotically-induced boundstones.

B.1.-Peloidal-micrite boundstones.- The peloidal microfabric (*clotted micrite*) consists of silt-size sub-spherical to irregular aggregates of carbonate mud with poorly-defined outlines and diameters of 20-100µm (smaller than normal pellets or pelloids). Pseudo-peloids can show a variable packing, form tightly to loosely packed, representing less than 50% of the rock volume, and are embedded in microsparite or surrounded by bundles of acicular crystals (originally of aragonite) (Fig. 7A). Scarce skeletal grains (1-5%) are present and consist of bryozoans (fenestellids and ramose fistuliporids), brachiopods, indeterminate biomolds (probably attributable to sponges), encrusting foraminifers like *Tuberitine* and tubular calcitornellids, echimoderms, bivalves, and polychaete worm micritic tubes (*Terebella* or *Thartarella*). In some areas, colonies of the problematic organism *Donezella* form a delicate net-

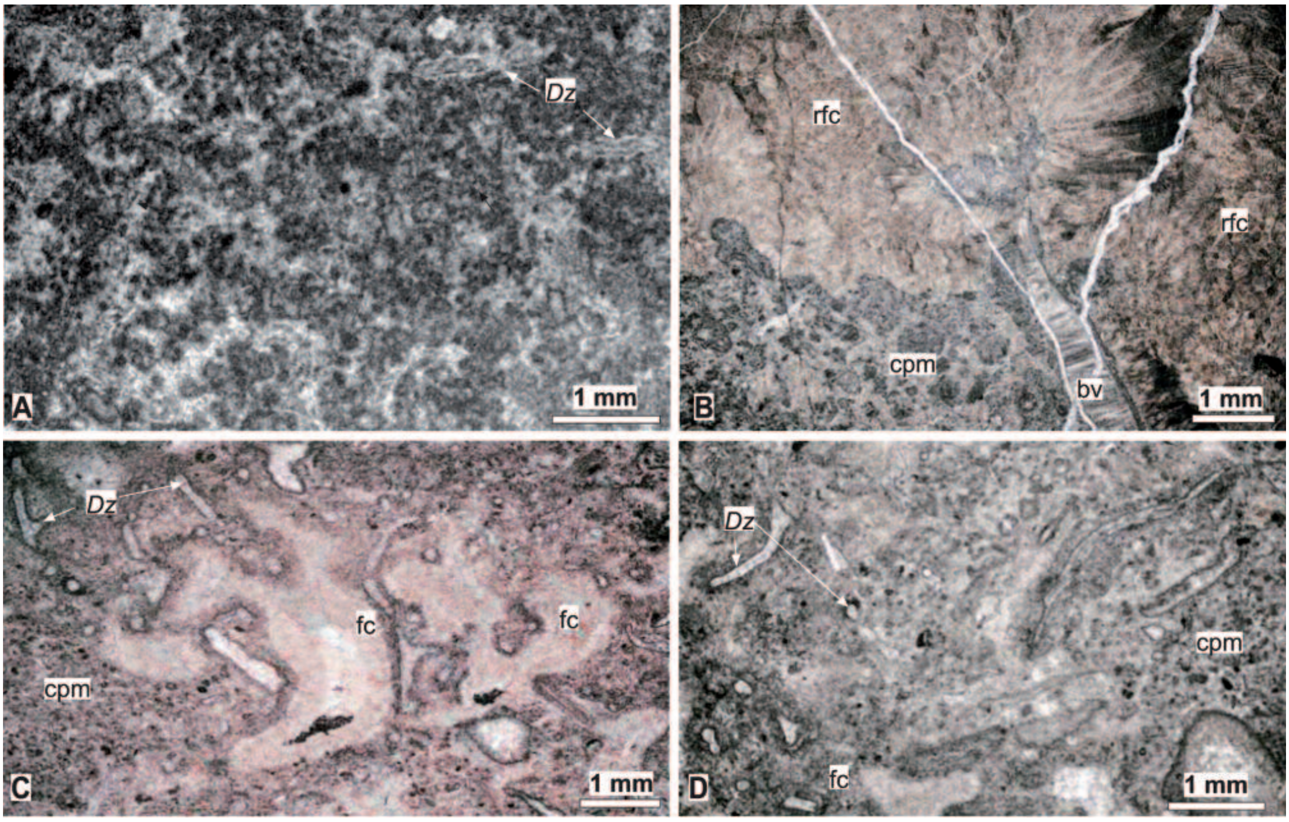

Fig. 7.- Photomicrographs of the slope microbial boundstones (facies *B.1*). A) Diagnostic peloidal microfabric of the facies *B.1*, in which the micrite clots (dark) are surrounded by microspar (white). Dz: *Donezella*. B) Stromatactis-type primary voids developed in a peloidal micrite (cpm) and filled with fibrous-radiaxial calcite cement (rfc). Bv: bivalve. C) Stromatactis voids in a peloidal micrite (cpm) with *Donezella* colonies (Dz). Stromatactis are filled with fibrous (fc) and spar calcite. D) *Donezella* colonies (Dz) in a peloidal micrite (clotted micrite) (cpm). Fz: fibrous cement.

work (Fig. 7D). Locally calci-microbes, such as *Renalcis*, *Ortonella* and *Girvanella,* have been observed. Irregular primary voids are characteristic of this sub-facies. They range from 1 mm to a few cm in size and are partially filled by multiple isopachous layers of radiaxial-fibrous marine cements (*stromatactis*-like voids) (Fig. 7B-C).

B.2.- Boundstones with accretionary laminated structures and botryoidal aragonite cement.- They consist of carbonate mud and microspar with peloidal and laminated microfabrics with accretionary and encrusting growth forms. The accretionary laminae are up to several cm in thickness (Fig. 8A, C) and include a skeletal community of calcimicrobes (*Renalcis*, *Girvanella*, *Ortonella*), fenestellid and fistuliporid bryozoans, sponges, *Donezella*, calcareous algae, encrusting foraminifers, brachiopods, and crinoids. The accretionary laminae form a network of cavities filled by aragonite botryoidal cement (Fig. 8A-B, D). Nowadays, the aragonite appears totally replaced by calcite, but locally the radial disposition of acicular crystals is preserved (Fig. 8D). Internal sediment including gastropod faecal pellets, ostracods and sponge spicules, or burial blocky cements fill up the remaining pore space.

Interpretation.- Peloidal micrite microfabrics have been interpreted as a product of the in-situ bacteria-mediated precipitation of calcium carbonate (Chafetz, 1986; Folk and Chafetz, 2000; Riding, 2000), although in some cases the precipitation has been related to abiotic organic-rich substratum (Macintyre, 1985, Trichet and Défarge, 1995; Reitner et al*.,* 1995). In Mississippian carbonate successions, peloidal micrites have been interpreted as the result of the calcification of siliceous sponge bodies, probably living under the influence of microbial communities (Warnke, 1995; Madi et al*.,* 1996). Reitner (1993) proposed that the final product resulting of the sponge tissue degradation is a micro-peloidal structure, also present in modern microbialites and in fossil sponge reefs. The rapid calcification of the sponge tissue could be linked to sulphate-reducing bacteria, whose metabolic activity in aerobic microenvironments would increase the alkalinity favouring the precipitation of microcrystalline peloidal calcites (Reitner and Schumann-Kindel, 1997). Degradation of the fleshy body of siliceous sponges would provide nutrients for the metabolism of the bacteria communities (cyanobacteria), being the production of micrite a post-mortem process occurring in early diagenetic stages, just before the marine cementation took place. The stromatactis-like voids have been interpreted as a biomoldic porosity resulting from the corrosion of a semi-consolidated calcareous substrate by changes in the pH and the action of organic acids derived from degradation of certain organism bodies (Tsien, 1985) such as the siliceous sponges (Bourque and Boulvain, 1993).

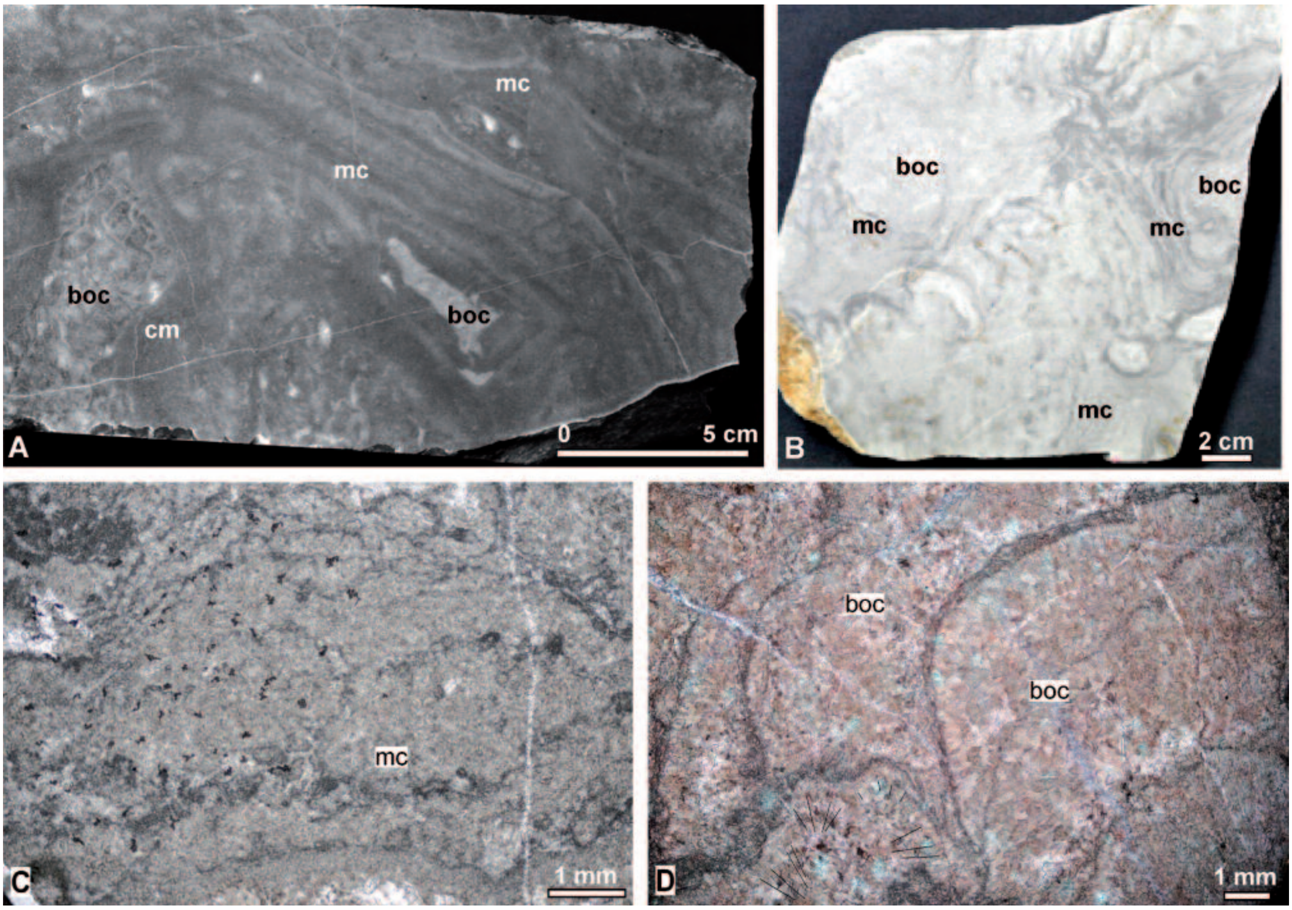

Fig. 8.- A and B) Polished slabs of the microbial boundstones (facies *B.2*) showing micro-laminated micrite crusts (cm) forming large primary cavity system filled by aragonite (in origin) botryoidal marine cement (boc). C) Microlamiated micrite crust (mcs) of facies *B.2*. D) Botryoidal marine cement (boc), originally of aragonitic composition, made of neomorphic spar.

Micritic microlaminated crusts (facies *B.2*) have been documented in the Carboniferous of Canada (Beauchamp, 1988; Davies et al., 1989), in the Lower Carboniferous of UK (Pickard, 1986), in the Cretaceous of the Basque-Cantabrian basin (Neuwailer et al*.,* 1999), amongst other places, and interpreted as in-situ precipitates of hard micrite and microsparite with microbial mediation; or as the product of incrustation of fungi or bacteria on calcareous fossils (Pickard, 1996). The early lithification of the micritic crusts would form a rigid framework supporting a high volume of primary cavities where botryoidal aragonite cement precipitated (Della Porta et al., 2003; Bahamonde et al., 2004).

Facies B is characteristic of the upper slope in the Cuera/Picos de Europa carbonate platform (Della Porta et al., 2003; Bahamonde et al., 2004), where it extends from the platform break down-slope to 250 m of paleo-water depth (assuming 0 m at the platform break) in the NW border of Picos de Europa (Bahamonde et al*.,* 2000) and to 350 in the Cuera section (Kenter et al., 2003). The lower limit of this facies seems to be controlled by the position of the thermocline, below which a detrital breccia-dominated lower slope occurs. Consequently, a similar same range of paleo-water depth is assumed for the facies B in the El Sueve outcrops.

The pervasive early marine cementation is a well documented process in shallow and well-agitated environments, but it is generally reduced in deep depositional settings. Van der Kooij et al. (2011) have proposed the existence of active upwelling currents over the Cuera carbonate platform flanks as the main mechanism to trigger the seawater circulation at a depth of several hundred metres.

C. Platform-top facies association

This facies association is only exposed in the Majada Les Espineres section, where it reaches 275 m in thickness, being characterized by its bedded character (Figs. 4 and 5), the abundance of carbonate grains (skeletal, ooids and coated grains), the presence of algal accumulations and a large predominance of blocky and syntaxial spar cements. These features sharply contrast with the massive character, the scarcity of calcareous grains and the abundance of early marine cements (botryoidal and radiaxial fibrous) that feature the slope boundstone facies. Skeletal grains include a highly diverse biota: echinoderms, foraminifers (fusulinids, textularidae, *Tuberitina*, *Bradyina*, *Endothyra*, *Tetrataxis*), fenestellids and ramose (fistuliporids) bryozoans, calci-sponge *Chaetetes,* siliceous sponge spicules, gastropods, ostracods, calcispheres, and calcareous algae (beresellids, ungdarellids). Less abundant are the problematic organism *Donezella*, rugose corals (aulaporids), bivalves, brachiopods, trilobites, and others calcareous algae (*Dvinella*, *Fasciella*, *Epimastopora*, *Uraloporella)*. Well-defined cycle patterns have not been detected. Five facies have been defined.

C.1. Bioturbated skeletal wackestones.- This facies forms the upper part of the Valdeteja Fm and consists of cm- to dm-thick wavy beds with marly interbeds. They are lime wackestones, more rarely lime mudstones made up of homogeneous, locally peloidal, micrite and skeletal grains, which are irregularly distributed as a result of bioturbation. The latter mainly consist of calcispheres, calcified siliceous sponge spicules and ostracods (Fig. 9A). Echinoderms, foraminifers and bryozoans are less common components. Locally, in situ calcareous sponges (*Chaetetes)* and *Donezella* colonies are found.

C.2. Skeletal lime pack- to grainstones.- This is the most common facies of the platform-top association. It displays a packstone texture, with patches of grainstone. Skeletal grains are diverse and dominated by foraminifers and echinoderms (Fig. 9B), other common grains are those of red algae (ungdarellids), of dasycladaceans (beresellids), and of the problematic organism *Donezella*. Common peloids and rare coated grains, intraclasts and oncoids account for the remaining grain types. Grains are tightly packed resulting in little interparticle porosity. Peloidal micrite is common and might represent a micrite cement. Bioturbation is moderate to weak.

C.3. Skeletal and coated-grain grainstones.- This facies comprises skeletal grains of a diverse biota and less common intraclasts, some of which display micritic coatings (coated grains). Inter-particle porosity is high, with an early generation of isopachous marine cement (Fig. 10A-B).

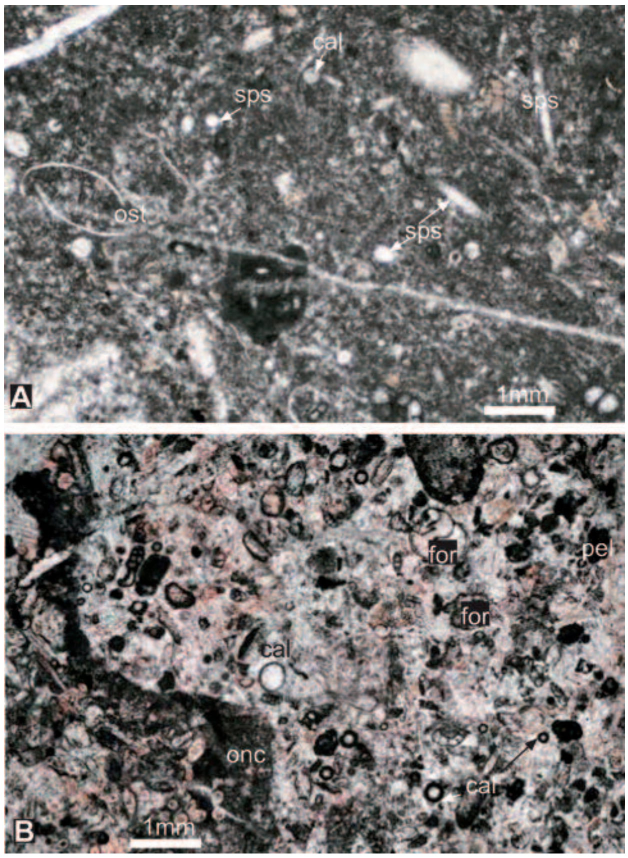

Fig. 9.- Microphotographs of restricted platform deposits. A) Bioturbated skeletal wackestone (facies *C.1*) containing siliceous sponge spicules (sps), ostracods (ost) and calcispheres (cal). B) Skeletal packstone (facies *C.2*) containing calcispheres (cal), foraminifers (for), pellets (pel), one oncoidal crust (onc) and peloidal micrite in pockets.

C.4. Ooidal grainstone.- Two intervals of well-sorted ooidal grainstone, several-metres in thickness each, have been found in the lower and middle part of the platform-top succession. Ooids exhibit radial microstructures and a skeletal nucleus (mainly foraminifers and echinoderms). This facies shows a high inter-particle porosity, partially filled by isopachous rims of an early generation of radiaxial marine cement (Fig. 10C-D).

C.5. Beresella boundstones.- They are uncommon in the platform-top succession and usually appear associated to skeletal pack- to grainstones (facies *C.2*). It consists of a set of tightly packed thickets of beresellid green algal tubes (Fig. 11) embedded in a homogenous micrite, locally peloidal. Other less abundant organisms are foraminifers, echinoderms, calcispheres and algal biomolds (probably *Anthracoporella*).

Interpretation.- Except for the grain-supported facies in the lower part of this stratigraphic domain, which could be assigned to an outer-platform setting, most of the beds are interpreted as inner platform deposits accumulated in shallow-water subtidal environments. The El Sueve area is relatively far from either the carbonate platform margin

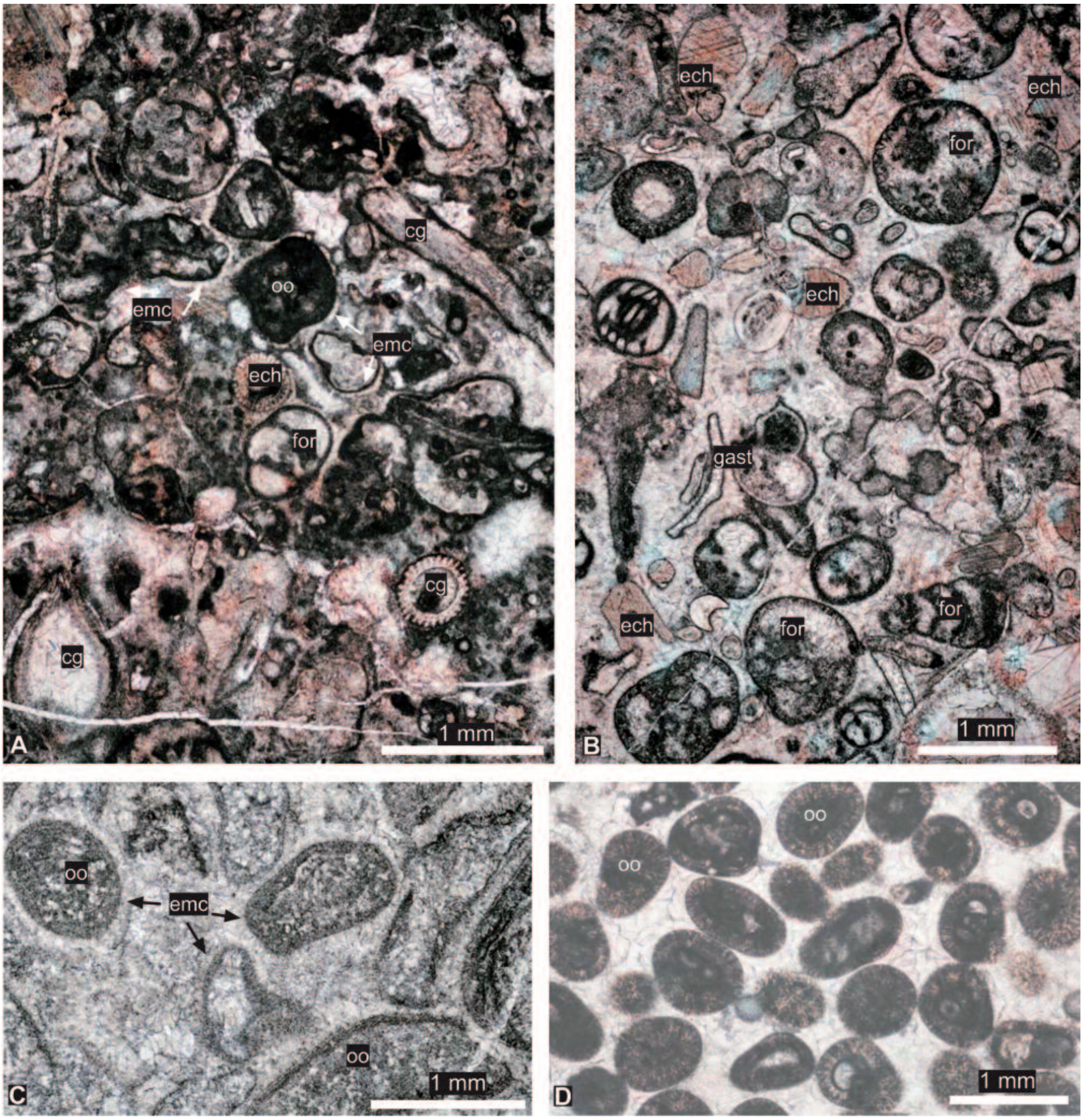

Fig. 10.- Microphotographs of grain-suported, high-energy platform-top deposits, showing early marine cementation (fmc). A) Skeletal grainstone (facies *C.3*) containing bioclasts (foraminifers, fo; echinoderms, eq) with a thin micrite envelope (coated grains, cg) and ooids (oo). B) Skeletal grainstone (facies *C.3*) with foraminifers (fo), echinoderms (eq), gastropod biomolds (gast) and a high volume of primary inter-particle porosity. C and D) Ooidal grainstones (facies *C.4*) with well sorted radial ooids (oo), neomorphosed in C, surrounded by thick isopachous rims of early marine cement (emc).

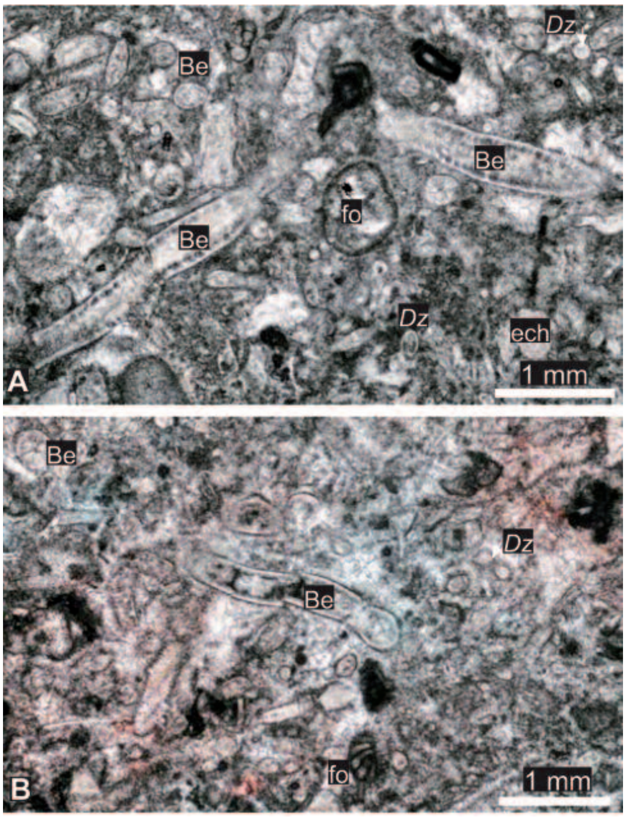

Fig. 11.- Microphotographs of platform-top algal boundstones (*C.5*). Both show sections of the problematic organism *Donezella (Dz)* and of the dasycladacean beresellid algae (Be). Other less abundant grains are foraminifers (fo) and echinoderms (eq).

exposed in the El Condado area (Salvador, 1993), located to the S of the studied outcrops, and the inferred eastern and western margins (see Discussion section).

Bioturbated skeletal wackestones (facies *C.1)* with abundant calcispheres and siliceous sponge spicules (replaced by calcite) are interpreted as deposited in low-energy subtidal environments, below the effective wave base. Similar facies have been described and interpreted in the Cuera succession by Della Porta et al. (2002b) and linked to (semi-) restricted environments on the platform interior during low sea-level stages, more prone to confined conditions. The presence of marly and argillaceous inter-beds in the uppermost part of the succession preludes the onset of siliciclastic input that finally will bury the carbonate platform top.

Skeletal pack- to grainstones (facies *C.2*) would form shoals or banks in high to moderate-energy, open marine shallow subtidal environments, above the effective wave base (Della Porta et al*.,* 2004). The microbial peloidal micrite locally present in this facies would act as microbial precipitates cementing and favouring the stabilization of the skeletal shoals during quiescence stages. The echinoderm-rich beds associated to this facies would record deeper conditions or minor drowning episodes on the platform top (James, 1997). Echinoderms (mostly crinoids) would form submarine meadows, which would be destroyed and reworked during storms giving rise to crinoidal sand bodies (Madi et al., 1996, Della Porta et al*.,* 2004).

Coated-grain and ooidal grainstones (facies *C.3* and *C.4*) are interpreted as lime sand deposits accumulated in high-energy shallow-water subtidal environments under permanent agitation (Wilson, 1975, Tucker and Wright, 1990). Their present day counterparts form dunes and mega-ripples in tropical marine settings, close to the carbonate platform margins (Tucker y Wright, 1990). The term coated grain refers to a grain with a calcareous cortex and in this study is used in two senses: a) an ooid in an early stage; and b) a sedimentary particle (usually a bioclast) with a thin micritic crust formed by endolithic micro-organisms. The latter type of grain was named cortoid by Flügel (1982). The early marine cementation described in this facies is often associated to very shallow-water environments (Macintyre, 1985).

Beresellid-dominated accumulations (facies *C.5*) are associated to shallow lagoon facies (facies *C.2*) and represent an open lagoon setting developed laterally and indicating that the restricted conditions did not prevail all over the platform (Mamet, 1991; Della Porta et al., 2002b). Local *Chaetetes* patch reefs confirm the open lagoon conditions in shallow water environments, presumably above wave base (Connolly et al., 1989). Concentrations of dasycladacean algae (like beresellids) with peloids are common deposits of tidal bars and channels of lagoons (SMF 18; Wilson 1975).

D. Facies associated to karstification and hydraulic fracturing

This facies association is dominated by carbonate breccias. Two different types of breccias have been observed in the El Sueve outcrops.

The first type consists of red-matrix breccias that are found as irregular patches unconformably overlying the carbonate platform succession (Fig. 12A), mainly in the Picu Pienzu section. They consist of poorly-sorted calcareous lithoclasts, derived from the Barcaliente and Valdeteja Fms, embedded in a red matrix made of micrite with some siliciclastic grains (Fig. 12B). These breccias have been interpreted as Permian karstic deposits developed on the Variscan massif. Breccias comparable to these and attributed to the same origin are found on variscan calcareous substrates elsewhere in the Cantabrian Zone (e.g. the Picos de Europa Province and Cuera area; Adrados-González et al., 2010).

The second type of breccias occurs in the Majada Les Espineres section area. There, the succession is cut by two sets of closely spaced joints, giving the rock a brecciated appearance (Fig. 12C-D). The joints are commonly filled by dolomite and/or calcite cements, suggesting the existence of a phase of brittle deformation associated to mineralizing fluid flow events. Comparable examples exist in the Cretaceous succession of the Basque-Cantabrian basin, which have been interpreted as the result of the migration of over-pressured fluids causing hydraulic brecciation and concomitant dolomite and calcite precipitation (Iriarte et al., 2012).

Fig. 12.- A) Outcrop photograph of red-matrix breccias resting unconformably on the Bashkirian succession and interpreted as Permian karstic deposits. B) Photomicrograph of karstic breccias containing angular poorly sorted clasts from the Barcaliente (B lith) and Valdeteja (V lith) formations, embedded in a red matrix (mr). C and D) Outcrop photographs of hydraulic fracturing breccias, where calcareous lithoclasts are surrounded by thick crusts of dolomite (dol) and of blocky spar (sp) cements.

Discussion

Interpretation of the carbonate platform succession in the El Sueve massif

Lateral changes in lithofacies and stratal patterns permit to distinguish two depositional zones in the Bashkirian-Moscovian carbonate system of the Picos de Europa Province, an internal zone (central and eastern sectors) and an external zone, surrounding the former (Bahamonde et al*.*, 2007). The internal zone represents the nucleation area of the carbonate platform, where very thick, massive microbial boundstones aggraded directly on the Barcaliente Fm. The carbonate system prograded away from the nucleation area, giving rise to the seismic-scale clinoforms that define the external zone. This external zone with a progradational stratal pattern is best exposed to the N of the Picos de Europa, in the Cuera area (Fig. 13), where a thick clinoformal unit of toe-of-slope alternations and lower-slope breccia units overlies the Barcaliente Fm and underlies upper-slope microbial boundstones (Bahamonde et al*.*, 1997).

The succession of the El Sueve massif described in this paper is comparable to that of the central part of the Picos de Europa Province, and differs from those typical of the external zone. The lower-slope breccia tongues, like those described in the Cuera and Las Llacerias cross-sections (external zone), have not been recognized in the El Sueve massif. Also, the absence of well developed stratal patterns indicates that the El Sueve area constitutes the nucleation area of a carbonate system probably different from the Cuera/Picos carbonate platform, and located to the NW of this. The El Sueve carbonate system aggraded and prograded at least towards the South and West. Southwards progradation took place until the El Condado (Figs. 2 and 13), where the Bashkirian carbonate platform pinches out below the basinal and slope shales of the Fresnedo Fm (Fig. 2). Although no intervening outcrops exist, the westward progradation of the El Sueve platform probably can be traced into the Peña Careses outcrops (see Fig. 13 for location).

Other important difference pertains to the timespan involved in the development of the El Sueve and the Cuera/Picos de Europa systems. In the former, the siliciclastic input from the orogen buried the carbonate-platform top in the late Bashkirian (Fig. 3; Villa, 1995), whereas the Cuera/Picos de Europa system kept being active until the late Moscovian. This longer lifespan of the carbonate system of the eastern areas of the basin favoured the development of flat-topped geometries and higher and steeper depositional slopes (until 40º in the Cuera section, Della Porta et al., 2003), which are prone to generate a breccia-dominated lower slope (Kenter et al., 2003).

Implications for the palaeogeographic reconstructions of the variscan foreland basin of the CZ during Bashkirian times

The foreland basin of the CZ shows a strongly asymmetric transversal depositional profile (Colmenero et al., 2002; Fernández et al., 2004), which is typical of foreland basins, with a highly subsiding proximal sector, adjacent to the orogen in the W, where thick siliciclastic successions accumulated, and more stable distal sectors to the E, where the large Cuera/Picos de Europa carbonate system developed. The data presented in this study suggest that, during the Bashkirian, the basin also presented a marked longitudinal asymmetry, from N to S and parallel to the orogen trend (see Steward, 1995; Weil et al., 2000, among others). In this sense, a carbonate domain (represented by the El Sueve outcrops) existed in the northern sectors of the Central Asturian Coalfield and passed towards the South into a dominant siliciclastic domain (Fig. 13). It is here interpreted that the El Sueve area constituted the internal area of nucleation of the platform, from which it later prograded, at least, towards the W and E. Nevertheless, the Variscan and Alpine tectonics, and the Permian-Cenozoic cover, hides the possible physical connection of the Bashkirian Sueve carbonates with those of the Cuera area, to the east, and with those of Peña Careses and of the Bodón and Aramo thrust units, to the west (Fig. 13). Consequently, the existence of a single and very large carbonate platform or an archipelago of several smaller carbonate buildings cannot be elucidated.

Conclusions

The Bashkirian carbonate succession exposed in the El Sueve massif (Valdeteja Fm) consists, from base to top, of three stratal domains: 1) a 150 m-thick well-bedded interval of dark and laminated lime mudstones, similar to the Barcaliente Fm facies, including some cm-thick calciturbidites and matrix-free carbonate breccia beds at the top, 2) a 500 m-thick massive interval made of cement-rich microbial boundstones; and 3) a 275 m-thick moderately to well-bedded interval of alternations of grain-supported skeletal-grains, coated-grain and ooidal grainstones, bioturbated wackestones and beresellid-algal boundstones. These three stratigraphic domains are interpreted, respectively, as basin-floor/toe-of-slope, depositional slope and platform-top facies belts of a high-relief microbial-dominated carbonate platform.

The studied succession in the El Sueve massif is comparable to those characterizing the central part of the Picos de Europa Province, where huge masses of massive microbial boundstone directly aggraded on the Barcaliente Fm; and differs from the clinoformal successions characterizing an external zone (Cuera or Las Llacerias cross-sections), where thick toe-of-slope alternations and lower-slope breccia units lie between the Barcaliente Fm and the upper-slope microbial boundstone.

This study confirms the existence of a microbial-dominated carbonate platform in the northern sector of the Central Asturian Coalfield, which pinches out towards the S, where siliciclastic sediments accumulated. This carbonate system could have been connected with the coeval carbonates of the Cuera area, to the E, and of the Peña Careses outcrops and the Bodón and Aramo thrust-sheet units, to the W, forming a very large calcareous domain covering

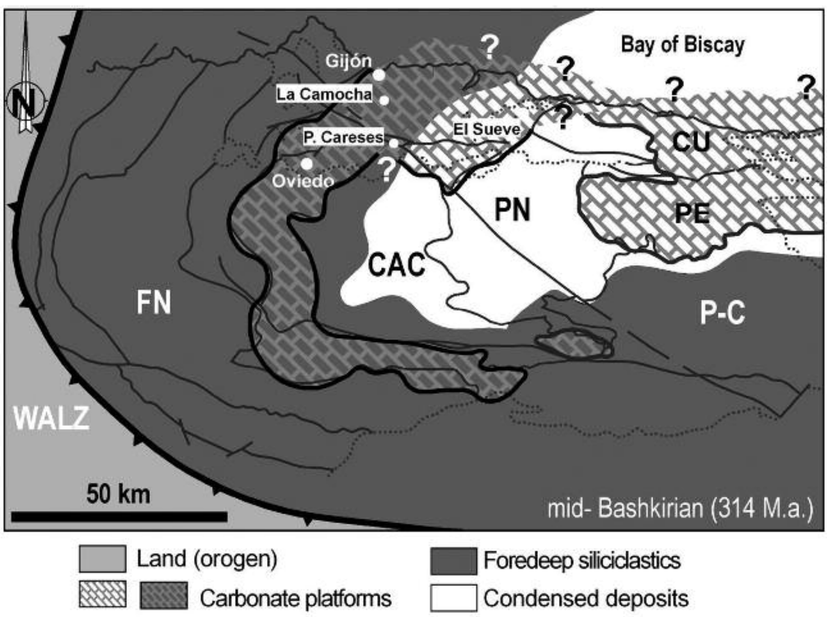

Fig. 13.- Schematic reconstruction of the Variscan foreland basin of the Cantabrian Zone during the Bashkirian, showing the lateral extent of the carbonate systems (present-day geographic coordinates; modified from Merino-Tomé et al., 2009). Question marks point out the possible connection amongst the carbonates exposed in the El Sueve, Cuera and Peña Careses outcrops and in the sub-surface of the La Camocha coal mine (both in the NE of the Fold and Nappe Province: FN). WALZ: West-Asturian-Leonese Zone. CAC: Central Asturian Coalfield. PN: Ponga Nappe Unit (except the Cuera area). PE: Picos de Europa Province. P-C: Pisuerga-Carrión Province.

the northern sector of the variscan foreland basin of the Cantabrian Zone. The existence of this calcareous domain implies a strong longitudinal asymmetry of the basin palaeogeography, parallel to the orogen, which is a peculiarity in this type of basins.

During the Bashkirian-Moscovian transition, the El Sueve portion of this northern calcareous domain was buried by the terrigenous wedges prograding from the proximal (western) sectors of the basin.

Acknowledgements

This research benefited from financial support through an agreement between Oviedo University Foundation (FUO) and a consortium integrated by Gas Natural, Vancast and Hunosa (FUO-EM-350-11). Daniel Muñiz is thanked for his assistance in the field. The editor Dr. Luis Miguel Nieto and the reviewers Dr. Juan Ramón Colmenero and Dr. Marc Aurell are thanked for suggestions and modifications in the revision of the manuscript.

References

Adrados-González, L., Alonso-Alonso, V., Bahamonde, J.R., Farias-Arquer, P., Fernández-González, L.P., Gutiérrez-Claverol, M., Heredia, N., Jiménez-Sánchez, M., Meléndez-Asensio, M., Merino-Tomé, O.A. and Villa-Otero, E. (2010): *Parque Nacional de los Picos de Europa: Guía Geológica*. Instituto Geológico y Minero de España (IGME), Serie Guía Geológicas de Parques Nacionales. Editorial Adrados, 337 p.

Alonso J.L., Marcos, A. and Suárez, A. (2009): Palaeogeographic inversion resulting from large out of sequence breaching thrusts: The León Fault (Cantabrian Zone, NW Iberia). A new picture of the external Variscan Thrust Belt in the Ibero-Armorican Arc. *Geologica Acta,* 7**:** 451–473.

Arp, G., Reimer, A. and Reitner, J. (2003): Microbialite in seawater of increased alkalinity, Satonda Crater Lake, Indonesia. *Journal of Sedimentary Research*, 73: 105–127.

Bahamonde, J.R., Colmenero, J.R. and Vera, C. (1997): Growth and demise of late Carboniferous carbonate platforms in the eastern Cantabrian Zone, Asturias, northwestern Spain. *Sedimentary Geology,* 110: 99–122.

Bahamonde, J.R., Vera, C. and Colmenero, J.R. (2000): A steep-fronted Carboniferous carbonate platform: clinoformal geometry and lithofacies (Picos de Europa Region, NW Spain). *Sedimentology*, 47: 645–664.

Bahamonde J.R., Kenter J.A.M., Della Porta, G., Keim L., Immenhauser A. and Reijmer J.J.G. (2004): Lithofacies and depositional process on a high, steep-margined Carboniferous (Bashkirian-Moscovian) carbonate platform slope, Sierra del Cuera, NW Spain. *Sedimentary Geology*, 166: 145–156.

Bahamonde, J.R., Merino-Tomé, O.A. and Heredia, N. (2007): Pennsylvanian microbial boundstone-dominated carbonate shelf developed in a distal foreland margin (Picos de Europa Province, NW Spain). *Sedimentary Geology*, 198: 167–193.

Bahamonde, J.R., Merino-Tomé, O.A. and Della Porta, G. (*in press*): Pennsylvanian carbonate platforms adjacent to deltaic systems in an active marine foreland basin (Escalada Fm., Cantabrian Zone, NW Spain). *Basin Research*.

Beauchamp, B. (1988): Lower Permian (Artinkian) sponge-bryozoan buildups, southwestern Ellesmere Island, Canadian Artic Archipelago. In: *Reefs (Canada and Adjacent Areas)* (H.H.J. Geldsetzer, N.P. James and G.E. Tebbutt, Ed.). *Canadian Society of Petroleum Geologists*, Memoir, 13: 575–585.

Bottjer, D.J. and Savrda, C.E. (1993): Oxygen-related mudrock biofacies. In: *Sedimentology Review 1* (V.P. Wright, Ed.). Blackwell Scientific Publications, 92-102.

Bouma, A.H. (1962): *Sedimentology of some flysch deposits: a graphic approach to facies interpretation*. Elsevier, Amsterdam, 168 p.

Bourque, P.A. and Boulvain, F. (1993): A model for the origin and petrogenesis of the red stromatactis limestone of Paleozoic carbonate mounds. *Journal of Sedimentary Petrology*, 63: 607–619.

Chafetz, H.S. (1986): Marine peloids: a product of bacterially induced precipitation of calcite. *Journal of Sedimentary Petrology*, 56: 812–817.

Colmenero, J.R., Fernández, L.P., Moreno, C., Bahamonde, J.R., Barba, P., Heredia, N. and González, F. (2002): Carboniferous. In: *The Geology of Spain* (W. Gibbons and M.T. Moreno, Eds.). Geological Society, London. 93–116.

Connolly, W.M., Lambert, L.L. and Stanton, R.J., jr. (1989): Palaeocology of Lower and Middle Pennsylvanian (Middle Carboniferous) *Chaetetes* in North America. *Facies*, 20: 139–168.

Davydov, V.I., Korn, D. and Schmitz, M.D. (2012): The Carboniferous period. In: *The Geologic Time Scale 2012* (v. 2) (F.M. Gradstein, J.G. Ogg, M.D. Smitz and G.M. Ogg, Eds.). Elsevier, Amsterdam, 603–650.

Davies, G.R., Edwards, D.E. and Flach, P. (1989): Lower Carboniferous (Mississippian) Waulsortian reefs in the Seal area of Nort-Central Alberta. In: *Reefs (Canada and Adjacent Areas)* (H.H.J. Geldsetzer, N.P. James and G.E. Tebbutt, Ed.). *Canadian Society of Petroleum Geologists*, Memoir 13: 643–648.

Della Porta, G. (2003): Depositional anatomy of a Carboniferous high-rising carbonate platform (Cantabrian Mountains, NW Spain). PhD Thesis, Vrije Universiteit, Amsterdam, 249 p.

Della Porta, G., Kenter, J.A.M. and Bahamonde, J.R. (2002a): Microfacies and paleoenvironment of *Donezella* accumulations accross an Upper Carboniferous high-rising carbonate platform (Asturias, NW Spain). *Facies*, 46: 159–168.

Della Porta, G., Kenter, J.A.M., Immenhauser, A. and Bahamonde, J.R. (2002b): Lithofacies character and architecture across a Pennsylvanian inner-platform transect (Sierra de Cuera, Asturias, Spain). *Journal of Sedimentary Research*, 72: 898–916.

Della Porta, G., Kenter, J.A.M., Bahamonde, J.R., Immenhauser, A. and Villa, E. (2003): Microbial boundstone dominated carbonate slope (Upper Carboniferous, N Spain): microfacies, lithofacies distribution and stratal geometry. *Facies*, 49: 175–208.

Della Porta, G., Kenter, J.A.M. and Bahamonde, J.R. (2004): Depositional facies and stratal geometry of an Upper Carboniferous prograding and aggrading high-relief carbonate platform (Cantabrian Mountains, NW Spain). *Sedimentology*, 51: 267–295.

Fernández, L.P., Bahamonde, J.R., Barba, P., Colmenero, J.R., Heredia, N., Rodríguez-Fernández, L.R., Salvador, C.I., Sánchez de Posada, L.C., Villa, E., Merino-Tomé, O.A. and Motis, K. (2004): La sucesión sinorogénica de la Zona Cantábrica. In: *Geología de España* (J.A. Vera, Ed.). SGE-IGME, Madrid, 34–42.

Folk, R.L. and Chafetz, H.S. (2000): Bacterially induced microscale and nanoscale carbonate precipitates. In: *Microbial Sediments* (R.E. Riding and S.M. Awramik, Eds.). Springer-Verlag, Berlin Heidelberg, 40–49.

Flügel, E. (1982): *Microfacies Analysis of Limestones*. Springer, Berlin, 633 p.

Golonka, J., Ross, M.I. and Scotese, C.R. (1994): Phanerozoic paleogeographic and paleoclimatic modeling maps. In: *Pangea: Global Environments and Resources* (A.F. Embry, B. Beauchamp and D.J. Glass, Eds.). *Canadian Society of Petroleum Geologists,* Memoir, 17: 1–47.

Harris, M.T. (1994): The foreslope and toe-of-slope facies of the Middle Triassic Latemar Buildup (Dolomites, northern Italy). *Journal of Sedimentary Research*, 64: 132–145.

Iriarte, E., López-Horgue, M.A., Schroeder, S. and Caline B. (2012): Interplay between fracturing and hydrothermal fluid flow in the Asón Valley hydrothemal dolomites (Basque-Cantabrian Basin, Spain). In: *Advances in Carbonate Exploration* (J. Garland, J.E. Neilson, S.E. Laubach and K.J. Whidden, Eds.). Geological Society, London, Special Publication, 370: 207–227.

James, N.P. (1997): The cool-water carbonate depositional realm. In: *Cool-water Carbonates* (N.P. James and J.A.D. Clarke, Ed.). SEPM, Special Publication, 56: 1–20.

Julivert, M. (1971): Décollement tectonics in the Hercynian cordillera of northwest Spain. *American Journal of Science*, 270: 1–29.

Kenter, J.A.M., Hoeflaken, F., Bahamonde, J.R., Bracco Gartner, G.L., Keim, L. and Besems, R.E. (2003): Anatomy and lithofacies of an intact and seismic-scale Carboniferous carbonate platform (Asturias, NW Spain): analogues of hydrocarbon reservoirs in the Pricaspian basin (Kazakhstan). In: *Paleozoic Carbonates of the Commonwealth of Independent States (CIS): Subsurface Reservoir and Outcrop Analogs* (W. Zempolich and H. Cook, Eds.). SEPM, Special Publication, 74: 185–207.

Macintyre, I.G. (1985): Submarine cements – the peloidal question. In: *Carbonate Cements* (N. Scheneidermann and P.M. Harris, Eds.). SEPM, Special Publication 36: 109–116.

Madi, A., Bourque, P.A. and Mamet, B.L. (1996): Depth-related ecological zonation of a Carboniferous carbonate ramp: Upper Viséan of Béchar Basin, Western Algeria. *Facies*, 35: 59–80.

Mamet, B. (1991): Carboniferous Calcareous Algae. In: *Calcareous Algae and Stromatolites* (R. Riding, Ed.). Springer-Verlag, Berlin, 370–451.

Merino-Tomé, O.A., Bahamonde , J.R., Samankassou, E. and Villa, E. (2009): The influence of terrestrial run off on the marine biotic communities: An example from a thrust-top carbonate ramp (Upper Pennsylvanian foreland basin, Picos de Europa, NW Spain). *Palaeogeography Palaeoclimatology Palaeoecology,* 278: 1–23.

Merino-Tomé O., Suárez-Rodríguez, A., Alonso-Alonso J.L., González-Menéndez, L., Heredia, N. and Marcos-Vallaure, A. (2011): *GEODE. Mapa Geológico Digital continuo de España Sistema de Información Geológica Continua*. SIGECO, J. Navas (Ed.). IGME. http://cuarzo.igme.es/sigeco.default.htm.

Middleton, G.V. and. Hampton, M.A. (1973): Sediment gravity flows; mechanics of flow and deposition. In: *Turbidites and deep-water sedimentation* (G.V. Middleton and A.H. Bouma, Eds.). Lecture Notes for a Short Course, SEPM, Pacific Section, Los Angeles, California, 1–38.

Pickard, N.A.H. (1996): Evidence for microbial influence on the development of Lower Carboniferous buildups. In: *Recent Advantages in Lower Carboniferous Geology* (P. Strogen, I.D. Somerville and G.L. Jones, Eds.). Geological Society London, Special Publication, 107: 65–82.

Reitner J. (1993): Modern cryptic microbialite/metazoan facies from Lizard Island (Great Barrier Reef, Australia): Formation and Concept. *Facies*, 29: 3–40.

Reitner, J., Neuweiler, F. and Gautret, P. (1995): Modern and fossil autimicrites: implications for mud mound genesis. *Facies*, 32: 4–17.

Reitner, J. and Schumann-Kindel, G. (1997): Pyrite in mineralized sponge tissue – product of sulfate reducing sponge-related bacteria? *Facies*, 36: 272–276.

Riding, R. (2000): Microbial carbonates: the geological record of a calcified bacterialalgal mats and biofilms. *Sedimentology*, 47: 179–214.

Salvador, C.I. (1993): La sedimentación durante el Westfaliense en una cuenca de antepaís (Cuenca Carbonífera Central de Asturias, N de España). *Trabajos de Geología, Universidad de Oviedo*, 19: 195–264.

Stewart, S.A. (1995): Paleomagnetic analysis of fold kinematics and implications for geological models of the Cantabrian/Asturian arc, north Spain. *Journal of Geophysical Research*, 100: 20079–20094.

Trichet, J. and Défarge, C. (1995): Non-biologically supported organomineralization. *Bulletin Institut Océanographique Monaco,* 14: 203–236.

Tsien, H.H. (1985): Origin of stromatactis –a replacement of colonial microbial accretions. In: *Paleoalgology: Contemporary Research and Applications* (D.F. Toomey and M.H. Nitecki, Eds.). Springer-Verlag, Berlin: 274–289 p.

Tucker, M.E. and Wright, V.P. (1990): *Carbonate Sedimentology*. Blackwell Scientific Publications, Oxford, 482 p.

Van der Kooij, B., Immerhauser, A., Steuber, T., Bahamonde, J.R. and Merino-Tomé, O. (2010): Controlling factors of volumetrically important marine carbonate cementation in deep slope settings. *Sedimentology*, 57: 1491–1525.

Villa, E. (1995): *Fusulináceos carboníferos del E de Asturias (N de España)*. Biostratigraphie du Paleozoïque, 13. Université Claude bernard-Lyon I, Lyon 261 p.

Warnke, K. (1995): Calcification processes of silicious sponges in Visean Limestones (Counties Sligo and leitrim, Northwestern Ireland). *Facies*, 33: 215–228.

Weil, A.B., Van der Voo, R., van der Pluijm, B.A. and Parés, J.M. (2000): The formation of an orocline by multiphase deformation: a paleomagnetic investigation of the Cantabria–Asturias Arc (northern Spain). *Journal of Structural Geology*, 22: 735–756.

Wilson, J.L. (1975): *Carbonate Facies in Geologic History.* Berlin, Springer-Verlag, 472 p.

Yurewicz, D.A. (1977): Sedimentology of Mississippian basin facies carbonates, New Mexico and west Texas—The Rancheria Formation. In: *Deep-Water Carbonate Environments* (H.E. Cook and R. Enos, Eds.). SEPM, Special Publication, 25: 203–219.

Manuscrito recibido el 16-10-2013
Recibida la revisión el 15-01-2014
Aceptado el manuscrito revisado el 28-01-2014