Stratigraphic record and palaeogeographic context of the Cambrian Epoch 2 subtropical carbonate platforms and their basinal counterparts in SW Europe, West Gondwana

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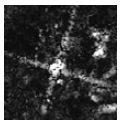

The Ibero-Armorican Arc is the main Variscan macrostructure in SW Europe. Its branches preserve the Cambrian record of a continuous margin of West Gondwana, from its southwestern edge (West Asturian-Leonese and Cantabrian zones and their lateral continuity into the Iberian Chains) to its northeastern extension (basement of the Cenozoic Aquitaine basin, Montagne Noire, southern Cévennes, and Sardinia). These Variscan relics allow the reconstruction of a Cambrian Epoch 2 carbonate belt that developed intermittently along West Gondwana. Facies associations show that the main centres of carbonate productivity were nucleated in ooidal and sand shoals, together with microbial and microbial-archaeocyathan reefs, developed in high energy regimes under subtropical arid conditions. Outside the inner carbonate belt, carbonate production was episodic and related to deposition of kerogenous black shales and phosphogenesis in the Central Iberian Zone and northern parts of Montagne Noire and Cévennes. Development of carbonate platforms along the margin was diachronous and discontinuous, due to poleward drifting and tectonically induced drowning and flooding. Biogeographic connection with similar subtropical carbonate platforms from East Gondwana (mainly South China) favoured the migration of equatorial and subtropical trilobite genera, such as *Dolerolenus*, *Eoredlichia*, *Metaredlichia*, *Protolenus*, *Redlichia*, and *Sardaspis*. • Key words: microbialites, archaeocyaths, reefs, trilobites, biogeography, anoxia, arid belt.

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Following a phase of predominantly siliciclastic sedimentation related to the Cadomian orogeny, a large-scale low-latitude carbonate depositional system was established in the SW-European margin of West Gondwana. From Ovetian/Atdabanian times (Cambrian Epoch 2), the carbonate belt intermittently persisted until the beginning of Cambrian Epoch 3 (*e.g.*, Bechstädt & Boni 1994, Debrenne *et al*. 2002, Álvaro & Debrenne 2010). The carbonate platforms were essentially biogenic and, accordingly, were strongly climate-sensitive and thus able to record evidence of major climatic changes. Some of them were primarily controlled by the Terreneuvian-Cambrian Epoch 2 poleward drifting of West Gondwana across a southern hemisphere arid belt (Álvaro *et al*. 2000a). Despite the recent study of some of these Cambrian carbonate-dominated platforms in SW Europe, their euxinic basinal counterparts have received less attention, probably as a result of the scarcity of fossil record and severe Variscan overprint. However, the gradual transition from these inner platforms to outer-platform, slope and basinal settings (characterized by gravitational-related facies, kerogenous limestones, and black shales) are locally preserved, and constitute key information that constrains the Gondwanan distribution of Cambrian anoxic conditions.

The aim of this paper is to contribute to the characterization of the climate-sensitive facies, stratigraphy, and palaeogeographic models of the Cambrian Epoch 2 platform-basinal transects that can be reconstructed in the SW-European margin of West Gondwana. The selected palaeogeographic areas, bent by the Variscan

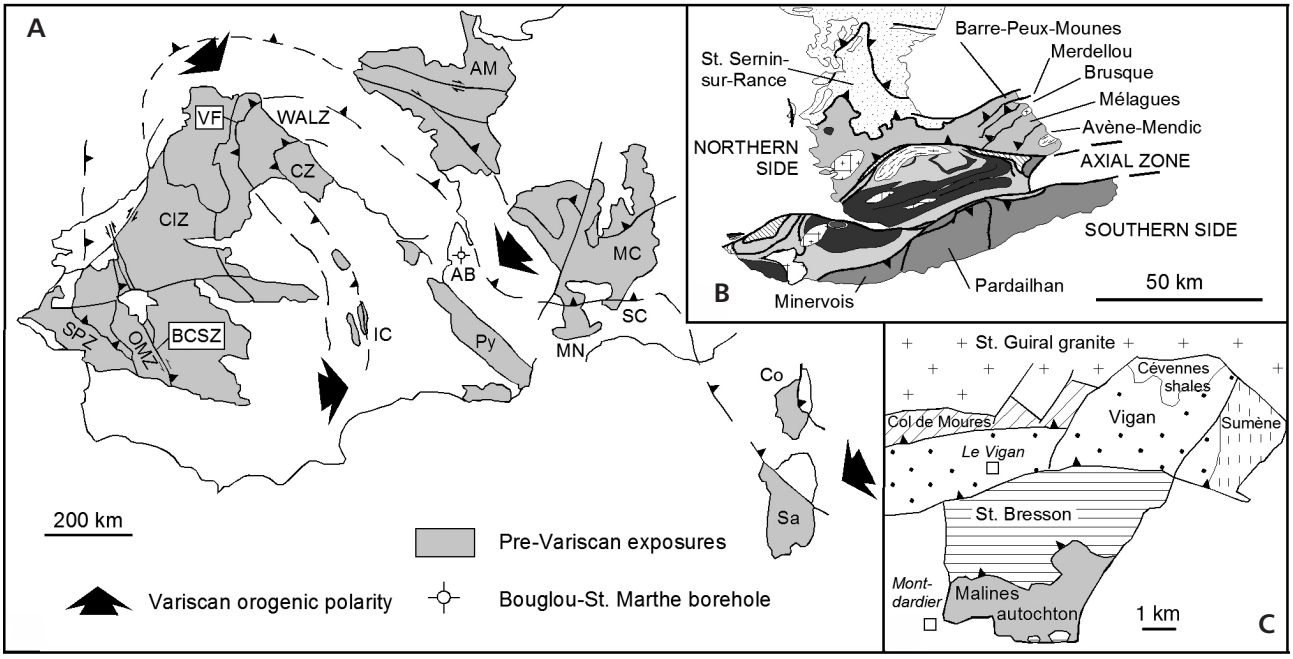

Figure 1. A – geological setting of the Variscan tectonostratigraphic units on which this work is focused, SW Europe: SPZ – South Portuguese Zone, OMZ – Ossa-Morena Zone, BCSZ – Badajoz-Córdoba Shear Zone, CIZ – Central-Iberian Zone, VF – Vivero Fault, WALZ – West Asturian-Leonese Zone, CZ – Cantabrian Zone, IC – Iberian Chains, Py – Pyrenees, AB – Aquitaine Basin, AM – Armorican Massif, MC – French Massif Central, MN – Montagne Noire, SC – Southern Cévennes, Sa – Sardinia, Co – Corsica; modified from von Raumer *et al.* (2003). • B – geological map of the Montagne Noire; modified from Clausen & Álvaro (2007). • C – geological map of the southern Cévennes; modified from Alabouvette *et al*. (1988).

Ibero-Armorican Arc, are (from SW to NE): the Iberian Chains (IC) and West Asturian-Leonese (WALZ) and Cantabrian (CZ) zones in Spain, the Montagne Noire (MN) and southern Cévennes (SC) in France, and Sardinia in Italy. New detailed descriptions and interpretations of the northern MN and SC regions are presented. Both the Ossa-Morena Zone and the Armorican Massif are excluded from the reported carbonate belt/basinal counterpart transect.

Palaeogeographic overview

In the Iberian Peninsula, the Variscan WALZ and CZ and their southeastern prolongation into the IC (Fig. 1) have been traditionally interpreted in terms of a single Cambrian basin, the so-called Cantabro-Iberian Basin. It was limited to the NE by the Cantabro-Ebroan Land Area, which also constituted the main source of sediments for the Pyrenean Basin, and to the SW by some uplifted areas that episodically supplied sediments (Aramburu *et al.* 1992, Álvaro *et al*. 2003). To the (present-day) NE of the Cantabro-Ebroan Land Area, a mosaic of platforms is preserved in the Cambrian exposures of the Pyrenees (Terrades area; Perejón *et al*. 1994), MN, SC, and their lateral equivalents in Sardinia.

The NW-SE-trending alignment of the Neoproterozoic Narcea antiform in NW Spain marks the boundary between two distinct Variscan tectonostratigraphic units: the WALZ and CZ. By contrast, the southeastern prolongation into the Neoproterozoic Paracuellos antiform does not separate significant palaeogeographic units, thus the IC will be described below as a single entity. The MN consists of a complex framework of Variscan nappes, which are grouped into three main structural domains that display distinct palaeogeographic units (Gèze 1949): (i) a metamorphic axial zone, comprising complex domes of gneisses and migmatites surrounded by Neoproterozoic mica schists; (ii) the southern flank composed of large nappes involving Cambrian to Carboniferous sedimentary rocks; and (iii) the northern flank consisting of imbricated tectonic nappes bearing Cambrian to Silurian rocks.

Although the Cambrian stratigraphy and palaeontology of southern France is well exposed in the MN, other neighbouring outcrops and borehole drilling have yielded fossil debris that suggests a Cambrian age. This is the case in some Cambrian-Lower Ordovician reddish limestones found in the Bouglou-St. Marthe borehole in the Cenozoic Aquitaine Basin (Bandelot & Fournier-Vilas 1984, Le Pochat 1984) and trilobite-bearing shales and limestones from the SC. The SC (Vigan region; Fig. 1) consists of a Variscan synmetamorphic nappe framework, structurally correlatable with the nappes of the northern MN (Bernier *et al*. 1970, Alabouvette *et al*. 1988, Faure *et al*. 1999, Matte 2007). The southernmost Malines mining district, which

has yielded some shell accumulations, is commonly subdivided into: (i) the Malines 'autochthon', a recumbent kilometre-scale syncline; and (ii) the Saint Bresson nappe, which overthrusts the Malines 'autochthon', with southward-directed tectonic transport (Fig. 1). Finally, the autochthonous Cambrian strata from SW Sardinia are surrounded by Cenozoic grabens and overthrusted by the allochthonous Arburese unit; previous works have recognized three palaeogeographic units: the Iglesiente and northern and southern Sulcis (Pillola *et al*. 1995).

The subdivision of the traditional "lower Cambrian" (Terreneuvian and Cambrian Epoch 2) by the *International Subcommission on Cambrian Stratigraphy* has not yet been completed. This complicates the correlation of these strata throughout SW Europe, where several regional chronostratigrahic scales are still being used. To solve this problem, a tentative correlation of global Cambrian chronostratigraphic units with the Siberian Terreneuvian-Cambrian Epoch 2 scale (mainly used for correlation of archaeocyathan-bearing units; Spizharski *et al*. 1986) and the Iberian Cambrian Epoch 2–3 scale (Liñán *et al*. 1993, Álvaro & Vizcaïno 1998) is proposed in Fig. 2.

West Asturian-Leonese and Cantabrian zones

A single phase of episodic carbonate deposition, late Ovetian/Atdabanian to early Cambrian Epoch 3 in age, is identifiable in the WALZ and CZ. It is lithostratigraphically represented by the Láncara and Vegadeo formations, 50–300 m thick. Their Cambrian Epoch 2 part contains distinct facies rich in birdseyes, microbial and microbial-archaeocyathan reefs and ooidal grainstones containing dolomite rhombs, pseudomorphs from calcium sulphate minerals (Russo & Bechstädt 1994), and scattered idiomorphic quartz interpreted as being characteristic of hypersaline conditions (Zamarreño 1972, 1975; Aramburu *et al*. 1992, 2004; Aramburu & García-Ramos 1993; Álvaro *et al*. 2000b). Both areas record the palaeogeographic establishment of a carbonate-dominated ramp that suffered a drastic tectonic influence during the Cambrian Epoch 2–3 boundary interval. The results being: (i) an immigration event of benthic shelly fauna which was recorded on the southeastern edge of the CZ (for a description of its trilobites and skeletonized microfossils, see Clausen & Álvaro 2006, Álvaro 2007), and (ii) virtual disappearence of carbonate production in the WALZ. According to Martínez Catalán *et al*. (1992) and Russo & Bechstädt (1994), the western boundary of the WALZ-CZ platforms was situated at the Vivero Fault (Fig. 1), coinciding with the boundary with the Variscan Central Iberian Zone (for a recent stratigraphic revision of the latter, see Jensen *et al*. 2010). To the west of the Vivero Fault, a basinal deposition probably represents the lateral equivalent of the Vegadeo and Láncara formations.

Iberian Chains

In contrast with the CZ and WALZ, the Ovetian-early Cambrian Epoch 3 carbonate production in the southeastern part of the Cantabro-Iberian Basin was interrupted by an early Bilbilian/Toyonian progradation of siliciclastic depositional systems related to the Daroca Regression (Álvaro & Vennin 1998). In the IC, the late Ovetian-Marianian carbonate episode is represented by mixed (carbonate-siliciclastic) deposits, comprising the Jalón, Ribota, and Huérmeda formations. The Jalón Formation, 250–350 m thick, consists of stromatolitic dolostones, sandstones, and variegated shales deposited under shallow subtidal, intertidal, and supratidal conditions, which yield common halite pseudomorphs in muddy shales. The overlying Ribota Formation, 30–120 m thick, is composed of dolostones and marls that represent the establishment of shoals and subsequent development of back-shoal, peritidal deposits with scattered halite moulds, frequently subjected to subaerial conditions; by contrast, the distal shoal dolostones have yielded anhydrite/gypsum pseudomorphs (Álvaro *et al*. 1995).

Montagne Noire

In the southern MN, an episodic carbonate deposition expanded, as in the CZ and WALZ, from the Ovetian/Atdabanian to the early Cambrian Epoch 3. The presence and distribution of carbonates allow definition of the Cambrian Epoch 2 Pardailhan and Lastours formations, where microbial-archaeocyathan reefs, ooidal shoals, and peritidal substrates are common (Álvaro *et al*. 1998, Debrenne *et al*. 2002). Konservat-Lagerstätten are known from the shale interbeds of the Pardailhan Formation, which have yielded remarkable soft-part preservation of arthropods (including bradoriids), sponges, chancelloriid cuticles, and trilobites (Vizcaïno *et al*. 2004, Vannier *et al.* 2005, Monceret & Monceret 2007). Evaporitic cauliflower-like nodules of anhydrite/gypsum occur in the upper member of the Lastours Formation, preserved within silica nodules and related to episodic subaerial exposure (Álvaro *et al*. 2000a). The distinctive tabular, peritidal and reef-dominated belt of the Pardailhan and Lastours formations was regarded as being developed only in a relatively persistent and narrow inner belt (Debrenne & Courjault-Radé 1986). This suggests that the Ovetian-Bilbilian (or Atdabanian-Toyonian) interval of carbonate productivity was a time of relative tectonic quiescence throughout the inner platform (southern MN).

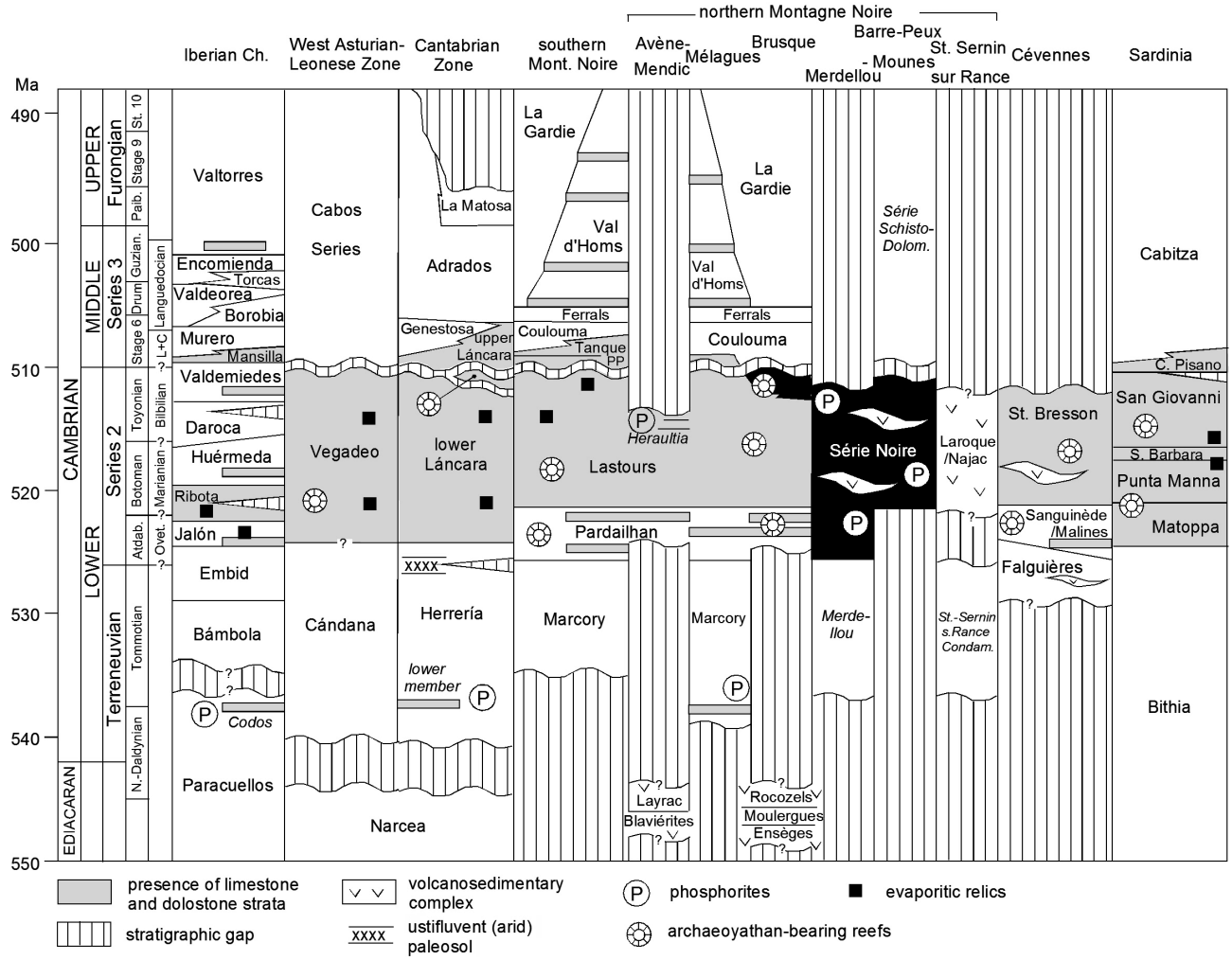

Figure 2. Terreneuvian-Cambrian Epoch 3 stratigraphic synthesis of the study area based on the papers reported in this text.

Poor biostratigraphic control has rendered uncertain the precise correlation of Cambrian epoch boundaries in the northern MN (Courjault-Radé 1985, Lescuyer & Giot 1987, Guérangé-Lozès & Burg 1990, Wotte *et al*. 2007); Fig. 2 provides a synopsis of the presently inferred temporal relationships of the Terreneuvian-Cambrian Epoch 3 units of the MN nappes. One of the most persistent dilemmas in the Cambrian stratigraphy of the northern MN has been to resolve the stratigraphic relationships between inner-platform carbonates (southern MN) and the black limestone/shale alternations of the northern MN. Although the facies of the Pardailhan and Lastours formations are recognisable in the Avène-Mendic autochthonous and the Mélagues and Brusque nappes, their sedimentary bodies have reduced thickness northwards and are subsequently replaced by the 'Série Noire' Formation. The latter, up to 500 m thick, consists of alternations of black and bluish limestones and black shales, the latter thinly laminated, fissile, and pyritic. Limestones, up to 2 m thick, show low-relief scouring, grading and, locally, conspicuous sliding structures, such as olistostromes and slumps on a metre- to decametre scale (Fig. 3A). Both the shales and limestones contain phosphatic nodules and crusts. The concentration of phosphate occurred by repeated alternations of low sedimentation rates and condensation (hardgrounds), *in situ* early-diagenetic precipitation of apatite, winnowing and polyphase reworking of previously phosphatized skeletons and hardground-derived clasts. The succession of repeated cycles of sedimentation, phosphate concentration, and reworking led to multi-event phosphate deposits rich in allochthonous particles (Clausen & Álvaro 2007). Phosphogenesis was primarily mediated by microbial activity, which is evidenced by the abundance of thromboid textures (Fig. 3B, C) and phosphatized microbial pseudomorphs that suggest the establishment of saprophytic to mutualistic, cyanobacterial-fungal consortia (Álvaro & Clausen 2010). Despite the general scarcity of shelly fossils, the top of some irregularly phosphatized limestones

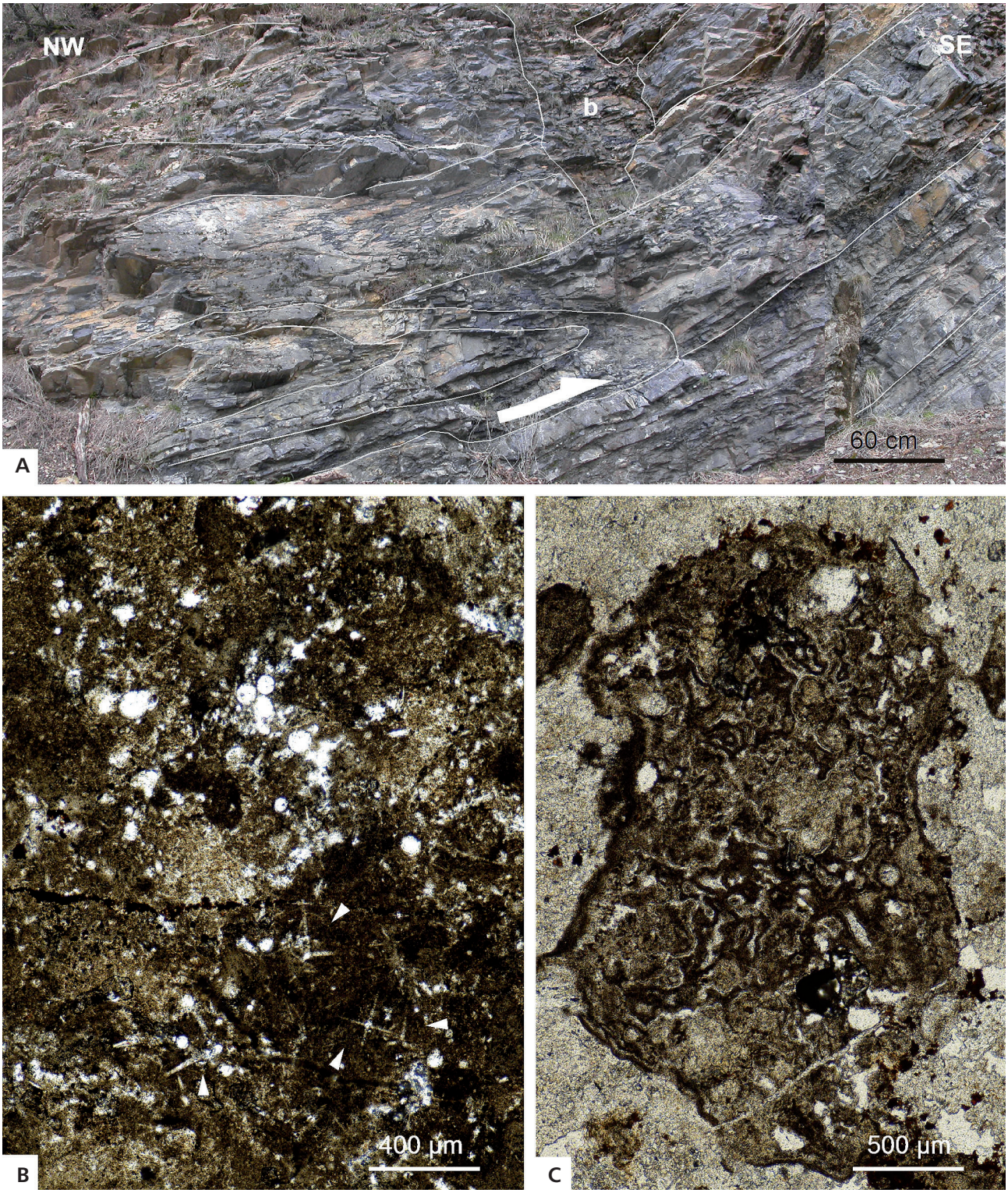

Figure 3. Field and microfacies aspects of the Série Noire in the vicinity of Peux, Barre-Peux-Mounes nappe, northern Montagne Noire. • A – preserved slump and collapsed breccia (b) flanking synsedimentary palaeowalls embedded in black limestone/shale alternations. • B – thin-section photomicrograph of a spiculite, rich in disarticulated hexactinellid sponge spicules (lower part, arrowed) and spherules of uncertain affinity (upper part), embedded in a thromboid texture; cap of a phosphorite crust. • C – thin-section photomicrograph of the centripetal infill of a secondary vuggy pore composed of biofilms and microbial mats alternating with micrite, fossil debris and, the remaining porosity, occluded with calcite cements.

are locally rife with: (i) a rich and diversified, phosphatized skeletonized microfauna composed of annelid and chancelloriid sclerites, brachiopods, crustaceans (branchiopods), halkieriids, molluscs (gastropods), trilobites, and problematica (Heuraltia Member; Kerber 1988); and (ii) hexactinellid and demosponge spicules (Série Noire; Prian 1979; Fig. 3B). These spiculites represent quiet-water, open-marine conditions, which contrast with the lagged base of some limestone strata, which contain common quartz silt, carbonate, phosphate, and glauconite clasts.

The Série Noire progressively thickens northward and the TOC content increases in that direction (up to 25 wt% in the Barre-Peux-Mounes nappe). This means that the oxygen content of bottom waters was decreasing as the water deepened in that direction, resulting from a decrease in terrigenous influx. The overall fine particle, thin laminae and TOC content suggest that the sedimentary conditions of the black shale interbeds were a quiet water, stagnant environment in which anoxic conditions were, at least, episodic; the occurrence of pyrite should not be used as an indicator of a sulphidic (anoxic) basin as the local abundance of burrowing structures suggests a low oxygenated substrate. The sponge biota also required an oxic or dysoxic substrate for their growth, as sponge metabolism requires free oxygen (Xiao *et al*. 2005). Therefore, although euxinic conditions predominated during deposition of the Série Noire, occasional currents may have brought free oxygen to the bottom water column necessary for the growth of sponges and the record of burrowing (Calvert & Piper 2009).

Some authors (*e.g.*, Guérangé-Lozès & Burg 1990) postulated an extremely rapid northward facies change from inner platform facies into black shale-dominated, basinal deposition in some nappes of the northern MN. Such a rapid facies change suggested the possibility of an inner-platform edge or fault escarpment, but the absence of thick breccia lobes within the northern nappes does not seem to support this model. However, a succession of relatively steepening slopes is still implied for the episodic presence of conspicuous submarine sliding. In the Barre-Peux-Mounes nappe, the Série Noire displays common olistostromes, slumps, and angular discordances bearing polyphase clasts derived from erosion of the underlying and contorted strata (Fig. 3). No preferential palaeocurrents have been measured, thus multidirectional sliding suggests that the northern MN platform was broken up into localized small-scale, fault blocks that respectively tilted in different directions.

Southern Cévennes

The southern Cévennes is a pre-Variscan inlier, flanked to the north by a Variscan pluton (the so-called Saint Guiral granite). From north to south, five tectonostratigraphic units can be distinguished: the Col de Moures-Arrigas, Col de Mourèzes, Sumène, Vigan and Saint Bresson nappes and the Malines autochthon (Alabouvette *et al*. 1986, Ortenzi 1986). The Cambrian stratigraphy of the Malines 'autochthon' and the Saint Bresson nappe (Fig. 1) is similar to that known from the MN and Sardinia (Verraes 1979, 1983; Ortenzi 1986), and the lithostratigraphic nomenclature and correlation with the southern MN are well established (Orgeval *et al*. 1997, 2000; Faure *et al*. 1999; Fig. 2). The Falguières (= Marcory) Formation, *ca* 300 m thick, consists of sandstones, acidic volcanoclastic strata and purple shales bearing hyolithids, chancelloriid and trilobite sclerites. It is overlain by the Sanguinède and Malines (= Pardailhan) formations. The former is composed of alternations of shales and carbonates, up to 70 m thick, locally rich in hyolithids, trilobites, bradoriids, and phyllocarids, whereas the limestones of the latter show ooidal textures reflecting shoal environments (Verraes 1979, 1983). Both units are overlain by the Saint Bresson (= Lastours) Formation, 300–400 m thick, which consists of massive dolostones that locally contain karstic cavities occluded by phosphatic crusts (Orgeval & Capus 1978). In the Sanguinède area, the lowermost strata of the Sanguinède Formation and the Saint Bresson dolostones that cap the so-called Saint-Bresson volcano have yielded Botoman archaeocyaths (Debrenne *et al.* 1976). The Saint Bresson Formation contains volcanosedimentary interbeds and sedex-type Pb-Zn ore mineralizations, similar to those known in the northern MN and Sardinia (see a synthesis in Orgeval *et al*. 2000). The Les Malines mine ores are Triassic in age and hosted within karstified dolostones of the Saint-Bresson Formation, whereas the Sanguinède and Montdardier mineralizations are hosted in the Sanguinède Formation. Some authors (Lacerda & Bernard 1984, Chantal & Leblanc 1986) have proposed the mineralization as being syngenetic stratiform deposits of Cambrian age, whereas others have suggested a Variscan (Michaud 1980a, b) or Mesozoic age (Verraes 1979; Charef & Sheppard 1988; Macquar *et al*. 1988, 1990). Le Guen *et al*. (1991) and Orgeval *et al*. (2000) subsequently synthesized the relationships between ore minerals and tectonic features and suggested a Variscan emplacement, similar to the mechanisms proposed for the northern MN, partially affected by Mesozoic reworking.

As in the case of the northern MN (Debrenne *et al*. 2002), the Cambrian Epoch 2 of the SC area has also been interpreted in terms of an inner carbonate-dominated platform (Sanguinède and Saint Bresson formations), probably less than 40 km wide, separated by the northern homogeneous fine-grained siliciclastic strata and black shales (the so-called crystalline slates of the Cévennes s.s. *sensu* Brouder 1963, 1964), by a volcanogenic palaeohigh and an

unpreserved slope masked by the presence of the Saint Guiral granite (Verraes 1979, Ortenzi 1986, Alabouvette *et al.* 1988).

Sardinia

As in the aforementioned carbonate-dominated successions, the carbonate sediments of SW Sardinia were also deposited from middle Ovetian/Atdabanian to early Cambrian Epoch 3 times. These include the Matoppa, Punta Manna, Santa Barbara, San Giovanni, Planu Sartu, and lower part of the Campo Pisano formations (Pillola *et al*. 1995, Perejón *et al*. 2000). The palaeogeographic framework of the area can be summarized as the chronological succession of a homoclinal ramp, a rimmed shelf, and an isolated platform (Bechstädt *et al*. 1985, 1988; Bechstädt & Boni 1989, 1994), with evaporitic precipitation in the last phase.

The Santa Barbara Formation contains evaporates found in two kinds of environmental setting: (i) arid, restricted tidal environments on a platform well-documented by the presence of moulds from anhydrite or gypsum, rosettes of former gypsum, and local idiomorphic gypsum/anhydrite crystals, probably of diagenetic origin (Cocozza & Gandin 1990); (ii) tidal environments characterized by subaerial tufas containing microbial carbonates, laminated fenestrae and evaporitic moulds on platform margins. Local cyclic sediments were deposited during repeated, small-scale tilting that formed tectonically enhanced grabens with small ponds infilled with partly slumped material and finally covered by laminated tidal to supratidal carbonates (Bechstädt & Boni 1989).

Palaeoclimatic conditions and anoxia

The study of several Variscan relics of SW Europe (in our case study, Iberian Peninsula, southern France, and Sardinia) allows reconstruction of some Cambrian Epoch 2 palaeogeographic features of West Gondwana. There, the end of the Cadomian orogeny and the subsequent infill of 'molasse' troughs recorded a change from synrift (mechanical subsidence) to post-rift (thermal subsidence) frameworks (Álvaro *et al*. 2008).

The margin was dominated by an extensional regime associated with prolific rift-related tholeiitic-alkaline volcanism in neighbouring areas, such as Morocco and Ossa-Morena (Gasquet *et al*. 2005, Pereira *et al*. 2006). The extensional regime resulted in the formation of graben and halfgraben systems, which controlled the distribution of carbonate platforms and slope and deeper basin facies (Fig. 4).

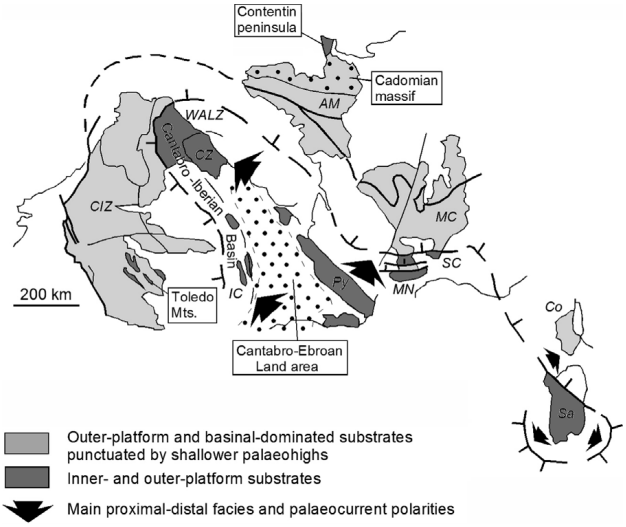

Figure 4. Tentative Cambrian Epoch 2 palaeogeographic reconstruction of the inner-platform/basin transects through the SW-European margin of West Gondwana.

The variety and abundance of ooidal shoals, microbial-archaeocyathan reefs, and primary to early-diagenetic evaporitic relics (gypsum, anhydrite, and halite) suggest that extensive arid conditions were locally associated with the evolution of the Cambrian Epoch 2 carbonate-dominated and mixed platforms. Carbonates were produced in the Cantabro-Iberian Basin and MN-Sardinia platforms during the late Ovetian/Atdabanian-early Cambrian Epoch 3 interval. The existence of a Terreneuvian-Cambrian Epoch 2 southern hemisphere arid belt is envisaged in West Gondwana (Álvaro *et al*. 2000a, Álvaro & Debrenne, 2010): arid climate conditions probably favoured the early, widespread and pervasive dolomitization of peritidal environments (lower Láncara in the CZ, Vegadeo Formation in the WALZ, Ribota and Valdemiedes formations in the IC, upper Lastours Formation in the MN, and Sta. Barbara Formation in Sardinia; Fig. 2).

As a result of tectonic activity and open-sea communication of inner platforms across the Cambrian Epoch 2–3 transition, this stratigraphic interval is commonly represented in the study area by dolostone/limestone and dolostone/shale contacts.

Another process recorded across the same epoch transition is a diachronous extensional phase, which led to the breakdown of all of the reported platforms (already established in the isolated Sardinian platform with the Sta. Barbara Formation), general drowning patterns related to Milankovitch-like cyclicity, and the end of carbonate productivity during the early Cambrian Epoch 3 (Álvaro *et al*. 2000c).

Both the Neoproterozoic-Cambrian transition and the Terreneuvian-Cambrian Epoch 2 were time spans of intense accumulation of sedimentary organic matter

worldwide. Although the Terreneuvian-Cambrian Epoch 2 was characterized by non-simultaneous organic matter deposition in shallow epeiric seas, especially in low and mid latitudes of the southern hemisphere, some authors have assigned most of the organic matter-rich deposits to global anoxic events. In fact, the so-called Sinsk event (Botoman in age) was proposed in Siberia to explain the decline and extinction of numerous taxonomic clades associated with the significant accumulation of non-bioturbated black shales in subtropical epeiric platforms (Zhuravlev & Wood 1996, Ivantsov *et al*. 2005). The Botoman Sinsk anoxic event is marked by a characteristic negative excursion in the $\delta^{13}C$ record of carbonates and organic matter, usually with a sharp drop from around +2.2‰ to –1.6‰ in Siberia, which was associated with enhanced burial of organic matter (Brasier *et al*. 1994). Other Tommotian-Atdabanian black carbonaceous limestones and shales are known worldwide, such as the Yangtze Platform (South China; Goldberg *et al*. 2007, Zhou & Jiang 2009), where sponge-rich Lagerstätten similar to those described in the northern MN phosphorites, are reported (Xiao *et al*. 2005). In our case study, the distribution of kerogenous limestones and black shales is restricted to the slope-to-basinal settings exposed in the northern MN and SC. Their age does not support an exclusive Botoman Sinsk event, although their youngest occurrence in the Brusque nappe (Debrenne & Courjault-Radé 1986) may suggest the maximum worldwide extension of the Sinsk event in subtropical, low and middle latitudes.

Trilobite-based biogeographic connections

The Ovetian-Marianian (or Atdabanian-Botoman, Cambrian Epoch 2) limestone and limestone/shale strata of SW Europe have yielded numerous trilobite assemblages dominated by endemic genera and species. However, some of these associations comprise distinct genera shared with other subtropical carbonate-dominated continental margins. These are: *Hebedescina* (Sardinia, South China and Australia), *Dolerolenus* (South China, Sardinia, IC, and the Himalayas), *Sardaspis* (= *Mianxianella*; Sardinia, South China), *Eoredlichia* (= *Archaeops*, *Saukiandops, Pararedlichia, Galloredlichia*; South China, Australia, Sardinia, MN, and Ossa-Morena), *Pagetiellus* (= *Delgadella*; Spain, Portugal, Sardinia, Siberia, Mongolia, Newfoundland), *Metadoxides* (Siberia, South China, Sardinia, CZ, MN, Bohemia), *Kuanyangia* (Sardinia, South China), and *Longduia* (Sardinia, South China); see references in Álvaro *et al.* (2003).

As a result, biogeographic connection with similar subtropical carbonate platforms from East Gondwana (mainly South China) favoured migration of equatorial and subtropical trilobite genera, such as *Dolerolenus*, *Eoredlichia*, *Metaredlichia*, *Protolenus*, *Redlichia*, and *Sardaspis*. This link would be episodically re-established during the late Languedocian (latest Cambrian Epoch 3)-Furongian time span, as a result of residual temperate-water carbonate production in West Gondwana (Álvaro *et al*. 2003, 2007).

Conclusions

The Cambrian Epoch 2 strata of SW Europe provide a key opportunity to reconstruct several palaeogeographic transects, subsequently bent by the Variscan Ibero-Armorican Belt, with a bathymetric range from shallow marine (IC, CZ, WALZ, southern MN, and Sardinia) to hemipelagic shelf and basin (northern MN and SC) settings. During the Cambrian Epoch 2, the CZ-WALZ carbonate platform (Vegadeo and lower Láncara formations) was characterized by a general westward-dipping inner-platform complex of ramps, bounded at the west by the Vivero Fault. The latter would represent the boundary with the basinal sedimentation recorded in the Central–Iberian Zone.

In contrast, the Cambrian Epoch 2 exposures of MN and SC have preserved a complex of northward-dipping platforms, including a complete facies transect ranging from peritidal, shoal and reef barrier (Pardailhan-Lastours formations and Sanguinède-Saint Bresson formations, respectively) to slope and basin (Série Noire in the northern MN and 'crystalline slates' in the Cévennes) settings. In the slope-to-basin palaeogeographic areas, the general facies trend was complicated by the onset of a complex tectonically enhanced palaeorelief, which resulted in strong lateral thickness and facies variation of black shales and kerogenous limestones.

Finally, the Cambrian Epoch 2–3 boundary interval recorded a conspicuous (although diachronous) extensional phase, which led to the diachronous breakdown of all the reported platforms (already begun on the isolated Sardinian platform), general drowning patterns, and the end of carbonate productivity during the early Cambrian Epoch 3.

During the Cambrian Epoch 2, the biogeographic connection of the margins of Gondwana (sharing similar subtropical conditions) and nucleation of carbonate factories favoured migration of equatorial and subtropical trilobite genera. After carbonate productivity ceased at the beginning of Cambrian Epoch 3, this biogeographic link disappeared and was only episodically re-established during the late Languedocian (latest Cambrian Epoch 3)-Furongian time span, as a result of residual temperate-water carbonate production in West Gondwana.

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