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Tectonic control on Cambrian sedimentation in South-Western Europe

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Key words: Tectonic activity, Cambrian, SW Europe

ABSTRACT

The Cambrian deposits of south-western Europe show the influence of syndepositional faulting processes, episodically developed under a generally extensional tectonic regime. These deposits record three main episodes of enhanced tectonic activity: during the Marianian or Botomian times (Early Cambrian), the Early-Middle Cambrian transition and the earliest Late Cambrian times.

The first episode is marked by beds of carbonate breccias and sedimentary slides, reflecting redeposition on local carbonate slopes. The second episode reflects the development of major intra-basin topographies, suggesting seafloors progressively differentiated into mosaics of topographic highs and lows, which induced great changes in basin geometries and subsidence regimes. The last one is marked by sedimentary slides, olistolithic blocks and slump folds, reflecting deposition on local terrigenous slopes.

RESUME

Les dépôts cambriens de l'Europe du sud-ouest montrent l'influence de processus tectoniques synsédimentaires, développés de façon épisodique, dans un contexte géodynamique de tectonique distensive. Ces dépôts enregistrent trois épisodes principaux d'activité tectonique : au cours du Marianien ou Botomien (Cambrien inférieur), à la transition Cambrien inférieur-moyen, et à la base du Cambrien supérieur.

Le premier épisode est caracterisé par des niveaux de brèches carbonatées et des structures sédimentaires de glissement attribuées à des dépôts d'une pente locale, en contexte carbonaté. Le second épisode correspond au développement d'une topographie intra-bassin où s'individualise une mosaïque de haut-fonds et bas-fonds topographiques; cette différenciation du fond marin entraine de grands changements dans la géometrie et la subsidence du bassin. Le dernier épisode est caracterisé par des structures de glissement, des blocs olistolitiques et des structures de slumping, qui correspondent à des dépôts de pente en contexte terrigène.

Introduction

Passive-margin basins are widely considered as environments of relative tectonic stability, but they are not totally devoid of tectonic activity. Commonly, uniform and slow rates of subsidence are assumed, which are unrealistic for fault-controlled basin evolution within "passive" margins.

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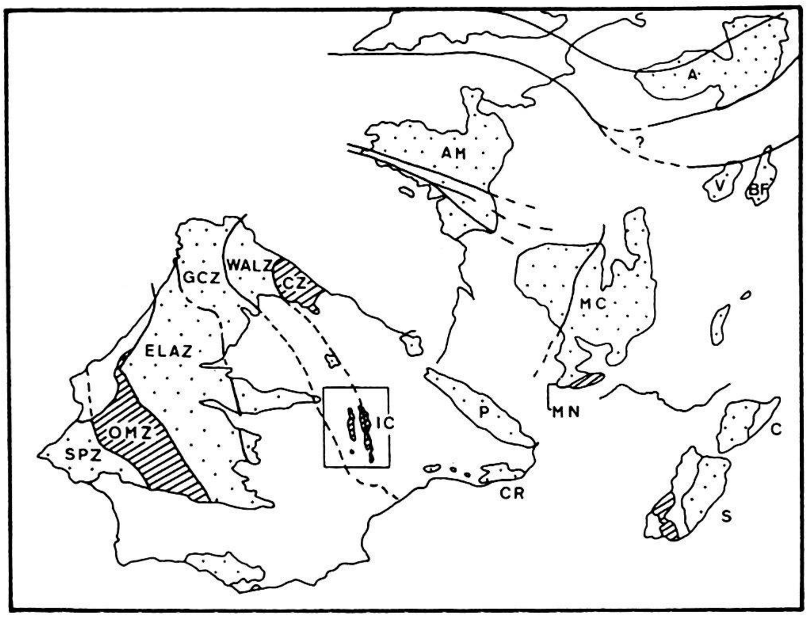


Fig. 1. The Variscan massifs of south-western Europe in a Cambrian reconstruction.

The recognition of the importance of tectonic activity in ancient shelf sequences has increased significantly in recent years. An understanding of syndepositional basin morphology, geodynamic evolution and depositional systems is necessary to reconstruct accurate paleogeographic schemes and facilitate intercontinental correlations.

The main criteria presented in this paper for the recognition of syndepositional faults are (1) associated gravity-induced deformation structures, (2) the overall facies and thickness changes along linear trends in isopach maps, and (3) the estimation of the intrabasinal relative subsidence rates.

The origin of lateral thickness variations may be due either to syndepositional tectonism or an inherited paleotopographic relief (Le Roux, 1989). However, larger increases in thickness over short lateral distances and the pattern of isopachs are difficult to account for other than by local subsidence in the vicinity of fault zones.

In the Cambrian sediments of south-western Europe (the whole Iberian Peninsula, the Montagne Noire in France and Sardinia; Fig. 1), recognizable stratigraphic and sedimentologic signatures representing the influence of small-scale paleotectonic movements of local structural areas have been observed. The Cambrian depositional system of these basins represents an area of interactive structural and sedimentary events.

This study will attempt to explain the origin, occurrence and preservation of syndepositional faulting processes in the Cambrian basins preserved in south-western Europe. Regional tectonic events will be dated and integrated into an extensional geodynamic model. For this purpose, the stratigraphic and sedimentologic evidence that argues for an episodic history of tectonic activity in this Gondwanian margin will be reviewed.

Episodes of enhanced tectonic activity

In the Cambrian sedimentary record of south-western Europe, the existence of remarkable episodes of enhanced tectonic activity has been proposed by several authors. Episodic syndepositional faulting operated during three main episodes: the Botomian or Marianian times (Early Cambrian), the Early-Middle Cambrian transition and the Late Cambrian times. The tectonic episodes separate periods of relative tectonic quiescence, during which subsidence and eustasy controlled the sedimentation of depositional sequences. The first and third episodes are concerned with the influence of local small-scale syndepositional faulting processes. During the first and third tectonic-induced episodes, neither comparable deposits nor disconformities in these Cambrian basins have been found. Therefore, a cause internal to the basin can be inferred: these slight slopes probably resulted from local tectonic breakdowns of the previous seafloor and not from sea-level falls. However, the second episode documents an apparent mosaic of topographic highs and lows, which is observed in the whole basins.

(1) The first episode

The Early Cambrian deposits of the Ossa-Morena Zone (southern Iberian Peninsula) show the existence of an important bimodal volcanic activity associated with an episodic tectonic instability. A rifting axis is supposed to be located somewhere south of the Ossa-Morena Zone. The Pulo do Lobo Unit, cropping out at the south of this zone (Oliveira 1990), includes an oceanic terrain (the Beja-Acebuches ophiolite; Munhá et al. 1986), which provides support for this interpretation. Liñán & Quesada (1990) described two periods of widespread tectonic instability, as evidenced by the appearance of volcanic activity, abrupt vertical and lateral facies variations, synsedimentary slumped beds and local unconformities. The first period corresponds to their intermediate Cambrian carbonate lithosome (included within the Ovetian-Marianian stages) and the second one during the late Bilbilian substage. No Upper Cambrian rocks are known in the Ossa-Morena Zone.

In the Iberian Chains (NE Spain), the first episode has been recognized within the Ribota Formation. It is characterized by the presence of sedimentary slides, debris flows and associated olistolithic and slumped beds, extensive breccia sheets and channel deposits (Alvaro et al. 1995). This assemblage of sedimentary features allows us to recognize isolated and local slopes. The absence of comparable layers or regional disconformities in platform-interior sites in other basins suggests a cause internal to the basin. Thus, the extensive breccia sheets and channel deposits of the distal part of the Iberian basin suggest the local breakdown and instability of the seafloor during this episode, as well as the development of depositional slopes.

South-western Sardinia is another neighbouring area in which a detailed study in geodynamic and paleogeographic features has been made. Several Early Cambrian episodes of extensional tectonic activity have been described, often characterized by slumping, debris flows, brecciation phenomena and associated mineralizations. Main tensional events occurred (according to Boni et al. 1981, Carannante et al. 1984, Bechstädt & Selg 1985, Gandin, 1987, Bechstädt et al. 1988, Pillola et al. 1995) during the deposition of the Punta Manna/Santa Barbara transition and the Santa Barbara/San Giovanni transition.

(2) The second episode

The second episode can be characterized by important lateral variations of thickness and facies. It represents the development of a major topography of the seafloor, which was differentiated into assemblages of relative horsts and grabens.

Block-faulting processes have been broadly exposed during early Middle Cambrian times in the Cantabrian Zone (northern Iberian Peninsula; Aramburu et al. 1992), across the Lower-Middle Cambrian transition on the southern side of the Montagne Noire (southern France; Courjault-Radé 1990) and during the deposition of the San Giovanni Formation in Sardinia (Gandin 1987).

Platforms were fragmented and progressively drowned. In-situ carbonate production in relative topographic highs gave rise to widespread condensed griotte facies. This facies has been defined, from a lithostratigraphic point of view, as Mansilla Formation (Iberian Chains), upper member of the Láncara Formation (Cantabrian Zone; Zamarreño 1972, 1978, Aramburu et al. 1992), "faux griottes" (Montagne Noire; Courtessole, 1973) and Campo Pisano Formation (Sardinia; Pillola 1987). The top of this griotte facies culminated with the flooding and breakdown of the platform and the siliciclastic fine-grained deposition of the Murero Formation (Iberian Chains), the Genestosa Member (Cantabrian Zone), the "Schistes à Paradoxides" Formation (Montagne Noire) and the Campo Pisano Formation (Sardinia).

The lack of accurate biostratigraphical data in the Cantabrian Zone, the Montagne Noire and Sardinia does not allow the relative importance of tectonic control to be quantitatively assessed. However, the paleontological wealth of the Early-Middle Cambrian transition in the Iberian Chains (NE Spain) will permit us to develop a quantitative study of the Iberian intrabasinal subsidence.

(3) The third episode

The third episode has only be elucidated from the Upper Cambrian sediments of the Iberian Chains (within the Encomienda and Valtorres Formations; Alvaro 1995). It is characterized by blocks of sizes up to a few decimetres, composed of cemented sandstones and laminated siltstones included within shales, slump structures and flute marks, which were deposited on slight to significant slopes (Alvaro & Vennin 1995). The blocks and olistrostromic beds are viewed as representing gravity-induced processes, indicating the presence of local marked topography within the basin.

The three studied episodes of enhanced syndepositional faulting have affected shallow-marine sediments, which were covered by deeper green shales, deposited in offshore environments of outer-platforms. Thus, according to the Cambrian relative sea-level curves proposed by Gandin (1987), Bechstädt et al. (1988), Aramburu et al. (1992) and Álvaro (1994, 1995b), these syndepositional tectonic processes were generated during main transgressive trends of relative sea-level change (or transgressive systems tracts). As Yose & Hardie (1990) envisaged, platform collapses related to local slope instabilities can be generated during sea-level rises, contrasting with the platform collapses associated with sea-level falls.

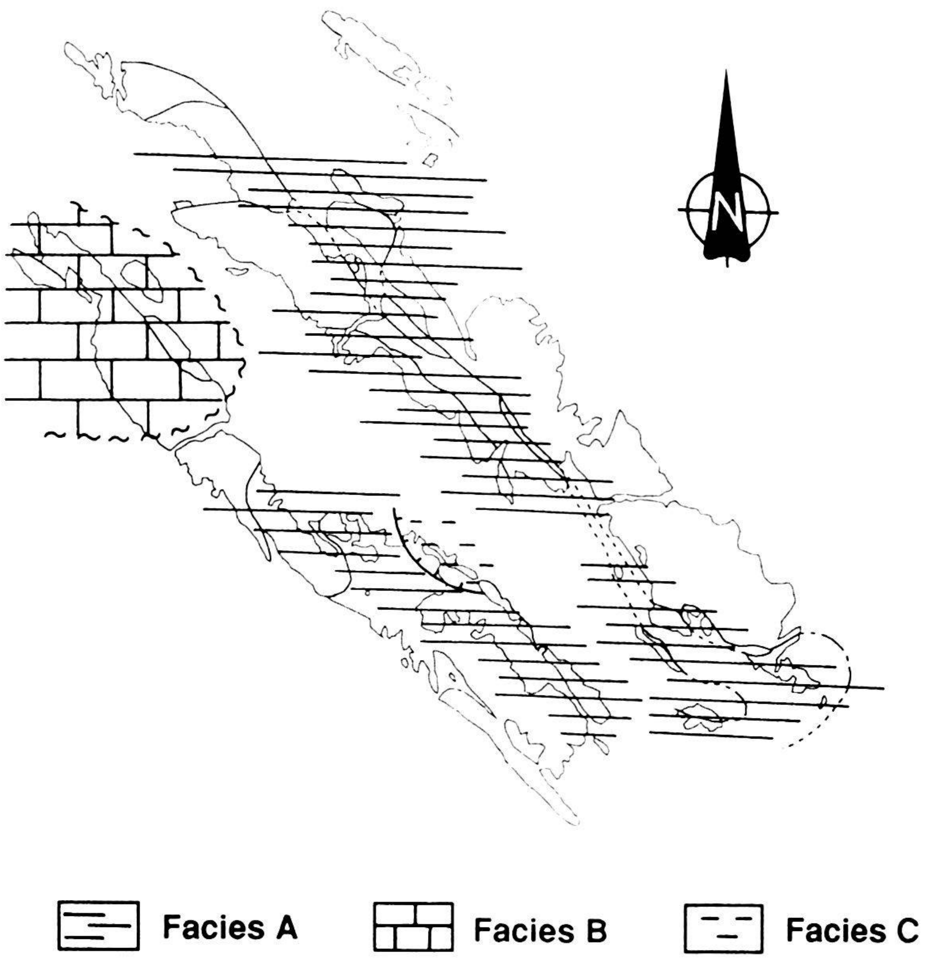


Fig. 2. Areal distribution of sedimentary environments during the Hamatolenus ibericus (latest Early Cambrian) biochron in the Iberian Chains (NE Spain; see boxed area in Fig. 1). Valdemiedes Formation. Further explanation in the text.

A Syndepositional tectonic model for the second episode

The Cambrian outcrops of the Iberian Chains exhibit a good litho- and biostratigraphic control that permit us to realize a complete paleogeographic reconstruction of the second tectonic episode.

The Valdemiedes and Mansilla Formations (20–200 m thick; Liñán et al. 1992) consist of alternating beds of green marly shales and carbonates. Both formations show heterogeneous lateral and vertical distribution of facies.

In the lower part of the Valdemiedes Formation (late Bilbilian), three main facies were developed in the Iberian basin (a detailed study of microfacies has been presented in Álvaro 1994). Facies A is composed of stromatolithic and algal-mat limestones, alternating with green shales. This facies represents the development of peritidal environments in the more proximal area of the basin. Facies B is composed of bioclastic limestones, rich in fauna. The eroded bases and graded units observed in this second facies imply storm-induced processes. Another upper offshore environment is represented in

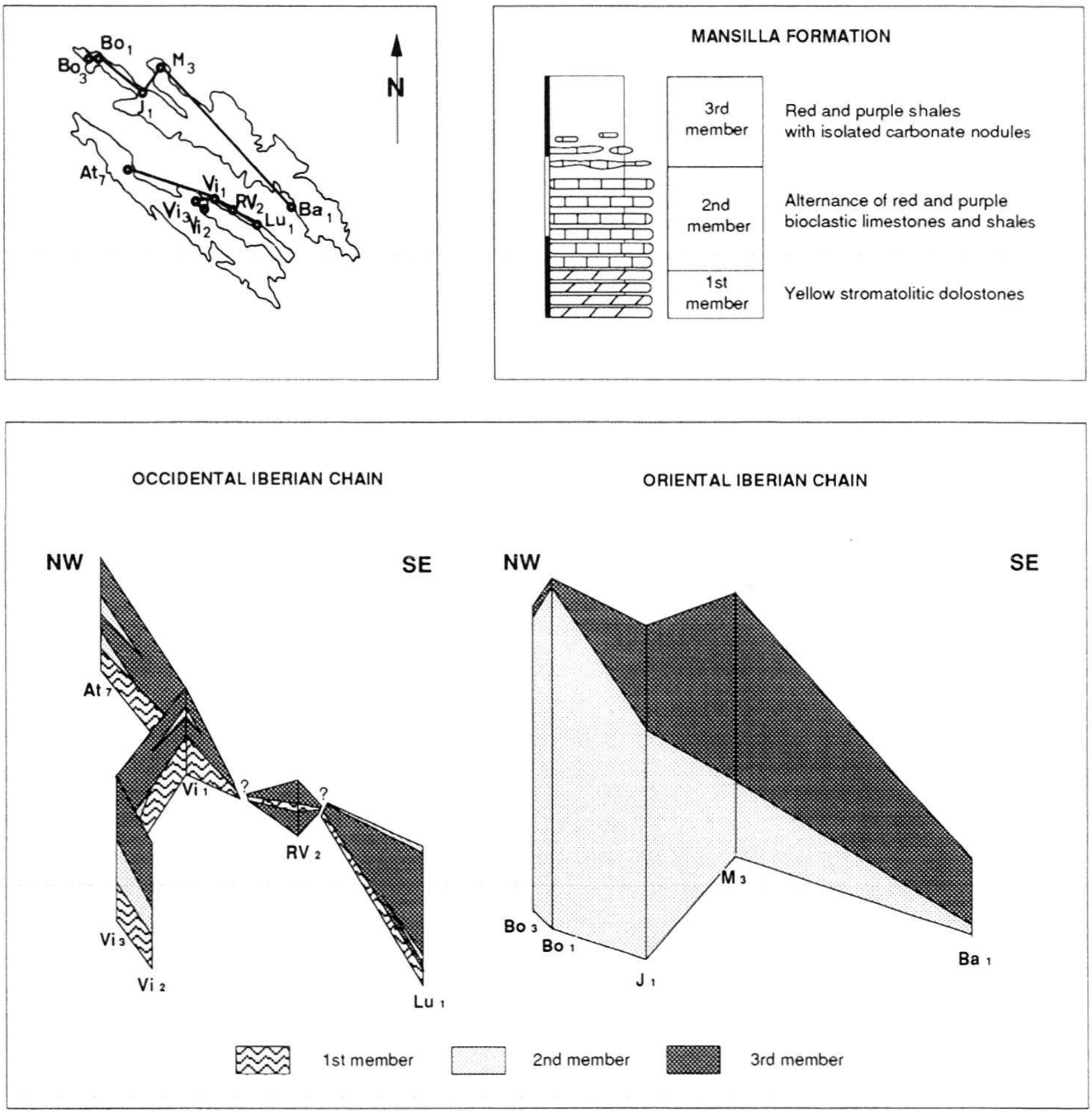


Fig. 3A. Stratigraphical correlation of the three members of the Mansilla Formation (Iberian Chains).

facies C. It consists of a monotonous green shale deposit, exhibiting a rich and complete fossil record.

During the *Hamatolenus ibericus* biochron (time representing the last biozone of the latest Early Cambrian; Liñán et al. 1993a; Álvaro et al. 1993), the deposition of fine-grained siliciclastic sediments below fairweather wave base (facies C), and their paleogeographical position (surrounded by the shallower deposits of facies A; Fig. 2), suggests that the seafloor was becoming differentiated into a series of topographic highs and lows. Taking into account the superposition of the Hercynian and Alpine phases of deformation, and the present-day structural setting of the pre-Hercynian outcrops of the Iberian Chains (Fig. 1), we can conclude that a main depressed area, located in the central part of the Western Iberian Chain (see Fig. 4), was developed during the latest Early Cambrian.

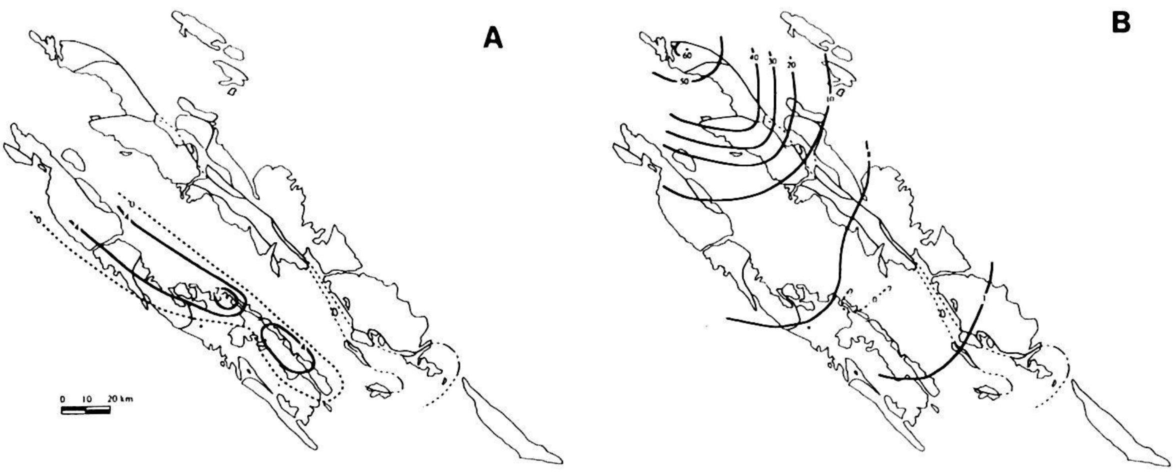


Fig. 3B. Isopach maps showing regional thickness of the first (A) and two last members (B) of the Mansilla Formation.

This depression is called the Villafeliche Graben, and it played an important role during early Middle Cambrian times.

In the Mansilla Formation (late Leonian times), the pronounced facies and thickness (2-70 m of thickness) variations, on a scale of km to tens of km (Fig. 3), suggest that the seafloor continued reflecting the development of slight paleohighs and depressions. In-situ carbonate production on topographic highs gave rise to local accumulation of alternating red and purple bioclastic limestones and shales (griotte facies) whilst, in the lows, green shale facies predominated. However, the absence of slump and limestone debris-flow beds implies that the development of this more marked seafloor topography was a gradual process and that topographic changes were slight. The differential subsidence of the blocks controlled the development of a residual topography, which was buried and fossilized by the green shales of the overlying Murero Formation.

A Graphic correlation method for the second episode

As envisaged above, the biostratigraphic data of the Early-Middle Cambrian transition in the Iberian Chains permit us to establish a quantitative analysis of the tectonic-induced subsidence.

Differential fault-induced subsidence can be quantitatively analysed by a graphic correlation method: Shaw's method (1964). This method is a graphic technique based on the correlation of indicators of geological time. In this case, the main indicator is the first appearance of fossil taxa (or bottom of biozones). Because the application of this method depends on a detailed biostratigraphy, only the second episode of tectonic activity will be studied.

Projecting on a two-axis graph the corresponding points of the compared stratigraphic sections of the Valdemiedes and Mansilla Formations, a Line of Correlation (LOC) is formed (Fig. 4). This LOC can be interpreted in terms of a relative "rock accumulation" rate.

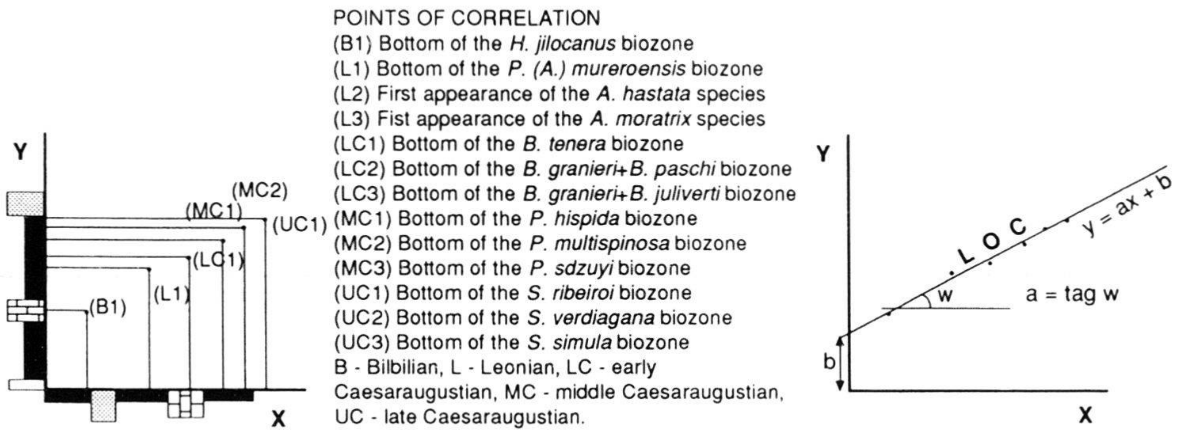


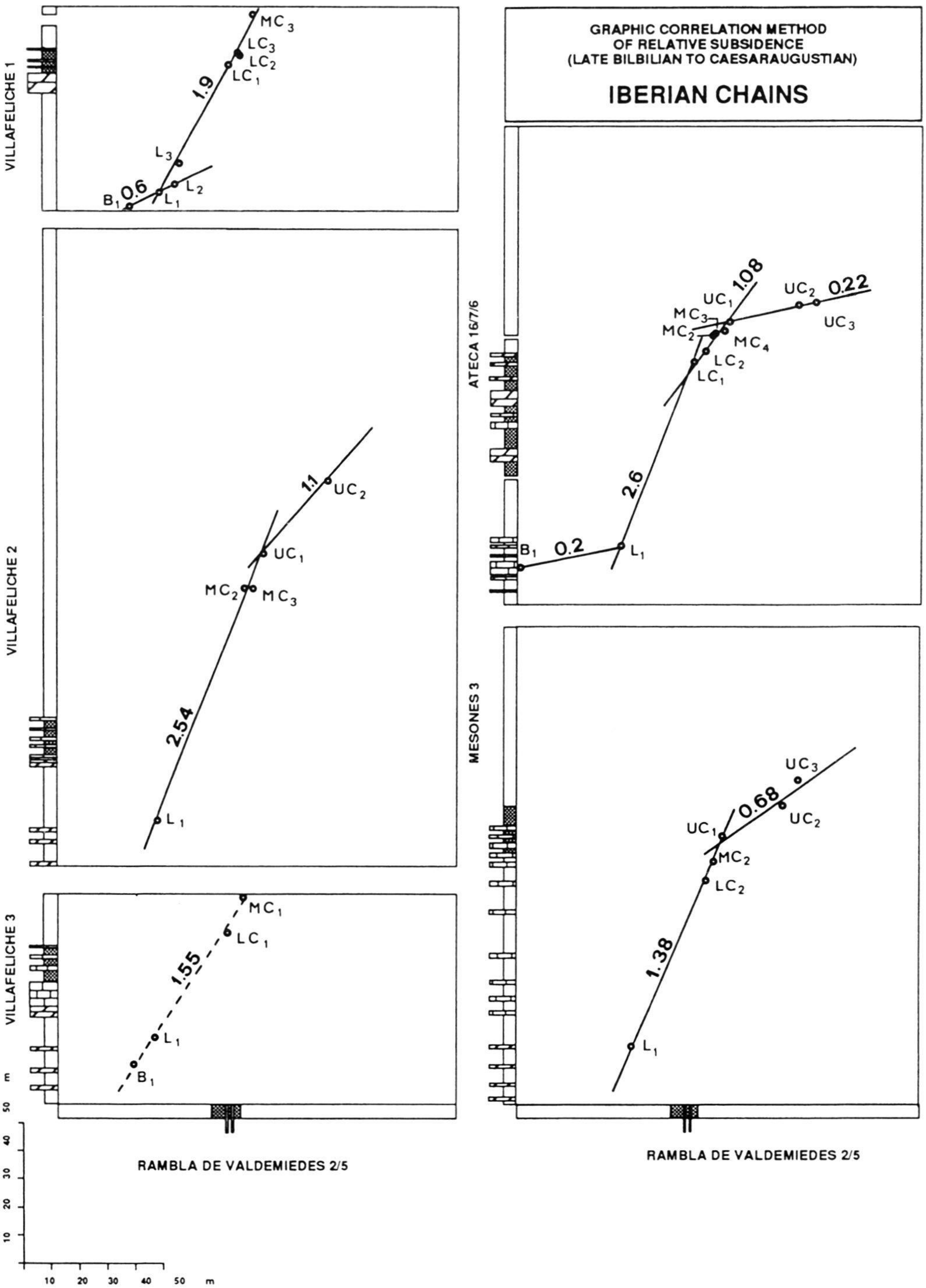
Fig. 4. Schematic illustration of the graphic correlation method used in this study. Further explanation in the text.

An apparent disturbance of this LOC may be due to different causes: a fault present within a profile (which would significantly change the stratigraphic thickness of biozones), the synsedimentary erosion of the seafloor, or decompaction differences among lithologies. To avoid these problems, selected profiles exhibit an excellent degree of stratigraphic continuity and fossiliferous wealth. In addition, to appraise the role of compaction, all the profiles were decompacted numerically according to the equations and curves postulated by Baldwin & Butler (1985); the assumed depth of burial is 8000 m. However, the decompacted profiles display stratigraphic relationships (and relative subsidence rates) very similar to those revealed by the non-decompacted rock profiles. Therefore, the non-decompacted profiles will be used in this paper.

Six stratigraphic successions have been selected in the upper Bilbilian-to-Caesaraugustian interval (Fig. 5). They differ in their depositional environments and geodynamic settings, and consist of predominantly argillaceous and carbonate deposits. Five profiles have been compared with the most complete and fossiliferous profile (RV2). The correlation graphs reveal well-defined linear trends (LOCs), but most of them are strongly segmented, showing similar ranges of gradients. These features indicate that, during this chronological interval, subsidence was highly differential and disturbances were quite strong. The segmented LOC indicates that the intrabasinal subsidence rates were highly variable in space.

The profiles of Fig. 5 have revealed two main disturbances in their rock accumulation rates relative to the RV2 reference-time profile. These graphs reveal that the main disturbances occurred at Early-Middle Cambrian boundary time and Middle-Late Caesaraugustian boundary time, according to the chronostratigraphic chart proposed by Liñán et al. (1993b).

Fig. 5. Correlation graphs for selected profiles from the Iberian Chains, including the late Bilbilian-to-Caesaraugustian interval. The values attached to the LOCs are their gradients (a-values).


GRAPHIC CORRELATION METHOD
OF RELATIVE SUBSIDENCE
(LATE BILBILIAN TO CAESARAUGUSTIAN)
IBERIAN CHAINS
VILLAFELICHE 1
VILLAFELICHE 2
VILLAFELICHE 3
ATECA 16/7/6
MESONES 3
RAMBLA DE VALDEMIEDES 2/5
RAMBLA DE VALDEMIEDES 2/5
1.9
0.6
2.54
1.1
1.55
2.6
0.2
1.08
0.22
1.38
0.68
m
10 20 30 40 50 m

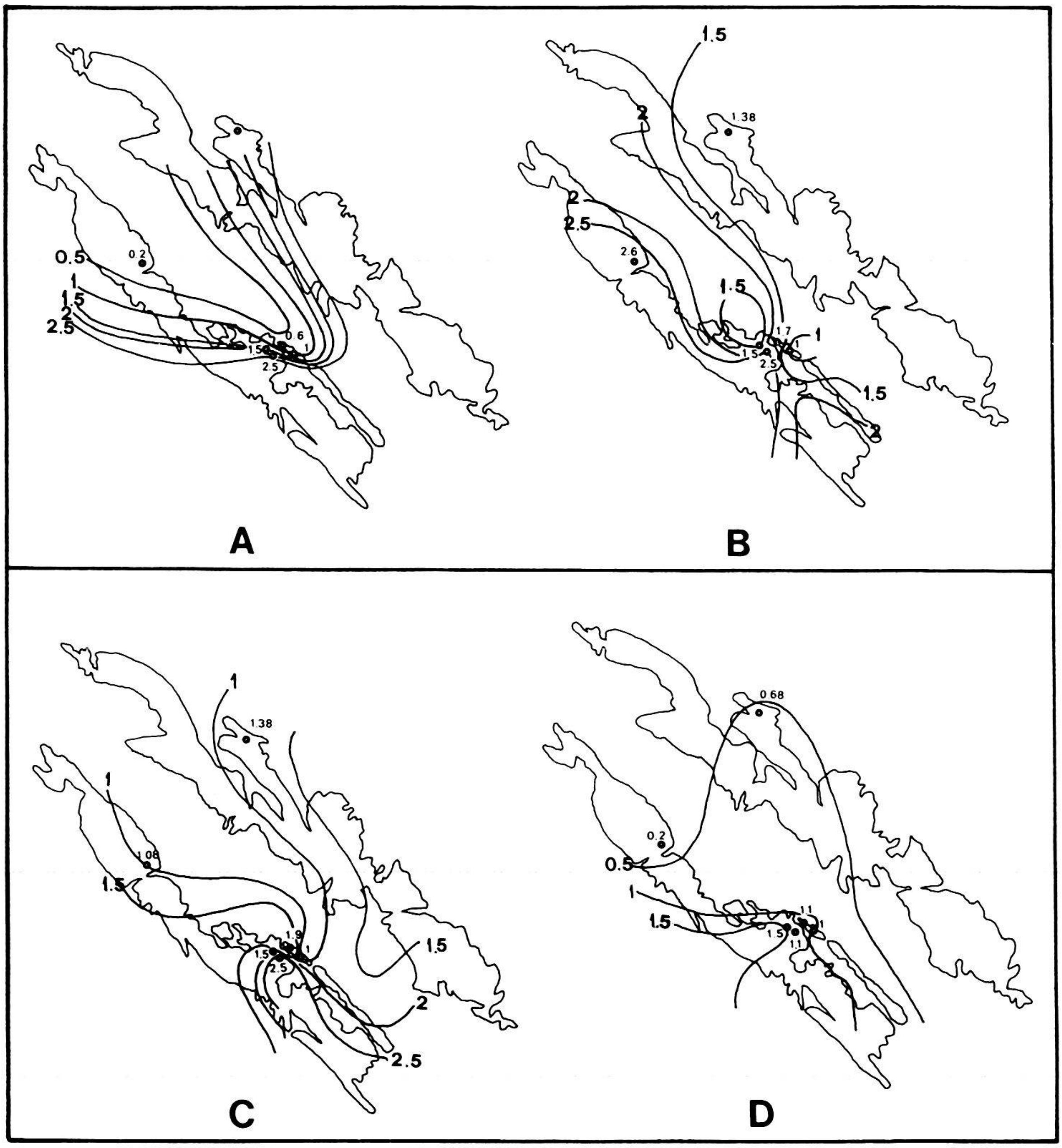


Fig. 6. Maps of differential rock accumulation („rock accumulation rate" relative to the RV 2 reference locality) for the (1) late Bilbilian, (2) Leonian, (3) early and middle Caesaraugustian, and (4) late Caesaraugustian times.

The time-distribution of these disturbances, relative to the RV2 record, has been used in maps of relative rates of rock of accumulation, in which RV2 has the data point (a = 1.0, in Fig. 4). Isograms of equal-relative-rock accumulation have been drawn by means of interpolation (Fig. 6).

Tectonic-induced disturbances produced a major rearrangement in the intrabasinal patterns of differential subsidence (from a NW-SE to a SW-NE trend of the isograms of equal-relative-rock accumulation; Fig. 6). The RV2 profile (included within the Villafeliche graben) is considered as the reference point of change.

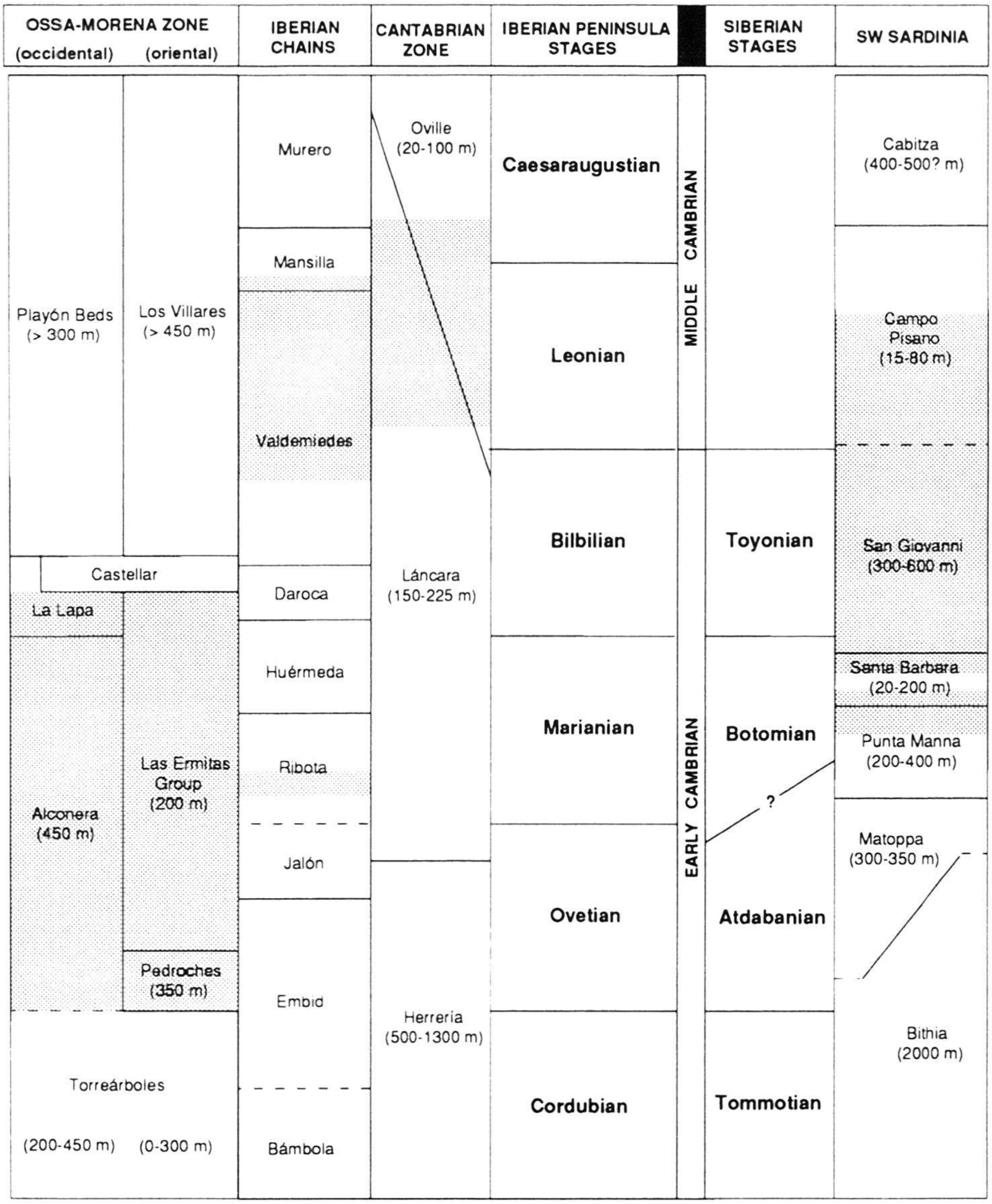


Fig. 7. Episodes of enhanced tectonic activity during Early and Middle Cambrian in the Iberian Peninsula and SW Sardinia.

Conclusions

Compilation of fault-induced data in the Cambrian sediments of south-western Europe, by stratigraphic and sedimentologic signatures, presents a complex framework. According to Cloetingh et al. (1985) and Cloetingh (1986), regional tectonic episodes on passive margins can be the result of variations in the intraplate stress regimes. These variations are related to changes in plate motions and major reorganizations at plate boundaries.

(1) Correlation of Cambrian tectonic episodes recorded in the Iberian Chains, the Cantabrian Zone, the Ossa-Morena Zone (Iberian Peninsula), the Montagne Noire (France) and Sardinia, allows us to integrate three main extensional episodes of tectonic activity (Fig. 7).

The first episode is recorded in three different paleogeographic domains of the Iberian Peninsula and Sardinia. Tectonic-induced deposits are composed of debrites and breccias. This episode may be associated with major plate reorganization related to the first rifting phase located in the Ossa-Morena Zone.

The second episode is characterized by a widespread tectonic breakdown of platforms. Condensed nodular limestones (griotte facies) were developed on a variety of topographic highs, whilst shales were deposited on relative lows. Tectonic-induced subsidence contributed to the gradual vertical transition from carbonate to fine siliciclastic sediments. This episode was induced by a great block reorganization during the Early-Middle Cambrian transition. These movements may be related to the second major rifting phase located in the Ossa-Morena Zone, and reorganizations in plate motions near this margin of Gondwana. This episode controlled the earliest Middle Cambrian paleogeographic configuration of the previous margin of Gondwana, and the strong increase in clastic terrigenous input.

The third episode is represented by local tectonic movements, which were controlled by fault lineaments. Tectonic-influenced deposits are composed of slumped and olistostromic beds redeposited on local marked slopes.

(2) The episodic fault-induced processes could be explained in the context of inferred periods of enhanced tectonism, developed under a generally extensional tectonic regime. A certain degree of correlation of short periods of rapid subsidence, specifically due to a tectonic mechanism, and main regional transgressive trends of relative sea level is suggested.

(3) In summary, the Cambrian platforms of the Gondwanian margin situated at high southerly latitudes (Scotese & Mc Kerrow 1990) were episodically broken up by extensional tectonic movements. These syndepositional tectonic episodes were followed by deposition of deep-marine sediments, reflecting a common evolution from slight slopes to outer platform deposition. As outlined above, in south-western Europe, the Marianian times (Early Cambrian) and the Early-Middle Cambrian transition show a deposition apparently related to structural features, indicating that this Gondwanian margin was particularly unstable during both episodes.

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