Z. dt. Ges. Geowiss. 157/4, p. 575–584, 7 figs., Stuttgart, December 2006 **Article**

The Early Palaeozoic in Iberia – a plate-tectonic interpretation

Jürgen F. von Raumer, Gérard M. Stampfli, Cyril Hochard & Juan Carlos Gutiérrez-Marco*

Raumer, J.F. von, Stampfli, G.M., Hochard, C. & Gutiérrez-Marco, J.C. (2006): The Early Palaeozoic in Iberia – a plate-tectonic interpretation. [Das untere Paläozoikum in Iberia – eine plattentektonische Interpretation.] – Z. dt. Ges. Geowiss., 157: 575–584, Stuttgart.

Abstract: The present-day distribution of the Ossa-Morena, Central Iberian, West Asturian-Leonese, and Cantabrian tectono-metamorphic Zones resulted from the complex Variscan evolution, juxtaposing along the Eurasian margin domains formerly located at the Gondwana margin in Early Palaeozoic times. Characterized by mainly thick detrital Cambrian and/or Ordovician sediments, all four regions with their different sedimentary evolution indicate specific emplacements along the Gondwana margin. The elaboration of tectonic subsidence curves for each region and their comparison during the Cambrian, result in a time-space relationship characterized by the following stages: Late Proterozoic to Early Cambrian Cadomian active margin setting (Ossa-Morena and Central Iberian Zones), potential accretion to Gondwana; since the Early Cambrian extending continental crust, leading to an initial subsidence in the Ossa-Morena Zone and to a strong subsidence in the West Asturian-Leonese Zone lasting until the Late Cambrian, related to the opening of the Prototethys. A new pulse of subsidence is recorded since the Arenigian, during the deposition of the “Armorican Quartzite” in the Central Iberian Zone, which is thought to represent a rim-basin forming behind the shoulder of the opening Rheic Ocean. The moderate subsidence in the Cantabrian Zone could be the expression of its evolution of a hinterland between the two passive margins.

Kurzfassung: Die heutige Zonengliederung des Iberischen Massivs in die Südportugiesische, Ossa-Morena, Zentraliberische, Westasturisch-Leonesische und Kantabrische Zone ist Folge einer komplexen variszischen Entwicklung, die verschiedene frühpaläozoische Kontinentaleinheiten des ehemaligen Gondwanarandes am Südrand von Eurasien zusammenführte. Durch eine mächtige detritische Entwicklung während des Kambriums und Ordoviziums charakterisiert, zeigen alle der vier letztgenannten Blöcke unterschiedliche Sedimentationsbedingungen und damit unterschiedliche Ablagerungsbedingungen am Gondwanarand an. Die Sedimentation ist in allen vier Gebieten durch spezifische tektonische Subsidenzkurven charakterisiert, und es lassen sich für die Zeit des Kambriums und Ordoviziums folgende plattentektonische Entwicklungsabschnitte unterscheiden: neoproterozoisch bis frühkambrischer aktiver Plattenrand (Ossa-Morena und Zentraliberische Zonen) und mögliche Akkretion an den Gondwanarand; seit dem Unterkambrium Dehnung der kontinentalen Kruste mit initialer Subsidenz in der Ossa-Morena Zone, und mit starker Subsidenz im Bereich der Westasturisch-Leonesischen Zone bis zum oberen Kambrium im Zusammenhang mit der Öffnung der Prototethys. Mit der Ablagerung des Armorikanischen Quarzits seit dem Arenig wird in der Zentraliberischen Zone eine neue Subsidenzphase erkennbar, die auf eine „Rim-Basin“-Situation hinter der Riftschulter des sich öffnenden Rheischen Ozeans gedeutet werden kann. Die relativ geringen Subsidenzraten in der Kantabrischen Zone könnten Ausdruck einer Entwicklung zwischen zwei passiven Rändern im Hinterland des Riftsystems sein.

Resumen: La distribución actual de las Zonas tectonometamórficas Cantábrica, Asturoccidental-Leonesa, Centroibérica y Ossa-Morena es el resultado de una compleja evolución que yuxtapuso, durante la deformación varisca, dominios emplazados en distintos lugares del margen de Gondwana durante el Paleozoico Inferior. La diferente evolución sedimentaria de estas cuatro regiones, caracterizadas principalmente por su potente sedimentación detrítica durante el Cámbrico-Ordovícico, indica un emplazamiento específico para cada una de ellas dentro del margen gondwánico. La reconstrucción de las curvas de subsidencia tectónica de cada zona y su comparación den-

* Addresses of the authors:
Prof. em. Dr. Jürgen F. von Raumer (Juergen.vonRaumer@unifr.ch), Université de Fribourg, Dépt. de Géosciences, Pérolles, CH-1752 Fribourg, Switzerland;
Prof. Dr. Gérard M. Stampfli (Gerard.Stampfli@unil.ch), Dr. Cyril Hochard (Cyril.Hochard@unil.ch), Université de Lausanne, Département de Géologie-Paléontologie, UNIL, BFSH2, CH-10105 Lausanne, Switzerland;
Dr. Juan Carlos Gutiérrez-Marco (jcgrapto@geo.ucm.es), Universidad Complutense, Facultad de Ciencias Geológicas, Instituto de Geología Económica, CSIC-UCM, E-28040 Madrid, Spain.

1860-1804/06/0157-0575 $ 4.50
DOI: 10.1127/1860-1804/2006/0157-0575

tro del marco de la evolución cambro-ordovícica perigondwánica, permite distinguir varias etapas en sus relaciones espacio-temporales. Así, en la primera (Neoproterozoico-Cámbrico inicial), un margen activo sobre corteza de tipo cadomiense se desarrollaba en la periferia de Gondwana (Zonas de Ossa-Morena y Centroibérica). La segunda etapa supuso la extensión de dicha corteza entre el Cámbrico Inferior a Superior, con subsidencia incipiente en Ossa-Morena, y fuerte subsidencia en la Zona Asturoccidental-Leonesa. Finalmente y a partir del Arenigiense, se registra un nuevo pulso subsidente en la Zona Centroibérica, ligado al depósito de la Cuarcita Armoricana, lo que permite interpretarla como una cuenca marginal ("rim basin") a espaldas del borde sobreelevado ("shoulder") creado en la apertura del Océano Rheico. La subsidencia moderada durante esta época en la Zona Cantábrica puede ser el resultado de su evolución como un traspaís ("hinterland") situado entre dos márgenes pasivos.

Keywords: Early Palaeozoic, Iberia, Gondwana margin, subsidence-patterns, plate tectonic reconstruction

1. Introduction

After Hernández Sampelayo's (1935) early attempt to characterize the Cambrian in Iberia, Lotze (1961) published a more precise account on this, including already the first results of doctoral theses of his students on the Iberian Peninsula. This will not and cannot be the place to mention all the detailed observations (references and discussion for part of the theses in Walter 1965, 1977a), and the reader is asked to consult the competent summaries for the Cambrian (Liñán et al. 2002, 2004, Gozalo et al. 2003) and the lower Palaeozoic evolution resumed in Gibbons & Moreno (2002) and Vera (2004) to discover the progress made during the last forty years.

The distinction of two areas with extremely thick Cambrian lithologies and the observation of littoral facies in the Ossa-Morena Zone and in the Asturian area motivated Lotze (1961) to claim the existence of two main geosynclinal troughs, the Cantabrian-Iberian in the Northeast (Cantabrian and West Asturian-Leonese Zones, Fig. 1) and the Andalusian in the Southwest (Ossa-Morena Zone, Fig. 1), both separated by a major uplift zone with reduced thicknesses or absence of Cambrian lithologies (Central Iberian Zone, Fig. 1). Although there is no doubt about the parallel evolution of these sedimentary troughs, the growing insight on the tectonic evolution (Pérez-Estaún & Bea 2004) and the advanced discussion of plate-tectonic reconstructions (Stampfli & Borel 2004, Stampfli et al. 2002, Raumer et al. 2003) lead to a concept, where relics of former independent sedimentary troughs evolved contemporaneously and were preserved in different tectonic units. Consequently, it is the aim of this paper to find a general plate-tectonic reconstruction for the Early Palaeozoic situation, which could explain the parallel evolution of the sedimentary troughs.

2. The sediments

The geographical maps of Cambrian lithologies (Liñán et al. 2002, Gozalo et al. 2003) show the distribution and evolution of the Cambrian sequences through time. Thick

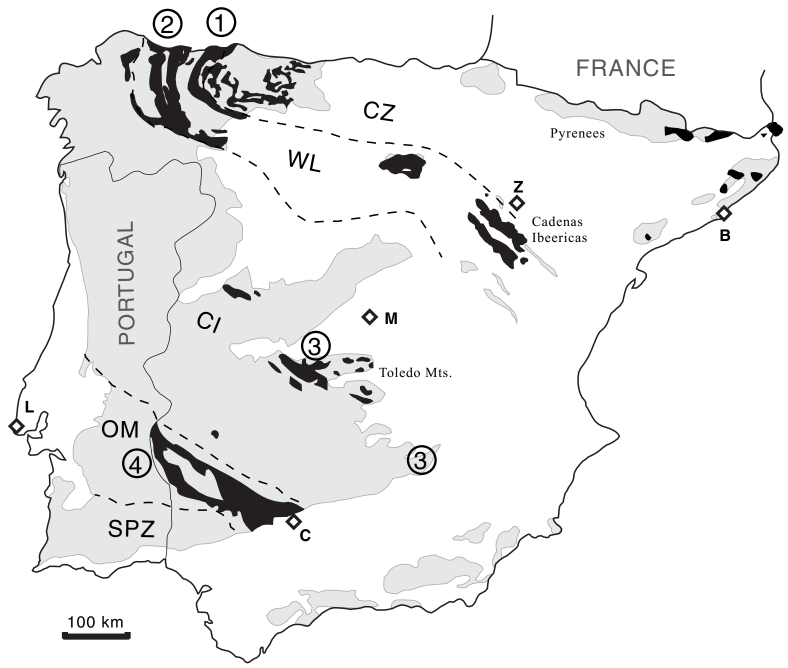

Fig.1: Pre-Mesozoic units in Iberia (grey, after Liñán et al. 2002) with the main Cambrian outcrop areas in Spain (black). The early Cambrian part of the "schist-greywacke complex" from the Central Iberian Zone is not represented.
CI = Central Iberian Zone, CZ = Cantabrian Zone, OM = Ossa-Morena Zone, SPZ = South Portuguese Zone, WL = West Asturian-Leonese Zone, B = Barcelona, C = Córdoba, L = Lisboa, M = Madrid, Z = Zaragoza. Hatched lines separate tectonostratigraphic zones (Pérez-Estaún & Bea 2004). Circled numbers – reference to subsidence curves in Fig. 3: 1 = Cantabrian Zone, 2 = West Asturian-Leonese Zone (WL), 3 = Central Iberian Zone (Almadén area, Saupé 1973; Eastern Sierra Morena, Kettel 1968), 4 = Ossa-Morena Zone (Valle syncline).

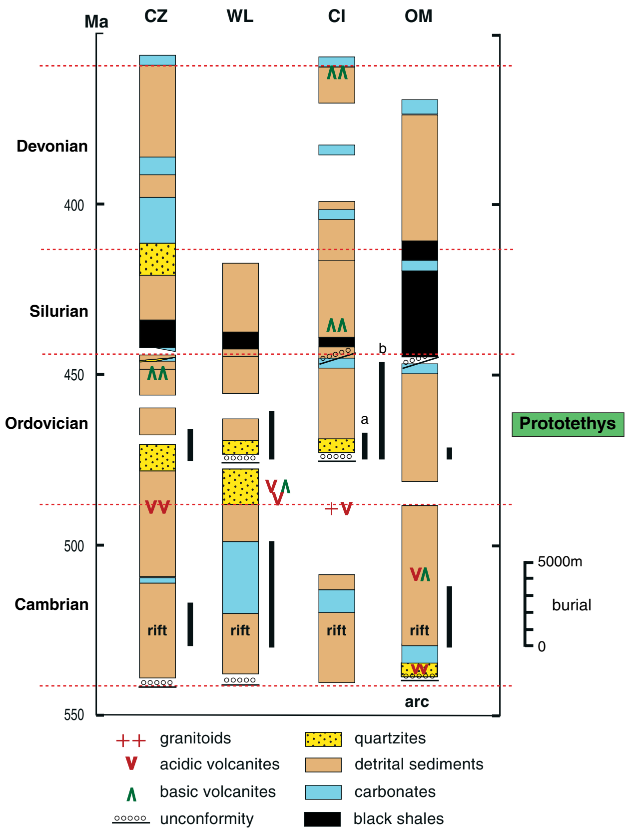

Fig. 2: Early Palaeozoic lithostratigraphic approximate type-columns from the Ossa-Morena (OM), Central Iberian (CI) (Almadén, Saupé 1973), West Asturian-Leonese (WL), and Cantabrian (CZ) Zones (data from Gutiérrez-Marco et al. 2002, Liñán et al. 2002, Radig 1961, Robardet & Gutiérrez-Marco 2004). Thick lateral scale indicates the thickness of sediments deposited during the Cambrian resp. Ordovician (a = Almadén area, b = Eastern Sierra Morena) time periods. For more details, the original publications should be consulted.

piles of mostly detrital sediments accumulated since the Cambrian in distinct tectonic units (Ossa-Morena and West Asturian-Leonese Zones, Fig. 2). They contrast with the Cantabrian Zone, where a more moderate evolution is recognized, and the Central Iberian Zone, characterized by the transgression of Arenigian sandstones above the Neoproterozoic basement or lower Cambrian sediments. Already Walter (1977b) had discussed such rather large variations of the Cambrian stratigraphy and subsequent lithologies for northwestern Spain, distinguishing mainly two domains, a more eastern located Asturian platform and a more western situated mobile zone. Liñán & Quesada (1990) saw a syntectonic evolution in the larger frame of a "Cambrian rift" and its tilted blocks ("Cubetas"), an idea which has been applied to the Ossa-Morena Zone (Sánchez-García et al. 2003, see also Perejón et al. 2004) and to the West Asturian-Leonese Zone (Pérez-Estaún et al. 1990, Marcos et al. 2004).

In the Iberian Peninsula the Lower Cambrian in general is characterized by the establishment of a carbonate platform (dolostones and limestones) above littoral to sublittoral sediments (Liñán et al. 2002) at the Gondwana margin (e.g. Elicki 2006), corresponding to the "European shelf" of Courjault-Radé et al. (1992). Additionally, in the Ossa-Morena Zone appear during this early period acidic and basic volcanics. Thick Middle and Upper Cambrian detrital sediments (West Asturian-Leonese Zone, Cantabrian Zone and Iberian Cordillera) were deposited in a proximal environment, testifying for a strong subsidence. In the Ossa-Morena Zone a comparable evolution was accompanied, mainly during the Middle Cambrian, by intrusion of subvolcanic and volcanic basic magmatic rocks. Interestingly, the Central Iberian Zone, lacking Middle and Upper Cambrian sediments, is characterized by very thick Arenigian sandstones, the so called Armorican Quartzite, which could represent a passive margin evolution as discussed by Liñán & Quesada (1990) for the general evolution. If reviewing the published data, characteristic subsidence patterns can be constructed for the different areas (Fig. 3, with references). All of them indicate a specific evolution for each concerned region, and reveal the influence of tectonic events on the sedimentation in the respective troughs. Interestingly, comparable curves of burial have been drawn for the Armorican areas (Paris & Robardet 1994).

2.1. Ossa-Morena Zone

The strong variation of Cambrian lithologies across the Ossa-Morena Zone had been already experienced by Lotze's students (Assmann 1959, Kalthoff 1963, Laus 1968, Suhr 1964, 1969), and was subject of comparison by Giese et al. (1994). For the subsidence curve the data found in Gibbons & Moreno (2002) and Vera (2004) were used. During the Early Cambrian, a rather strong subsidence is documented by detrital sediments, beginning with a basal conglomerate, followed by littoral to sublittoral detrital sediments. The subsequent carbonates, dolostones, and limestones indicate a platform installation that seals this first phase of rifting. The Middle Cambrian appears in the subsidence curve as a period of thermal uplift, and the sediments are characterized by interlayers of sublittoral and littoral conglomerates and sandstones and, in the western zone, alkaline acidic and basic volcanics underline the rifting character of the sedimentary trough. Contemporaneous subvolcanic intrusions (e.g. Barcarrota Subvolcanic Complex; Galindo & Casquet 2004) into the Lower Cambrian sediments underline the rifting character of this evolution. During the Ordovician (Gutiérrez-Marco et al. 2002) grey-green shales and siltstones represent the time-equivalent of the

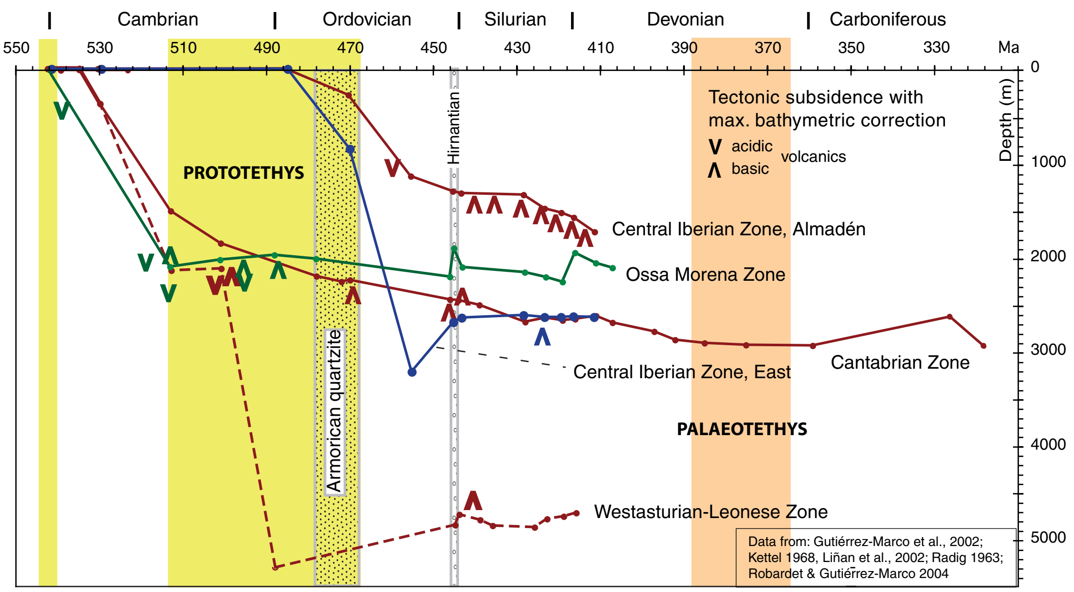

Fig. 3: Reconstruction of tectonic subsidence with maximum bathymetric correction for the Cantabrian, West Asturian-Leonese, Central Iberian, and Ossa-Morena Zones during the Early Palaeozoic (data from Jaritz & Walter 1970, Gutiérrez-Marco et al. 2002, Kettel 1968, Liñán et al. 2002, Radig 1961, Robardet & Gutiérrez-Marco 2002, 2004).

Armorican Quartzite of other regions, covered by rather reduced Middle Ordovician dark shales and sandstones, and the subsequent Upper Ordovician series are characterized by sandstones, some pelmatozoan limestones, and microconglomeratic beds recalling glaciomarine distal deposits. The Silurian (Robardet & Gutiérrez-Marco 2004) is represented by a thin series of black graptolitic shales and limestones. When interpreting the subsidence curve, the area seems to have reached, from the Ordovician onwards, a near isostatic equilibrium as shown by continuous platformal deposits; therefore it was certainly part of a passive margin setting all along that time.

2.2. West Asturian-Leonese Zone

In the West Asturian-Leonese Zone a rather strong subsidence (curve constructed from data in Gibbons & Moreno 2002, Vera 2004, Radig 1961) is documented in the Cándana Group (Lotze 1957) since the earliest Cambrian (compare Walter 1968, Färber & Jaritz 1964) with a thick pile of conglomerates, sandstones and siltstones and, still beginning during the Lower Cambrian, a carbonate platform established lasting to the paraconformable Middle Cambrian. After this rather quiet period new tectonic and volcanic activity began during the Middle Cambrian, accompanied by the formation of a thick pile of conglomerates, sandstones, quartzites, and shales (Cabos Group, Lotze 1957, Walter 1962, 1968, Färber & Jaritz 1964), continuing to the Lower Ordovician with formation of quartzites, corresponding to the Armorican Quartzite in the adjacent areas. The discovery of 2nd order sequences in the Middle Cambrian to lower Ordovician detrital sediments of the Iberian Chain reveal, in contrast to stable cratonic areas, four major sedimentary cycles (Schmitz 2006). Such observations are of high interest, as they support the tectonic activity strongly influencing subsidence and sedimentation in the West Asturian-Leonese Zone. Ash falls of Arenigian age (Gutiérrez-Marco & Bernárdez 2003) are the fingerprints of rifting events in the near-by areas. The Ordovician period seems to be influenced by thermal uplift and, since the Silurian, the emplacement of basic volcanics accompanied a new tectonic activity. Besides the temporary interruption by a carbonate platform, this area is characterized by the continuous changes of more or less distal shelf quartzite/sandstone layers with silt-shale interbeddings, culminating in thick turbidites and indicating the continuous, mainly extensional tectonic activity from the Lower Cambrian to the Upper Ordovician. The total thickness of the sedimentary pile increases from about 2 km in the West (present-day coordinates) to more than 11 km in the East (Jaritz & Walter 1970), the source of material being located in the East, which should be the so-called "Umbral Cántabro-Ibérico" (Aramburu et al. 2004).

2.3. Central Iberian Zone

This zone is characterized by a short period of Lower Cambrian sedimentation locally conformable on the thick Neoproterozoic-Cambrian schist-greywacke Formation

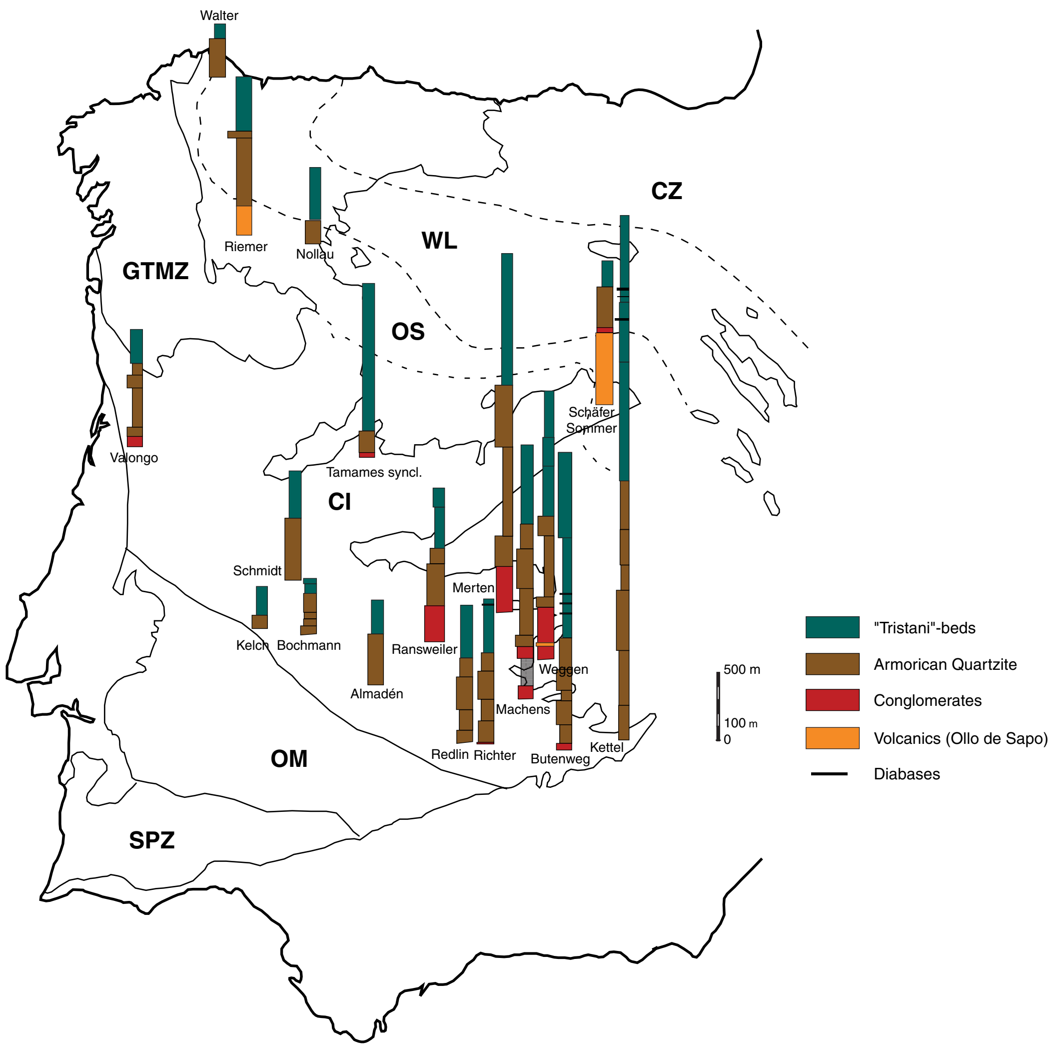

Fig. 4: Comparison of Lower and Middle Ordovician ("Tristani"-beds, Oretanian to Dobrotivian) evolution in the Central Iberian Zone. Data from Saupé (1973, Almadén), Diez Balda (1983, Tamames syncline), Robardet (2002, Valongo), and from Lotze's students (Bochmann 1956, Butenweg 1968, Kelch 1957, Kettel 1968, Machens 1954, Merten 1955, Ransweiler 1968, Redlin 1955, Richter 1967, Schmidt 1957, Weggen 1956).
GTMZ = Galicia – Trás-os-Montes Zone (allochthonous to parautochthonous), CZ = Cantabrian Zone, WL = West Asturian-Leonese Zone, CI = Central Iberian Zone, OS = Ollo de Sapo domain, OM = Ossa-Morena Zone, SPZ = South Portuguese Zone.

of the Cadomian suite (e.g. shale, sandstone-shale and carbonate formations from Tamames; Díez Balda 1986), and comparable observations were made by Lotze's students (Butenweg 1968, Kettel 1968, Machens 1954, Redlin 1955, Richter 1967, Weggen 1956). A strong sedimentation started with the characteristic Armorican Quartzite, going in parallel with subsidence since the Arenigian, locally accompanied by the formation of acidic volcanics. When comparing the sedimentary piles for the Arenigian-Llandovery time period (Saupé 1973, Díez Balda 1986, Robardet 2002) and the observations by Lotze's students (Bochmann 1956, Butenweg 1968, Kelch 1957, Kettel 1968, Machens 1954, Merten 1955, Ransweiler 1968, Redlin 1955, Richter 1967, Schmidt 1957, Weggen 1956) for the area spanning between Buçaco in the West to the eastern Sierra Morena, considerable changes of thicknesses of sediments become evident, as the sedimentary piles change from the Ossa-Morena limit with about 500–800 m in northeastern direction up to 3,500–4,000 m of detrital sediments (Fig. 4), indicating increasing subsidence in the northeastern Central Iberian Zone. Interestingly, Robardet (2002) discussed the same direction for the polarity of Middle Ordovician detrital sediments in this area. When comparing with the subsidence patterns, the strong evidence of subsidence is apparent, and basic volcanics do not only appear locally during the Llandovery period, but increase in number during the Upper Silurian, thus indicating the general tendency of rifting.

2.4. Cantabrian Zone

In the Cantabrian domain, a discontinuous sedimentation is documented since the Lower Cambrian, just unconformable on the schist-greywacke Cadomian basement, comprising mostly conglomerates, sandstones, and shales, with temporary evolution of a carbonate platform during the Lower and the paraconformable Middle Cambrian. As shown by the subsidence pattern, the sedimentary trough evolved as an epicontinental marine environment, where the interruptions, periodic formation of sandstone/quartzite levels, and emplacement of volcanic rocks are the expression of rifting pulses.

3. The Early Palaeozoic plate-tectonic evolution

All four regions with their distinct evolution indicate differences in their emplacement in the frame of an extending continental crust. How can the lithologic columns be interpreted in a plate-tectonic evolution from the uppermost Neoproterozoic to the Devonian? Undoubtedly, the Variscan orogenic events have strongly influenced the present-day distribution of the Lower Palaeozoic units in the Iberian Peninsula (e.g. Pérez-Estaún & Bea 2004), their local erosion and their partially strong metamorphic overprint during these events resulting often in a complete disappearance of all information. Consequently, the main regions have to be interpreted independently to find a satisfying model, which should include the general observation of the continuity of faunal provinces from the Cambrian to the Devonian (Robardet 2002, 2003). From the late Neoproterozoic (e.g. Stampfli et al. 2006) in the Iberian Massif a general situation of active margin setting is admitted at the Gondwana margin (Martínez Catalán et al. 2004b, Murphy et al. 2004, 2006, Linnemann et al. 2004), and relics of a Neoproterozoic-Cambrian arc can be identified in the Ossa-Morena (Bandrés et al. 2002) and in the northern Central Iberian Zones (Fernández-Suárez et al. 2000, Rodríguez Alonso et al. 2004). Based on a comparison with northern Brittany, Normandy, and Saxothuringia, this Cadomian arc is regarded as being accreted to Gondwana around 540 Ma, and is possibly an exotic terrane. The 2 Ga basement of Brittany could be derived from Africa as often suggested, but also from other continental blocks such as North China-Tarim as proposed here. This old basement and late accretion to Gondwana make the Cadomian terrane a separate entity from the "Cadomian" Avalonia domain of Keppie et al. (1996, 2003). The local very thick Neoproterozoic to Early Cambrian flysch like deposits found in central Iberia could correspond to a subduction trough type basin invaded by large deltaic deposits. A shift from active margin volcanism to extension related volcanism during the Late Neoproterozoic was demonstrated for a large portion of the Gondwana margin, where the Avalonian blocks were located (Keppie et al. 2003). This implies the opening of a back-arc along that margin or a transform margin setting, when westward, the Cadomian exotic terrane was being accreted. This observation shows that different scenarios have to be applied to different segments of the Gondwana margin. The Iberic domain is actually close to the transition between the two areas just mentioned.

During the Cambrian epicontinental sediments were deposited on the rifting Gondwana margin in marine to intra-cratonic basins and river deltas, the latter recycling the erosion products of the cratonic areas of the hinterland through long-river transport (Zeh et al. 2001; see also their geochemical homogeneity noted by Ugidos et al. 2003) and of remnant Cadomian reliefs, producing the complex zircon age populations in the Central Iberian domain (Martínez Catalán et al. 2004a). Pull-apart basins or isolated rift basins arranged in longitudinal continuity recorded the maximum subsidence, accompanied by volcanism, for example, at the limits between Ossa-Morena and Central Iberian Zones of the Iberian Massif (Bandrés et al. 2002, Rodríguez-Alonso et al. 2004). Consequently, different consecutive scenarios may be distinguished through the quantity of sediments accumulated in the sedimentary troughs.

Fig. 5 illustrates the general situation of the Gondwana margin for the Late Cambrian, where most of the basement areas known from Central Europe were located (Stampfli et al. 2006). In this model the future Variscan blocks, now found from Central America to the Caucasus, have been spread along the Gondwana margin, representing a future ribbon-like terrane of more than 10,000 km long (its Eurasian part being called Galatian Terrane). It is obvious that the same geodynamic scenario cannot be applied to the entire margin. The ocean opening between Avalonia and Gondwana is usually named Rheic, however, Avalonia did not extend over the all length of the margin, and the ocean opening north of the Galatian Terranes is not the Rheic Ocean s.str. We regard it as the Prototethys ocean opening during the separation of a ribbon continent (the Hunian Terrane) accreted later on to the Tarim-North China block, whereas Avalonia was accreted to North America-Baltica. Another major distinction we make is that the portion of Gondwana margin where the Galatian blocks were situated experienced ophiolite obduction between 400–380 Ma, the traces of which can be found in Spain (e.g. Ordenes complex), France, Germany, and were used to reconstruct the Galatian Terrane geometry (Stampfli et al. 2006). This event is

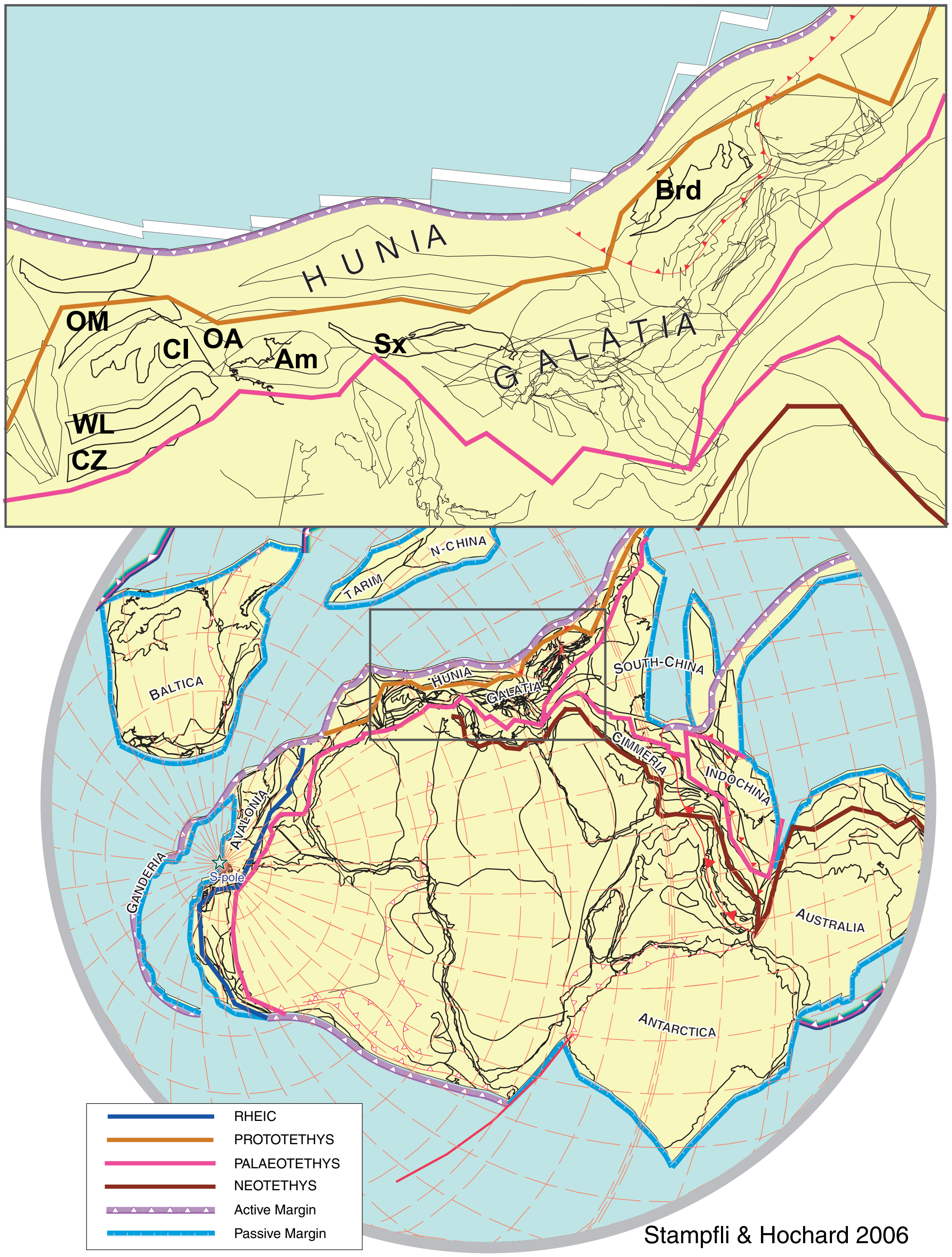

Fig. 5: Tentative Late Cambrian (490 Ma) reconstruction (after Stampfli et al. 2006) of the Gondwana margin, with location (inset) of Ossa-Morena (OM), West Asturian-Leonese (WL), Central Iberian (CI, Central Iberia clockwise rotated to compensate Variscan oroclinal bending), and Cantabrian (CZ) areas.
Am = Armorica, Brd = Barrandian, OA = Ordenes allochthonous slices, Sx = Saxothuringia.
Blue line: future Rheic opening; orange line: future opening of Prototethys; purple line: future opening of Palaeotethys; brown line: future opening of Neotethys.

not known at the southern margin of the Rheic Ocean s.str., consisting of the north and Central American terranes, accreted later on to Laurentia.

In Fig. 5 (globe) the traces of the future peri-Gondwanan oceans are indicated. In the inset, the Central Iberian terrane (CI), together with future Armorica (Am) and Ossa-Morena (OM), represent neighboring blocks. The opening of the Rheic Ocean around 470–460 Ma years ago and the contemporaneous separation of the Avalonian Terrane was preceded by the opening of a back-arc basin and drifting of the Ganderia Terranes in Cambrian times (e.g. Valverde-Vaquero et al. 2003). On the Galatian transect, the active margin also led to the opening of back-arc basins, as early as Late Cambrian (e.g. Chamrousse Ultramafic body, Ménot et al. 1984), some of these were closed soon after their opening, most likely due to the subduction of the mid-ocean ridge. This was followed by renewed back-arc opening (Prototethys) during the Middle to Late Ordovician that led to the formation of a passive margin along the Galatian-Gondwanan border, pleading for a general rifting environment with formation of tilted blocks including marine spaces (Raumer et al. 2006). It is on this margin that ophiolite obduction took place in Early Devonian time, generating the Eovariscan HP metamorphic event (see Stampfli et al. 2002 for references). Subduction inversion following this obduction induced the opening of Palaeotethys in middle Devonian times, accompanied by the drifting of the 10,000 km long Greater Galatian Terrane. Apparently the opening of Paleotethys is nearly synchronous all along the margin and the onset of spreading took place in the Late Devonian.

The strong input of detrital sediments, in the four regions reviewed here, would generally reflect the erosion of rift shoulders of the evolving passive/active margin. In this general scenario, the different areas registered distinct evolutions through time.

Ossa-Morena Zone: Ossa-Morena was probably located near and above an Early to Middle Cambrian rift (or pull-apart) located close to the former suture between Cadomia and Gondwana. It represents a displaced terrane, having migrated from its former more external and opened Gondwanan platform to its present day location through the extrusion of the Iberian block during the final Variscan collision. From a biogeographic view no narrow relationship existed with Avalonia or Baltica, and faunas correspond to a "hercynian" type, opposed to the "rhenanian" type observed in the Central Iberian and Cantabrian areas. Parallels of faunal evolution with the Barrandian area can be explained through the equivalent plate-tectonic location along the margin of Prototethys.

Central Iberian Zone: The Central Iberian Zone seems to represent an isolated rim basin behind the border of the rift system with formation of tilted blocks and their conglomeratic fans originating near the fault planes.

West Asturian-Leonese Zone: The West Asturian-Leonese Zone could represent a strike-slip/pull-apart environment since the Lower Cambrian, and the strong subsidence from the Upper Cambrian onwards seems to indicate the neighborhood of a larger fault zone with rather great changes of subsidence, induced by repeated extension (grading from Prototethys rifting to Palaeotethys rifting).

Cantabrian Zone: In contrast to the Ossa-Morena Zone, the Cantabrian Zone would be the expression of a subsiding continental block in the hinterland of the rift system, mentioned as "Umbral Cántabro-Ibérico" by Aramburu et al. (2004).

After the rifting heralding the opening of the Prototethys ocean, all four domains have in common a subsiding evolution indicating a renewal of rifting since the Late Ordovician-Silurian accompanied by volcanic activity, confirming the extensional tectonics discussed for the northern part of the Central Iberian Zone (Martínez Catalán et al. 1992), and also for its southern limit (Gutiérrez-Marco et al. 1990), where it is accompanied by a strong volcanic activity (Saupé 1973). It is during this evolution that the Palaeotethyan rift appeared (Fig. 5), with the contemporaneous drifting of the "Galatian Terranes" (former Hun Superterrane; Stampfli et al. 2002) representing the future Variscan basement areas of Central Europe (Stampfli et al. 2006).

4. References

Aramburu, C., Méndez-Bedia, I., Arbizu, M. & García-López, S. (2004): Zona Cantábrica. La secuencia preorogénica. – In: Vera, J.A. (ed.): Geología de España: 27–34, Madrid (Soc. Geol. España; Inst. Geol. Min. España).

Assmann, W. (1959): Stratigraphie und Tektonik im Norden der Provinz Huelva (Spanien). – Doct. thesis, Univ. Münster: 148 p., Münster (unpublished).

Bandrés, A., Eguíluz, L., Gil Ibarguchi, J.I. & Palacios, T. (2002): Geodynamic evolution of a Cadomian arc region: the northern Ossa-Morena zone, Iberian massif. – Tectonophysics, 352: 105–120, Amsterdam.

Bochmann, H.G. (1956): Stratigraphie und Tektonik der zentralen Extremadura im Bereich von Cáceres und der östlichen Sierra de San Pedro (Spanien). – Doct. thesis, Univ. Münster: 195 p., Münster (unpublished).

Butenweg, P. (1968): Geologische Untersuchungen im Ostteil der Sierra Morena nordöstlich von La Carolina (Prov. Jaén, Spanien). – Münster. Forsch. Geol. Paläont., 6: 1–126, Münster.

Courjault-Radé, P., Debrenne, F. & Gandin, A. (1992): Palaeogeographic and geodynamic evolution of the Gondwana continental margins during the Cambrian. – Terra Nova, 4: 657–667, Oxford.

Díez Balda, M.A. (1986): El Complejo Esquisto-Grauváquico, las series paleozoicas y la estructura hercínica al Sur de Salamanca. – Acta salmanticensia, secc. Ciencias, 52: 1–162, Salamanca.

Elicki, O. (2006): Microfacies analysis of Cambrian offshore carbonates from Sardinia (Italy): environment reconstruction and development of a drowning carbonate platform. – Notebooks on Geology, Article 2006/01: 1–22.

Färber, A. & Jaritz, W. (1964): Die Geologie des westasturischen Küstengebietes zwischen San Esteban de Pravia und Ribadeo (NW Spanien). – Geol. Jb., 81: 679–738, Hannover.

Fernández-Suárez, J., Gutiérrez-Alonso, G., Jenner, G.A. & Tubrett, M.N. (2000): New ideas on the Proterozoic-Early Palaeozoic evolution of NW Iberia: insights from U-Pb detrital zircon ages. – Precambrian Res., 102: 185–206, Amsterdam.

Galindo, C. & Casquet, C. (2004): El magmatismo prevarisco de la zona de Ossa-Morena. – In: Vera, J.A. (ed.): Geología de España: 190–194, Madrid (Soc. Geol. España; Inst. Geol. Min. España).

Gibbons, W. & Moreno, T. (eds.) (2002): The geology of Spain: 649 p., London (Geol. Soc.).

Giese, U., Hoegen, R. von, Hymann, K.H., Kramm, U. & Walter, R. (1994): The Palaeozoic evolution of the Ossa Morena Zone and its boundary to the South Portuguese Zone in SW Spain: geological constraints and geodynamic interpretation of a suture in the Iberian Variscan orogen. – N. Jb. Geol. Paläont. Abh., 192: 383–412, Stuttgart.

Gozalo, R., Liñán, E., Palacios, T., Gámez Vintaned, J.A. & Mayoral, E. (2003): The Cambrian of the Iberian Peninsula: an overview. – Geol. Acta, 1: 103–112, Barcelona.

Liñán, E., Gozalo, R., Palacios, T., Gámez Vintaned, J.A., Ugidos, J.M. & Mayoral, E. (2002): Cambrian. – In: Gibbons, W. & Moreno, T. (eds.): The geology of Spain: 17–29, London (Geol.. Soc.).

Liñán, E., Perejón, A., Gozalo, R., Moreno-Eiris, E., & Oliveira, J.T. (2004): The Cambrian system in Iberia. – Publ. Inst. Geol. Min. España, Ser. Cuad. Mus. Geomin., 3: 1–63, Madrid.

Linnemann, U., McNaughton, N.J., Romer, R.L., Gehmlich, M., Drost, K. & Tonk, Ch. (2004): West African provenance for Saxo-Thuringia (Bohemian Massif): Did Armorica ever leave pre-Pangean Gondwana? – U/Pb-SHRIMP zircon evidence and the Nd-isotopic record. – Int. J. Earth Sci., 93: 683–705, Berlin (Springer).

Lotze, F. (1957): Zum Alter nordwestspanischer Quarzit-Sandstein-Folgen. – N. Jb. Geol. Paläont. Mh. 1957: 464–471, Stuttgart.

Lotze, F. (1961): Das Kambrium Spaniens. Teil I: Stratigraphie. – Akad. Wiss. Lit. Mainz, Abh. math.-nat. Kl. 1961: 283–498, Wiesbaden.

Machens, E. (1954): Stratigraphie und Tektonik der südöstlichen Iberischen Meseta im Bereich des oberen Guadiana. – Doct. thesis, Univ. Münster: 173 p., Münster (unpublished).

Marcos, A., Martínez-Catalán, J.R., Gutiérrez-Marco, J.C. & Pérez-Estaún, A. (2004): Estratigrafía y paleogeografía, Zona Asturoccidental-leonesa. – In: Vera, J.A. (ed.): Geología de España: 49–52, Madrid (Soc. Geol. España; Inst. Geol. Min. España).

Martínez Catalán, J.R., Hacar Rodríguez, M.P., Villar Alonso, P., Perez-Estaún, A. & González Lodeiro, F. (1992): Lower Paleozoic extensional tectonics in the limit between the West Asturian-Leonese and Central Iberian Zones of the Variscan fold-belt in NW Spain. – Geol. Rdsch., 81: 545–560, Stuttgart.

Martínez Catalán, J.R., Gutiérrez-Marco, J.C., Hacar Rodríguez, M.P., Barros Lorenzo, J.C., Gonzalez Clavijo, E. & Gonzalez Lodeiro, F. (2004a): Secuencia preorogénica del Ordovícico-Devónico, Dominio del Ollo de Sapo. – In: Vera, J.A. (ed.): Geología de España: 72–75, Madrid (Soc. Geol. España; Inst. Geol. Min. España).

Martínez Catalán, J.R., Fernández-Suárez, J., Jenner, G.A., Belousova, E. & Díez Montes, A. (2004b): Provenance constraints from detrital zircon U-Pb ages in the Iberian Massif: implications for Palaeozoic plate configuration and Variscan evolution. – J. Geol. Soc. London, 161: 463–476, London.

Merten, R. (1955): Stratigraphie und Tektonik der nordöstlichen Montes de Toledo (Spanien). – Doct. thesis, Univ. Münster: 109 p., Münster (unpublished).

Murphy, J.B., Pisarevsky, S.A., Nance, R.D. & Keppie, J.D. (2004): Neoproterozoic - Early Palaeozoic evolution of peri-Gondwanan terranes: implications for Laurentia-Gondwana connections. – Int. J. Earth Sci., 93: 659–682, Berlin (Springer).

Murphy, J.B., Gutiérrez-Alonso, G., Nance, R.D., Fernández-Suárez, J., Keppie, J.D., Quesada, C., Strachan, R.A. & Dostal, J. (2006): Origin of the Rheic Ocean: rifting along a Neoproterozoic suture? – Geology, 34: 325–328, Boulder/CO.

Paris, F. & Robardet, M. (1994): Paleogeographic synthesis. – In: Keppie, J.D. (ed.): Pre-Mesozoic geology in France and related areas: 172–176, Berlin (Springer).

Perejón, A., Liñán, E. & Quesada, C. (2004): Cámbrico, Zona de Ossa-Morena. – In: Vera, J.A. (ed.): Geología de España: 166–169, Madrid (Soc. Geol. España; Inst. Geol. Min. España).

Pérez-Estaún, A. & Bea, F. (eds.) (2004): Macizo Ibérico. – In: Vera, J.A. (ed.): Geología de España: 19–230, Madrid (Soc. Geol. España; Inst. Geol. Min. España).

Pérez-Estaún, A., Bastida, F., Martínez Catalán, J.R., Gutíerrez-Marco, J.C., Marco, A. & Pulgar, J.A. (1990): Stratigraphy. – In: Dallmeyer, R.D. & Martinez Garcia, E. (eds.): Pre-Mesozoic geology of Iberia: 92–114, Berlin (Springer).

Radig, F. (1961): Zur Stratigraphie des Devons in Asturien (Nordspanien). – Geol. Rdsch., 51: 249–267, Stuttgart.

Ransweiler, M. (1968): Stratigraphie und Tektonik der Extremadura im Bereich der Orte Herrera del Duque, Helechosa und Villarta de los Montes (Mittelspanien). – Doct. thesis, Univ. Münster: 100 p., Münster (unpublished).

Raumer, J.F. von, Stampfli, G.M. & Bussy, F. (2003): Gondwana-derived microcontinents – the constituents of the Variscan and Alpine collisional orogens. – Tectonophysics, 365: 7–22, Amsterdam.

Raumer, J.F. von, Stampfli, G.M. & Hochard, C. (2006): The Gondwana-derived microcontinents in Central Europe – new aspects. – Abstr. IGCP 503 Ann. Conf. Glasgow, Abstr. Vol.: 41–42, Glasgow.

Redlin, K. (1955): Stratigraphie und Tektonik in der mittleren Sierra Morena im Bereich des Valle de Alcudia (Spanien). – Doct. thesis, Univ. Münster: 192 p., Münster (unpublished).

Richter, P. (1967): Stratigraphie und Tektonik in der Sierra de San Andrés (östliche Sierra Morena/ Spanien). – Münster. Forsch. Geol. Paläont., 3: 1–144, Münster.

Robardet, M. (2002): Alternative approach to the Variscan Belt in southwestern Europe: Preorogenic paleobiogeographical constraints. – In: Martínez Catalán, J.R., Hatcher, R.D. Jr., Arenas, R. & Díaz García, F. (eds.): Variscan-Appalachian dynamics: the building of the Late Paleozoic basement. –Geol. Soc. America spec. paper, 364: 1–15, Boulder/CO.

Robardet, M. (2003): The Armorica "microplate": fact or fiction? Critical review of the concept and contradictory palaeobiogeographical data. – Palaeogeogr., Palaeoclimatol., Palaeoecol., 195: 125–148, Amsterdam.

Robardet, M. & Gutiérrez-Marco, J.C. (2004): The Ordovician, Silurian and Devonian sedimentary rocks of the Ossa-Morena Zonne (SW Iberian Peninsula, Spain). – J. Iber. Geol., 30: 73–92, Madrid.

Rodríguez Alonso, M.D., Peinado, M., López-Plaza, M., Franco, P., Carnicero, A. & Gonzalo, J.C. (2004): Neoproterozoic-Cambrian synsedimentary magmatism in the Central Iberian Zone (Spain): geology, petrology and geodynamic significance. – Int. J. Earth Sci., 93: 897–920, Berlin (Springer).

Sánchez-García, T., Bellido, F. & Quesada, C. (2003): Geodynamic setting and geochemical signatures of Cambrian-Ordovician rift-related igneous rocks (Ossa-Morena Zone, SW Iberia). – Tectonophysics, 365: 233–255, Amsterdam.

Saupé, F. (1973): La géologie du gisement de mercure d'Almadén, Province de Ciudad Real, Espagne. – Sci. Terre, Mém., 29: 1–342, Nancy.

Schmidt, H.-J. (1957): Stratigraphie und Tektonik der nördlichen Estremadura im Bereich der Flüsse Tajo und Alagón (Spanien). – Doct. thesis, Univ. Münster: 115 p., Münster (unpublished).

Schmitz, U. (2006): Sequence stratigraphy of the NE Spanish Middle Cambrian to Early Ordovician section. – Z. dt. Ges. Geowiss., 157: 629–646, Stuttgart.

Stampfli, G.M. & Borel, G.D. (2004): The TRANSMED transects in space and time: constraints on the paleotectonic evolution of the Mediterranean domain. – In: Cavazza, W., Roure, F., Spakman, W., Stampfli, G.M. & Ziegler, P. (eds.): The TRANSMED Atlas: the Mediterranean region from crust to mantle: 53–80, Berlin (Springer).

Stampfli, G.M., Raumer, J.F. von & Borel, G. (2002): The Paleozoic evolution of pre-Variscan terranes: from Gondwana to the Variscan collision. – In: Martínez Catalán, J.R., Hatcher, R.D. Jr., Arenas, R. & Díaz García, F. (eds.): Variscan-Appalachian dynamics: the building of the Late Paleozoic basement. – Geol. Soc. America spec. paper, 364: 263–280, Boulder/CO.

Stampfli, G.M., Hochard, C. & Raumer, J.F. von (2006): Reconstructing the Palaeozoic Gondwana margin and its redistribution – new aspects. – Geophys Res. Abs. 8, EGU06-A-02708, web:unil.ch/igp/page22636.html.

Suhr, O. (1964): Stratigraphie, Magmatismus und Tektonik im Süden der Provinz Badajoz (Spanien). – Doct. thesis, Univ. Münster: 110 p., Münster (unpublished).

Suhr, O. (1969): Stratigraphie, Magmatismus und Tektonik im Süden der Provinz Badajoz (Spanien). – Münster. Forsch. Geol. Paläont., 14: 207–232, Münster.

Ugidos, J.M., Billström, K., Valladares, M.I. & Barba, P. (2003): Geochemistry of the Upper Neoproterozoic and Lower Cambrian silicilastic rocks and U-Pb dating on detrital zircons in the Central Iberian Zone, Spain. – Int. J. Earth Sci. 92: 661–676, Berlin (Springer).

Valverde-Vaquero, P., Staal, C.R. van, Velden, A. van der & Dunning, G.R. (2003): Acadian orogenesis and high grade metamorphism in the Central Mobile Belt of central Newfoundland. – Geol. Soc. America, Northeastern Sect. Ann. Meeting, Abstracts with Programs, 35: 23, Halifax.

Vera, J.A. (ed.) (2004): Geología de España: 884 p., 1 CD-ROM, Madrid (Soc. Geol. España, Inst. Geol. Min. España).

Walter, R. (1962): Stratigraphie und Tektonik in der nordöstlichen Provinz Lugo (Nordwest-Spanien). – Doct. thesis, Univ. Münster: 144 p., Münster (unpublished).

Walter, R. (1965): Die unterschiedliche Entwicklung des Alt-Paläozoikums östlich und westlich des Kristallins von Vivero-Lugo (Nordwest-Spanien). – N. Jb. Geol. Paläont. Mh., 1965: 740–753, Stuttgart.

Walter, R. (1968): Die Geologie in der nordöstlichen Provinz Lugo (Nordwest-Spanien). – Geotekt. Forsch., 27: 3–70, Berlin.

Walter, R. (ed.) (1977a): Zwei geologische Traversen durch die südliche Iberische Meseta, Spanien. – Münster. Forsch. Geol. Paläont., 42: 1–55, Münster.

Walter, R. (1977b): Paläogeographie des Altpaläozoikums in Nordwest Spanien. – Münster. Forsch. Geol. Paläont., 43: 93–120, Münster.

Weggen, K. (1956): Stratigraphie und Tektonik der südlichen Montes de Toledo. – Doct. thesis, Univ. Münster: 98 p., Münster (unpublished).

Zeh, A., Brätz, H., Millar, I.L. & Williams, I.S. (2001): A combined zircon SHRIMP and Sm–Nd isotope study of high-grade paragneisses from the Mid-German Crystalline Rise: evidence for northern Gondwana and Grenvillian provenance. – J. Geol. Soc. London, 158: 983–994, London.

Manuscript received: 28.05.2006
Accepted for printing: 27.09.2006