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Late Permian to Early Triassic transition in central and NE Spain: biotic and sedimentary characteristics

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Abstract: The Late Permian to Early Triassic (P/T) transition represents one of the most important Phanerozoic mass extinction episodes. Data from this transitional period are very scarce in continental basins, and reliable correlation with marine series is still a matter of debate. In this paper, information on the P/T transition in the continental series of central and NE Spain and the Balearic Islands is presented and compared with some coeval western European basins. The Iberian Ranges sections contain detailed information on the P/T transition, with sediments interpreted as alluvial fans, sandy and gravelly braided rivers and high sinuosity rivers with extensive floodplains, dated by means of pollen and spore assemblages. However, the fossil record contains two barren intervals throughout the study area, one in the Late Permian (Thuringian) and another during the latest Permian to Early Triassic. The possible causes of these gaps include the very likely relationship with the emplacement of the basaltic large igneous provinces (LIP) of SE China and western Siberia during this period of time.

The Permian–Triassic sediments of central and NE Spain and the Balearic Islands (Fig. 1) can be broadly described by the classic Germanic trilogy: Buntsandstein, Muschelkalk and Keuper, capped by a Late Triassic to Early Jurassic carbonate-evaporite complex. These sediments and the associated Early Permian and Late Triassic volcanic rocks were deposited during an extensional regime after the Hercynian orogeny. The rift basins went through several synrift and post-rift cycles, and there is evidence of frequent marine transgressive-regressive cycles from the Middle-Triassic (Early Anisian) time until the Triassic–Jurassic transition. These cycles are especially well documented in the Iberian Ranges (Figs 2 & 3).

A more detailed examination of the sedimentary record reveals a much more complex situation due to lateral changes of facies, basin compartmentalization and the absence of some units in vast domains; the main characteristics of the Permian–Triassic sediments of Spain are now well known after a wealth of data have been published since the 1970s (Virgili *et al.* 1976, 1979, 1983; Hernando 1977, 1980; Sopeña 1979, 1980; Ramos 1979, 1980; Arribas 1985; Ortí 1987; Sopeña *et al.* 1988; Jurado 1990; López-Gómez & Arche 1993; Calvet & Marzo 1994; Ortí & Pérez-López 1994; López-Gómez *et al.* 1998, 2002; Sopeña & Sánchez-Moya 2004; Sánchez-Moya & Sopeña 2004; Arche *et al.* 2004).

The long and complex extensional tectonic regime following the Hercynian orogeny spans the Early Permian to the Late Cretaceous. During the Late Permian to Early Triassic, a series of continental rift basins evolved in central and NE Spain; their main basin boundary faults (Fig. 3) trended NW–SE and were Hercynian or older lineaments reactivated as arcuate, listric normal faults with NE–SW trend and associated N–S strike-slip fault systems acting as transfer fault systems accommodating different extension rates along segments of the main, normal basin boundary faults (Arche & López-Gómez 1996). The origin and evolution of these basins have been studied by Salas & Casas (1993), Doblas *et al.* (1993), Arche & López-Gómez (1996), Van Wees *et al.* (1998), López-Gómez *et al.* (2002) and Sánchez-Moya & Sopeña (2004).

During the Alpine orogeny, many of the normal faults were reactivated as thrust faults in a general compressional tectonic regime leading to widespread inversion processes. It is very important to separate the earlier extensional basins (Iberian Basin, Ebro Basin and Catalan Basin) from the more recent folded and thrusted alpine structures (Iberian Ranges and Catalan Ranges), which are also not coincident geographically. The Iberian Basin was bounded by the Serranía de Cuenca and the Ateca Palaeozoic highs (Fig. 3), the Ebro Basin by the Ateca and Lérida Palaeozoic highs and an ill-defined Palaeozoic high in the Pyrenean domain (Fig. 3), and the Catalan Basin by the Lérida and Gerona Palaeozoic highs (Fig. 3). These Palaeozoic highs or basin shoulders were created in the footwall

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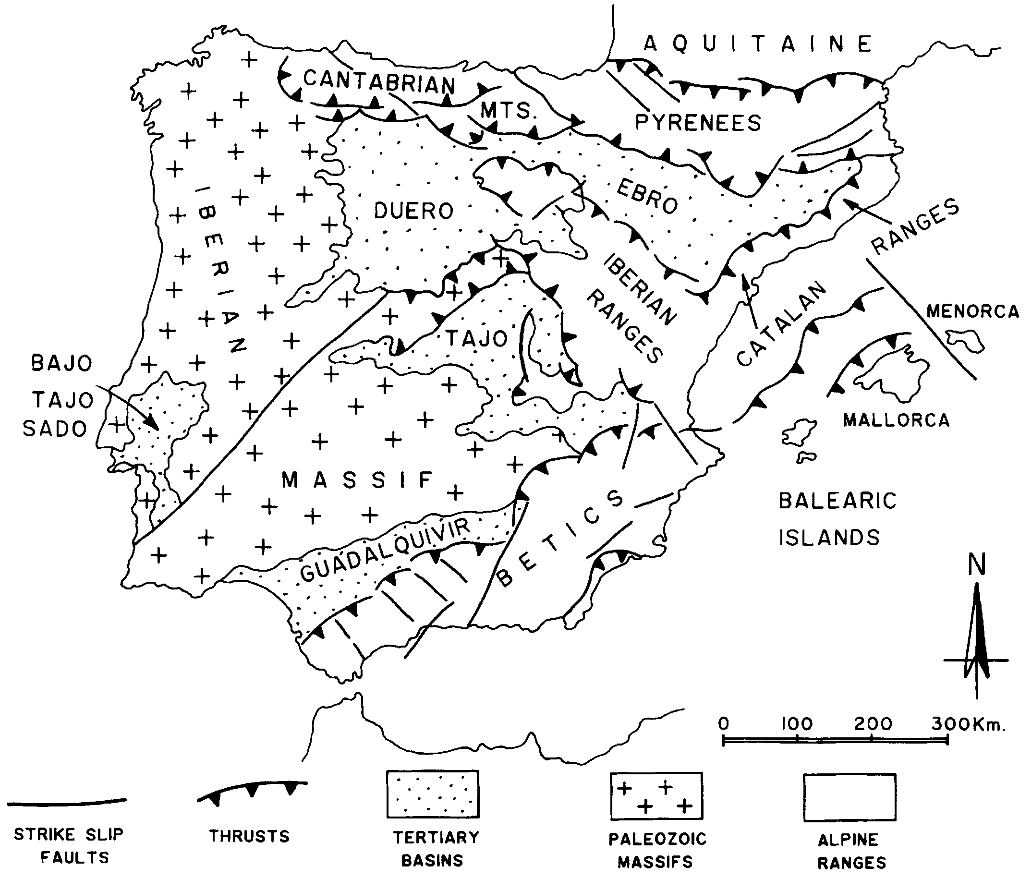

Fig. 1. The Iberian Peninsula and its major geological units.

and hanging-wall blocks as the extensional basin boundary faults, and their configuration changed with time. They were partially drowned by the first marine transgression of the Tethys during the Middle Triassic (Anisian) and ceased to exist as basin divides at the end of the Middle Triassic (late Ladinian).

During the Late Permian to Early Triassic, the eastern margin of the Iberian microplate was located 400–800 km west of the shore of the Neotethys sea. Topographic elevations in this portion of the collapsing Hercynian range are estimated at 2 000–3 000 m (Fluteau *et al.* 2001), and Iberia was at an estimated latitude of 10–15°N (Ziegler & Stampfli 2001; Eren *et al.* 2004), which is in an area dominated by a monsoon regime and important topographically generated rains (Barron & Fawcett 1995). In this paper we will deal mostly with the sedimentary record of the Iberian Basin, where most of the available biostratigraphical data have been obtained and draw correlations with the coeval basins in Spain, based on biostratigraphical data, presence of regional angular unconformities and/or hiatuses and sedimentological and petrological data for each basin.

The sedimentary record

The limitations of the classic lithostratigraphical terminology of the Permian and Triassic were obvious since the first modern studies (Virgili 1979; Sopeña *et al.* 1988) for two main reasons: the presence of major angular unconformities and hiatuses inside the sedimentary record and the lateral changes of facies between shallow marine carbonate and siliciclastic deposits and continental siliciclastic deposits. The sedimentary record of the Permian–Triassic in the study area has been subdivided into several formations, based upon biostratigraphical, lithological and sedimentological data (Sopeña *et al.* 1988; Calvet

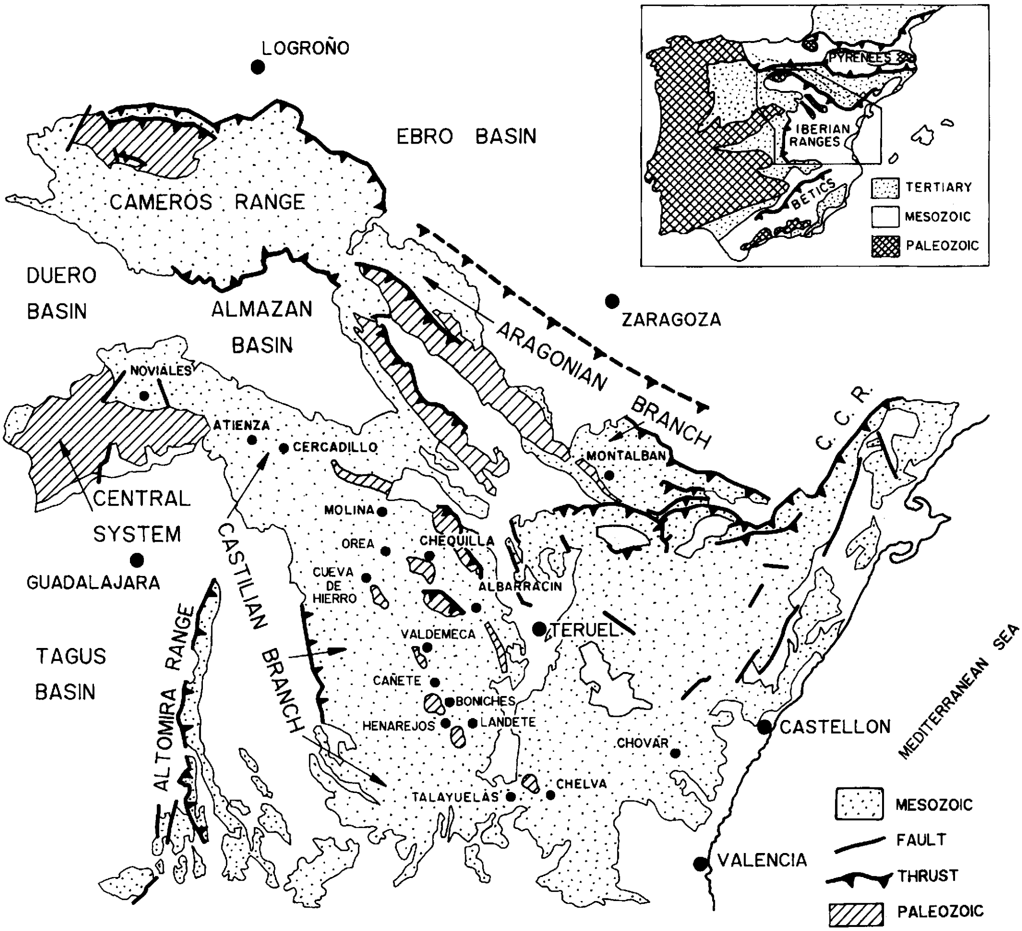

Fig. 2. Present-day configuration of the Iberian Ranges and main localities cited in the text.

& Marzo 1994; López-Gómez *et al.* 1998, 2002; Arche *et al.* 2004).

Iberian Ranges

The present-day Iberian Ranges (Fig. 2) can be subdivided into two main structural units: the Castilian Branch to the SW and the Aragonese Branch to the NE, with the Tertiary Calatayud–Teruel Basin in between. During the Permian and most of the Triassic, the Iberian Basin was bounded by the Serranía de Cuenca and Ateca Palaeozoic highs (Fig. 3), the latter now partially exposed along the Aragonese branch; they were part of the footwall and hanging-wall block of the syn-sedimentary basin boundary fault systems; the structural framework of the extensional basin also included oblique transfer fault systems trending NNE–SSW to N–S, which were responsible for some prominent transverse highs such as the Cercadillo, Cueva de Hierro and Teruel highs (Fig. 3). The Permian–Triassic sedimentary record has been subdivided into seven major sedimentary cycles (Fig. 4) (López-Gómez *et al.* 2002; Arche *et al.* 2004), but only the second and third ones are studied in this paper, with marginal mentions of the first one.

First sedimentary cycle

The oldest sediments, of Early Permian (Autunian) age, in some locations associated with andesitic volcanic rocks, were deposited in small, isolated half-graben basins along the trace of the future Iberian Basin. The continental deposits show a variety of facies, from lacustrine to coarse alluvial fans and thickness ranging from 15 m to more than 700 m, because local tectonic control determined the creation of accommodation space for the sediments and the amount of clastic supply to the basins (Fig. 4). In

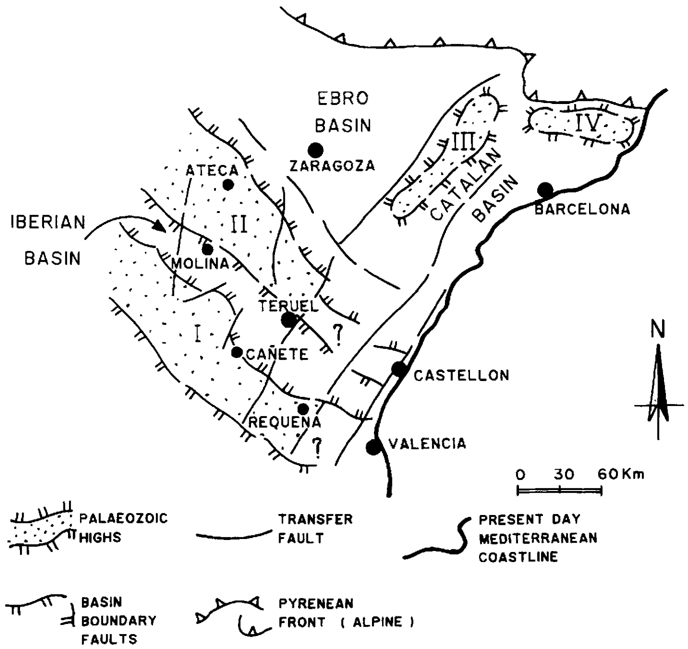

Fig. 3. Palinspastic reconstruction of the continental rift basins in central and NE Spain during the Late Permian and associated Palaeozoic highs. I, Serranía de Cuenca high; II, Ateca high; III, Lérida high; IV, Gerona high. Note the protruding Orea-Cueva del Hierro transversal high between Molina and Cañete.

some areas, the lower part of the succession contains andesitic rocks, as in Atienza, Molina de Aragón, Orea and Montalbán (Fig. 2), followed by red breccias, red sandstones and/or black shales (Hernando 1977, 1980; Sopeña 1979, 1980; Ramos 1979, 1980; Pérez-Arlucea & Sopeña 1985). In other areas, such as Boniches, only a few metres of red breccias are found (López-Gómez 1985; López-Gómez & Arche 1994). Most of the outcrops have been dated by means of pollen and spore assemblages dominated by the presence of *Vittatina* and *Potonieisporites* (Sopeña *et al.* 1995). The Minas de Henarejos outcrop is an exception in the Iberian Ranges because it contains coal measures exploited commercially, with a rich macroflora of Stephanian C (?)-Autunian(?) age (Wagner *et al.* 1983; Melendez *et al.* 1983).

The Early Permian (Autunian) sedimentary cycle always lies unconformably on the Hercynian basement and is unconformably covered by the Late Permian to Early Triassic second or third sedimentary cycles. Calc-alkaline volcanism is represented in both the Castilian and Aragonian branches of the Iberian Ranges (Muñoz *et al.* 1985; Lago *et al.* 2002, 2004) with volcaniclastic deposits, sills, dikes and lava flows. They were emplaced in two phases, represented by amphibolic andesites and daci-andesites (first phase) and gabbros, pyroxenic andesites, basalts and rhyolites (second phase). Absolute ages for these volcanic rocks range from 293 ± 2.5 Ma to 283 ± 2.5 Ma (Hernando *et al.* 1980; Conte *et al.* 1987; Lago *et al.* 1991), which fall within the Sakmarian stage of the Cisuralian (Lower Permian), according to the scales of Gradstein *et al.* (2004) and Menning (2001).

Second sedimentary cycle

The second sedimentary cycle is bounded by two angular unconformities (Figs 4 & 5) and was deposited in a single symmetric graben basin of complex longitudinal geometry (Arche & López-Gómez 1996). It consists of quartzite conglomerates at the base, which are of limited lateral extent (Boniches Formation) and is conformably overlain by red mudstones, sandstones and rare conglomerates of the Alcotas Formation (Ramos 1980; Pérez-Arlucea & Sopeña 1985; López-Gómez & Arche 1993). Its age is Late Permian (Thuringian, *sensu* Visscher 1971), as will be discussed in the biostratigraphy section of this paper. This cycle has been compared to the 'Saxonian' facies in central Europe, but this term is not precise and should be abandoned in Iberia, because the age of the central European

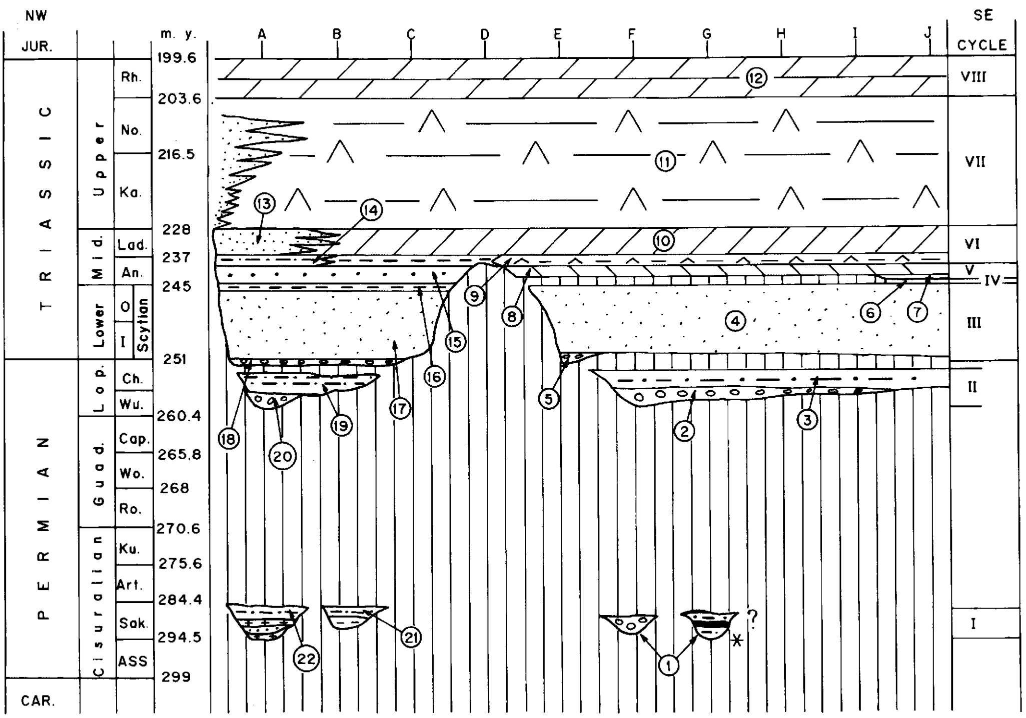

Fig. 4. Sketch of the lateral distribution of the Permian–Triassic sedimentary cycles (I–VIII) in the Iberian Basin. Locations: A, Noviales; B, Molina de Aragón; C, Chequilla; D, Cueva del Hierro; E, Valdemeca; F, Cañete-Boniches; G, Henarejos; I, Chelva; J, Chóvar. Chronostratigraphical units and absolute ages according to Gradstein *et al.* (2004). Formations: 1, Unnamed units in Henarejos and Tabarreña Breccias; 2, Boniches Conglomerates; 3, Alcotas Mudstones and Sandstones; 4, Cañizar Sandstones; 5, Valdemeca Conglomerates; 6, Eslida Sandstones; 7, Marines Mudstones; 8, Landete Dolomites (=Albarracín Dolomites); 9, El Mas Mudstones; 10, Cañete Dolomites (=Tramacastilla and Royuela Dolomites); 11, Keuper Facies; 12, Imón Dolomites; 13, Cuevas de Ayllón Sandstones; 14, Carrascosa Mudstones; 15, Cercadillo Sandstones; 16, Prados Sandstones and Mudstones; 17, Rillo de Gallo Sandstones; 18, Hoz del Gallo Conglomerates; 19, Montesoro Mudstones (=Cañamares Mudstones); 20, Cañamares Conglomerates; 21, Ermita Mudstones; 22, Cañamares Conglomerates and Sandstones. Based on Arche *et al.* (2004). Star indicates coal measures.

sediments are ill-determined or range from Lower to Upper Permian.

The Boniches Formation lies with angular unconformity on the Hercynian basement or on Lower Permian sediments. Sedimentation of this formation was controlled by the activity of the Serranía de Cuenca fault system (Fig. 3) (López-Gómez & Arche 1993), which created steep relief in the footwall block and short, steep transverse drainage networks. Laterally, thickness changes from 130 m in the central part of the basin (Henarejos) to less than 30 m in the NW and SE extremes (Valdemeca and Chelva). Its age is Late Permian (Thuringian) according to pollen and spore associations found in the upper part of the formation in Talayuelas (Doubinger *et al.* 1990).

The Boniches Formation has been subdivided into four members. The lowermost, composed of fining-upwards sequences of massive and cross-stratified conglomerates with palaeocurrents transverse to the basin axis, is interpreted as proximal alluvial fan facies dominated by channel longitudinal bars formed by diffuse gravel sheets migrating over the original bar core; they evolve in time to bar-and-channel complexes with superimposed high-and low-stage deposits (Miall 1981; Crowley 1983, Ashmore 1991; López-Gómez & Arche 1997).

The two middle members consist of fining-upward sequences with gravel cross-stratified basal bodies and increased sandy bodies at the top. They are interpreted as transverse and composite mid-channel bars and associated low-stage sand bars in medial and distal parts of a braided alluvial fan system. The uppermost member consists of thin, fining-upward sequences of

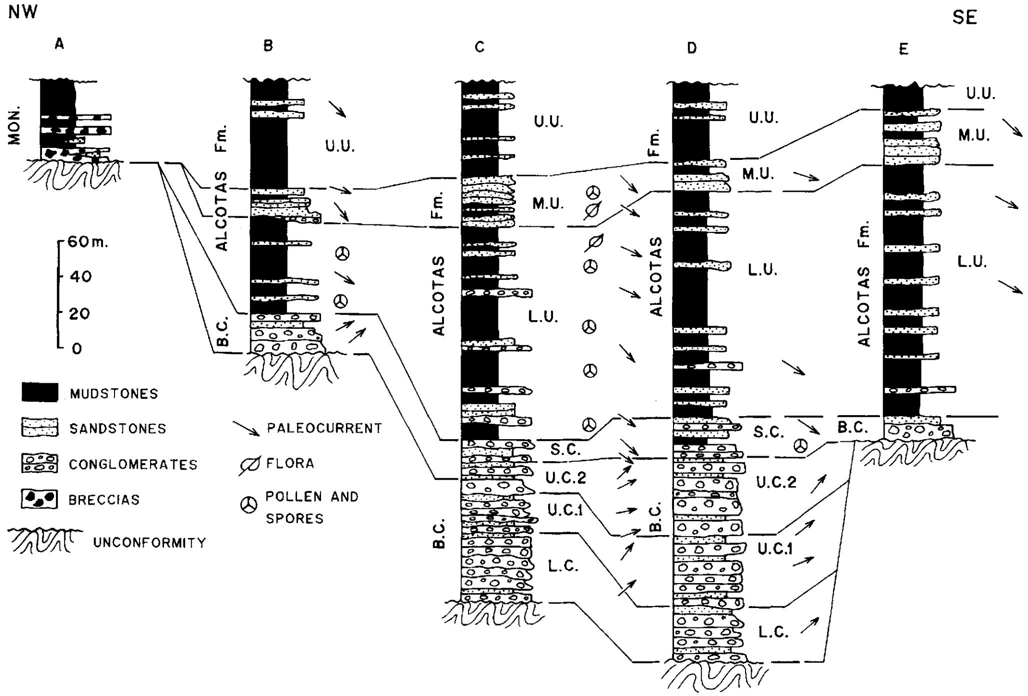

Fig. 5. Second sedimentary cycle correlation along the central and SE Iberian Basin and main pollen and spores localities. A, Molina de Aragón (Barranco de la Hoz section); B, Albarracín (Fuente de la Señora section); C, Cañete (Cañizar section); D, Talayuelas (Arroyo de la Vid section); E, Chelva (Barranco de Alcotas section). Data from Ramos (1979), Temiño (1984), Pérez-Arlucea (1985) and López-Gomez (1985). B.C., Boniches Conglomerates; L.C., Lower Conglomerates; U.C.1, Upper Conglomerates 1; U.C.2, Upper Conglomerates 2; S.C., Sandy Conglomerates; L.U., Lower Unit; M.U., Middle Unit; U.U., Upper Unit; MON, Montesoro Formation.

gravels and sands, interpreted as distal reaches of a braided, mixed load fluvial system. In this member, the transverse drainage pattern changes into a longitudinal drainage system.

The Alcotas Formation lies conformably above the Boniches Formation and consists of red mudstones and sandstones with some conglomerate lenses (Fig. 4).Thickness ranges from 82 m in Valdemeca to 168 m in Chelva, and the formation crops out along the Iberian Basin except in the Cueva de Hierro Palaeozoic high. Red mudstones are the dominant lithology (about 70%) consisting of illite, kaolinite and quartz (Alonso-Azcárate *et al.* 1997) and traces of feldspar and hematite. The illite/kaolinite ratio increases to the SE. Red to pink sandstones (about 27%) consist of subrounded quartz and feldspar grains, mica flakes and slate fragments, with clay matrix and quartz cements. Bulk lithology changes from arkose in the Landete area to protoquartzites and greywackes in the Boniches area and protoquartzites in the Chelva area (López-Gómez 1985).

The age of the Alcotas Formation is well constrained by several pollen and spore assemblages found in the central and SE Iberian Ranges in the lower and middle part of the unit; the upper part is always barren (Boulouard & Viallard 1971; Ramos & Doubinger 1979; Doubinger *et al.* 1990; Sopeña *et al.* 1995). The formation can be subdivided into three fining-upwards units or members separated by sharp erosive surfaces of regional lateral extent. The lower member is 20–40 m thick and consists of lenses of conglomerates, 4–6 m thick, which are embedded in red mudstones; the conglomerate bodies present cross-stratification, lateral accretion surfaces and reactivation surfaces. The mudstone facies are usually massive, with rippled intervals and some dolomitic horizons; calcic palaeosols with laminar and nodular structures are found in this member. It is interpreted to represent gravelly braided river deposits with high avulsion rates and broad, fine-grained floodplains. The instability of the channels can be interpreted as the response to active synsedimentary tectonics leading to constant changes in local slope (Smith 1970; Miall 1987), with sediment supply keeping pace or exceeding the rate of subsidence (Alexander & Leeder 1987).

The middle member shows a sudden change in lithofacies and fluvial style: sandstones are the dominant lithology (up to 70% in some sections). These single-storied sandstone bodies show tabular geometry, internal structures dominated by trough cross stratification at the base and current ripples at the top and sometimes lateral accretion surfaces littered with comminuted plant remains (López-Gómez & Arche 1994) and some large silicified tree trunks. This member can be interpreted as a transition from distal sandy braided rivers to high sinuosity, meandering rivers; reactivation surfaces point to marked seasonality in flow (Puigdefábregas 1973; Allen 1983; López-Gómez 1985; Ashmore 1991). The banks were probably vegetated by tree-sized plants, sometimes uprooted by the lateral migration of the channels; the fine-grained deposits are interpreted as floodplain deposits.

The upper member, 20–35 m thick, consists of red mudstones (about 85%) containing thin, lenticular sandstone bodies up to 1.5 m thick; no palaeosols or macro-or microflora have been found in this interval. This unit is interpreted as a distal, very low-energy, sandy braided river system with high avulsion rates and marked seasonality, flowing in an extensive floodplain subject to frequent crevassing and flooding (Collinson 1970; Cant & Walker 1978; Walker & Cant 1979; O'Brian & Wells 1986).

Third sedimentary cycle

The third cycle consists of two formations (Figs 4 & 6): the Hoz del Gallo Formation and the Cañizar (= Rillo de Gallo) Formation, and is limited by an angular unconformity at the base and a hiatus or a conformable contact at the top. The P/T transition lies inside this cycle, as will be discussed later in this paper. This cycle can be compared to the Buntsandstein facies *sensu stricto* of central Europe.

The Hoz del Gallo Formation lies unconformably on the Hercynian basement or on the Alcotas Formation. Its age is Late Permian (Thuringian) at the base, well constrained by several pollen and spore assemblages found in its

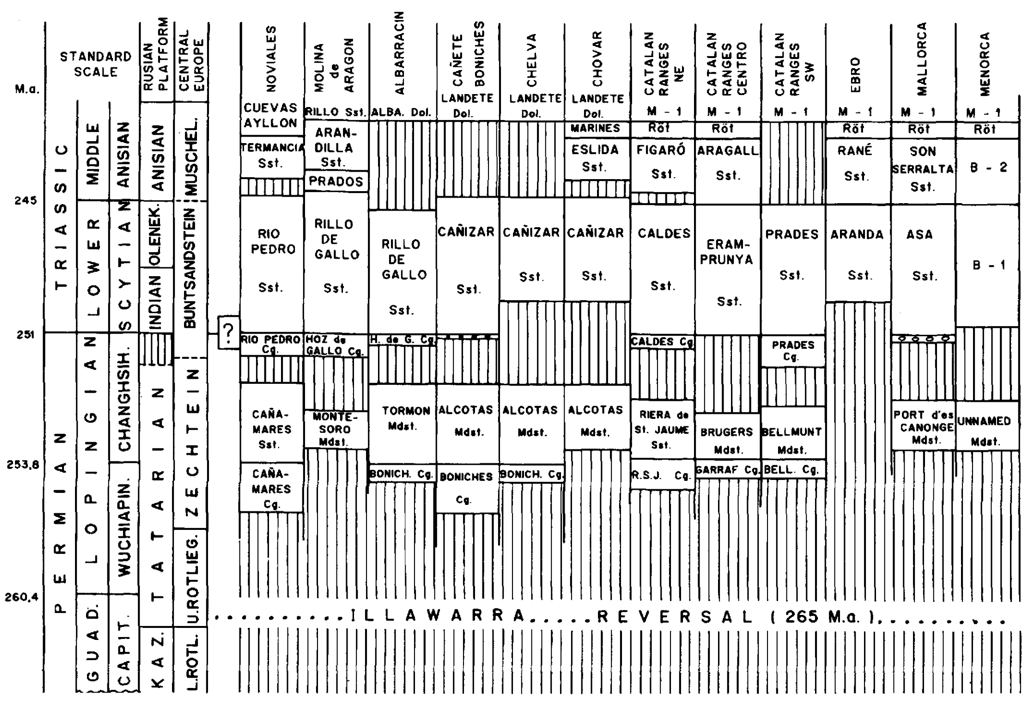

Fig. 6. Third sedimentary cycle correlation along the central and SE Iberian Basin and pollen and spores localities. A, Molina de Aragón; B, Albarracín; C, Valdemeca; D, Boniches; E, Chelva. Data from Ramos (1979), Temiño (1984), Pérez-Arlucea (1985), Horra (2004) and López-Gómez (1985). L.C., Lower Conglomerates; U.C., Upper Conglomerates.

lower part (Ramos 1979; Ramos & Doubinger 1979; Ramos & Sopeña 1983; Pérez-Arlucea 1985; Ramos *et al.* 1986). Thickness of the Hoz del Gallo Formation can change from a maximum of 150 m in the Molina de Aragón area to 60–80 m in the Albarracín area and only 5–10 m in the Orea and Valdemeca-Boniches areas; it pinches out in the Talayuelas area.

A major erosive bounding surface divides the formation into two members: the lower and upper conglomerates: The upper conglomeratic member is more laterally extensive than the lower and is found from Valdemeca to Boniches, lying on older sediments or the Hercynian basement. The lower member is composed of truncated, fining-upward conglomeratic, cross-stratified sequences with erosive, concave bases, internal trough and planar cross-stratification and some sandstone lenses at the top. Fines of overbank origin are seldom preserved, but they contain the pollen and spore assemblages found in the formation. This member has been interpreted as bar-and-channel associations in a proximal to distal alluvial fan system with frequent lateral switches of the active channels (Ramos *et al.* 1986).

The upper member is dominated by tabular sets of massive and trough cross-stratified conglomerates bounded by extensive planar erosion surfaces. The sudden change in fluvial style is associated with the presence of white, igneous derived vein quartz pebbles, ventifacts (=dreikanters) and a switch of palaeocurrents from the NE to the SE (Ramos & Sopeña 1983; Ramos *et al.* 1986; M. Durand, pers. comm.). This member is interpreted as a more stable, coarse-grained, braided alluvial system with clear lateral aggradation, deeper channels and a more distal source area containing igneous and/or metamorphic rocks, in contrast with the monomictic quartzite composition of the lower member, derived from local sources.

The Cañizar Formation (Figs 4 & 6) lies in sharp, conformable contact with the Hoz del Gallo Formation or unconformably on the Alcotas Formation. The age of its upper part is early Middle Triassic (early Anisian), but the age of the base is unknown up to now; the age of the lower part of the underlying, conformable Hoz del Gallo Formation is Late Permian; the P/T transition lies somewhere between the upper part of the Hoz del Gallo Formation and the lower part of the Cañizar Formation (Arche *et al.* 2004).

The Cañizar Formation was deposited all over the Iberian Basin, and its thickness ranges from 80 to 170 m; its petrographical composition changes from arkoses in the NW to protoquartzites in the SE, the change taking place in the Cañete–Landete area, probably due to feldspar abrasion during downstream transport (López-Gómez & Arche 1994). As the palaeocurrents point to the S and SE (Fig. 6) with dispersions that rarely exceed 50 degrees, the drainage was parallel to the axis of the basin, and the source area was far away to the NW. The basin configuration was a symmetric graben limited by the basin boundary fault systems, the Serranía de Cuenca to the SW and the Ateca to the NE (Fig. 3).

Within these sandy braided river deposits, almost devoid of fine materials, six multilateral, multi-storey sandstone sheets have been identified, separated by planar erosive surfaces of regional extent (López-Gómez & Arche 1993). The lower two units are made up of truncated, fining upward-sandstone sequences up to 1.2 m thick with thin pebble lags at the base, organized in amalgamated vertical sequences. They are interpreted as sandy, braided channel fill with a very high width/depth ratio (over 25), comparable to the present-day North Platte River (Miall 1978; Crowley 1983) or the South Saskatchewan River (Cant & Walker 1978).

The three middle units mark a progressive change towards more complex, sandy amalgamated units with cross-stratification, reactivation surfaces and downward accretion structures showing overpassing; they are interpreted as sand flats of composite bars infilling the active channels of broad, braided river systems, comparable to some Old Red Sandstone examples (Campbell 1976). The two uppermost units reflect a sudden energy increase in the braided river depositional system, with complex sand flat and composite bar infillings of the broad active channels. Frequent convex reactivation surfaces point to repeated flood and dry period cycles with marked discharge fluctuations (Jones 1977). The laterally equivalent, coeval Rillo de Gallo Formation in the NW Iberian Basin has been interpreted broadly in the same terms by Ramos *et al.* (1986) and Pérez–Arlucea & Sopeña (1985).

Catalan Ranges

The three sedimentary cycles described in the Iberian Ranges can be identified in the Catalan Ranges (Fig. 1). During the Permian to Lower Triassic interval, the Catalan Basin was subdivided into three tectono-sedimentary domains: Montseny-Llobregat (NW), Garraf (central) and Miramar-Prades-Priorat (SW), partially bounded by the Lérida and Gerona Palaeozoic highs (Figs 3 & 6) (Marzo 1980).

The siliciclastic deposits of the Catalan Basin considered here remain undated by biostratigraphical methods, so the correlations with other areas are based only on lithostratigraphical considerations and must be considered provisional (Arche *et al.* 2004). Basal breccias are found in small outcrops in the NE and SW domains, lying unconformably on the Hercynian basement and unconformably overlain by the second or third sedimentary cycles. The lithological characteristics and tectono-stratigraphical position of these unnamed breccias is identical to the Tabarreña Breccias in the Iberian Basin (Fig. 4), so a Lower Permian age is attributed to these sediments.

A second sedimentary cycle, bounded by angular unconformities, is found in the three domains, but its lateral extent is limited (Fig. 6). It consists of the Riera de Sant Jaume, Garraf and Bellmunt quartzitic conglomerates, conformably overlain by the Riera de Sant Jaume, Brugers and Bellmunt red mudstones and sandstones. Again, even in the absence of biostratigraphical data, a tentative correlation can be proposed using lithological and tectono-stratigraphical analogies: the basal conglomeratic units are the time equivalents of the Boniches Formation, and the overlying red mudstones and sandstones, of the Alcotas Formation (Arche *et al.* 2004).

A new sedimentary cycle, found all along the Catalan Ranges (Fig. 7), lies unconformably on the Hercynian basement, on the first or the second sedimentary cycles. The third sedimentary cycle consists of quartzitic conglomerate in the NE and SW domains (Caldes and Prades units) conformably overlain by arkosic pink sandstones of multi-storied, amalgamated internal geometry (Caldes, Eramprunyá and Prades units). The top of the cycle is marked in the SW domain by a well-developed hiatus surface enriched in Fe oxides.

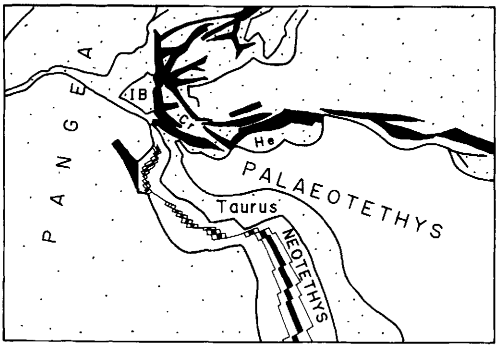

Fig. 7. Reconstruction of the central western Tethys at the end of the Permian; in black, the main continental rifts. From Eren *et al.* (2004), slightly modified. IB, Iberia; Cr, Carnian Alps; He, Hellenides.

The correlation with the Iberian Basin is reasonably drawn as follows: the conglomeratic units can be the time equivalents of the Hoz del Gallo Formation and the sandstone units, of the Cañizar (=Rillo de Gallo) Formation. Synsedimentary extensional tectonics is evident in the Catalan Basin (Marzo 1980), and differential subsidence along the axis of the basin created the three different domains and the lateral changes of facies and thickness.

Ebro Basin

Duing the Permian, the Ebro Basin was separated from the Iberian Basin by the Ateca Palaeozoic high (Fig. 3) and was connected with the Catalan Basin at its SE corner. The SW margin of the Ebro Basin is now exposed along the Aragonese branch of the Iberian Ranges (Fig. 2), but most of it is now covered by Tertiary sediments, so essential information can be obtained only from commercial oil well logs and cores (Arribas 1984, 1985; Jurado 1988, 1990) (Fig. 6).

Isolated outcrops of volcaniclastic rocks associated with grey mudstones and lying unconformably on the Hercynian basement are found from Reznos to Montalban (Fig. 2). They have been termed the Arroyo Riduero Formation by Rey & Ramos (1991) and contain rich pollen and spore assemblages of Lower Permian (Autunian) age (De la Peña *et al.* 1977). The straightforward correlation with the Ermita Formation and equivalents in the Iberian Basin, that is, with the first sedimentary cycle, is based on similar palynofloras, identical volcanic rocks and identical tectono-stratigraphical position at the base of the Permian sedimentary record. A second sedimentary cycle lies unconformably on the Hercynian basement or on the first sedimentary cycle (Arribas 1984, 1985). It consists of the Moncayo Conglomerates Formation and the Tabuenca Mudstones Formation. Although it is not dated, its correlation with the second sedimentary cycle of the Iberian Basin, that is, the Boniches and Alcotas formations, is most plausible.

Lying unconformably on the second cycle, a third cycle, composed of one sedimentary unit, the Aranda Formation, is found throughout the basin (Arribas 1985), capped by a hiatus surface or conformably overlain by the Carcalejos Formation and the Rané Mudstones and Sandstones Formation. This cycle is not dated, but its petrographical, sedimentological and tectono-stratigraphical characteristics are identical to the Cañizar Formation of the Iberian Basin.

Balearic Islands

The Balearic Islands show a good sedimentary record of the Late Permian–Triassic time interval (Rodriguez-Perea *et al.* 1987; Ramos & Doubinger 1989; Ramos 1995), but the correlation with mainland Iberia has been seldom attempted (Arche *et al.* 2002), probably due to its present-day position in the Betic alpine orogenic belt (Fig. 1). The siliciclastic deposits of Mallorca (Fig. 6), lying unconformably on the Hercynian basement on the northern coast of the island, have been subdivided into three formations by Ramos (1995). From base to top they are: Port d'es Canonge Formation, Asá Formation and Son Serralta Formation. There is a sharp contact between the first and second formation and a transitional one between the second and the third ones.

A similar succession has been described in Menorca (Bourrouilh 1973; Rosell *et al.* 1988; Broutin *et al.* 1992), but no formal stratigraphical units have been described on this island. Above a few metres of polymictic breccias, a red mudstone unit equivalent to the Port d'es Canonge Formation in lithology and tectono-stratigraphical position is covered unconformably by massive red sandstones (B1 unit) and alternating mudstones and sandstones (B2 unit), equivalent to the Asá and Son Serralta formations.

Several palynological assemblages have been found in both islands and are described in detail in a later section of this paper. The correlation with the Iberian Basin (Arche *et al.* 2002) is clear according to lithological, sedimentological and biostratigraphical criteria: the Port d'es Canonge Formation and the basal red unit of Menorca are the time-equivalents of the Alcotas (=Tormón and Montesoro) Formation, the Asá Formation and the B1 unit correlate with the Cañizar (=Rillo de Gallo) Formation and the Son Serralta Formation and the B2 Unit with the Eslida (=Prados and Arandilla) Formation.

Biostratigraphical data

The Permian and Lower Triassic continental sediments of the Iberian Basin and the Balearic Islands have yielded numerous pollen and spore assemblages in many localities since the 1970s. Detailed descriptions and references can be found in Bourrouilh (1973), Ramos & Doubinger (1989), Doubinger *et al.* (1990), Broutin *et al.* (1992), Sopeña *et al.* (1995) and Díez (1997). The scarce palynological data for the Catalan Basin (Middle and Upper Triassic only) are found in Solé de Porta *et al.* (1985, 1987). The Ebro Basin sediments remained undated, as the scarce attempts to find microfossils in borehole samples have been unsuccessful up to now.

Iberian Basin

The sediments of the first sedimentary sequence (Fig. 7), not studied in this paper, have yielded rich palynological and macrofloral assemblages of typical Lower Permian (Autunian) age (Ramos *et al.* 1976; Doubinger *et al.* 1978; Ramos & Doubinger 1979; Sopeña 1979; Melendez *et al.* 1983; Wagner *et al.* 1983), in good agreement with the absolute ages obtained for the interstratified volcanic rocks: 283 ± 2.5 to 293 ± 2 Ma, Sakmarian stage (Hernando *et al.* 1980; Lago *et al.* 2004).

The sediments of the second and third sedimentary sequences (Figs 5 & 6) have yielded rich palynological assemblages of Late Permian (Thuringian) age in the Boniches, Alcotas (=Tormón and Montesoro) and Hoz de Gallo formations. Boulouard and Viallard (1971) found a pollen and spores assemblage in the Alcotas Formation of the Landete section (Fig. 2) composed of: *Lueckisporites virkkiae, Taeniasporites albertae, T. noviaulensis, Limitisporites sp., Pilasporites calculus, Nuskoisporites dulhuntyi, Jugasporites delasaucei, Vesicaspora ovata* and *Platysaccus umbratus.* These are of Late Permian (Thuringian) age.

In the region of Molina de Aragón (Fig. 2), Ramos & Doubinger (1979) found a palynological assemblage near the base of the Hoz de Gallo Formation composed of: *Punctatisporites* sp., *Endosporites* sp., *Trizonaesporites grandis, Nuskoisporites dulhuntyi, Cordaitina* sp., *Lueckisporites virkkiae, Paravesicaspora splendens, Jugasporites delasaucei, Protohaploxipinus microcorpus, Striatopodocarpites* sp., *Gardenasporites heisseli, Falcisporites schaubergerii* and *Cycadopites* sp. These are also of Late Permian (Thuringian) age, but this formation lies unconformably on the Alcotas Formation in this section. This apparent anomaly remained unexplained for a decade.

In the SE domain of the Iberian Basin, Temiño (1982) described a palynological assemblage in the middle part of the Alcotas Formation near Albarracín (Fig. 2), composed of *Lueckisporites virkkiae, Nuskoisporites dulhuntyi, Falcisporites schaubergerii* and *Bisaccates* sp., of

Late Permian (Thuringian) age. In the same region, Pérez-Arlucea (1985), Pérez-Arlucea & Sopeña (1985) and Sopeña *et al.* (1995) found palynological assemblages in several localities, both in the Hoz del Gallo and Tormón (=Montesoro and Alcotas) formations, composed of: *Angustiporites anguinus, Densoisporites* sp., *Converrucosisporites deasauey, C. eggeri, Uvaesporites* sp., *Acanthotriletes* sp., *Lycospora* sp., *Nuskoisporites dulhuntii, N. klausii, Trizonaesporites grandis, Wilsonites* sp., *Klausipollenites schaubergeri, Paravesicaspora splendens, Jugasporites delasaucei, Jugasporites* sp., *Alisporites* sp., *Sulcatisporites ovatus, Gardenasporites* sp., *Pytiosporites* sp., *Falcisporites zapfei, Lueckisporites virkkiae, Crucisaccites variosulcatus, Protohaploxipinus sewardi, Striatopodocarpites rarus, Lunatisporites* sp. and *Crustaesporites* sp. All of them are of Late Permian (Thuringian) age.

In the Cañete-Boniches area (Fig. 2), López-Gómez *et al.* (1984) and Doubinger *et al.* (1990) found a palynological assemblage in the upper part of the Boniches Formation composed of: *Klausipollenites schaubergeri, Lueckisporites virkkiae, Cedripites* sp., *Lycospora* sp., *Nuskoisporites dulhuntyi, Paravesicaspora splendens, Potonieisporites* sp., *Protohaploxipinus microcorpus, Verrucosisporites* sp. and *Vittatina* sp. Typical Thuringian forms, such as *Lueckisporites virkkiae* and *Nuskoisporites dulhuntyi* are associated with typical Autunian forms such as *Vittatina* sp. and *Potonieisporites* sp. This indicates an older age than the assemblages of the Alcotas Formation, but still in the Thuringian.

The same authors have found in the middle part of the Alcotas Formation of the Talayuelas section (Fig. 2) an assemblage composed of: *Lueckisporites virkkiae, L. microgranulatus, Klausipollenites schaubergerii, Nuskoisporites dulhuntyi, Protohaploxipinus microcorpus, Trizonaesporites grandis, Falcisporites zapfei* and *Plaifordiaspora crenulata.* They are of Late Permian (Thuringian) age. In the lower part of the Alcotas Formation, in the Minas de Henarejos section (Fig. 6), the same authors have found an assemblage composed of: *Lueckisporites virkkiae, L. microcorpus, Nuskoisporites dulhuntyi, Paravesicaspora splendens, Lundbladispora* sp., *Klausipollenites schaubergeri, Falcisporites zapfei, Protohaploxipinus sevardi, Platisaccus papillionis, Jugasporites perspicus, Gardenasporites oberrauchi* and *Converrucosisporites eggeri.* They are of Late Permian (Thuringian) age. In the classic section of Landete (Fig. 2), they found in the Alcotas Formation an assemblage composed of: *Lueckisporites virkkiae, Nuskoisporites dulhuntiy, Klausipollenites schaubergeri, Falcisporites nuttialensis, Platysaccus papillionis, Playfordiaspora crenulata, Jugasporites perspicuous* and *Corisaccites* sp. They are of Late Permian (Thuringian) age.

In the upper part of the Cañizar Formation of the Cañete section (Fig. 2), Doubinger *et al.* (1990) found a palynological assemblage composed of: *Allisporites toralis, Falcisporites cf. stabilis, Leiotriletes* sp. and *Lycospora* sp. These are of early Middle Triassic (early Anisian) age.

Catalan Ranges

The palynological data from this region are scarce (Visscher 1967; Solé de Porta *et al.* 1985, 1987). The Figaró Formation has yielded a poor assemblage, containing *Lundbladispora* sp. and *Cycadopytes* sp., of Early Triassic (?) age. Some units of the Muschelkalk and Keuper facies have yielded palynological assemblages of Mid-Late Triassic age.

Balearic Islands

The Late Permian to Early Triassic sediments of Mallorca and Menorca have yielded some rich palynological assemblages. Ramos (1979) and Ramos & Doubinger (1989) found an assemblage near the base of the Asá Formation composed of: *Nuskoisporitres dulhuntyi, Lueckisporites virkkiae, Klausipollenites schaubergeri, Falcisporites zapfei, Protohaploxipinus microcorpus, Paravesicaspora splendens, Lunasporites delasaucei, Crucisaccites variosulcatus, Endosporites velatus* and *Crustaesporites* sp. These are of Late Permian (Thuringian) age. Also, near the top of the Son Serralta Formation, there is an assemblage dominated by *Porcellispora longdonensis* and *Sulcosaccispora minuta*, which is of early Middle Triassic (Anisian) age.

The same formations can be identified in Menorca, where Bourrouilh (1973) found in the unnamed red mudstones at the base of the sequence an assemblage very similar to the one in the Port d'es Canonge Formation, which includes: *Lueckisporites virkkiae, Falcisporites schaubergeri, Nuskoisporites dulhuntyi* and *Taeniasporites angulistriatus.* They are of Late Permian (Thuringian) age. In the same outcrops on the northern coast of the island, Broutin *et al.* (1992) found in the same red mudstones an assemblage composed of: *Lueckisporites virkkiae, L. singhii, Lunatisporites* cf. *novicus, Klausipollenites schaubergeri, Falcisporites stabilis, Illinites unicus* and *Striatoabietites richteri.* They are of Late Permian (Thuringian) age.

Biostratigraphical significance of the Late Permian and Middle Triassic palynofloras

The palynofloras found in the Alcotas and Hoz del Gallo Formations contain the typical elements of the Thuringian Stage *sensu* Visscher (1971) (=Zechstein), such as *Lueckisporites virkkiae, Nuskoisporites dulhuntyi* and *Paravesicaspora splendens*, that he correlates with the Tatarian Stage of the Upper Permian of the Russian Platform. This assemblage is also comparable to Zone 29 of Gorsky *et al.* (2003), who also studied the palynofloras of this classic (Russian) area. There are numerous common elements, such as *Lycospora* sp., *Protohaploxipinus sevardi, Platysaccus papilionis, Lueckisporites virkkiae* and *Paravesicaspora* sp. The age of this assemblage is late Thuringian (=late Tatarian). As stated before, it is important to point out that the upper part of the Alcotas Formation is barren of organic remains

More problematic is the attribution of an age to the assemblage found in the Boniches Formation. The coexistence of typical Late Permian forms, such as *Lueckisporites virkkiae* and *Nuskoisporites dulhuntyi*, with typical Early Permian (Autunian) forms, such as *Vittatina* sp. and *Potonieisporites* sp., is found in Zones 30 and 31 of the Permian of the Russian Platform (Gorsky *et al.* 2003), which is from the lower Tatarian (Upper Permian) to the upper Kazanian (Middle Permian).

The sedimentary continuity between the top of the Boniches Formation and the base of the Alcotas Formation is evident in any field section. As the former is only 80–100 m thick, it is reasonable to assume that it could accumulate in only a few thousand years if we take into account that present-day deposits of comparable environment, thickness and extension can accumulate in about 30 000 years (Harvey 1990) or in 10 000–170 000 years in well-calibrated ancient examples, such as in Montserrat and Sant Llorens de Munt Fans, Eocene, Catalunya, Spain (López-Blanco *et al.* 2000). If this assumption is correct, only the top of Zone 30 of the Upper Permian of Gorsky *et al.* (2003) is recorded in these sediments.

As the duration of the Tatarian is 15 Ma (265–251 Ma: Menning 1995, 2002), only its uppermost part is represented in the Hoz del Gallo, Alcotas and Boniches formations, which is in the Thuringian of western Europe, as defined by Visscher (1971) and Uttig & Piasecki (1995). There is also a major hiatus between the Lower Permian (=Autunian) and the Upper Permian (Thuringian) deposits. This hiatus comprises part of the Sakmarian, the Artinskian, Kungurian and Kazanian stages, in sharp contrast with the more or less complete record of the Russian Platform. According to these data, Spain was part of the western European realm (Visscher 1971; Gorsky *et al.* 2003).

From the data, it is evident that the Permian–Triassic transition must lie somewhere between the upper part of the Hoz del Gallo Formation and the lower part of the Cañizar Formation, as will be discussed at length in the next section. The Illawarra magnetic anomaly, dated as 265 Ma (Menning 2002), which is, in the Guadalupian (Middle Permian), is much older than the base of the second sedimentary cycle and therefore is not recorded in Spain (Fig. 6).

The location of the Permian–Triassic transition in the Iberian Basin

As stated earlier in this paper, the Iberian Ranges hold one of the best-dated records of the Late Permian to Middle Triassic in the Iberian microplate, so the location of the Permian–Triassic transition will be discussed here, and, then, correlations with other areas will be drawn. The second sedimentary cycle is of Late Permian (Thuringian) age, but it is important to point out that the upper third of the Alcotas Formation is devoid of all organic remains, soil profiles and thick sandstone bodies.

A die-off of the flora and the absence of soil profiles could be related to local tectonic or fluvial sedimentology factors, but as this is a general feature over more than 400 km in the Iberian Ranges and a general feature in the Ebro and Catalan basins, it can only be explained by an extra-basinal, general process, not by local tectonic, climatic or taphonomic causes, as no geochemical, mineralogical, tectonic or sedimentological changes within the middle and upper parts of the formation have been identified. The most plausible cause is the coeval emplacement of the China Emeishan basalts, a large igneous province of moderate size (Thompson *et al.* 2001). If this hypothesis can be confirmed, a good chronostratigraphical reference horizon will be established in the search for the position of the Permian–Triassic transition in the Iberian basin and the rest of central and NE Iberia.

The absolute age of the Emeishan basalts is now well established at 259 ± 3 Ma for the main phase of volcanism (Zhou *et al.* 2002), which is clearly in the Tatarian stage. The widely quoted analytical results of Lo *et al.* (2002), giving an absolute age of 252.8 ± 1.3 Ma for the same levels, have been questioned and rejected by Courtillot & Renne (2003) because of flawed and incorrect analytical procedures.

The Emeishan basalts are older than the Permian–Triassic transition in the standard section of Meishan, China (Mundil *et al.* 2001*a*,*b*, 2004; Yin *et al.* 2001) and their emplacement should be related to the so-called 'end-Guadalupian' biotic crisis (Ali *et al.* 2002; Thompson *et al.* 2001; Courtillot & Renne 2003), in spite of the small discrepancy between the accepted age for the Guadalupian–Lopingian boundary and the youngest part of the Emeishan basalts (Courtillot *et al.* 1999; Wignall 2001). The upper part of the Alcotas Formation could be coeval with the emplacement of the Emeishan basalts because pollen and spore assemblages of Zone 29 of the upper Tatarian of the Russian Platform (Gorsky *et al.* 2003) are found immediately beneath it, and the proposed absolute ages of this zone are similar to the above-mentioned ones for the basaltic flows of SE China. The causal relationship between the volcanism and the absence of any organic remains after a severe biotic crisis caused by atmospheric pollution by aerosol and gas poisoning of the atmosphere during the deposition of the upper part of the Alcotas Formation is at least reasonable, if not proven beyond any doubt.

The third sedimentary cycle, lying unconformably on the second one after a phase of uplifting and erosion more marked in the NW part of the Iberian Basin, started with renewed extensional tectonics along the SW basin boundary fault (Serranía de Cuenca fault), a situation comparable to the beginning of the second sedimentary cycle.

The presence of Late Permian (Thuringian) pollen and spore assemblages in the lower part of the Hoz del Gallo Formation, at the base of the cycle (Fig. 7), mark a biotic recovery after the barren period at the top of the underlying Alcotas Formation and different preservation conditions (Ramos & Doubinger 1979; Ramos & Sopeña 1983; Sopeña *et al.* 1995). Renewed tectonic activity created high topographical areas and energetic relief that could provide a refuge for vegetation, since they created topographical rains at a time when the Late Permian icecaps melted away completely (Beauchamps & Baud 2002), increasing the temperatures at the equatorial belt and enhancing the cyclonic storms in the Western Tethys (Stampfli & Borel 2002).

The age of the palynological assemblages found in the Hoz del Gallo Formation is identical to the ones found in the Alcotas Formation, so the unconformity at the base of the third sedimentary cycle is intra-Late Permian, and the Permian–Triassic must lie above it and the lower part of the Hoz del Gallo Formation. The upper part of the Hoz del Gallo Formation is barren of organic remains and marks a sudden change in palaeocurrents, sedimentological and petrological characteristics (Ramos & Sopeña 1983; Ramos *et al.* 1986), caused by another tectonic pulse on the Serranía de Cuenca fault system leading to the enlargement of the rift basin and the tapping of new source areas to the NW containing igneous and metamorphic rocks.

The youngest formation considered in this paper, the Cañizar Formation, in well-defined, conformable contact with the underlying Hoz del Gallo Formation or unconformably on the Alcotas Formation, is interpreted as deposits of sandy, braided rivers of extreme channel instability and frequent shifting of the active depositional zone (Arche & López-Gómez 1999). These fluvial systems found no obstacles for the lateral migration of active channels across a wide, flat alluvial plain, in spite of small to moderate stream power, as indicated by the metric scale of the internal structures. No organic remains have been found in this formation except a lower Anisian pollen and spore assemblage at the top (Doubinger *et al.* 1990).

The vertical transition from Late Permian high-sinuosity rivers, with thick floodplain deposits, rich in plant and pollen and spore remains to Late Permian – Early Triassic sandy, braided river systems devoid of fines and organic remains is a remarkable feature of very distant, coeval sedimentary basins, such as the Karoo Basin, South Africa (Smith 1995; Ward *et al.* 2000; Smith & Ward 2001; Retallack *et al.* 2003), the Sydney Basin, Australia (Miall & Jones 2003), the Sanga do Cabral-Santa Maria Basin, Brazil (Zerfass *et al.* 2003), the Collio and Orobic basins, Italian Alps (Ronchi & Santi 2003) and the South Devon Basin, England (Audley-Charles 1970; Smith *et al.* 1974; Laming 1980), among many others. According to the biostratigraphical data presented previously, the Permian–Triassic transition can be placed between the upper part of the Hoz del Gallo Formation and an undetermined level of the lower part of the Cañizar Formation, but it is possible to constrain the possible location to a narrower bracket if we consider global palaeogeographic and geodynamic aspects of this period. The presence of alluvial plains without significant vegetation cover, increased bed-load, a substantial decrease in the fine supply from the source area and the high instability of the active channels over thousands of kilometres cannot be explained by just local or even regional tectonic activity or regional climatic change because of the large area where these features are present; a global cause may be the explanation.

The hypothesis of a rapid episode of plant die-off at the Permian–Triassic transition has been proposed by Smith (1995) and Ward *et al.* (2000) for the Karoo Basin, combined with substantial decrease of oxygen and parallel increase of CO_2 in the atmosphere (Retallack *et al.* 2003). These phenomena could explain the general vertical transition from the Alcotas Formation to the Hoz del Gallo and Cañizar formations. In any case, the ultimate cause of the die-off needs an explanation.

Once again it is very tempting to invoke a major volcanic event, such as the emplacement of the West Siberia Basaltic LIP. These basaltic rocks, up to 6500 m thick, covered more than 4 million km^2 in about 600 000 years, from 251.7 ± 0.4 Ma to 251.1 ± 0.3 Ma (Renne *et al.* 1995; Reichow *et al.* 2002; Büchl & Gier 2003; Kamo *et al.* 2003). If the age of the Permian–Triassic Transition at Meishan, SE China has been established at 251.4+–0.2 Ma (Yin *et al.* 2001; Menning 2001; Wardlaw & Schiappa 2002), the gigantic outburst of basaltic magma was coeval with the Permian–Triassic transition. It is now very important to establish some precision in the absolute age of this transition at the standard section of Meishan, because the value of 251 ± 0.2 Ma (Menning 2001), in total coincidence with the ages proposed for the Western Siberia basalts (Renne *et al.* 1995; Reichow *et al.* 2002; Büchl & Gier 2003; Kamo *et al.* 2003) has been revised by Mundil *et al.* (2004) and corrected to 252.1 ± 1.6 Ma. Even if this new age for the transition is accepted, the biotic crisis at the base of the Triassic and the emplacement of the Western Siberia Basalts coincide, if we consider the error margins of the analytical methods and the minor inconsistencies in the comparison of absolute age datasets obtained by different geochemical procedures (Bowring *et al.* 1998; Metcalfe & Mundil 2001; Metcalfe *et al.* 2001; Mundil *et al.* 2001*a*,*b*). The enormous amounts of SO_2, CO_2, HF, Cl and other gases released in a brief period of time into the atmosphere would trigger a rapid climatic change with increased temperatures, poisoning by acid rain and disruption of the food chains, leading to major biotic extinctions both on land and in the sea (Renne & Basu 1991; Erwin 1994; Renne *et al.* 1995; Twitchett *et al.* 2001). The die-off of most terrestrial vegetation, from peat to conifers, would cause a switch to a braided configuration of the alluvial channels due to the loss of bank stability normally provided by the riparian vegetation. Bedload would increase because of the rapid denudation of unprotected regoliths in source areas, geochemical cycles leading to the formation of clays would virtually cease in absence of humic acids and the impact on terrestrial vertebrates would be enormous (Michaelsen 2002). For a period of time around and immediately after the Permian–Triassic transition, extensive areas of semi-desert or desert climate were created in equatorial and tropical Pangaea. In the continental rift basins of the Western Tethys realm (Fig. 7), sheet-like, sandy braided river deposits were accumulating not only in the small Iberian and Catalan basins, but in many other interconnected or isolated basins.

As the emplacement of the Western Siberia Basalts is coeval with the Permian–Triassic boundary, and one of the consequences of the die-off of most of the terrestrial vegetation would be the establishment of sandy braided river systems, then the Permian–Triassic transition can be placed in a narrow vertical bracket (Fig. 6) where the fluvial style changes: the top of the Hoz del Gallo Conglomerates Formation and the first few metres of the Cañizar Sandstones Formation. If this causal connection is correct, it would also explain the absence of any organic remain in most of the third sedimentary cycle. At the beginning of the Middle Triassic (early Anisian), the recovery of the environment allowed a radiation of new plants, and pollen and spores are found again at the top of the Cañizar Formation (Doubinger *et al.* 1990), and a new change in fluvial style led to the deposition of a new sedimentary cycle (the fourth) (Fig. 4), composed of more than 60% red mudstones and isolated simple sand ribbons or laterally restricted multistorey channel fills (Eslida Formation, not examined in this paper, also dated as Anisian, marking the recovery of the terrestrial ecosystems: López-Gómez *et al.* 2002).

If a constant rate of accumulation is assumed for the Cañizar Sandstones Formation, and the age of its top is placed at the early Anisian (about 244 Ma), and the age of the lower part of the Hoz del Gallo Conglomerates Formation is estimated as latest Permian (about 252 Ma), this rate can be estimated at 15 m per million years. In this case the probable position of the Permian–Triassic boundary can be placed in the lower 10 m of the Cañizar Formation, but uncertainties about the exact age of the topmost beds of the Hoz del Gallo Formation cannot rule out the possibility of this boundary being there, although, if this is the case, extremely conservative rates of accumulation should be assumed for the latter unit.

If the proposed position of the Permian–Triassic Basin is correct, then the P/T transition in other basins of the Iberian microplate (Fig. 8) can be located with some precision: the top of the Rio Pedro Conglomerates (T1.1) and the base of the Rio Pedro Sandstones Formations (T1.2)

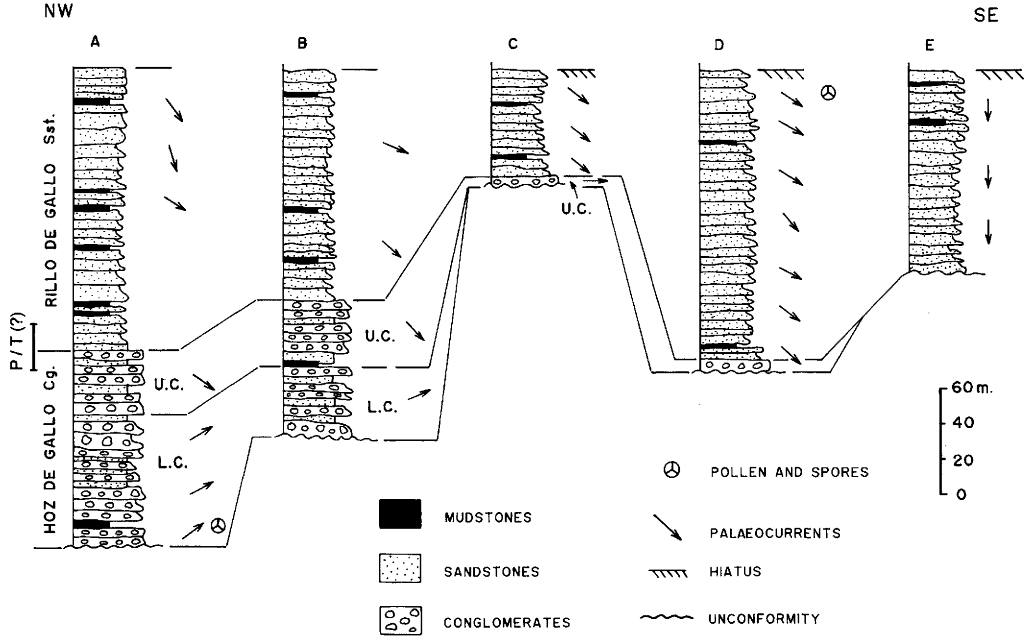

Fig. 8. Proposal of correlation of the Late Permian–Mid-Triassic sediments in central and NE mainland Spain and the Balearic Islands, and the most probable position of the Permian–Triassic transition. Note the uncertainty bracket on the left. Modified from Arche *et al.* (2004). A, Molina de Aragón; B, Albarracin; C, Valdemeca; D, Cañete; E, Chelva; U.C., Upper Conglomerates; L.C., Lower Conglomerates.

(Hernando 1977, 1980) in the NW Iberian Basin (Fig. 4); the top of the Prades and Caldes Conglomerates and the base of the Prades, Eramprunyá and Caldes formations in the Catalan Basin (Fig. 6); the base of the Aranda Formation in the Ebro Basin (Arribas 1984, 1985) (Fig. 6) or its subsurface equivalents; the B-1 conglomerates and the base of the B-2 sandstones (Jurado 1988) and the base of the Asa Formation in Mallorca (Ramos 1995) and the B-1 unit of Menorca (IGME 1989). This is according to the general correlation for the Permian and Triassic deposits of central and Spain proposed by Arche *et al.* (2002). It is evident that further palynological, vertebrate and palaeomagnetic research is needed to confirm this correlation and to locate more precisely the P/T transition, combined with geochemical and ichnofossil data. However, the available data allow for a great advance in comparison with previous studies.

Finally, there is a fact that needs further consideration: the apparent heterochrony between the sedimentological change from high-sinuosity, clay-rich fluvial environments of the Late Permian (middle and upper units of the Alcotas Formation) to the low-sinuosity, sandy braided river deposits of the latest Permian to Early Triassic (lower part of the Cañizar Formation), a sedimentological evolution found in several basins around the world. The Permian–Triassic transition is located in the upper part of the clay-rich unit in the Karoo Basin, South Africa (Retallack *et al.* 2003), before the sedimentological change, but it is located in the overlying sandy unit or 'Verrucano Sardo' in Sardinia, Italy (Fontana *et al.* 2001), in well-dated sections such as Lu Caparoni and Cala Viola, the Iberian Basin of Spain, of the Serbian Karpathos (Maslarevic & Krstic 2001). These problems can be solved if we consider the difficulties in establishing detailed correlations based in different fossil groups of distant faunal and floristic provinces. Another clue to this apparent anomaly is the often neglected fact that there are two successive extinction events very close in time: the 'end-Guadalupian' one, related to the SE China basalt flows, and the 'end-Permian' one, related to the Western Siberia basalt flows.

Conclusions

1. The most complete sections and most accurate biostratigraphical data to investigate the Permian–Triassic transition in central

and NE Spain are found in the Iberian Ranges.
2. An angular unconformity of Late Permian age separates the second and third sedimentary cycles in the Iberian Ranges and other basins of Spain, so the P/T transition lies above it.
3. Biostratigraphical data show two barren intervals in the sedimentary record: one at the top of the Alcotas Formation (second sedimentary cycle), during the Late Permian, and another at the top of the Hoz del Gallo Formation and most of the Cañizar Formation (third sedimentary cycle), during the latest Permian to Early Triassic.
4. The two barren intervals are possibly the consequence of the emplacement of the SE China (Emeishan) and Western Siberia Large Igneous Basaltic Provinces.
5. The P/T transition in the Iberian Ranges can be placed in a narrow sedimentary interval between the upper part of the Hoz del Gallo Formation and the lowermost part of the Cañizar Formation, according to biostratigraphical data and calculations of absolute rates of sedimentation in this period.
6. The barren interval in the Cañizar Formation, spanning about 4 Ma, agrees well with the slow recovery of the terrestrial environments after the end-Permian extinction event.
7. The probable position of the P/T transition in other parts of central and NE mainland Spain and the Balearic Islands is proposed based on a general correlation among these basins.

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