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The siliciclastic Permian-Triassic deposits in Central and Northeastern Iberian Peninsula (Iberian, Ebro and Catalan Basins): A proposal for correlation

A. ARCHE[1] **J. LÓPEZ-GÓMEZ**[1] **M. MARZO**[2] **and H. VARGAS**[1]

[1] **Instituto de Geología Económica, CSIC-UCM, Facultad de Geología, Universidad Complutense**
Antonio Novais 2, 28040 Madrid. Arche E-mail: aarche@geo.ucm.es López-Gómez E-mail: jlopez@geo.ucm.es
Vargas E-mail: henar@geo.ucm.es

[2] **Departament d'Estratigrafia, Paleontologia i Geociències Marines, Facultat de Geologia, Universitat de Barcelona**
Zona Universitaria de Pedralbes, 08071 Barcelona. E-mail: mariano@ub.edu

ABSTRACT

The siliciclastic deposits of the Iberian, Ebro and Catalan Basins have been described for more than a century, but facies similarities and a lack of biostratigaphic data have difficulted the correlation of the local stratigraphic units in a general framework up to now. Combining pollen and spores data, the identification of the regional unconformities and hiatuses and the quantitative analysis of the subsidence by backstripping methods, a new correlation scheme for these facies is proposed.

KEYWORDS **Permian. Triassic. Iberian Peninsula. Stratigraphy. Basin Analysis.**

INTRODUCTION

The Permian-Triassic sediments of Central and Northeastern Iberian Peninsula can be broadly described by the classic Germanic trilogy: Buntsandstein, Muschelkalk and Keuper, capped by a Late Triassic-Early Jurassic carbonate-evaporite complex.

These sediments, and the associated volcanic rocks found in several localities, were deposited under extensional regime after the Hercynian Orogeny, with several syn-, post-rift cycles of variable magnitude and temporal extension.

A more detailed examination of the sedimentary record, however, reveals changes of facies, thickness variations and even the absence of some units in several areas; the stratigraphy of these deposits is still a matter of debate in several domains and a general correlation has not been attempted up to now. In this paper we try to start infilling this gap by proposing a general scheme of correlation for Central and NE Iberia (Fig. 1A).

The main characteristics of the Permian-Triassic siliciclastic sediments of the area are now well established and a wealth of data have been published since the 70's (see Virgili et al., 1976, 1977, 1983; Hernando, 1977; Ramos, 1979;

Sopeña, 1979; Arribas, 1985; Marzo and Calvet, 1985; Ortí, 1987; Sopeña et al., 1988; Jurado, 1988; López-Gómez and Arche, 1993; Calvet and Marzo, 1994; Ortí and Pérez-López, 1994; López-Gómez et al., 2002 among many others). A recent revision of the related Triassic carbonate-evaporite sediments is found in López-Gómez et al. (1998).

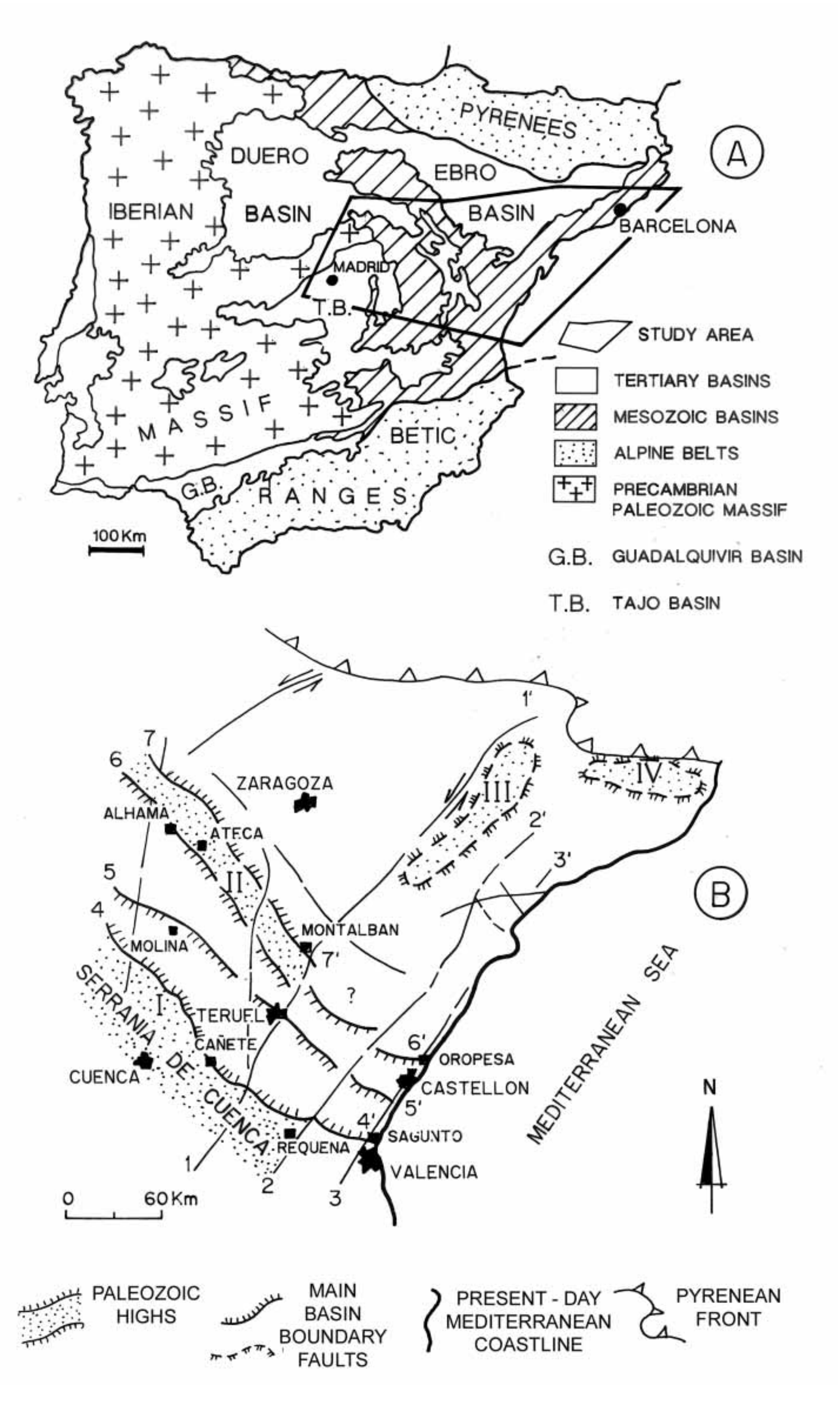

FIGURE 1 **A) Geological sketch of the main geological units of the Iberian Peninsula and study area. B) Sketch of the main Permian-Triassic basins of the area, Paleozoic highs and basin boundary faults. I: Serranía de Cuenca; II: Ateca-Montalbán High; III: Lérida High; IV: Gerona High. 1-1´: Teruel-Segre Fault; 2-2´: Requena Fault; 3-3´: Castellón Fault; 4-4´: Serranía de Cuenca Fault; 5-5´: Molina Fault; 6-6´: Alhama-Vinalopó Fault; 7-7´: Ateca-Montalbán Fault.**

The sedimentary basins were formed under extensional tectonic regime and had a long and complex story (Arche and López-Gómez, 1996), spanning from the Early Permian (about 290 Ma) to the Triassic-Jurassic boundary (about 205 Ma) and beyond. The basin boundary faults were hercynian or older lineaments reactivated during this period, specially those trending NW-SE; otherwise, there are younger, new synsedimentary fault systems trending NE-SW or N-S. The origin and evolution of these basins have been studied by Salas and Casas (1993); Doblas et al. (1993); Arche and López-Gómez (1996); Van Wees et al. (1998) and many others (see López-Gómez et al., 2002 for a complete survey).

In this paper, the terms Iberian Basin, Ebro Basin and Catalan Basin are using referring to the extensional Permian-Triassic basins, not to younger structures. It is important to remark that the Iberian Basin was bounded by the Serranía de Cuenca and Ateca Paleozoic Highs, the Ebro Basin by the Ateca and Lérida Paleozoic Highs and by an ill-defined high in the Pyrenean zone, and the Catalan Basin by the Lérida and Gerona Paleozoic Highs (Figs. 1B and 2).

These Paleozoic highs or basin shoulders were created in the footwall blocks of the extensional basin boundary faults and their configuration changed in time. They were partially drowned by shallow marine and continental deposits during the Anisian an ceased to exist as basin dividers during the Late Triassic. The Ateca and Serranía de Cuenca Highs disappeared just short of the present-day Mediterranean coastline and the Catalan, Ebro and Iberian Basins merged into a single structure in what is now the eastern Maestrazgo and the Valencia area.

It is important to distinguish these terms from Cenozoic structures such as the Iberian Ranges, the Ebro Basin and the Catalan Ranges. The Iberian Ranges are a Cenozoic compressional structure that incorporates most of the Permian-Triassic Iberian Basin, the Ateca High and the SW margin of the Permian-Triassic Iberian Basin.

The Ebro Basin is a complex Cenozoic basin infilled by marine and continental sediments during and after the emplacement of the Pyrenean and Iberian Ranges. The Cenozoic structure incorporates the Permian-Triassic Ebro Basin, the Lérida and Gerona Highs and the western part of the Permian-Triassic Catalan Basin. The Catalan Ranges are also a compressional structure where part of

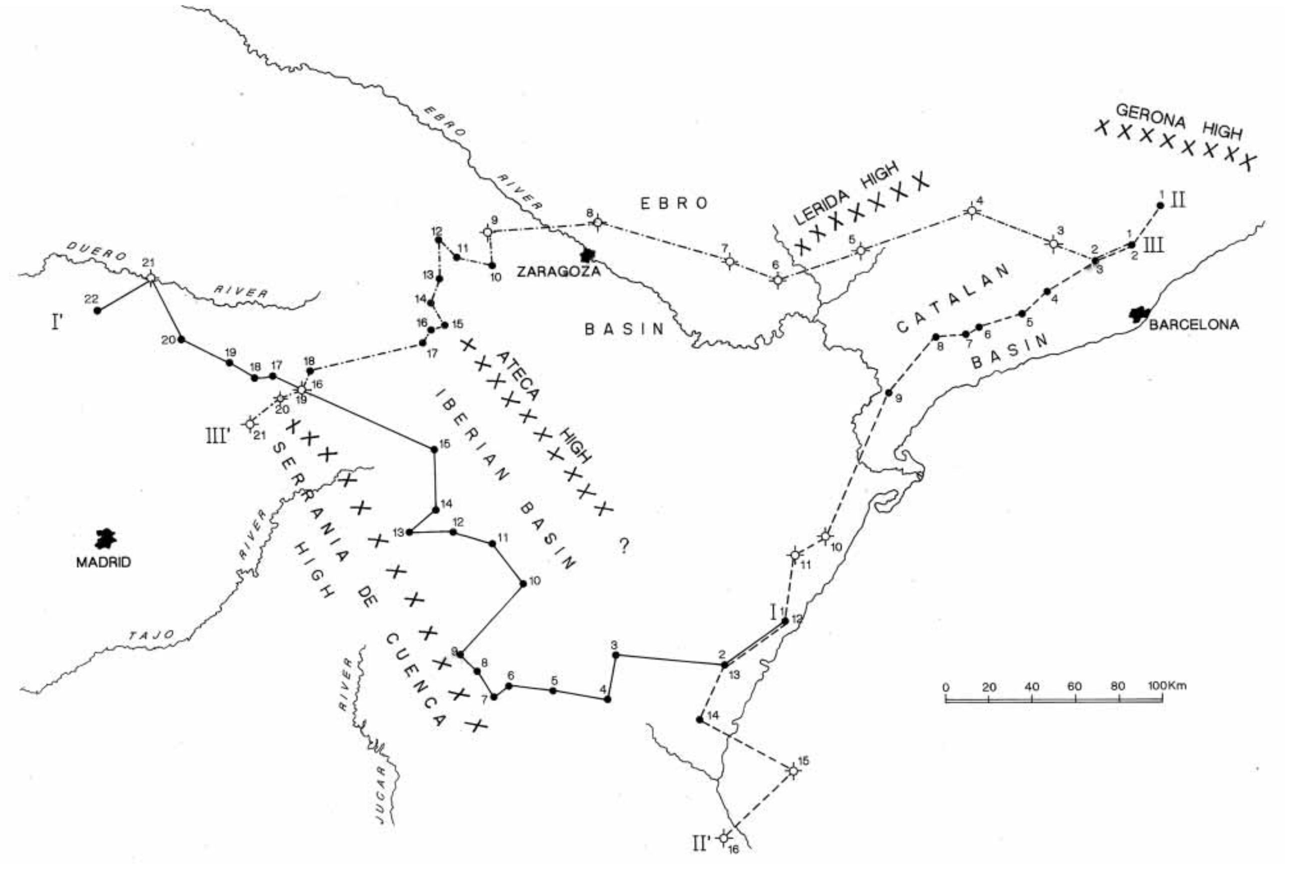

FIGURE 2 **Localities, Paleozoic highs, Permian-Triassic basins and correlation lines. Black dots: field sections; open dots with cross: boreholes.**

the Permian-Triassic Catalan Basin crops out. The eastern margin of this basin lies far to the east and is not well defined up to now.

In this paper we try to summarize the lithostratigraphy of the siliciclastic, usually red beds, described in the Iberian Ranges, Central and Eastern Ebro Basin and the Catalan Ranges, to review the available biostratigraphic evidence, to subdivide the sedimentary record by means of unconformities and hiatuses and, finally, to propose a correlation for the formations in the study area.

THE PERMIAN-TRIASSIC SILICICLASTIC UNITS OF THE IBERIA, EBRO AND CATALAN BASINS

From the wealth of available data, we have selected 59 field sections and borehole logs for this study (Fig. 2), but many others could have been selected in these or surrounding areas.

The limitations of classical terminology, i.e., Buntsandstein, Muschelkalk and Keuper were obvious since the first modern studies (see Virgili, 1979), as lateral changes of facies between shallow marine carbonates and siliciclastics became obvious after accurate datations and field mapping became available (Sopeña et al., 1988). These shallow marine and evaporitic facies will be described briefly in this chapter in order to clarify its age and position.

On the other hand, it is misleading and erroneous to use the classic terms where no carbonates of Anisian or Ladinian age exist, that is, in the Hesperian Realm (López-Gomez et al., 1998), or where only the upper carbonate level exists (Iberian Realm) and it is not clearly established if the lower carbonate level has disappeared pinching out against the basement or there is a lateral change of facies into coastal siliciclastics.

The base of the dolomitic Imón Formation (Goy et al., 1976; Arnal et al., 2002) is the top of the time interval studied in this paper and the Hercynian basement is the base of sections and logs.

In spite of the previous reserves, the main lithostratigraphic units used here can be associated in the following divisions:

Autunian facies

Continental deposits of igneous and/or sedimentary origin found at the base of the Alpine cycle lying unconformably on the Hercynian basement in the Iberian and Ebro Basins and of much more restricted geographic extension and problematic age in the Catalan Basin.

It consists of volcanic and volcanoclastic andesites, associated dykes and sills and grey mudstones, sandstones and dolomites (De la Peña et al., 1977; Hernando, 1977; Ramos, 1979; Sopeña, 1979).

Coeval basins contain red-bed successions more than 700 m thick (Sopeña, 1979) or only 20-40 m of red breccias (López-Gómez and Arche, 1993).

“Saxonian” facies

A loose term applied to unconformity-bounded Late Permian red, continental deposits found in the study area and the Pyrenees-Cantabrian zone. It consists of red mudstones, conglomerates and sandstones, with some well-developed caliche profiles (López-Gómez et al., 2002).

Buntsandstein (*sensu estricto*) facies

This term should be restricted to continental and coastal siliciclastic sediments of Late Permian to Early Triassic age (Sopeña et al., 1988; Arche and López-Gómez, 1996; López-Gómez and Arche, 1993; Calvet and Marzo, 1994). It consists of two sedimentary cycles separated by a hiatus, with conglomerates, sandstones and mudstones.

Muschelkalk facies

The classic Muschelkalk facies consists of two carbonate units separated by a mudstone-evaporite unit (López-Gómez et al., 1998), interpreted as two transgressive-regressive cycles. Along the present-day Mediterranean coast of Valencia-Murcia and probably in most of the Prebetic and Subbetic realms only a single carbonate unit is found as the intermediate mudstones and evaporites pass laterally into shallow-water, open marine carbonate

Towards the West, in the present-day Iberian Ranges, the carbonate units either pinch out against the basement or pass laterally into siliciclastic units (López-Gómez et al., 1998) a fact that has caused a lot of confusion in the correlation and nomenclature of the units.

In the Catalan Basin, a wedge of red fluvial sandstones is found in the upper part of the Middle Muschelkalk (Castelltort, 1986).

Keuper facies

It consists of two major evaporite, mudstones and dolomite cycles; in both the Catalan (Salvany and Ortí, 1987; Salvany, 1986, 1990) and the Iberian Ranges (Ortí, 1974; Sopeña, 1979), the cycles are grey and red in colour from bottom to top respectively, with a sharp, conformable contact. In the Ebro Basin (Jurado, 1988), the lower and upper cycles are separated by a red clay interval and in the Levantine area and most of the Prebetic area a prominent sandstone unit, the Manuel Formation (Ortí, 1974, 1990; Ortí and Pérez-López, 1994) separates two evaporitic cycles.

It is very important to stress that identical facies can be found from the Early Permian to the Late Triassic and that correlations can be problematic in the absence of marine carbonates or/and the absence of precise dating.

LITHOSTRATIGRAPHICAL NOMENCLATURE AND SUBDIVISIONS

The subdivision of the siliciclastic Permian-Triassic sediments into formations is now well established in the study area, as well as the existence of three angular unconformities and/or hiatuses inside them. It is also very important to stress that identical facies can be found from the Early Permian to the Late Triassic and that correlations can be problematic in the absence of marine carbonates or/and the absence of precise dating. Very extensive literature on these subdivisions is reviewed in Sopeña et al. (1988), Calvet and Marzo (1994) and López-Gómez et al. (1998, 2002). On the other hand, the analysis of the major breaks in the sedimentary record, that is, of unconformities and hiatuses, combined with refined biostratigraphic data, discussed in the next chapter, allow for a more detailed correlation than before.

Most of the lithostratigraphic units within the formation category (formally defined or not) in Central and NE Iberia are reviewed here as a background to the proposed correlations presented in this paper.

Iberian Ranges

The present-day Iberian Ranges can be subdivided in two units: the Castilian Branch to the SW and the Aragonese Branch to the NE. In this paper we deal with the area between Segovia-Soria and the Mediterranean coastline (Fig. 1).

During the Permian and part of the Triassic a longitudinal Paleozoic high (Ateca High, Figures 1B and 2) separated the Iberian Basin to the SW from the Ebro Basin to the NE. Its boundary to the SE is still a matter of debate. Another, ill-defined Paleozoic high, the Serranía de Cuenca High, bounded the Iberian basin to the SW, as exposed in the Torremocha borehole (Fig. 2, III-III´ number 20; Fig. 5, number 20).

The structural framework of the Iberian Basin also includes two prominent transversal highs: The Cercadillo and the Orea-Cueva de Hierro Highs. The origin and evolution of the Iberian Basin, the dynamics of its basin boundary faults and associated transfer fault systems and a quantification of the subsidence rates during the syn-rift and post-rift phases are reviewed in Arche and López-Gómez (1996, 1999) and Vargas et al. (2004). Seven major sedimentary cycles represent these sediments:

First major sedimentary cycle

The oldest sediments, of Early Permian age, were deposited in a series of isolated half-graben basins from Noviales to Chóvar-Eslida (Fig. 3) (Hernando, 1977; Ramos, 1979; Sopeña, 1979; Pérez-Arlucea and Sopeña, 1985; López-Gómez and Arche, 1994).

In the NW part, Hernando (1977, 1980) describes a succession, from base to top, composed by: La Castellana andesites, La Castellana siltstones, Cañamares andesites, and Peña Blanca siltstones and sandstones (P1 cycle), conformably overlain by the Alpedroches siltstones and conglomerates (P2 cycle). The P1 cycle is probably equivalent in origin and age to the Valdesotos, Retiendas and Pálmaces formations of Sopeña (1979, 1980) not represented in Fig. 3.

In the Molina de Aragón area (Fig. 3), a succession of volcaniclastic deposits, variegated siltstones and dolomites and grey-black siltstones (Ermita Fm, Ramos, 1979) is found unconformably lying on the Hercynian basement.

Beyond the Orea-Cueva de Hierro High, several outcrops of volcanic-volcanoclastics rocks are found scattered along the basin: the Basal Volcanic Complex (Pérez-Arlucea, 1987; Pérez-Arlucea and Sopeña, 1985) and red breccias (Tabarreña Breccias Fm, López-Gómez and Arche, 1994).

The Minas de Henarejos outcrop contains coal measures and grey sandstones and siltstones with a rich flora of reputed Stephanian C age (Meléndez et al., 1983).

The Early Permian deposits always lie unconformably on the Hercynian basement and are unconformably overlain by the Late Permian-Early Triassic sediments.

Second major sedimentary cycle

It starts with red conglomerates and siltstones, not always present in the study area (Saxonian facies). They lie unconformably on the Hercynian basement or the Autunian deposits and are unconformably covered by the Buntsadstein, *sensu stricto*, facies.

The Saxonian facies in the NW area consists of siltstones, sandstones and conglomerates (Cañamares Fm, P3, Hernando, 1977, 1980). In the central area (Fig. 3) a red siltstone and sandstone succession (Montesoro Fm, Ramos, 1979, 1980), lies unconformably on the Ermita Fm In the SE area, massive red conglomerates (Boniches Fm) are overlain by red siltstones, sandstones and conglomerates (Tormón and Alcotas Fms, Pérez-Arlucea and Sopeña, 1985; Arche et al., 1983; López-Gómez, 1985; López-Gómez and Arche, 1993).

Third and fourth sedimentary cycles

The Buntsandstein, *sensu stricto*, facies record the opening of the Iberian Basin to the Tethys sea. Two superimposed cycles can be separated by a hiatus: a lower one, composed by laterally restricted conglomerates and widespread sandstones (Río Pedro Conglomerates Fm (T1.1) and Río Pedro Sandstones Fm (T1.2), Riba de Santiuste Conglomerates and Riba de Santiuste Sandstones Fms, Hoz de Gallo Conglomerates Fm and Rillo de Gallo Fms and Cañizar Sandstones Fm (Hernando, 1977, 1980; Ramos, 1979; Sopeña, 1979; López-Gómez, 1985; García-Gil, 1990), and an upper one of irregular lateral distribution including the Termancia Conglomerates Fm (T1.3) and the Termancia Sandstones Fm (T1.4), the Arandilla and Prados Fms and the Eslida Sandstones and Siltstones Fms (Fig. 3).

Fifth to seventh sedimentary cycles

Above the four sedimentary cycles, siliciclastic sediments are found to the NW of Molina de Aragón, but the term Buntsandstein should not be applied to these sediments in absence of the Muschelkalk facies. The lower carbonates of this facies (M-1), of Anisian age (Landete and Albarracín Fms) pass laterally into the Rillo de Gallo Fm (Pérez-Arlucea, 1985) while the upper carbonates (M-3) (Cañete, Tramacastilla and Royuela Fms) pass laterally into the Cuesta del Castillo Sandstones Fm. (García-Gil, 1990, 1994). The intermediate (M-2) marls and evaporates unit (El Mas, Torete and Tramacastilla Sandstones and Siltstones Fms) pass laterally into the Carrascosa Siltstones Fm (Hernando, 1977, 1980).

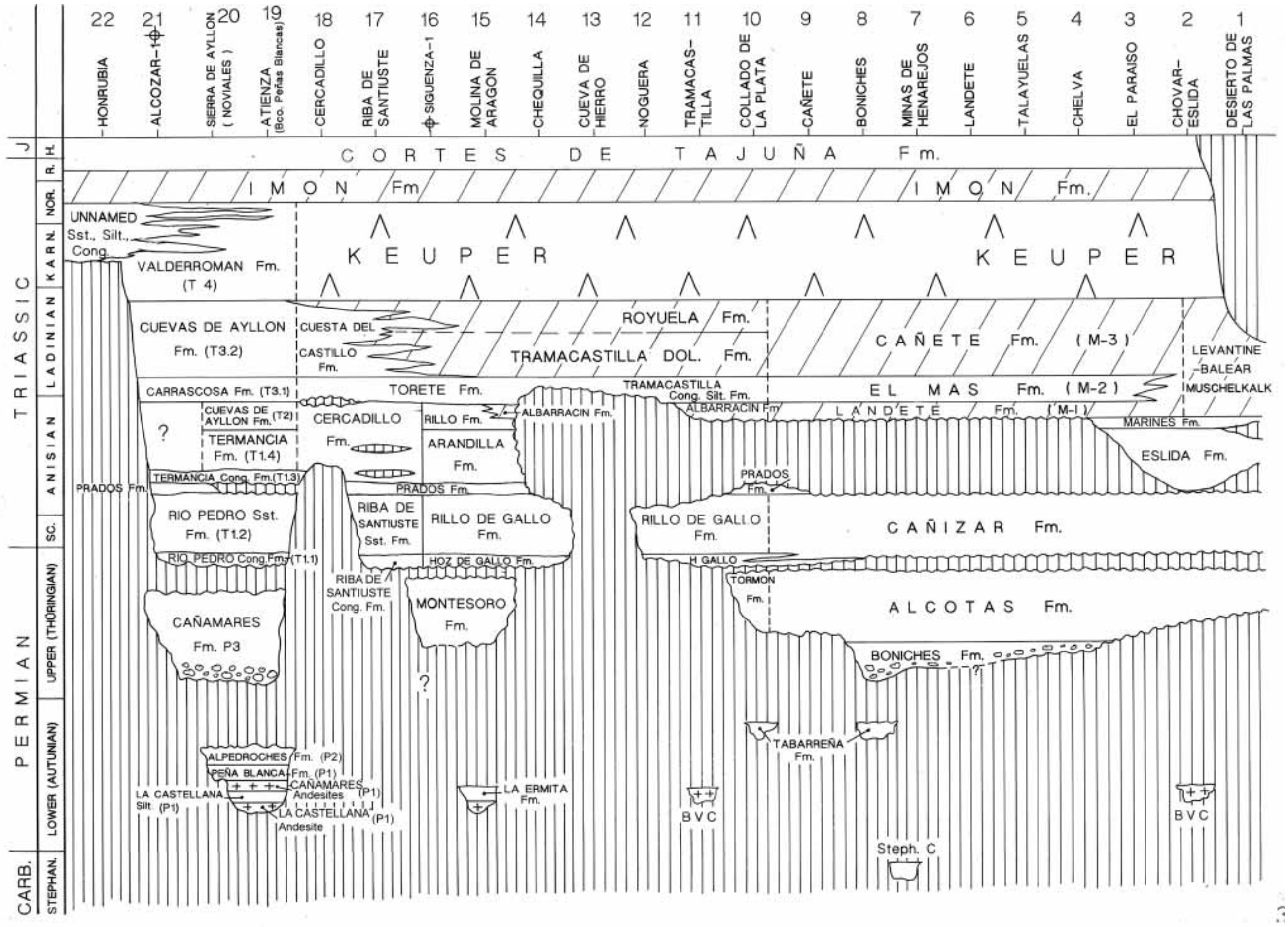

FIGURE 3 **Correlation line I-I´ along the Iberian Ranges and part of the Central System. Data from the following sources: 1 to 9, López-Gómez and Arche, 1993, 1994; 10, De las Llanderas, 1984; 11, 12 and 14, Pérez-Arlucea, 1987; 13, López-Gómez, 1985; 15, Ramos, 1979; 16 and 21, IGME, 1987; 17 and 18, García-Gil, 1994; 19 and 20, Hernando, 1977; 22, Vázquez, 1981.**

Finally, an unnamed siliciclastic unit is found in the NW margin of the Iberian Basin that pass laterally into the Keuper facies from Honrubia to Ayllón (Hernando, 1980; Vázquez, 1981).

Catalan Ranges

The siliciclastic deposits of Permian-Triassic age of this area can be subdivided into three domains (Fig. 4): Montseny-Llobregat, Garraf and Miramar-Prades-Priorat (Marzo, 1980; Calvet and Marzo, 1994). The Catalan Permian-Triassic Basin was partially bounded by the Paleozoic Gerona and Lérida Highs (Figs. 1B and 2).

Unnamed basal breccias are found locally in the first and third domains, lying unconformably on the Hercynian basement and are overlain by the Riera de Sant Jaume and Bellmunt Conglomerates units (Fig. 4). In the type sections, the conglomerates are conformably overlain by alternating red mudstones and sandstones, the Riera de Sant Jaume and Bellmunt units (pro parte) and the Brugers unit, but their lateral extension are limited.

A new sedimentary cycle, found all along the Catalan Ranges, starts in sharp contact with the Hercynian basement, the breccias or the Bellmunt, Brugers or Riera de Sant Jaume units. It consists of conglomerates (Prades and Caldes Conglomerates formations, F. 4), overlain by pink sandstones (Prades, Eramprunyá and Caldes Sandstones formations).

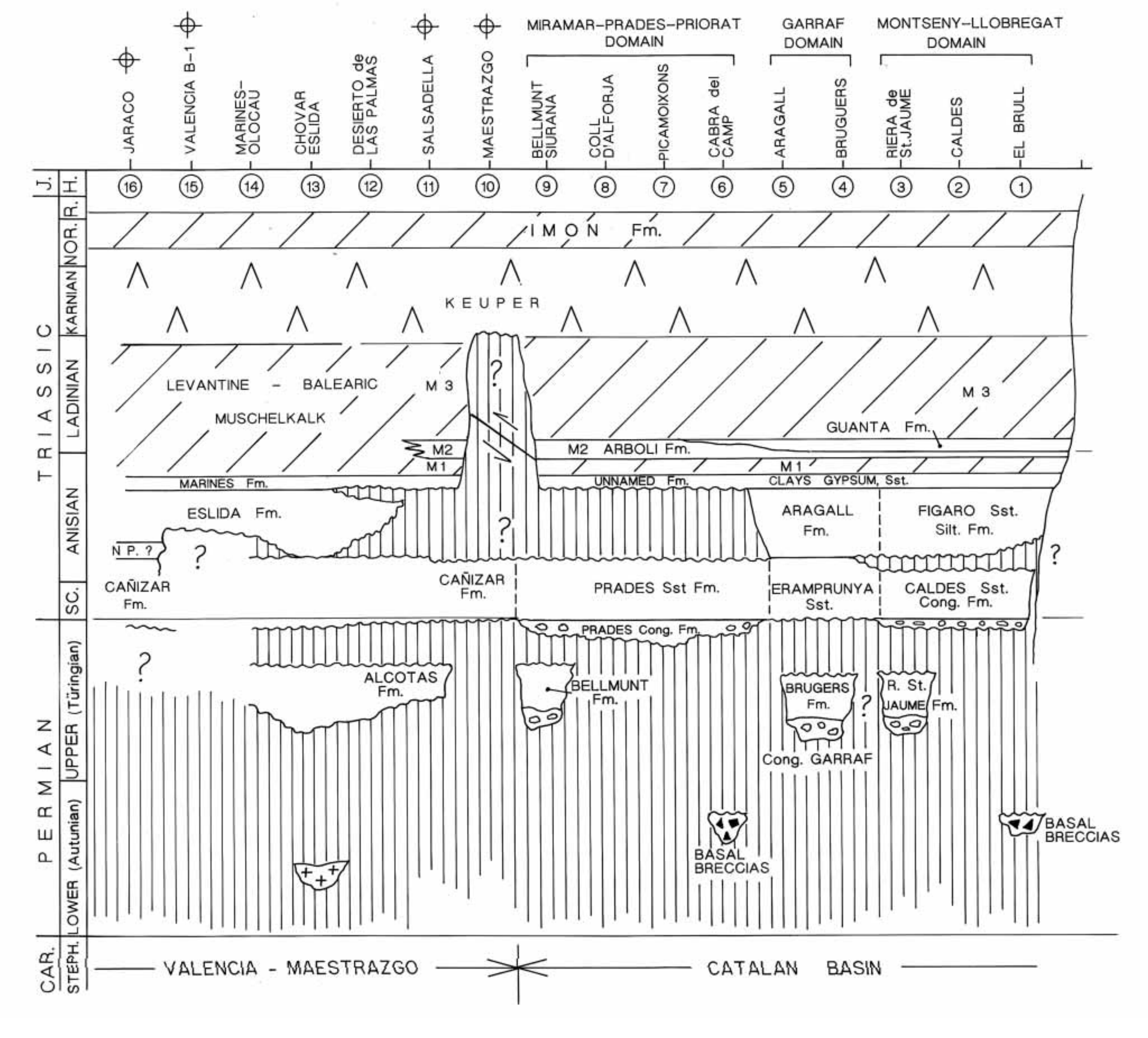

FIGURE 4 **Correlation line II-II´along the Catalan Ranges and the Valencia-Maestrazgo area. Sources of the data: 1 to 9, Marzo, 1980 and Calvet and Marzo, 1994; 10, 11, 15 and 16, IGME, 1987; 12 to 14, López-Gómez and Arche, 1993, 1994.**

Finally, a thick, complex alternations of red mudstones and sandstones (Figaró and Aragall units) are found in the first and second paleogeographic domains but is absent in the third domain, where a well developed paleosoil marks the top of the Prades units.

The shallow-marine siliciclastic and evaporitic Röt Facies cap the sequences all over the Catalan Ranges (Marzo, 1980).There is a siliciclastic level in the middle Muschelkalk facies (M-2) of the two northern domains (Guanta Sandstone Fms, Castelltort, 1986), that passes laterally into shallow marine mudstones and evaporites to the SW (Arbolí unit).

Ebro Basin

The Ebro Basin was separated from the Iberian Basin during the Permian and the Early Triassic by the Paleozoic Ateca High (Fig. 2).

The deposits of Permian-Triassic age are exposed only along the Aragonese Branch of the Iberian Ranges (Arribas 1984, 1985; Arribas et al., 1985; Rey and Ramos, 1991); much of the information should be obtained from commercial oil boreholes that penetrate the Tertiary cover (Jurado, 1988, 1990).

From base to top (Fig. 5), the following deposits have been described:

Autunian Facies

Isolated outcrops of volcanic and volcaniclastic rocks and associated grey mudstones are found from Reznos (Zaragoza) to Montalban (Teruel), along the SW margin of the Ebro Basin (De la Peña et al., 1977; Del Olmo et al., 1983; Conte et al., 1987; Rey and Ramos, 1991; Lago et al., 2002). They have been termed Arroyo Riduero Fm in the Reznos area (Rey and Ramos, 1991). More than 200 meters of quartzitic conglomerates of unknown age are found unconformably lying on the Hercynian basement in the Paniza section (Fig. 5, number 15).

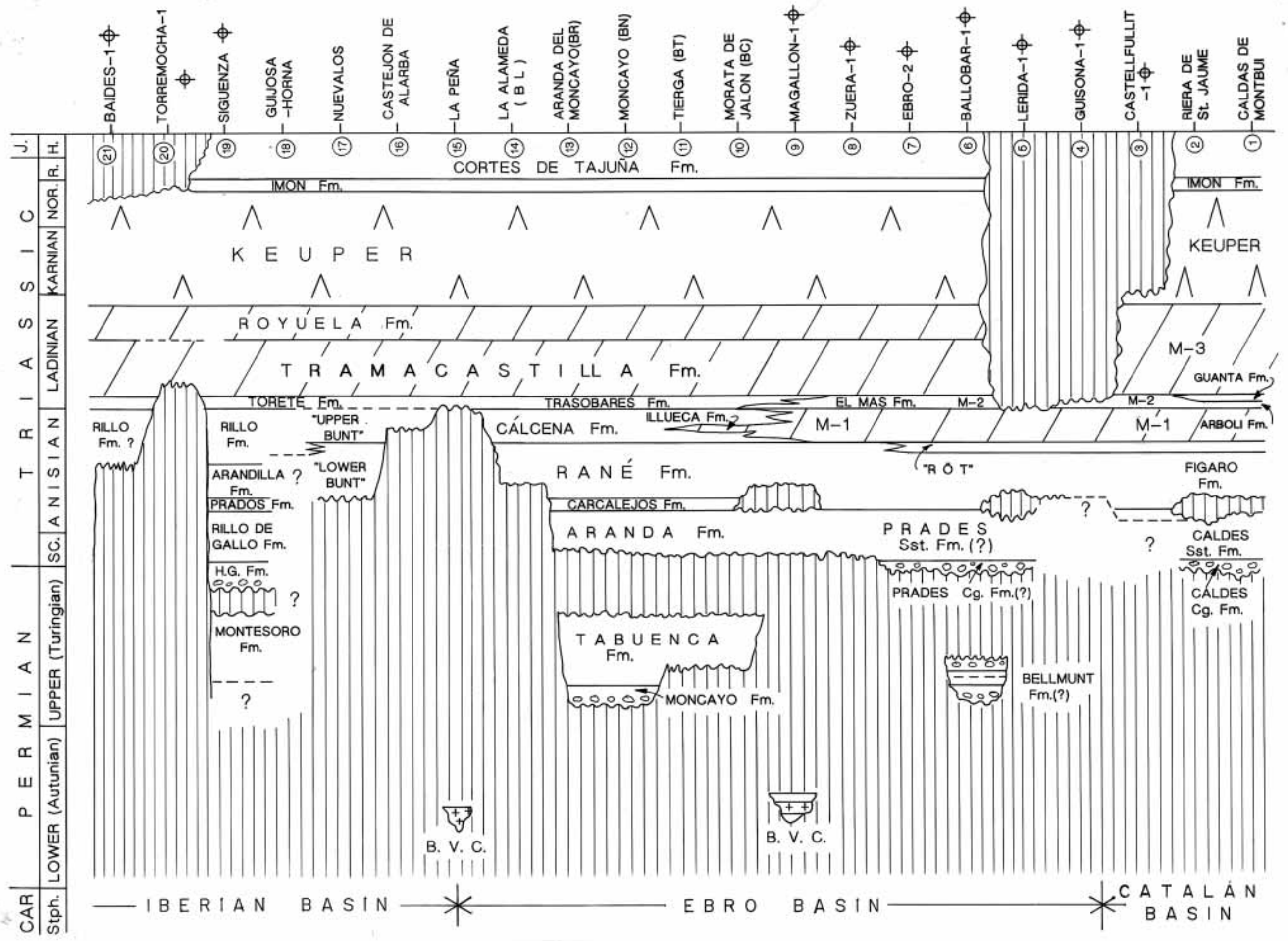

FIGURE 5 **Correlation line III-III´ along the Catalan Ranges, the Ebro Basin and the Iberian Ranges: Sources of the data: 1 and 2, Marzo, 1980; 3 to 9, IGME, 1987 and Jurado, 1988; 10 to 14, Arribas, 1984, 1985; 15 to 17, García-Royo and Arche, 1987; 17 and 18, García-Gil, 1994; 19 to 21, IGME, 1987.**

Saxonian Facies

An unconformity-bounded cycle of sediments is described by Arribas (1984, 1985) as the Araviana Unit, subdivided into the Moncayo Conglomerates Fm and the Tabuenca Mudstones and Sandstones Fm (Fig. 5).

Buntsandstein (sensu stricto) Facies

Above a probably angular unconformity, the Tierga unit of Arribas (1984, 1985), is subdivided by the author into the Aranda Sandstone Fm, the Carcalejos Mudstone Fm and the Rané Mudstones and Sandstones Fm. In some sections the middle unit is missing, and a hiatus separates the lower and the upper unit (i.e., in the Morata de Jalón section, Figs. 5 to 7).

Younger siliciclastic units

Above these formations lies conformably the Cálcena Mudstones and Sandstones Fm It is very interesting to point out that, to the NE, a dolomitic unit termed the Illueca Dolomite Fm (Arribas, 1984, 1985) is found in the middle part of the Cálcena Fm, and can be traced into Lower Muschelkalk facies to the E and the NE. The siliciclastic Trasobares Mudstones Fm is found conformably lying on the Cálcena Fm

BIOSTRATIGRAPHY AND ABSOLUTE AGES

Most of the siliciclastic formations described in the previous chapter have been dated by means of pollen and spore assemblages that will be described in a condensed way. For complete revisions of the palynological data see Boulouard and Viallard (1982); Arche et al. (1983); Doubinger et al. (1990); Díez et al. (1994); Sopeña et al. (1995) and López-Gómez et al. (2002).

Iberian Basin

The main results of palynological research in this area are summarised in Table 1. It is important to point out that more than thirty localities have yielded palynofloras of stratigraphic interest, one of the richest areas of Western Europe.

Every sedimentary cycle has been dated, and former controversies about the correlation of the second described cycle, for example, have been solved after the findings of Temiño (1982), and Pérez-Arlucea (1985), as summarised in Sopeña et al. (1988, 1995) and López-Gómez et al. (2002).

The absolute age of the Autunian rocks is also well constrained now. The andesiteic rocks of the Atienza outcrop have been dated as 282±12M.a. (Hernando et al., 1980) (whole rock, K/Ar method), the Fombuena andesitic rocks, as 283±2.5 M.a. (biotite, K/Ar method). Both outcrops are situated on the Ateca Paleozoic High. The andesitic rocks in the Tramacastilla-Orea area are dated as 292±4 M.a. (biotite, K/Ar method) (Conte et al., 1987; Lago et al., 1991, 1996, 2002).

Catalan and Ebro Basins

As for the Iberian Basin, the main palynological results for these two basins are summarised in Table 2. More detailed list of palynomorphs and discussions about their biostratigraphic significance can be found in Visscher (1967); De la Peña et al. (1977); Solé de Porta and Torrentó (1985); Solé de Porta et al. (1987); Marzo and Calvet (1985); Rey and Ramos (1991); Calvet and Marzo (1994) and Díez et al. (1994). Up to now, the palynological record of these areas is not as rich as in the Iberian Ranges, in sharp contrast with the marine faunas in the marine carbonates, that are more abundant and varied in the Catalan Ranges.

Data for the Ebro Basin come from outcrops along the Aragonian Branch of the Iberian Ranges, as no subsurface data are available.

REGIONAL UNCONFORMITIES AND HIATUSES

A powerful correlation tool to be combined with lithostratigraphic and biostratigraphic data is the analysis of angular unconformities and hiatuses that subdivide the sedimentary record into unconformity-bounded units.

The basal unconformity of the series is not always of the same age, as sediments from Early Permian to Late Triassic age can lie unconformably on the hercynian basement, and therefore should be discarded as correlation tool (Figs. 3, 4 and 5).

Two angular unconformities, one separating the first and second cycle (Early Permian-Late Permian) and another separating the second and the third cycle (intra Late Permian) can be found all along the study area (Figs. 3, 4 and 5), and should correspond to regional tectonics events, not local, as they are found in areas more than 600 Km apart.

As the sedimentary formations in between are dated in some localities, its equivalent position in the different areas can support the attribution of certain ages to undated deposits in other areas; for example, most of the lower part of the red-bed succession in the Catalan Basin, like the Basal Breccias on the Riera de Sant Jaume, Brugers and Bellmunt Fms, are in identical position than the Ermita, Tabarreña, Boniches and Alcotas Fms, and a similar age

TABLE 1 | **Summary of the main results of the Permian and Triassic palynological research in the Iberian Ranges.**

Unit/facies	Palynological content	Age	References
Ermita Fm	*Potonieisporites novices* *Vittatina costabilis* *Pytiosporites westfaliensis*	Autunian (Early Permian)	Doubinger et al., 1977 Ramos, 1979
Retiendas Fm	*Potonieisporites novices* *Vittatina costabilis*	Autunian (Early Permian)	Sopeña, 1979
"Saxonian" facies	*Lueckisporites virkkiae* *Nuskoisporites dulhuntyi* *Falcisporites schaubergeri*	Thuringian (Late Permian)	Boulouard and Viallard, 1971
Cañizar Fm	*Allisporites toralis* *Triadispora staplini*	early Anisian (Middle Triassic)	Doubinger et al., 1990
Rillo de Gallo Fm	*Hexaccites muelleri* *Triadispora falcata* *Allisporites cf. grauvogeli*	upper Anisian-lower Ladinian (Middle Triassic)	Ramos, 1979
Marines Fm	*Allisporites cordiformis* *Illinites chitinoides* *Leiotriletes sp.*	Anisian (Middle Triassic)	Doubinger et al., 1990
Cuevas de Ayllón Fm	*Paracirculina tenebrosa* *Praecirculina granifer* *Duplicisporites granulatus*	Karnian (Upper Triassic)	Hernando, 1977, 1980
Imón-Cortes de Tajuña Fm	*Classopollis classoides* *Circulina meyeriana* *Circulina granulata* *Convavisporites torus*	Hettangian (Lower Jurassic)	Vázquez, 1981

can be assumed until biostratigraphic data prove or falsifie this hypothesis.

Similarly, the unconformity bounded cycle composed by the Moncayo and Tabuenca Fms in the SW Ebro Basin can be easily correlated with the identically positioned Boniches and Alcotas Fms in the SE Iberian Basin and the Tormón and Montesoro Fms in the NW Iberian Basin.

A third key structure is the hiatus developed on top of the prominent sandstone formation of Late Permian-Early Triassic age that crops out all along the study area, known as Cañizar, Prades, Aranda or Rillo de Gallo (among other names) Fms Bleached horizons, soil profiles and iron-rich crusts are found at the top of the sandstones and represent a short break in sedimentation with subaerial exposure of regional, not local extension (Figs. 3, 4 and 5), between the third and fourth sedimentary cycles of early Anisian age.

In this way, the sedimentary record can be subdivided in four parts, facilitating the analysis and correlations.

A PROPOSAL FOR CORRELATION

The analysis of the previous set of data show that there are two sound criteria for correlation of these siliciclastic deposits: biostratigaphic data and regional unconformities and hiatuses.

Other promising tools to be fully developed are magnetostratigraphy, clay mineralogy and sandstone petrology, but more work on these fields is needed before they can be used with an acceptable degree of precision.

The first depositional cycle

It consists of local deposits only a few kilometres or less in lateral extension lying unconformably on the Hercynian basement and always covered unconformably by younger sediments.

In the Iberian Basin and the SW margin of the Ebro Basin there are volcanic and volcaniclastic rocks at the beginning of this cycle: the La Castellana and Cañamares

TABLE 2 | **Summary of the main results of the Permian and Triassic palynological research in the Catalan Coastal Ranges and Ebro Basin.**

CATALAN BASIN

Unit/facies	Palynological content	Age	References
Figaró Fm	*Lundbladispora sp.* *Cycadophytes sp.*	Anisian (Middle Triassic)	Marzo and Calvet, 1985 Calvet and Marzo, 1994
“Mudstone-evaporite complex”	*Voltziaesporites heteromorpha* *Stellapollenites thiergarti* *Triadispora crassa*	low-mid. Anisian (Middle Triassic)	Marzo and Calvet, 1985 Calvet and Marzo, 1994

EBRO BASIN

Unit/facies	Palynological content	Age	References
“Grey mudstones of Reznos”	*Callipteris conferta* *Cathaysiopteris whitney* *Lebachia piniformis* *Umbellaphyllites annularioides*	Autunian (Early Permian)	De la Peña et al., 1977 Rey and Ramos, 1991
Cálcena Fm	*Allisporites sp.* *Triadispora crassa* *Triadispora staplini* *Voltziaesporites heteromorpha*	late Anisian (Middle Triassic)	Díez et al., 1994
Trasobares Fm	*Hexasaccites muelleri* *Paracirculina granifer* *Voltziaesporites heteromorpha*	late Anisian (Middle Triassic)	Díez et al., 1994

Andesites (Fig. 3 numbers 19 and 20), the lower La Ermita Fm (Fig. 3 number 15) and the Basal Volcanic Complex (Fig. 3, number 11; Fig. 4, number 13; Fig. 5, numbers 9 and 15); they are usually covered conformably by grey or red sediments or they do not exist in other parts of the Basins and red breccias represent this cycle (Tabarreña Breccias Fm) (Fig. 3, numbers 8 and 10; Fig. 4, numbers 1 and 6; Fig. 5, number 9). This cycle is of Early Permian (Autunian) age.

The second depositional cycle

This cycle is also unconformity-bounded, more extensive than the previous one and totally devoid of volcanic rocks. The unconformities were recognized at the beginning of the modern studies of the area (Sopeña et al., 1988; Virgili et al., 1976) that probably correspond to the Saalian and Pfalzic unconformities of Western Europe. This second cycle of Late Permian (Thüringian) age consists of red beds denominated “Saxonian” facies and is present all over the study area. It can begin with conglomerates such as the Boniches Conglomerates (Fig. 3, numbers 4 to 8), the upper Cañamares Conglomerates (Fig. 3, numbers 19 and 20), the Riera de Sant Jaume, Garraf and Bellmunt Conglomerates (Fig. 4, numbers 3, 4, 5 and 9) and the Moncayo Conglomerates (Fig. 5, numbers 12 and 13). They are conformably overlain by a characteristic red mudstone-sandstone association: the Cañamares Fm (Fig. 3, numbers 20 and 21), the Montesoro Fm (Fig. 3, numbers 15 and 16), the Alcotas and Tormón Fms (Fig. 3, numbers 1 to 11), the Riera de Sant Jaume, Brugers and Bellmunt Fms (Fig. 4, numbers 3, 4, 5 and 9) and the Tabuenca Fm (Fig. 5, numbers 10 to 13). Well-developed soils are found at the top of this cycle in the Montseny-Llobregat domain of the Catalan Ranges (Marzo, 1980; Calvet and Marzo, 1994) and in the Boniches-Minas de Henarejos area of the Iberian Ranges (López-Gómez and Arche, 1994). An angular unconformity is found at the top of the cycle from Molina de Aragón to the NW in the Iberian Ranges (Ramos, 1979; Sopeña, 1979). In addition, petrographic composition of sandstones (sublithoarenites) differs drastically from sandstones (arkoses) of the above cycle in the Aragonese Branch of the Iberian Ranges (Arribas, 1985).

The third depositional cycle

This cycle is remarkably homogeneous all over the study area, and the sandstone formation at its top is a prominent feature of the landscape (and the boreholes) known as the “Rodeno” sandstone. The laterally discontinuous conglomerates at the base are: the Río Pedro, Riba de Santiuste and Hoz de Gallo Fms in the Iberian Ranges (Fig. 3, numbers 15 to 17, 19 and 20), the Prades and Caldes unitsin the Catalan Ranges (Fig. 4, numbers 1, 2, 6 to 10) and an unnamed conglomeratic unit in the Ebro Basin (Fig. 5, numbers 6 and 7) probably equivalent to the Prades Conglomerates of the Catalan Ranges. The Hoz de Gallo Fm pass laterally into the base of the overlying Cañizar Formation between the Collado de la Plata and Cañete sections (Fig. 3, numbers 9 and 10). The bulk of the third cycle consists of pink to red sandstones of arkosic composition, not sublithoarenitic as in the two previous cycles, consisting of amalgamated sequences of braided systems fluvial origin almost devoid of fines. Its age, homogeneous composition and internal structures allow for a sure correlation as a marker horizon all over the studied basins. They are the Río Pedro, Riba de Santiuste, Rillo de Gallo and Cañizar Fms in the Iberian Basin (Fig. 3, numbers 1 to 13, 15 to 17 and 19 to 21), the Prades, Caldes and Eramprunyá Fms in the Catalan Basin (Fig. 4, numbers 1 to 8; Fig. 5, numbers 1 to 8) and the Aranda Fm in the Ebro Basin (Fig. 4, numbers 8 to 13).

The fourth depositional cycle

This cycle usually lies on the top of the Cañizar Fm or equivalent sandstones by means of a hyatus, but its lateral extension is limited. In some cases, however, a sharp but normal contact is found at the base; in this case, mudstones and sandstones (Prados Formation) is found at the base of the cycle (Fig. 3, numbers 10, 15 to 21). In the Ebro Basin, the equivalent deposit is the Carcalejos Formation (Fig. 4, numbers 11 to 13) that probably is present in some boreholes (Fig. 4, numbers 3, 6 to 8).

Above these deposits, a complex and sometimes very thick alluvial succession is found in the Iberian Basin: the Termancia, Arandilla, Cercadillo and Eslida Fms, even with conglomerates at the base (Fig. 3, numbers 15 to 21). In the Ebro Basin the Rané Fm (Figure 4, numbers 5 to 14) is found all along the basin and correlates with the Figaró and Aragall units of the Catalan Basin (Fig. 5, numbers 1 to 4). The fourth cycle is absent in large parts of the Iberian Basin (Fig. 3, numbers 4 to 14), the Catalan Basin (Fig. 5, numbers 5 to 11) and some areas of the Ebro Basin (Fig. 4, numbers 9 and 10).

The fifth depositional cycle

This cycle is related to the lateral change of facies or pinch-out of the carbonates of the first transgressive cycle of the Neotethys on the Iberian Microplate. Sometimes a lateral passage can be observed on the sections: in the Molina de Aragón area (Fig. 3, number 15) or in the SW margin of the Ebro Basin, in the Tierga and Morata de Jalón area (Fig. 4, numbers 10 and 11), but in many other places a hyatus is found at the base of the cycle. Where the lateral change is well documented, the Marines (Röt) Fm and the carbonate Landete-Albarracín (M-1) Fm pass laterally into the siliciclastic Rillo, Cercadillo and Cuevas de Ayllón Fms (Fig. 3, numbers 15 to 21). In the Ebro Basin, the passage is made between the carbonate Illueca Fm (M-1) to the siliciclastic Cálcena Fm (Fig. 4, numbers 9 to 14).

The sixth depositional cycle

This cycle is, again, related to the lateral change of the shallow marine siliciclastic El Mas and Tramacastilla (M-2) Fms and the carbonate Cañete (M-3), Tramacastilla and Royuela (M-2) Fms into the Cuesta del Castillo and Cuevas del Castillo Fms (Fig. 3, numbers 15 to 21).

The seventh depositional cycle

Finally, this siliciclastic cycle is found in the NW part of the Iberian Basin, where the evaporite-mudstone Keu-

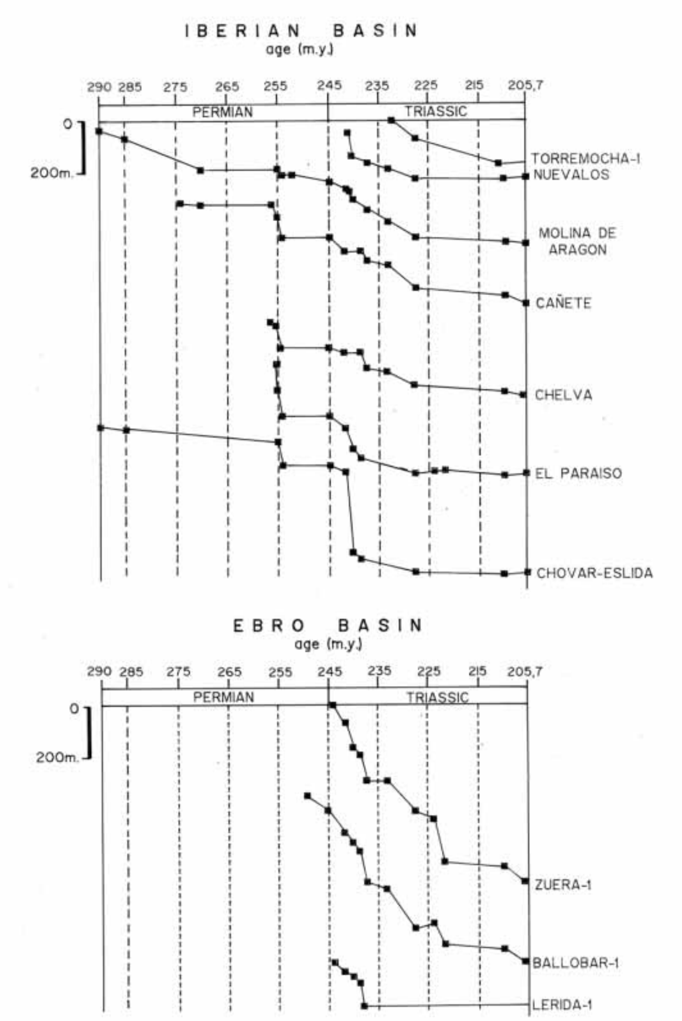

FIGURE 6 **Backstripping curves for the Permian-Triassic interval calculated for some Iberian and Ebro Basins sections. From Vargas, 2002, and Vargas et al., 2004.**

per facies pass laterally into red sandstones and conglomerates, unnamed up to now, of alluvial fan origin (Fig. 3, numbers 21 and 22).

BASIN EVOLUTION AND CONTROLS ON THE SILICICLASTIC SEDIMENTATION

The sedimentation, lateral extension and sedimentology of the deposits studied in this paper are the result of the interaction of structural, climatic and eustatic processes taking place during the Permian-Triassic interval. Only the structural aspects will be briefly reviewed here.

The post-Hercynian history of the Iberian, Ebro and Catalan Basins is linked to an extensional regime related to the opening and closure of the Tethys and Atlantic oceans (Vegas and Banda, 1982; Sopeña et al., 1988; Van Wees et al., 1998; Ziegler and Stampflyi, 2001; Vargas, 2002).

One of the most synthetic and powerful tools for subsidence analysis in a sedimentary basin is the backstripping technique (Jarvis and McKenzie, 1980; Royden and Keen, 1980; Steckler and Watts, 1978), applied in the study area by Álvaro (1987), Sánchez-Moya et al. (1992) and Arche and López-Gómez (1996) among others.

Improved biostratigraphic data and backstripping computer programs allow for a more precise analysis of the syn- and post-rift phases during the Permian-Triassic extensional processes (Vargas, 2002; Vargas et al., 2004) and the decoupling of syn- and post-rift phases in more detail than the previous analysis. The results are presented in Figs. 6 and 7 for selected sections and boreholes of the Iberian and Ebro Basins, but a larger data set is exposed in Vargas (2003). It is not the goal of the paper to discuss the structural evolution of the Iberian, Ebro and Catalan Basins and its causes, but the results of this kind of subsidence analysis are criteria that can be used in combination with litho and biostratigraphic data for correlation of the siliciclastic Permian and Triassic sediments.

The first and second syn-rift pulses (Figs. 6 and 7) are found only in the Iberian Basin (290-270 M.a.) in sections wide apart; thus, the resulting angular unconformities are basin-wide events that can be considered coeval events and can be correlated even in absence of direct datation of the intercalated red beds.

The third syn-rift pulse (Figs. 6 and 7) (245-237 M.a.) is clearly an Iberian Microplate event at the base, as it is found in every studied section and borehole, but then, it is subdivided in two pulses during the Thuringian in sections like Cañete and Chelva, end up very early, like in the Chelva-Eslida section, or very late like in the Molina de Aragón and El Paraiso sections. In the Ebro Basin this pulse is subdivided in two parts with a brief post-rift phase in the late Anisian.

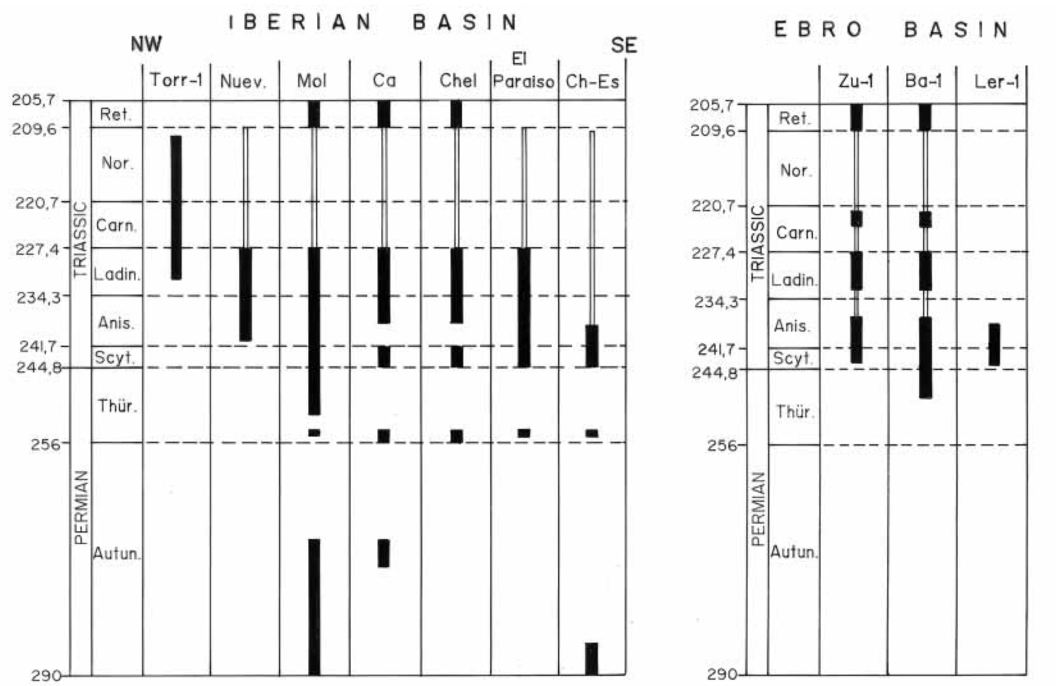

FIGURE 7 | **Syn-rift phases (wide, black lines) and post-rift phases (narrow, white lines) for the same sections in figure 6. Note the short-lived, multiepisodic syn-rift phases. From Vargas, 2002 and Vargas et al., 2004.**

This kind of analysis show that some of the breaks in sedimentation observed in sections and boreholes are the consequence of basin-wide or plate tectonic events, that can be used after backstripping analysis or correlation tools, that some other conspicuous unconformities are only local event or heterochronous events.

A final conclusion of this analysis is that sections very close or on Paleozoic rift shoulders, like the Torremocha borehole, have a particular evolution that cannot be extrapolated to the central part of the basin.

CONCLUSIONS

The siliciclastic sediments of NE Iberian Peninsula show a red-bed succession of similar petrologic and sedimentologic characteristics but have different ages.

Seven sedimentary cycles have been separated in the sections of the Iberian, Ebro and Catalan Basins.

Correlations in the Permian-Triassic red-bed succession must be backed by a simultaneous application of biostratigraphic, lithostratigraphic and structural analysis.

Three unconformities and hiatuses have regional extension and allow a subdivision of the sedimentary record.

Some of the siliciclastic cycles (5th to 7th) have shallow marine equivalents.

The multiepisodic extensional regime explains the emplacement of some of the short lived alluvial fan sequences.

The application of several correlation techniques allow for a formation-scale correlation of the Permian-Triassic sediments of the studied area.

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