The Permian-Triassic rocks of the eastern Iberian Ranges: A general approach in the context of the first stages of the break-up of Pangea.

Pan- European Correlation of the Triassic. 10th International Field Workshop.

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CONTENTS

1. INTRODUCTION

This field guide has been prepared for the 2013 10th International Field Workshop of the Pan-European Correlation of the Triassic. The Field Workshop has been organized as a four-day geological excursion and the guide covers sedimentary aspects of the continental and marine Permian-Middle Triassic rocks of the Iberian Ranges, Spain (Fig.1), but also on related topics such as tectonics, mineralogy, paleoclimate, paleontological content, paleosols, and biotic crises. The stops of the first and second days are located in the Castilian Branch, near the Boniches and Henarejos anticlines (Cuenca province). In that area, we will visit outcrops of continental rocks of Lower, Middle-Late Permian, and Lower Triassic age. The last two stops of the second day are concerned with Middle Triassic marine rocks (Fig. 2). The third and fourth days are located in the Aragonese Branch of the Iberian Ranges, around the Montalbán area (Teruel province). These days we will focus on the Triassic rocks of the SW Ebro Basin margin, trying to clarify the differences of sedimentological characteristics and sedimentary units between the Iberian Basin and the Ebro Basin (Fig. 1).

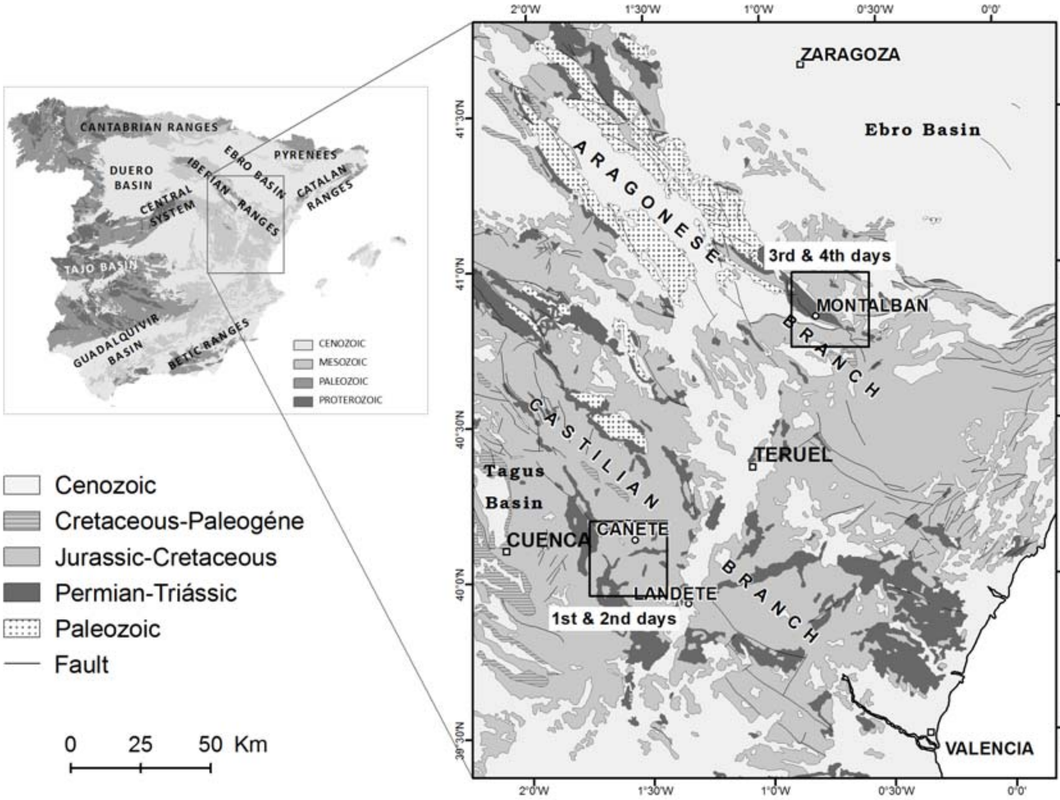


Fig. 1: Map of the Iberian Ranges showing the Aragonese and Castilian branches, and main geological units. The location of the stops of the field trip is indicated by black squares.

The Permian and Triassic rocks of the Iberian Ranges are in general well exposed along the chain. Most of the outcrops are related to anticlines resulting from Cenozoic compressional events, and clearly inherit the ancient fault lineaments (Variscan or older) that controlled the early phases of sedimentation in the Iberian Basin. These rocks show specific characteristics related to the asymmetrical evolution of the Iberian Basin in each of its sectors. However, there are some common features within the entire basin, such as the continental origin of the rocks of Early Permian to early Middle Triassic age and the marine influence since Middle Triassic time, when the Tethys, coming from the east, covered part of the basin for the first time.

The Iberian Ranges is a NW-SE intraplate fold belt located in Central-Eastern Spain. It is an uplifted or inverted Mesozoic basin (the Iberian Basin) (Fig. 1). Extensional tectonics created this basin in the Permian, after the extensional collapse of the Variscan Belt, and evolved during the Mesozoic as complex systems of grabens with several syn-rift and post-rift phases that preserved continental and marine deposits (Fig. 2; van Wees *et al*., 1988; Vargas *et al*., 2009).

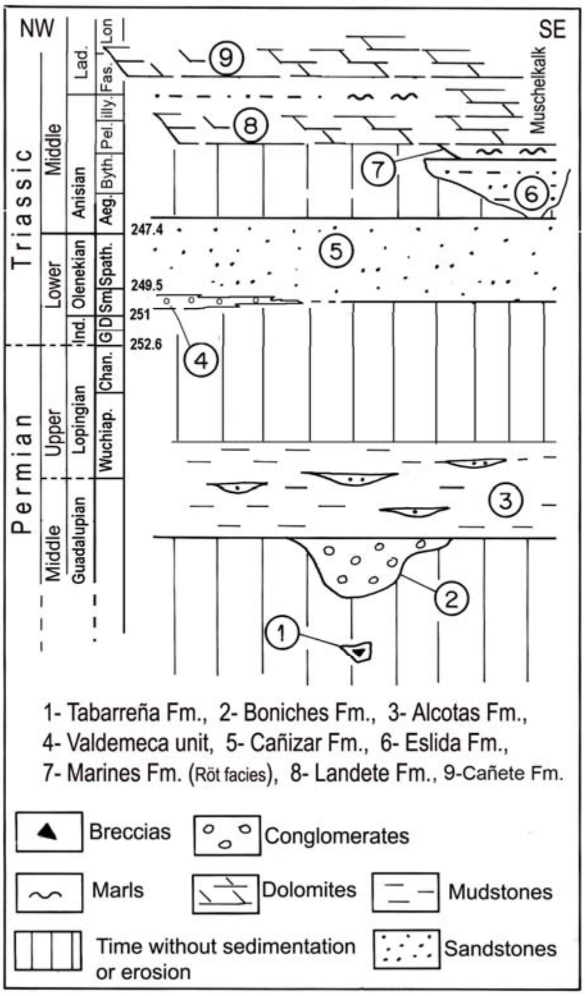


Fig. 2: Permian and Triassic units of the Castilian Branch of the SE Iberian Ranges. The outcrops of the Cuenca area are located towards the NW and those ones of the Castellón area (where the Eslida and Marines Fms appear) are located towards the SE.

Previous NW-SE and NE-SW variscan faults conditioned the development of the first extensional structures (Arche and López-Gómez, 1996). The main basin boundary faults have been interpreted as lystric faults dipping to the NE associated with antithetic fault arrays that isolated and elevated several basement highs. Differences in extensional rates were accommodated by transfer faults trending NNE-SSE (Fig. 3).

At the beginning of the Cenozoic the tectonic regime switched to compressional in response to the collision of the Iberian and European plates along the Pyrenees. Compression started by early-middle Eocene times (Casas *et al*., 2000) and the deformation peak can be placed within the late Oligocene, and ended at the Oligocene-Miocene boundary. Subdued compressional deformation was still active during the early-Middle Miocene (Calvo *et al*., 1996; González *et al*., 1988). The deformation differs along the chain as a result of thickness of the Mesozoic cover, presence/absence of detachment levels and geometry of the extensional faults, but in general, the. crustal shortening on the region has been estimated as 55-75 Km (Guimerá *et al*., 1996; Salas *et al*., 2001).

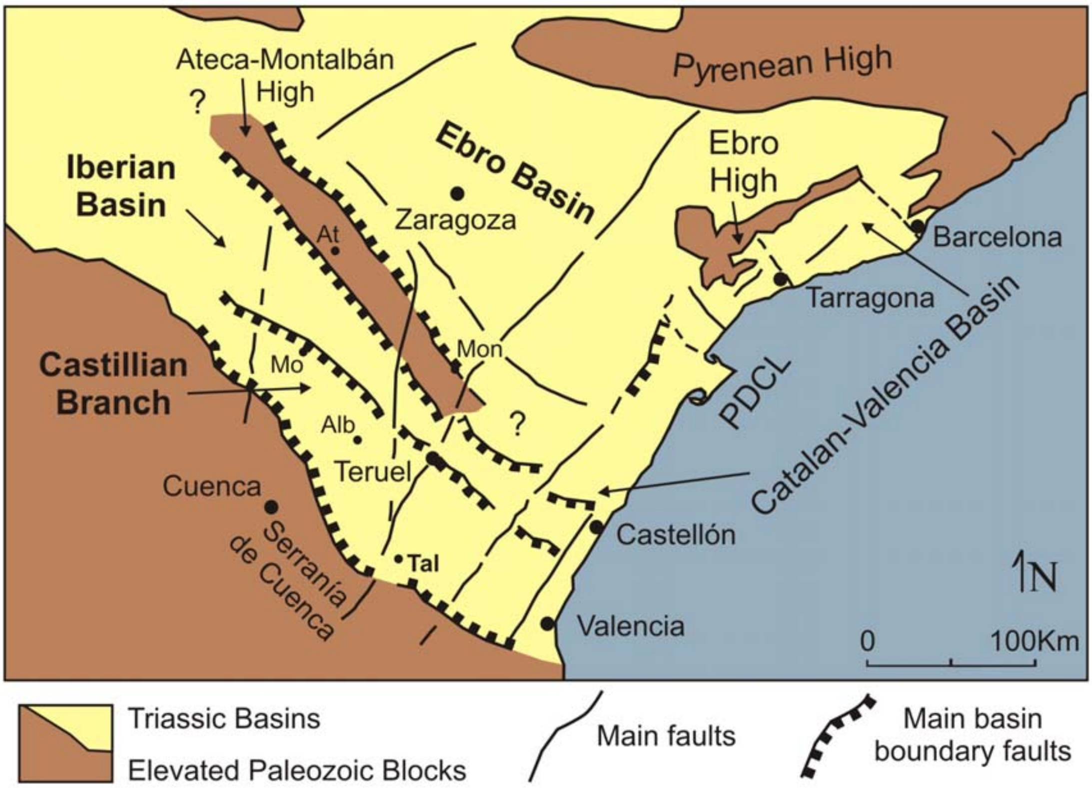


Fig. 3: Reconstruction of the Iberian basin at the base of the Triassic showing the main Paleozoic highs, basin boundary fault systems, and related transfer faults. The eastern area (Teruel-Castellón area) was a depocenter during the early Anisian. Based on Arche and López-Gómez (1996).

The present-day Iberian Ranges is divided into two approximately parallel structural units, with their associated Cenozoic basins: The Castilian Branch to the south and the Aragonese Branch to the north (Figs. 1, 3). This geographical subdivision is related to the Alpine tectonic controls that allowed to the development of relative highs and lows. Both branches are oriented NW-SE and represented subsiding areas during much of the Permian and Mesozoic times. Therefore, the Castilian Branch roughly corresponds to the Iberian Basin, while the Aragonese Branch formed the SW border of the Ebro Basin (Fig. 3).

Early regional studies of the Permian-Triassic rocks began in the middle of the 19^{th} Century. Recent works, dealing mainly with sedimentary and tectonic aspects appeared in the last decades: e.g. Sopeña *et al*. (1988), Ramos *et al*. (1985), López-Gómez and Arche (1993a, b), Arche and López-Gómez (1996, 1999a), Vargas *et al.* (2009), De Vicente *et al*. (2009) among others. New research lines are focused on the Middle-Late Permian and Permian-Triassic transition biotic and paleoenvironmental crises: e.g., Benito *et al.* (2005), Arche and López-Gómez (2005), De la Horra *et al*. (2008; 2012) and Gand *et al.* (2010). Provenance and paleogeographic aspects are reviewed in Sánchez-Martínez *et al.* (2012) and López-Gómez *et al.* (2012).

2. SYNSEDIMENTARY TECTONICS ALONG THE MARGINS OF THE IBERIAN AND EBRO BASINS DURING THE PERMIAN TRIASSIC INTERVAL

The existence of syn-sedimentary extensional phases in the Iberian and Ebro Basins during the Permian-Middle Triassic times has been previously documented (Sopeña *et al*., 1988; Arche and López-Gómez, 1996; Vargas *et al*., 2009). The origin and evolution of the rift basins and associated Paleozoic-age highs (Fig. 3) were controlled by a series of parallel normal fault systems of lystric nature trending NW-SE (Iberian fault family) and NE-SW (Catalonian fault family). The subsidence history of these basins, now well established, shows a pattern of asymmetrical sediment infilling of semigrabens, lateral migration of the depocentres and important spatial and temporal variations in facies and thickness within the studied area (Fig. 4). The main basin boundary faults have a shallow, listric geometry, flattening out at 12-15 km depth. The temporal evolution of these faults explains the observed asymmetric distribution of both facies and depocenters.

Four successive phases of extensional deformation, each one subdivided into syn-rift and post-rift phases, have been identified in the basins controlling the deposition of the siliciclastic units examined in this fieldtrip (Vargas *et al*., 2009) (Fig. 5). The syn-rift phases took place in the Early Permian (Autunian) (c. 274-270 Ma), Middle-Late Permian (Thüringian) (c. 256-254

Ma), Early Triassic (c. 244.8-242 Ma) and Middle Triassic (c. 238-235 M.a.), followed by thermal post-rift phases. While continental deposition occurred during the syn- rift phases, elevation, tilting and partial erosion of the previous sediments took place during the post-rift phases, resulting in angular unconformities and hiatuses of regional extent. The widespread spatial development of these discontinuities can be related to intraplate processes in central Pangea (Bourquin *et al*., 2011; López-Gómez *et al*., 2012).

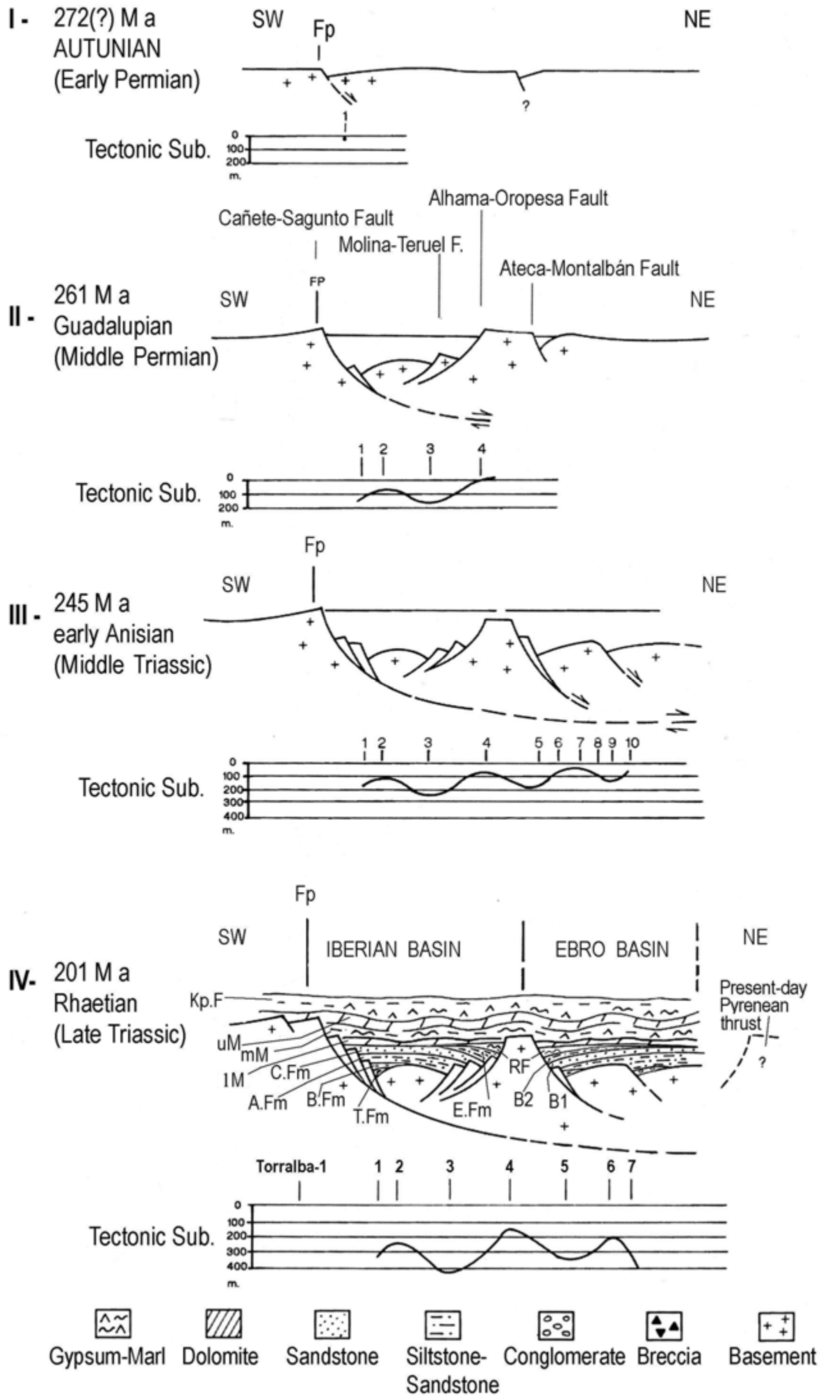


Fig. 4: Tectonic context of the evolution of the Ebro and Iberian basins during the Early Permian to Late Triassic. The main syn-sedimentary fault lineaments, lithostratigraphic units and highs are shown. Modified after Vargas *et al*. (2009).

Formations: T-Tabarreña, B-Boniches, A- Alcotas, C-Cañizar, E-Eslida, lM- lower carbonatic unit of the Muschelkalk facies, mM-middle unit of the Muschelkalk facies, uM-upper carbonatic unit of the Muschelkalk facies, Kpf-Keuper facies.

A basement central high or horst (the Ateca-Montalbán High) separated the Iberian and the Ebro basins for most of the Permian-Triassic period (Figs. 3, 4). The main difference between the Cañete-Boniches area of the Iberian Basin and the southern Ebro Basin (Montalbán area) is that the syn-rift phases of the Middle-Late Permian are almost absent in the Ebro Basin, while the Early Permian and Late Triassic tectonic phases are found in both regions (Fig. 5). This fact is a clear indication of the progressive migration, to the NE, of the extensional processes in Central Iberia during the Permian-Triassic.

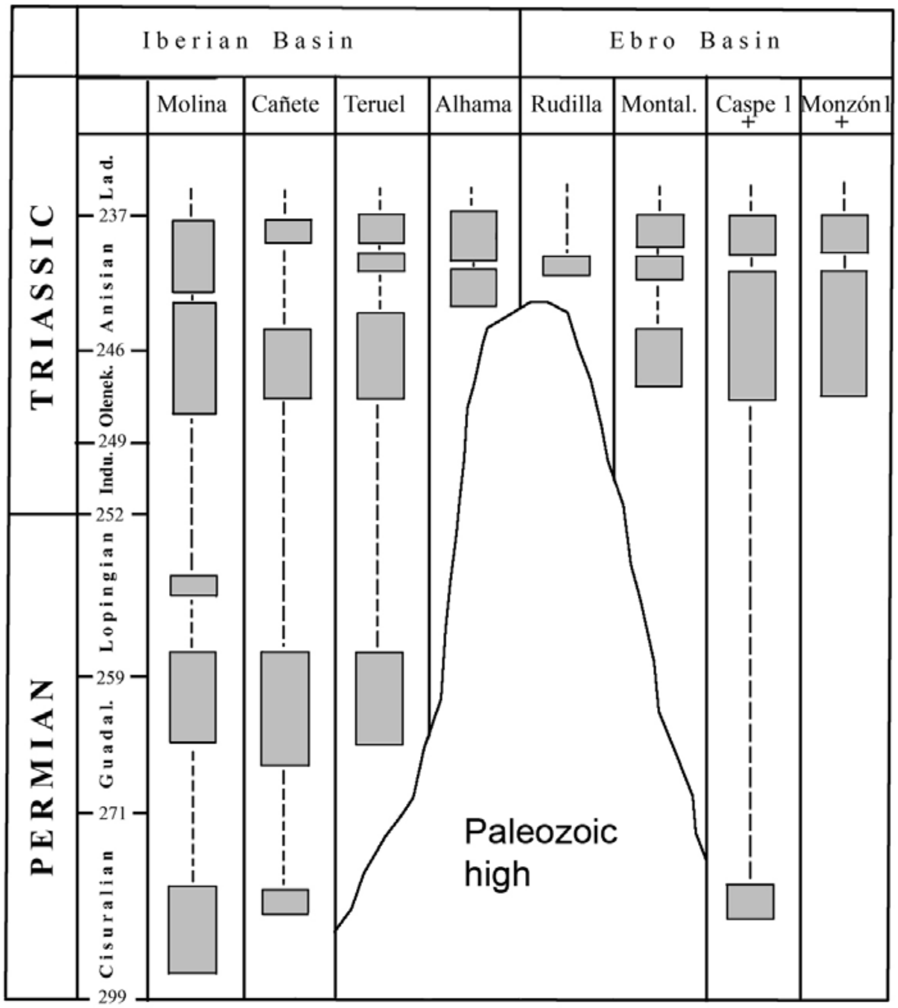


Fig. 5: Syn-rift phases during the Permian-Middle Triassic interval. Boxes: Syn-rift phases, Dotted lines: Post-rift phases. Duration of the post-rift phases is approximate because part of the corresponding sedimentary record is eroded. Based on Van Wees *et al.* (1998) and Vargas *et al.* (2009).

3. THE ROCKS IN THE IBERIAN BASIN

This section provides a brief description of the alluvial – shallow marine Permian- Middle Triassic formations in the Iberian Basin, while a detailed sedimentological interpretation is given in the descriptions of the stops.

Permian and Triassic sedimentation in the Iberian Basin records the beginning of the extensional tectonic regime of the Alpine cycle. NW-SE-oriented rift activity took place on a deformed Variscan basement, composed of Ordovician-Silurian-age slates and quartzites affected by low-grade metamorphism. The rifts were initially unfilled by Permo-Triassic sediments (Arche and López-Gómez, 2005) (Figs. 3, 4). As in the rest of the Iberian Peninsula, and all the western and central basins of Europe, the Permian rocks are clearly separated from the Triassic ones by a sedimentary hiatus that corresponds at least to the late Lopingian, and probably lasted until Olenekian times (Bourquin *et al*., 2007).

3.1. Permian

In the Iberian Basin, Permian rocks are represented by the Tabarreña, Boniches and Alcotas formations (Fig. 2), all of which have been extensively studied in the last decades (Sopeña *et al*., 1988; Alonso-Azcárate *et al*., 1997; Arche and López-Gómez, 1999a; López-Gómez *et al*., 2002; Benito *et al*., 2005; De la Horra *et al*., 2008; Vargas *et al*., 2009). Pedogenic processes and geochemical aspects in the Alcotas Fm. are reviewed in De la Horra *et al*. (2008; 2012) and Benito *et al.* (2011). The rocks are mainly alluvial fan and fluvial deposits (López-Gómez *et al*., 2002). These continental depositional environments lasted until Anisian (Triassic) times, when the NeoTethys Sea, represented by the carbonate ramps of the lower Muschelkalk facies, reached the eastern margin of the Iberian Plate (Arche and López-Gómez, 1999a).

3.1.1. Tabarreña Formation

The Tabarreña Formation, represents the first major Permian sedimentary cycle in the Cañete-Boniches area (Arche *et al*., 2004), it crops out in a series of isolated, small basins, separated by local highs of basement rocks (Figs 2, 4I). This unit lies unconformably on the Variscan basement and consists of clast- and matrix-supported red breccias, with angular clasts of quartzites and slates. An angular unconformity separates these rocks from the overlying formation. Based on comparisons with well-dated equivalent sediments in the NW Iberian Ranges, an Early Permian age has been proposed for this unit (López-Gómez and Arche, 1994).

3.1.2. Boniches Formation

The Boniches Fm. represents the beginning of the second Permian sedimentary cycle. It consists of clast-supported conglomerates, mainly well-rounded quartzite clasts and lies unconformably on the Variscan basement or, locally, on the Tabarreña Fm. (López-Gómez and Arche, 1997) (Figs. 2, 4II). The age of this formation was established by means of palynological assemblages as Thüringian (Doubinger *et al*., 1990), an imprecise time unit which can be broadly correlated with the Capitanian (Middle Permian), and the Wuchiapingian (Late Permian). The conglomerates gradually pass vertically into the Alcotas Fm. which also forms part of the second Permian sedimentary cycle.

3.1.3. Alcotas Formation

The Alcotas Fm. lies conformably on the Boniches Fm. or unconformably on the Variscan basement (Figs. 2, 4II). This unit consists of red mudstones and siltstones, with intercalated red to pink sandstones beds, conglomerate lenses at the base of some sections, and paleosol horizons (Arche and López-Gómez, 2005; De la Horra *et al*., 2008, 2012; López-Gómez *et al*., 2012). The Alcotas Fm. has been also dated as Thüringian based in associations containing: *Klausipollenites, Lueckisporites, Alisporites*, among others (Doubinger *et al*., 1990). Recently, Arche and López-Gómez (2005) provided a more precise age of early Lopingian (Wuchiapingian, Late Permian). Nevertheless, the application of standard palynological techniques in continental settings is limited in terms of chronostratigraphic precision. Despite this limitation, the Alcotas Fm. is clearly younger than the Boniches Fm., because the latter contains *Vittatina*, an specimen of Autunian (Lower Permian) affinity in the palynological associations (Doubinger *et al*., 1990; Diéguez and Barrón, 2005) and the former is devoid of them. A fossil trunk of *Dadoxylon* and plant remains and have been also described in this formation (Diéguez *et al.*, 2005, 2007). An angular unconformity separates the Alcotas Fm. from the overlying Valdemeca or Cañizar Fms, of Early Triassic age (Fig. 2).

3.2. Triassic

The Triassic rocks in the study area, as in the rest of the Iberian Peninsula, contain the three facies that broadly correspond to the three units of the Triassic of Germanic type: Buntsandstein, Muschelkalk and Keuper, although they lack any significant chronostratigraphic value. The Buntsandstein facies is represented in the study area by three lithological units of continental origin: the Valdemeca unit, the Cañizar Fm. and The Eslida Fm. (Fig. 2). These units are the main Triassic rocks examined in this guide and represent the third sedimentary cycle in the Iberian Range.

3.2.1. Valdemeca Unit

The Valdemeca unit represents the lower part or the first member of the Cañizar Fm. (Figs. 2, 4). It was defined by De la Horra *et al*. (2005) as the lateral equivalent of the upper part of the Hoz de Gallo Upper Conglomerates (Ramos *et al.*, 1985). It consists of sandy, matrix- and clast-supported, subrounded to subangular quartzite conglomerates and interbedded sandstones. It reaches a thickness of c. 4 m in the Boniches area. The conglomerates show a range of internal sedimentary structures including planar and trough cross-stratification, and ripple cross-lamination. Some beds have very well rounded grains and isolated ventifacts. Its age is estimated as Early Triassic due to its stratigraphical location, but is not dated up to now. The base of the Valdemeca unit shows a transverse drainage to the basin margin with a rather radial pattern. Paleocurrents at the top of the unit are parallel to the axis of the basin, pointing to the SE.

3.2.2. Cañizar Formation

The Cañizar Fm. (López-Gómez and Arche, 1993a; López-Gómez *et al.*, 2012) is the most representative continental unit of the Early-Middle Triassic in the Iberian Ranges due to its spectacular outcrops. Although its name changes from one geographic area to another, the basic features are similar. It lies unconformably on the Middle-Upper Permian rocks (Alcotas Fm.) or conformably on the Valdemeca Unit, and thus, together with the Valdemeca Unit, represents the onset of the Alpine cycle of sedimentation (Figs. 2, 4). Its thickness ranges from 80 to 120 m. It is mainly composed of red sandstones (subarkoses) with different grain sizes, and isolated subrounded quartzite clasts. The main internal structures are planar and trough cross-stratification, parallel lamination, and current ripples. The formation is subdivided into six members separated by major boundary surfaces. A pollen and spore assemblage retrieved from the upper part of the formation suggests an early Anisian age (Doubinger *et al*., 1990), and, thus, most of the formation may be Olenekian in age (López-Gómez *et al*., 2012), although the age of its base is still a matter of debate. Paleocurrents were parallel to the axis of the basin, pointing to the SE. In the SW Ebro Basin margin (Montalbán area) most of the formation is of aeolian origin (Soria *et al*., 2011).

3.2.3. Eslida Formation

This formation appears only in the eastern part of the Iberian Ranges (Arche and López-Gómez, 1999b) and in the Ebro Basin margin. It always overlies conformably the Cañizar Fm. and generally this boundary surface is a hiatus (Figs. 2, 4). It grades upwards into the overlying Marines Fm., the so called Röt facies. The formation consists of alternating red sandstones and siltstones. The sandstones are fine- to coarse-grained arkoses and subarkoses (0.1-0.4 mm). The sandstones show internal structures such as planar and trough cross-stratification, parallel lamination, current and wave ripples and parting lineation; siltstones show horizontal lamination, and contain paleosols, root prints and plant remains. Formation thickness ranges from a few meters to > 600 m in an important depocenter in the Castellón area (Fig. 2). Footprints and plant remains have been recently found near Cedrillas (Gand *et al*., 2010 and Galan-Abellán 2011, respectively). Its age is Anisian, since both the underlying and the overlying units have this age. In the SW Ebro Basin margin (Montalbán area) some of the fluvial sequences show partial aeolian reworking.

3.2.4. Marines Formation.

This formation only crops out in the SE of the Iberian Ranges and in the SE Ebro Basin margin, linked to the top of the Eslida Fm. (Fig.2). The unit reaches its maximum thickness (35 m) near the Mediterranean sea, thinning out to the west. It mainly consists of red lutites and marls although thin-bedded sandstones, (typically showing wave ripples, lenticular to flaser lamination and burrows), and dolostones are also present. The latter commonly show irregular, parallel laminations of cryptalgal origin. Pseudomorphs of evaporites are abundant. The carbonate content increases towards the top of the unit in a transitional contact with the overlying carbonates of the Landete Fm. Also show a colour gradation being predominately red in the base and changing upwards into yellow, green and grey at the top (López-Gómez and Arche, 1992). The Marines Fm. has been dated as Anisian by means of a pollen association (Doubinger *et al*., 1990) and is interpreted as lagoonal-tidal flat deposits, representing the first marine influenced deposits of the Mesozoic in the Iberian Basin.

3.2.5. Landete Formation

The Landete Fm. constitutes the lower part of the Muschelkalk facies, and represents the culmination of the first marine transgression in the Iberian basin during the Mesozoic. To the west this unit lies uncorformably on the Buntsandstein facies; to the east has a transitional lower limit with the Marines Fm. (López-Gómez *et al.*, 1993). In general the unit has an average thickness of 30 meters decreasing out to the west (Fig. 2). It mainly consists of decimetric banks of well-bedded grey dolomicrites with sandy dolomites levels at the base of the unit. Occasionally small levels of grey-yellow clay dolomites appear intercalated. These carbonates were deposited in a shallow marine carbonate ramp. Despite the pervasive dolomitization of the unit, many original features of the deposits (as well as fossil remains including foraminifers, ammonites and bivalves) can be observed. These fossil assemblages allow to age-date the unit as Middle-Late Anisian (Escudero-Mozo *et al*., 2012). Different fossils have been described in this formation and are listed in Apendix I, at the end of this manuscript.

3.2.6. Mas Formation

This unit corresponds to the middle Muschelkalk facies in the Iberian basin, and shows a lower and upper transitional contact with the Landete and Cañete Fms. respectively (Fig. 2). It consists of variegated marls, gypsum and some intercalated dolomite and sandstone beds (López-Gómez y Arche, 1993). The Mas Fm. together with the two carbonate units of the Muschelkalk facies (Landete and Cañete Fms.) represent two general transgressive-regressive cycles clearly developed in most of eastern Iberian Peninsula (López-Gómez *et al*., 1993, 1998). The age of this formation is late Anisian-early Ladinian based on pollen assemblages (Doubinger *et al*., 1990).

3.2.7. Cañete Formation

The Cañete Fm. corresponds to the upper Muschelkalk facies, and represents the second and more widespread transgression of the Tethys Sea in the Iberian basin during the Triassic. The base of the unit is a transitional contact with the Mas Fm. except in the northwesternmost part of the basin and the Ateca Paleozoic High where it lies directly over the basement (Figs. 2, 4). The upper contact is always transitional with the Keuper facies and shows evidence of subaerial exposure towards the northwest of the basin (López-Gómez *et al*., 1993). The Cañete Fm. shows a maximum thickness of 85 m in Cañete area and thins out towards the northwest, where it even lies unconformably on the Paleozoic basement of the Ateca Paleozoic High (Fig. 4).

This unit consists of carbonates deposited in a shallow carbonate ramp. The base of the Cañete Fm. mainly consist of grey dolomites with planar cross-stratification, ripples, cryptalgal lamination, algal mounds and some bioclastic levels. The upper part of the unit is less dolomitized and consists of grey- ochre limestone/dolomite and some levels of green and yellow marls, with ripples, bioturbation, evaporite pseudomorphs, tempestites, mud-cracks and tepees. The bioclastic levels are more abundant in the upper part of the formation, containing some good preserved fossils as conodonts, bivalves, foraminifers, chondrichthyes and ammonoids, allowing to date the Cañete Fm. as Ladinian in age (López-Gómez *et al*., 1998). Different fossils have been described in this formation and are listed in Apendix I, at the end of this manuscript.

4. MINERALOGICAL COMPOSITION OF THE PERMIAN-TRIASSIC CONTINENTAL SEDIMENTARY ROCKS

The mineralogical composition of the Permian and Triassic sedimentary rocks of the SE Iberian Range has been reported in different studies (Alonso-Azcárate *et al*., 1997; Barrenechea *et al*., 2004; Benito *et al*., 2005; Martín-Martín *et al.*, 2007; De la Horra *et al*., 2008; 2012; Galán Abellán *et al*., 2008), and can be related to the paleogeographical evolution of the basin, the sedimentary environments, and climatic evolution (Fig. 6). Each formation contains specific clay mineral associations (Alónso-Azcárate *et al*., 1997).

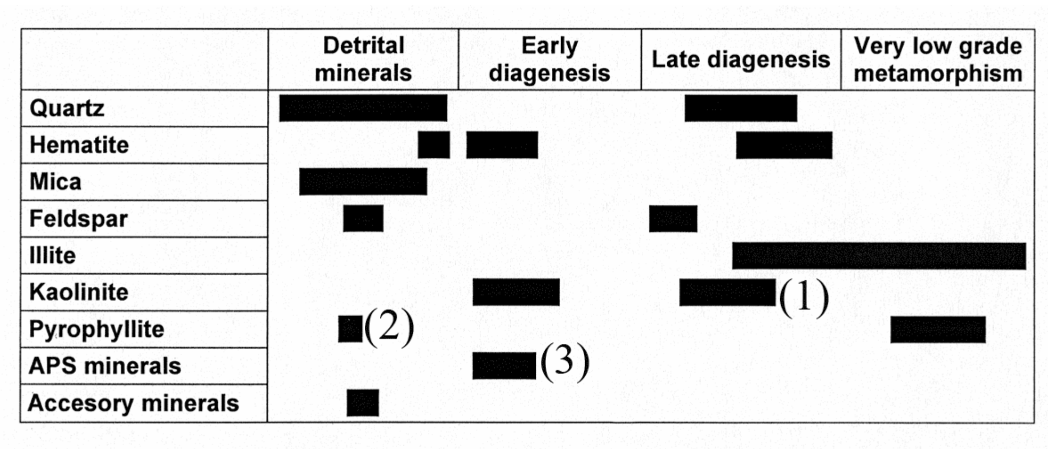


Fig. 6: Mineralogical composition of the Permian-Triassic continental sedimentary rocks from the SE Iberian Range, including the approximate relative timing of formation. (1)Kaolinite is extensively transformed into dickite during late diagenesis (Martin-Martin *et al*., 2007). (2)Pyrophyllite in the Boniches and Tabarreña Fms. was regarded as an inherited phase by Alonso-Azcárate *et al*. (1997). (3)APS minerals occur exclusively within the Cañizar and Eslida Fms (Galán-Abellán *et al*., 2008).

The Tabarreña and Boniches Fms. correspond to slope breccias and conglomerates (alluvial fans) with a matrix composed by quartz, hematite, illite, kaolinite and pyrophyllite (Alonso-Azcárate *et al*., 1997). Most of the samples from the Alcotas to Eslida Fms. (fluvial origin) are fine- and very fine-grained sub-litharenites, sub-arkoses and, to a lesser extent, quartz-arenites, in which quartz is the dominant component (45 to 90 %), along with detrital mica, hematite, rock fragments, and minor amounts of feldspar. Rutile, zircon, ilmenite, tourmaline, xenotime, monazite and apatite are present as accessory minerals. In addition, Sr-rich aluminium-phosphate-sulphate (APS) minerals have been recognized in several horizons of the Cañizar and Eslida Fms within the study area (Barrenechea *et al*., 2004; Benito *et al*., 2005; Galán-Abellán *et al*., 2008; 2013a; Galán-Abellán, 2011). These occur as tiny (< 2 Å) crystals or as polycrystalline aggregates that replace detrital micas or fragments of metamorphic rock (phyllites, schists); and textural relationships point to an early diagenetic origin, prior to the compaction of the sediment (Galán-Abellán, 2008; 2011). The clay mineral assemblages are dominated by illite, with minor amounts of kaolinite, and pyrophyllite present in some samples. According to Martín-Martín *et al.* (2007), kaolinite resulted from the early diagenetic transformation of detrital muscovite. This early kaolinite was extensively transformed to dickite during later stages of diagenesis, with subsequent cementation by quartz and illite. The bulk mineral assemblage in these rocks is indicative of prevailing oxidizing conditions in an arid or semi-arid region. The presence of APS minerals in the Cañizar and Eslida Fms, together with the absence of carbonates and the widespread occurrence of hematite can be considered as indirect evidence of lower pH values in the system, according to the criteria proposed by Benison and Goldstein (2002). Different mechanisms might operate within the soil or sediment in order to lower the pH of waters, resulting in more acid ground waters and streams.

The evolution from continental (Buntsandstein facies) to marine environments (Röt and Muschelkalk facies represented by the Marines, Landete, Mas and Cañete Fms.) resulted in drastic changes in the mineralogy. The clay association of these sandstones, mudstones, marls and dolostones is composed of illite, chlorite, vermiculite and mixed-layer chlorite/smectite, chlorite/vermiculite and illite/chlorite. According to Alonso-Azcárate *et al.* (1997) the presence of these Mg-rich clay minerals is related to shallow-marine environments, with seawater causing a very early diagenesis of the detrital clays that were carried by the rivers into the basin.

5. PALEOGEOGRAPHY, BIOTIC CRISIS, AND PROVENANCE OF SEDIMENTS

During the Permian and the Triassic, the Iberian Plate was situated at the eastern margin of Pangea, facing the Neotethys Sea at latitudes ranging from 5º N to 20º N (Stampfli and Borel, 2002; Dinarés-Turell *et al.*, 2005; Stampfli and Hochard, 2009). During this period of time, the extensional collapse of the Variscan Belt and the westwards propagation of the Neotethys Sea created a series of rifting episodes that affected Iberia and Western Europe. These episodes have been resolved into a series of discrete, short-lived (1-5 M. y.) syn-rift, post-rift pulses in Iberia (Vargas *et al.*, 2009). They are reflected in the sedimentary record as angular and/or erosional unconformities separating the sedimentary sequences that will be examined during the fieldtrip.

The first stage of widespread continental rifting in the Iberian Basin took place during the Middle-Later Permian (Figs. 4, 7). A series of interconnected half-grabens were formed across Iberia, trending NW-SE. Continental sediments were sourced locally in the surrounding Variscan highlands (Sánchez-Martínez *et al.*, 2012). This stage represents the beginning of the breakup of Pangea in the Iberian microplate. Calk-alkaline and alkaline volcanism coeval with the sedimentation of the Permian red beds is found in Cantabria and the Pyrenees (Lago *et al.*, 2004). Alkaline volcanic rocks have been found in the SE Iberian Ranges in the locality of

Alfondeguilla (Valencia province) (Lago *et al*., 2011) in a similar geometrical relation with the Permian sedimentary rocks. They also have similar chemical composition.

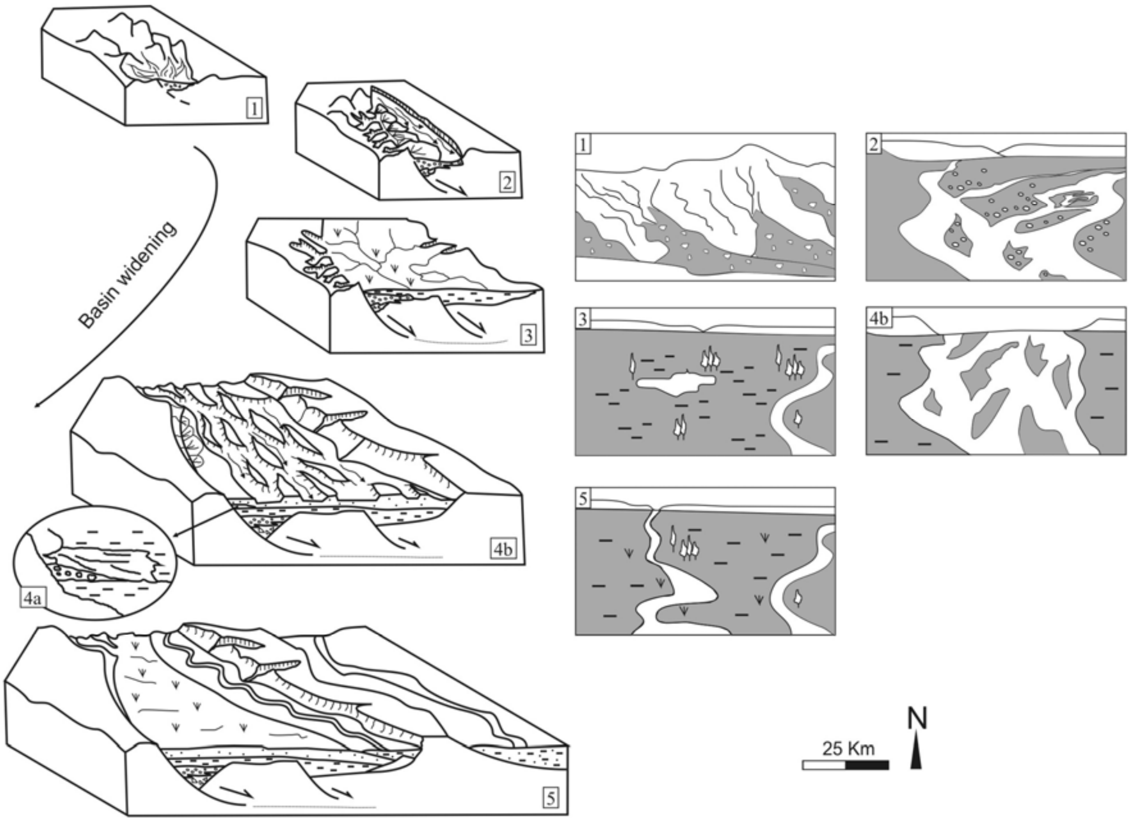


Fig. 7: Block diagrams and landscape reconstruction of Permian-Triassic-age continental settings in the Iberian Basin. (1) Tabarreña Fm., (2) Boniches Fm., (3) Alcotas Fm., (4a) Valdemeca Unit, (4b) Cañizar Fm., (5) Eslida Fm. See also figure 2 for their stratigraphical distribution.

A period of rapid paleoenvironmental change and biotic extinction is recorded in the upper third part of the Middle-Late Permian continental sediments in the Iberian Ranges (Diéguez *et al*., 2007; De la Horra *et al*., 2012). The regional character of the extinction interval and its proximity with the Middle–Late Permian transition could be related with the global mid-Capitanian biotic turnover described in this period of time in other marine basins. However, the common difficulties of dating with precision non-marine rocks make this relationship difficult to probe in the Iberian Basin.

At the end of the Permian, a major biotic crisis took place in the Earth, accompanied by drastic climatic and environmental changes within a time interval estimated at 700 kyrs (Huang *et al*., 2011, Shen *et al*., 2011). These changes are probably related to the emplacement of the Siberian Traps Large Igneous Province (Svensen *et al*., 2009). Increased atmospheric and marine water temperatures, in excess of 8ºC in comparison with previous ones during the Latest Permian- Earliest Triassic (Joachimsky *et al.*, 2012) retarded the biotic recovery during this period. The Permian-Triassic boundary is not present in the sedimentary record of the Iberian Ranges but the aftermath of the extinction event has been identified in the Early-Middle Triassic sediments (Galán-Abellán, 2011; López-Gómez *et al.*, 2012).

The second stage of rifting activity took place during the Early Triassic, when wider, symmetrical graben basins were created (Figs. 4, 7). The fluvial systems infilling these basins not only taped local Variscan source areas but also more distant ones situated in the Avalonian and Laurentian domains to the NW (Sánchez-Martínez *et al.*, 2012; López-Gómez *et al.*, 2012). Its correlative sediments are represented by the Cañizar Fm. A similar evolution is recorded in the Irish Sea Basin, to the N (Tyrrell *et al.*, 2007) and other western Europe localities.

The Iberian, Ebro and Catalan Basins were interconnected in this period (Fig. 3). Aeolian sediments developed in the two latter ones during this period, and were fed by locally sourced fluvial systems that dried out before reaching the sea for long periods. In contrast, the Iberian Basin that was fed by axial rivers sourced in more distant, humid northern areas (Fig. 7) and contains almost exclusively alluvial sediments.

A major erosive surface (Major Boundary Surface 5, López-Gómez *et al.*, 2012) separates the lower and the upper part of the Early Triassic Cañizar Formation. This surface is recognized all along the Iberian Basin and represents a tectonic pulse that led to a major reorganization of the drainage of the Basin. It is considered equivalent to the Hardegsen Unconformity of Central European Basin (López-Gómez *et al.*, 2012), and represents a tectonic event of regional extension (Western Europe) that changed regional slope and led to a reorganization of the fluvial network.

During the Anisian and the Ladinian, the third and fourth rifting stages combined with major transgressive eustatic pulses in the Tethys Sea, which reached for the first time the eastern margin of Iberia. These combined processes led to a complex distribution of emerging and subsiding areas and contrasting styles in the sedimentary record: more than 1,000 metres in the SE domain (Montán-Eslida area) and only a few metres in the central domain (Cañete-Landete area) (López-Gómez and Arche, 1993, Arche and López-Gómez, 1996).

6. DESCRIPTION OF THE GEOLOGICAL ITINERARY AND STOPS

This four-day excursion, which begins and ends in Madrid, will examine some key outcrops of Permian and Triassic rocks in the Iberian Ranges. The general outline of the field trip will illustrate the progressive evolution of the Iberian basin from its early stages (Early Permian) to the first and second marine incursions of Tethys (Middle Triassic) in this area. The itinerary of the excursion in the Castilian Branch is shown in figure. The itinerary followed in the Aragonese Branch is displayed in the figure 24 A brief description of the stops is as follows:

The workshop begins in Madrid with a three hour coach trip eastwards to the city of Cuenca, where a short academic ceremony will open the workshop in the Science Museum. Then we travel east about one hour to overnight at Cañete village (Figs. 1, 8). Close to Cañete, the first day of the excursion starts looking at the Variscan basement (stop 0) and continues examining three outcrops representing the three Permian units formally described in this area (stops 1, 2 and 3); they constitute the beginning of the Iberian basin deposition. The last stop of the first day will be at the unconformity between the uppermost Permian unit and the base of the lowermost unit of the Early Triassic, the Valdemeca unit (stop 4). Overnight at Cañete village.

The first stop of the second day focuses on Cañizar Fm. (stop 5). This fluvial unit extends all over the Iberian Ranges and beyond, and represents the syn-rift climax. After that, the excursion continues traveling from Cañete to the south, near Boniches village, where an outcrop representing the first Tethys incursion (Landete Fm., middle-late Anisian) on the Iberian plate will be examined (stop 6). At midday the excursion proceeds eastwards to Henarejos-Moya anticline area. There, we observe the Cañete Fm. (Ladinian), that represents the second incursion of the Tethys Sea (stop 7). After a two-and-a-half hours coach trip across the Iberian Ranges, overnight at Utrillas village (Teruel province, Figs. 1, 24).

The third day begins near the Montalbán area (Fig. 24), at the Peñarroyas section along the Rio Martín. The Carboniferous basement is overlain by the Cañizar Fm., here dominated by aeolian deposits and the Eslida Fm. (Stop 8). Also, the normal contact with the Marines Fm. (Röt facies) will be examined. The first incursion of the Tethys in this area will be studied in the stop 9. In this stop, the marine facies shows different characteristics to the ones observed in the equivalent unit of the Castilian Branch. Overnight at Utrillas village.

The first stop of the fourth day, near Torre de las Arcas village, will examine the Middle-Late (?) Permian rocks (Feliciana Fm.) and the unconformity with the late Early Triassic Cañizar Fm. (stop 10). Near the stop 10, the Marines Fm. (Röt facies) and a general overview of a complete section of the Muschelkalk facies (Landete, Mas and Cañete Fms) will be also examined (stop 11). The last outcrop is located close to Hoz de la Vieja village, where sills of Permian age of calcalkaline affinity are cutting the basement (stop 12). After finishing this stop, the coach will go back to Madrid.

7. FIRST DAY: BONICHES AREA (SERRANÍA DE CUENCA, SE IBERIAN RANGES)

From Cuenca city coming from Madrid, take the N420 to Teruel. In about 50 minutes, we will reach Cañete village (72 Km). Four kilometers before arriving to this village, take right to the CM-215 road to the surroundings of the Boniches locality, from where the first day of the field trip begins (Fig. 8)

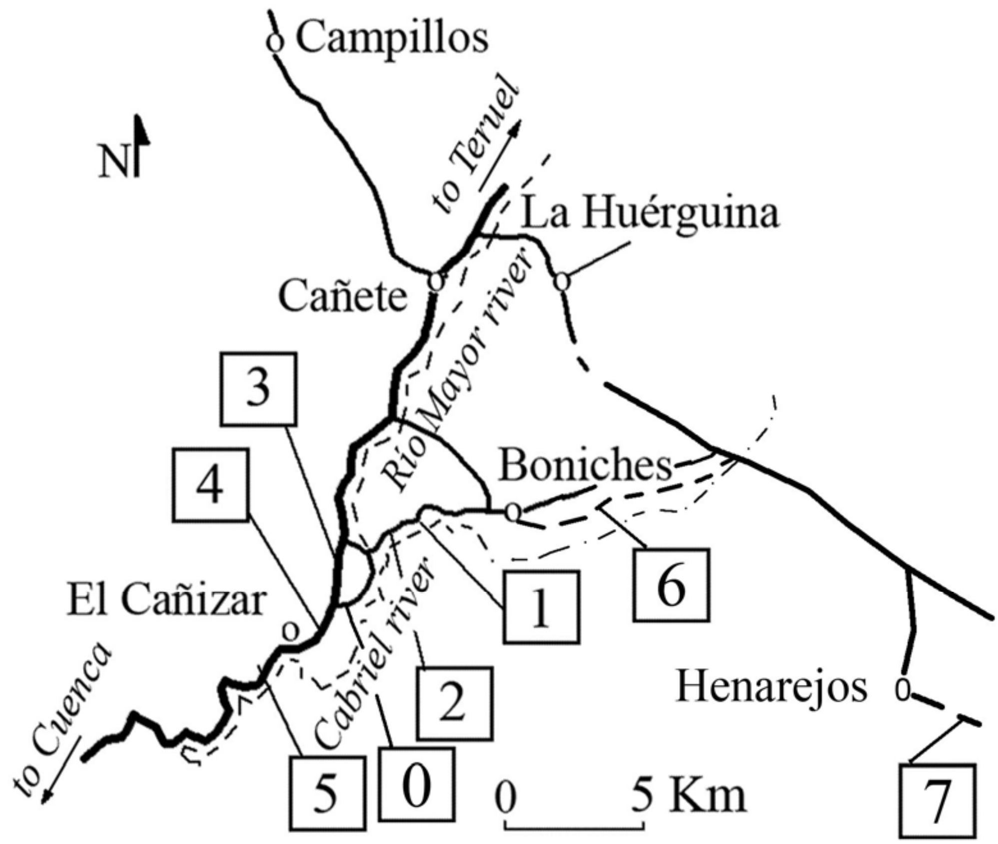


Fig. 8: Itinerary for the first and second day stops in the Boniches-Cañizar-Henarejos area.

Stop 0

Introduction to the field trip

Location: Coming from Cuenca city, along the nN420, take the CM-215 to Boniches. After 950 m, stop to the right at the Retuerta view-point (Fig. 8).

Observations: The Paleozoic basement is exposed in a large outcrop at the core of the Boniches anticline. It consists of grey-green slates and yellowish quartzites tightly folded during the Variscan Orogeny but not metamorphosed beyond the chlorite isograde (Fig. 9). These rocks have been dated as Sheinwoodian (Wenlock, Middle Silurian) by several Graptolite sites in this anticline and in the Sierra de Valdemeca anticline to the north.

During the Alpine compression, the basement, the Permian and Early-Middle Triassic sediments deformed together and the middle part of the Muschelkalk and the Keuper acted as detachment levels.

Fig. 9: General aspect of the Paleozoic basement at stop 0.

Stop 1

Tabarreña Breccias Fm.: the origin of the Iberian Basin (Early Permian)

Location: From the first stop, follow 1.6 Km towards the village of Boniches and stop in front of a conglomerates outcrop (Fig. 8). Walk 90 m north through a vineyard to reach a small stream. The breccias of the Tabarreña Fm. lie unconformably on the Silurian slates (Fig. 10).

Observations: A detailed sedimentological study of this formation can be found in López-Gómez and Arche (1994). These authors describe the purplish to red breccias as formed by poorly sorted, coarse- and very coarse angular clasts (Fig. 11). The breccias are cm-dm thick and generally clast-supported, grading upwards to matrix-supported breccias near the top of the formation. The thickest bodies (1.8 m) are commonly located at the base of the section and generally have poorly defined sedimentary structures and a chaotic aspect. Sometimes, these bodies show inverse grading. Near the top of the formation, the thickness of the beds decrease and normal graded bedding and cross-bedding can be observed. This unit reaches a maximum thickness of 31 m.

Fig. 10: General aspect of the Tabarreñas Fm. at stop 1.

The characteristics of the lower part of the Tabarreña Fm. suggest deposition by gravity flows of high density and viscosity, resulting in typical debris flow deposits. These deposits are related to processes of rockslides and creeping in steep slopes (Fig. 7.1). The uppermost part of the formation show fluvial characteristics, such as small bars with cross-bedding in incipient channels. In this case, hyperconcentrated flows and clear water flood processes were probably alternating during deposition.

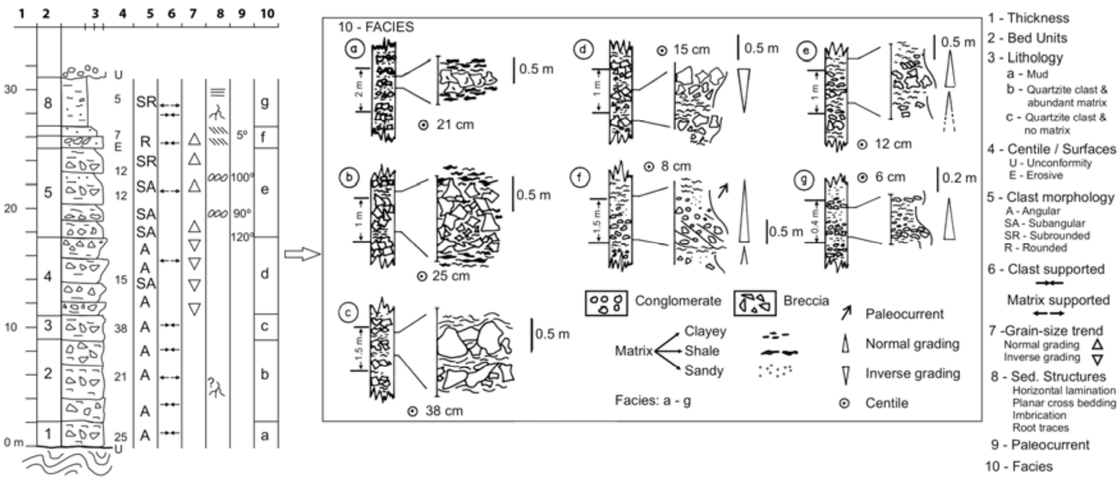


Fig. 11: Stratigraphic log and main sedimentary structures observed in the breccias of the Tabarreña Fm. Modified from Arche and López-Gómez (1994).

Stop 2

Boniches Fm.: sedimentation along the basin flanks

(Middle Permian)

Location: Walk back to the road from Stop 1 and continue to the west about 300 m (Fig. 8), turn right, walk 15 minutes along the Castillo del Rey creek (Fig. 12). At this point, climb towards the prominent conglomerate ridge located to the left.

Fig. 12: The Boniches Fm. From the Castillo del Rey .Stop 2.

Observations: The Boniches Fm. lies on a sharp unconformable contact with the breccias of the Tabarreña Fm. The texture of the gravel in the Boniches Fm. changes with respect to the Tabarreña Fm. The dominant quartzite clasts are mainly subrounded, although subangular and well-rounded specimens also appear (Fig. 13). The conglomerates are clast-supported and matrix (generally sandy) is almost absent. Some sandstone beds, with poorly developed internal sedimentary structures, such as planar cross-stratification and current ripples, are intercalated with the conglomerates, (López-Gómez and Arche, 1997).

From the ridge, an excellent panoramic view of the different subdivisions of the conglomerates can be observed (Fig. 12). The conglomerates have been divided into 17 tabular bodies separated by second-order bounding surfaces (Miall´s 5th order). In addition, the entire section can be divided by means of major boundary surfaces (Miall´s 6th order), into four subunits, the Lower, Upper-1, Upper-2, and Sandy conglomerates. The latter subunit represents a change, or reorganization, along in the basin margin passing from alluvial fan deposits into braided deposits, and from paleocurrents normal to the axis of the basin to parallel (López-Gómez and Arche, 1997). Low and high angle planar cross stratification are the most common internal structures, with rare trough cross-bedding, clast imbrication and reactivation surfaces also present. Each conglomerate body can be interpreted in terms of braided channel deposition; longitudinal and transverse bars have been recognized. In general, the sedimentary characteristics and detailed measures of paleocurrents (trending to the E) of the lower part of the formation suggest deposition in an alluvial fan system. In the upper part of the formation, the marked decrease in grain size and the abundant sandy matrix, together with an increase of sandy bodies is interpreted as transverse and linguoid conglomeratic bars, sandstone dunes, and a SE general paleocurrents direction, that suggest a change to a braided fluvial system (Fig. 7.2).

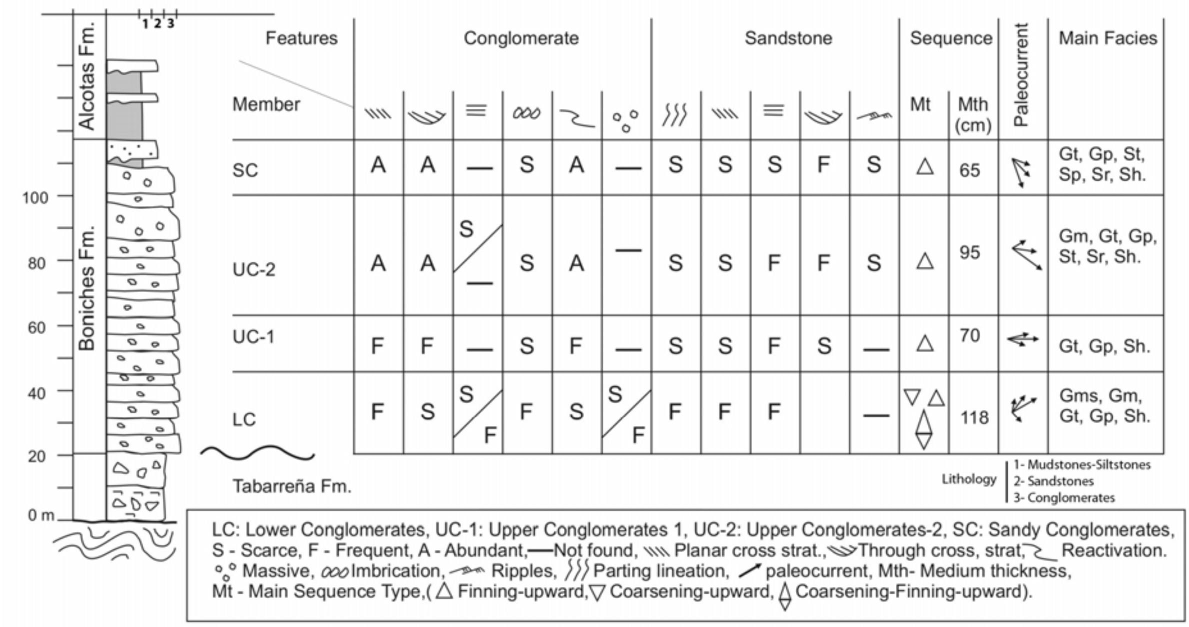


Fig. 13: Stratigraphic log and main sedimentary structures observed in the conglomerates of the Boniches Fm. at the Barranco del Rey section (Stop 2). Modified from Arche and López-Gómez (1997). Facies nomenclature from Miall (1996). Lithology: a- Fine-grained sandstone or siltstone; b- Sandstone; c- Conglomerate.

Deposition of the Boniches Fm. occurred in a humid climate as suggested by the internal sedimentary structures of the conglomerates, indicating frequent depositional events, with continuous transport and deposition by running water, which leads to reworking of coarse clasts, removal of finer clastics, and poor preservation conditions for paleosols. In addition, the relatively abundance of kaolinite, possibly derived from kaolinitic saprolites developed on the Variscan basement, suggests a humid or seasonally humid climate in the source area (Alonso-Azcárate *et al*., 1997).

Stop 3

Alcotas Fm.: Development of the rift basin

(Middle-Late Permian)

Location: From the stop 2, walk back to the road and take the coach towards Cuenca city. Turn at the intersection with the N-420, drive 420 m towards Cañete and park in the entrance of an old abandoned house (Fig. 8). From this point, walk back some meters 230 m along a narrow path way going parallel to the main road until reaching a point from which it is possible to observe the contact between the Silurian basement and the red siltstones, sandstones, and conglomerates of the Alcotas Fm (Fig. 14).

Fig. 14: The Alcotas Fm. on the slates and quartzites of the Silurian basement. See interpretation in figure 16.

Observations: At this locality, both the Tabarreña and the Boniches Fms pinch out against the Paleozoic basement when compared to the previous stop. The Alcotas Fm. represents a different sedimentary environment in comparison with the two previous ones. It has a wider geographical extent, and a greater paleontological content and lithological variety. The sedimentology of the Alcotas Fm., and its northwestern equivalents, has been reviewed by López-Gómez and Arche (1986), Sopeña *et al*. (1988), and Arche and López-Gómez (1999a; 2005). The formation has been divided into three subunits (Fig. 15): Lower (LP), Middle (MP) and Upper (UP) (Arche and López-Gómez, 2005; De la Horra *et al*., 2008). The formation is interpreted as sandy or gravely braided and meandering fluvial systems, located in extensive floodplains, with rare small, scarce and isolated ponds, as well as several prominent pedogenic horizons. Most of the paleocurrents are oriented towards the SE. In detail, the three parts of the Alcotas Fm., show characteristic sedimentological features typical of fluvial environments (De la Horra *et al*., 2008).

At this stop, we focus on the Lower Subunit which consists of large lensoid sandstone bodies with erosional bases and flat tops, interbedded with massive red siltstones containing carbonate paleosols (Fig. 16).

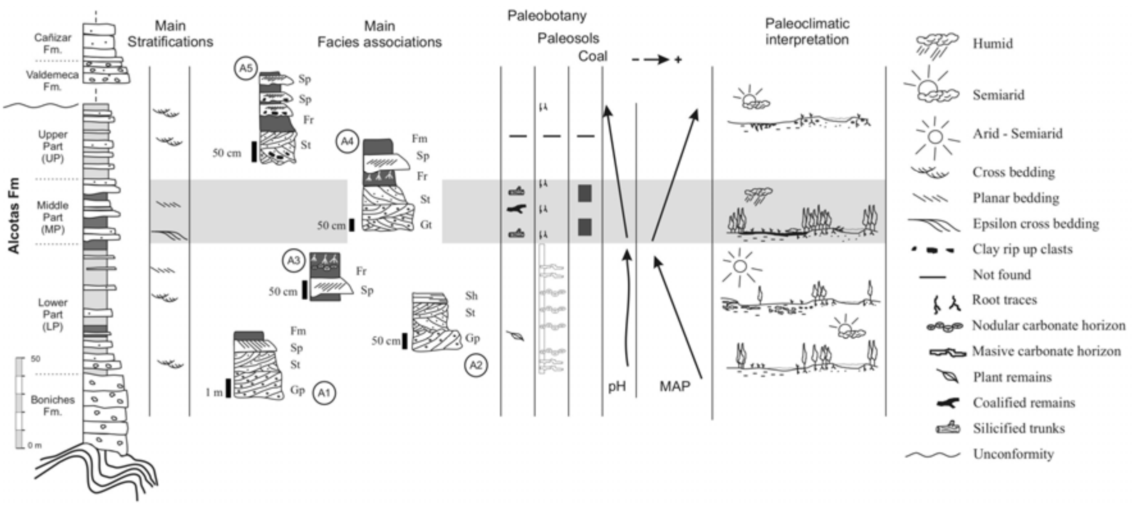


Fig. 15: Summary log of the Alcotas Fm., with main facies associations, paleobotanic data and paleoclimatic interpretation. Modified from (De la Horra *et al*., 2008; 2012). MAP: Mean Annual Precipitation.

Towards the base of some nearby sections, there are also thin conglomerate horizons. The sand bodies are arranged in incomplete fining-upwards sequences with trough and planar cross-stratification at the base, and current ripples and bioturbated siltstones at the top. This part of the Alcotas Fm. is interpreted as having been deposited in a permanent to semi-permanent sandy braided river system flowing towards the SE and crossing extensive floodplain areas. Active channels show evidence of instability and high avulsion rates (Arche and López-Gómez, 2005).

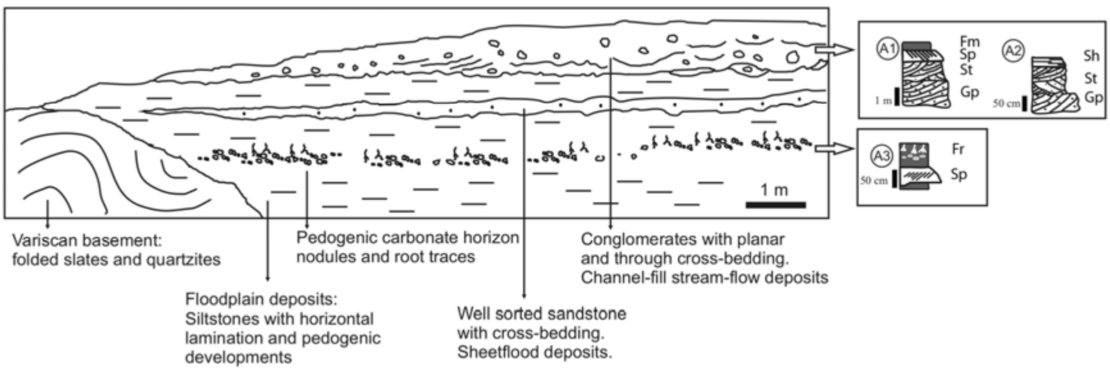


Fig. 16: Sketch of the outcrop at stop 3. The influence of paleorelief was important during the first stages of development of the basin. The Alcotas Fm. directly overlies the Variscan basement. The Tabarreña and Boniches formations are absent at this location. A1 to A3 represent the main facies associations.

The Middle Subunit is characterised by the predominance of sandstone bodies with epsilon cross-stratification (lateral accretion) structures, abundant plant remains and rare coal beds. A wider range of paleocurrents are observed (N60º to 265º). This subunit was interpreted as a permanent sandy fluvial system with medium-high sinuosity of vegetated banks (Arche and López-Gómez, 2005) (Fig. 7.3).

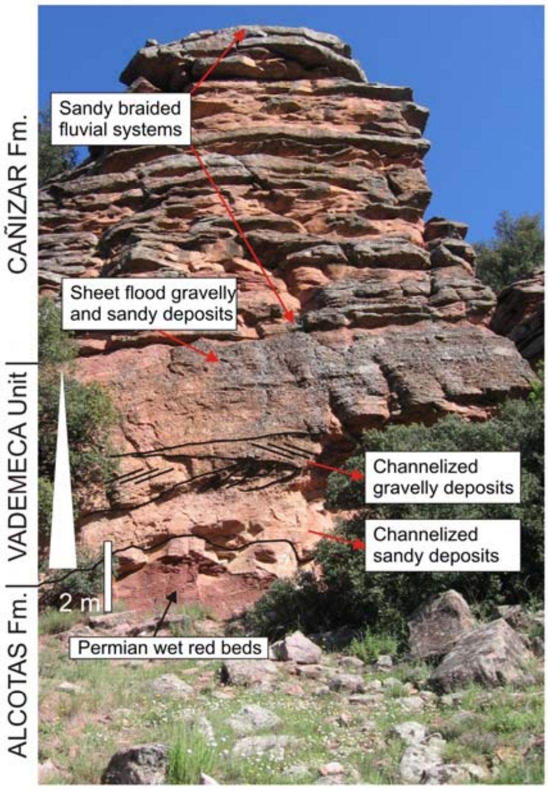
Finally, the Upper Subunit is interpreted having been deposited in semi-permanent sandy braided river systems, generally isolated in extensive floodplain areas (Arche and López-Gómez, 2005). The sandstone bodies are normally single storey, although a few multi-storey bodies were also observed.

A regional biotic crisis is described on the basis of palynological analysis (Dieguez *et al.*, 2005), and the absence in the whole basin of macro- and microflora, coal levels, and paleosols, but also with a change of fluvial style from meandering to braided systems (De la Horra *et al.*, 2008). These characteristics are associated with changes in the mineralogy and geochemistry that indicate significant environmental changes including a shift to high weathering conditions. Although climatic and tectonic factors have been considered, the biotic crisis and associated anomalies described are consistent with other Middle–Late continental basins related with mass extinctions. The regional character of the extinction interval and its proximity with the Middle–Late Permian transition biotic crisis detected in the Alcotas Fm. could be related with the global mid-Capitanian biotic crisis described in this period of time in other marine basins (De la Horra *et al.*, 2012).

Stop 4

Valdemeca Unit: Beginning of the Mesozoic cycle

(Early Triassic)



Location: Take the coach and travel west towards the city of Cuenca city. Stop in Km 1.3 north of Casas del Cañizar (Cañizar in figure 8). Climb the slope towards the cliff formed by the sandstones in the "Buntsandstein" facies.

Observations: An erosional unconformity separates the upper part of the Alcotas Fm. and the base of the Valdemeca Unit, which represents the first sedimentary unit of Triassic-age in the area (Fig. 17).

Fig. 17: Interpreted outcrop at stop 4.

Some of the sedimentary characteristics of the Valdemeca Unit include planar stratification and cross-bedding, lateral accretion in the channels, ripple cross-lamination with inverse grading, very well sorted and rounded grains, polished pebbles with depressed facets (dreikanter or ventifacts) and deflation lags (Fig. 18). The Valdemeca Unit is performed by sandy and gravelly channelized stream deposits with a radial pattern of paleocurrents, and unconfined sheet flood deposits associated with stream-channel alluvial-fan systems.

The presence of intercalated windblown desert sands and wind abraded clast or ventifacts, together with the general absence of a vegetated cover, are suggestive of arid to very arid climatic conditions probably coincident with the dry period described for the middle-late Smithian in Central-Western Europe (Durand, 2006; Bourquin *et al*., 2011).

We will discuss in the field the depositional model for this unit, its age, its relation with the overlying Cañizar Fm., and the significance of the observed features in relation to an arid climate.

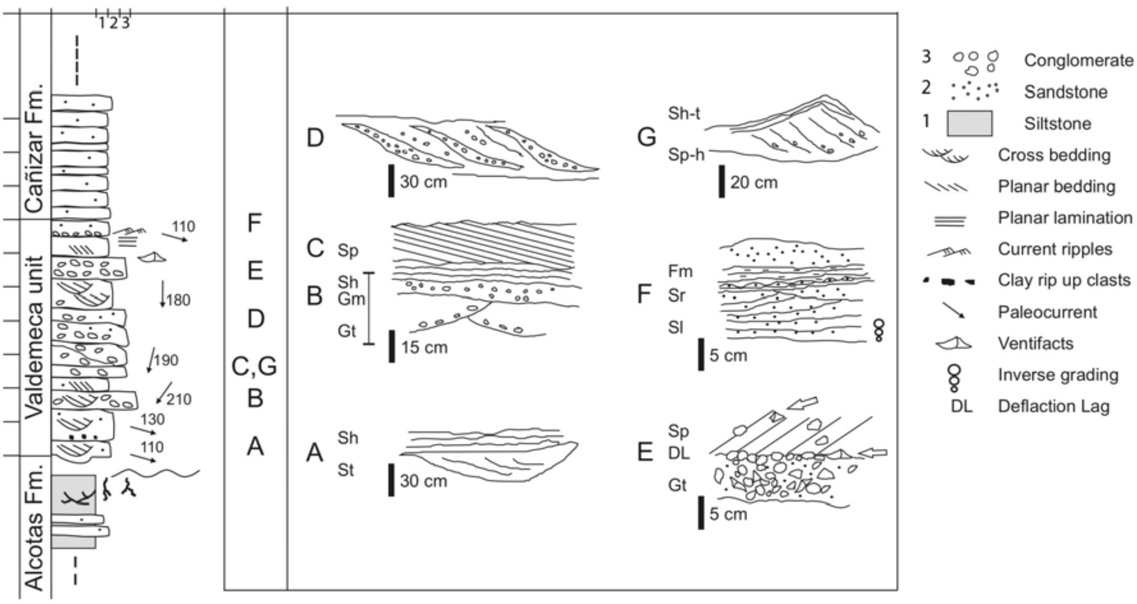


Fig. 18: Stratigraphic log and main sedimentary structures of the Valdemeca Unit in the Cañizar area. Although most of the structures are interpreted as the result of fluvial processes, some aeolian influences can be observed, such as faceted pebbles (dreikanters or ventifacts). A- G: facies associations.

8. SECOND DAY: BONICHES AND HENAREJOS AREAS

There are three stops in the second day, one focusing on the upper unit of the Buntsandstein in this area (stop 5), and the last two ones dedicated to the first and second marine incursions of the Tethys Sea (Muschelkalk facies) in the eastern Iberian plate during the Middle Triassic (stops 6 and 7, respectively). The first and second stops are located in the Boniches anticline, while stop 7 is located near Henarejos village, a half-hour travel towards the east (Fig. 8).

Stop 5

Cañizar Formation: Climax of the syn-rift phase
(Early-Middle Triassic)

Location: Take the N 420 from Cañete, heading to Cuenca city, until we come to a water gauge station after 15.2 km, (there it is possible to park the coach). The section at this stop begins on the opposite side of the road (Figs. 8, 19).

Observations: Based on detailed facies analysis, this unit was initially interpreted by López-Gómez and Arche (1993a), Arche and López-Gómez (2005) and López-Gómez *et al*. (2012) as a braided fluvial system where floodplains were either not developed or preserved due to total lack of vegetation and unstable channel banks. The rivers flowed to the SE and consist of bars in channels that were rapidly abandoned. In some cases, channel fill ends shows evidence of reworking of the top as a result of aeolian processes. This comprises cm-dm high-angle cross stratification with very well rounded grain horizons (Fig. 20).

Fig. 19: General aspect of the Cañizar Fm. at stop 5.

Most of the unit was deposited under alternating dry-wet seasonal conditions. However, some isolated paleosols and roots prints occur in the upper part of the formation, indicating a change to more humid conditions (Fig. 21). This unit represents a period of relatively tectonic stability and shows the beginning of the biotic recovery after the Permian-Triassic crisis (Galán-Abellán, 2011; Galán-Abellán *et al.*, 2013b). The bounding surfaces can reflect subtle topographic changes after movements in the faults. The SW margin of the Iberian Basin is dominated by fluvial sediments. Rivers were sourced in distal, humid areas to the NW. The NE margin of the basin and the Ebro Basin only received occasional fluvial input from local sources and were dominated by aeolian sediments (Fig. 21) (López-Gómez *et al.*, 2012).

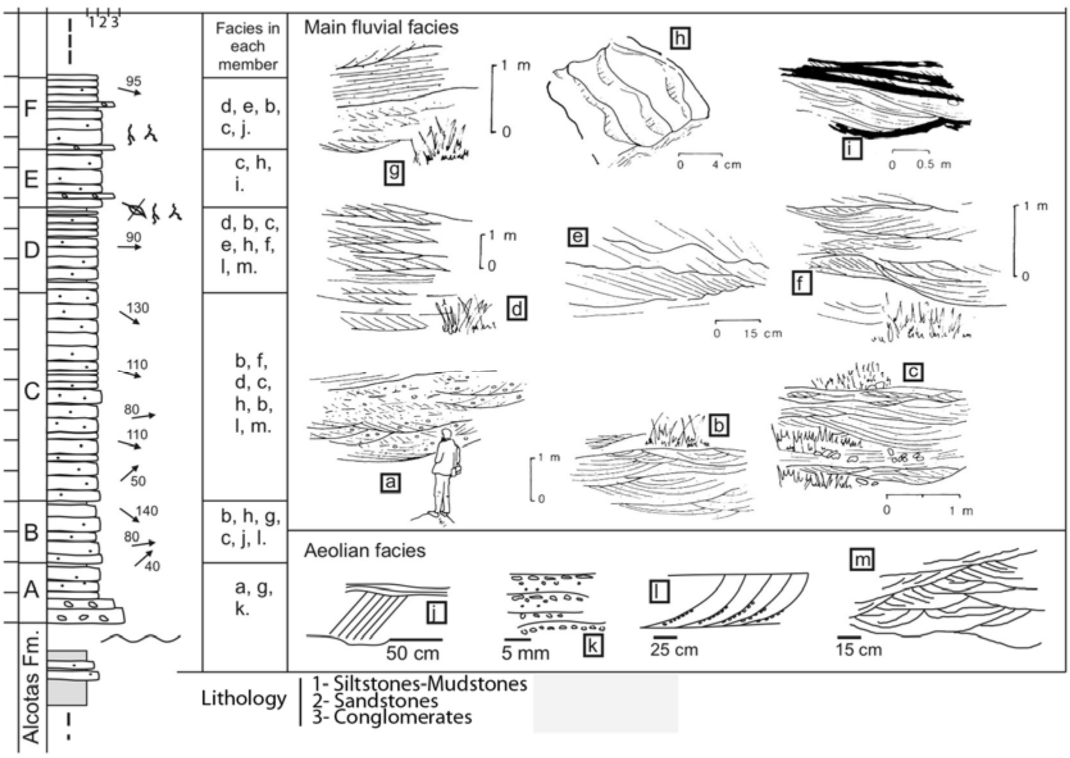


Fig. 20: Stratigraphic log and main sedimentary structures of the sandstones of the Cañizar Fm. in the Cañizar area. A to F: members; a to m: differentiated facies. Modified from López-Gómez and Arche (1993a).

Facies: a- Sandy conglomerates and pebbly sandstones with planar and trough cross-stratification, b- Medium-scale trough cross-bedded sandstones with rippled intervals, c- Small-scale trough cross-bedded sandstones with rippled intervals, d- Large-scale planar tabular cross-bedded sandstones, e-Large-scale planar cross-bedded sandstones with reactivation surfaces, f- Small-scale planar tabular cross-bedded sandstones, g- Parallel laminated sandstones, h- Current-rippled sandstones, i- Massive mudstones-siltstones with intercalated current-rippled sandstones, j- High-angle planar cross-stratified well-rounded grain sandstones, k- Thin-layered of inverse-graded medium to coarse and well-rounded grain sandstones, l- Grain flow in high-angle asymptotic foresets of planar cross-stratified well-rounded grain sandstones, m- Fine to medium-grained, well-sorted containing subangular to well-rounded quartz grains with planar-shaped and trough-shaped tongues of inversely graded sand between 10 to 20 mm thick.

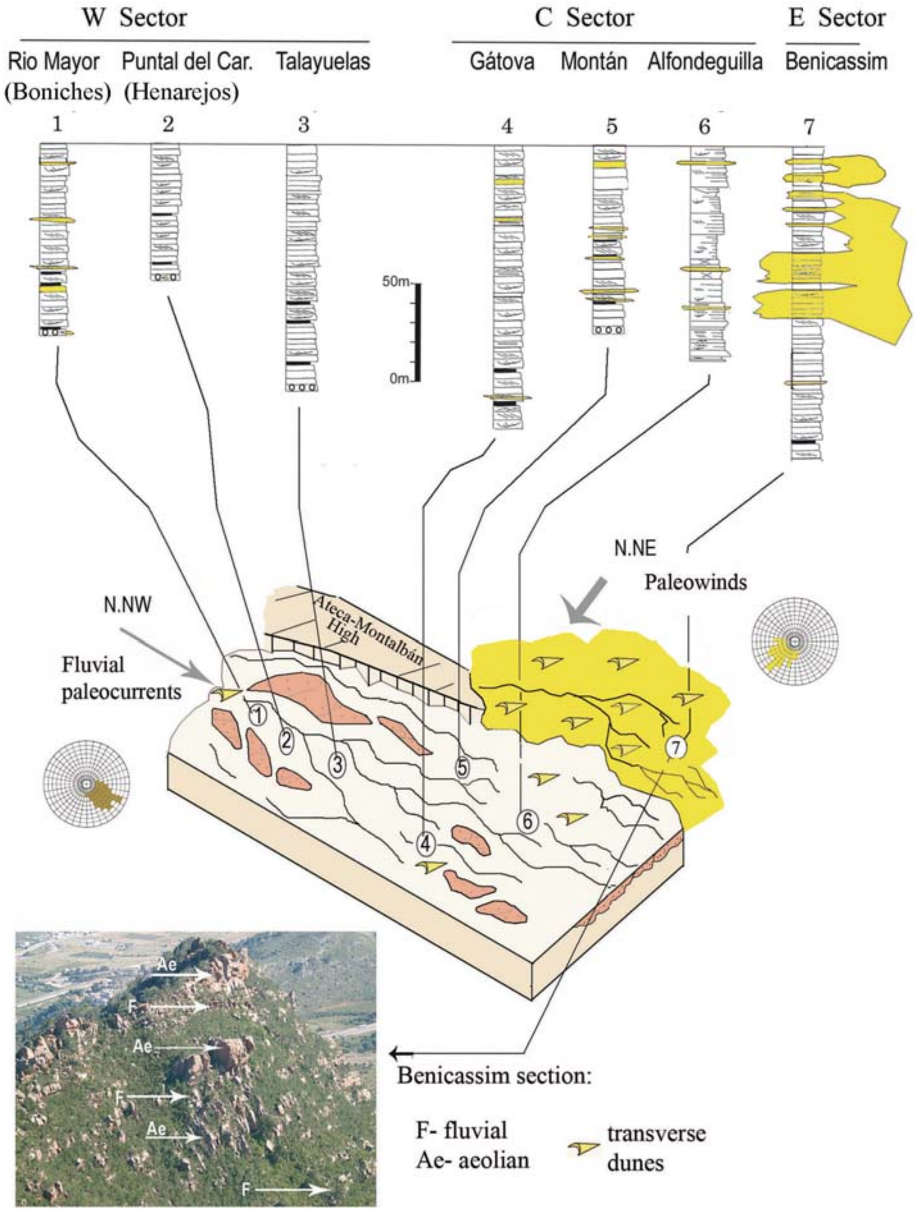


Fig. 21: Paleogeographical reconstruction of the Cañizar Fm. in the Iberian Ranges showing fluvial dominance in the western area and Aeolian-fluvial towards the eastern areas. Stop 5 belongs to the Río Mayor section. Palaeohighs, as the one of Ateca-Montalbán (see also figure 3), constituted clear barriers during the sedimentation of the tectonically stable stage (mainly during the Spathian) in which the Cañizar Fm. was deposited. Modified from López-Gómez *et al*., 2012).

Stop 6

The Landete Formation: First incursion of the Tethys Sea in the Iberian Plate (Anisian, Middle Triassic)

Location: In the road CM-215, at the exit of the Boniches village, take a local road that follows about 3.2 Km up the Cabriel River (total travel is about 15 minutes) (Fig. 8).

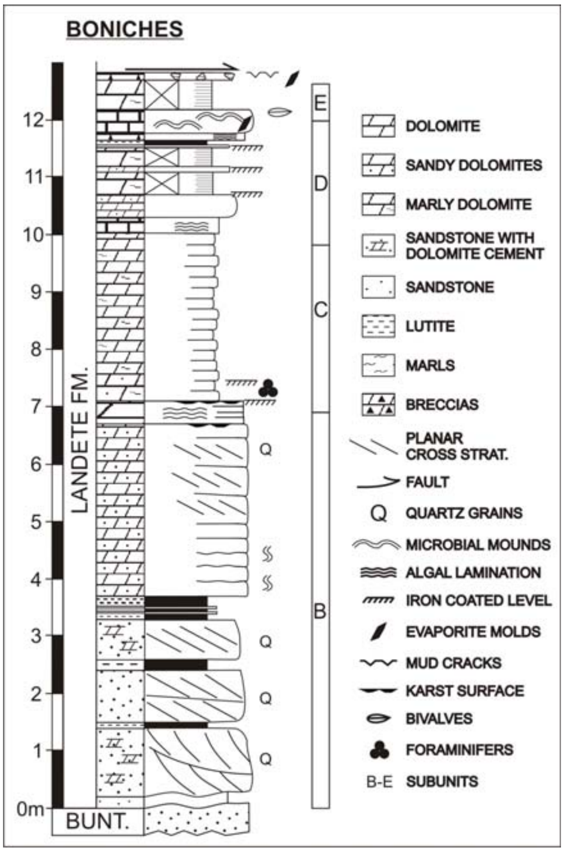


Fig. 22: Section of the Landete Fm. (Anisian) east of Boniches village. This unit is mainly constituted by dolomites and represents the evolution of a shallow ramp showing a general transgeressive-regressive trend developed during the first incursion of the Tethys sea in the Iberian Plate during the Triassic.

Observations: The Landete Fm. represents the first marine transgression of the Tethys sea (Illyrian, middle Anisian) in the Iberian Plate during its westward propagation. The Landete Fm. was deposited on the Cañizar Fm. The contact between these units represents a sedimentary gap that covers all the early Anisian (about 1 M.a.). During that time of non-deposition, the area was subaerially exposed, representing a non-subsiding area controlled by major NE-SW oriented faults. These faults were related to the new rift system that was opening from the NE, and following main Central Europe orientations (Arche and López-Gómez, 1996).

The visited outcrop shows the evolution of a shallow ramp, with a general transgressive-regressive trend (López-Gómez *et al*., 1998). It starts with a basal sedimentary lag deposit, related to the removal of the previous continental sediments during the marine transgression. After this basal bed, a shallow carbonate ramp was developed. Different facies can be observed in the outcrop (Fig. 22), which represent shallow marine deposits of sub, inter and supratidal environments. The small low thickness of the unit and the presence of surfaces of subaerial exposure (paleokarst) suggest the dominance of low subsidence rates in the area. Signals of interruption and arrival of continental waters can also be observed indicating the proximity of the border of the basin. Based on biostratigraphic data, the age of this unit has been recently revised as Pelsonian-Illyrian (middle to late Anisian) (Escudero-Mozo *et al*., 2012).

Stop 7

The Cañete Formation: Second incursion of the Tethys Sea in the Iberian Plate (Ladinian, Middle Triassic)

Location: From Boniches village, take local roads and drive SE to Henarejos village (Fig. 8). From Henarejos, continue the road to Garaballa and stop at Km 2.9, where the outcrop is located just along the local road, a few meters from the river and a picnic area. Total travel time from Boniches is about 25 minutes.

Fig. 23: The Cañete Fm. at stop 7

Observations: The second main transgressive pulse of the Tethys Sea during the Middle Triassic caused a larger, widespread marine incursion in eastern Iberia and developed wide carbonate ramps, dominated by shallow water marine deposits, now represented by the Cañete Fm. (Figs. 23, 24). For the first time during the Triassic, very uniform environmental and depositional conditions prevailed over vast areas of the Eastern Tethys Domain. This new scenery was in part controlled by the general thermal subsidence regime that prevailed in the area during the sea-level rise period (Arche and López-Gómez, 1996; van Wees *et al*., 1998; Vargas *et al.*, 2009). The second transgression of the Tethys Sea on the Iberian Plate took place after an important regressive stage represented by El Mas Fm. constituted by clays, marls sandstones and gypsum. Lacking the El Mas Fm., an omission surface separates the two transgressive pulses.

The complete succession of this stop outlines a well-defined transgressive-regressive cycle. The section is 90m thick and consists of grey to ochre dolostones. Despite the pervasive dolomitization, the original, depositional features of the carbonates can be easily recognized. These features allow to define different facies and sequences of sub, inter and supratidal environments (López-Gómez *et al.*, 1993, 1998; Escudero-Mozo *et al.*, 2012). The age of this unit is Ladinian (Middle Triassic) deduced by the recovered Ammonite faunas (Goy, 1995). The general fossil content of this unit is listed in the appendix I at the end of this work.

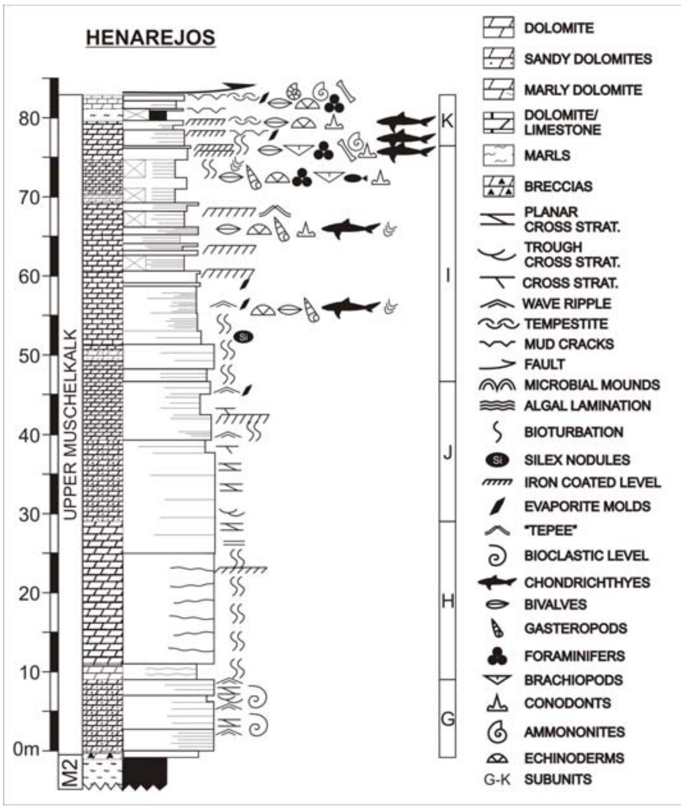


Fig. 23: Section of the Cañete Fm. (Ladinian) from the Henarejos area. This unit represents the second incursion of the Tethys Sea in the Iberian Plate during the Triassic. It is mostly constituted by ochre dolomites that represent the evolution of a shallow ramp with different sub-, inter- and supratidal environments showing a general transgressive-regressive trend.

9. THIRD DAY: PEÑARROYAS AREA (NE IBERIAN RANGES)

From Cañete, we take the N-420 road northward, traversing the Castilian Branch and the Calatayud-Teruel Tertiary Basin, a late, post-orogenic Alpine structure infilled by Miocene continental sediments. We reach the Montalbán area at the Aragonian Branch, where the next stops are located (Fig. 24).

The Aragonian Branch of the Iberian Ranges was the SW border of the Ebro Basin during the Triassic (Fig. 3), and was separated from the Iberian Basin by the Ateca-Montalbán high. Both basins merged in the Maestrazgo area, to the SE. The sedimentation started in the Aragonian Branch with the Araviana Fm. (Arribas, 1985; Fig. 25), subdivided into the Moncayo Mb. and the Tabuenca Mb. The Moncayo Mb is composed of conglomerates organized in a fining-thinning upwards sequence, interpreted as retrograding alluvial fan facies (Díez *et al*., 2007). The Araviana Mb. is composed by siltstones and rare sandstone levels, interpreted as lake deposits and distal braided rivers and floodplains. No palynological assemblages have been found in the Araviana Fm., but this unit is correlated with the Boniches and Alcotas Fms. of the Iberian Basin, and thus, a Thüringian (Middle-Late Permian) age is attributed to this formation (Arche *et al*., 2004; Díez *et al*., 2007).

Fig. 24: Itinerary for the third and fourth day stops in the Montalbán-Peñarroyas-Torre de las Arcas area.

A new sedimentary cycle of Triassic age starts with the Tierga Fm. (Fig. 25). From base to top, it is subdivided into: Aranda Mb., Carcalejos Mb., and Rane Mb. The Aranda Mb. unconformably overlies the Tabuenca Mb. and consists of medium grained sandstones and interbedded siltstones. It is correlated with the Cañizar Fm. (Arche *et al*., 2004). The equivalent of the Valdemeca Unit is absent in the Aragonian Branch. The Rane Mb. consists of alternations of sandstones and siltstones. It contains rich macroflora and palynological assemblages of early-middle Anisian age (Díez *et al*., 2007) and it has been correlated with the Eslida Fm.

The Röt facies and the Landete Fm. of the Castilian Branch correspond to the Cálcena Fm. of the Aragonian Branch. The Illueca Mb. corresponds to part of the Landete Fm. and thick towards the SE of the Aragonian Branch in the Montalbán area. It contains palynological assemblages of Anisian age (Diéz *et al.*, 2007). The Cañete Fm. of the Castilian Branch is correlated with the unnamed "calcareous group" of Arribas (1985).

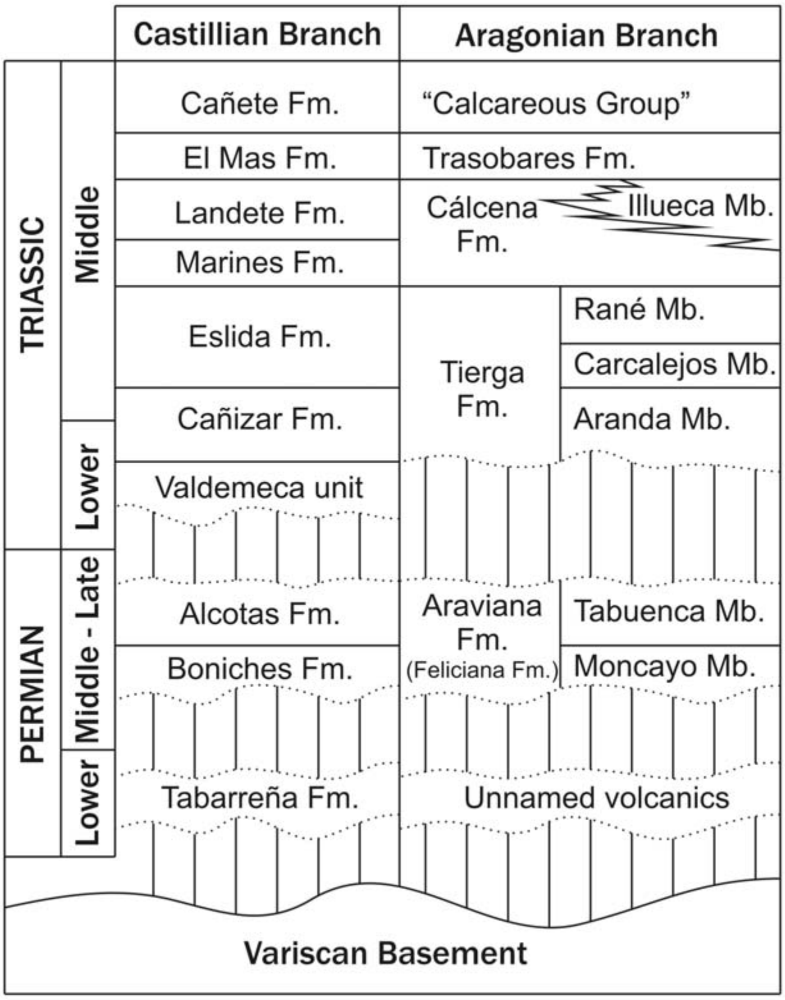


Fig. 25: Correlation panel of the SE Iberian Basin and the Aragonese Branch. Based on Arche *et al*. (2004) and Diez *et al*. (2007)

Stop 8

Eslida Formation (or B-2 Unit): Connection of the rift systems (Anisian, Middle Triassic)

Location: From Cañete, take the coach and travel northward to the city of Teruel along the N 420 road (c. 1.1 hr) and continue along the same road until coming to Montalbán-Peñarroyas area (c. 50 min) (Fig. 24). The first observation point is at the entrance to the village of Peñarroyas, where there is a parking area. At this point, it is possible to observe very well the exposed Carboniferous (turbidites) basement. Cross the village and follow a narrow way for 500 m that goes towards a cliff. At this point the Cañizar Fm. is well exposed. Follow the path 800 m, to reach the col where the Eslida Fm. is well exposed (Fig. 26).

Fig. 26: The Eslida Fm. under the carbonates of the Cañete Fm. at stop 8. The equivalent of the Cañizar Fm. of the Iberian Basin can be observed at the right lower corner of the picture.

Observations: In the Peñarroyas area, the B-1 Unit, interpreted as having been deposited in braided fluvial systems (Aurell *el al*., 2001), corresponds to the Cañizar Fm. and the Aranda Mb. (Fig. 25). Along the southern border of the Ebro Basin, the B-1 Unit has been interpreted as an aeolian complex (erg) with some wadi deposits at the base by Soria *et al*. (2011). As most of the sediments in this section and others around the Montalbán anticline are of aeolian origin, the extreme arid conditions of this area contrast with the coeval dominant fluvial sediments of the Cañizar Fm. in the Castilian Branch (López-Gómez *et al*., 2012) (Fig. 15). The aeolian deposits at the base of the Triassic-age sections of the Río Martín and Hoz de la Vieja areas are approximately coeval with the fluvial deposits of the Cañizar Fm. in the Cañete region (López-Gómez *et al*., 2012) and may represent a time interval of c. 1 Ma or more. This residence time for the aeolian sands could be equivalent to the present-day Namib Erg (Vermeerch *et al*., 2010).

On top of the B-1 Unit, the B-2 Unit is well exposed. This latter unit is the focus of this stop (Fig. 27). The B-2 Unit has been interpreted as alluvial by Aurell *et al*. (2001), and corresponds with the Rané Mb. in the Aragonian Branch (Fig. 25; Arribas, 2005) and the Eslida Fm. of the Iberian Basin (Fig. 25; Arche and López-Gómez, 1999b)

The Eslida Fm. was studied and interpreted in detail in the province of Castellón, 110 km east of the Peñarroyas area (Arche and López-Gómez, 1999b). In Peñarroyas area, sandstones were interpreted as representing the infilling of fluvial channels in mainly braided and sometimes meandering systems. Siltstones were interpreted as floodplains deposits, crossed by the fluvial channel systems and crevasse splay deposits. However, some parts of the succession of this unit, mainly in the upper half, show also evidence of aeolian deposits (Fig. 27; López-Gómez *et al*., 2011).

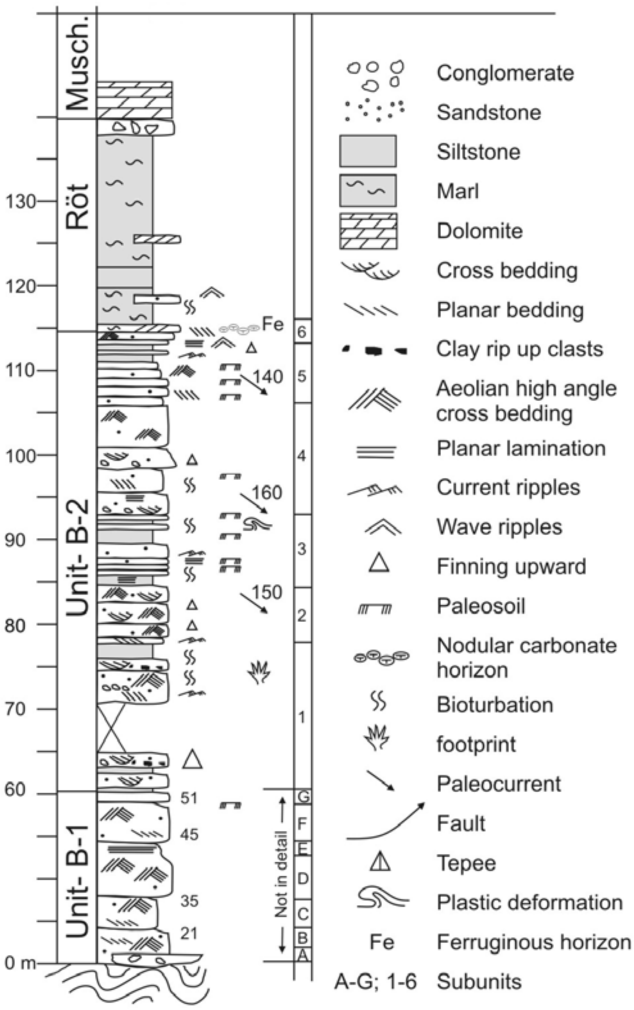


Fig. 27: Section of the Eslida Fm. (or B-2 Unit) (Anisian) near Peñarroyas village. This unit is conformably on the Cañizar Fm. (or B-1 Unit) and is mainly constituted by intercalated sandstones and siltstones related to fluvial but also aeolian deposits.

The local aeolian sedimentary structures in the Montalbán-Peñarroyas section are not present in many of the other areas of the Iberian Ranges where the Eslida Fm. crops out (Arche and López-Gómez, 1999a, b). The underlying Cañizar Fm. (i.e. B-1 Unit of Aurell *el al*., 2001) in this area shows also general aeolian characteristics which are rarely evident in other areas of the Castilian Branch, and thus we have to consider that the northern margin of the Aragonese Branch of the Iberian Ranges was acting as an important barrier for the dry winds coming from the north (and central Europe), as described by Bourquin *et al*. (2011). Additionally, the presence of common plants fragments and well-developed paleosols indicate an evolution towards more humid conditions for this unit when compared with the underlying Cañizar Fm. (B-1 Unit).

An outstanding feature, is that this unit only occurs in the eastern parts of the Iberian Basin and the Ebro Basin, where rapid subsidence during the early Anisian (Arche and López-Gómez, 1999b), resulted in the formation of significant accomodation space. This was due to the reactivation of a NNE-SSW rift system that linked other subsiding branches of the SW European Plate (Arche and López-Gómez 1996).

Stop 9

The Landete Fm. (Anisian, Middle Triassic) in the "Levantine Muschelkalk" paleogeographical context.

Location: Follow the path across the Eslida Fm from the stop 8 and reach the last meters of this unit.

Observations: The transition from the Buntsandstein facies and the Landete Fm. in Muschelkalk facies is represented by the Marines Fm. in Röt facies (Fig. 25). The main objective of this stop is the Landete Fm (Fig. 28).

Fig. 28: The Landete Fm. at the Aragonese Branch.

The Landete Fm. in this area is very close to the Levantine-Balear Muschelkalk domain (López-Gómez *et al*., 1998), were the Cañete Fm. is on the Landete Fm. and the Mas Fm. is lacking in between (Figs. 2, 25). This stop shows a well exposed outcrop with the complete Landete Fm. Facies, sedimentary cycles, and sequential stratigraphic represent the first incursion of the Tethys Sea in this area (Fig. 29).

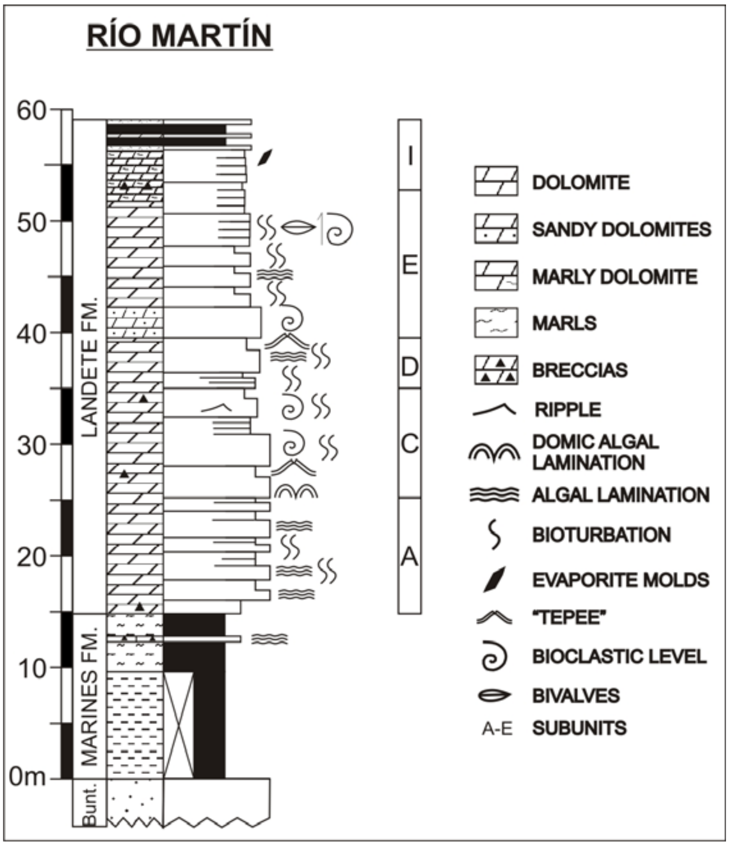


Fig. 29: Section of the Landete Fm. (Anisian) near Peñarroyas village. This unit lies conformably on the Marines Fm. (Röt, facies) showing a clear transitional contact between the Buntsandstein and the Muschelkalk facies.

The Landete Fm. reaches 44 m of thickness in this area and is mostly defined by a succession of small-scale carbonate cycles of peritidal origin. It shows a general transgressive-regressive trend from the upper part of the Marines Fm. to the top of the unit. In this section, the carbonate facies of the Landete Fm. shows different characteristics when compared to the ones observed in the Castilian Branch, especially in base of the unit, as the calcarenitic facies are absent in this area. Vertical stacking patterns of these cycles allow a quantitative approach to accommodation changes throughout the unit, which will be discussed in the field.

10. FOURTH DAY: TORRE DE LAS ARCAS AND HOZ DE LA VIEJA AREAS (NE IBERIAN RANGES)

This day is the last one of the field trip and it is constituted by three stops around Montalbán anticline area: the first two near to Torre de las Arcas, and the last one near to Hoz de la Vieja.

Stop 10

The Feliciana Fm. (Middle-Late Permian) and its unconformity with the Triassic Buntsandstein sedimentary cycle near Torre de las Arcas.

Location: We travel by coach eastward from Utrillas village, crossing Montalbán village and continue until reaching deviation to TE-1334 local road that ends in Torre de las Arcas village (Fig. 24). The stop is located 1.100m to the left of the road before reaching the village.

Observations: The Permian continental succession unconformably below the Buntsandstein sedimentary cycle. The Permian rocks in this area are represented by the Feliciana Fm., described by Marin (1974). It consists of angular to subangular conglomerates with intercalated sandstones showing important lateral thickness variation. In this stop, this unit is just 5 m thick and it is mainly represented by different fining-upwards sequences 0.55m-1.45m thick representing gravelly braided fluvial deposits. They show channel-fill deposits and sandy abandon facies at the top of the sequences where roots related to soils are developed (Fig. 30). An important point of this stop is the unconformities that this unit shows on the quartzites of the basement and the unconformably contact above with the Buntsandstein sedimentary cycle.

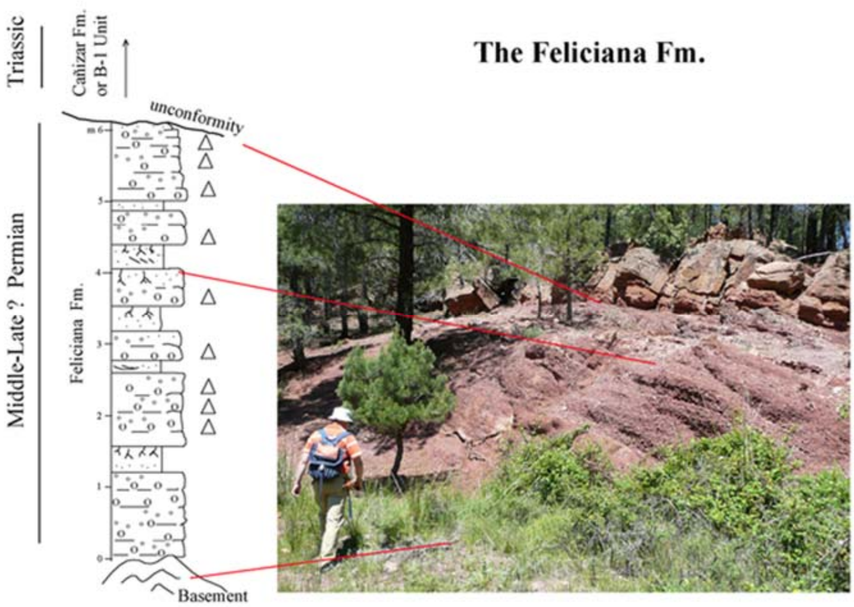


Fig. 30: Section of the Feliciana Fm. (Permian) near Torre de las Arcas showing the unconformities with the basement and the Buntsandstein sedimentary cycle above.

Stop 11

The Marines Fm. (Röt facies) and the transition to the Muschelkalk facies near Torre de las Arcas.

Location: This stop is located 130m of the previous stop following the TE-1334 road towards Torre de las Arcas.

Observations: The complete Marines Fm (Fig. 31). and its transitional contacts with both Eslida Fm. (below) and the Landete Fm. (above). From the distance it is also possible to observe the whole Muschelkalk facies and the transitional contact with the Keuper facies.

Fig. 31: The Marines Fm. on top of the Eslida Fm. Note the presence of red lutites and the levels of evaporites.

The Marines Fm. shows important lateral lithology changes (Fig. 32). In this area, it is represented by green marls, red lutites and yellow evaporites (gypsum) with scarce pink thin sandstone beds. It represents a coastal plain depositional environment which corresponds to the onset of the first marine transgression in the eastern Iberia. In this section, the Marines Fm. reaches 15.5 m (Fig. 32) and interesting sedimentary structures as ripples, mud-craks, tepee, cross-stratification and dissolution breccias can be observed. The outcrop clearly shows the progressive upwards increase of carbonate also identified by the change in colour of the beds.

At the end of this stop, following the road only 50m towards the village of Torre de las Arcas, it is possible to observe the whole Muschelkalk facies from a corner of the road. The Muschelkalk facies here is represented by the Landete Fm., the Cañete Fm. and the Mas Fm. in between. This latter unit, however, shows an important thickness reduction when compared with the western Iberian Ranges, reaching only 15m.

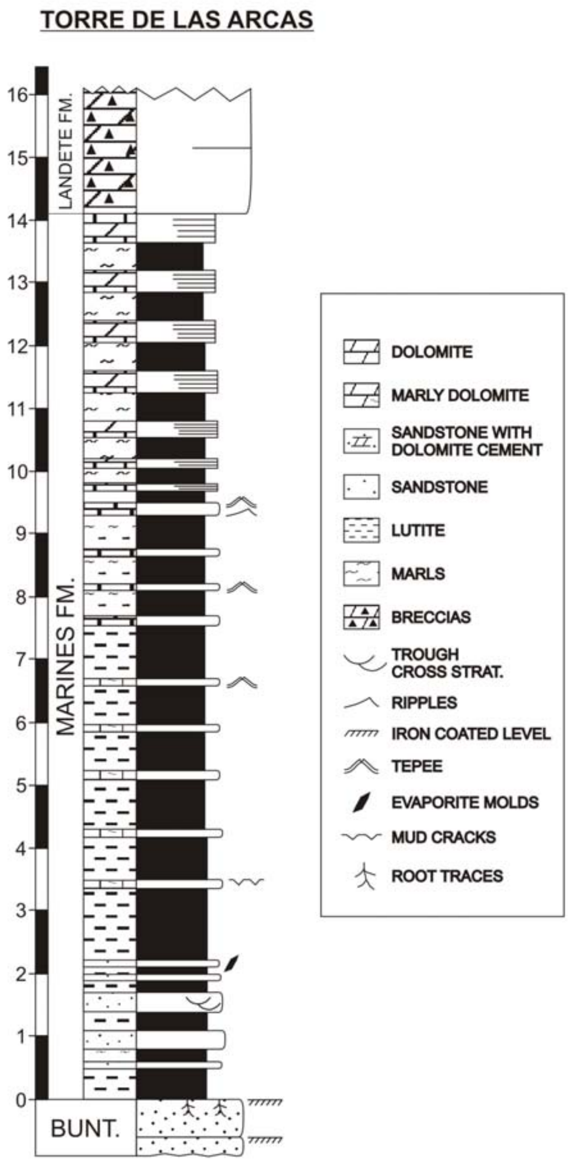


Fig. 32: Section of the Marines Fm. (Röt facies) near the Torre de las Arcas village. This unit shows a transitional contact with both Eslida Fm. (below) and the Landete Fm. (above).

Stop 12

Paleorelief of the Ateca-Montalbán High, Early Permian volcanic rocks and the Eslida Fm.: The Aragonese Branch of the Iberian Ranges and the margin of the Ebro Basin (Anisian, Middle Triassic)

Location: From Montalbán village, take the A-222 road to Zaragoza and stop 950 m before the village of La Hoz de la Vieja (Fig. 24).

Observations: There are three main points to observe at this stop: the characteristics of the underlying sills cutting the basement, the control of the basement on sedimentation, and the Eslida Fm.

The underlying basement in this section is cut by sills. These rocks, dark-yellow in colour, are composed of hipovolcanic intrusions (anfibolitic and pyroxene-rich andesites) with a calc-alkaline affinity (Fig. 33). K/Ar analyses indicate an age of 292 Ma (Lago *et al*., 2004a) and similar characteristics with other sills in neighbouring basins. The sedimentary characteristics of the Eslida Fm. at this stop are very similar to the ones observed at stop 8 (Fig. 34).

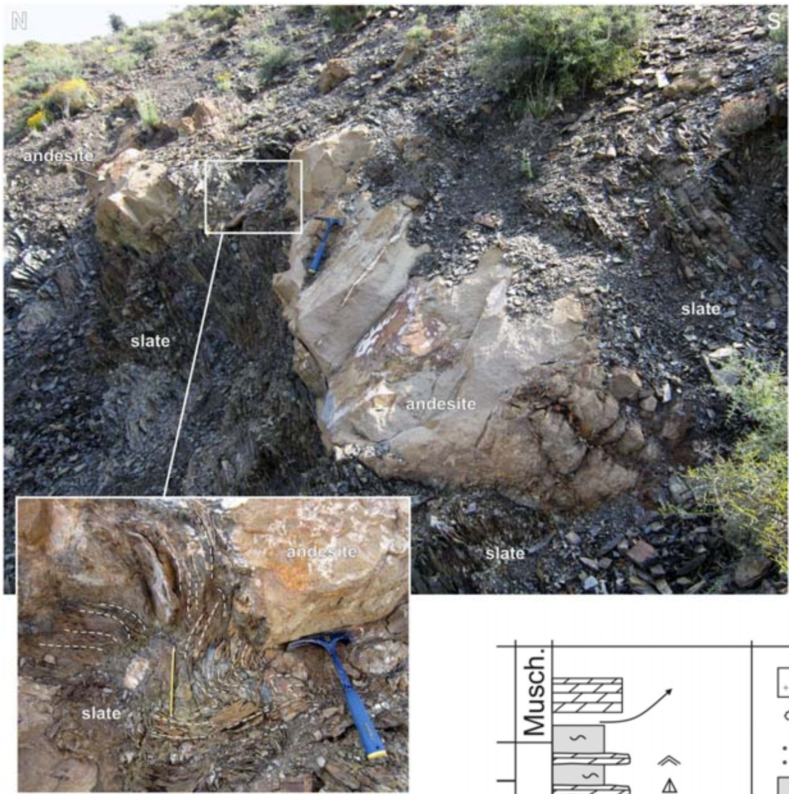


Fig. 33: The Paleozoic basement of slates cut by subvolcanics andesitis sills at stop 12.

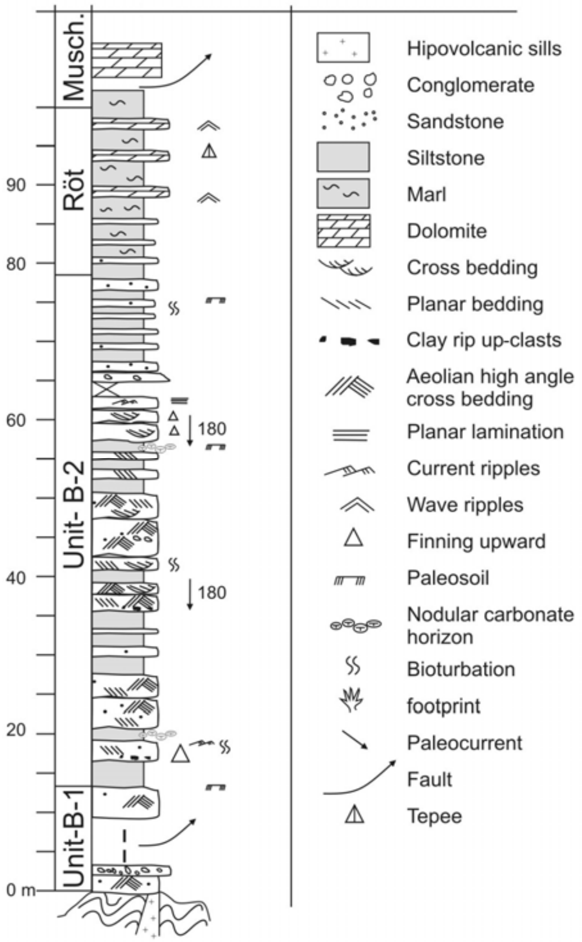


Fig. 34: Section of the Eslida Fm. and the Permian hipovolcanic intrusions of calc.alkaline affinity in the basement near Hoz de la Vieja village.

The control of the basement on Middle Triassic sedimentation is evident in this sector of the southern margin of the Ebro Basin (Fig. 3). At this stop, the Eslida Fm. (or B-2 Unit) is similar in thickness to the Peñarroyas area, but the Cañizar Fm. (or B-1 Unit) is reduced to < 50 % of the thickness observed there. However, moving to the NW, it is very clear that the total thickness of the two units progressively decreases over a few kilometers, and eventually they disappear and onlap against the Ateca-Montalbán High. There, the marine Middle Triassic in Muschelkalk facies, directly overlie the Paleozoic basement (Fig. 35).

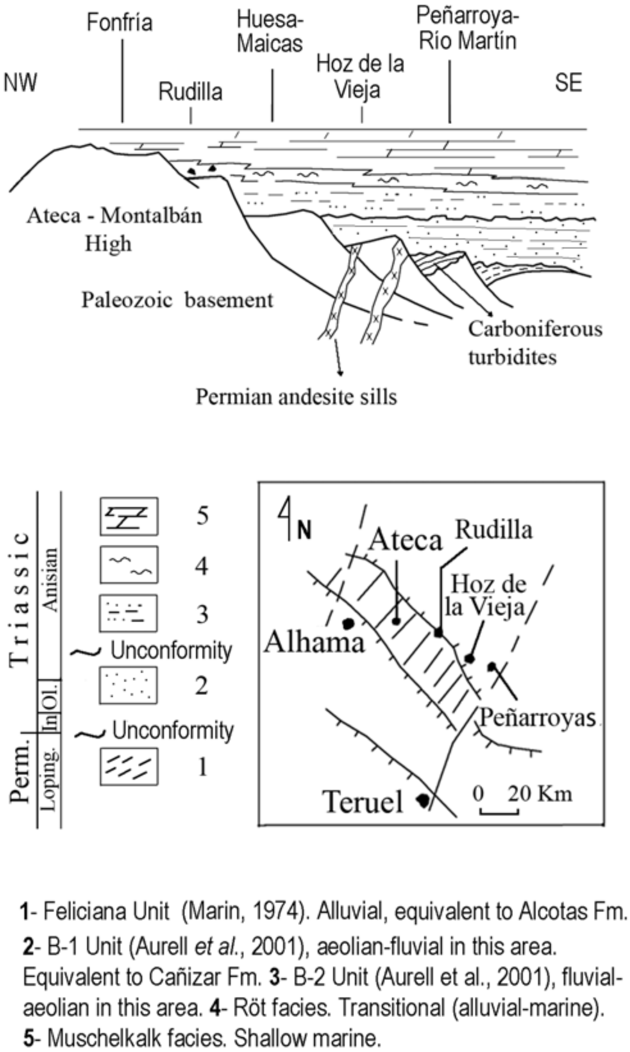


Fig. 35: Cross-section for the late Anisian along the Montalbán high area in the Aragonese Branch. See figure 1 for a more detailed location. There were different active highs controlling sedimentation up to Ladinian times. Some of these highs were controlling even the Middle Triassic Tethys incursions, but most of them were mainly active until the Early Triassic, as is also shown in figure 21.

The westward entrance of the Tethys Sea on the Iberian Plate shows a landward expansive onlap. This arrangement allowed the carbonate sediments of the Cañete Fm. to be deposited unconformably on the Variscan basement in some areas of the central Iberian Basin (Fig. 35). This situation contrasts with the eastern areas of this basin, where almost 900m of Permian-Triassic sediments were piled up before the sedimentation of the Cañete Fm. took place (Arche and López-Gómez, 2005).

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APENDIX I

Fossils described in the Landete and Cañete Fms. by Doubinger *et al*. (1990); Goy (1995), López-Gómez *et al*. (1998), Márquez *et al*. (2005), Diéguez and Barrón (2005), Plasencia (2009), Ros (2009), Escudero-Mozo *et al*. (2012).

Landete Fm.

Ammonoids: Schreyerites and Ptychitidae;
bivalves: *Astartellopsis* sp., *Burmesia posteroradiata* Cox, *Elegantina* sp., *Hoernesia socialis* (Schlotheim), *Hoernesia* sp., *Modiolus minuta* Goldfussi, *Modiolus* sp., *"Myophoria" orbicularis* Bronn, *Myophoria* sp., *Myophoria vulgaris* (Schlotheim), *Neoschizodus* sp., *Neoschizodus laevigatus* (Goldfussi), *Unionites fassaensis Wismanns*;
foraminifers: *Hoyenella sinensis* (Ho), *Glomospira cf. triphonensis* Baud, Zaninetti et Brommimann, *Endothyra kueperi* (Oberhauser*), Meandrospira cf. Dinarica* Kochansky-Devide et Pantic, *Meandrospira* sp., *Paulbronnimannia judicarensis* (Permoli-Silva), *Turriglomina mesotriasica* (Koehn-Zaninetti); **braquiopods:** (*Mentzelia*).
Others: gastropods, equinoderms, pollen associations, porifers and a single fragment of a coral.

Cañete Fm.

Ammonoids: *Eoprotrachyecras* sp., *Eoprotrachyceras curionni* (Mojsisovics), *Eoprotrachyceras villanovae* (D'Archiac), *Iberites* sp., *Proarcestes* sp., *Proarcestes subtridentinus* (Mojsisovics), *Anolcites* sp., *Anolcites* cf. *doleriticum* (Mojsisovics), *Gevanites* sp., *Gevanites archei* Goy, *Protrachyceras* sp., *Protrachyceras hispanicum* (Mojsisovics);
bivalves: *Bakevellia* sp., *Bakevellia costata* (Schlotheim), *Elegantina sublaevis* (Schmidt), *Gervillia joleaudi* (Schmidt), *Leptochondria alberti* (Goldfussi), *Modiolus myoconchaeformis* (Philippi), *"Mytilus eduliformis"* (Schlotheim), *Neoschizodus laevigatus* (Goldfussi), *Paleonucula goldfussi* (Alberti), *Paleoneilo eliptica* (Goldfussi), *Pseudoplacunopsis teruelensis* Wurm, *Pseudoplacunopsis* sp, *Pseudocorbula gregaria* (Munsteri), *Umbostrea cristadifformis* (Schlotheim) and *Unionites munsteri* (Wissmann);
brachiopods: *Coenothyris* sp., *Lingularia* sp., *Lingularia* cf. *smirnovae* (Biernat y Enig);
foraminifers: *Aulatortus praegaschey* (Khoen-Zaninetti), *Calcitornella* sp., *Cornusipira paraprisca* (Ho), *Dentalina* cf. *bicornis* (Terquem), *Dentalina* cf. *gerkei* Styk, *Dentalina terquemi* D'Orbigny, *Dentalina hoi* Trifonova, *Dentalina subsiliqua* Franke, *Dentalina zlambachensis* Kristan-Tollmann, *Endotriadella wirzi* (Khoen-Zaninetti), *Hoyenella sinensis* (Ho), *Ichtyolaria* cf. *phylloidea* (Kristan-Tolmann), *Lamelliconus multiespirus* (Oberhauser), *Lamelliconus procerus* (Oberhauser), *Lamelliconus ex gr ventroplanus biconvexus* (Oberhauser), *Nodosaria ordinata* (Trifonova), *Nodosaria shablensis* (Trifonova), *Nodosaria* sp., *Planiinvoluta carinata*

(Leischner), *Spirillina oberhauseri* Styk, *Tolypammina gregaria* (Wendt), *and Triadodiscus eomesozoicus* (Oberhauser);
conodonts: *Pseudofurnishius murcianus* (Van den Boogard), *Sephardiella mungoensis* Diebel);
gastropods: *Loxonema* sp., *Nática* sp., *Natica* cf. *stanenesis* Pichler, "*Turbonilla" dubia* (Münsteri), *Zigopleura* sp.);
microfishes: *Pseudodalatias henarejensis* Botella, *Hybodus plicatilis* Agassiz, *Lissodus* aff. *lepagei* Duffin, *Hybodus burgarensis* Pla, *Palaeobates angustissimus* Agassiz, *Prolatodon buchery* Cuny, *Prolatodon contrarius* Johns;
Others: vertebrates remains (Paraplacodus, Notosaurius, scaphopods), equinoderms and some **pollen associations:** *Ovallipollis ovallis*, *O. minimus*, *O. pseudoalatus*, *Triadispora aurea*, *T. staplini*, *T. plicata*, *T. suspecta*, *Enzonalasporites sp*., *E. tenuis*, *Camerosporites secatus*, *Patinasporites densus*, *Praecirculina granifer*, *P. radialis*, *Cuneatisporitis radialis*, *Calamospoa sp*., *Cycadophites).*

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