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# Identification of the Early Permian (Autunian) in the subsurface of the Ebro Basin, NE Spain, and its paleogeographic consequences

## Identificación del Pérmico Inferior (Autuniense) en el subsuelo de la Cuenca del Ebro, NE de España, y sus consecuencias paleogeográficas

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Abstract

The Early Permian (Autunian) has not been identified up to now in the subsurface of the Tertiary Ebro Basin because of the scarcity of oil well boreholes reaching the Variscan basement and the systematic attribution of a Carboniferous age, without any paleontological data, to the unmetamorfosed siliciclastic sediments found at the base of some of them, clearly above the Early Paleozoic basement. Grey and black shale samples recovered from cores preserved in the REPSOL-YPF archives of the Caspe-1 oil well between meters 1.437 and 1.449 have yielded palynological assemblages dominated by *Vittatina costabilis*, *Potonieisporites novicus*, *Potonieisporites* sp., and other poorly preserved elements. This association has an Early Permian (Autunian) age and closely resembles other findings in the Iberian Ranges, the Pyrenees and the southern margin of the Iberian Massif, shading new light on the early stages of the extensional events taking place in central and NE parts of the Iberian Microplate just after the main compressive phases of the Variscan orogeny.

*Keywords*: Permian, Autunian, Ebro Basin, Palynology, Carboniferous.

Resumen

El Pérmico Inferior (Autuniense) no había sido identificado hasta ahora en el subsuelo de la Cuenca Terciaria del Ebro dada la escasez de pozos de petróleo que alcanzasen el basamento varisco de la zona y la sistemática atribución de una edad Carbonífero, sin dato paleontológico alguno, a los sedimentos siliciclásticos no metamórficos encontrados en la base de algunos de ellos, claramente sobre el basamento del Paleozoico Inferior. Se recuperaron muestras de lutitas grises y negras de testigos conservados en los archivos de REPSOL-YPF del sondeo Caspe-1, entre los metros 1.437 y 1.449, que han proporcionado una asociación de palinomorfos compuesta por *Vittatina costabilis*, *Potonieisporites novicus*, *Potonieisporites* sp., y otros elementos peor conservados. Esta asociación tiene una edad Pérmico Inferior (Autuniense) y tiene gran similitud con otras descritas en la Cordillera Ibérica, los Pirineos y el borde S del Macizo Ibérico, arrojando nueva luz sobre los primeros eventos extensivos que tuvieron lugar en el centro y NE de la Microplaca Ibérica inmediatamente después de las principales fases de compresión de la orogenia Varisca.

*Palabras clave*: Pérmico, Autuniense, Cuenca del Ebro, Palinología, Carbonífero.

## 1. Introduction

The Early Permian is the time when an embryonic extensional regime was established in the Iberian Microplate after the main Variscan compressive phases. This tectonic regime lasted during the rest of the Permian and most of the Mesozoic in several phases. During the Early Permian, a series of small, isolated continental basins were created in the Iberian Microplate along NW-SE normal fault systems and coeval N-S sinistral strike-slip fault systems in response to the intraplate stress field induced by two major dextral strike-slip fault systems along its northern and southern margins: the Bay of Biscay and Chedabucto-Gibraltar ones, related to the structural collapse of the Variscan orogen (Arthaud and Matte, 1975, 1977; Lorenz, 1976; Lorenz and Nichols, 1984; Sopeña *et al*., 1988; Doblas *et al*., 1994, 1998; Arche and López-Gómez, 1992, 1996).

The Iberian Ranges (Fig. 1) contain a series of small outcrops of continental volcanic, volcanoclastic and/or sedimentary rocks, some of them dated as Early Permian (Autunian) by rich macro- and microfloristic assemblages and absolute dating of volcanic rocks (Virgili *et al*., 1976; De la Peña *et al*., 1977; Sopeña, 1979; Ramos and Doubinger, 1979; Arche *et al*., 1983; Sopeña *et al*., 1988; Rey and Ramos, 1991; Lago *et al*., 1991, 2004a; Sopeña *et al*., 1995, Innocent *et al*., 1994). The biostratigraphic data obtained in localities such as Retiendas, Valdesotos, Reznos or Molina de Aragón are in good agreement with absolute ages obtained for the basal volcanic rocks, rang-

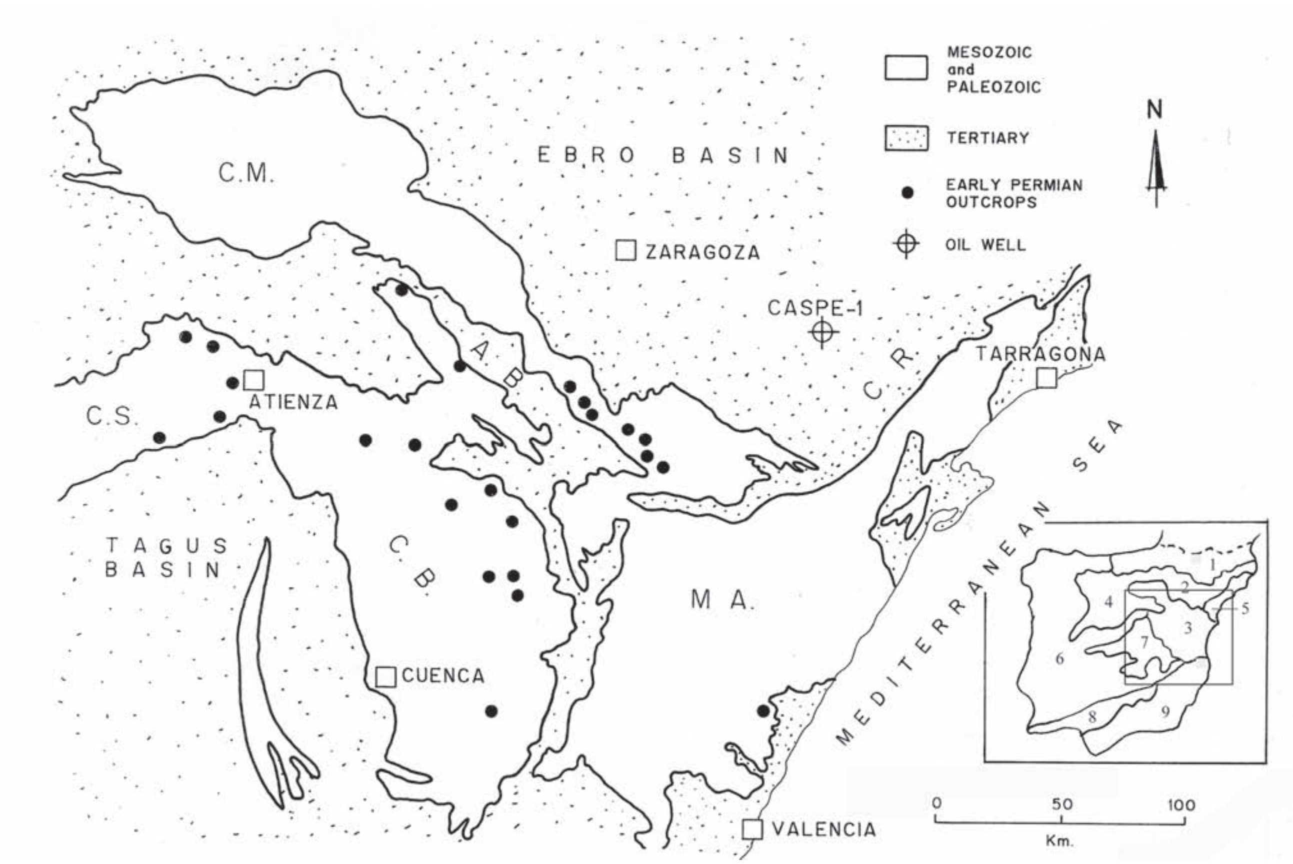


Fig. 1.- Main geological units in central and NE Iberia. Black circles represent some of the dated Early Permian outcrops in the Iberian Ranges and the Central System. The studied Caspe-1 borehole is located in the Ebro Basin. C.: Cameros Basin, C.R.: Catalan Ranges, MA.: Maestrat Basin A. B.: Aragonian Branch of the Iberian Ranges, C.B.: Castilian Branch of the Iberian Ranges, C.S.: Central System. Lower right part shows the present-day ranges and sedimentary basins in the Iberian Peninsula: 1- Pyrenees, 2- Ebro Basin, 3- Iberian Ranges, 4- Duero Basin, 5- Catalan Basin, 6- Iberian Massif, 7- Tagus Basin, 8- Guadalquivir Basin, 9- Betic Cordillera. The provided area is the one enlarged at the left side.

Fig. 1.- Principales unidades geológicas en el centro y NE de Iberia. Los círculos negros representan algunas de las localidades bien datadas como Pérmico Inferior en la Cordillera Ibérica y el Sistema Central. El sondeo estudiado, Caspe-1, está localizado en la Cuenca del Ebro. C.M.: Cuenca de Cameros, C.R. Cordillera Catalana, M.A.: Cuenca del Maestrat, A.B.: Rama Aragonesa de la Cordillera Ibérica, C.B.: Rama Castellana de la Cordillera Ibérica, C.S.: Sistema Central. En la parte inferior derecha se muestran las cordilleras y cuencas actuales de la Península Iberica: 1- Pirineos, 2- Cuenca del Ebro, 3- Cordillera Ibérica, 4- Cuenca del Duero, 5- Catalan Ranges, 6- Macizo Ibérico, 7- Cuenca del Tajo, 8- Cuenca del Guadalquivir, 9- Cordillera Bética. La zona enmarcada es la ampliada a la izquierda.

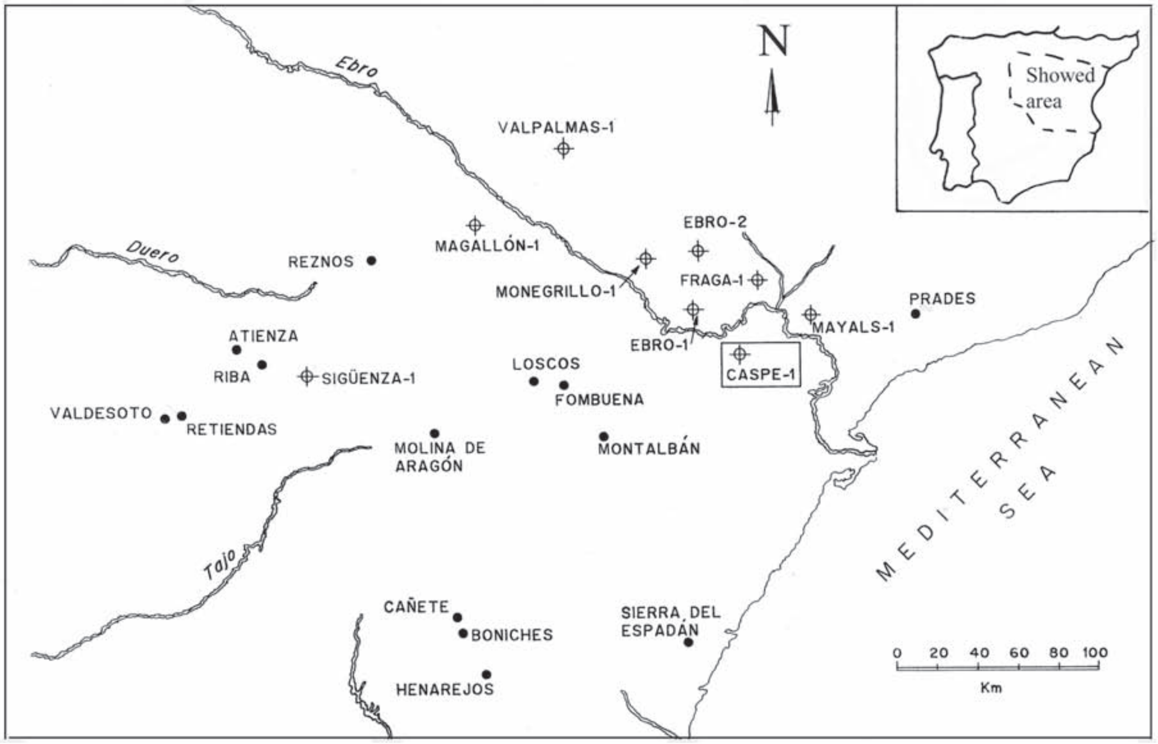


Fig. 2.- Location of the Caspe-1 borehole and other Ebro Basin and Iberian Ranges boreholes and localities cited in the text.
Fig. 2.- Localización del sondeo Caspe-1 y otros sondeos y localidades de la Cuenca del Ebro y de la Cordillera Ibérica citados en el texto.

ing from 293 ± 2,5 M.a. in Loscos (Lago *et al*., 1991), 283 ± 2,5 M.a. in Fombuena (Conte *et al*., 1987) and 287 ± 12 M.a. in Atienza (Hernando *et al*., 1980) (Fig. 2). More precisely, these ages fall into the Sakmarian stage of the Early Permian (Cisuralian).

Similar basins have been described and dated in the Central System, the Pyrenees and the southern margin of the Iberian Massif (Sopeña *et al*., 1988; Innocent and Briqueu, 1995; Innocent *et al*., 1994; Briqueu and Innocent, 1993; Lucas and Gisbert, 1995; Debon *et al*., 1995; Broutin and Gisbert, 1983; López-Gómez *et al*., 2002; Sopeña and Sánchez-Moya, 2004), but, up to now, these rocks have not been identified in the subsurface of the Tertiary Ebro Basin (Jurado, 1988, 1990). This apparent anomaly can be explained by two mutually exclusive reasons: either there is a genuine absence of Early Permian deposits in the area and, in consequence, the post-Variscan continental Ebro domain underwent a peculiar tectonostratigraphic evolution in this period of time, or conversely, there are some erroneous age attributions to sedimentary materials drilled by some commercial oil wells of the Ebro domain and have been assimilated to the Variscan basement. The stratigraphic and tectonic implications of this alternative are of fundamental character for the correct reconstruction of the evolution of the Iberian Microplate in this period. Based on the study of an oil-well (Caspe-1) new data relevant to this problem are presented in this paper and one of the alternatives is supported by them.

## 2. The sediments at the base of the Caspe-1 oil well. New paleontological and petrological data

Commercial oil wells drilled in the tertiary Ebro Basin provide the only direct source of data about the Permian and Triassic sediments (or their absence) in the area. The first stage of our research was a reinterpretation of the electric wireline logs of some of them (Fig. 3) in order to determine the presence of sedimentary-volcanic rocks situated underneath the Late Permian-Early Triassic red beds and above the metamorphosed Variscan basement. These rocks were identified in at least six of them in the central area of the Ebro Basin (Fig. 2) but, unfortunately, only the Caspe-1 offered the possibility of direct examination of the rocks, because it is the only one in which drilling cores were recovered from this particular interval (Fig. 3). Time-equivalent sediments are probably present in the lowermost part of the Sigüenza-1 oil well (Fig. 2), in the Iberian Basin domain, but, again, no biostratigraphic data are available from this well.

The Caspe-1 oil well was drilled in 1973, to a depth of 1,810 meters. Underneath the tertiary cover, the Middle Triassic-Late Permian succession can be recognized to a depth of 1,160 meters (Jurado, 1988, 1990, and our interpretation) (Fig. 3). The lowermost part of the well, from meter 1,160 to meter 1,810 crossed a monotonous alternation of fine sandstones and grey shales with gas shows. The well was abandoned before reaching the variscan basement.

The subdivision of the upper part of the sedimentary succession into formations defined in the Iberian Ranges and the Catalonian Ranges is possible even in absence of biostratigraphic data using lithological criteria, structural analysis of the extensional deformation during the sedimentation and the identification of major unconformities and/or hiatuses (Arche *et al*., 2004; Sanchez-Moya and Sopeña, 2004; Arribas, 1985; López-Gómez, 1985; Marzo, 1980; Ramos, 1979). Our interpretation of the Permian-Triassic record of the Caspe-1 oil well is as follows (Fig. 3):

-1,160 to 1,125 meters: Boniches Formation. Defined in the Castilian Branch of the Iberian Ranges and equivalent to the Moncayo Formation of the Aragonese Branch of the Iberian Ranges that represented the SW margin of the Permian-Triassic Ebro Basin.

- 1,125 to 923 meters: Alcotas Formation. Defined in the Iberian Ranges and equivalent to the Tabuenca Formation in the Ebro Basin and Bellmunt Formation in the Catalan Coastal Range.

- 923 to 885 meters: Hoz de Gallo Formation. Defined in the Iberian Ranges, probably the upper part only, and equivalent to the Prades Formation in the Catalan Coastal Range.

- 885 to 705 meters: Cañizar Formation. Defined in the Iberian Ranges and equivalent to the Aranda Formation in the Ebro Basin and Prades-Eramprunyá Formation in the Catalan Coastal Range.

- 705 to 580 meters: Eslida Formation. Defined in the Iberian Ranges and equivalent to the Rané Formation in the Ebro Basin and Aragall Formation in the Catalan Coastal Range.

- 580 to 561 meters: Marines Formation. Defined for the Iberian Ranges and equivalent to the Röt facies in the Catalan Coastal Range.

- 561 to 457 meters: Landete Formation. Defined in the Iberian Ranges and equivalent to the Illueca Formation in the Ebro Basin and M-1 Unit in the Catalan Coastal Range.

- 457 to 364 meters: El Mas Formation. Defined for the Iberian Ranges and equivalent to the Trasobares Formation in the Ebro Basin and M-2 Unit in the Catalan Coastal Range.

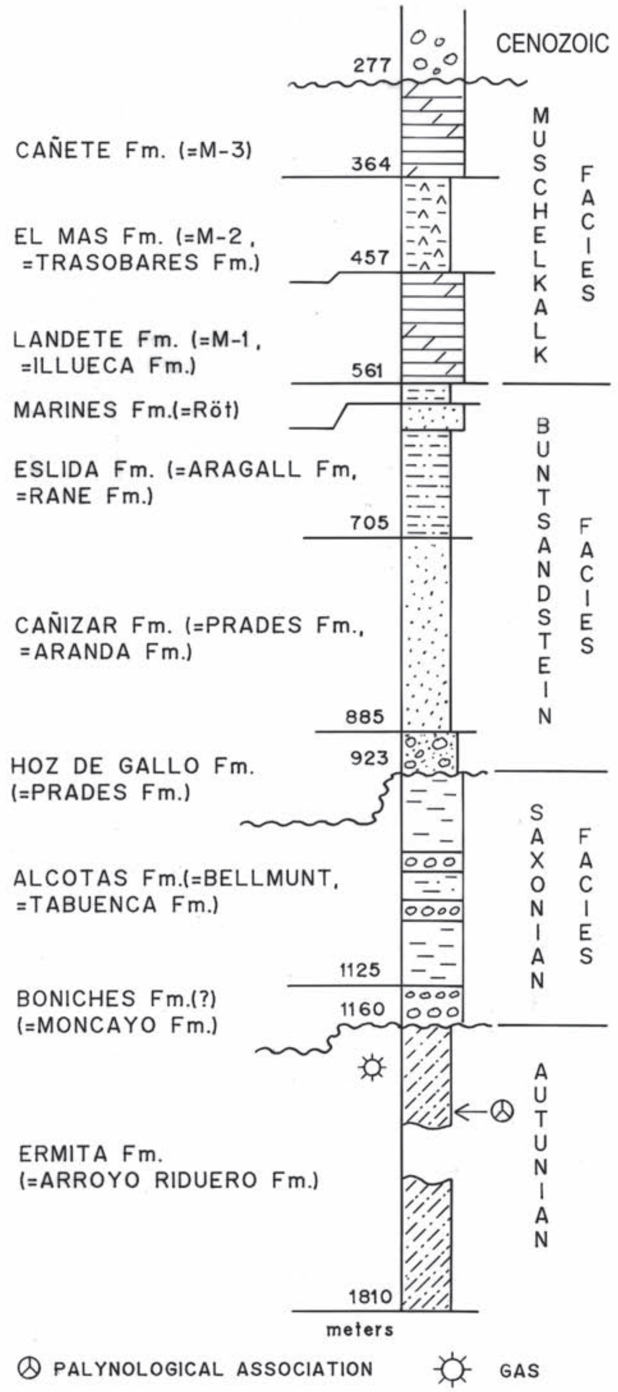


Fig. 3.- Stratigraphic interpretation of the Permian-Triassic record of the Caspe-1 borehole. See text for the names, ages and geographical location of the formations.

Fig. 3.- Interpretación estratigráfica del registro de sondeo Caspe-1. Ver texto para los nombres, edades y localización geográfica de las formaciones citadas.

- 364 to 277 metres: Lower part of the Cañete Formation. Defined for the Iberian Ranges and equivalent to the M-3 Unit of the Catalan Coastal Range. Top eroded by continental Miocene sediments.

## 3. Petrological composition

Seventeen sandstone samples were recovered for petrologic studies in thin section from the 1,437-1,449 meters interval; this lithology is, by far, the most abundant in the cored interval.

The fine to medium grained sandstones consist of quartz, feldspar, rock fragments, micas, amphibols, pyroxenes and opaque ferruginous grains, that is, of greywacke composition.

Quartz grains are the most abundant fraction (27-33 %) and present two distinct types: rounded to subrounded (30-45%), with wavy extinction most of them, and angular, subidiomorphic, with corrosion pockets and inclusions of mica, rutile and fluids (55-70%). The rounded grains have an extrabasinal origin, coming from distant igneous and/or high-grade metamorphic source areas or recycled from pre-variscan sandstones from the uplifted footwall blocks of the rifted basins. The angular grains have a volcanic origin and come from very proximal source areas of andesite-rhyolite composition; transport of this type of grains was very short because they preserve their original external shape almost intact.

Feldspars (10-32%) are generally potasic (ortose) with minor quantities of plagioclase, usually zonated and sometimes weathered into sericite and chlorite.

Rock fragments can be abundant (3-39%) and consist of fresh to weathered grains composed of amphibols, Pyroxene, micas and quartz, sometimes with internal fluidal structures. They have a volcanic origin and very short transport.

Amphibols (2-5%), pyroxenes (1-6%), micas (2-12%) and Fe opaques (1-3%) are minor componets of the sandstones.

Matrix is always abundant (up to 24%) and consists of clays, silica and Fe oxides.

The sandstones of the lowermost part of the Caspe-1 well have a petrologic composition very close to some well-dated Early Permian sediments of volcanoclastic nature cropping out in the Iberian Ranges and the eastern Central System (Gabaldón and De la Peña, 1973; De la Peña *et al*., 1977; Sopeña, 1979; Rey and Ramos, 1991; Lago *et al.*, 2004a), classified as hybrid arenites or greywackes, mainly derived from volcanic areas emplaced near the sedimentary basins.

Thin white calcite veins cut the primary sedimentary structures of the cored interval and should be related to a latter tectonic-hydrothermal event, probably related to the alpine compressional tectonics during the Oligocene-Miocene.

## 4. Sedimentological interpretation

The dominant primary internal sedimentary structures in the core are: unidirectional current ripples, climbing ripples, parallel lamination and millimeter dark grey siltstone laminae, organised in decimeter fining-upwards sequences. The latter intervals were sampled for palynological studies. As the electric wireline logs for the interval under consideration are of poor quality, but very uniform, a homogeneous composition for the interval between meters 1,160 and 1,810 can be assumed.

The interpretation of the depositional sedimentary environment can be only preliminary due to the very limited available evidences, only a few meters of continuous core out of more than 600 meters drilled and poor quality electric wireline logs for the studied interval.

The sediments were laid down under water by low-energy, unidirectional flows, with decelerating pulses and short, repeated quiescent periods. Detrital organic matter of vegetal origin was abundant in the environment and the geochemical conditions allowed for its preservation.

It could be originated in a distal, swamped alluvial floodplain area or, more probably a shallow, fast subsiding lake basin.

## 5. Biostratigraphic data and interpretation

Seven sediment samples of dark grey siltstones were retrieved from the interval between meters 1,437 and 1,449. They were processed using classical protocols of extraction at the laboratory of the Instituto de Geología Económica, CSIC-UCM, Madrid, but only two of them at levels 1,439 and 1,441 were positive. The extracted assemblages are poor and their preservation is very bad, but some elements could be classified.

The palynological assemblage is composed of scarce and poorly preserved elements including the following taxa (Fig. 4):

*Potonieisporites novicus* Bharadwaj (1954)
*Potonieisporites* sp.
*Vittatina* cf. *costabilis* Wilson (1962)
*Falcisporites* sp.
*Knoxisporites* sp.
*Limitisporites* sp.
*Lunatisporites* sp.
*Platysaccus* sp.
*Punctatisporites* sp.
Bisaccates unidentified.
Spores unidentified.

This palynomorph assemblage is very small, but enough to consider these levels as of Asselian-Sakmarian (Early

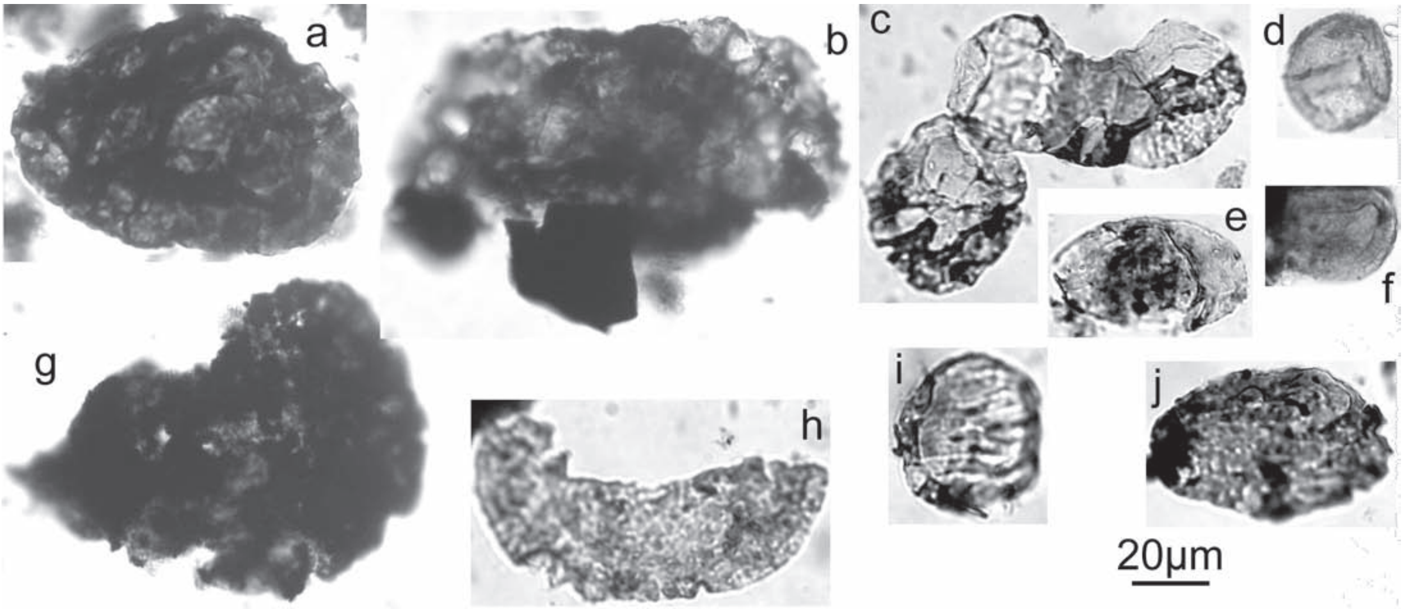


Fig. 4.- Identified Palynological assemblage (x 500): a, b: *Potonieisporites novicus* Bharadwaj 1954, c: *Platysaccus* sp., and unidentified bisaccate, d: *Punctatisporites* sp., e: *Falcisporites* sp., f: *Knoxisporites* sp., g, h: *Potonieisporites* sp., i, j: *Vittatina costabilis* Wilson 1962.

Fig. 4.- Asociación palinológica identificada (x 500): a, b: *Potonieisporites novicus* Bharadwaj, c: *Platysaccus* sp., d: *Punctatisporites* sp., e: *Falcisporites* sp., f: *Knoxisporites* sp., g, h: *Potonieisporites* sp., i, j: *Vittatina costabilis* Wilson 1962.

Permian) age. The datation is comparable to well-studied palinomorph assemblages of Western Europe (Warrington, 1996) of Early Autunian age, to the "Zone A2" (Doubinger, 1974; Bouroz and Doubinger, 1977) of the Autun Basin in France, of several Switzerland Early Permian basins (Hochuli, 1985) and other Western Europe Early Permian basins, mainly in Germany and England (Clayton *et al*., 1977).

This association compares well with other rich, well dated assemblages of Early Permian age in the western Peritethyan realm, like the Central Pyrenees (Broutin and Gisbert, 1983; Gisbert, 1983; Lucas and Gisbert, 1995), Guadalcanal (Broutin, 1973, 1974), Retiendas-Valdesotos (Sopeña *et al*., 1974; Arche *et al*., 1983), Molina de Aragón (Sierra de Aragoncillo) (Ramos *et al*., 1976, Ramos, 1979), Busaco (North Portugal) (Gomes *et al*., 2004) and the Sardinian (Italy) fossil localities of Perdasdefogou and Lu Caparoni (Ronchi *et al*., 1998) and Guardia Pisanu (Pittau *et al*., 2002).

It is important to put a cautionary note on the exact age of the palynomorph assemblage, because, in spite of its Autunian characteristics, Broutin and Gisbert (1983) and Broutin *et al.* (1986, 1999) have highlighted the uncertainties inherent to the macro-and microfloras in the Carboniferous-Permian boundary. In the western European continental rift basins of this period there are alternations of hygrophile "Stephanian" microflores and mesoxerophitic "Autunian" microfloras, that is, there is a climatic control on the type of flora independent of its exact age in this period. Up to now, a Late Carboniferous age for our palynomorph assemblage cannot be ruled out.

## 6. Paleogeographic consequences and comparison with related basins

The identification of an Early Permian (Autunian), Asselian-Sakmarian palynomorph assemblage in the basal part of the Caspe-1 oil well is proof that sedimentary basins were created in the Ebro domain during this period. The palynomorph assemblage and the lithological characteristics of the sediments that contain it are very similar to some of the classic outcrops in the Iberian Ranges, like Atienza, Reznos, Loscos, Fombuena, Montalban or Molina de Aragón and probably to the base of the Permian succession of the Sierra del Espadán (Fig. 2), the NE Central System, like Valdesotos and Retiendas (Fig. 2). The correlation with the basal breccias and red-beds of the Cañete-Boniches area, the Prades-Baix Ebre region or with the coal measures of Minas de Henarejos (Fig. 2) is possible, but very difficult to prove beyond doubt in this moment.

In the Ebro domain, the presence of coeval sediments at the base of several oil wells (Fig. 5), like Fraga-1, Magallón-1, Valpalmas-1, Ebro-1, Ebro-2 and Monegrillo-1 is very likely because of identical stratigraphic position at the base of the Permian-Triassic succession and above the Variscan basement, even in absence of any fossil remain. It is also possible the presence of these materials in the NW Ebro domain. If this is the case, the Ebro domain is related to the Iberian dominant regions which show effusive volcanism, that supplied substantial percentages of sand-sized volcniclastic material to the subsiding basins. The Ebro domain evolved during the Early Permian in a similar way to the Iberian Ranges and the NE Central System; a single transtensional stress field created in the interior of the Iberian microplate a series of small, isolated extensional basins with variable subsidence rates in response to dextral strike-slip stress along its northern and southern margins (Arche and López-Gómez, 1996; López-Gómez *et al*., 2002; Sopeña and Sánchez-Moya, 2004). NW-SE fault arrays of oblique extensional nature associated to coeval N-S arrays of strike-slip nature controlled the creation of small continental basins and coeval volcanic activity in the elevated basement blocks in between the basins.

The Ebro domain, therefore, was part of the same structural domain of the Iberian Ranges and the NE Central System, that is, an intraplate domain with extensive but patchy sedimentary-volcanic record during the Early Permian and total absence of Middle Permian rock record, in contrast with the thick and more complete record of this period along the Cantabrian and Pyrenean domains to the north, controlled by the first order strike-slip Bay of Biscay fault system (Lago *et al*., 2004 b).

It is not clear now why some parts of the Castilian Branch of the Iberian Ranges, like the Cañete-Boniches-Minas de Henarejos region and the whole Catalan Ranges do not have volcanic or volcanoclastic rocks, in contrast with the more common mixed nature of the sedimentary infilling of the rest of the Early Permian basins in Iberia, but this question exceeds the limits of this paper.

## 7. Conclusions

- A palynological assemblage has been recovered from levels 1,441 and 1,439 meters of the Caspe-1 oil well cores preserved in the REPSOL-YPF archives, both of them of Asselian-Sakmarian (Cisuralian, Early Permian) age. This sedimentary record was previously attributed to a Carboniferous age.

- The stratigraphic position of the sedimentary interval in the lower part of the Caspe-1 oil well is identical to the coeval sediments in the Iberian Ranges, to which they can be correlated with certainty.

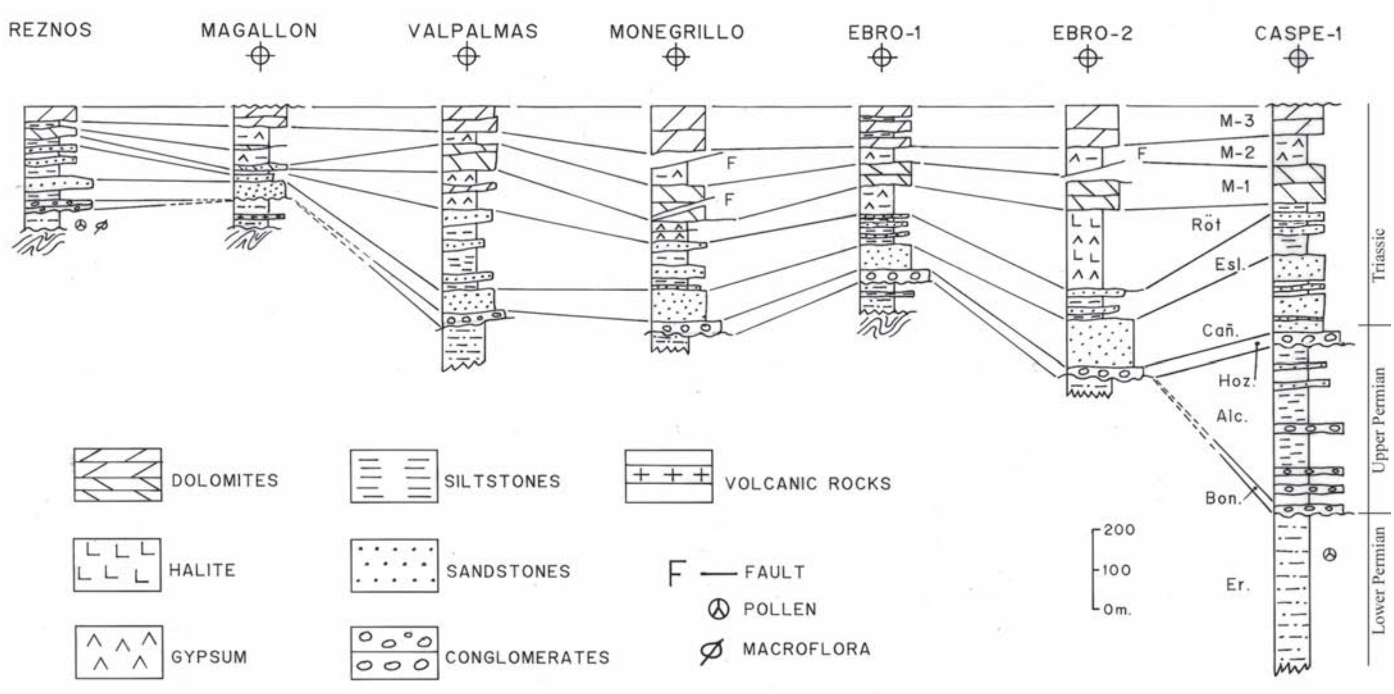


Fig. 5.- Correlation between dated Early Permian localities (Reznos and Caspe-1 borehole) and other possible boreholes where Early Permian sediments can be present. The Late Permian-Triassic record of these boreholes is also interpreted and correlated. See figure 2 for the location of these boreholes and the Reznos section. M-1 to M-3 represent the three carbonate levels of the Muschelkalk facies, Esl.- Eslida Formation, Cañ.- Cañizar Formation, Hoz- Hoz del Gallo Formation, Alc.- Alcotas Formation, Bon.- Boniches Formation, Er.- Ermita Formation.

Fig. 5.- Correlación de algunas localidades donde se ha datado el Pérmico Inferior (Reznos y Sondeo Caspe-1) y otros sondeos donde es posible la existencia de sedimentos del Pérmico Inferior. También se presenta la correlación del registro pérmico-triásico de los sondeos figurados. Ver la figura 2 para la localización de los sondeos y la sección de Reznos. M-1, M-2 y M-3, representan los tres niveles carbonatados de la facies Muschelkalk, Esl., Formación Eslida, Cañ.- Formación Cañizar, Hoz- Formación Hoz del Gallo, Alc.- Formación Alcotas, Bon.- Formación Boniches, Er.- Formación Ermita.

- The Ebro domain contain several sedimentary sequences in similar position drilled by commercial oil wells not dated because no cores were preserved, but can confidently be correlated with the Early Permian (Autunian) sediments and volcanic rocks of the Iberian Ranges and the Pyrenees.
- A uniform transtensional tectonic regime affected the whole of the Iberian Microplate during the Early Permian, induced by the movement of the block along two major dextral strike-slip fault systems along its northern and southern boundaries.

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