SHALE GAS ASSESMENT IN SPAIN

Basin and Formation Description

MINISTERIO
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Este informe es resultado de los trabajos efectuados en el marco del proyecto:

PROYECTO DE EXPLORACIÓN DE HIDROCARBUROS NO CONVENCIONALES EN ESPAÑA (HCNC)

SERVICIO DE RECURSOS ENERGÉTICOS

Dirección:

Alicia Arenillas González

Autores:

Alicia Arenillas González
Ricardo Molinero Molinero
Jesús García Crespo
Jose Francisco Mediato Arribas
Ruxandra Nita

ÁREA DE RECURSOS MINERALES

DEPARTAMENTO DE INVESTIGACIÓN EN RECURSOS GEOLÓGICOS

INSTITUTO GEOLÓGICO Y MINERO DE ESPAÑA (IGME)

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➢ CANTABRIAN MASSIF (BASIN 1)

The Cantabrian Massif extends over the NE part of the Iberian Massif and represents the external zone of the Variscan Orogen in the NW of the Iberian Peninsula. It comprises materials varying in age from the Precambrian to the Carboniferous.

Geologically, a division of the Cantabrian Zone has been established in seven different units, that are from west to east: Somiedo, La Sobia-Bodón, Aramo, Central Carboniferous Basin, Mesozoic-Tertiary Cover, Ponga and Picos de Europa Units.

The base rocks are composed by the Lancara Limestones, Oville slates and sandstones and the Barrios quarzites with a **Cambric-Ordovician** age. The **Silurian** is formed by the Formigoso slates and Furada sands. **Devonic** is represented by the Rañeces complex, Moniello Limestones, Naranco sands, Candás Limestones and Candamo Limestones. The **Carboniferous** sequence is constituted by the Griotte and Montaña Limestones and the Lema and Sama groups (alternation between marine and continental deposits with coal beds).

The Cantabrian Massif extends over an approximate surface of 19,000 km^2. Two hydrocarbon wells were made in the area with an approximate equivalent of 0.1 wells for every 1,000 km^2.

Presence of mine gas has been known since long ago (methane with ethane traces, etc.) in the coal mines especially in the **Central Carboniferous Basin.** Also, the presence of mineral oils, distillates and condensates, parafin remains, ozoquerites, etc. is detected in the host rock as well as in the coal beds. All these hydrocarbon displays (solid, liquid and gas) prove that the carboniferous materials constitute a source rock.

The first discovered surficial natural gas emanation was the Mecheru de Caldones in 1915, when a prospective coal well reached 563m depth after crossing the Permian cover. Two more

emanations in nearby wells appeared in 1920 and 1923. These surficial gas showings boosted a prospection campaign with non-satisfactory results.

The first natural gas drilling in Asturias was the Caldones-1 well in 1967 by CIEPSA in the Gijón Basin. The well reached a depth of 1846 m. The Carboniferous was found at 330m, after crossing the Permo-Liassic cover. Gas presence was detected at various intervals associated to siltstones and clay levels, and rarely to sandstones and carbonates, but were considered non-profitable. Gas was composed of methane in 95.51%, ethane in 2.14% and Nitrogen in 1.89%, with a hydrogen content of 0.46%.

In 1979 the IGME conducted a **bituminous shale** study of the Quirós, Teverga and San Emiliano Carboniferous Basin (Asturias), within the Spanish Bituminous Shale Exploration project. The objective of the study was to understand the possibilities of bituminous shales in the Carboniferous Basin of Quirós and Teverga, focusing on the productive levels of the Lena and Sama groups, but it was concluded that there was no interest.

In 1992, Hunosa underwrote a protocol with the Spanish subsidiary of the North-American company Union Texas for surveying methane resources in their sites in order to understand the possibilities of exploitation and commercialization. The objective of this evaluation was part of the diversification policy undertaken by the state company. The research campaign focused on the Sama and El Entrego Sinclines associated to the most modern productive mining packages of the Central Carboniferous Basin. The wells drilled were Asturias Central-1 (1575m) and Modesta-1 (2038m), which spanned several layers of coal, with contents of 8-10 m^3/t y 9-14 m^3/t.

Another priority area was the unit from La Justa-Aramil, with a resource estimate of 1,400 Mm^3 distributed in different areas (Río Miñera, La Justa, Barros-Tablado y Aramil).

Thermogenic methane (temperature of up to 150°, limit between medium and low volatile bituminous coal) was located in the northern and central part of the Central Carboniferous Basin. Other zones are in the semiantracite-antracite limit. (>200°), with lesser methane accumulation potential. It is estimated that coal layers could accumulate a gas volume between 6 and 15 m^3/t.

CBM projects in this region focus on four surveys, one located in the Caldones Basin (Gijon), -accomplished by Ciepsa in 1967- and subsequent wells drilled in the middle of Central Carboniferous Basin, in which hydraulic fracturing was used experimentally. Later on, in the vicinity of the Barros well (Langreo), the Asturias CBM-1 survey was carried out, with the aim of assessing petrophysical parameters that affect the gas flow from coal beds.

The considered most favorable zones:

Out-cropping carboniferous basins:

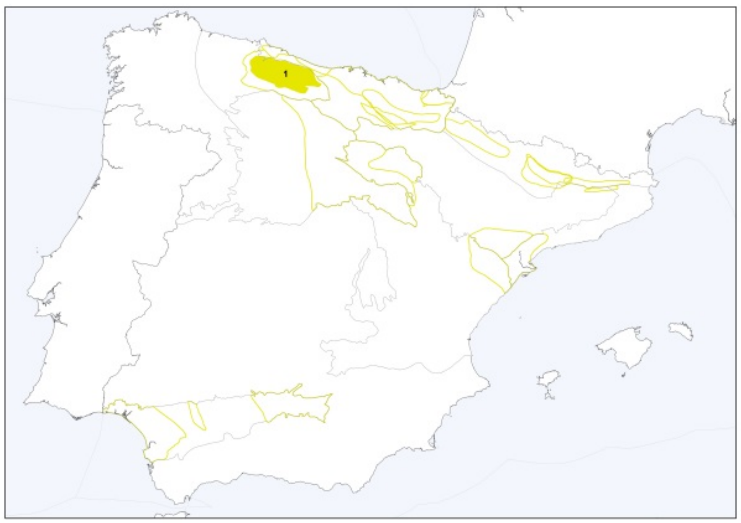
- Sama, El Entrego y Turón Sinclines, in the section comprised between -600 and -2,000m.
- Riosa-Olloniego Unit under -500 m.
- Central Carboniferous Basin, in abandoned mine workings such as Aller (Hunosa).
- Quirós y Teverga Coal Basins.

- Structural traps in carboniferous terranes, i.e. Aller, Pola de Lena and Nalón valley (Repsol, Anschutz).

Coal basins hidden under the Permo-Mesozoic cover with thickness between 400m-800m overlying productive coal basins. The most favorable are:

- Permotriasic basin near Gijón, with gas possibilities in the Carboniferous (i.e Caldones).
- Carboniferous zone underlying the Permo-Mesozoic basin underlaying the Permo-Mesozoic basi, i.e. La Justa-Aramil unit in the section between Aramil and Lieres (Siero).
- Permian basin of Cabranes-Villaviciosa, overlaying the productive Carboniferous corresponding to the northern extension of the Central Basin. It outcrops in Viñón. Probable extension in the covered Carboniferous similar to Malón and Siero.
- Allochtonous of the Aramo Unit that thrusts over the Riosa-Olloniego Unit.

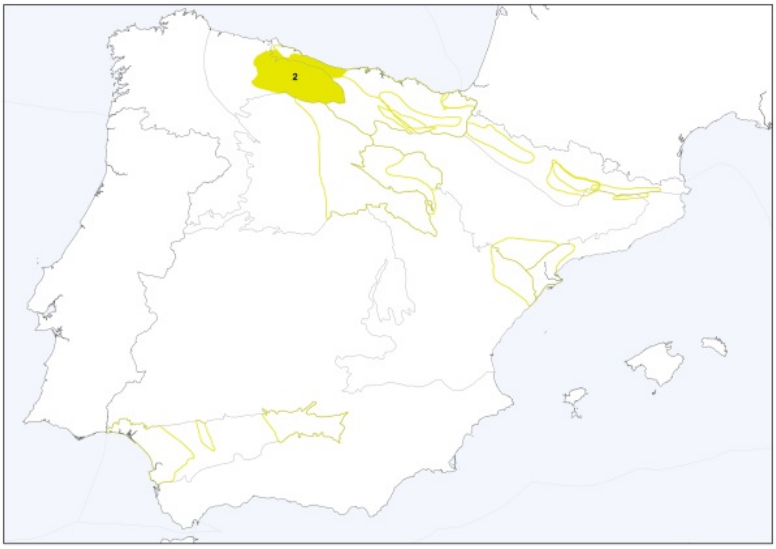
❖ CANTABRIAN MASSIF SILURIAN. FORMIGOSO FM (Formation No. 1)



It is located in the **Somiedo Unit** with a thickness of 70 to 200 meters. It is formed by black and gray shales, with thin interbedded bio-turbated siltstones and sandstones (quartzarenites) progressively more abundant toward the top, with frequent graded layers of shales. The dominant organic matter is of amorphous non-fluorescent type (amorfinita). Vitrinite particles are very small. The average reflectance of the pseudo-vitrinite is 1.09%. With transmitted light, a brown amorphous organic matter is predominant indicating a TAI (Thermal Alteration Index) of 3. The color of pollen and spores is consistent with a vitrinite reflectance around 1.1%. Reflectance values and color palinomorphs indicate that the organic matter is within the window of wet gas. The values of S1 and S2 are very low, not reaching 0.1 between them, so the potential of the Formigoso Formation as source rock is doubtful. However, it should be noted that this values are obtained from outcrop samples, so the values of this data should be

verified with undisturbed samples. The value of HI (5) confirms that the generated hydrocarbon would be natural gas.

❖ **CANTABRIAN MASSIF CARBONIFEROUS (Formation No. 2)**



- ***SAN EMILIANO FM.***

San Emiliano Formation is within the **Sobia-Bodon Unit** and is a predominantly a terrigenous succession of up to 2,000 meters thick with Namurian-Westfalian age. It has thin limestone levels in the middle and some coalbeds towards the top. The dominant type of organic matter is vitrinite. Inertinite is less common and is represented by inertodetrinite. The amorphous organic matter is granular with a fluorescence of light brown tones. The average vitrinite reflectance is 0.66%. The amorphous organic matter is yellowish brown in color, indicating a 2.5 TAI. Pollen and spores are amber, corresponding to a vitrinite reflectance of about 0.65%. Vitrinite reflectance values and palinomorphs color indicate that the organic matter is in an early stage of maturity within the oil generation window. The vitrinite reflectance indicates that it is in the oil generation window (0.66%), at an early stage. S1 and S2 values do not, a priori, suggest a suitable source rock. The value of HI is 9 indicating potential natural gas generation.

- ***FRESNEDO FM.***

Fresnedo Formation is located in the **Central Carboniferous Basin**. It is predominantly shaly, interbedded with minor sandstones (about 7% of the total) up to 470 meters thick containing some turbidites, breccias and calcareous olistolites, individualized, where present, between two important levels of interbedded limestones: the Mountain Limestone (Fms Barcaliente and Valdeteja) and the Massive Limestone. The Fresnedo package is Westphalian in age and is laterally arranged with the Valdeteja Formation, wedging where this formation exists.

Vitrinite is the predominant organic matter type. Inertinite is also frequent and is represented by inertodetrinite. The amorphous organic matter is granular and sometimes weakly fluorescent. Vitrinite average reflectance is 1.07%. The amorphous organic matter is brown, suggesting TAI 3. The pollen and spores are brown and its color also fits with a vitrinite reflectance of about 1.1%. Vitrinite reflectance values and color palinomorphs indicate that the organic matter is within the window of wet gas.

S1 and S2 sum does not allow the Fresnedo package to qualify as source rock. The value of HI (3) confirms that the generated hydrocarbon potential would be natural gas.

➢ ***BASQUE-CANTABRIAN BASIN (Basin 2)***

The Basque-Cantabrian Basin is a Mesozoic-Cenozoic basin generated by two stages of subsidence (rifting): Triassic and Lower Cretaceous. It features a powerful sedimentary record that was later folded and faulted during the Alpine Orogeny and represents the western extension of the Pyrenean Range. To the W it is limited by the Cantabrian Massif and to the east by the Paleozoic Basque Massif. The southern edge borders the Cenozoic basins of Duero and Ebro.

The Basque-Cantabrian basin contains in its central part a mid-Triassic to lower Neogene very thick series of several thousand meters of marine sediments, with Buntsandstein fluvial sediments of clays, sandstones and conglomerates at its base. Subsequent thick layers of evaporite sediments (gypsum, anhydrite and salt) were deposited, forming the Keuper facies in the basin, which later formed a series of diapirs. Source rocks shows in the Jurassic and Lower Cretaceous and reservoir rocks are composed of Lower Cretaceous sandstones and Upper Cretaceous limestones when they preserve their original porosity or have been fractured. The

Basque-Cantabrian Basin has been considered since the beginning of oil exploration the most interesting area in Spain because of the presence of abundant surface indications such as tar sands in the core of the Zamanzas anticline or asphalts present on the edge of most diapirs, like Maeztu. It occupies an area of approximately 21,000 km^2 with 202 exploration wells, thus having a ratio of 9 wells per 1,000 km^2.

Exploratory activities have taken place since the 1950s, principally in the **Navarro-Cántabro Trough** where boreholes were drilled, particularly in anticlinal structures. The boreholes were Zúñiga-l (year 1954-1955) and Alda-1 (1956-1959), both on the Gastiain anticline. These wells found gas in the Albo-Cenomanian siliciclastic complex (lateral equivalent of the Valmaseda and Utrillas formations), defining an exploratory objective that remains under investigation (**Lower Cretaceous-Upper Cretaceous Hydrocarbon System**). Alda-1 was later re-drilled (in the seventies) to reach the Triassic Keuper also finding gas traces in the Jurassic series.

In this early stage of the systematic exploration, several major exploration targets were defined, conventional reservoirs, which have been subsequently explored in the Basque-Cantabrian Basin: Purbeck series, Jurassic carbonates (Lias and Dogger) and Albian-Cenomanian siliciclastic complex.

As the wells (Castillo-1, Castle-2, Zuazo- 1 Antezana-1, Vitoria W-1, Vitoria W-2, Castillo-3, Castillo-4, Osma-1, Castillo-5) bored into the later called **Valmaseda formation**, all of them drained a certain gas volume. In most cases there was no evident trap (anticlines, domes, or stratigraphic traps), nor porous and permeable rocks that could be cataloged at that time as hydrocarbon reservoirs. Although it was known that the Valmaseda formation had a certain content of organic matter, it couldn´t be proved that it was the system source rock. Wells that investigated the eastwards lateral equivalent of Valmaseda formation found similar responses in siliciclastic Albien-Cenomanian formations.

In the North-Castilian Platform area, Cadialso-1 well (1983-1984) discovered a non-commercial gas accumulation, with spectacular signs of gas in the argillaceous limestones and Dogger marls (source rock). It is really an accumulation of non-conventional hydrocarbons (shale gas type and / or tight gas) in a reservoir with a barely permeable matrix.

In the **Navarro-Cántabro Trough**, exploration continued around the Castillo Gas Field, having the Valmaseda formation as the main objective. The Armentia-1 (1997) well was designed to vertically cut the Valmaseda formation with the highest density of natural fractures possible. It was supposed that natural fractures could provide further formation porosity and permeability. Only the upper 447 meters of the Valmaseda formation were drilled, which are predominantly silts and shales (without porous or permeable levels). Still, in a test of long-term production, without any stimulation/fracturing, it supplied more than 0.5 BCF of dry gas, almost pure methane. It is clear that the Valmaseda formation should be treated as an unconventional gas reservoir.

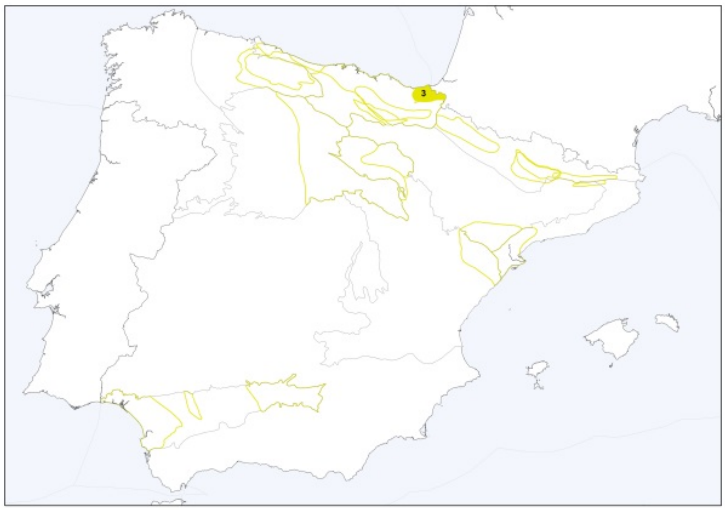
The first oil field found in Spain was the small **Castillo Gas Field**, discovered in 1960. It produced gas until 1981 that was sold to the local industry of Vitoria. The reservoir consists of Cenomanian-Turonian fractured limestones. The source rock could be the Jurassic marl or the Cretaceous or Cenomanian-Turonian clay formations with high organic content.

The second discovery, the **Ayoluengo Field**, was made in 1964. It is in a faulted anticline, over a diapiric pad located between the Sedano and Polientes sub-basins. The reservoir is in the detrital facies of the Purbeck-Weald, consisting of numerous lenticular bodies and highly fractured and faulted sandstones. The cover consists of clays that are intercalated between sand packs. The hydrocarbon source rock has been attributed to a Pliensbachian and lower Toarcian black marine marl with a high content of organic material. The field began production in 1966 and is still producing oil in small quantities.

The third discovery in the Basque-Cantabrian Basin was made by ENIEPSA in 1980. The **Gaviota** Field of gas/condensate is located in the Cantabrian Sea about 10 km N of Bermeo. The reservoir consists of a fractured Upper Cretaceous limestone with complex structure formed during the late Eocene and Oligocene. Carboniferous coal and clay deposits are probably the source of these hydrocarbons. Production started in 1986 and the field was sold in 1994, having produced a total of 536,000 tons of condensate and 7,286 billion cubic meters of gas. The site and its facilities have been converted to an underground gas storage site.

The fourth discovery was the **Albatros**, a small field of gas/condensate located NW of the Gaviota field and in a similar position.

❖ BASQUE-CANTABRIAN CARBONIFEROUS (Formation No. 3)



The Gaviota Field source rock consists of Westphalian-Stephanian bituminous coals with maturity level values ranging from 0.6 to 0.9 R_o.

Even though only two wells reached the Carboniferous, geochemical analysis and the lack of other source rocks, leave no doubt that the source rock character is in the Stephanian B and C.

The Carboniferous source rock of Gaviota Field was deposited in a marginal marine environment and its organic richness is present in the thin bituminous coal levels, as well as in

the shales that characterized most of the 500 m cut by the wells. A description of this potential source rock can be summarized as follows:

Type II-III kerogen, lipid rich.

TOC varying between 28% for the shales and 51 % for the coals and coaly shales.

IF very variable, between 145 and 260.

S2 also variable, ranging from 40 to 150 mg/g.

❖ **BASQUE-CANTABRIAN LIASSIC. CAMINO FM (Formation No. 4)**

Diffraction shows that the rocks have high contents of carbonates, quartz and feldspars with illite and pyrite and clorites as accessory minerals. Pliensbachian black shales TOC average values range between 3 to 6 wt %. Maximum values are usually found for the black shale horizon developed during the *T. iberx* zone, coinciding with the minimum carbonate content of the succession. Those samples exhibit TOC values up to 8.7 wt %.

The rest of the Pliensbachian hemi-pelagic facies show lower TOC values. This content varies between 0.4 wt % for non-organic marls to 2.4% in organic marls.

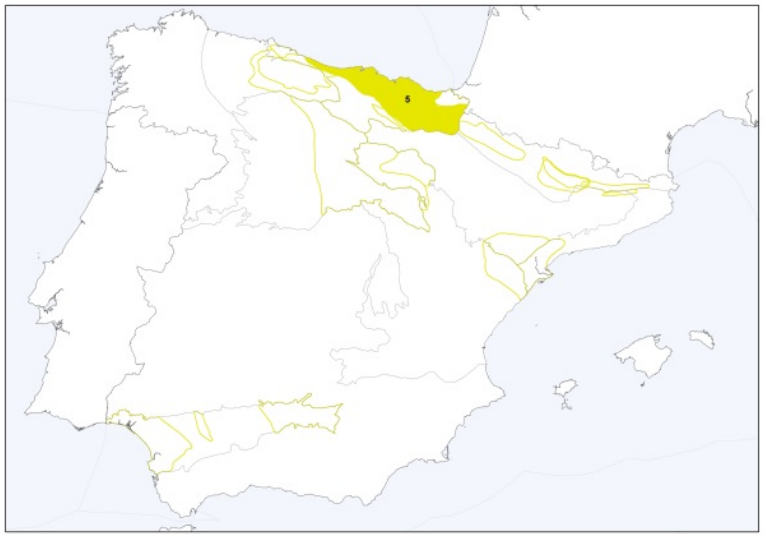
The lower Toarcian sediments are organically lean (TOC<1%), however, a TOC peak is observed within the back shale interval of the late *Tenuicostatum* - Early *Sepentinus* zones (TOC up to 1.8%). The lowest TOC of the succession corresponds to the upper Domerian unit of limestones developed at the end Pliensbachian.

The **hydrocarbon potential** of the black shales and organic marls has been evaluated from Pyrolysis S2. In mature black shales samples it averages 5-10 mg/g but can reach values up to 20 mg/g. Immature black shales samples yielded excellent values with maximum peaks between 10 and 57 mg HC/g. Finally, over-mature samples collected in the deepest parts of the Polientes-Sedano Trough only yielded poor amounts of hydrocarbons (1.5 mg HC/g). The

hydrocarbon potential decreases dramatically in the limestone-marl alternations, with maximum values of 2-3 mg HC/g for immature samples.

The average **Hydrogen Index** of the samples shows that the black shales are characterized by hydrogen rich type I/II kerogens. Mature samples of the Polientes-Sedano Trough show average values between 350-450 mg HC/g TOC. Samples of the immature Southwestern Marginal Domain reveal initial Hydrogen Index values of up to 600-750 mg HC/g TOC. Finally, over-mature samples from the central Polientes-Sedano trough are characterized by extremely low HI values (>50 mg HC/g TOC). The organically leaner limestones and marls show lower HI values of about 100 and 200 mg HC/g TOC.

- **BASQUE-CANTABRIAN LOWER CRETACEOUS. ERRENAGA, LAREO; PEÑASCAL, ELEKORTA and PATROCINIO FMS (Formation No. 5)**



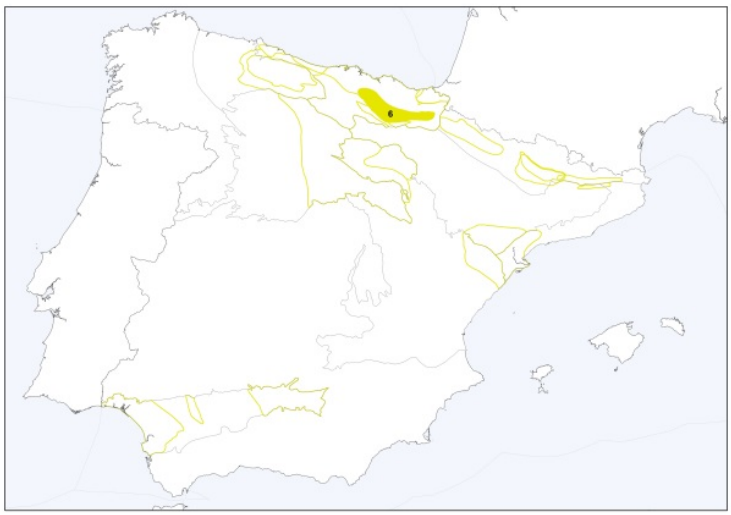
From east to west, **TOC** results of the Errenaga Formation are all below 0.6% in the Iribas section, and below 1% in the Igaratza section (most of them below 0.75%). In the Ataun section (only the central shaly part) all lie below 1%, and all but two are below 0.75%. In general terms, the Errenaga Formation shows an increase in TOC content from east (Iribas) to west (Ataun). This trend parallels an increase in the siliciclastic character and thickness of the Formation. The lutite interval within the *D. weissi* and *D. deshayesi* zones is relatively poor in TOC. Practically all values from this interval lie below 0.5%, with maximum of 0.28% in Iribas, 0.63% in Igaratza and 0.87% in Ataun.

TOC results of the Lareo Formation have a minimum of 0.28% and maximum of 2.09%. The values of T max are between 494°C and 550°C.

The Peñascal and Elekorta Formations are up to 1,000 m thick. Black shales equivalent to the OAE 1a are located around meter 600 in the *D. deshayesi* ammonite zone, and TOC values reach up to 1.7% and 0.5 % average.

The total organic carbon content of the Patrocinio Formation (80m) in the Florida section is relatively low, with values ranging from 0.1 to 0.5 wt%. In the Cuchía section it is slightly higher than in the La Florida section, all values are below 1 wt% (i.e. 0.1 to 0.8 wt%). Other authors obtained values ranging from 0.12% and 1.37%.

❖ BASQUE-CANTABRIAN UPPER CRETACEOUS. VALMASEDA FM (Formation No. 6)



The thick Cretaceous (Albian-Cenomanian) Valmaseda Formation contains the **Enara Shale**, which holds an estimated 185 Bm^3 (6.5 TCF) of shale gas based on a study of 13 wells in the Gran Enara basin in northern Spain. A shale gas exploration program has been proposed. However, no details in the TOC or other properties accompanied this initial shale gas assessment. San Leon Energy`s separate characterization of the Valmaseda Formation and the Enara Shale indicates that the TOC, while up to 3.6% locally, averages only about 1%. Traditionally the shales and/or black siltstone of the Valmaseda formation have a TOC between 1.5% and 2% for the thicker sections. The total thickness of Valmaseda Formation is over 2,000 m.

In the **Navarro-Cántabro Trough**, continuing the exploration around the Castillo Gas Field targeting the Valmaseda formation, three wells were drilled: Marinda-1, San Antonio-1 and Armentia-1. The first two showed a reservoir with low porosity and permeability. The third, operated by SHESA, was designed to cut Valmaseda formation with the highest density of natural fractures, that could provide porosity and permeability to the formation. 447 meters of silts and shales of the Valmaseda formation were cut. The long-term production test, without stimulation, provided over 0.5 BCF of dry gas, almost pure methane. Towards the east, 7 additional surveys were drilled to determine the potential of the lateral equivalents of the Valmaseda formation. All wells had dry gas.

➢ *PYRENEES BASIN (Basin 3)*

The Pyrenean range stretches from the Gulf of León in the Mediterranean to the Bay of Biscay in the Atlantic. Structurally it has double verging tectonics. The eastern boundary of the South-Pyrenean slope is the Mediterranean Sea, the western boundary is represented by the structural alignment formed by the Basque-Cantabrian basin. To the south it borders the Rioja-Ebro Basin and at the eastern end with the Catalonian Chain.

The South-Pyrenean Basin is part of the Pyrenean range where Precambrian to Cenozoic materials outcrop. It is a structurally complex area, with a number of south verging sheets from the Alpine orogeny between the axial part of the Pyrenees in the N and the thrust over the Ebro Basin in the S.

The South-Pyrenean domain encompasses the areas of the eastern, central and west Pyrenees, and has an area of about 20,000 km^2 in which 63 wells have been drilled (3 wells per 1,000 km^2). ENPASA has been the most active company in this area with 24 exploratory wells, followed by ENIEPSA/Hispanoil with twenty surveys between 1978 and 1986 and Campsa and Valdebro with 3 wells each, Campsa in the 80's and Valdebro in the decade of the 60's. The maximum number of boreholes drilled per year was in 1964 with 11 wells, 8 of them in the area of the Benabarre structure.

The area was highly explored between 1960 and 1975 without any success, finally in 1975 ENIEPSA discovered the Serralbo gas field in 1978. The reservoir consists of two powerful calcareous megabreccias of turbiditic origin forming two separate fields, the middle and upper Eocene. The gas source rock may be the dark hemipelagic clays with a low content of organic material, but over 300 m thick. Production began in 1984 and ended in 1989, when the field became an underground gas storage site.

Two sites have been discovered, Jaca and Serrablo (1978). The Serrablo-1 discovered the deposit which together with the Jaca has produced a total of 931 Mm3 of gas.

The last exploratory wells drilled have been Jaca-18 and Jaca-22 in 2003 by Enagas, for the development of depleted reservoir for the current gas storage site. Despite a gas potential in the Eocene materials, the drilling rate is considered to be low. In 2003 four research permits (Abiego, Peraltillo, Barbastro and Binéfar) were granted to the Petroleum Development Associates Iberica (PDAIs) company. A year later Cepsa obtained the research permits of Vallfogona East and Vallfogona West that were subsequently resigned.

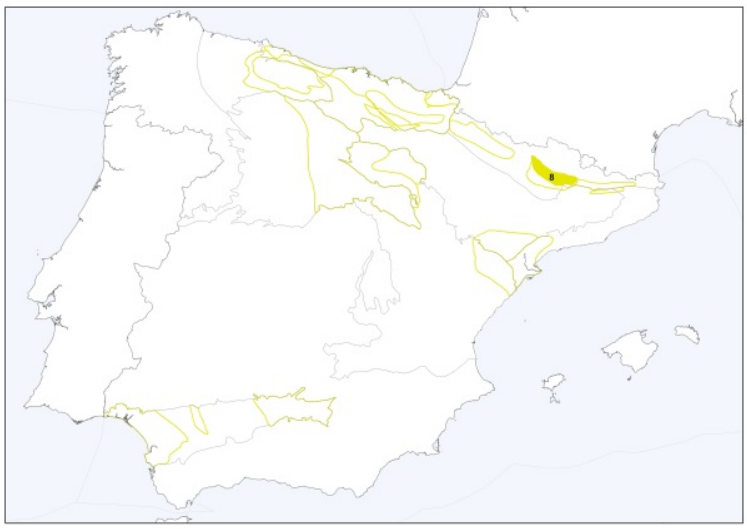
❖ PYRENEES LIASSIC (Formation No. 7)

The study area is located in what is called **Central South-Pyrenaic Unit**, which is made up from South to North, of the marginal ranges of Montsec and Bòixols thrust sheets, formed by cover materials (Mesozoic and Paleogene). The Jurassic sequence has two differentiated sections with possible interest due to kerogen contents, the lower is located at the Lias base, immediately over sandy and silty sediments with breccia levels and ofite boulders constituting the so-called ferruginous lower Lias breccia. The other section is constituted by the Upper-Middle Lias laminated black marl, possibly Toarcian.

The thickness of the section with kerogenic calcschists does not exceed 7 m, some levels have punctually 85 and 115 L/t of kerogen.

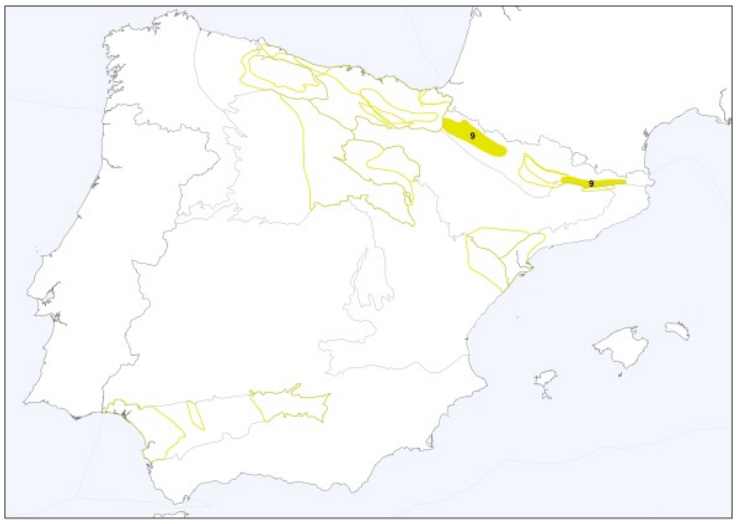
❖ PYRENEES LOWER CRETACEOUS. CABÓ FM (Formation No. 8)

The study area is located in what is known as **Central South-Pyrenaic Unit**, which is composed from south to north, of the Bòixols thrust sheet. The sequence comprises a series of interbedded limestones and marlstones spanning from late Barremian to early Aptian.



It is formed by intermittent dark limestone and marlstone layers associated with extremely low diversity and scarce benthic fauna, low bioturbation index (0–3) and high TOC (up to 1.7 wt %), that indicate recurrent oxygen-deficient conditions within the lowest 31 m of the section and more uniform oxygenation in the upper 54 m. EDS analyses confirmed the presence of clastics (mainly aluminum silicates) in the matrix. X-ray diffraction (XRD) results attest for sustained terrestrial fluxes as the source of nutrients to the basin because of a 30% average non-carbonate bulk mineral content in the sediment. The non-carbonate fraction is dominated by quartz (average, 14%) whereas the clay mineral assemblages are characterized by high illite content (>73 relative %) with minor concentrations of kaolinite (<5%), illite/smectite mixed layers (<17%) and chlorite (<15%). TOC values between 0.5-1.74%.

- **PYRENEES EOCENE (Formation No. 9)**



- ***WESTERN ZONE. BURGUI FM.***

The **Jaca Basin** occupies the eastern sector of the major Jaca-Pamplona basin, an east-west elongated basin located within the Gavernie structural unit of the western Pyrenees. It is flanked by the Exteriores range to the south, the upper Cretaceous-Paleocene carbonate platform to the north, the Boltaña anticline to the east and the Navarra diapiric lineation to the west, delimiting an area of 150 x 45 km.

The Jaca Basin formed during the early pyrenean convergent phase, when the initial thrusting increased subsidence and produced a dramatic paleogeographic change: the shallow marine Mesozoic and early Tertiary environment of the Jaca high evolved into deep-water conditions during Cuisian times. Since then, this syn-tectonic sedimentary trough experienced a complex depositional and tectonic history until sedimentary infill and tectonic activity halt during Miocene times.

The **Burgui marl and limestone** has been recognized as the source rock for the Serrablo field. Other authors have previously postulated the existence of deeper source rocks in the Upper Cretaceous or Triassic intervals. The Burgui marl and limestone comprises hemipelagic slope facies deposited during the early tectonic phases on the backlimbs and troughs of the early Eocene ramps. Its sedimentation is controlled by its structural position. There is a facies between the carbonate facies (Guara Fm.) accumulated at the highs of the frontal ramps and the marly facies (Burgui Fm.). Consequently, there is strong structural control on the location and extent of the source rock, which youngs to the south as a consequence of the progradation of the thrust front.

Limited geochemical studies were conducted on samples from several wells indicating that the Eocene sediments present low organic matter content with average TOC values between 0.1 to 0.4% (maximum 0.57%). The organic matter consists of inertite and woody material and locally herbaceous and algae material has been described. The maturity level of the Eocene section has been determined by spore coloration and vitrinite reflectance methods.

The Eocene flysch is generally immature. Only the lowermost flysch section is mature. This lower flysch comprises argillaceous limestone interbedded with marls. In some wells, a few metres in thickness, dark shales interval has been encountered.

It is a thick section (300 m) of Ypresian hemipelagic shale, kerogen type III with TOC below 0.6% and R_o (%) between 1.0 and 1.3 values. This poor source rock quality is compensated by its significant thickness.

- ***EASTERN ZONE.VALLFOGONA FM.***

The area is located in the Cadí thrust sheet, which is made up of very thick Lower-Middle Eocene and Paleocene sediments. The Vallfogona Fm is composed of deep water marine sediments (up to 900 m in thickness) deposited by high density gravity currents. The shales are dominant in the lower part, occasionally alternating with sandstones characterized by Bouma sequences. In the upper part, slumps are predominant and turbiditic facies are more proximal.

Organic analysis and petrographic observations allow us to distinguish two types of samples (A and B) in accordance with their organic characteristics. In type A samples, the Rock-Eval pyrolysis shows Hydrogen Index (HI) values from 236 to 365, Total Organic Carbon (TOC) from

0.83 to 0.99%, Tmax from 437 to 439°C, and S2 from 1.91 to 18.42 mg HC/g rock. Type B samples have HI values from 287 to 390, TOC from 0.64 to 1.09%, Tmax from 433 to 439°C, and S2 from 1.84 to 4.25 mg HC/g rock. The recognizable organic elements in both types are mainly constituted by filamentous algae, occurring as continuous lamina with yellow fluorescence, dinoflagellates, and resinite. Vitrinite is only present in minor amounts in type B samples. The organo-mineral matrix could present framboidal and disperse pyrite and, in type A samples, the presence of dolomite crystals is frequent.

➢ *DUERO BASIN (Basin 4)*

The Duero Basin is located in the northwest quadrant of the Iberian Peninsula. It has traditionally been considered an intraplate basin with complex evolution which began at the end of the Cretaceous.

The Mesozoic substrate of the basin includes deposits from the Triassic to Upper Cretaceous. It contains an accumulation of tertiary pre and syntectonic materials that reach 3,500m although most of the outcrops correspond to Tertiary postectonic deposits.

Depending on the tecto-sedimentary features several sectors are distinguished:

- **North sector**, which behaves as a foreland basin of the Cantabrian mountain range at least since the Eocene.

- **Eastern Sector**, related in the same way with the Alpine evolution of the Iberian Range.

- **Western and south-western sector**, which is characterized by horst and grabens tectonics with NE-SW faults and its conjugates, mainly during the Paleogene.

- **South Sector**, which acted as a foreland basin of the Central System during the Oligocene-Miocene.

With an approximate total area of 47,500 km^2, 16 boreholes have been drilled in the Cuenca del Duero-Almazan (0.36 wells per 1,000 km^2). Valdebro company was the most active drilling with five wells between 1955-1961. Phillips explored new areas with 3 wells between 1962 and 1963. The five other wells were drilled by different companies. El Campillo-1 well is the latest drilled by Repsol in 1990. No oil system has been found so far. ENDESA currently has drilled deep boreholes for CO_2 storage research in the area of Sahagún.

Deep boreholes are very abundant in the Duero basin. They are particularly concentrated in its eastern part and reflect the existence of an eastern-northern very thick strip that continues in the Almazan Basin and into the Ebro Basin along the corridor of the Bureba.

The Paleozoic is found at a depth of 799 m. (San Pedro-3) and 2,849.5 m. (Villameriel-1). Found lithologies attributed to the Carboniferous are: dolomites at 2,517 m. (Alcozar-1), gray sandstone and claystone at 1,581 m (The Gredal-1), and slates at 1,000 m. (Quintana Redonda).

❖ DUERO CARBONIFEROUS (Formation No. 10)

In the Duero basin there are no Paleozoic outcrops, however under the Mesozoic and Tertiary cover in the northern and eastern part of the basin, we can expect the continuation of the basement constituting the Paleozoic of the **West Asturian-Leonese** and **Narcea Antiform**.

The first is a series of Stephanian basins outcrops west of the Cantabrian Zone. The materials rest discordantly on a Cambrian, Ordovician and Silurian series. The most important outcrop of the area is in the Bierzo basin, although other smaller basins exist towards the NW (Tormaleo

and San Antolín basins). The stratigraphic sequence in all of them is formed by quartzite conglomerates at the base followed by levels of shales and sandstones with carbonaceous levels. Ages are Stephanian B-C. The total thickness reaches 1,800 m, decreasing northward.

East of the above, in an innermost position with respect to the Asturian Arc, there is a series of Stephanian outcrops over the Precambrian (and Cambrian) of Narcea, similar to the above which could be of interest. The largest is the Villablino basin, with a 3,000 m thick series. The basal sedimentation is represented by breccias and polygenic conglomerates. Following these materials are cyclic sandstones, shales and coalbeds. The age of the set is Stephanian B-C. Other basins of interest are Tineo (800 m thick), Cangas del Narcea (200 m), Carballo (800 m), Rengos (1,500 m), La Magdalena (1,500 m).

➢ ***EBRO BASIN (Basin 5)***

The Tertiary Ebro Basin is, geographically, a triangular depression, framed by the Pyrenees to the north, the Iberian Range to the south and the Costero-Catalana chain to the east. At its western end it joins the Duero Basin along the corridor of the Bureba.

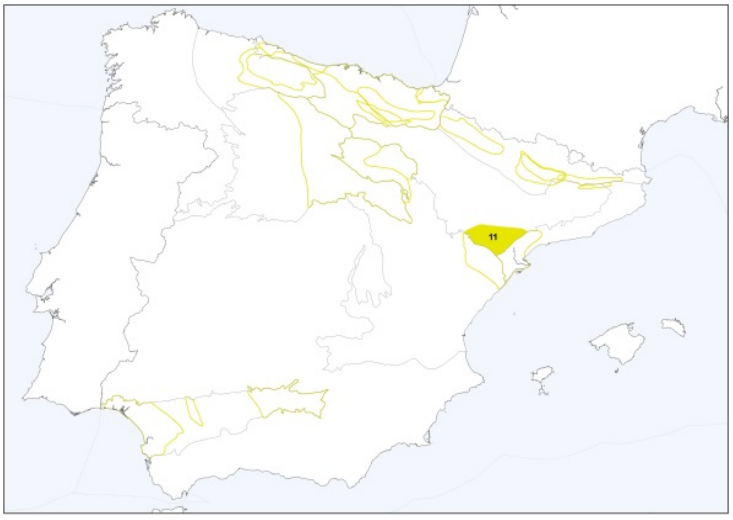
The base of the Tertiary is located more than 3,000 meters below sea level in the Pyrenean mountain range and presents a trend of expansive overlap to the south, with the oldest materials covering the Pyrenees margin and the most modern the Iberian margin.

The Ebro Basin occupies an area of about 39,700 km^2 and has a total of 41 drilled boreholes (1 well per 1,000 km^2).

The exploration of the area began in 1947 with the Oliana-1 well operated by Ciepsa. The maximum activity occurred in the 60s, between 1960 and 1964 more than half of the total wells were drilled in this basin by Enpasa, Esso, Valdebro, Erap, Ciepsa and Cepsa companies. Later exploration decreased significantly to one or two wells per year. In the 80's Campsa began drilling the Rioja-4 and 5 wells showing the existence of a gas system in Mesozoic formations below powerful tertiary series. Studies in the area suggest the existence of Jurassic source rocks, and Jurassic reservoirs of reefs or oolitic bars type.

The last exploration well drilled in the area has been Viura-1 (2010) by the company Oil & Gas Skills, and has led to the discovery of a new deposit in the area.

- **EBRO CARBONIFEROUS (Formation No. 11)**



The only Paleozoic outcrop is the **Puig Moreno**, located in the central area of the basin, near the border with the Iberian and Costero-Catalana chains. It consists of three Carboniferous spots under the Paleogene series, similar to the series of Montalban (Central Spain) and located to the NE of it. It covers an area of about 2 km^2 and the series is dated as Lower Carboniferous and Namurian-Westphalian. The stratigraphic sequence consists of sandstones, calcarenites, greywacke and quartzite levels. However, some authors have dated this outcrop as Stephanian and linked it to the Carboniferous of the Cantabrian Zone, so that the Carboniferous of Puig Moreno and the Montalban region (Central Spain) would not be contemporaries. Exploratory wells near the area of interest that found Paleozoic substrate are:

Ebro-1. At 1,893 m Paleozoic consisting of clays, siltstones and sandstones.

La Zaida. At 1,577 m schist.

Mayals-1. At 1,365 m undetermined Paleozoic.

Caspe-1. Contact Buntsandstein-Paleozoic at 1,160 m

- **EBRO EOCENE. ARMÀNCIES FM (Formation No. 12)**

The Armancies Formation is an Eocene carbonate slope succession in the **Catalonian South Pyrenean basin**. It ranges from 500 to 700 m in thickness. The first 200 m are made of a thin-bedded facies of wackestones alternating with dark pelagic fauna of miliolids, ostracods, bryozoans, and planktonic foraminifers and show significant bioturbation. They also show a low organic content (< 0.5% TOC). The lime-mudstone beds show a massive structure or planar millimeter laminations. They may contain sparse pelagic fossils of planktonic foraminifers, ostracods, and dinoflagellates; they do not show any bioturbation, and have high TOC values, which can reach individual scores of about 14%. They qualify, therefore, as a typical oil shale. Rock-Eval Pyrolysis analysis affords a mean S2 value of 25 mg HC/g. Mean S1 value is around 1.0 mg HC/g. As is typical of an initial oil window, T max maturity parameter ranges from 432 to 440°C (mean = 434°C). This degree of evolution is in accordance with the very low value of carbonyl and carboxyl groups, as determined by IR spectrometry and NMR on Fischer assay extract. The proton NMR shows an aromatic/aliphatic hydrocarbon ratio of 1:4, as expected in earlier stages of catagenesis. N-alkane gas chromatography profiles show n-C 15 to n-C 19 prevalence and that neither even nor odd carbon numbers prevail. This distribution perfectly matches that of typical sediments of marine origin and also agrees with obtained hydrogen index values (mean HI = 500 mg HC/g TOC). Sedimentological and geochemical results indicate an autochthonous marine organic matter and the potential of these slope shales is good oil-prone source beds.

Though the presence of many oil shows and the existence of a good source rock (i.e. the deep slope facies of the Armàncies Formation) have attracted interest from oil companies in exploring the southeastern Pyrenees, they have yet to discover any prospective reservoir. The combination of complex tectonic structures and basin evolution makes it difficult to apply successful exploration strategies. The Terrades quarries are located in the most eastern part of the **Cadí thrust sheet**, in the shelf facies of the Armàncies Formation. Rock-Eval pyrolysis of the most shaly levels in the quarries yields S1 values up to 1.9 mg HC/g of rock, S2 up to 22.6 mg

HC/g of rock, TOC up to 2.8% in weight and an average Tmax of 343°C. The extracts of the source rocks, and the oil shows associated with fractures, have saturated hydrocarbon fractions characterised by the dominance of C17-C22 n-alkanes with an even-carbon-number preference and pristane/phytane ratios b1. These molecular signatures reflect the anoxic, carbonate-depositing environment of the source rock.

➢ ***CATALONIAN CHAIN (Basin 6)***

It is a narrow belt of mountains, linked in origin to the Iberian Range, which is divided into three main units: Litoral Chain, Prelitoral Depression and Prelitoral Chain (E to W). The Northern half consists mainly of granites and metamorphic rocks of the Paleozoic, while the southern half consists of predomantly Mesozoic outcrops.

Carboniferous outcrops are grouped into two sectors, southern (Priorat and Sierra de Miramar, in Tarragona) and Northern (Montnegre, Montseny and around Barcelona).

In the area of Catalonian Chain 24 boreholes have been drilled (less than 2 wells per 1,000 km^2). The first well was drilled in 1953, La Bisbal-1 by Sepsa. The peak years were 1962 and 1974 with 2 wells in each. Since 1979 a short break in the drilling occurs, until today. No proven petroleum systems are known.

Wells near the Enlace zone are Reus-1, Martorell-1 and San Sadurní-1 that cut across the Mesozoic and Tertiary materials, reaching an indeterminate Paleozoic in Martorell-1 at 2,247m.

❖ CATALONIAN CHAIN CARBONIFEROUS (Formation No. 13)

In the southern sector of the Catalan Coastal Chain the Carboniferous occupies a considerable extent, all around the Prades mountains and the Priorat.

The basal part is formed by a level of lidites with phosphatic nodules, 10 to 20 m thick and probably Tournaisian in age. Above the lidites a carbonate horizon can be found formed by limestones commonly dolomitized or recrystallized or green and purple shales with thin layers of limestone.

Above is a thick succession with the typical **Culm facies** (=flysch), typical of the Hercynian syntectonic series. This series is best represented in The Priorat, where it reaches more than 2,000 m thick. It consists essentially of shales, sandstones, conglomerates and several limestone horizons intercalated in the lower half of the series.

Age would be Namurian-Westphalian, which match the ages assigned to the Montalbán Massif in the Iberian Chain.

In the Carboniferous of the Priorat area, the conodontal elements extracted from the carbonate levels of the base of the Culm series have CAI values of 6.5; 7; 7,5 and 8, which would indicate a possible over-maturation of organic matter.

➢ *IBERIAN CHAIN (Basin 7)*

The Iberian Chain (or Iberian System) and the Costero-Catalana Chain are two partially eroded alpine structures located east of the Iberian Peninsula. Both, form two tectonic units of similar age and style. This is a series of mountain ranges of NW-SE (Central Spain) and NE-SW (Cordillera Costero-Catalana) that link in its eastern and southern ends, through El Maestrazgo.

Overall, the degree of deformation is moderate, with very little alpine foliation and a very low degree of metamorphism.

The materials forming the Iberian System are mainly Mesozoic and Tertiary age, although locally outcropping Paleozoic base materials integrated in the Alpine folding. At the same time there are subsiding depressed areas in which, especially during the Early Cretaceous, thick layers of sediment, such as Cameros and Maestrazgo basins, were accumulated.

We can distinguish six sectors with different characteristics, two of them may have potential shale gas formations:

Cameros-Sierra de la Demanda Structural Unit

This unit is located on the northern tip of the Iberian Range, and is formed by the mountains of La Demanda, Cameros, Urbión and Cebollera, in which the E-O guidelines predominate. The Sierra de la Demanda is essentially constituted by Paleozoic materials, while in Cameros emerges especially the Upper Jurassic and Cretaceous.

Aragonian Branch

It is located SE of the structural unit Cameros - Demanda. It consists of the Moncayo, La Virgen, Victor, Algairén and Cucalón Sierras, forming a marked NW-SE direction. The tertiary basin of

Calatayud is located within the Aragonian Branch. Paleozoic materials outcrop in the cores of the structures, and Mesozoic materials around them.

The Iberian Range has an area of about 65,000 km^2 in which have been drilled 18 boreholes (0.27 wells per 1,000 km^2). In 1963 and 1981 up to three surveys/year were drilled, which was the highest rate of drilling in this area. Operators who have most explored in the area have been Amospain, Auxini, Enpasa, Campsa, Shell, INI-Coparex and Tenneco. The explorations have not found effective petroleum systems in the area to date.

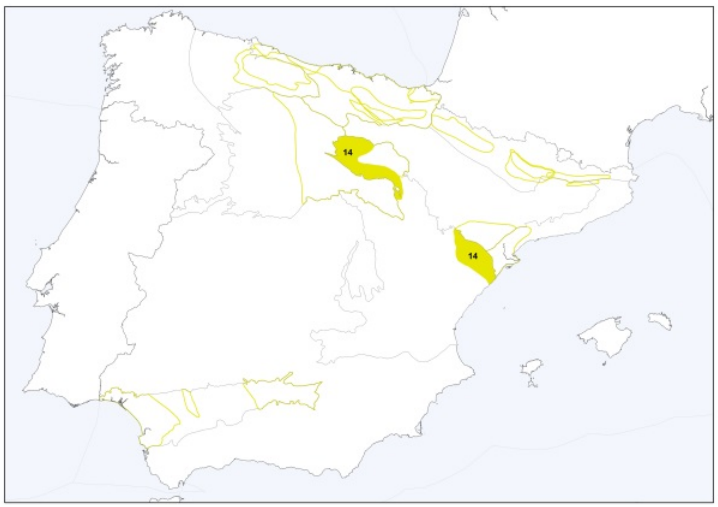
The highest drilling activity occurred during the sixties and seventies, when most of the wells were developed.

The latest well drilled in the domain was Cameros-1 (Ciepsa), in 2002.

In the area of Cameros, boreholes like Castilfrío-1, Ucero-1 and Aldehuela-1 cut the Mesozoic, reaching a maximum depth of 2,650 m in the case of Aldehuela-1, but not reaching the Paleozoic .

Inside the Maestrazgo area the wells Mirambel-1, Bobalar-2, Maestrazgo-1, Maestrazgo-2 and Salsadella-1 reach the Permian (Mirambel-1) or Estefano-Permian (Maestrazgo-1, Salsadella-1).

❖ IBERIAN CARBONIFEROUS (Formation No. 14)



Paleozoic massifs of the Iberian Range have traditionally been located as part of the West Asturian-Leonese Zone of the Hesperian Massif, maintaining this situation at least since the Lower Cambrian to Middle Devonian.

The Carboniferous outcrops in reduced surface areas, isolated and far between, forming part of more extensive Paleozoic massifs. There are two important outcrops: one located in the northernmost sector of the Cordillera, in the Sierra de la Demanda, and another in the central

sector, in the core of the Montalban anticline. Aside from them, only the small outcrops of Puig Moreno (Ebro Basin) and Henarejos can be mentioned.

With regard to the possibilities of unconventional resources in the Carboniferous, potential sectors would be in the Sierra de la Demanda (Carboniferous NW Iberian) and Montalbán Massif.

- **CAMEROS BASIN - SIERRA DE LA DEMANDA**

The Sierra de la Demanda consists of a Paleozoic massif located in the northwestern end of the Iberian Range, composed mainly of Cambrian-Ordovician materials resting on a basal formation attributed to the Precambrian. In the western sectors the Lower Paleozoic is covered by carboniferous materials.

The succession of Stephanian-Westfalian age, is composed of two major groups:

- **Lower set**, consisting of an alternation of conglomerates, sandstones and shales with carbon levels and rich flora. Conglomerates are divided into three levels that are decreasing in thickness and grain size to top.

- **Upper set** of finely laminated sandstones and shales with abundant marine fauna, presenting to the top lenticular dolomitic levels.

The total succession can be subdivided into five mega-sequences. Each megasequence comprises two terms:

- A lower detrital term composed of conglomerates and coarse sandstones.

- An upper term consisting of fine sandstones and shales, including carbonated lenses.

- **ARAGONIAN BRANCH**

The Paleozoic **Montalbán Massif** forms the core of an anticlinal structure of NW-SE direction. The Montalbán Massif is formed mostly by carboniferous materials which lie unconformably on the Devonian. The Carboniferous is unconformably covered by Triassic materials and, locally, by a possibly Permian unit.

In the Montalbán Massif the general succession is summarized in:

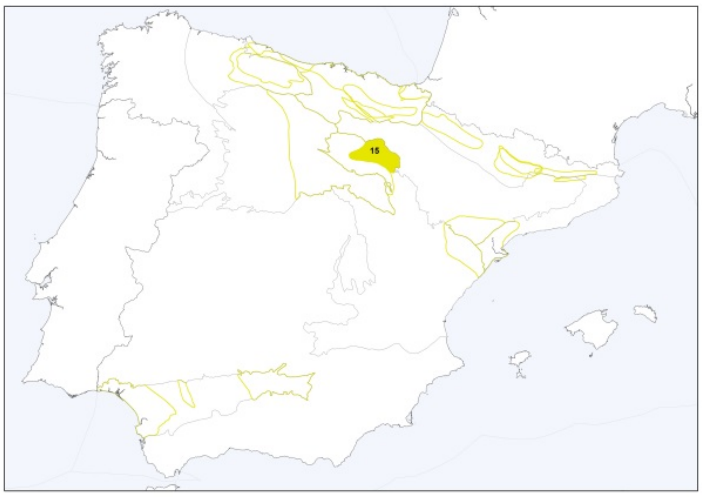
• Sandstones, sandstone flysch, greywackes and slates, Namurian-Westphalian.

• Sandstones, quartzites, limestone flysch, slates and greywackes, Namurian.

• Ordovician shales and sandstones.

The set of Lower Carboniferous terms corresponds to the sequence of Montalban, which is affected by intense diastrophism. The Carboniferous of the Sierra de la Demanda, which is posterior in age, has a net postectonic character, so it is justified to think that it lies unconformably on Montalbán carboniferous.

❖ IBERIAN LOWER CRETACEOUS (Formation No. 15)



There are several pre-extensional deposits that are potential source rocks, such as the **Pozalmuro Fm** (Callovian in age), a siliciclastic-carbonate platform sequence with black-shales deposits, and the **Torrecilla and Aldealpozo Fms** (Oxfordian and Kimmeridgian in age respectively), carbonate units formed in a shallow carbonate ramp environment.

In the syn-extensional record the most of the depositional sequences contain dark carbonate and/or fine-grained deposits, which suggest potential source rocks for the basin. The largest and most abundant of these deposits are found in the DS3 (Valdeprado Fm, Berrasian in age), constituted by thinly laminated black-shales, deposited in coastal wetlands and shallow depositional environments. In the DS7 (Abejar Fm, Late Barremian and Early Aptian in age) dark-grey shale intervals appear interbedded with sandstone bodies, deposited in a fluvial-lacustrine system. In the same DS7 (Enciso Gr, Late Barremian and Early Aptian in age) dark shale-marlstone deposits interbedded with sandstone and limestone beds appear too generated in fluvio-lacustrine coastal wetland depositional systems. In the DS8 (Escucha Fm, Late Aptian-Early Albian) thin layers of shaly-coal and shales are interbedded with sandstones originated in a fluvial and coastal depositional environment.

For these deposits the original type of kerogen is inferred from interpretation of the depositional environment: Type II for the Jurassic marine deposits, Type I for the DS3 deposits and Type III-Type I for the DS7 deposits.

In the northern and central sectors of the basin rocks attained over-mature to dry-gas thermal conditions, whereas rocks in the southern sector and in the footwall of the thrust only reached the immature to early oil-window thermal condition. In the southern sector of the Cameros Basin they are characterized by abundant organic matter remnants (TOC from 2 to 17%) and immature to early oil-window thermal conditions (0.38-0.75% R_o), indicating a high hydrocarbon potential for these rocks (S2 from 11 to 123 mg HC/g and HI values from 23 to 715 mg HC/g TOC), whereas in the central and northern sectors only residual kerogen composed of vitrinite, inertinite and solid bitumen particles is observed.

➢ GUADALQUIVIR BASIN (Basin 8)

Guadalquivir Basin is an elongated depression ENE-WSW direction, which is a foreland basin type and is located between the Betic orogen at the south and the passive Iberian Massif margin at the north. Its genesis takes place as a result of the deformation of the lithosphere caused during the placement and stacking of External Betic Units.

The sedimentary basin fill takes place between the Tortonian and Pleistocene. During the Tortonian, the compressive stresses in the foreland fold belt brought down olistostromes from the South. The northern boundary of the basin is defined by an almost straight line separating the Paleozoic and Mesozoic rocks of the Cenozoic Sierra Morena basement.

The substrate of the Neogene basin is composed of metamorphic or igneous Paleozoic rocks. In its eastern and western margins the Mesozoic formations emerge, consisting of a basal Triassic in the germanic facies and a Jurassic-Cretaceous carbonate series which progressively appears more complete eastward.

The upper Quaternary-Miocene filling is divided into several units, which form five depositional sequences that prograde from the north, east and south margins towards the center of the basin and are named by age order: Atlantis, Bética, Andalusia, Marismas and Odiel.

Guadalquivir basin covers an area of about 23,000 km^2, in which 90 wells have been drilled (almost 3.9 per 1,000 km^2).

Exploratory activity is concentrated in two clearly distinct periods:

1.- 1945 - 1969 research period primarily conducted by Adaro, in which wells were drilled to increase the knowledge of the basin but there were no oil discoveries

2.- 1981-2004 initiated by the Chevron exploration company that interprets the Guadalquivir Basin as a landwards continuation of the gas fields discovered in the Gulf of Cadiz. In this period 51 boreholes were drilled.

The Palancares-1 well drilled by Chevron in 1982, was the first discovery. Other operating companies in addition to Chevron are Repsol, Ciepsa and, in recent years, Petroleum Oil & Gas which has drilled from 2000 to 2007, the most current surveys in the area.

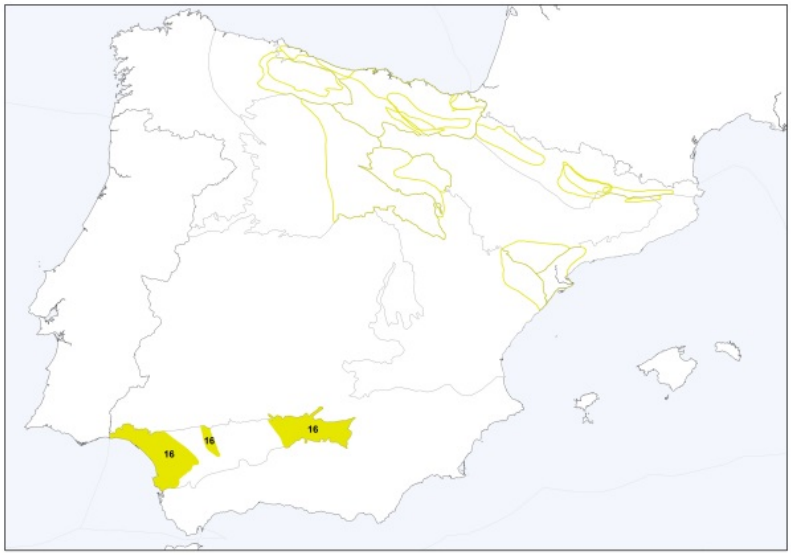
The success rate, defined as wells put into production, is higher in the case of Chevron, which carries more than 50% of drilled boreholes (80% of its wells find gas, although not all are commercial).

Of the boreholes drilled in the second period 16 were put into production, which provides an overall success rate of more than 30% or 1 in 3 boreholes drilled for commercial discoveries.

Total production provided by the Guadalquivir fields (biogenic gas with 98% methane) to December 2004 amounted to 1,199,026 MNm3, of which nearly 90% comes from the Campos de Marismas (1,047 MNm3).

The interest of this basin for potential shale gas reservoirs, focuses on the Paleozoic substrate. The degree of uncertainty is high, since the Paleozoic has usually been the level of completion of exploration oil drilling and no petrophysical data are available. Three zones, where the Paleozoic is covered by Miocene-Quaternary sedimentary series with a variable thickness up to approximately 3500m, are considered.

❖ GUADALQUIVIR CARBONIFEROUS (Formation No. 16)



- **SOUTH-WESTERN ZONE.**

The south-western zone ranges from the Atlantic coastline to the province of Sevilla, following the structural trend of WNW-ESE Sud-Portuguese Zone and the northern boundary of the **Culm facies** of the area. This facies can be considered equivalent to the Lower Alentejo Flysch Group located in the Portuguese Algarve that has been assessed as a shale gas objective. In particular the Mértola, Mira and Brejeira formations of Carboniferous age were studied. Together they form a turbidite sequence that progrades to the southwest. The age ranges from the top Visean to the top Moscovian. TOC values vary between 0.26 and 1.86%, with a mean of 0.81, 0.91 and 0.72 respectively. Most of the samples have values of 0.5 to 1.0%. However, it can be assumed that these values represent 40% of the original, due to carbon consumption during the maturation process. Recalculating the initial TOC values, they would result in a range of 0.65 to 4.59, with mean values of 2.02, 2.28 and 1.80, most often between 1.0 to 4.0%.

- **WESTERN CENTRAL ZONE**

The western-central zone is smaller and coincides with the hypothetical extension of the The Mariánicas coal basin, through the Villanueva del Río y Minas coalfield towards the SE, in concordance with the syncline of Viar, within the area of Ossa-Morena. We can distinguish three zones: a western area formed by Permian materials; a central area formed by upper-Carboniferous successions of lower Devonian, faulted and refolded on which there is a NW-SE syncline consisting of conglomerates, sandstones and carbonaceous shales of the Upper Carboniferous and a eastern metamorphic zone. There is no background study of this shale on the content and status of organic matter. However in the 80's, IGME was carried out a campaign to estimate **bituminous shales** across the country. The Ossa-Morena coalfields, located to the NW (Maimona, Bienvenida, Fuentes del Arco and Casas de Reina), were studied but without conclusive results. The Puertollano coalfield, located about 200 km NE in the Central Iberian Zone, was also investigated.

This site was the subject of exploitation of oil shales and coal between 1953 and 1966. The three horizons are called A, B and C, in-between of two layers of coal, sandstones and graywackes with about 110-130 m thick.

These levels, considered at the time as exploitable for oil, had oil yields of 5-6%, 12-24% and 10-14% respectively, resulting in an average yield of 10.5% by weight. The mineralogical composition is 40% mica, 25% kaolinite and 20% quartz. The distillate oil has a C/H ratio of around 7.5 and contents of S and N of around 0.6 and 0.8% respectively. The distillate gas reaches a yield of 40 Nm^3/t.

- **EASTERN ZONE.**

In the eastern part of the Guadalquivir basin it is estimated that resources can be found associated with shales and greywackes of the **Culm de los Pedroches** (within different units), associated with the Obejo-Valsequillo domain of the Central Iberian Zone, which would be under the discordant sequence of the sedimentary basin.

Within the **Pedroches Unit**, the Culm facies consists of alternating sandstones and shales that can be divided into several sections: basal section of very fine grained purple slates, with

interbedded volcaniclastic materials; fine-grained green slates with interbedded carbonate; and sandstones filling submarine channels.

Inside the **Guadalbarbo Unit**, SW from the above, the Culm includes: very fine grained gray shales interbedded between basaltic lava flows and medium grained dark greywackes, which together indicate shallower conditions than the previous platform.

Further south, the **Guadiato Unit** contains, in the southernmost part, a detrital subunit of Culm facies formed by alternating conglomerates, shales and sandstones with calcareous levels and volcanic rocks and other subunit, further north, detrital-carbonated with black shales and sands with plant remains.

Palynological studies have provided preliminary information about the state of maturation of the organic matter from thermal alteration index (TAI). Thus, in the three zones the TAI is between 6 and 7, equivalent to R_0 2 to 4, indicating a range between semi-anthracite and anthracite, except a case where it would be 2/3 (0.3 to R_0 0.4) corresponding to the lignite-subbituminous rank.