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# Preliminary study of the potential for natural-gas recovery and geological $CO_2$-sequestration in lutite from the Cantabrian Basin

Medio Ambiente

*This article presents a study of four fine-grained detrital sedimentary rock types (lutites) of the Cantabrian Basin, from 57 samples taken in seven sections. The interest of this study resides in the fact that they might contain a worthwhile amount of natural gas and/or make up a suitable $CO_2$ sequestration sink. Properties of these rocks were determined by mineralogical and geochemical techniques; the results show that the most suitable rock formation in terms of its natural-gas generation potential is the Paquete Fresnedo, which appears on the eastern limit of the Cuenca Carbonífera Central (Central Coal Basin). Although use of these rocks for $CO_2$ sequestration is not ruled out, saline aquifers would in theory be the best option.*

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It goes well beyond the remit of this work to attempt any exhaustive analysis of short- and medium-term worldwide energy supply trends. There is already a host of detailed literature, most of it confirming a significant future contribution from fossil fuels. Best estimates point to a 44% rise in energy demand from 2007 to 2030. This rise would be met mainly by increasing the production of oil, coal (especially) and natural gas; this would in turn increase global $CO_2$ emissions from the current 31 Gt to 40.4 Gt by 2030.

Coal reserves are fairly evenly shared out worldwide, whereas 65% of natural gas reserves are owned by Russia and Middle Eastern countries (Iran, United Arab Emirates, Qatar and Saudi Arabia). The European Union has only 2.7%.

*The sedimentary fine-grained rocks under study are made up mainly by quartz and phyllosilicates. The USA has been tapping into rocks of this type for natural gas for over a century*

Spain's demand is expected to grow in line with the abovementioned global trends. Spain in general suffers from a high energy dependence, producing itself only 0.25% of the gas it consumes. Coal supply also largely comes from abroad. Interested readers can check on the feasibility and applicability of other alternative energy sources at http://www.eia.gov/forecasts/ieo/pdf/0484(2011).pdf (p. 86-91).

The United States has been tapping into the natural gas content of certain lutite levels (informally known as «shale») for over a century; this shale is a common rock type in sedimentary basins. Accumulations of this type, among others, are dubbed "Unconventional Natural Gas Resources", in contrast to the generally worked fields (conventional), which include a hydrocarbon source rock, a reservoir rock and cap rock. One of the most characteristic properties of lutites is very low permeability; this rules them out as a good reservoir rock but they can in many cases make up a good cap rock.

Unconventional natural gas sources include shale gas; shale here plays the role of source rock, reservoir rock and cap rock simultaneously.

Geological $CO_2$ sequestration also comes into play here as a partial emission-reduction solution, using the subsoil as a $CO_2$ sink after a capture and injection process: the free $CO_2$ would be injected as a supercritical fluid at depths of at least 800 metres, remaining stored there safely for a long period of time (hundreds to thousands of years).

The idea of carbon sequestration arose in the United States and Canada, where deep injection of hazardous liquid waste and deep geological storage of radioactive waste has been under study and even implemented for some decades now. The first industrial geological $CO_2$ sequestration operation has already been carried out in Sleipner (North Sea, Norway). Since that time the company Statoil has been injecting 1 million tonnes a year into a saline aquifer (Utsira Formation) 1000 metres below the seabed. According to the figures of NETLs (National Energy Technology Laboratory of the US's Department of Energy (DOE), CCS Worldwide Database (see www.netl.doe.gov/), there are now 254 geological $CO_2$ capture and/or sequestration operations up and running in over twenty countries. In the abovementioned projects, and in the vast literature available on this matter, consideration has been given to four geological $CO_2$ sequestration options, depending on the type of storage. In order of importance, these are the following:

- Deep-lying porous and permeable formations (or «saline aquifers»).
- Worked-out oil- and/or gas-fields.
- Deep coal layers, not economically exploitable.
- Sedimentary fine-grained rock (shale or lutite) rich in disperse organic matter.

The great majority of today's demo projects are carried out in saline aquifers. Their main advantage is their huge storage capacity and good injectability. The specialised literature cites only studies underway into geological $CO_2$ sequestration in shale or lutite, most of them in embryonic state in the US [1,2].

In light of all the above, this work has been carried out with two main aims:

- Determine whether or not the rocks under study contain worthwhile quantities of potentially recoverable natural gas.
- Estimate in which cases and sites these formations might be suitable for geological $CO_2$ sequestration.

## The location and properties of the rocks under study

This study has chosen four levels of lutite rock to ascertain their worthiness in terms of gas production and $CO_2$ sequestration. Figure 1 shows the classic geological breakdown of the Cantabrian Zone into the various geological units. From west to east these units are called: Unidad de Somiedo, Unidad de La Sobia-Bodón, Unidad del Aramo, Unidad de la Cuenca Carbonífera Central (hereinafter, CCC), Cobertera Mesozoico-Terciaria, Unidad del Ponga and Unidad de Picos de Europa. Alonso et al. (2009)[3] have produced an interesting work discussing this classic breakdown and advocating a new scheme.

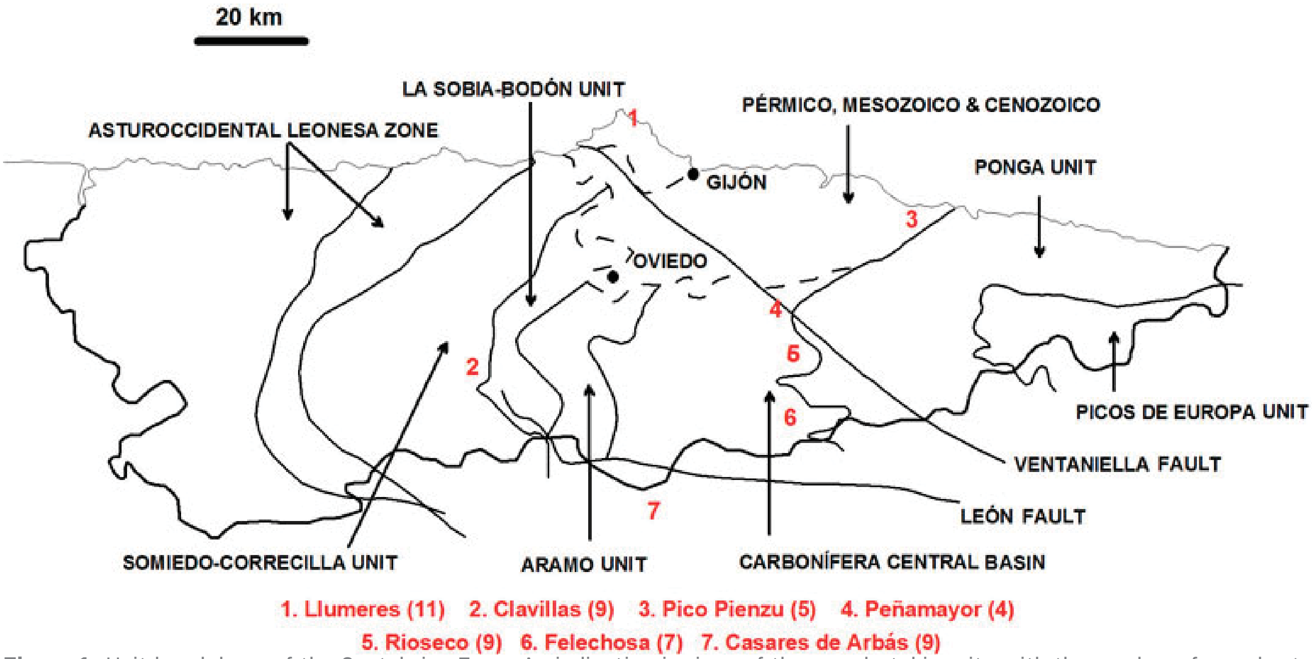



**Figure 1.** Unit breakdown of the Cantabrian Zone. An indication is given of the sample-taking site with the number of samples taken at each site in brackets .

*Tapping into the natural gas contained in rocks of this type would help to reduce Spain's heavy dependence on foreign fuel sources*

Within the Unidad de Somiedo the Formigoso Formation was chosen for study (70 to 200 metres thick), made up by black and grey slate intercalated with wafers of bioturbated siltstone and sandstone (quartz sandstone), becoming more abundant towards the surface and with frequent graded lutite layers. See some of the specific works for more detail on this rock [5,6].

In the Unidad de La Sobia-Bodón, and specifically in the Bodón mantle, the San Emiliano Formation was sampled and studied, a predominantly terrigenous succession up to 2000 metres thick and dating from the carboniferous period (Namurian-Westphalian). It has thin limestone layers in the middle part and some coal layers in the upper part [7,8].

Two rock types were chosen as sample studies in the Unidad de la CCC:

- The *Paquete Fresnedo*, a predominantly lutite unit with smaller sandstone wafers (making up about 7% of the whole [9]) up to 470 metres thick, containing some turbidite intercalations and calcareous breccias and olistoliths, which, where present, are separated between two sizeable limestone levels called *Caliza Masiva* and *Caliza de Montaña* (or *Calcaire des Canyons*) (*Barcaliente* and *Valdeteja* Formations). The *Paquete Fresnedo* dates from the Carboniferous period (Westphalian A) and is laid out laterally through the *Valdeteja* Formation[10], forming wedge shapes where this formation exists.
- The *Pizarras del Sueve* Formation, which outcrops only in a narrow band between *Rioseco* and *Sierra del Sueve*, bordering on the CCC Units to the west and the Ponga region to the east. Although predominantly made up by shale and slate there are intercalated layers of siltstone and sandstone in the lower part of the succession. Its thickness is variable, ranging from 50 to 100 metres, averaging out at 60 metres. The most detailed study of this level has been written by Gutiérrez-Marco *et al*. (1996) [11].

Figure 1 shows the location of the sampled sections [7], which provided a total of 57 samples. The *Formigoso* Formation was sampled in *Ensenada de Llumeres* (point 1, fig. 1) and in *Clavillas* (point 2, fig. 1). The *Pizarras del Sueve* Formation was sampled in the typical locality (section of *Pico Pienzu*, point 3, fig. 1, see [10]) and at *Collado de Peñamayor* (point 4, fig. 1). The *Paquete Fresnedo* was also checked in two sections (*Rioseco* and *Felechosa*, points 5 and 6, fig. 1), and the *San Emiliano* Formation in the section of *Casares de Arbás* (province of *León*, point 7, fig. 1).

Figure 2 shows the field aspects of the sampled rocks.


a
b
c
d
e
f

## Materials and methodology

A description is now given of the materials used and methods followed in each one of the various studies that had to be carried out:

1. Polarised Optical Microscopy (POM). Whenever possible (51 out of the 57 samples), thin sample sheets were prepared for examination under a Leica DMLP petrographic polarisation microscope, in transmission mode, to determine the mineralogy and texture and then classify each one of the samples. Some polished sections were also analysed with the same equipment, this time in reflection mode.
2. X-ray diffraction (XRD). This technique was used as a complement to optical microscopy to identify mineral phases with such a small grain size (under 2 m) that they could not be identified by the latter procedure. For this reason the powder XRD method was used in all cases (18 samples) and a Philips X' Pert Pro powder diffractometer fitted with a copper anode tube.
3. Scanning electron microscopy. Due to its power of resolution and its electronic image-formation procedures, this technique is particularly suitable for the study of mineral phases and textures of a very small grain size, especially mineral inclusions. The equipment used was a JEOL JSM 5600 scanning electron microscope using secondary and back-scattered electrons and a secondary-electron image resolution, in High-Vac mode, of up to 3.5 nm (300,000 times magnification).
4. X-ray fluorescence (XRF). The geochemical analysis of the inorganic sample fraction was carried out by X-ray fluorescence (XRF) on a variable amount of subsample (about 10-20 grams, previously dried and ground in a ring mill) on the whole set of 57 samples. Two XRF analysers were used for this purpose, Niton's Xlt3 and Oxford's X-MET 3000 TXS+. Both analysers have copper anode X ray tubes (maximum working voltages of 50 and 40 kV, respectively). The approximate measuring time in all cases was 180 seconds.
5. Total organic carbon (TOC) content. This was conducted on a subsample (~ 1 g) of each one of the 57 original samples, determining the sample's content in total carbon (TC) and inorganic carbon (IC), then obtaining the difference between both readings. The readings were taken by a Shimadzu Total Organic Carbon analyser TOCV SSM-5000A.
6. Vitrinite reflectance. Vitrinite reflectance readings (vitrinite is one of the coal macerals) is one of the commonest coal ranking procedures. This parameter is bound up with the degree of aromaticity of the components and, ipso facto, their maturation. These analyses were conducted in Weatherford Labs in Houston (Texas, USA), following the procedure detailed in ASTM D2798-09a (equivalent to ISO 7404).
7. Whole-rock pyrolysis (Rock-Eval test). This test, involving controlled heating (whole-rock pyrolysis) in an inert atmosphere (usually of He, up to 550 º C), is commonly used for oil and gas exploration, since it gives information on the tested sample's potential as hydrocarbon source rock (~100 mg). These readings were taken in the same laboratory as the vitrinite reflectance test.
8. The instrumental techniques detailed in points A, B and C are applied to find out the sample's mineralogical and textural properties and pore spectrum. This result is especially important in terms of its storage behaviour, whether to assess how far the gas it might contain would be recoverable [12] or to ascertain its $CO_2$ sequestration capacity. For its part, technique D establishes the inorganic geochemistry of the samples; this then serves as the basis for estimating the organic matter's hydrocarbon production capacity (in particular the Fe/S and Ni/Ni+V ratios). Finally, techniques E, F and G are bound up mostly with the first of the proposed objectives, allowing us to ascertain the amount of organic matter, its degree of maturation and the amount and type of hydrocarbon that might be generated.

**Table 1. Summary of the results of the various studies carried out on the samples.**

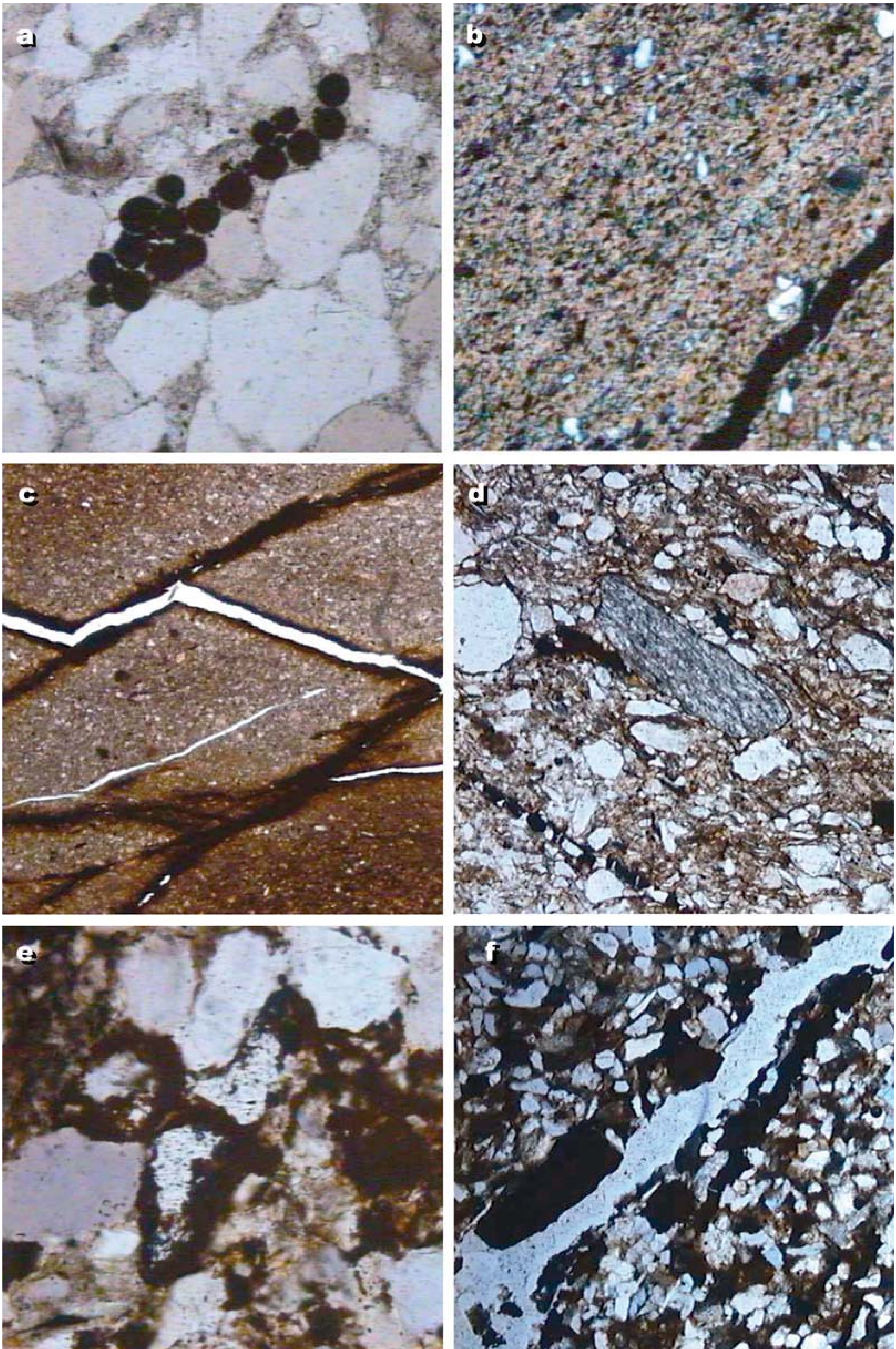
| Rock | | | Formigoso Formation | Sueve Formation | Fresnedo Formation | San Emiliano Formation |
|---|---|---|---|---|---|---|
| Classification | | | Lutite | Lutite | Lutite | Lutite |
| Mineralogy | | | Q, Op, Mos, FR, Il, Dick, Cli, Pir | Q, Op, Mos, Ill, Cli | Q, Op, Mos, FR, Cli | Q, Op, Mos, FR, Cli, Kad |
| Voids (%m visible) (mean) | | | 0-4,5 (2,39) | 1-26 (7,66) | 0-5 (2,09) | 1-4 (2,06) |
| Inorganic geochemistry | Major elements | | Si, O, Fe, K | Si, O, Fe, K | Si, O, Fe, K | Si, O, Fe, ¿K? |
| | Minor elements | | Ti, S (Zr) | Ti, Mn, Ca | Ti, S (Mn) | Ti, Ca (Mn) |
| | TOC (o) | Max. | 1.23 | 0.75 | 2.08 | 5.71 |
| | | Min. | 0.15 | 0.1 | 0.07 | 0.19 |
| | | Mean | 0.576 | 0.31 | 0.67 | 1.01 |
| | $R_o$ (%) | Max. | 1.31 | 1.79 | 1.31 | 0.83 |
| | | Min. | 0.89 | 1.60 | 0.90 | 0.50 |
| | | Mean | 1.09 | 1.69 | 1.07 | 0.66 |
| | Kerógeno | | Amorphous MO | Liptinite | Liptinite | Vitrinite |
| | Rock-Eval | S1 | 0.03 | 0.04 | 0.01 | 0.02 |
| | | S2 | 0.06 | 0.05 | 0.07 | 0.54 |
| | | S3 | 1.35 | 0.54 | 0.78 | 0.98 |
| | | $T_{Max.}$ | 489 | 433 | 506 | 459 |

## Results

Table 1 shows the results of the tests carried out on the field samples. The symbols of the mineralogy row stand for the following: Q (quartz), Mus (muscovite), RF (rock fragments), Op (opaque minerals), Cli (clinochlore), Ill (illite), Dick (dickite), Pyr (pyrophyllite) y kaol (kaolinite). S1 and S2 are expressed in mg HC/g of rock, S3 in mg $CO_2$/g of rock and Tmax in ºC.

*The organic carbon content of the Formigoso, San Emiliano and Paquete Fresnedo formations makes them, a priori, promising in terms of natural gas generation*

Figures 3 and 4 show some representative images of sample mineralogy and texture, the first taken with polarised optical microscopy and the second with scanning electron microscopy.


a
b
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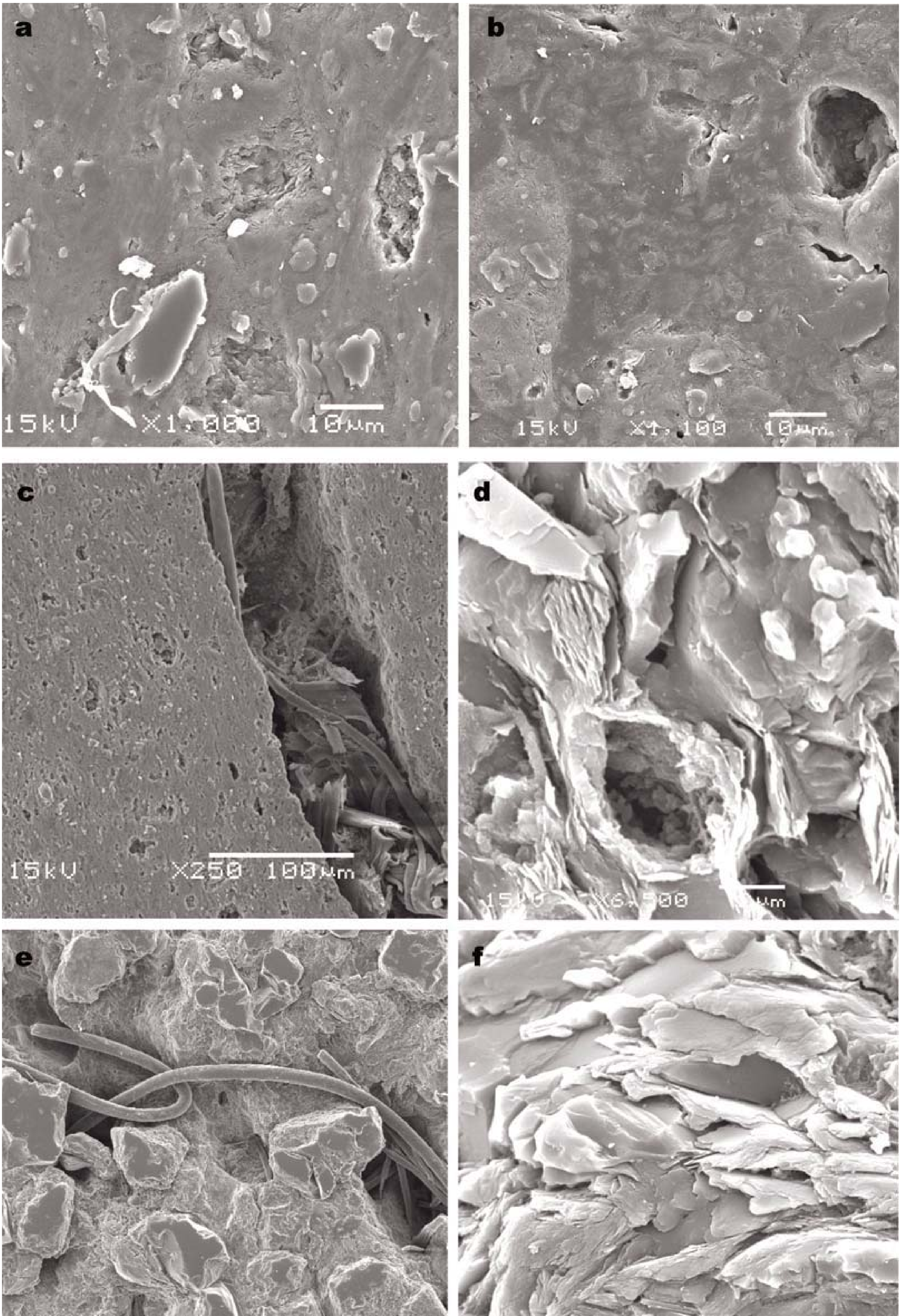
The microscopy results (POM and SEM) are unequivocal: they confirm that the sample rocks are predominantly lutites (sensu stricto), that there are no clear signs of metamorphism in any of the cases and that the fundamental mineralogy is quartz and muscovite, plus some other phyllosilicates in moderate quantities.

X-ray techniques show the presence of clinochlore in the matrix (moderate cation exchange capacity for a phyllosilicate, 10-40 meq/100g); furthermore, associated minor elements always include Ti and, in some cases, S, Mn, Ca and Zr. In any case none of the abovementioned aspects represent anything unusual for lutite rocks. The content of S, Ni and V often falls below the detection limit or comes out as a score or so of mg/kg, so it would not be reliable to make any interpretations about the Fe/S or Ni/(Ni+V) ratios.


a
15kV X1,000 10µm
b
15kV X1,100 10µm
c
15kV X250 100µm
d
e
5kV X100 100µm
f
X3,000 5µm

*The porosity (voids) of this type of rock is closely bound up with open microfractures: those bigger than 1 µm added up to about 2% of total rock volume*

Total organic carbon (TOC) analyses were conducted for all 57 samples, the readings varying from 0.1% to 5.71% in weight, most falling within the interval 0.5 to 1%. According to the data shown in table 1, the Pizarras del Sueve formation is the only rock that, on average, does not record the minimum threshold that would make it worthwhile for hydrocarbon generating purposes (0.5% in weight of organic carbon [14]). The hydrocarbon-generation potential of the Formigoso and Paquete Fresnedo formations would be moderate (0.5-0.7%), while that of the San Emiliano formation falls on the good-moderate border (1%).

The rest of the specific analyses to establish the properties of organic matter were conducted on four samples, the ones showing the highest TOC reading of all those studied. As already pointed out, ranking was determined by vitrinite reflectance. Readings are now given for each rock and the relation with kerogen constituents:

- *Formigoso formation.* The dominant organic matter, scarce in any case, is the non fluorescent amorphous type (amorphinite). The particles of the type of vitrinite («pseudo-vitrinite», given that the rock dates from the Silurian period; as such it cannot contain vitrinite) are very small. On the basis of seven readings on the bigger particles, the mean reflectance of pseudo-vitrinite is 1.09%. Under transmitted light the predominant organic matter is amorphous, brown in colour, indicating a TAI (Thermal Alteration Index) of 3. The pollen and spores also show up as brown, this colour chiming in with a vitrinite reflectance of ~1.1%. The reflectance readings and colour of the palynomorphs show that the organic matter falls within the wet gas window.
- *Pizarras del Sueve formation.* Kerogen is dominated by low quality non-fluorescent amorphous matter. Also present were carbonaceous particles and algal material (post mature) in moderate quantities. The TAI would therefore come out at close to 4, based on brownish monolete spores. The kerogen is classified as type II, with a medium-low gaseous hydrocarbon generation potential. Vitrinite reflectance shows the kerogen to be mature and in the wet gas window.
- *Paquete Fresnedo.* The vitrinite is predominantly organic matter. Inertinite is also frequent and is represented by inertodetrinite. The amorphous organic matter is granular and, on occasions, weakly fluorescent. Based on 50 readings, the mean vitrinite reflectance is 1.07%. The amorphous organic matter is brown, suggesting a TAI of 3. Pollen and spores are also brown and their colour tallies with a vitrinite reflectance of ~1.1%, close to the mean value. The vitrinite reflectance values and the colour of the palynomorphs show that the organic matter falls within the wet gas window.
- *San Emiliano formation.* Vitrinite is the dominant type of organic matter. Inertinite is less frequent and is represented by inertodetrinite. The amorphous organic matter is granular with a light-brown-hued fluorescence. Based on 50 readings, the mean vitrinite reflectance is 0.66%. The amorphous organic matter is a yellowish brown colour, indicating a TAI of 2.5. The pollen and spores are amber coloured, corresponding to a vitrinite reflectance of ~0.65%, similar to the mean value. The vitrinite reflectance values and the palynomorph colour show that the organic matter is in an early maturity state within the oil generation window.

Finally, the whole-rock pyrolysis test tells us the type of kerogen, the hydrocarbon-generation capacity and maturity, basically in terms of four parameters: S1, S2, S3 and Tmax (see table 1). As in the case of TOC, a direct estimate can be made of the hydrocarbon-generation potential from the value of S1 and S2, as shown in table 2.

The type of hydrocarbon generated can be estimated from the hydrogen index (HI), defined as HI=(S2 x 100)/TOC, and the reference values as shown in table 3.

**Table 2. Potential as source rock in terms of the S1 and S2 values[13].**

| S1 (mg HC/g rock) | S2 (mg HC/g rock) | Hydrocarbon generation potential |
|---|---|---|
| <0,5 | <2,5 | Poor |
| 0,5-1 | 2,5-5 | Moderate |
| 1-2 | 5-10 | Good |
| >2 | >10 | Very good |

**Table 3. Type of hydrocarbon generated in terms of the HI and S2/S3 values [13].**

| HI (mg HC/g Corg) | S2/S3 | Type of hydrocarbon generated |
|---|---|---|
| 0-150 | 0-3 | Gas |
| 150-300 | 3-5 | Oil and gas |
| >300 | >5 | Oil |

The Rock-Eval test results are discussed below for each rock type in turn:

- *Formigoso formation.* The S1 and S2 values are very low, not adding up to 0.1 between them, so the source rock potential of the Formigoso formation would be dubious. Consideration must also be given here, however, to the fact that the samples were taken from outcrops, so these findings need to be borne out with unaltered rock massif samples. The HI value (5) confirms that the hydrocarbon generated would be natural gas (see table 3). Tmax is not valid since S2 is lower than 0.2. The type of kerogen, by visual analysis, is mainly amorphous organic matter, more habitual in oil source rocks.
- *Pizarras del Sueve formation.* The S1 and S2 readings are very similar to those of Formigoso formation, so the same considerations apply. Likewise the value of HI (7) confirms that the hydrocarbon generated would be natural gas. Tmax is again invalid for establishing the rank.
- *Paquete Fresnedo.* The S2 value, albeit somewhat higher than for the Formigoso and Pizarras del Sueve formations, is also too low to validate the calculated data for Tmax. The sum of S1 and S2 would not qualify Paquete Fresnedo as source rock (see similar comments for the Formigoso formation). Once more the HI value (3) confirms that natural gas would be the hydrocarbon generated.
- *San Emiliano formation.* Vitrinite, as already pointed out, shows a reflectance corresponding to the oil generation window (0.66%), in an early state of maturation. S2, in this case, presents a value that validates the calculated Tmax and is the highest of all, although the sum of S1 and S2 does not, a priori, suggest a suitable source rock (see comments made for the Formigoso formation). The HI value (9), however, indicates natural-gas generation potential rather than oil.

## Conclusions

*The degree of maturation of the organic matter contained in the rocks shows that the Formigoso, Pizarras del Sueve and Paquete Fresnedo formations could generate natural gas, while the San Emiliano formation would have oil-generation potential*

The first conclusions to be drawn from this work concern the potential of each of the studied rocks as worthwhile unconventional natural gas sources:

- The fundamental mineralogy of these rocks is very similar in all cases: quartz, muscovite and opaque minerals as grains (to a lesser degree, zircon and rock fragments) and, as matrix, quartz again (sometimes chert), clinochlore.
- They are also fairly similar from the organic geochemical point of view, with Fe (3-5%), K (2-3%), Si and O as the main elements (perhaps also Al and Mg, which could not be determined due to limitations of the techniques used). Minor elements include Ti (0.5-1%) and, on occasion, some others (S>Ca>Mn>Zr).
- Total organic carbon readings range from 0.31% of the Pizarras del Sueve formation to 1.01% of the San Emiliano formation, with intermediate values for the Formigoso and Paquete Fresnedo formations (0.57% and 0.67%, respectively). Considering exclusively this last factor, the prospects of serving as hydrocarbon generating source rock would be good or moderate for the San Emiliano formation, moderate for Paquete Fresnedo and Formigoso and poor for Pizarras del Sueve.
- In the four cases their potential as source rock is limited and always for natural gas, barring the San Emiliano formation. In no case does the Rock-Eval pyrolysis reading reach the established threshold for hydrocarbon source rock (S1+S2>0.2). In all cases both S1 and S2 are less than 0.1, except for S2 in the San Emiliano formation (0.54). S1 and S2 readings, taken from outcrops, may well not reflect the true underlying situation of the bedrock.
- The calculated rank parameters (vitrinite reflectance, TAI) situate the Formigoso formation and Paquete Fresnedo in the early states of the wet gas window, the Pizarras del Sueve formation in the middle of the wet gas window and the San Emiliano formation in the oil generation window.

- Looking at future priorities for natural gas exploration, the San Emiliano formation can be ruled out as insufficiently mature. Of the remaining three, which do lie in the wet gas window, the best possibilities are presented by Paquete Fresnedo, for three main reasons: a) it is the thickest of the three and hence is most likely to have the best reserves; b) the TOC is appreciably higher than those of the Formigoso and Pizarras del Sueve formations; and c) the S2 value is significantly higher than for the other rocks.

> *In light of the data obtained, future work should focus on the Paquete Fresnedo formation, a succession almost 500 m thick appearing on the eastern border of the central Asturian basin*

As for their potential for future geological $CO_2$ sequestration, the following factors have to be taken into account:

- The percentage of voids bigger than 1 μm (intergranular and due to open fracturing, much commoner) is similar (2 to 2.5%) for the formations Formigoso, San Emiliano and Paquete Fresnedo. The Pizarras del Sueve formation shows much higher values, coming out as 7.66% on average. The SEM images show very rugged rocks at micrometric observation scale and with many voids not identifiable with optical microscopy and therefore not quantified in earlier data.
- Simple geometric considerations show that all of them reach suitable depths relatively close to their respective outcrop areas (over 800 metres).
- As regards the formations Formigoso, Pizarras del Sueve and Paquete Fresnedo, the $CO_2$ that might be sequestered there would come mainly from the centre of the region, where there are several thermal power plants and two cement plants. Bearing in mind such salient factors as the thickness of each one, their proximity to the emitting sources and the fact that organic matter would play the role of absorbent, it is the Paquete Fresnedo that once more comes across as the best option.
- For the Paquete Fresnedo the most suitable area would be that lying between the Sierra de Peñamayor and El Condado (Laviana), with a mean westwards dip. According to structural data the Paquete Fresnedo would attain the depth of 800 to 900 metres westwards of the zone of contact with the overlying rock (Caliza de Peñarredonda formation). z The San Emiliano formation, along the same lines as in the above paragraph, would be a possible candidate for sequestering emissions from the La Robla thermal power plant, lying 15 kilometres (minimum distance) from the nearest outcrop. It is the thickest formation with the most clayey texture and also the richest in organic matter. Apart from transport considerations, therefore, it would be the best option, though it does lie vertically in the study zone and this could prove a handicap. u

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## BY WAY OF A GLOSSARY

**Geological $CO_2$ sequestration**. This involves the injection of $CO_2$ as a supercritical fluid (so that it behaves as a liquid) into the spectrum of pores and fractures of a rock so that it remains sequestered there safely for a long period of time.

**Shale Gas**. Natural gas recovered from very fine-grain sedimentary rock made up by quartz and clayey minerals with a certain organic matter content of sufficient maturation for gas generation.

**Inertinite**. One of the components (organic component) of the carbonaceous matter formed by the remains of vegetal tissues, previously oxidised and/or altered.

**Kerogen**. Organic matter fraction insoluble in benzene and other common organic solvents.

**Lutite**. Fine- to very-fine grained detrital sedimentary rock of which over 75% of its constituents have a grain size of less than 30 microns.

**Palynomorphs**. Continental palynomorphs, made up by pollen, spores and remains of freshwater algae, are those of interest for hydrocarbon exploration purposes.

**Reflectance (or reflectivity)**. Light fraction (polarised or not) reflected by a mineral or maceral, with respect to a known pattern and under standard lighting conditions. It is expressed as a percentage.

TAI (Thermal Alteration Index). A number scale 1 to 5 for estimating the rank (degree of maturation) of organic matter according to the colour of the pollen and spore remains by comparison with a standard card. It is correlated with vitrinite reflectance.

**«Gas window»**. Interval of vitrinite reflectance values corresponding to the maturation states of organic matter in which the latter is capable of generating natural gas. Usually represented in a Dow diagram.

**«Oil window»**. See above definition, replacing «natural gas» by «oil».

Vitrinite. Another of the components (organic constituent) of carbonaceous matter formed by remains of vegetal tissues, buried in fresh state or little altered. It is the prime component of most humic coal.

## TO FIND OUT MORE


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