Characterization of geological formations of the Lusitanian Basin (onshore) for natural gas production (unconventional gas)

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Abstract

The current dissertation, Characterization of geological formations of the Lusitanian Basin (onshore) for natural gas production (unconventional gas), aims to characterize morphologically potential areas of natural gas occurrence, in other words, areas where the probability of natural gas existence is greater. Initially, on what the lithology of the Lusitanian Basin is concerned, specifically Brenha and Candeeiros formations, the definitions of the concept and types of unconventional natural gas are presented, in order to identify which of the types of gas can eventually occur. A comparison between concepts, existing lithologies and the properties of internationally known reservoirs was established and, therefore, only shale and tight gas formations are most likely to exist in the basin. A working computational model was created, from topographic maps of the top and the bottom surfaces of the formations, with ArcGis software, to characterize its areas and volumes. Finally, dry and wet gas target zones were identified and, their area, volume and thickness were calculated with the purpose of estimating, through porosity, the volume of empty spaces that each zone has and may be filled with natural gas.

Keywords: Lusitanian Basin; Unconventional natural gas; shale gas; tight gas

1 Introduction

With Men's ever growing needs of energy and resources, the mining industry broadens its boundaries to limits never seen before. The quest for cheaper, cleaner and sustainable new energy sources, are ideas that are being talked about by mass media and world leaders with a growing concern. The wide spread notion that the discovery of conventional oil sources, cheap and easy to develop, is far from responding to the foreseeable peaks of demand. The long overlooked sources of unconventional resources are now regarded with much interest not only by the oil industry, but also by the countries that hold these resources, expecting its great revenues.

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2 Natural Gas

Recent technological advances turned natural gas into a versatile resource, as oil. It's applications range from electricity and heat generation to powering all types of vehicles. According to USA's Environmental protection agency, and shown in the following table, natural gas is the cleanest fossil fuel.

Pollutant	Natural Gas	Oil	Coal
Carbon Dioxide	117000	164000	208000
Carbon Monoxide	40	33	208
Nitrogen Oxides	90	448	457
Sulfur Dioxide	1	1122	2591
Particulates	7	84	2744
Mercury	0	0.01	0.02

Table 1: Emission level per fossil fuel in Lbs per billion Btu (U.S. Energy Information Administration, 1998).

2.1 Economic Reference

The evolution of production versus consumption of natural gas world wide, according to the British Petroleum (BP) Statistics of 2010, shows a consistent increase of both variables since 1985. Portugal, has also been showing an upward trend since the introduction of this resource (1997), with a 6.7% rise in consumption from 2009 to 2010, but it is still positioned in lowest class of consumption per capita with the total consumed natural gas of 4.5 Mtoe. The figures, made available by Instituto Nacional de Estatística show that both Oil and natural gas are imported resources. This causes an unbalance in the foreign exchange balance, shifting to the import side, especially because 70.2% of the country's power supply in 2008 came from either oil (52.5%) or natural gas (17.7%). In what price is concerned, also according to BP, Germany had the highest average price at 8.01 dollars and Canada had the lowest at 3.69 dollars per million Btu of natural gas. When comparing to oil whose average price in the countries of the Organization for Economic Co-operation and Development (OECD), of which Portugal is a member, was 13.47 dollars per million Btu (including insurance and freight), it can be seen that natural gas is not only versatile but also cheap.

3 Unconventional Gas

A precise, stable and consensual definition of unconventional gas is hard to find due to the dynamics of the concept. In a comprehensive manner, unconventional gas is the gas that is harder and less profitable to produce as the technology to do it is either immature or too expensive. Normally, to produce unconventional gas from it's reservoir, it needs to undertake a severe hydraulic fracturing treatment, acidizing and horizontal drilling in order to maximize the exposed area of the reservoir to the wellbore possible. For better understanding of the Unconventional gas concept, Masters and Grey developed a theory, depicted in what is called the resource triangle. In the upper part of this triangle are the conventional types of gas, easy to develop but in smaller amounts. In the base of the triangle there are the unconventional types of gas, harder to develop but with larger available amounts. This rise of volume and "unconventionality" is often concurrent with a decrease of permeability and increase of necessary technology to produce them, leading to higher production costs (Holditch et al, 2007).

3.1 Unconventional Gas types

3.1.1 Deep Gas

This type of natural gas, is nowadays seldom called unconventional. The unconventionality of this resource was due to its location, below 15 thousand feet. As the drilling technology progressed this type of gas has shifted its status to a conventional one, but there are still authors who consider it as unconventional. In what production costs are concerned, this category fits between conventional and unconventional (Natural Gas, 2011a).

3.1.2 Coal Bed Methane (CBM)

This type of gas, usually methane, is the natural gas that is found within coal seams or in the surrounding rock of coal masses. Throughout all coal mining history coal bed methane has been an undesirable by-product that was responsible for numerous serious accidents. The gas that could brake out during the coal mining operations was diluted by inflated fresh air and flowed freely from the underground to the surface, otherwise it would accumulate. What was once seen as a danger and an undesirable product is now a valuable resource for the coal mining industry and a large source of natural gas (Thakur et al, 2011).

3.1.3 Geopressurized Zones

These geopressurized zones are natural gas reservoirs that have an abnormally high pressure/depth ratio. These are layered mud, silt and sand formations that have deposited and packed very quickly, trapping water and gas in a more porous and absorbing layer. Due to the high compression, the gas is confined in pores under very high pressures. Geopressurized zones are typically located in depths between 10 and 25 thousand feet into the earth's crust. These two factors combined, pressure and depth, make this an unconventional type of natural gas. According to the International Energy Agency (IEA) these kinds of reservoirs are one of the largest sources of natural gas (Natural Gas, 2011a).

3.1.4 Arctic Gas

Arctic gas is the natural gas located in the northern part of the earth, in countries like Canada, USA (Alaska), Russia and Denmark (Greenland). These kinds of reservoirs are no different from conventional reservoirs but, as their location has one of the hardest climates Man and machines can endure, they are labeled Unconventional (Natural Gas, 2011a).

3.1.5 Sub-Sea Hydrates or Gas Hydrates

Methane hydrates were the most recent kind of unconventional natural gas discovered. These hydrates are solid crystals, where methane is trapped inside a lattice of ice, forming a "cage" for the gas. Gas hydrates were originally discovered in the permafrost regions of the globe, but shortly after it was discovered that they were more common than initially thought, occurring also in the porous space of marine sediments, forming cements, nodes or layers, near the continental margins that are stable over 300 meters of depth. Gas hydrate reservoirs can have underneath them conventional gas reservoirs, in this case, they act as a cap rock, blocking the upward flow of the gas. These kinds of reservoirs are called hydrate-capped in which the hydrates perform two roles: The first being the reservoir cap; The second, a recharger of the conventional reservoir, as a consequence of the pressure drop when producing the gas below, hydrates melt and gas is released filling the reservoir (Thakur et al, 2011).

3.1.6 Tight Gas

Tight gas is a a type of unconventional natural gas that exists in unusually tight and impermeable hard rock formations, sandstone (tight sands) or in very impermeable and compact limestones (tight carbonates) that produce mainly dry gas. These kinds of reservoirs need to be stimulated with extensive hydraulic fracture treatments, acidizing and horizontal drilling methods in other to achieve the production of commercially interesting gas flows, by increasing the area of the reservoir exposed to the wellbore (Holditch, 2006).

3.1.7 Shale Gas

Shale gas is, perhaps, the most well known type of unconventional natural gas. This gas, along with tight gas, account for more than 50% of USA's production. Shales that contain natural gas are very fine grained sedimentary rocks with a wide mineralogical composition ranging from mainly clay minerals to mainly quartz and feldspar minerals, with variable amounts of calcite and dolomite. These shales act both as the source rock and gas reservoir, this indicates that its deposition was simultaneous with the deposition of the organic matter that generated natural gas. These types of reservoirs have to undergo the same methods of stimulation and drilling as tight gas reservoirs, in order to produce commercially viable amounts of natural gas (Speight, 2008; Thakur et al, 2011).

3.2 Shale Gas and Tight Gas

After analyzing all the specific details of these seven types of unconventional natural gas, only shale and tight gas reservoirs fit in the scope of the onshore zone of the Lusitanian basin. The other four types are either geographically improbable to exist in this specific area (arctic gas and gas hydrates) or represent physical characteristics (pressure and depth) that any kind of reservoir can be subjected to (geopressurized gas and deep gas).

The next table shows the main expectable differences or characteristics in shale and tight gas reservoirs. This table can be a basis or a guideline and is not to be taken as a rule due to the fact that reservoirs with mixed characteristics can also exist. A good example of this can be found in the Montney reservoir in Alberta, Canada which has some characteristics related to shale gas and others related to tight gas (Hall, 2011).

	Shale gas	**Tight gas**
Grain size	Mostly Mud	Substantially silt or fine sand
Porosity	Up to 6%	Up to 8%
TOC	Up to 10%	Up to 7%
Permeability	Up to 0.001 mD	Up to 1mD
Source	Mostly self-sourced	Mostly extra formation
Trap	None	Facies or Hydrodynamic
Gas	Substantially adsorbed	Almost all in pore space
Silica	Biogenic, crypto-crystalline	Detrital quartz
Brittleness	From silica	From carbonate cement

Table 2: Expected properties of shale and tight gas reservoirs (Hall, 2011).

4 Data Summary

All the data received from Divisão para a Pesquisa e Exploração de Petróleo (DPEP) will be briefly summarized in this section.

4.1 Project MILUPOBAS

The Multidisciplinary geological and geophysical Investigation of the Lusitanian and Porto Basins (MILUPOBAS) project was carried out by Geological Survey of Denmark and Greenland (GEUS) and led, among other things, to the creation of structural maps of geological formations of the Lusitanian basin. These maps were the result of seismic interpretation and were corrected with the information of exploration wells. From this project we obtained four structural maps: two of them were the structural maps of the top of Brenha and Candeeiros Formations, and the other two were the structural maps of the bottom of the Brenha formation (top Coimbra Formation) (Lomholt et al, 1996).

4.2 Wells

Two exploration wells, that had gas shows, were analyzed. One, Aljubarrota-2, drilled in 1998 in the Aljubarrota area, district of Batalha. The other, Benfeito-1, drilled in 1982 in the district of Alenquer.

4.3 BEICIP-FRANLAB

Beicip-Franlab, a consulting company in the area of oil and gas, conducted, in 1996, a geochemical evaluation of the hydrocarbon potential generation in the Lusitanian basin. This evaluation generated a series of isomaturation maps of the potential source rocks of this basin, one of which was used (isomaturation map of the top of Brenha and Candeeiros formations).

5 The Lusitanian Basin

The Lusitanian basin is a sedimentary basin that developed in the western Iberian margin during the Mesozoic. Its sedimentary dynamic is related to the Pangea's fragmentation, more precisely during the opening of the north Atlantic sea. It is characterized as a distensive basin, belonging to a non volcanic rift continental margin, occupies twenty thousand square kilometers in the western Iberian margin and approximately two thirds of it is located in the onshore zone of Portugal (Kullberg et al, 2006).

5.0.1 Brenha and Candeeiros formations

According to Martins et al. (2010), the Brenha formation was deposited in a deep-water marine shelf environment and its facies are recorded to have their thickest development in a central belt parallel to the present-day coastline. In this area the facies are represented by variably bituminous shales and impure, fine-grained lime mudstones deposited under predominantly euxinic conditions during the late Sinemurian-early Pliensbachian. This formation is laterally equivalent to the shallow-water carbonates of the Candeeiros formation. The interfingering of these two formations, starting in Aalenian-Bajocian times, is attributed to a relative sea-level regression and to a high rate of carbonate deposition. With time, the shallow water facies became more developed in the E/SE part of the basin (Candeeiros facies), while there was a retraction of the more deeper marine facies (Brenha facies) to the W/NW. With relative tectonic stability, low rate homogeneous subsidence, dominant tendency of sea level raise, subtropical climate and a low grade topographic substrate, the carbonate ramp depositional system that was initiated on Early Jurassic evolved into a high energy carbonate ramp with its maximum expression during Bathonian times. The deposition of the Candeeiros carbonates, mainly of high energy, represents an inner ramp environment. Facies belts include well-defined upper shoreface, foreshore, backshore and tidal flat/lagoon sub-environments. The stacked, high-energy grainstones and subordinate lime mudstone prograded westward during the late Bajocian and Bathonian. Stacking and vertical accretion of facies is suggested to have resulted from high rates of in situ sediment production, sufficient to accommodate the effects of shoreface erosion and washover during sea level rise. Although less frequent than in overlying formations, some biostrome/reefal facies were also formed.

6 Procedure

In order to build a working computational model of Brenha and Candeeiros formations it was necessary to vectorize all the maps with AutoCAD software. It allowed the insertion of mapping scale and georeferences. With Dxf2xyzm (2.0 version) it was possible to make the AutoCAD output files compatible with the ArcGIS software. With the ArcGIS software we created maps of the top and bottom surfaces of the Brenha and Candeeiros formations, as well as determined the thickness, area and volumes of the formations. Afterwords, the isomaturation map of the top of the Brenha and Candeeiros formations was inserted, after being vectorized and georeferenced, and the areas, volumes and thickness of the formations, under the gas zones, were calculated and drawn into maps for better visualization. Finally, an estimation of the volume of empty spaces (pores) was made with values of porosity ranging from 0 to 25%.

7 Results

The top surface (Figure 1) has the approximated area of 204,500.08 ha, its highest reach is 600 m above mean sea level and its deepest is 3800 m below the mean sea level. The bottom surface (Figure 2) has the approximated area of 187,272.28 ha, its highest reach is 300 m below the mean sea level and its deepest is 6385 m below the mean sea level. Their conjoined areas, projected to zero level is 228,468.32 ha.

The thickness of the the Brenha and Candeeiros formations (Figure 3) ranges from 44 m to 3721 m and the total volume of this structure is 2,313.55 km^3.

The total area of the gas zones is 40,026.96 ha and the thickness of the formations in this zones ranges from 66 m to 2313 m (Figure 4.

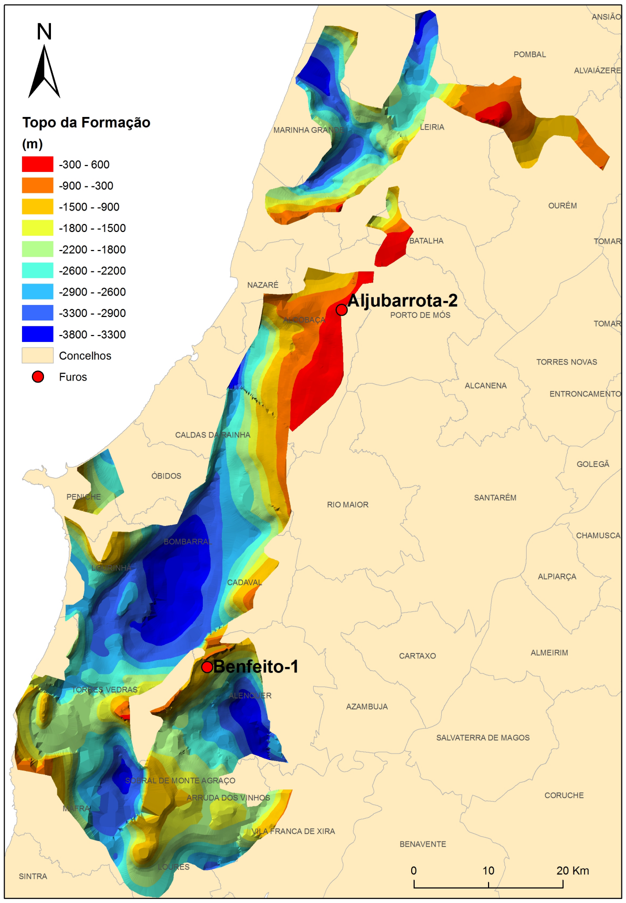

Figure 1: Top surface structural map (Brenha and Candeeiros formations).

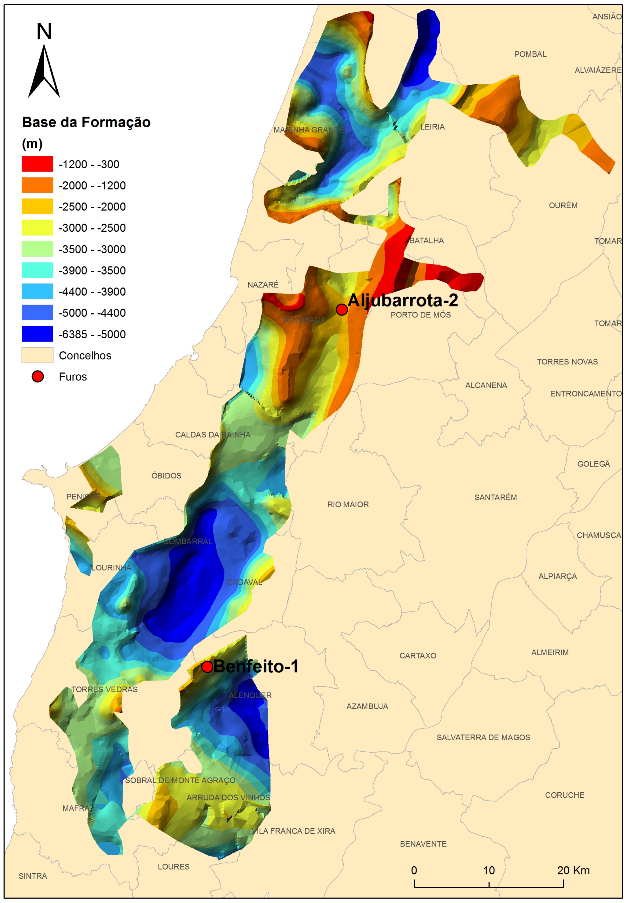

Figure 2: Bottom surface structural map (Brenha formation).

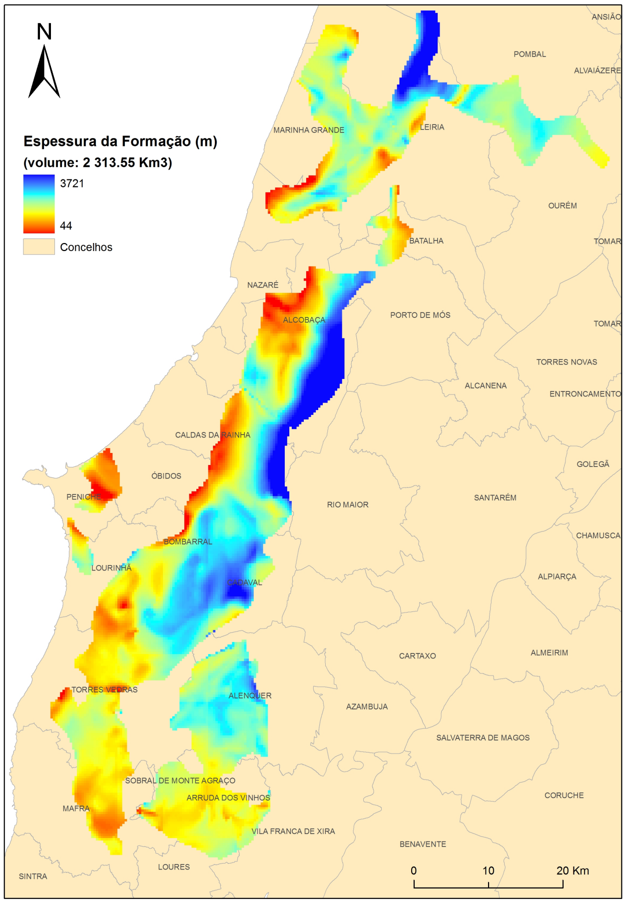

Figure 3: Formation thickness in meters (Brenha and Candeeiros formations.

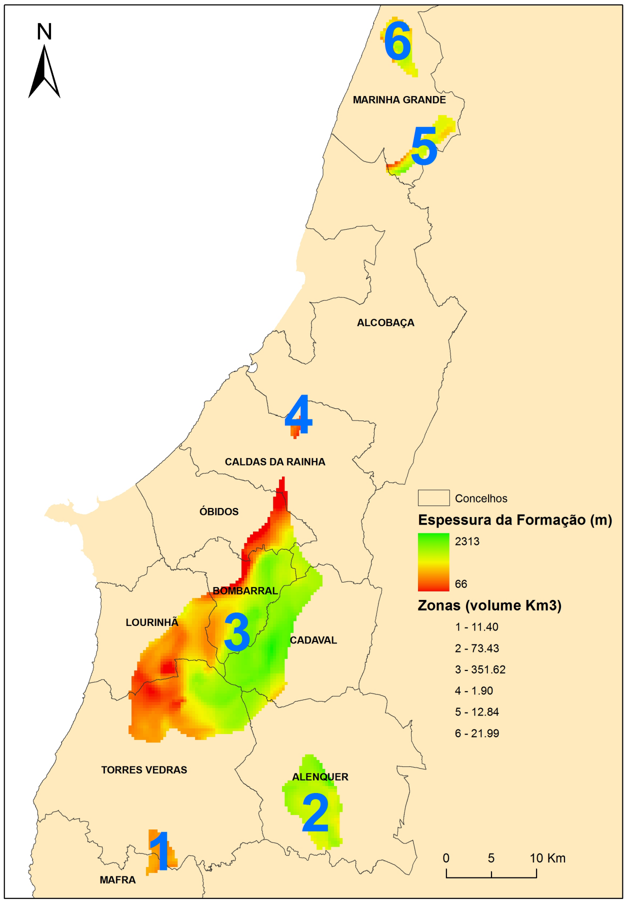

Figure 4: Formation thickness and volume in the gas zones (Brenha and Candeeiros formations).

The estimation of the pore space volume of each of the gas zones is shown in Figure 5 and in Table 3.

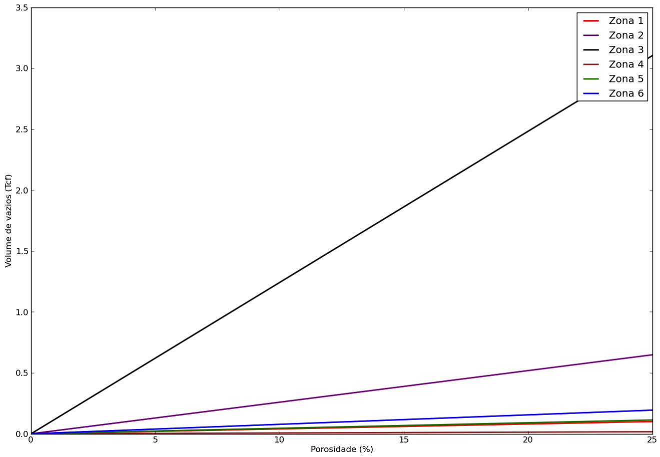

Figure 5: Graphic of the volume of pore spaces according to porosity values in each zone.

Zone	**Total Volume (Tcf)**	**Porosity**					
		2.50%	5.00%	7.50%	10.00%	12.50%	15.00%
1	0.4	0.01	0.02	0.03	0.04	0.05	0.06
2	2.59	0.07	0.13	0.19	0.26	0.32	0.39
3	12.47	0.31	0.62	0.93	1.24	1.55	1.86
4	0.07	0	0	0.01	0.01	0.01	0.01
5	0.45	0.01	0.02	0.03	0.05	0.06	0.07
6	0.78	0.02	0.04	0.06	0.08	0.1	0.12
Total	**16.76**	**0.42**	**0.84**	**1.25**	**1.67**	**2.09**	**2506**

Table 3: Table of the volume of pore spaces (Tcf) according to porosity values in each zone.

The normalization of the pore space volume by the respective area of each zone is shown in Figure 6. Zone 2 is the one that, per unit area, has the largest pore space volume followed by zone 6, 3, 1, 5 and 4.

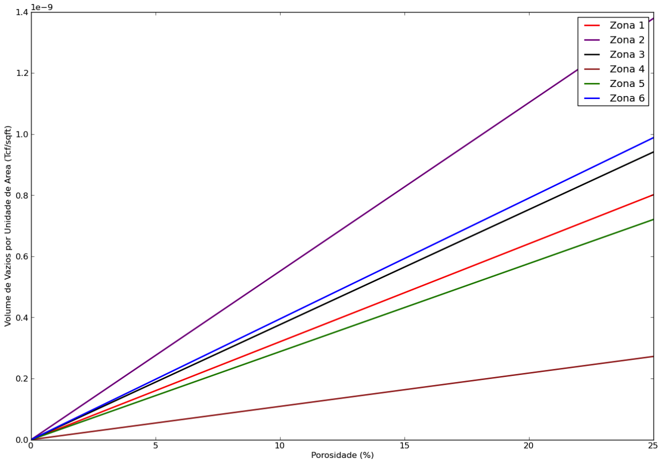

Figure 6: Graphic of the volume of pore spaces per area unit in each zone.

8 Conclusions

Natural Gas is cleaner and cheaper than the other fossil fuels (oil and coal) and recently became as versatile. All the natural gas consumed in Portugal is imported, leading to an unbalanced commercial exchange. The local production of this resource would be of utmost importance because it would allow an increasing energetic independence, job creation, infrastructure building and capital gains. The exploration of hydrocarbons on the onshore zone of the Lusitanian basin has been going on for the last century and found some good indicators that accumulations of these resources exist in this area, but for whatever reason their production never became a reality. Apart from conventional sources of hydrocarbons there is also potential, in this basin, for the existence of accumulations of unconventional resources, particularly shale gas and tight gas. The normalization of the volume of pore spaces by the area of each gas zone, on the Brenha and Candeeiros formations, lead to the conclusion that the area marked as number 2 in the previous maps, in Alenquer, should be the first one to be explored, as the pore ratio per area is the largest.

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