UNCONVENTIONAL SHALE AND TIGHT RESERVOIRS OF ARGENTINA. OPPORTUNITIES AND CHALLENGES

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ABSTRACT

Resources of 800 TCF and 27 BBO estimated for unconventional shale reservoirs together with more than 50 TCF of gas associated with tight rocks have generated great expectation in Argentina. Actually, the country is very active in developing this type of reservoirs. The formations are located in six main hydrocarbon-producing basins covering a surface of approximately 545,000 km^2 known as Paleozoic, Cretaceous, Cuyana, Neuquén, Golfo San Jorge and Austral. The associated source rocks are eleven, all of them with potential to be unconventional shale reservoirs. Five are marine in origin while the others were deposited in lacustrine environments. Ages range from Late Devonian to Early Cretaceous. Average TOC are in between 0.5 to 11 (wt%) with variable thicknesses up to 2,000 meters. Vertical wells targeting these objectives range in depths from 2,000 to 5,000 meters. In the particular case of Vaca Muerta Formation, a world class example and the most important unconventional shale reservoir currently being developed, horizontal wells can reach up to 2,000 m long with 20 fracture stages at a cost that varies from U$D 20 MM to 10 U$D MM. More than 650 wells drilled during the last 5 years are currently producing 50,000 bbls/d. Regarding tight clastic and carbonate reservoirs, there are at least eight formations, being the most important in the Neuquén basin. Average vertical wells have 12 fracture stages and cost U$D 9 MM. Tight gas reservoirs represent 20% of the total gas production of the country. Different scenarios consider that unconventional reservoirs could cover 50% of the country hydrocarbon´s demand in 15 years. The current stage of the projects suggests a promising future considering the favourable geological, engineering, political, environmental and social conditions. Consequently, the most important challenge focuses in optimizing operations, services and logistics with substantial cost reductions through time.
Key Words (Optional): shale, tight, Argentina, resources

INTRODUCTION

Resources of 800 TCF and 27 BBO estimated for unconventional shale reservoirs together with more than 50 TCF of gas associated with tight rocks have generated great expectation in Argentina. This paper presents the most relevant geological characteristics of the unconventional shale and tight reservoirs and describes the exploration, drilling, completion, production activities and key economic aspects of them.

The need to increase hydrocarbon reserves challenges Argentina with a novel concept in oil prospecting. This challenge needs the implementation of new prospecting techniques and basin modelling for locating and assessing potential petroleum systems and optimizing production resources. Forecasting the presence of source rocks, reservoirs, seals, overburden rocks, as well

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as the development of traps requires a thorough knowledge of the stratigraphic and structural evolution of the deposits within a sedimentary basin. This latter involves basin analysis which from a geodynamic point of view helps understand how these large lithospheric structures —that contain hundreds of thousands of meters of sediments— are formed and how they are filled in (Barredo, 2012). When basins hold unconventional shale and tight reservoirs the mechanical properties of the rocks must also be studied in detail. Their characteristically low permeability derives from the depositional history, the resulting mineralogy and the chemical conditions during diagenesis (Stinco, 2001), and all of them constrained by tectonic, eustatic and climatic variations. Thus, the sedimentary infill must be studied, from the tectonic/geodynamic and paleoclimatic approach, but focusing the reconstruction on the sequential arrangement of its elements.

After USA, Argentina is the most active country developing unconventional shale and tight reservoirs. Environmental impact studies together with hydrological ones are being performed in the different basins for establishing the proper project planning, engineering design and feasibility analysis (including technical, economical, environmental and social aspects). Different scenarios consider that unconventional gas could satisfy 50% of the country gas demand in 15 years.

GEOLOGICAL SETTING OF ARGENTINA'S SHALE AND TIGHT RESERVOIRS

The shale and tight reservoirs are located in six main hydrocarbon-producing basins covering a surface of approximately 545,000 km^2 known as Paleozoic, Cretaceous, Cuyana, Neuquén, Golfo San Jorge and Austral (Figure 1).

In order to model the petroleum systems within Argentina's basins an integrated surface and subsurface tectosedimentary study is required to perform (Stinco and Barredo, 2016). Most of the basins were located within the Gondwanides (Keidel, 1916), a wide belt of older accreted Eopaleozoic terrains sutured along the southwestern Gondwana margin. Extensional and compressional alternating events gave place to various basin geometries, which led to notable thickness variations and the resulting different burial histories. The infill comprises clastic, carbonatic, evaporitic, pyroclastic and volcaniclastic rocks derived from continental and marine realms. Tectonic evolution and sea level variations were the main controls on the marine sedimentation of some of the most prolific troughs, whereas the non-marine record seemed to have been controlled by the occurrence of large lacustrine bodies (presently significant hydrocarbon source rock) under the influence of the tectonic and/or climatic fluctuations. Integrated surface/subsurface regional analysis carried out in these basins reveals that tectonic evolution, climate and local and/or global sea-level variation seem to have conditioned the accumulation and preservation of the organic matter.

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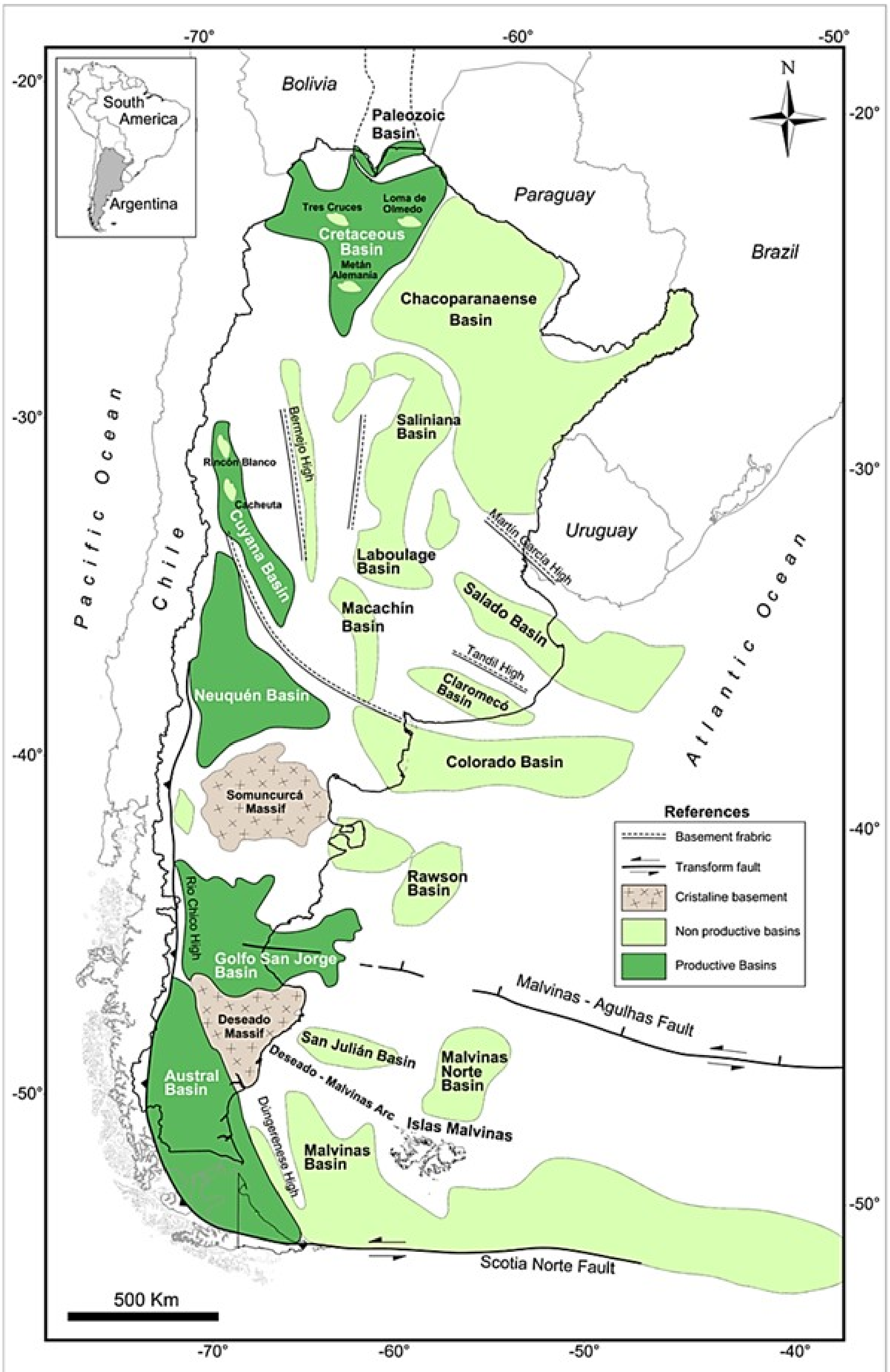

Figure 1: Argentinian sedimentary basins map (Stinco and Barredo, 2016)

Paleozoic Basin

The Palaeozoic (or Tarija) Basin is almost 25,000 km^2 in Argentina although it is mostly developed in Bolivia. When considered together with the Cretaceous Basin they are referred to as Northwest Basin. The Paleozoic Basin started as a peripheral foreland basin in the Proterozoic but lately changed to a backarc basin in the Cambrian and Ordovician times and later to a retroarc foreland basin during the Ordovician and Silurian times as a consequence of the recurrent history of subduction and collision developed in the western margin of Gondwana

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(Barredo and Stinco, 2013). The geometry of the basin illustrates the combination of lithospheric flexure and local deepening by reactivation of the old Cambrian – Ordovician rift faults. Several depocentres with local sedimentation were developed and infilled with marine and transitional deposits controlled mainly by eustatic variations. The high accommodation space reached during Middle to Upper Devonian times favored the accumulation of a thick pile of shales with interbedded sandstones, the Los Monos Formation, the source rock of the active petroleum system and a potential unconventional shale and tight reservoir. The formation has an average TOC that varies from 0.5 to 1.5%, Romax (%) 1.8 to 2.2, Hydrogen Index 300-400 mg HC/gTOC, SPI from 1 to 3 t HC/m2, kerogen type II/III to III/IV and a VKA (Legarreta and Villar, 2011), which suggests important terrestrial input during lowstands. The thickness of the Los Monos Formation ranges from 500 to 1,000 metres and extends all over the region, providing a high rock volume which compensates for the relatively low organic content. The orogenic cycle ended by Upper Carboniferous to Lower Permian with the presence of a magmatic arc to the west of Gondwana followed during Mid Permian to Lower Triassic by an extensional period due to the declination (Barredo, 2012) and or end of the subduction of the Panthalassa´s margin (Llambías and Sato, 1995). Hundreds of wells have penetrated partially or totally the formation as part of the exploration and development of the basin. The majority of them has oil and gas shows and in some cases production has been documented. However until now, all the limited efforts for producing these hydrocarbons were done following a conventional approach. Hydraulic fracturing costs together with water availability are the most important challenge to resolve. Volume estimates are around 40 TCF. The Paleozoic Basin is very prolific and has produced more than 2.1×10^8 barrels of oil and more than 5.3×10^{12} scf of gas.

Cretaceous Basin

As a result of the backarc regime that affected the Paleozoic Basin, the basin itself dismembered into two independent troughs, the Paleozoic and Cretaceous basins and both separated from the Chacoparanaense Basin, presently a frontier basin. The Cretaceous Basin extends over an area of 53,000 km^2 and includes three significant depocentres: Metán-Alemanía, Lomas de Olmedo and Tres Cruces, all of them with an asymmetric shape. Sedimentation, represented by the Salta Group, comprises shallow marine to non-marine and volcanic rocks controlled by faults propagation and sea level variation, with minimal influence from the incipient lithospheric flexure (Barredo and Stinco, 2010). Thick black shales, carbonates and evaporates were developed in a complex geological setting composed of a hypersaline (hydrologically-closed) lacustrine environment combined with a marked high frequency wet-dry cyclicity probably influenced by marine transgressions. The continental lacustrine and alternating marine clastic and carbonatic facies is the Yacoraite Formation, the source rock of the basin. It has an average TOC that varies from 0.6 to 6%, Romax (%) 0.6 to 1, Hydrogen Index 300-750 mg HC/gTOC, SPI of 1 t HC/m2, kerogen type II to III and a VKA of algal amorphous (Legarreta and Villar, 2011). The thickness of Yacoraite Formation ranges from 5 to 50 metres, being developed mostly within the Lomas de Olmedo depocentre, and hence limiting the total volume of rock. Volume estimates are around 5 TCF. Additionally, the interbedded coarser intervals have potential as tight reservoirs. The formation was not drilled as an unconventional reservoir so far. The basin´s production of oil has been documented since 1936 totalizing more than 1.25×10^8 barrels of oil.

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Cuyana Basin

The Cuyana Basin is 43,000 km^2 in area. By Early Middle Triassic - Early Jurassic times, the inception of a new juvenile magmatic arc associated with the renewal of the subduction processes, added extra intraplate extensional forces (Llambías et al., 2007). Consequently, rapidly subsiding, fault-bounded, narrow back arc-related troughs were formed and arranged in an echelon pattern like (Ramos and Kay, 1991; Rincón et al., 2010; Barredo et al., 2012). The basin consists of rapidly subsiding, fault-bounded troughs (Barredo et al., 2008; Ramos and Kay, 1991; Rincón et al., 2011). The Cuyana Basin is a NW trending elongate passive rift filled with continental deposits with a geometry derived from reactivated structures whose attitude towards the extensional regime controlled the style of the rifts (mainly dip-slip or oblique to strike-slip dominated), (Barredo, 2012). The resulting depocentres consisted of scoop-shaped sub-basins separated by intrabasinal highs. The Cuyana Basin developed a hydrologically closed lacustrine environment under a semi-arid, seasonally humid climate, leading to the accumulation of the kerogen type I rich shale rocks of the Cerro de Las Cabras Formation during Middle Triassic times. It may reach a TOC (total organic carbon content) up to 10% but up to now the explored levels display low thermal maturation, which limits its potential as source rock. The overlying alluvial fan and deltaic deposits of the Potrerillos Formation are considered tight reservoirs. The uppermost horizons corresponding to lacustrine deposits have some organic matter but up to now negligible. A reactivation in the fault system and a subtle change in the climatic conditions from sub-tropical to temperate, seasonally dry climate during Middle to upper Triassic times, gave rise to the development of balanced fill lakes subjected to climatic base-level fall-to-rise turn-arounds (Barredo, 2012). This environment was ideal for the accumulation of the organic matter of the Cacheuta Formation - presently the most important source rock of the basin. This formation contains an average TOC that varies from 3 to 10%, Romax 0.6 to 1%, Hydrogen Index 600-900 mg HC/g TOC, SPI from 3 to 10 t HC/m2, kerogen type I and a VKA (visual kerogen analysis) of algal amorphous with limited terrestrial contribution (Legarreta and Villar, 2011). The thickness of the Cacheuta Formation ranges from 50 to 400 metres, although maturation took place in restricted portions of the depocentre. Hundreds of wells have penetrated the formation with oil shows when drilling for deepermost conventional reservoirs. Volume estimates are around 15 TCF. Since 1886, the Cuyana Basin has been producing oil and current studies assign at least 1.32×10^9 barrels of recoverable oil.

Neuquén Basin

Neuquén Basin covers an area of 115,000 km^2. During Upper Triassic/Lower Jurassic times a series of continental clastic and pyroclastic sediments, informally identified as Precuyo Cycle (Gulisano et al., 1984) were deposited in a juvenile rift, the Neuquén Basin, located southward of the Cuyana Basin. The climate was semi-arid seasonally humid, the lake was closed and underfilled and could accumulate the organic matter which is presently the source rock of Puesto Kauffman Formation or Precuyano. It has an average TOC that varies from 2 to 11%, Romax (%) 0.4 to 0.8, Hydrogen Index 300- 900 mg HC/gTOC, SPI from 10 t HC/m2, kerogen type I to mixed I/III and a VKA (Legarreta and Villar, 2011), suggesting significant terrestrial woody input over the algal lacustrine production. Thickness ranges from 50 to over 1,100

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metres as a consequence of the marked rifting topography. The majority of wells that reached the Precuyano are located to the east and centre of the basin - many of them with oil and gas shows and very few with limited production as tight reservoir. Volume estimation assigns 2 to 5 TCF to this formation.

During the Middle Jurassic up to the Lower Cretaceous period, the basin experienced repeated drowning by the sea with the development of important source rock, in the Los Molles, Vaca Muerta and Agrio formations, all of them alternating with periods of continentalisation. These formations are the important unconventional reservoirs of the country, up to the moment. Los Molles Formation has an average TOC that varies from 1 to 5%, Romax (%) 0.8 to 2, Hydrogen Index 300-500 mg HC/gTOC, SPI of 6 t HC/m2, kerogen type II-III and a VKA of algal amorphous with variable terrestrial contribution (Legarreta and Villar, 2011). The thickness of Los Molles Formation ranges from 100 to 800 metres. Tight reservoirs are distributed widely within the formation, being controlled by the paleotopography and the channelized submarine fans. Current development of unconventional reservoirs is focused on tight gas and oil reservoirs mainly encountered within the vicinity of the depocentre of the basin, and is mostly related to gas-prone basin-centred gas systems. Volume estimates range from 130 to 190 TCF. As the basin swallowed, the deltaic and litoral clastic deposits of the Lajas and Punta Rosada formations proved to be excellent conventional reservoirs and are also tight gas reservoirs that have been under production for more than 40 years.

Vaca Muerta Formation is the most important source rock in Argentina and has an average TOC that varies from 3 to 8%, Romax (%) 0.8 to 2, Hydrogen Index 400-800 mg HC/gTOC, SPI 5 to 20 t HC/m2, kerogen type I/II and IIS in marginal areas, and VKA of high quality amorphous (Legarreta and Villar, 2011). The thickness of the Vaca Muerta Formation ranges from 25 to 450 metres reaching at least 25,000km^2. Regional surface data suggests that vertically (time domain) and laterally (space domain) the formation comprises a wide variety of lithologies: shales, marls, carbonates, calcareous sandstones and sandstones (Stinco and Barredo, 2014a). Thousands of wells have penetrated partially or totally the formation as part of the exploration and development of the basin. The majority of them has oil and gas shows and in many cases there is production of hydrocarbons. Beginning in 2010, different companies drilled exploration and production wells targeting the unconventional oil and gas shales of Vaca Muerta Formation that have accumulated more than 50 MMboe (56% of which corresponds to oil). Its world class source rock characteristics have driven the economic activity within the basin. Volume estimates range from 170 to 220 TCF. The top of the formation is marked by an unconformity (Leanza, 2009), followed by the marine deposits of the Mulichinco (a conventional and the second most important tight reservoir) and Agrio formations. To the north it is overlaid by the Chachao Formation while to the east of the basin there is a transition of the unit towards the limestones and siltstones of the Quintuco and Loma Montosa formations and to the south turns into the Carrín Curá and Picún Leufú formations (Leanza and Hugo, 1997).

The last Pacific ingression corresponds to the Agrio Formation (middle early Cretaceous) which took place during an important change in the subsidence regime: the gradual and pulsatile transition to the foreland phase under a dry climate (Barredo and Stinco, 2010). The Agrio

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Formation has an average TOC that varies from 2 to 5%, Romax (%) 0.6 to 1, Hydrogen Index 300-700 mg HC/gTOC, SPI from 4 to 12 t HC/m2, kerogen type II to II/III and a VKA of algal amorphous with variable terrestrial contribution (Legarreta and Villar, 2011). The thickness of the Agrio Formation ranges from 50 to 400 metres. Oil and gas shows were documented in many cases as well as production of hydrocarbons. Current exploration and development of unconventional reservoirs is focused to the west and north of the basin. Volume estimates range from 20 to 40 TCF.

Since 1918 there is hydrocarbon´s production in Neuquén Basin, having being discovered more than 5 $x10^9$ barrels of oil and 3.2 $x10^{13}$ scf of gas related to conventional reservoirs and currently opening new opportunities as the result of the developing of the huge resources related to unconventional shale and tight reservoirs.

Golfo San Jorge Basin

The Golfo San Jorge Basin is a complex continental and aulacogenic basin developed in a cratonic position (Barredo and Stinco, 2010) during the gradual breakup of Gondwana. The Golfo de San Jorge Basin covers an area of 170,000 km^2 (Sylwan et al., 2008), one third of which is located offshore. The synrift comprises continental clastic and volcaniclastic rocks controlled by tectonic subsidence. Pozo Anticlinal Aguada Bandera and Cerro Guadal formations were developed in balanced-fill, strongly cyclic lakes. These rocks together are informally known as the Neocomian sequence, and are one of the source rocks of the basin developed in a deep euxinic environment controlled by high angle limiting faults. The Neocomian sequence has an average TOC that varies from 0.5 to 3%, Romax (%) 0.8 to 2.6, Hydrogen Index 300-600 mg HC/gTOC, SPI of 1 t HC/m2, kerogen type II/III and a VKA of algal amorphous and structural terrestrial (Legarreta and Villar, 2011). The thickness of the sequence ranges from 500 to 1,800 metres. Technically recoverable resources are in the order of 50 TCF for this sequence. The resulting deep basin geometry and its starved condition favored the deposition of thick shales of the Pozo D-129 Formation, the main source rock and potentially the unconventional reservoir of the basin. In our present context, this formation is probably the most relevant after the Neuquén Basin shales. It has an average TOC that varies from 0.5 to 3%, Romax (%) 0.6 to 2.4, Hydrogen Index 300-650 mg HC/gTOC, SPI of 10 t HC/m2, kerogen type I/II to II/III and a VKA of algal amorphous with minor terrestrial contribution (Legarreta and Villar, 2011). The thickness of Pozo D-129 Formation reaches up to 2,000 metres, which together with its areal distribution represents an excellent target. Current development of unconventional reservoirs is focused on tight gas and oil reservoirs distributed all over the basin. Although still limited in number, wells drilled targeting this formation as unconventional reservoirs have demonstrated its capability of becoming an important objective as oil production is reaching 220 barrels per day and gas 130,000 scf/day. Volume estimates are around 100 TCF.

Austral Basin

Further south and during the Cretaceous to Tertiary times, first the Rocas Verdes Basin back-arc basin and then the Austral foreland basin were developed, covering 146,000 km^2. The first one comprised synrift bituminous shales formed in underfilled to balanced fill lakes, that constitutes

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the second most important source rock of the basin, the Serie Tobífera. It has an average TOC that varies from 1 to 3%, Romax (%) 0.6 to 1.2, Hydrogen Index 300-500 mg HC/gTOC, SPI of 1 t HC/m2, kerogen type II to III and a VKA of algal amorphous. The thickness of Serie Tobífera ranges from 5 to 25 metres. The formation has interbedded sandstones that are considered as tight reservoirs. Due to its limited thickness and areal distribution, it is not considered as important as the Palermo Aike Formation - the main source rock developed during the thermal relaxation of the rift - yet with decreasing fault activity and high stand of the sea level (Barredo and Stinco, 2010). This formation has an average TOC that varies from 0.5 to 2%, Romax (%) 0.8 to 1.8, Hydrogen Index 300-750 mg HC/gTOC, SPI of 1 t HC/m2, kerogen type II-III and a VKA of algal amorphous (Legarreta and Villar, 2011). The thickness of the Palermo Aike Formation ranges from 50 to 400 metres. Since 2011, oil and gas companies have been evaluating the feasibility of this unit as a shale gas/oil unconventional reservoir, with estimated technically recoverable resources of 160 TCF.

Tables 1 and 2 summarize the characteristics of the most important source rocks that are currently being considered as unconventional shale reservoirs of hydrocarbons (Stinco and Barredo, 2016).

Table 1. Main characteristics of the source rocks for the Cuyana and Neuquén basins

Unit	Cacheuta	Precuyano	Los Molles	Vaca Muerta	Agrio
Thickness (m)	50 - 400	50 - 1100	100 - 800	25 - 450	50 - 400
Average TOC (%)	3 - 10	2 - 11	1 - 5	3 - 8	2 - 5
K Type	I	I to I/III	II - III	I/II	II to II/III
Romax (%)	0.6 - 1	0.4 - 0.8	0.8 - 2	0.8 - 2	0.6 - 1
HI (mgHC/gTOC)	600 - 900	300 - 900	300 - 500	400 - 800	300 - 700
SPI (t HC/m^2)	3 - 10	10	6	5 - 20	4 - 12
Age	Triassic	Upper Triassic Lower Jurassic	Early Jurassic	Upper Jurassic	Early Cretaceous
Environment	Lacustrine	Lacustrine	Marine	Marine	Marine

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Table 2. Main characteristics of the source rocks for the Paleozoic, Cretaceous, Golfo San Jorge and Austral basins

Unit	Los Monos	Yacoraite	Neocomian	Pozo D-129	Serie Tobífera	Palermo Aike
Thickness (m)	500 - 1000	5 - 50	500 - 1800	1000 - 2000	5 - 25	50 - 400
Average TOC (%)	0.5 - 1.5	0.5 - 6	0.5 - 3	0.5 - 3	1 - 3	0.5 - 2
K Type	I/II to III/IV	II - III	II/III	I/II to II/III	II to III	II - III
Romax (%)	0.5 - 1.5	0.6 - 1	0.8 - 2.6	0.6 - 2.4	0.6 - 1.2	0.8 - 1.8
HI (mgHC/gTOC)	300 - 400	300 -750	300 - 600	300 - 650	300 - 500	300 - 750
SPI (t HC/m^2)	1 - 3	1	1	10	1	1
Age	Silurian Late Devonian	Upper Cretaceous	Early Cretaceous	Early Cretaceous	Middle/Upper Jurassic	Early Cretaceous
Environment	Marine	Lacustrine	Lacustrine	Lacustrine	Lacustrine	Marine

SHALE AND TIGHT RESOURCES

Some authors (SEN, 2011; EIA, 2013; Barredo and Stinco, 2013; Stinco and Barredo, 2014b) applying different methodologies have estimated important amounts of resources for the unconventional shale reservoirs in Argentina (Table 3).

SEN (2011), has estimated 741 TCF applying Schmoker (1994) methodology for Los Monos, Los Molles, Vaca Muerta, Pozo D-129 and Palermo Aike formations.

EIA (2013) has calculated technically recoverable resources of 801.3 TCF of gas and 27 BBO of oil. The methodology includes geological and reservoir characterization of the evaluated units within the basin, areal extent of the shales, definition of the prospective area, estimation of the risked shale gas/oil and an estimation of the technically recoverable shale gas and shale oil resource. Unfortunately, this report does not take into consideration resources associated with the Palaeozoic, Cretaceous and Cuyana basins, effective source rocks of proven petroleum systems that have produced (and are currently producing) a significant amount of oil and gas over more than a century.

Barredo and Stinco (2013) and Stinco and Barredo (2014b), have estimated gas resources of 800 TCF applying a stochastic modelling on the variables defined by Schmoker (1994) (area, thickness, source rock density, TOC, HI, retention factor, recovery factor, seal presence and efficiency, burial history and existing fields within the basin) and adjusted according to Kurchinskiy et al. (2012).

As per the tight reservoirs, volume estimation has more uncertainty. The SEN (2011) report assigns 30 TCF for the petroleum system Los Molles-Lajas (!) applying a probabilistic model. The study does not include the volumes related to the rest of the formations considered to be tight reservoirs in the six producing basins; therefore the country gas estimates are incomplete.

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Nevertheless, taking into account the effective petroleum systems and the number of producing fields and formations in each basin, the moderate to high preservation chance and the current production volumes it is valid to assume that resources could be 2 to 3 times more.

Table 3. Argentina's hydrocarbon resources estimated for unconventional shale reservoirs

Formation	TCF
Los Monos	34
Los Molles	259
Los Molles-Lajas	2
Vaca Muerta	109
Pozo D-129	246
Palermo Aike	91
Total	**741**
SEN, 2011	

Formation	TCF	BBO
Ponta Grossa	3.2	0
Los Molles	275.3	3.7
Vaca Muerta	307.7	16.2
Neocomiano	50.8	0
Pozo D-129	34.8	0.5
Palermo Aike	129.5	6.6
Total	**801.3**	**27**
EIA, 2013		

Basin	Formation	TCFe
Paleozoic	Los Monos #	40
Cretaceous	Yacoraite #	5
Cuyana	Cacheuta #	15
Neuquén	Precuyano *	5
Neuquén	Los Molles *	190
Neuquén	Vaca Muerta *	220
Neuquén	Agrio *	40
Golfo San Jorge	Neocomiano #	20
Golfo San Jorge	Pozo D-129 *	100
Austral	Serie Tobífera #	5
Austral	Palermo Aike *	160
Total		**800**
Barredo and Stinco, 2013*; Stinco and Barredo, 2014b#		

SEN, 2011: recoverable gas resources; EIA, 2013: technically recoverable gas and oil resources; Barredo and Stinco, 2013; Stinco and Barredo, 2014b: recoverable gas resources. TCF: Trillions cubic feet; TCFe: equivalent Trillions cubic feet; BBO: Billion barrels of oil.

Annual country consumption is close to 1.5 TCF for gas and 0.204 BBO for oil, therefore the implications of estimated resources are vast and could have a profound impact on future projects. Production from shale gas reservoirs is around 5% while tight gas reservoirs represent 20% of total consumption.

DRILLING, PRODUCTION AND COSTS IN VACA MUERTA FORMATION

By the end of 2016 more than 700 wells have been drilled in the unconventional shale reservoirs with more than 97% having Vaca Muerta Formation as the main target. Almost 80% are effectively producing hydrocarbons with the rest nonproductive due to technical and operational reasons. Oil production is almost 35,700 bbls/d while for gas 173 x10^6 scf/day.

Around 25% of the wells are horizontal with a markedly growing proportion of them in the last 2 years. Total drilling depths ranges from 2,000 to 3,000 metres in average with some exceptions for the exploration wells down to 4,500 metres. Most common horizontal legs are around 1,500 metres with a few reaching 2,000 metres. Frac stages varies from 10 to 20, performing 4 to 5 operations per day.

Environmental issues that include soil preservation, air quality, water usage, effluents disposal and treatment, flora and fauna preservation, chemical products storage and transport, human and equipment movements and social impact are considered at different stages during exploration and production activities according to the best industry practices and laws, decrees and norms that contemplate not only conventional but unconventional exploitation activities also.

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Figure 2 summarizes information related to numbers of wells drilled, average drilling days per well, number of fractures per well, length of the horizontal leg, oil and gas production per day since year 2010.

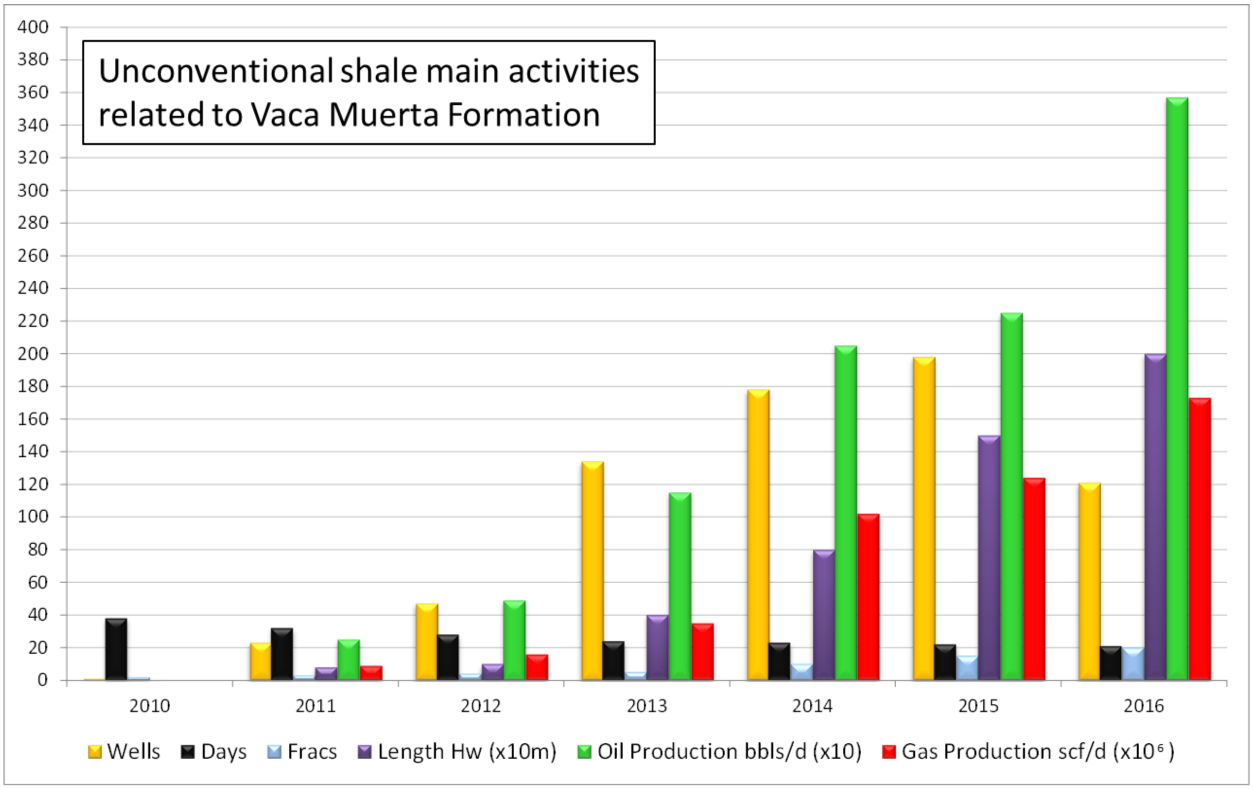

Figure 2: Unconventional shale main activities in Vaca Muerta Formation since 2010

So far, Vaca Muerta Formation production data demonstrates that the best section is restricted to the lowermost portion of the unit. Additionally, and in order to reduce costs, some operators are developing areas placing up to 6 wells at the same location. Some companies have performed casing drilling operations but then discarded as horizontal wells have much better productions. Vertical development wells costs are in the range of 7.5 to 12 MMUSD, while exploration well costs are close to 15.0 MMUSD. Costs for horizontal wells are generally double those of vertical wells.

On the whole, facilities, pipelines, roads, energy and infrastructure are available as the unconventional fields are located in the same geographic areas that comprise the conventional oil and gas production assets for more than 70 years. Therefore, these issues do not have a critical impact when performing the economics of any project.

DRILLING, PRODUCTION AND COSTS IN TIGHT RESERVOIRS

By December 2016, more than 720 wells have been drilled in the unconventional tight reservoirs located in Neuquén Basin and less than 10 in the other basins. Almost 87% are

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successfully producing hydrocarbons, the rest nonproductive ones are due to technical and operational causes.

Regarding hydrocarbon´s cumulative production (more than 860 Bcf) Lajas Formation is 43%, Mulichinco Formation 29%, Los Molles Formation 11%, Precuyano 10% and Punta Rosada Formation 7%, respectively. Lajas Formation is the most important gas tight reservoir of the country producing over 370 $x10^6$ scf/day and Mulichinco Formation around 230 $x10^6$ scf/day. Total tight gas production is close to 800 $x10^6$ scf/day.

Only 5% of the wells are horizontal but in the recent years the trend shows that this percentage is increasing. Total drilling depths ranges from 2,000 to 4,300 metres. Most common horizontal legs are around 1,000 metres with a few up to 1,500 metres. Frac stages vary from 5 to 15, performing up to 6 operations per day.

The environmental concerns related to the tight reservoirs are similar to the ones mentioned for the unconventional shale reservoirs.

Figure 3 summarizes information related to numbers of wells drilled, average drilling days per well, number of fractures per well and gas production per day since year 2010.

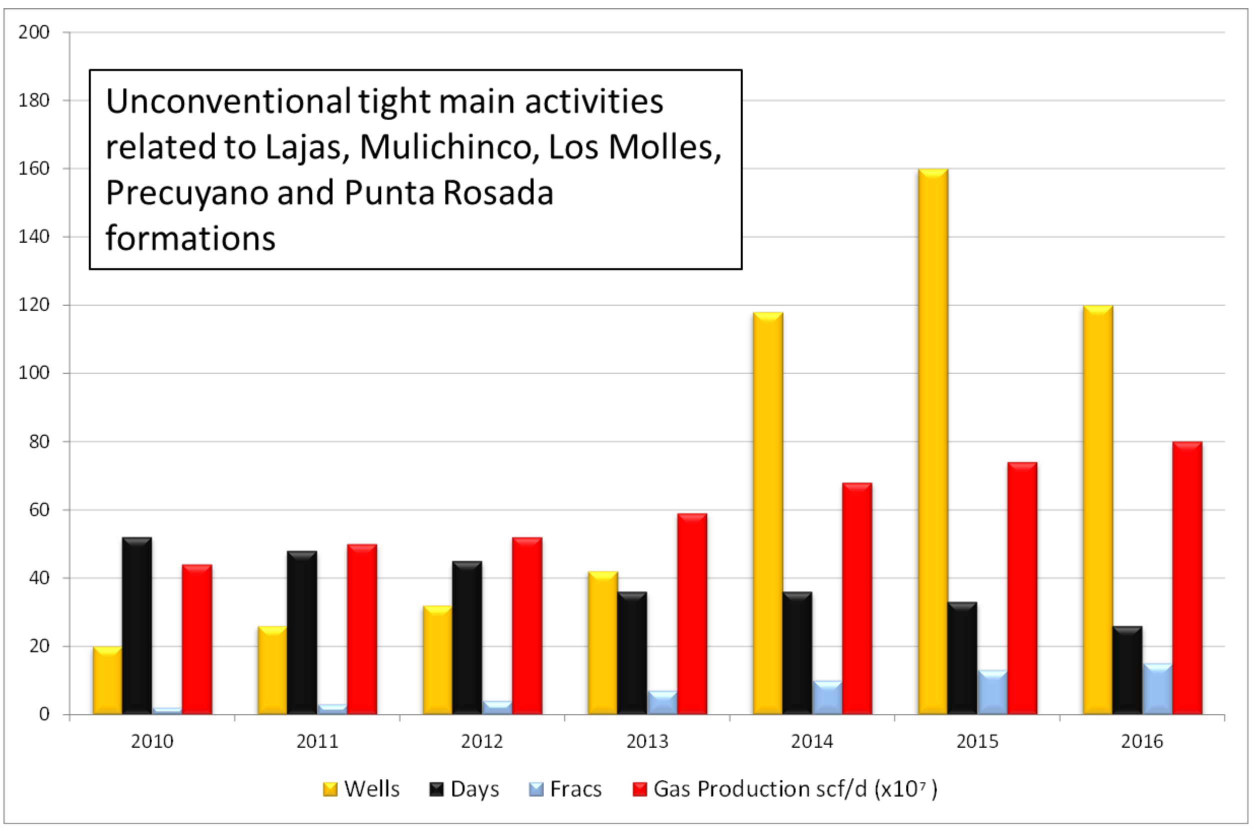

Figure 3: Unconventional tight main activities since 2010

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Costs of the exploration and development of tight wells are in the order or slightly higher compared to the shale ones mainly due to the drilling deeper targets.

As in the case of the unconventional shale reservoirs, the tight ones are located in the same blocks and concessions of the conventional fields therefore facilities, pipelines, roads, energy and infrastructure are available and minor adjustment should be done in order to accomplish production.

OPPORTUNITIES AND CHALLENGES

Argentina is the most active country developing unconventional shale and tight reservoirs after USA. Different scenarios consider that unconventional gas could cover 50% of the country gas demand in 15 years.

However, a widespread perception stresses that equipment, services and logistics are the bottleneck for development these reservoirs. Despite that local companies are developing technology an important amount of it is still imported, thus increasing costs. The same case applies for the proppants, currently imported but slowly being replaced with local materials.

A positive evolution in reducing uncertainty of the geoscience knowledge, drilling and fracking costs as well as improving the environmental concerns and legal issues could be seen over the last 5 years of activity. Nevertheless, cost reducing is still an important concern in order to achieve USA standards and to make more attractive these kinds of projects. For the unconventionals it is necessary to remember that investment flows are quite high and sustained in time, with long repayment periods (over 10 years) and low yields.

A major boost was achieved through the enactment of the new hydrocarbons law (27007) in year 2014. It contemplates and differentiates conventional, unconventional and offshore projects separately favoring the concept of development activities over longer periods of time.

Argentina´s oil production reached its peak in 1998 while gas in 2001. Since then, both productions show declination with a clear tendency of not being able to recover production unless new projects are successful, such as: new discoveries from exploration, implementation of improved/enhanced oil recovery plans and unconventional reservoirs development.

Nowadays, the most important challenge is developing and adopting the proper learning curve for each reservoir, together with substantial cost reductions. Success with this latter could help in the case of fluctuating oil/gas prices in the near future, that could otherwise have a negative impact in the early stages of development of Argentina's unconventional shale and tight reservoirs.

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