

URTeC: 1922563

Vaca Muerta Formation: an Example of Shale Heterogeneities Controlling Hydrocarbon's Accumulations

Luis Stinco*. Universidad de Buenos Aires (UBA), Argentina. Instituto Tecnológico de Buenos Aires, (ITBA). Oleum Petra S.R.L.

Silvia Barredo. Departamento de Ingeniería en Petróleo, Instituto Tecnológico de Buenos Aires, (ITBA). Buenos Aires, Argentina. Instituto del Gas y del Petróleo, IGPUBA, Universidad de Buenos Aires (UBA), Argentina.

Copyright 2014, Unconventional Resources Technology Conference (URTeC)

This paper was prepared for presentation at the Unconventional Resources Technology Conference held in Denver, Colorado, USA, 25-27 August 2014.

The URTeC Technical Program Committee accepted this presentation on the basis of information contained in an abstract submitted by the author(s). The contents of this paper have not been reviewed by URTeC and URTeC does not warrant the accuracy, reliability, or timeliness of any information herein. All information is the responsibility of, and, is subject to corrections by the author(s). Any person or entity that relies on any information obtained from this paper does so at their own risk. The information herein does not necessarily reflect any position of URTeC. Any reproduction, distribution, or storage of any part of this paper without the written consent of URTeC is prohibited.

Abstract

Vaca Muerta Formation, a thick Upper Jurassic unit covering at least 25,000km², is located in Neuquén Basin and represents the most important source rock in Argentina. Its geological and petrophysical variations are significantly linked to the geodynamic history of the basin strongly related to the transition from extensional reactivation to thermal relaxation which characterized basin's evolution through time. Major cyclic events related to sea oscillations provided the proper marine environment conditions to promote the development of several source rocks within the basin apart from Vaca Muerta Formation, such as Los Molles and Agrio formations.

Regional surface data suggests that vertically (time domain) and laterally (space domain) Vaca Muerta Formation comprises a wide variety of lithologies: shales, marls, carbonates, calcareous sandstones and sandstones. Subsurface data, obtained from mud logging, cores and open hole logs also demonstrate it. Both sources provide sufficient sampling density for interpreting the different facies of the unit from the Lower Tithonian to the Lower Valanginian and also considering its areal extent within the basin.

These variations are related to the basement fabric, post-rift subsidence interrupted by inverse reactivation, east-west basin asymmetry and climate changes from semiarid seasonally humid to warm and dry.

A summary of these characteristics are: a) a prograding NW carbonatic ramp best represents depositional environment; b) formation thickness increases to the west and north; c) carbonates are better developed in proximal areas; d) organic matter content increases at the base of the formation; e) paleotopography clearly controls facies distribution; f) to the north of the basin hydrocarbons are related to organic rich argillaceous limestones, to the center of the basin are mostly pelithic sediments while to NE correspond to a mixture of the above mentioned, to the south the euxinic conditions favored hydrocarbons with increased sulfur concentration.

Consequently these vertical and lateral facies variations control key aspects such as: areal distribution, depth, thickness, porosity, permeability, heterogeneity, TOC, mineral composition, reservoir pressure and geomechanics.

In this paper a comprehensive analysis using outcrop, well, and laboratory data of the Vaca Muerta Formation are presented summarizing the main hydrocarbon's accumulations with its unconventional reservoir characteristics.

Introduction

In Argentina, 545,000 km² correspond to hydrocarbon producing basins known as Paleozoic, Cuyana, Austral, Neuquén, Golfo San Jorge and Cretaceous, while the non-hydrocarbon producing ones cover 2,500,000 km² (Figure 1). The related source rocks are eleven, all of them with potential to be unconventional reservoirs. Five being marine in origin while six deposited in lacustrine environments with ages ranging from Late Devonian to Early Cretaceous (Barredo and Stinco, 2013). Figure 2 summarizes the main characteristics of all of them.

The most important source rock is the Lower Tithonian (147 ma) to Lower Valanginian (135 ma) Vaca Muerta Formation (Leanza, 2012) that covers at least 25,000 km² of the Neuquén basin.

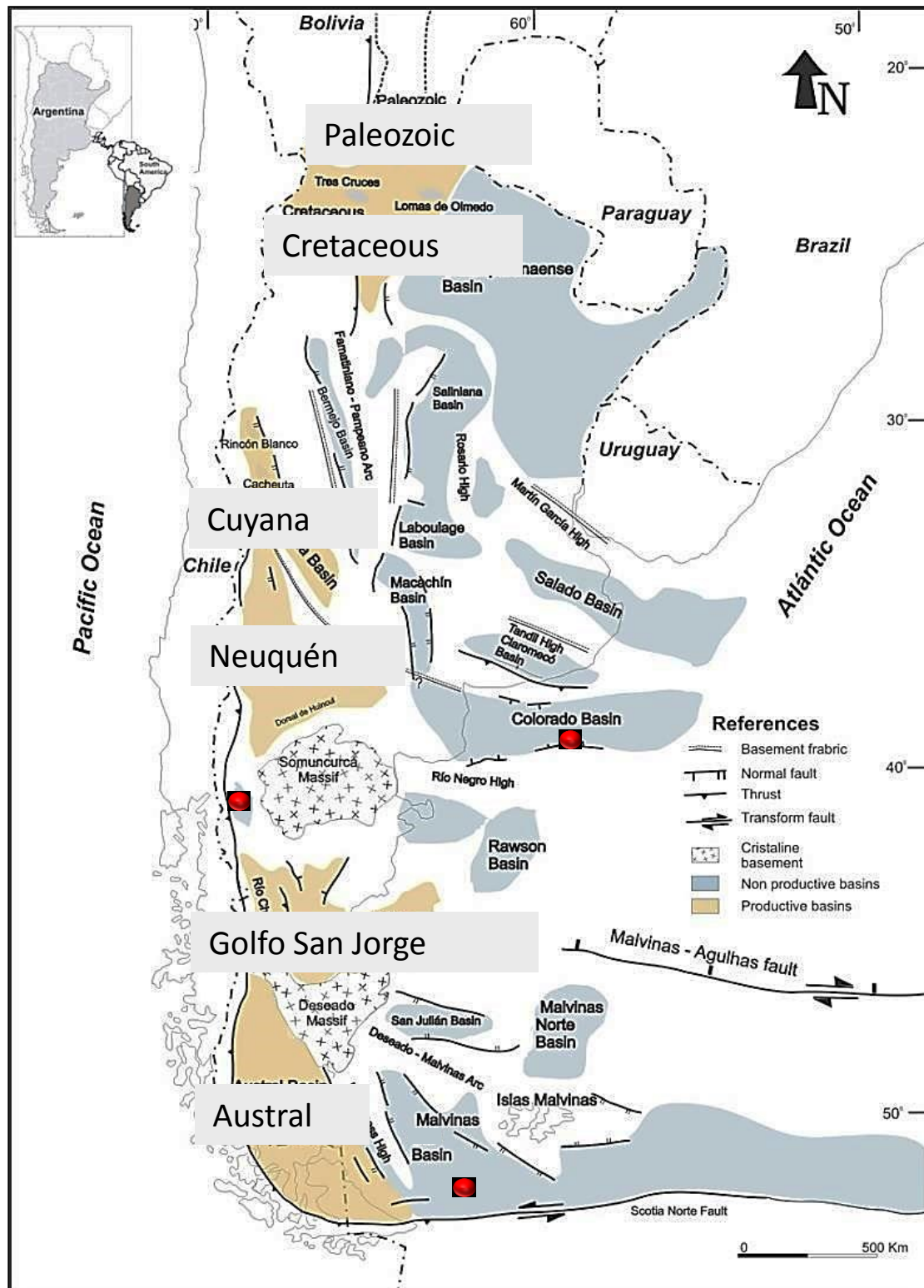


Figure 1: location map of the productive/non productive basins and regional structures (Barredo and Stinco, 2013)

Unit	Los Monos	Yacoraite	Cacheuta	Precuyano	Los Molles	Vaca Muerta	Agrio	Neocomiano	D-129	S. Tobífera	Palermo Aike
Thickness (m)	500 to 1000	5 to 50	50 to 400	50 to 1100	100 to 800	25 to 450	50 to 400	500 to 1800	1000 to 2000	5 to 25	50 to 400
TOC (%)	0,5 to 1,5	0,5 to 6	3 to 10	2 to 11	1 to 5	3 to 8	2 to 5	0,5 to 3	0,5 to 3	1 to 3	0,5 to 2
K Type	II/III to III/IV	II - III	I	I to I/III	II - III	I/II	II to II/III	II/III	I/II to II/III	I to III	II - III
Age	Silurian Late Devonian	Upper Cretaceous	Triassic	Upper Triassic Lower Jurassic	Early Jurassic	Upper Jurassic	Early Cretaceous	Early Cretaceous	Early Cretaceous	Mid/Upper Jurassic	Early Cretaceous
Environment	Marine	Lacustrine	Lacustrine	Lacustrine	Marine	Marine	Marine	Lacustrine	Lacustrine	Lacustrine	Marine

Figure 2: summary of the main characteristics of the source rocks of Argentina. Ref: K= kerogen type; TOC= total organic carbon content

From a total of 800 TCF of estimated resources, around 27% (220 TCF) are assigned to Vaca Muerta Formation (Figure 3).

Basin	Formation	Resources (TCF)
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	D-129	100
Austral	Serie Tobífera	5
Austral	Palermo Aike	160
Total		800

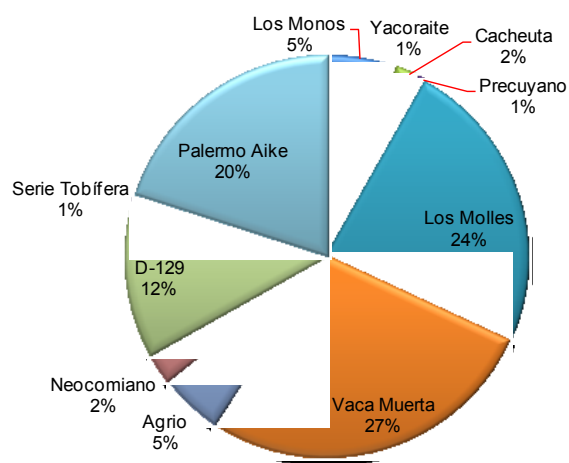


Figure 3: estimated resources by source rock (Barredo and Stinco, 2013)

Neuquén Basin

The Neuquén basin has an elongated northwest to southeast shape (Figure 1). Consistent with its morphostructural and sedimentary characteristics different geographic areas can be recognized: thrust belt to the west, northeastern platform, embayment in the center and coincident to the depocenter, the East area, the Huincul's High and the Picún Leufú sub-basin to the south (Figure 4). Its origin is related to the occidental history of Gondwana which was active since the Proterozoic (Ramos, 1988) and conditioned to a flexural subsidence in most of the regions. As a result of this, during Permo-Triassic times, an extensional regime evolved with the development of back arc basins which, in some cases, had embayments in the foreland such as the Neuquén basin.

This deformation was favored by the relatively high geothermal gradient due to the magmatism of the arc that diminished the lithosphere resistance, composed by a relatively thick crust (Llambías et al., 2007) that allows the development of a gentle rift with deep faults.

During the Upper Triassic, the first stages of the infilling of the Neuquén Basin (Precuyo cycle) proved to be very complex (Barredo and Stinco, 2013). Pyroclastic deposits cover large and different areas of the basin. To the east, interfingering shales deposited in underfilled, strongly cyclic lakes are presently source rocks and probably unconventional reservoirs of the basin (Barredo and Stinco, 2013). It has a TOC that varies from 2 to 11%, Romax (%) 0.4 to 0.8, Hydrogen Index up to 900 mg HC/gTOC, SPI from 10 t HC/m², kerogen type I to mixed I/III and a

Visual Kerogen Analysis (VKA) suggesting significant terrestrial woody input over the algal lacustrine production (Legarreta and Villar, 2011). Thickness ranges from 50 to over 1,000 meters as a consequence of the marked rifting topography. The majority of wells that reached the Precuyano are located to east and center of the basin with many of them with oil and gas shows. Volume estimation assigns 2 to 5 TCF to this formation, the conventional Puesto Kauffman reservoir (Barredo and Stinco, 2013).

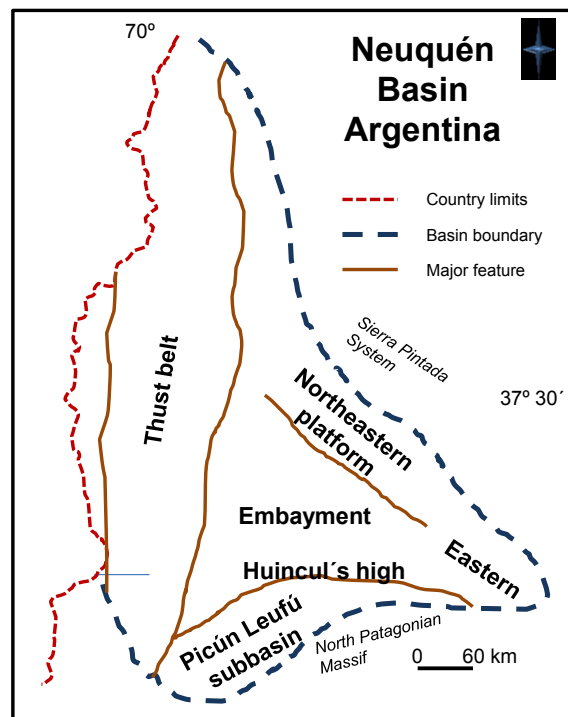


Figure 4: morphostructural areas of the Neuquén Basin.

The extensional phase lasted up to the Jurassic nevertheless an important reactivation can be observed in the Upper Triassic-Lower Jurassic (Fernández Seveso et al., 1996; Barredo et al., 2008). This stage is represented by the marine and continental facies controlled by eustatic (Legarreta and Gulisano, 1989) and tectonic variations of the Cuyo Group (Los Molles and Lajas formations). The basin keeps under a subsidence regime due to the second rift stage and starts to evolve into a post rift stage. An expansion of the marine realm flooded the basin that was linked to the proto-Pacific through openings in the arc (Howell et al., 2005). According to Barredo et al. (2008) areas close to the Huincul High, were under a compression regime with inversion of the old extensional structures. To the east, positive zones limited the marine ingression of the Los Molles Formation.

The transition from the rift climax to the early post-rift started in Middle Jurassic, coetaneous with the first marine ingression, the Los Molles Formation, while the definite thermal relaxation of the post-rift stage occurred in the upper Middle Jurassic onwards (Gulisano y Gutierrez Piembling, 1994; Barredo et al., 2008) with the Vaca Muerta and Agrio formations (Barredo and Stinco, 2013).

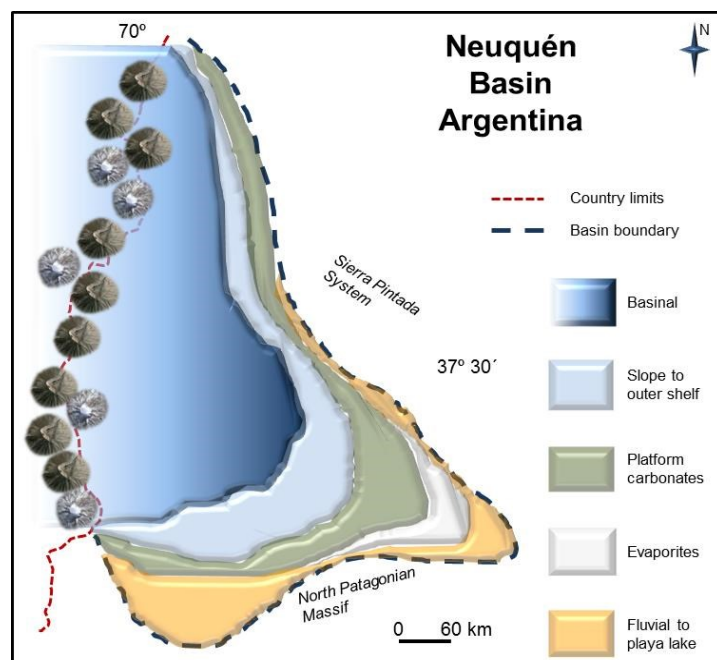


Figure 5: facies distribution during Lower Cretaceous (modified from Uliana & Legarreta, 1993; Howell et al., 2005)

Climate was first semiarid seasonally humid but by Middle Jurassic it was warm to temperature with wet-dry cycles, warm and dry in the Upper Jurassic and more humid during the Cretaceous. Post-rift subsidence was disturbed by repeated inverse reactivation of the ancient extensional faults associated with the uplifting of the Dorsal de Huincul (Huincul's High) during Jurassic times and the change to a retroarc flexural subsidence during the foreland stage that have occurred from the Cretaceous times onwards. Consequently, both eustasy and tectonism (subsidence rate and localized uplift) helped to control source rock deposition and preservation while the high lands of the eastern portion of the basin generated by the inversion of ancient Triassic faults, limited marine ingression to the hinterlands (Barredo and Stinco, 2013).

Being the second most important unit in the basin, Los Molles Formation has a 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). Thickness of Los Molles Formation ranges from 100 to 800 meters. Tight reservoirs are widespread distributed within the formation being controlled by the paleotopography and the channelized submarine fans (Barredo and Stinco, 2013). Thousands of wells have penetrated partially and hundreds totally the formation as part of the exploration and development of the basin. Most of them have oil and gas shows and in many cases there is consistent production of hydrocarbons. Current development of unconventional reservoirs is focused on tight gas and oil reservoirs mainly encountered within the vicinity of the depocenter of the basin, mostly related to gas prone basin centered gas systems. Volume estimation assigns 130 to 190 TCF to this formation (Barredo and Stinco, 2013).

From a tectosedimentary viewpoint this stage corresponds to an underfilled basin associated to the climax of the second rift. Following this phase of maximum accommodation space, the sedimentation rate increased during the transition to the early post rift stage in response to the gradually thermal dominated subsidence.

Vaca Muerta Formation is the most important source rock in Argentina and has a 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). Thickness of Vaca Muerta Formation ranges from 25 to 450 meters covering an area of at least 25,000km². Thousands of wells have penetrated partially or totally the formation as part of the exploration and development of the basin. Most of them has oil and gas shows and in many cases there is production of hydrocarbons. Since 2010 different companies started to drill exploration wells targeting the unconventional oil and gas shales of Vaca Muerta Formation. Its world class source rock characteristics have mobilized the economic activity within the basin and around 180 wells have been drilled with initial productions of 95 bbls/day for horizontal ones and 42 bbls/day for the vertical wells. Although there is a limited production history, EUR @ 25 years for the vertical wells are 176,000 bbls while for the horizontal ones around 300,000 bbls. Volume estimation assigns 170 to 220 TCF to this formation (Barredo and Stinco, 2013).

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). Agrio Formation has a 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). Thickness of the Agrio Formation ranges from 50 to 400 meters. Hundreds of wells have reached the formation as part of the exploration and development of the basin. Oil and gas shows were documented in many cases as well as production of hydrocarbons (Barredo and Stinco, 2013).

The Precuyano, Los Molles, Vaca Muerta and Agrio formations are the different source rocks located in Neuquén basin, nevertheless Vaca Muerta Formation is the most important in estimated resources volumes and in the number of projects currently being developed by operating companies. Figure 6 is a type log and stratigraphic column for the sequence that includes source rocks and conventional hydrocarbon reservoirs.

Vaca Muerta Formation

Bodenbender in 1892, informally described for the first time the outcrops of the highly bituminous shales with oil shows in the nucleus of ammonites (Leanza, 2012) and Weaver (1931) formally adopted the name Vaca Muerta Formation for the most important source rock of the Neuquén Basin.

This unit, within the stratigraphic column, overlies with sharp contact the continental deposits of the Tordillo and Quebrada del Sapo formations denoting the Tithonian transgression. Nevertheless, in some areas it can overlay in angular discordance on different pre-Tithonian units (Leanza and Hugo, 1997; Leanza, 2009). The top of the formation is indicated in the depocentre area of the basin by a clear unconformity, followed by the marine deposits of the Mulichinco and Agrio formations of Late Valanginian-Early Barremian age (Leanza, 2009; Parent et al., 2013). To the north it is overlaid by the Chachao Formation (Leanza et al., 1977). 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 while to

the south turns into the Carrín Curá and Picún Leufú formations, Tithonian and partially Berriasian in age (Leanza et al., 1977; Leanza and Hugo, 1997).

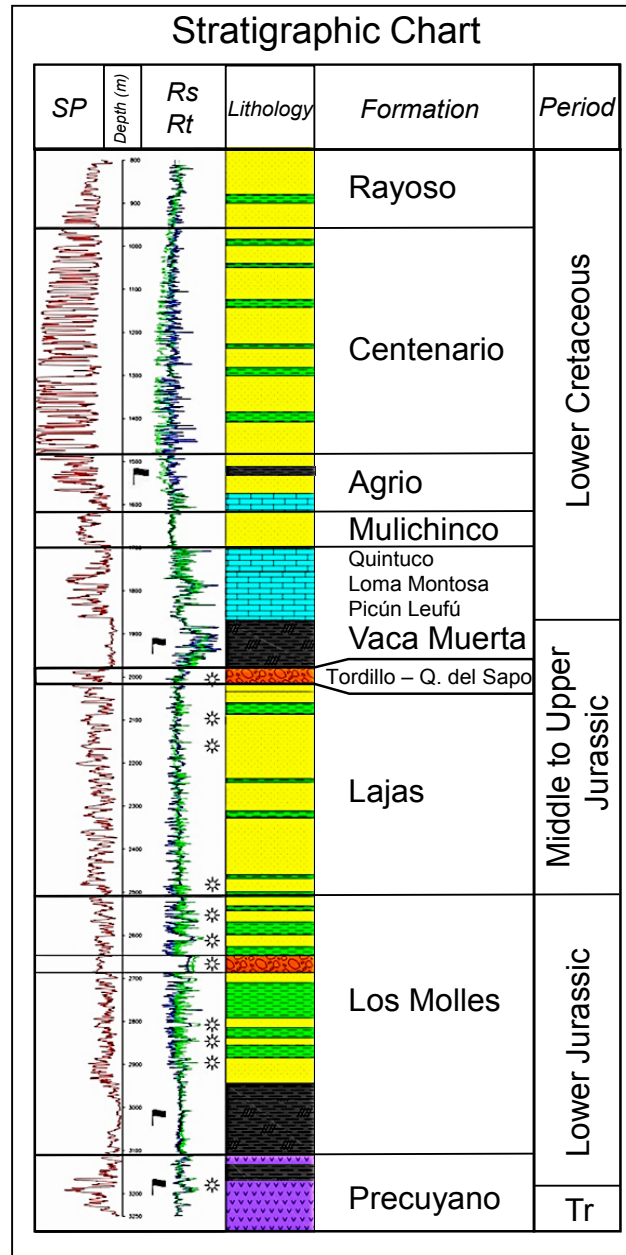


Figure 6: type log and stratigraphic column for the sequence.

The formation is characterized by a rhythmic alternation of marls, shales and limestones related to an external ramp (Spalletti et al., 2000; Scasso et al., 2002) distributed as depositional sequences with proximal facies prograding to the west (Mitchum and Uliana, 1985; Legarreta and Gulisano, 1989). Additionally, to the west margin, sandy gravitational flows are encountered denoting the asymmetry of the basin (Leanza et al., 2003).

Depending on the geographical position of the Vaca Muerta Formation substantial facies differentiation can be seen (Figure 5). To the south-southeast of the basin, the deposits of Vaca Muerta Formation comprises carbonates and marls deposited under tidal influence that include the rhythmites of the Los Catutos Member (Scasso et al., 2002) which change to the carbonate-siliciclastic nearshore sediments of the Carrín Curá and Picún Leufú formations (Leanza, 1973; Spalletti et al., 2000; Leanza et al., 2011). Within the embayment area, the basinal deposits of the Vaca Muerta Formation change towards the east to the shoreface deposits of the Quintuco Formation and to the sabkha deposits of the Loma Montosa Formation forming a mixed carbonate-siliciclastic depositional system (Gulisano et al., 1984; Mitchum and Uliana, 1985; Carozzi et al., 1993). In addition, minor tuff episodes representing characteristics horizons covering wide extensions and denoting the influence of the volcanic arc can be recognized. To the west, the Vaca Muerta Formation comprises the slope facies represented by a turbidite episode of the Huncal Member (Leanza et al., 2003) and in the Chilean territory pass into shallow marine/volcanic deposits (Leanza et al., 2011; Kietzmann and Vennari, 2013; Kietzmann et al., 2014). To the north of the basin, the basinal to middle ramp deposits of the Vaca Muerta Formation are covered by the middle to inner ramp oyster-deposits of the Chachao Formation (Kietzmann et al., 2014).

Sedimentary dissimilarities among different areas are related to the basement fabric that still impinges in the paleotopography over which Vaca Muerta Formation developed, the Huincul's High, the siliciclastic input due to latitudinal position (Volkheimer et al., 2008) and a complex interaction of the supply of sediments, the availability of the accommodation space (both with tectonic components), sea level variations (which also may have a significant tectonic influence) and climate variations (Barredo, 2012).

Figures 7 and 8 are outcrop photographs of the formation 40 kilometers apart each other showing two of the different facies that characterize Vaca Muerta Formation.



Figure 7: rhythmic succession of marls and limestones of Vaca Muerta Formation outcropping in Los Catutos area (Barredo, 2014).



Figure 8: sequence of the shales of Vaca Muerta Formation outcropping in Picún Leufú area (Barredo, 2014).

Thin section analysis (Kietzmann and Vennari, 2013; Kietzmann et al., 2014) performed in different outcrops within the thrust belt also demonstrate the high variability of the Vaca Muerta Formation facies (Figures 9 and 10).

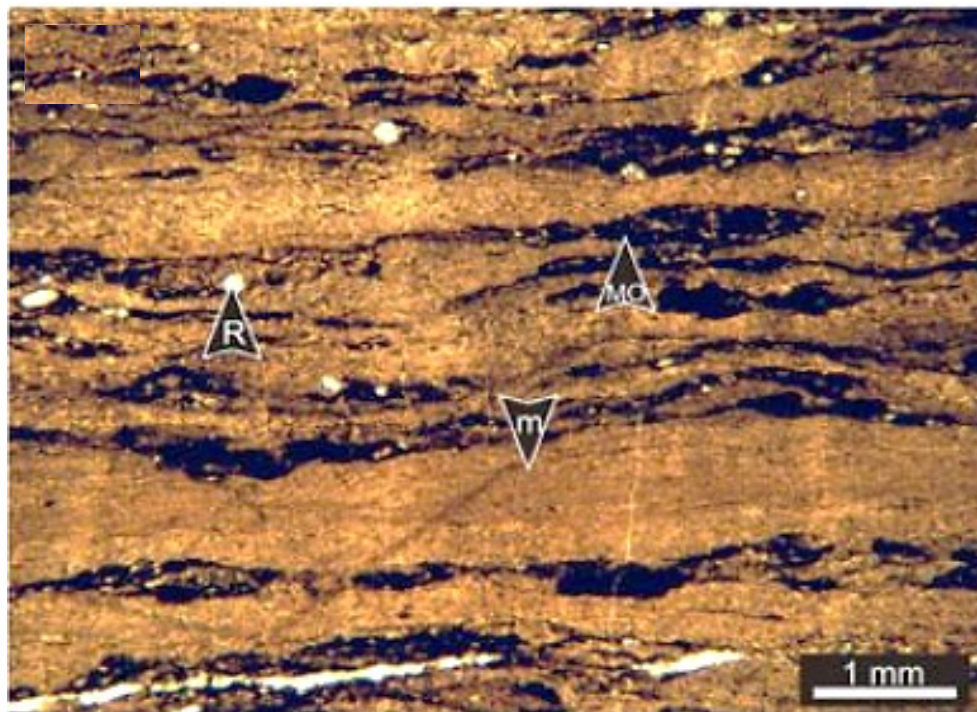


Figure 9: Vaca Muerta Formation thin section of a thinly laminated finegrained limestones, rich in organic matter (m) microbial laminae, (MO) organic matter, (R) radiolarians. Marl/limestone ratio is 3:1. (Kietzmann et al., 2014).

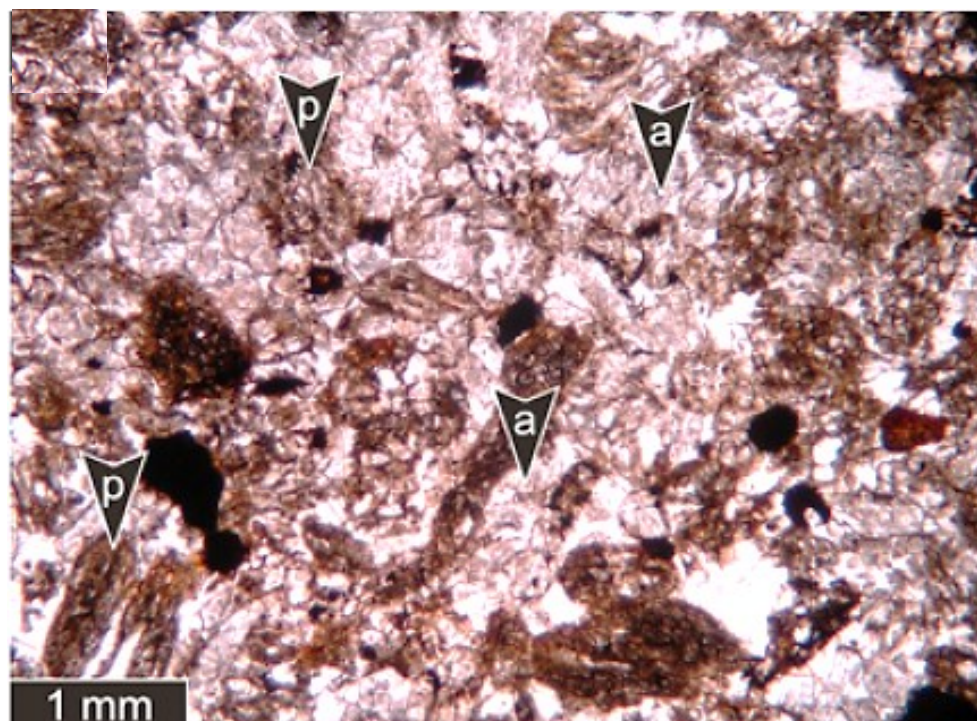


Figure 10: Vaca Muerta Formation thin section of algal rudstones/floatstones with pumiceous fragments (p), calcareous algae (a) (Kietzmann and Vennari, 2013).

The subsurface dilemma

Having said all the previous, among others we can formulate some questions: a) why we should expect homogeneity in the subsurface? b) can we extrapolate the surface knowledge into subsurface? c) are these variations influencing the mechanical response of the rock? d) can we correlate facies with mineralogical changes? e) are we able to see these with indirect methods? f) can we predict them in order to optimize completions and reduce costs? g) should we drill vertical, horizontal or both types of wells? A wide diversity of data collected in different basin positions can be correlated with surface information providing decisive indications on the unconventional reservoir characteristics of the Vaca Muerta Formation that can be used to answer some of the questions. The following figures demonstrate this approach.

Figure 11 is a map showing thermal maturation and oil and gas fields distribution for Vaca Muerta Formation.

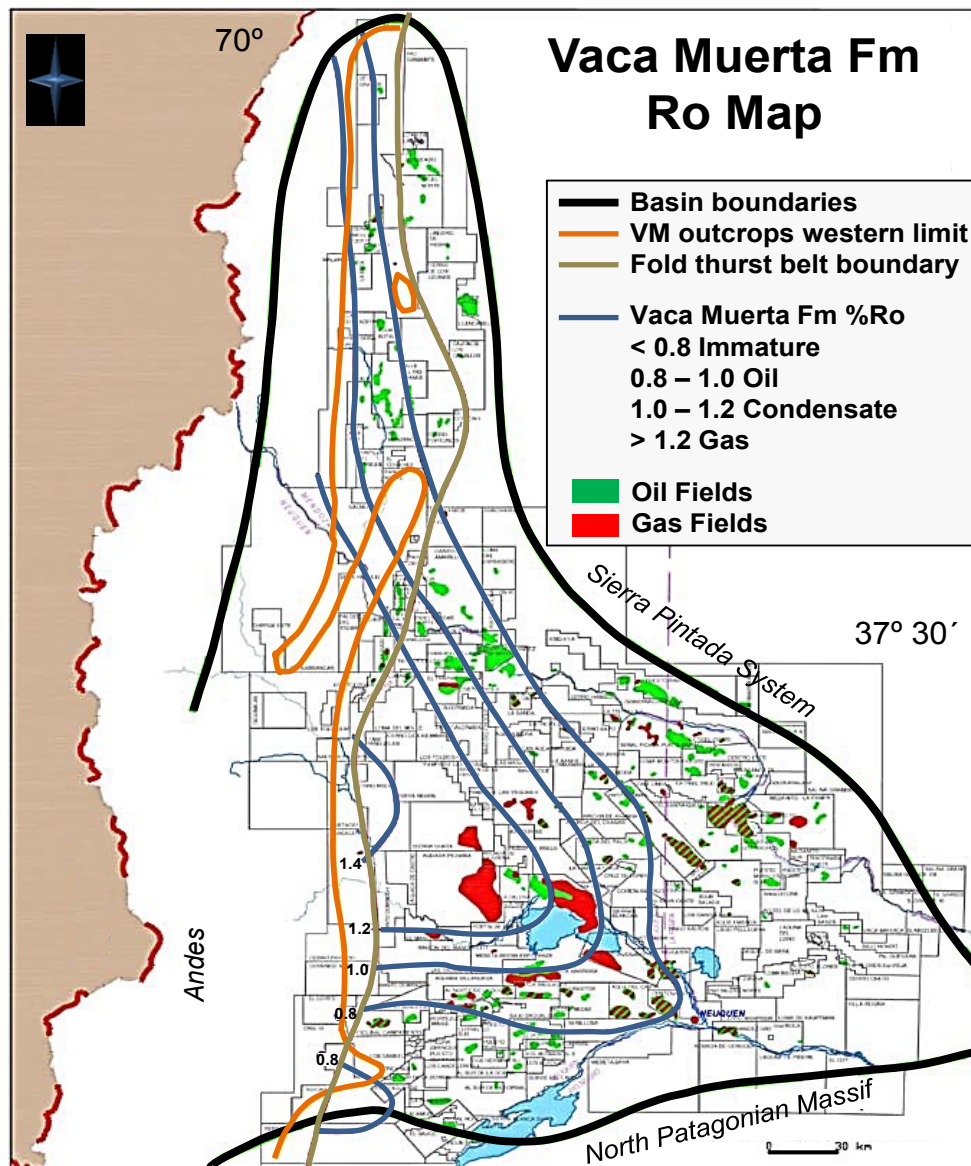


Figure 11: map showing thermal maturation and oil and gas fields distribution (modified from Kozlowki, 2011).

Figures 12, 13 and 14 display Vaca Muerta Formation in subsurface in different positions within the basin: northeastern platform, eastern area and Huincul's High showing strong variations in facies that impact over electric logs as well as over TOC lab measurements and estimated through logs (Passey et al, 1990; Stinco, 2003).

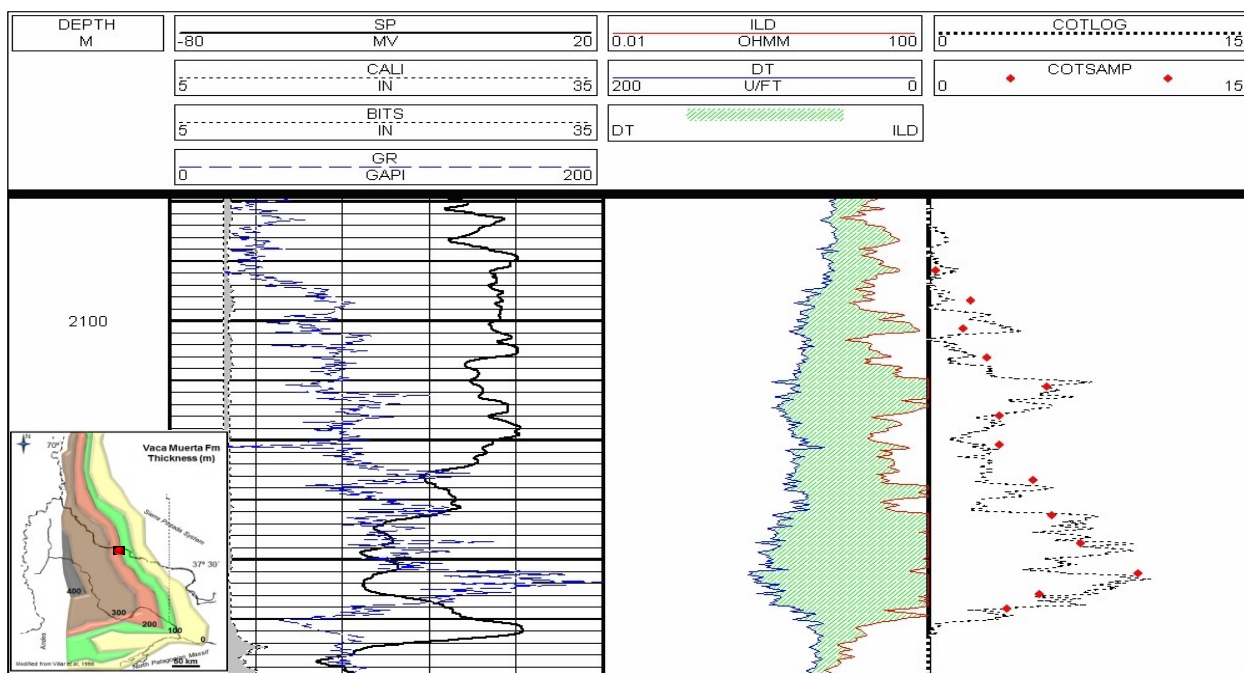


Figure 12: electric logs: SP: Spontaneous Potential, mV; CALI: caliper, inches; BITS: bit size, inches; GR: Gamma Ray, GRAP; ILD: Deep Induction, Ohmm; DT: compressional transit time, microseg/ft; COTSAMP: TOC lab measurements; COTLOG: TOC estimated from logs in the northeastern platform (Stinco, 2003)

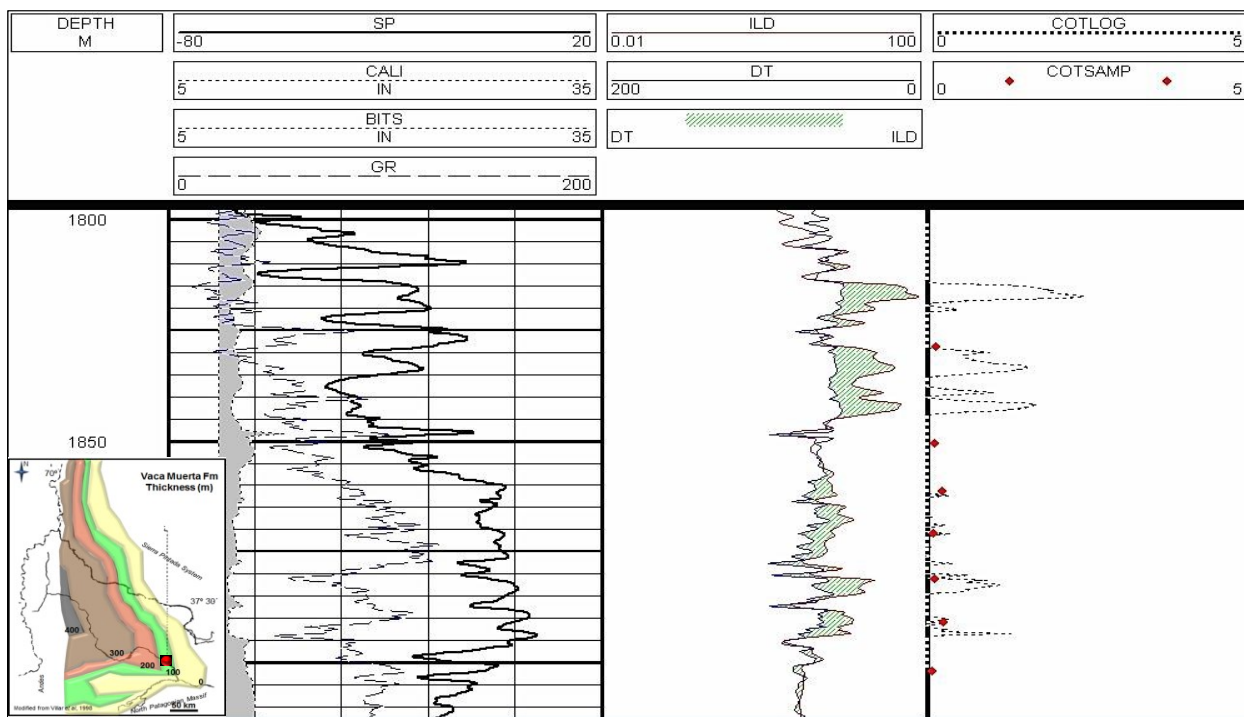


Figure 13: electric logs, TOC lab measurements and estimated from logs in the eastern area (Stinco, 2003), see figure 12 for references on tracks

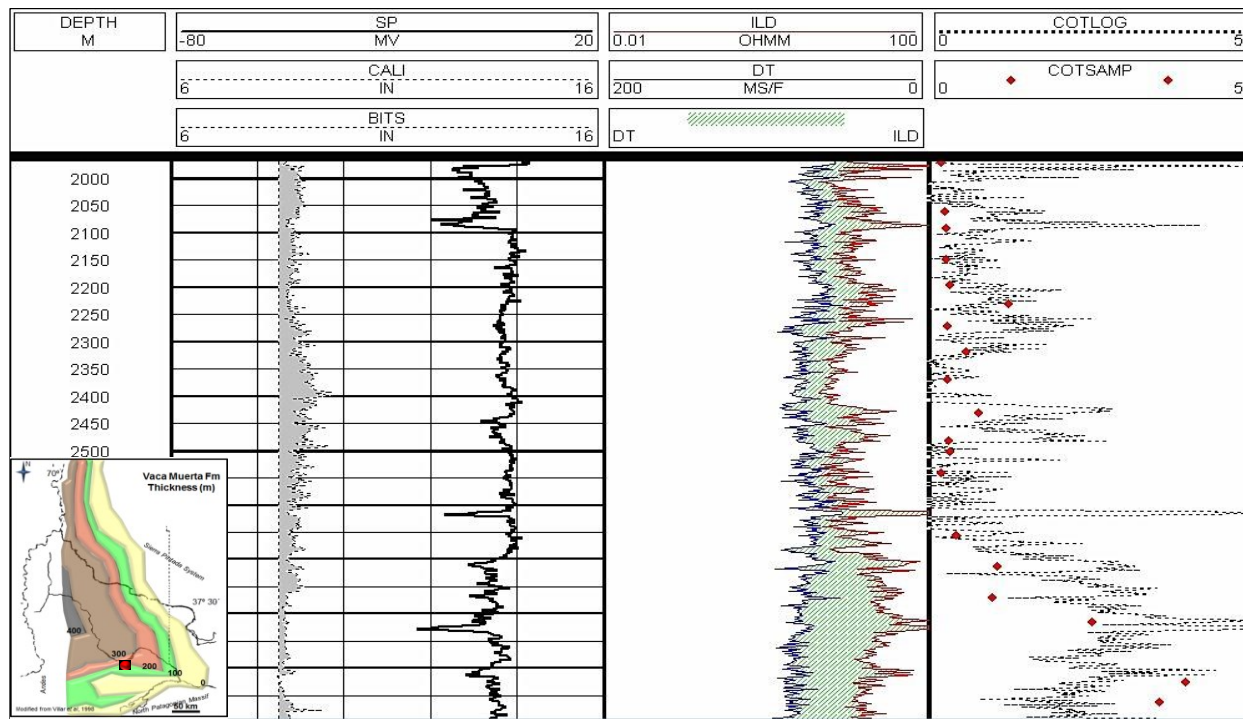


Figure 14: electric logs, TOC lab measurements and estimated from logs in the Huincul's High (Stinco, 2003), see figure 12 for references on tracks

As it was described by different authors through studies in outcrops and from subsurface data (Spalletti et al., 2000; Scasso et al., 2002; Leanza et al., 2003; Stinco, 2003; Legarreta et al., 2005; Volkheimer et al., 2008; Kietzmann et al., 2014), mineralogical changes within Vaca Muerta Formation are related to its paleogeographical position and its diagenetic evolution. TOC percentages vary from almost 15% at the base of the unit down to 2 % to the top. Quartz and clay content decrease from base to top inversely to carbonates.

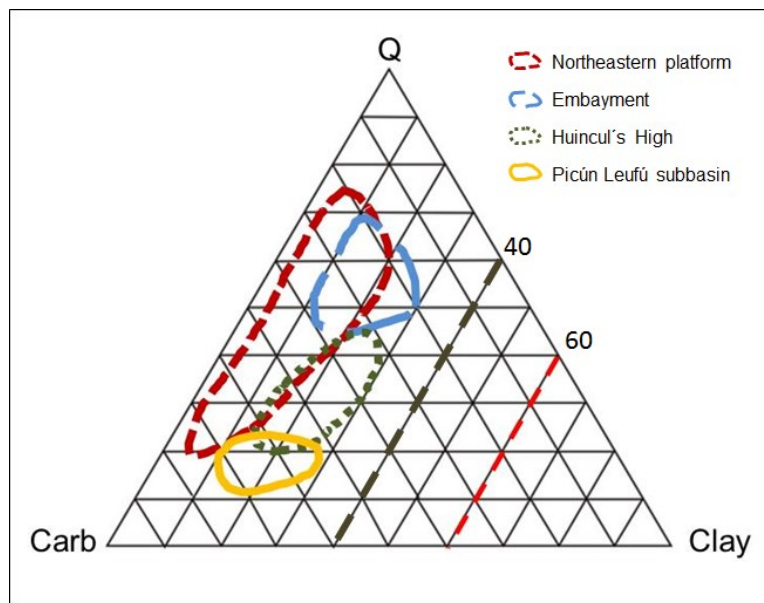


Figure 15: mineralogical distribution of Vaca Muerta Formation in different paleogeographical areas (modified from Askenazi et al., 2013). References: Q= quartz, Carb=carbonates, Clay= clays

Legarreta and Villar (2012) have also shown variations in kerogen types (from I to II and IIS), pristanes/n-C17 to phytanes/n-C18, and steranes describing different hydrocarbon maturity which also correlates with marls predominance to the northeastern platform compare to the shales prevalence to the Picún Leufú subbasin with euxinic conditions. Figure 15 is a ternary diagram that relates main mineralogical content with its paleogeographical position within the basin: northeastern platform, embayment, Huincul's High and Picún Leufú subbasin (see figure 4 for geographical reference).

Facies variations also impact on the geomechanics of the formation resulting in widespread ranges for the Young modulus and Poisson ratio as follows: a) geographical distribution of the paleoenvironments coeval with the large depositional area; b) lithological and organic matter content changes over thickness and location; c) diverse burial history and overburden rocks within the basin (Figure 16).

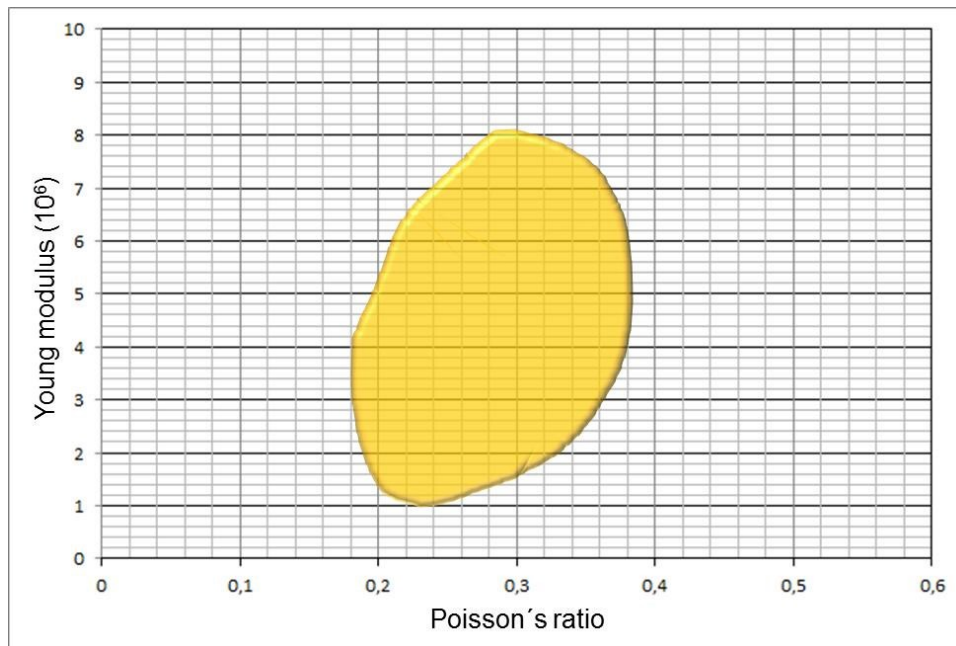


Figure 16: depicts the widespread ranges encountered for the Young modulus and Poisson ratio within Vaca Muerta Formation

As it was demonstrated, Vaca Muerta Formation shows different facies related to depositional characteristics and its position within the basin, variations related to the morphostructural setting, thickness variations and thickening to the west, TOC disparities from almost 15% at the base down to less than 2%, porosities ranging from 2% to 16%, permeabilities between 10^{-7} to 10^{-2} mD, higher concentrations of quartz and clays at the base with carbonates increasing to the top, variable intercalation of tuffaceous material that negatively affect hydraulic fracturing and a widespread variation of the mechanical properties.

At present, 180 wells are producing around 15,000 bbls/day, being mostly located within the embayment and northeastern platform, incidentally the areas with higher production rates. A very few of them are horizontal although production for these wells seems to double the vertical ones. The main concern related to this type of wells is still the lack of confident data in order to diminish uncertainty when defining the sweet spots within Vaca Muerta Formation. Heterogeneity undoubtedly drives development of the formation.

Up to now, production data demonstrates that the best section is circumscribed to the lowermost portion of the unit that coincides with the intervals with higher TOC content. Additionally, and in order to reduce costs, some operators are developing areas placing up to 4 wells at the same location and with casing drilling. Expectations are based on start production and once a base volume is achieved start to drill horizontal wells in the best areas confirmed by the vertical ones.

Conclusions

As many other unconventional shale reservoirs of the world, Vaca Muerta Formation has much more heterogeneities than were presumed just a few of years ago. An areal distribution of at least 25,000km² plus a vertical thickness that in subsurface can reach 450 m provides an enormous volume of rock that is not simple to understand, characterize

and predict. Therefore, locating optimum wells imply following not only best practices but a thorough understanding of the rock.

Studies performed in outcrops could be used to increase the geological, geophysical, petrophysical and engineer knowledge that can be extrapolated and correlated with subsurface information. Therefore, analogy with outcrops should be considered a must. Subsurface information is crucial and should be prioritized during the “learning curve phase” of exploration and development of Vaca Muerta Formation.

As it was presented in the paper, there is still room for improvement and a methodological approach should be followed in order to properly develop any asset related to Vaca Muerta Formation.

References

Askenazi, A., P. Biscayart, M. Cánova, S. Montenegro and M. Moreno, 2013. Analogía entre la Formación Vaca Muerta y Shale Gas/Oil Plays de EEUU. Primer concurso de jóvenes profesionales de la SPE Argentina.

Barredo, S., 2012. Geodynamic and Tectonostratigraphic Study of a Continental Rift: The Triassic Cuyana Basin, Argentina. In *Tectonics - Recent Advances*. Edited by Evgenii Sharkov, ISBN 978-953-51-0675-3. pp 99-130.

Barredo, S., E. Cristallini, O. Zambrano, G. Pando, and R. García, 2008. Análisis tectosedimentario del relleno de edad precuyana y cuyana inferior de la región septentrional del alto de Kauffman, Cuenca Neuquina. VII Congreso de Exploración y Desarrollo de Hidrocarburos; VI Congreso de Exploración y Desarrollo de Hidrocarburos. Actas 443-446 p.

Barredo S. and L. Stinco, 2010. Geodinámica de las cuencas sedimentarias: su importancia en la localización de sistemas petroleros en Argentina. *Petrotecnia*. Instituto Argentino del Petróleo y del Gas (2): 48-68. Argentina.

Barredo, S. and L. Stinco, 2013. A Geodynamic View of Oil and Gas Resources Associated to the Unconventional Shale Reservoirs of Argentina. Unconventional Resources Technology Conference (URTeC). ID: 1593090.

Carozzi, A., I. Orchuela and M. Rodriguez Schelotto, 1993. Depositional models of the Lower Cretaceous Quintuco–Loma Montosa Formation, Neuquén Basin, Argentina. *Journal of Petroleum Geology* 16, 421–450.

Fernández Seveso, F, G. Laffitte and D. Figueroa, 1996. Nuevos plays jurásicos en el engolfamiento neuquino, Argentina. XIII Congreso Geológico Argentino y III Congreso de Exploración de Hidrocarburos. Actas I: 281 p.

Gulisano, C. and A. Gutiérrez Pleimling, 1994. Field trip guidebook, Neuquina Basin, Neuquén Province. IV International Congress on Jurassic Stratigraphy and Geology.

Gulisano, C., A. Gutiérrez Pleimling and R. Digregorio, 1984. Análisis estratigráfico del intervalo Tithoniano-Valanginiano (Formaciones Vaca Muerta, Quintuco y Mulichinco) en el suroeste de la provincia de Neuquén. 9 Congreso Geológico Argentino, Actas, 1, pp. 221–235.

Howell, J., E. Schwarz, L. Spalletti and G. Veiga, 2005. The Neuquén basin: and overview. Veiga, G., Spalletti, L., Howell, J. and Schwarz, E. (eds) 2005. *The Neuquén Basin, Argentina: A Case Study in Sequence Stratigraphy and Basin Dynamics*. Geological Society, London, Special Publications, 252, 1–14.

Kietzmann, D. and V. Vennari, 2013. Sedimentología y estratigrafía de la Formación Vaca Muerta (Tithoniano-Berriasiano) en el área del cerro Domuyo, norte de Neuquén, Argentina. *Andean Geology* 40, 41–65.

Kietzmann, D., R. Palma, A. Riccardi, J. Martín-Chivelet and J. López-Gómez, 2014. Sedimentology and sequence stratigraphy of a Tithonian–Valanginian carbonate ramp (Vaca Muerta Formation): A misunderstood exceptional source rock in the Southern Mendoza area of the Neuquén Basin, Argentina. *Sedimentary Geology* 302: 64-86.

Kozlowski, E, 2011. Jornada del SPE: “Estimación de Recursos de Petróleo y Gas en la República Argentina”. ¿Qué se conoce, qué se puede inferir, qué perspectivas se visualizan en los recursos convencionales y no convencionales en las 5 cuencas más exploradas? SPE Argentina, Buenos Aires.

Leanza, H.A., 1973. Estudio sobre los cambios faciales de los estratos limítrofes Jurásico–Cretácicos entre Loncopué y Picun Leufú, Provincia del Neuquén, República Argentina. *Revista de la Asociación Geológica Argentina* 28, 97–132.

Leanza, H., 2009. Las principales discordancias del Mesozoico de la Cuenca Neuquina según observaciones de superficie. *Revista del Museo Argentino de Ciencias Naturales, N.S.*, 11: 145-184.

Leanza, H., 2012. The Vaca Muerta Formation (Late Jurassic—Early Cretaceous): History, Stratigraphic Context and Events of this Emblematic Unit of the Neuquén Basin, Argentina. *AAPG Search and Discovery Article #90165*.

Leanza, H. and C. Hugo, 1997. Hoja Geológica 3969-III, Picún Leufú, Provincias del Neuquén y Río Negro, República Argentina. – *Boletín del Instituto de Geología y Recursos Minerales, Servicio Geológico Minero Argentino*, 218: 1-89.

Leanza, H., H. Marchese and J. Riggi, 1977. Estratigrafía del Grupo Mendoza con especial referencia a la Formación Vaca Muerta entre los Paralelos 35° y 40° l.s. Cuenca Neuquina-Mendocina. *Revista de la Asociación Geológica Argentina* 32, 190–208.

Leanza, H., C. Hugo, D. Repol and M. Salvarredy Aranguren, 2003. El Miembro Huncal (Berriasiano inferior): un episodio turbidítico en la Formación Vaca Muerta, Cuenca Neuquina, Argentina. *Revista de la Asociación Geológica Argentina* 58 (2): 248-254.

Leanza, H., F. Sattler, R. Martinez, O. Carbone, 2011. La Formación Vaca Muerta y equivalentes (Jurásico Tardío–Cretácico Temprano) en la Cuenca Neuquina. In: Leanza, H., Arregui, C., Carbone, O., Daniela, J., Vallés, J.M. (Eds.), *Geología y Recursos Naturales de la Provincia del Neuquén, Neuquén*, pp. 113–129.

Legarreta, L. and C. Gulisano, 1989. Análisis estratigráfico de la Cuenca Neuquina (Triásico Superior-Terciario Inferior). In *Cuencas Sedimentarias Argentinas. Simposio Cuencas Sedimentarias Argentinas* (Chebli, G.; Spalletti, L.; eds). Universidad de Tucumán, Serie Correlación Geológica 6: 221-243. Tucumán.

Legarreta, L. and H. Villar, 2011. Geological and Geochemical Keys of the Potential Shale Resources, Argentina Basins. *Search and Discovery Article #80196* (2011).

Legarreta, L. and H. Villar, 2012. Las facies generadoras de hidrocarburos de la Cuenca Neuquina. *Petrotecnia*, agosto, 14-39.

Legarreta, L., H. Villar, G. Laffitte, C. Cruz and G. Vergani, 2005. Cuenca Neuquina: balance de masa enfocado a la evaluación del potencial exploratorio de los distritos productivos y de las zonas no productivas. VI Congreso de Exploración y Desarrollo de Hidrocarburos. Instituto Argentino del Petróleo y del Gas.

Llambías, E.J., H. Leanza, and O. Carbone, 2007. Evolución tectono-magmática durante el Pérmico al Jurásico temprano en la cordillera del viento (37°05'S – 37°15'S): Nuevas evidencias geológicas y geoquímicas del inicio de la Cuenca Neuquina. *Revista de la Asociación Geológica Argentina* 62 (2): 217-235 p.

Mitchum, R. and M. Uliana, 1985. Seismic stratigraphy of carbonate depositional sequences, Upper Jurassic- Lower Cretaceous, Neuquén Basin, Argentina. In *Seismic Stratigraphy 2. An integrated approach to hydrocarbon analysis* (Berg, B.R.; Woolverton, D.G.; editors). American Association of Petroleum Geologists, Memoir 39: 255-83. Tulsa.

Parent, H., A. Garrido, G. Schweigert and A. Sherzinger, 2013. The Tithonian stratigraphy and ammonite fauna of the transect Portada Covunco-Cerrito Caracoles (Neuquén Basin, Argentina). *N. Jb. Geol. Paläont. Abh.* 269/1 (2013), 1–50 Article. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart.

Passey, Q., Creaney, S., Kulla, J., Moretti, F. and Stroud, J., 1990. A practical model for organic richness from porosity and resistivity logs. *American Association of Petroleum Geologists Bulletin*, 74: 1777-1794.

Ramos, V.A., 1988. Tectonic of the Late Proterozoic – Early Paleozoic: a collisional history of Southern South America, *Episodes* 11(3): 168-174 p.

Scasso, R., S. Alonso, S. Lanés, H. Villar, H. Lippai, 2002. Petrología y geoquímica de una ritmita margal caliza del Hemisferio Austral: El Miembro Los Catutos (Formación Vaca Muerta), Tithoniano medio de la Cuenca Neuquina. *Revista de la Asociación Geológica Argentina* 57: 143-159.

Spalletti, L., J. Franzese, S., Matheos, and E. Schwarz, 2000. Sequence stratigraphy of a tidally dominated carbonate siliciclastic ramp; the Tithonian-Early Berriasian of the Southern Neuquén Basin, Argentina. *Journal of the Geological Society* 157: 433-446.

Stinco, L. and A. Mosquera, 2003. Estimación del contenido total de carbono orgánico a partir de registros de pozo para las formaciones Vaca Muerta y Los Molles, Cuenca Neuquina, Argentina. II Congreso de Hidrocarburos, IAPG, Buenos Aires, Argentina.

Weaver, C. 1931. Paleontology of the Jurassic and Cretaceous of West Central Argentina. University of Washington, Memoir 1: 594 p. Seattle.

Volkheimer, W., O. Rauhut, M. Quattrocchio, M. Martinez, 2008. Jurassic paleoclimates in Argentina, a review. *Revista de la Asociación Geológica Argentina* 63, 549–556.