PHENOMENOLOGICAL MODELLING OF BASIN CENTRED GAS ACCUMULATION

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RESUMEN

Modelado Fenomenológico de una Acumulación de Gas de Centro de Cuenca
Las formaciones Lajas y Punta Rosada son 2 reservorios no convencionales depositados en un ambiente marino poco profundo durante la fase de ante arco de la Cuenca Neuquina. En estas formaciones, se ubican acumulaciones significativas de hidrocarburos que se encuentran extensivamente desarrolladas en los bloques de Lindero Atravesado o Rio Neuquén por ejemplo.
El *play* Lajas reúne todas las características de un Gas de Centro de Cuenca (Basin Centred Gas o BCG):
- Un régimen anormal de presión (una sobrepresión importante con un gradiente equivalente de 0.7psi/ft registrado en el bloque de Aguada San Roque);
- El contacto directo con la roca madre (Fm. Los Molles en este caso);
- Ausencia de sello o contacto con agua.

En el bloque Aguada San Roque, las arenas profundas de la formación Lajas fueron ensayadas en 2 pozos:
- Well-A tuvo una producción promedio de 80 Sm^3/d de gas, el primer mes de producción con poca producción de agua (Water Gas Ratio, WGR, de 0.03 m^3 de agua por 1000 m^3 de gas).
- Well-B, ensayado durante varias semanas antes ser abandonado debido a la alta producción de agua (WGR cerca de 0.5m^3/km^3).

El contraste en producción de agua entre los 2 pozos fue, al principio, interpretado como resultante de una comunicación con el filón volcánico intruído en la Fm. Lajas, comprobado con agua. No obstante, la comparación con análogos locales y de EE.UU. confirma la alta variabilidad de WGR encontrada en los sistemas BCG (factor 1 a 10 común en el mismo reservorio). La literatura discute ampliamente la importancia de buscar y encontrar "*sweet-spots*" en este entorno de BCG pero no provee resultados que justifiquen la formación de los mismos ni herramientas permitiendo su ubicación.
Con el objetivo de entender mejor los mecanismos que gobiernan las acumulaciones en estos sistemas particulares, se sugiere un modelo fenomenológico representando la migración de hidrocarburos y su acumulación en un corte de la cuenca Neuquina pasando por el bloque de Aguada San Roque. La formación Lajas se encuentra saturada con agua al inicio y se va cargando progresivamente desde la capa inferior sobre-presurizada que representa la roca madre de los Molles. El modelo se corrió sobre tiempos geológicos (ajustando la permeabilidad) y se ajustó según puntos de calibración en saturación y en presión. El análisis de la distribución de gas al tiempo corriente es consistente tanto con la presencia de agua móvil en niveles Lajas y punta Rosada como con contraste observado de WGR entre Well-A y Well-B. Además, esta herramienta puede ser usada para la ubicación de *sweet-spots*. De hecho, la modelización de heterogeneidades tanto estructurales como petrofísicas al nivel de un bloque permite la identificación de caminos preferenciales de migración y de acumulaciones.

INTRODUCTION

The Bajocian-Bathonian Lajas Fm. was deposited during the back-arc phase of Neuquén basin development and had a widespread development sub-parallel to the magmatic arc. The thickness ranges from a few tens of meters on the eastern sector to more than 800 m in the centre of the basin. Lajas Fm. is made of shallow marine deltaic deposits that prograde from SE to NW overlying and inter-fingering with deep marine and slope deposits of Los Molles Fm. (that constitutes the source rock of the system). The Lajas Fm. is overlain by the fluvial deposits of Punta Rosada Fm.

According to the Argentine Secretaria De Energía data base ("Capitulo IV"), the cumulated gas production as of December 2016 for the entire Neuquén basin was 29Gm^3 for the Lajas Fm. (509 active wells) and 5Gm^3 for the Pta.Rosada Fm. (35 active wells).

As illustrated in Figure 1, the main fields that are currently producing the Lajas and Pta. Rosada Fms are located in the southern part of Neuquén basin on the northern structural trend of the Dorsal of Huincul where the Jurassic and post Jurassic deformation have uplifted the sedimentary column. These fields (Centenario, Cupen Mahuida, Estacion Fernandez Oro) have normal pressure regimes. Two other fields (Lindero Atravesado and Rio Neuquén) located basinward have the Lajas and Pta. Rosada reservoirs in a deeper position and with an over-pressured regime.

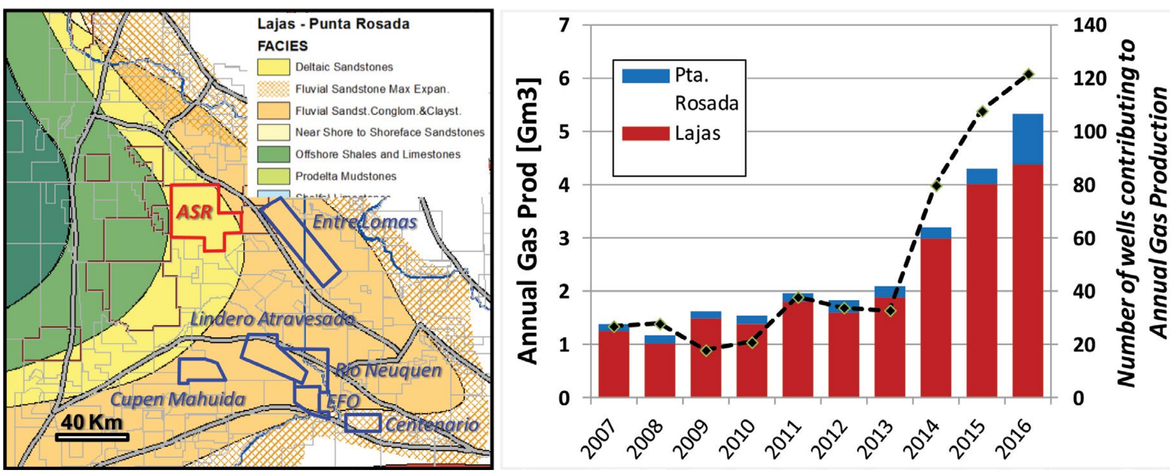

Figure 1. Lajas & Pta.Rosada producing fields and cumulated Gas Production [Gm3] @ Dec 2016

Figure 1 illustrates the annual gas production of Lajas and Pta Rosada formations for the entire Neuquén Basin. One can observe the increase in drilling activity since 2013 and the corresponding increase of gas production (from 2Gm^3 in 2013 to 5Gm^3 in 2016). This growth in drilling activity shows the increasing interest in non-conventional tight reservoirs such as Lajas Fm.

LAJAS PLAY CHARACTERIZATION

The Lajas Fm. is part of the Cuyo Group which is divided into three formations arranged vertically in a coarsening-upward succession, as shown on the stratigraphic chart of Figure 2:

- The Los Molles Fm. was deposited during the first phase of marine transgression, immediately after the rifting. It corresponds to moderate to deep marine black shales and constitute the source rock of the system (Type II/III). It has a low to medium source rock potential and reached the gas generation window in the deepest part of the Neuquén Basin (see Figure 3). Gas generation took place 140 to 40 million years ago and essentially exhausted Los Molles potential.
- The Lajas Fm. was deposited during a phase of reduced basin subsidence and is made of a succession of deltaic progradation oriented SE-NW that constitutes a thick sedimentary column – about 850 m in the Aguada San Roque area. The Lajas Fm. is characterized by delta front to internal delta facies (siltstones to sandstones, principally tide dominated). The reservoir burial is about 3500m in the San Roque block, where average porosities are around 3-4% and permeabilities at lab conditions are generally below 0.1mD.
- The Punta Rosada Fm.: corresponding to continental lateral equivalent of Lajas deltaic deposits (continental claystones locally intersected by continental channels).

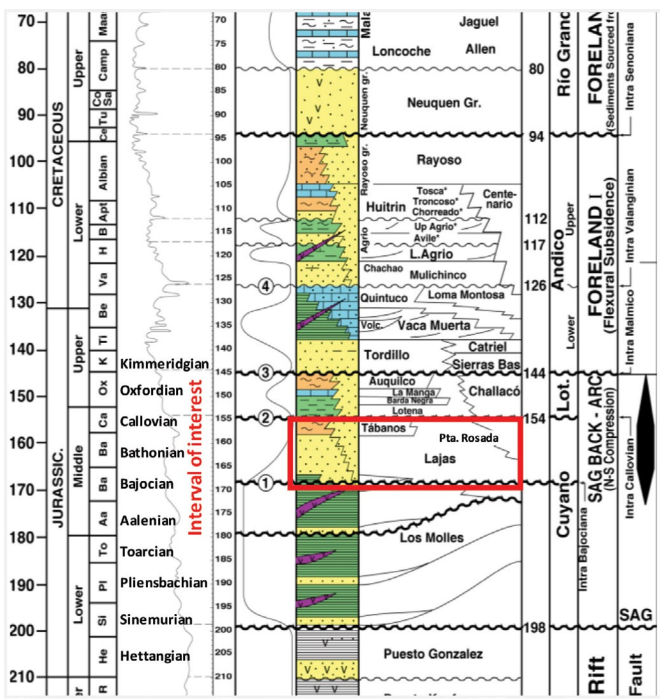

Figure 2. Neuquén Basin Stratigraphic Chart

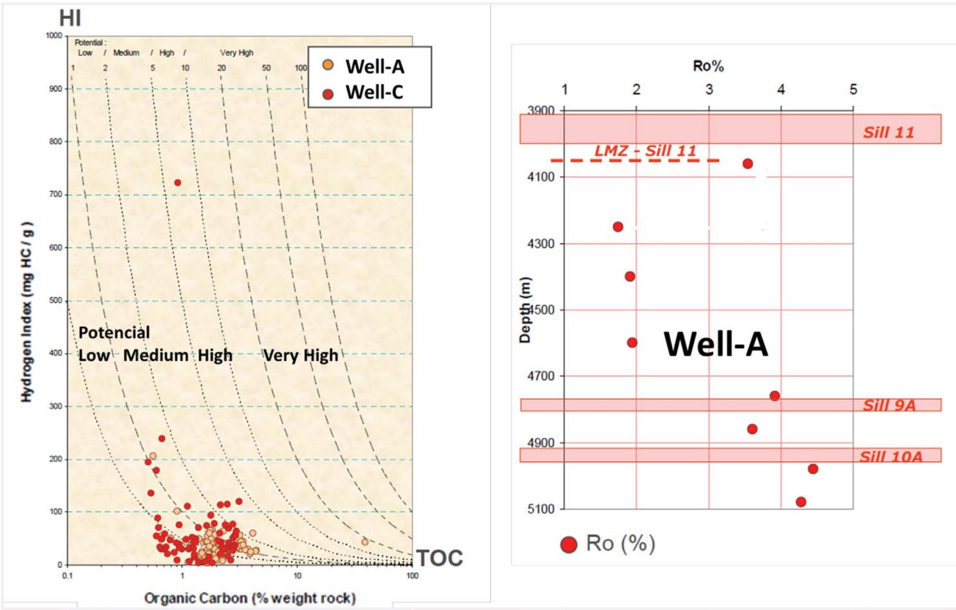

Figure 3. Left: Los Molles source rock potential; Right: Los Molles maturity (Ro%)

Even in the absence of a conventional seal, due to the close proximity to Los Molles, Lajas sands are found to be gas saturated throughout the Neuquén basin in a pervasive gas accumulation. While the Lajas Fm. was charged with gas at high pressures, initial formation water was progressively expulsed. Present day pressure acquisitions show that the whole Pta. Rosada-Lajas-Molles system is still over-pressured in the deepest part of the basin, as shown in Figure 4. The tight nature of those sands did not allow the system to relax to equilibrium. As a whole, Lajas gathers all the characteristics of Basin Centred Gas accumulation, written BCG, in over-pressure regime.

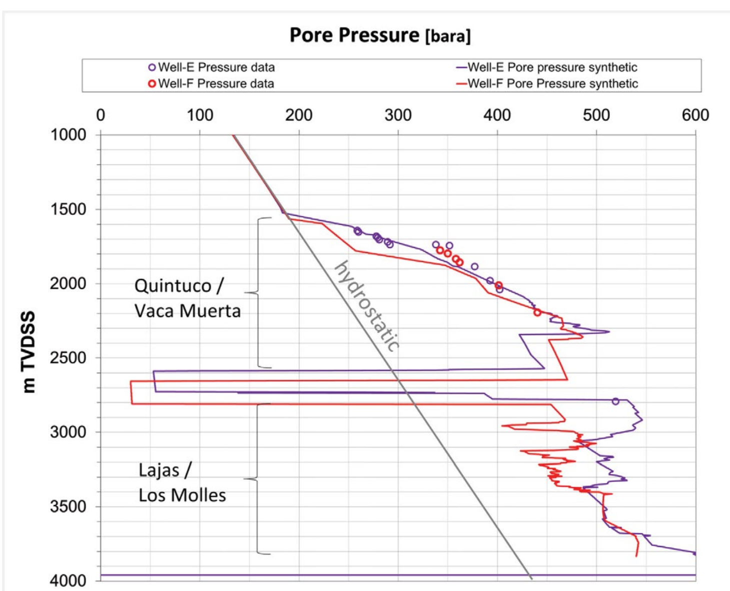

Figure 4. Lajas/Los Molles over-pressure on Aguada San Roque wells

LAJAS DEVELOPMENT IN THE AGUADA SAN ROQUE BLOCK

The San Roque block is located in the central and eastern part of the Neuquén basin. It is operated by Total Austral (24.71%) with YPF (34.11%), Wintershall (24.71%) and Pan American Energy (16.47%) as partners.

The historical development of the block is based on the production from highly different thematics: Aguada San Roque clastics sands (conventional gas accumulations within the Lower Cretaceous Centenario/Mulichinco), volcanic sills intruded within the Quintuco-Vaca Muerta interval (Sill Loma Las Yeguas, Aguada San Roque Filón 3C) or in the Lajas-Molles interval (F9 sill in of Rincon Chico) to Vaca Muerta shale oil development.

To date, a total of 126 wells were drilled within the San Roque block since 1969, under the operatorship of YPF and from 1994 by Total Austral S.A. Of those wells, 6 wells reached the Lajas Fm: Well-A and Well-B, located in the centre part of the block ; Well-D drilled by YPF in in 1980 that reached TD just after crossing the top of the Lajas Fm, Well-E, Well-C and Well-F, all located in the eastern part of the block.

From the 6 wells crossing the Lajas interval, only two were completed in this formation and have dynamic information:

- Well-A was drilled in 2010 with volcanic sills 11 and 10 as primary targets. Due to the negative testing of these sills, 2 intervals were perforated and fractured within Lajas tight sands. 3 years of production data (over 30MSm^3 of gas produced), a long term test including 2 build-ups periods and 2 PLT (Production Logging Test) surveys are available for this well.
- Well-B was drilled in 2014 and targeted the Lajas and Sill 11. Sill 11 was tested with water and abandoned. 3 fracture jobs were performed in Lajas between 2014 and 2016, each one followed by PLT surveys. Well-B cumulated about 2MSm^3 and was finally not connected.

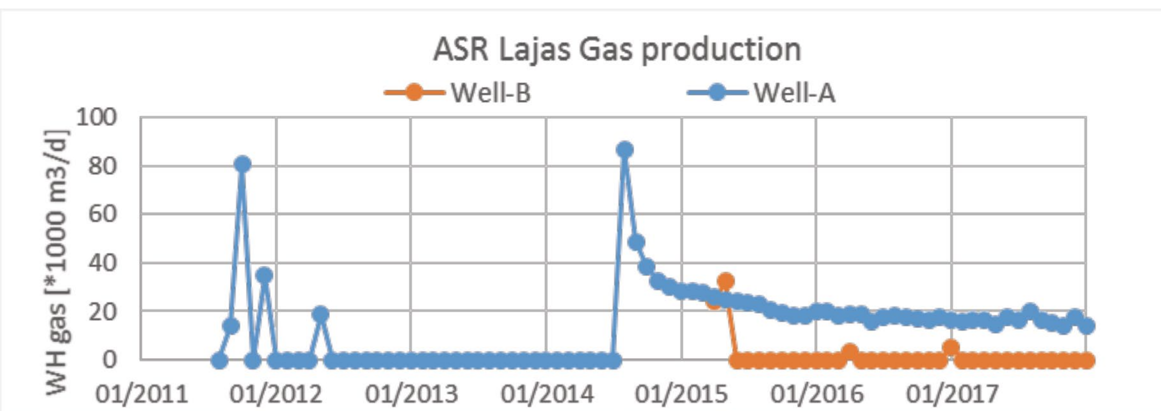

Figure 5. Well-A and Well-B monthly gas production

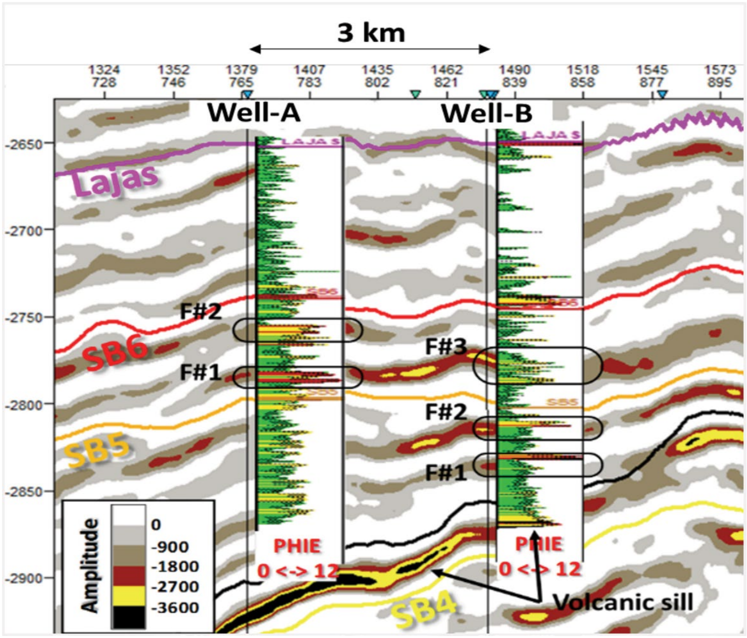

Figure 6. Seismic amplitudes vs porosity log for Well-A and Well-B

Well-A was fracked in the SB6 sequence targeting the best quality sand intervals (fracs F#1 and F#2) of mouth-bar deposits that may be interpreted on seismic amplitude as shown in Figure 6. Interpretation of the PLT surveys showed that the well was essentially producing from F#1 with little to no contribution form the uppermost interval.

Applying the same idea on Well-B, 3 intervals were fracked F#1, F#2 and F#3. The well was tested in 2015 and showed a gas potential comparable to Well-A, though water production was much higher, as shown in Figure 7. Due to operational complications, fracture #1 was abandoned. The well was tested again in 2017 and showed highly degraded gas productivity with a similar level of water gas ratio. PLT runs carried out in 2015 and 2017 both showed a contribution from F#2 exceeding 75% of total well production.

LAJAS, AN “INEFFICIENT”[1] BCG SYSTEM

The observed contrast in water production between Well-A and Well-B, at about 3km distance, raised questions on water provenance. Well-A’s low WGR (Water Gas Ratio) would be due to Lajas water saturations being close to residual (connate water). On the contrary, Well-B test results tend to show a substantial amount of mobile water.

Because Well-B was fracked within 50 m of water saturated volcanic sill 11, water was initially attributed to communication with the sill through fractures (natural fractures as well as hydraulic

[1] “Inefficient” BCG system would refer to a pervasive gas accumulation that did not totally expulsed initial water due to insufficient hydrocarbon generation, uneven gas sweeping or late water re-imbibition. Mobile water would exist within the abnormally pressured zone.

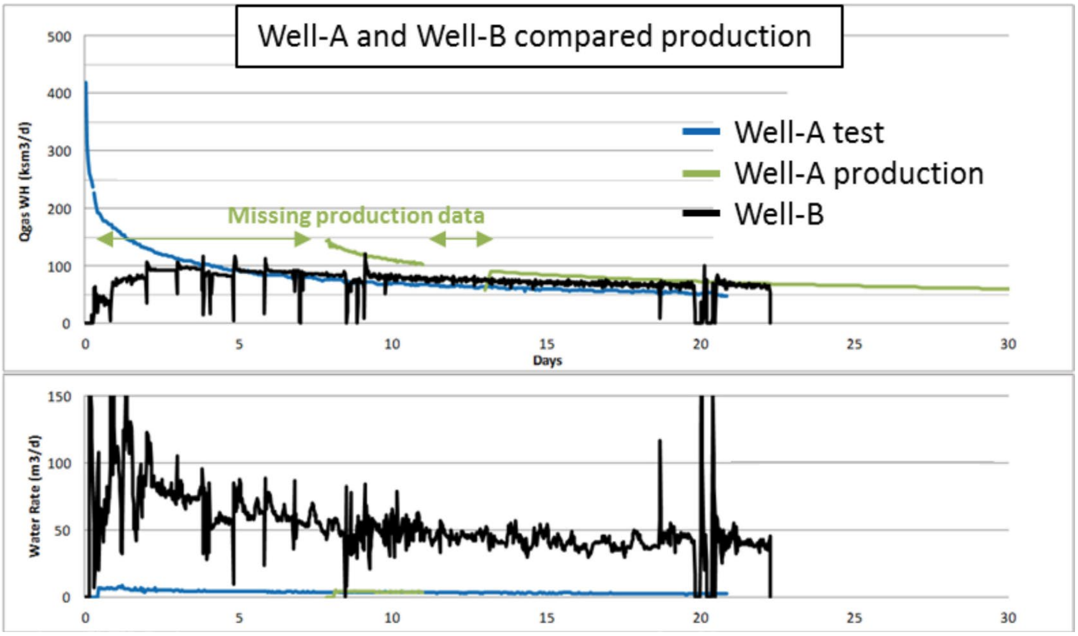

Figure 7. Well-A and Well-B initial tests and early production profiles

fracs). Tracing water chemicals or salinity did not help in discriminating water provenance. However, the 2017 test and PLT survey demonstrate that clear isolation of the fracture F#1 interval did not reduce well GWR and that water was produced from the uppermost fractured interval F#3. For this reason, it was concluded that water production was due to mobile water within Lajas sands.

In order to assess water production variability within Lajas and compare it to local analogues and other BCG analogues, tested water rates are plotted against gas rates - see Figure 8 and Figure 9. Tested rates for Well-A and Well-B were superposed to observed rates for analogues' wells (from

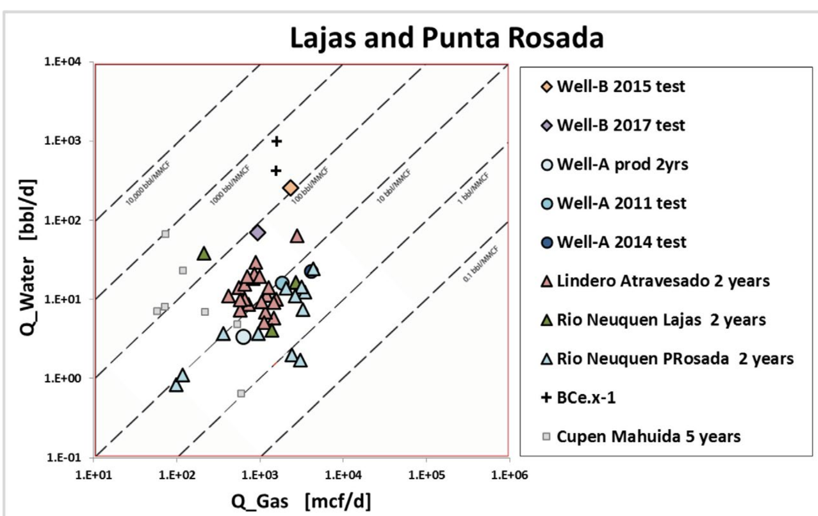

Figure 8. WGR comparison with local Lajas and Punta Rosada analogues

Secretaria de Energía – Capitulo IV). Each point corresponds to average production over 3 month periods for one well – except for Well-A, Well-B and BCe.x-1 tests data.

- Comparison to local analogues includes data from Lindero Atravesado, Rio Neuquén fields (over-pressured, as per Lamberghini *et al* 2017) and Bandurria Centro -, as well as the Cupen Mahuida reservoir - extensively fractured and normally pressured. Data is plotted for each well 2 years after Start-Up (SU) and 5 years after SU when data is available.
- Comparison to US analogues (see Figure 9) is performed with 2 over-pressured fields of the Greater Green River Basin, Jonah Field and Pinedale anticline as well as Wind River Basin developments, both conventional and tight over-pressured reservoirs.

Given that diagonal dashed lines on those graphs represent iso-WGR one may observe:

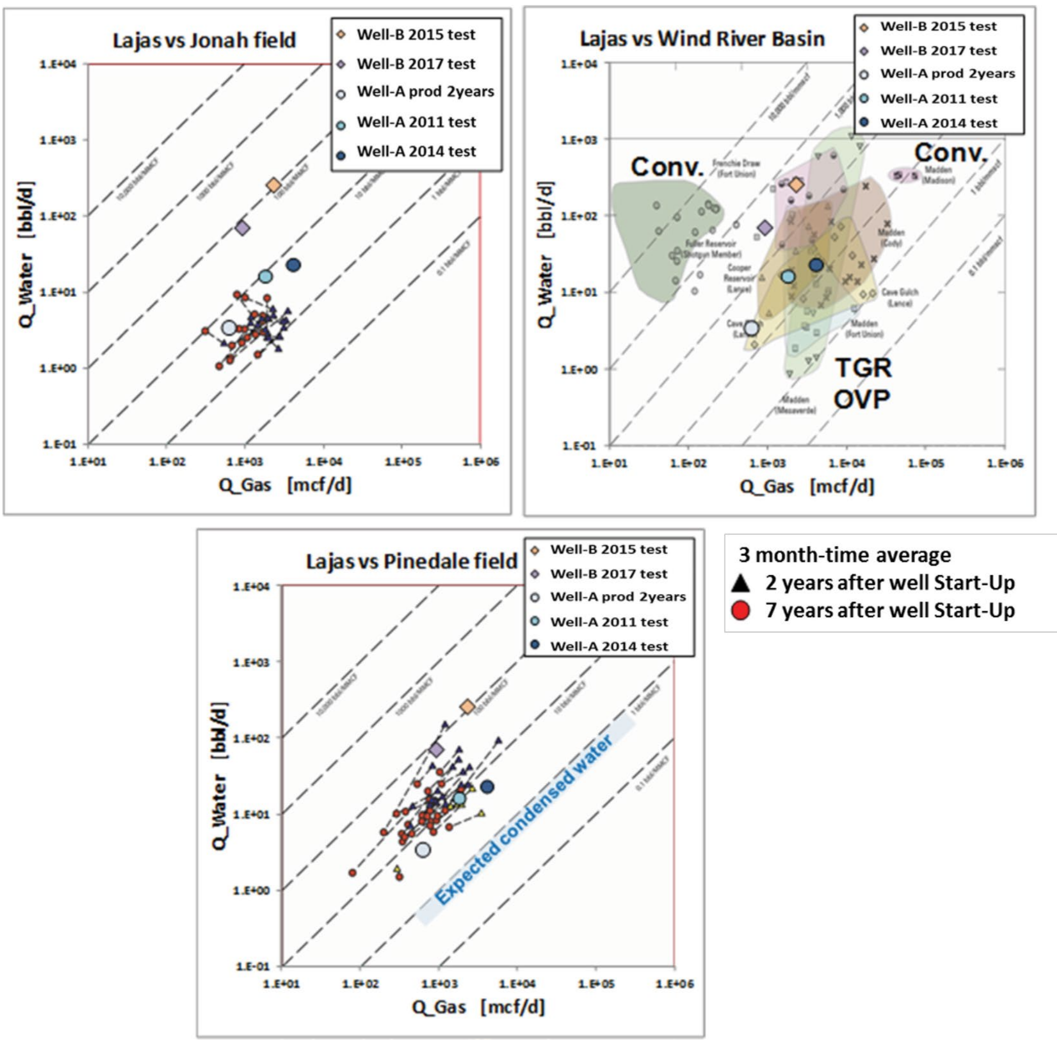

Figure 9. WGR comparision between ASR Lajas wells and US BCG analogues (modified from Nelson *et al* 2009)

- The variability of WGR levels between fields ranges from 1bbl/Mscf (0.006m^3/km^3), up to 100bbl/Mscf (0.6m^3/km^3). In any case, water production is generally above the WGR expected from condensation water (about 1 bbl/Mscf).
- The variability of WGR between wells within a field is typically of 1 to 10 (up to 1 to 50). This corresponds to the observed scatter between Well-A and Well-B.
- For the presented analogues, no noticeable variation of WGR distribution at 2 years after Start-Up and at 7 years after SU. For this reason, we may conclude that completion fluids are back-produced in a shorter term.
- If Well-A sits in intermediate to low levels of WGR, Well-B lies on the high side of the distributions of WGR in BCG fields (after only few weeks of production after flow-back). One should note that the documented wells have a minimum of 2 years of production and therefore represent the economically producible wells (outlying wells with high water production were probably not connected).

The Jonah field and Pinedale anticline are examples of economic developments within an "inefficient" Basin Centred Gas accumulation. Indeed, both developments rely on conventional traps (an anticline for Pinedale and a sealing wedge in the case of Jonah) that constitute sweet-spots within a well-known pervasive gas accumulation.

The analogy with Lajas implies that Lindero Atravesado wells, Río Neuquén wells and Well-A would sit in a sweet-spot zone of Lajas accumulation – with WGR comparable to Jonah and Pinedale wells, while Well-B demonstrates the "inefficient" nature of the BCG system that did not allow full expulsion of mobile water. If Lindero Atravesado and Río Neuquén actually sit on the same four-way-dip structure that may be considered as a conventional trap, Well-A does not clearly appear to benefit from such a trap.

BASIN SECTION PHENOMENOLOGICAL MODELLING

To get a proper understanding of the mechanisms driving gas accumulation in this particular BGC system, a phenomenological dynamic model was created to represent gas migration and accumulation in the basin.

2D Model description

The 2D dynamic model represents a slice of the Neuquén basin passing through the ASR block. Modelled heterogeneities are:

- 3 zones of different petrophysical characteristics: Lotena, Lajas/Pta Rosada and Massive Lajas.
- The permeability varies with both porosity (from K-Phi Law derived from Well-C Lajas

plug measurements at lab conditions) and with burial (permeability at lab conditions are multiplied by a factor 0.1 to account for confined stress to 10 going up to surface). The kv/kh was arbitrarily set to 0.01 (vertical to horizontal permeability ratio).

- 3 sets of relative permeability (referenced as kr) curves are assigned by range of permeability. Those relative permeability curves for tight reservoirs are derived from literature (Cluff *et al* 2010), see Figure 11.

	Min	Mean	Max	σ^2	Radius of circular variogram for good sand facies
Lotena	0%	3%	10%	3.5%	15km
Pta Rosada/Lajas	0%	3%	10%	1.5%	1km
Massive Lajas	3%	5%	10%	2%	1km

Figure 10. Effective porosity distribution within Lajas Phenomenological model

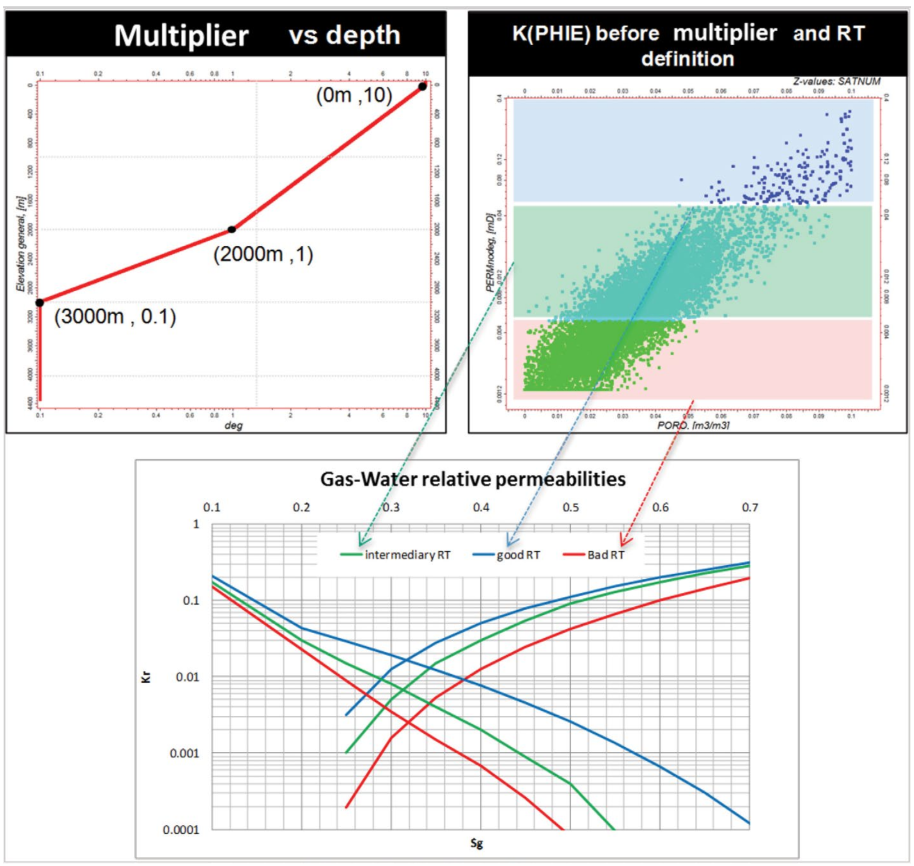

Figure 11. Phenomenological model petrophysical properties

The model was initially saturated with water and progressively loaded by the gas saturated bottom layer representing the over-pressured source rock (dummy well injecting at constant pressure). A production well is set to impose hydrostatic gradient on the shallow edge of basin.

The model is run over equivalent geological time by scaling permeabilities.

Injection is maintained during 40 Myrs as per transformation timing of the Los Molles source rock illustrated by Legarreta *et al* 2005 (gas generation from -100 Myrs to -60 Myrs). The model then relaxes for 60 Myrs.

Model Calibration

Evolution of gas saturations and pressure distribution is observed within the model. Permeability and injection pressure (theoretically corresponding to release pressure of gas from Los Molles) are adjusted in order to match current saturations and pressures in the basin after 100 Myrs of equivalent simulation time. Matching points are:

- MDT and DFIT pressure points in Lajas from and Well-A.
- Static pressure points from Pta Rosada/Lotena in updip producing fields as plotted on Figure 13. The distribution shows a scatter representing virgin pressure to depleted pressures due to production.

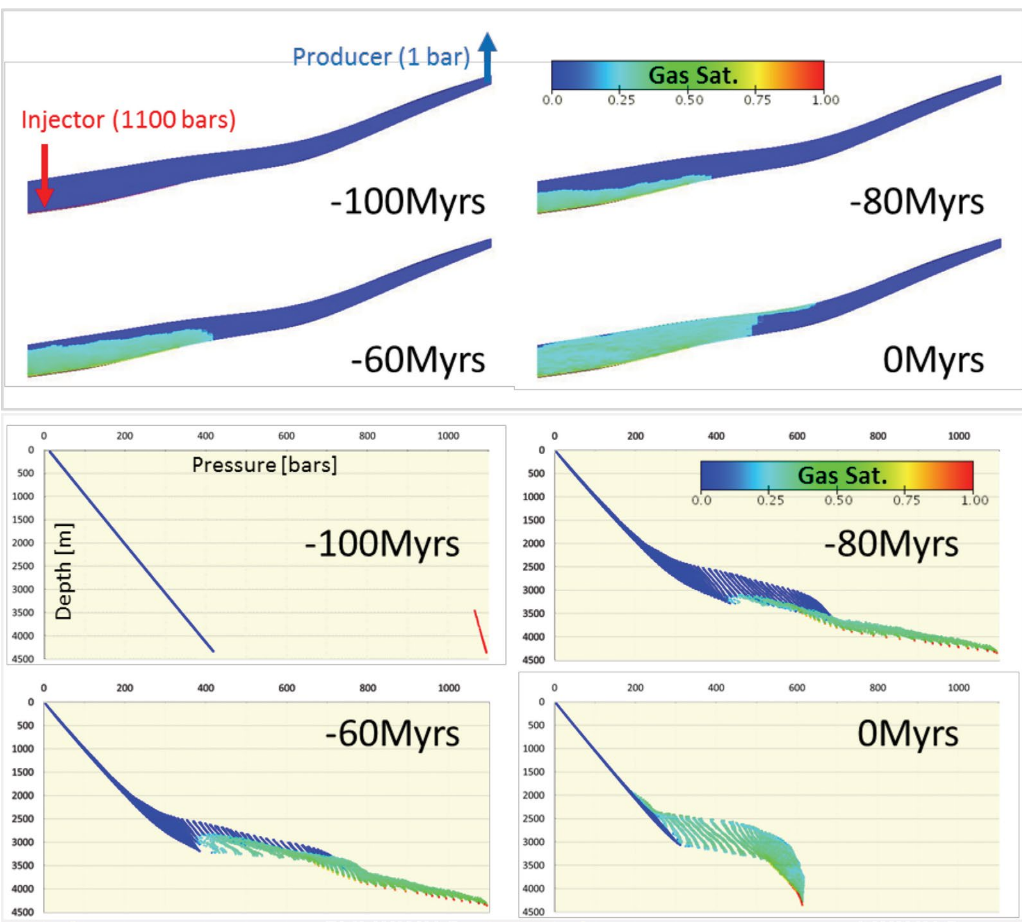

Figure 12. Top: Gas saturation grid evolution vs time, bottom: Pressure vs depth plot evolution, coloured by gas saturation

- Structures located on the margins of the Neuquén Basin such as Cupen Mahuida (Raggio *et al*, 2004) show hydrostatic regime in Lajas
- First intervals of Lotena sands in ASR wells show high water saturation.

To honour those criteria, permeability was reduced by a factor 10 while control pressure for injection was set to 1100bars.

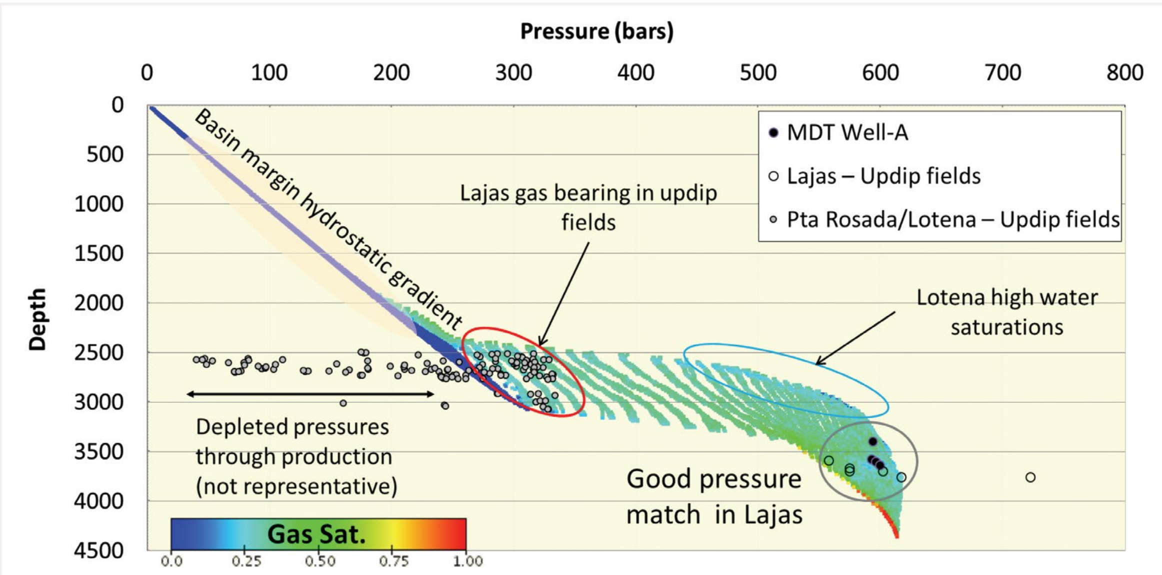

Figure 13. Model match of Pressure vs depth plot at 0Myrs (100Myrs equivalent simulation time)

Model Results

The gas saturation grid after 100Myrs equivalent simulation time was analysed to get an expected range of gas saturation at the level of Well-A and Well-B within the Aguada San Roque block. Figure 14 shows the corresponding distribution. One can observe that:

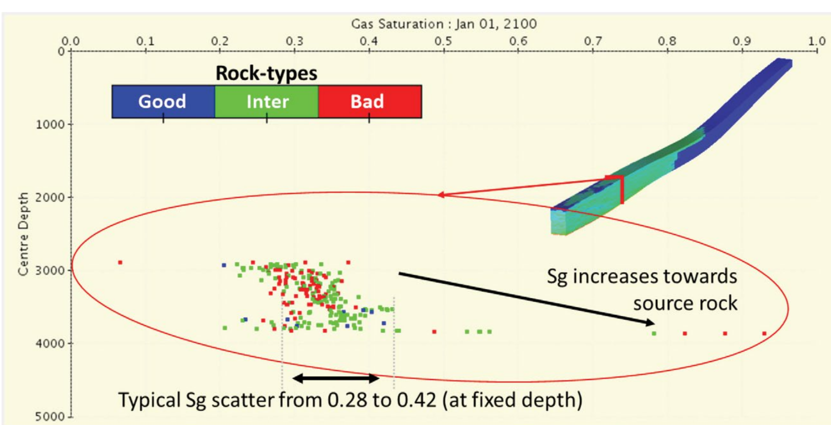

Figure 14. Simulated current gas saturation vs depth distribution at Well-A and Well-B

- Gas saturation increases towards the source rock
- The gas front saturation is about 0.30 (driven by relative permeability curves)
- Within a short depth range, gas saturation may change from 0.28 to 0.42.

Relative permeability curves were converted to fractional-flow plots versus gas saturation at surface conditions to get the expected WGR for a well completed in a cell at a given gas saturation:

$$WGR = \left(\frac{Q_g}{Q_w}\right)_{surface} = \frac{kr_g(Sg)/\mu_g}{kr_w(Sg)/\mu_w} \,.\, B_g$$

From this curves, we get the expected scatter of WGR corresponding to the observed range of Sg, from 0.28 to 0.42 at a given depth (see Figure 14). As shown in Figure 15, WGR would vary from 0.01 to 1.0m^3/km^3. This variation is explained by the shape of the kr curves for tight rocks implying a substantial change in gas fractional flow within a short range around the cross-over between krg and krw. One should note that this range is in agreement with WGRs observed in Well-B with 0.5m^3/km^3 and Well-A with 0.03m^3/km^3.

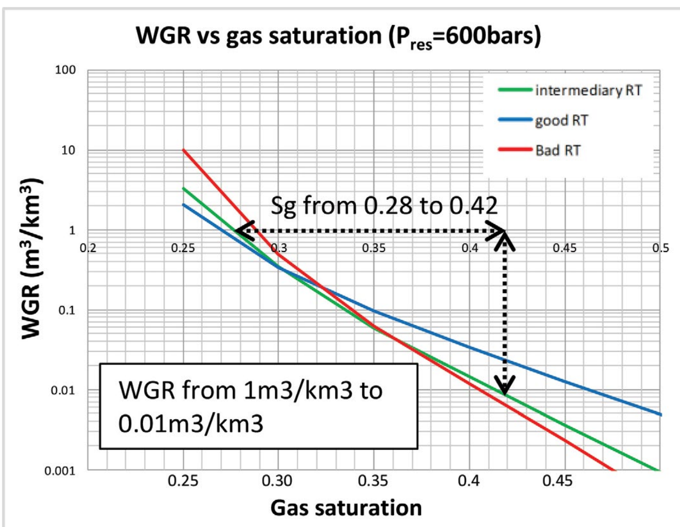

Figure 15. Surface condition WGR vs gas saturation from relative permeability curves

As a result, simple modelling of heterogeneities of permeabilities and rock types within the dynamic accumulation allows high variations of WGR to be captured and acknowledges the importance of targeting sweet-spots. As presented in Figure 16, showing a plot of permeability vs gas saturation (for the deepest half of the model - swept by gas), gas saturation does not exhibit correlation to permeability or porosity. The presence of gas saturation contrasts is attributed to distributed baffles or preferential paths for gas migration. Consequently, such a dynamic system differs from conventional accumulations where sweet-spots are generally essentially driven by local petrophysical properties.

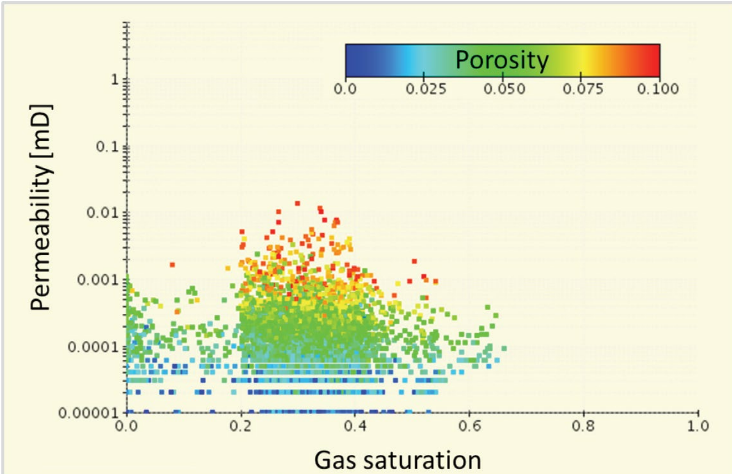

Figure 16. Gas saturations (deepest half of the model) vs permeability coloured by porosity

An identified driver for sweet-spot identification would be close proximity to the source rock, as it consistently represents a zone of higher gas saturation. However, the Los Molles-Lajas system is by nature the superposition of the Los Molles source-rock with a thick column of tight sands (Pta Rosada and Lajas) with little to no source-rock inter-bedding. Consequently, targeting the vicinity of the source rock implies drilling deeper wells and does not necessarily take advantage of the good quality mouth-bar sands of the Massive Lajas.

For an exploration as well as development point of view, being able to identify secondary structural or depositional features leading to preferentially gas saturated targets appears to be paramount.

ASR BLOCK MODELLING AND SWEET-SPOT CHARACTERIZATION

To continue with this approach, a refined 3D model for Lajas in the ASR block has been used. This model, by providing a detailed representation of geological heterogeneities, enables gas migration and accumulation at block scale to be simulated. The resulting gas distribution would allow identifying sweet-spot zones within the concession in order to propose future well targets. The following part aims at providing a simulation workflow to locate the highest potential zones within the block. It does not provide a complete assessment of existing uncertainties.

3D Model construction

The 3D grid was constructed based on a set of faults and structural depth maps provided by 3D seismic interpretation (7 horizons interpreted).The model was vertically divided into 176 layers and horizontally divided into square cells of 500 m dimension resulting in a more-than-500 thousands cells grid.

Depositional facies were populated within the grid based on the interpreted distribution of 3 depositional environments (delta plain, delta front and prodelta) within the block. This distribution relies on:

- The identification of depositional environments at wells using well logs.
- The use of the acoustic impedance cube to guide the distribution of depositional environments far away from the wells. Indeed, an in-house seismic reservoir characterization study showed that acoustic impedances were related to the Lajas Massive sandstones distribution: high acoustic impedances are generally associated to sand prone facies.

Within each depositional environment, electro-facies were derived at well scale and distributed in the model using both object modelling to distribute "distributary channels" within the delta plain environment, and Truncated Gaussian Simulation to model mouth-bars within delta front environment. Even if volcanic sills are identified in the model to allow a specific treatment, for the sake of this paper they were treated as the rest of the reservoir. A section of the resulting facies distribution is shown in Figure 17.

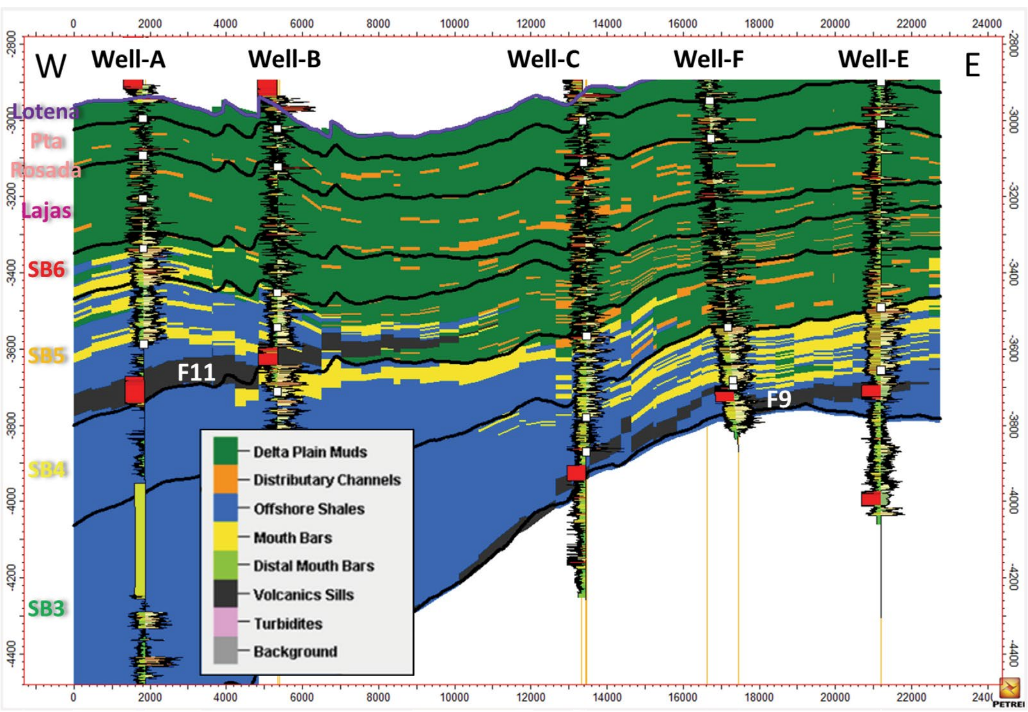

Figure 17. West-East well section showing output Facies distribution

NTG and porosity were then distributed per sequence and per facies using average statistics at wells. In addition, horizontal permeability was derived from the porosity computation using a k-Phi relationship obtained from cores (at lab conditions - without applying confining stress). The obtained permeability grid was degraded in order to account for the important tight sands permeability dependence on confining stress (Vassilellis *et al* 2004). A factor of 10 was used within the whole model. Vertical permeability was obtained by using kv/kh=0.01.

Relative permeability curves used in the basin section (Figure 11) were attributed by facies as follows:

Facies	Rock type
Delta plain muds	Bad
Distributary channels	Intermediate
Offshore shales	Intermediate
Mouth bars	Good

Figure 18. Rock-type definition

Dynamic boundary conditions

The main difficulty related to this model is to properly impose boundary conditions that would reproduce gas charge and discharge of the ASR Lajas sands.

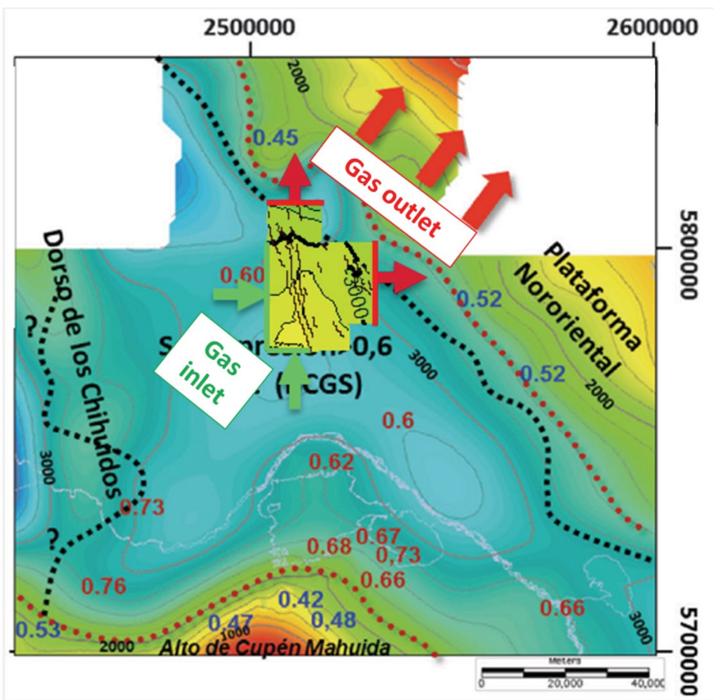

Figure 19. Boundary conditions configuration (Top Lajas horizon of the model is superposed to regional Top Lajas depth map and over-pressures, modified from Raggio *et al* 2014).

Firstly, constraining the model extension to the ASR block does not allow the imposition of hydrostatic pressure on one edge of the model, as performed in the previous basin section. Even though pressure dissipates towards the North-East of the basin, the ASR block is still expected to be entirely over-pressured as it was observed in Well-E in Figure 4. In order to simulate gas migration and pressure dissipation to the Northeast of the model, the northern and eastern edges of the models were connected to dummy production wells.

Secondly, current gas accumulation in Lajas is the consequence of both in-situ gas charge (where timing is constrained by the Los Molles maturation through burial history of the Neuquén basin) and migration from surrounding over-pressured blocks to the ASR block (timing not constrained). In order to emulate gas charge of the model, from maturation of the Los Molles source rock and from down-dip gas migration, gas was injected via dummy wells on the down-dip edges of the model (gas enters the model from bellow southwestern edges and from the bottom layer).

Therefore, boundary conditions are poorly constrained and a lot of heavy/costly simulation work would be required to find a case that would:

- Match current overpressure and saturation at wells
- Satisfy the timing for maturation of Los Molles.

Knowing that the final goal is to end up with a gas distribution satisfying well data and generated through the proposed modelling of gas migration, reasonable boundary conditions were imposed and gas saturation grids honouring observed pressure and saturation at wells were identified. Timing for gas charge and discharge was used as a matching parameter rather than input. For the sake of simplicity, recent uplift and erosion phenomena (that may have provoked late gas expulsion and change in pressure regime) were not accounted for.

Various cases were investigated varying the pressure of injection, the pressure of production and the duration of gas injection before relaxation of the model. For each of the cases, the simulation time providing the best match of well pressure and saturation data was retained:

	Inj. – Prod. pressure	Duration of injection	Relaxation time to match
1	700 - 250	50 Myrs	No pressure match (too low)
2	900 – 250	50 Myrs	10 Myrs
3	1100 - 250	50 Myrs	15 Myrs
4	700 - 150	50 Myrs	No pressure match (too low)
5	900 – 150	50 Myrs	5 Myrs
6	1100 - 150	50 Myrs	10 Myrs
7	700 - 350	50 Myrs	No gas saturation match (too low)
8	900 – 350	50 Myrs	20 Myrs
9	1100 - 350	50 Myrs	25 Myrs
10	700 - 350	70 Myrs	0Myrs
11	900 – 350	70 Myrs	10Myrs
12	1100 - 350	70 Myrs	15Myrs

Figure 20. Simulated boundary conditions and respective matching relaxation time

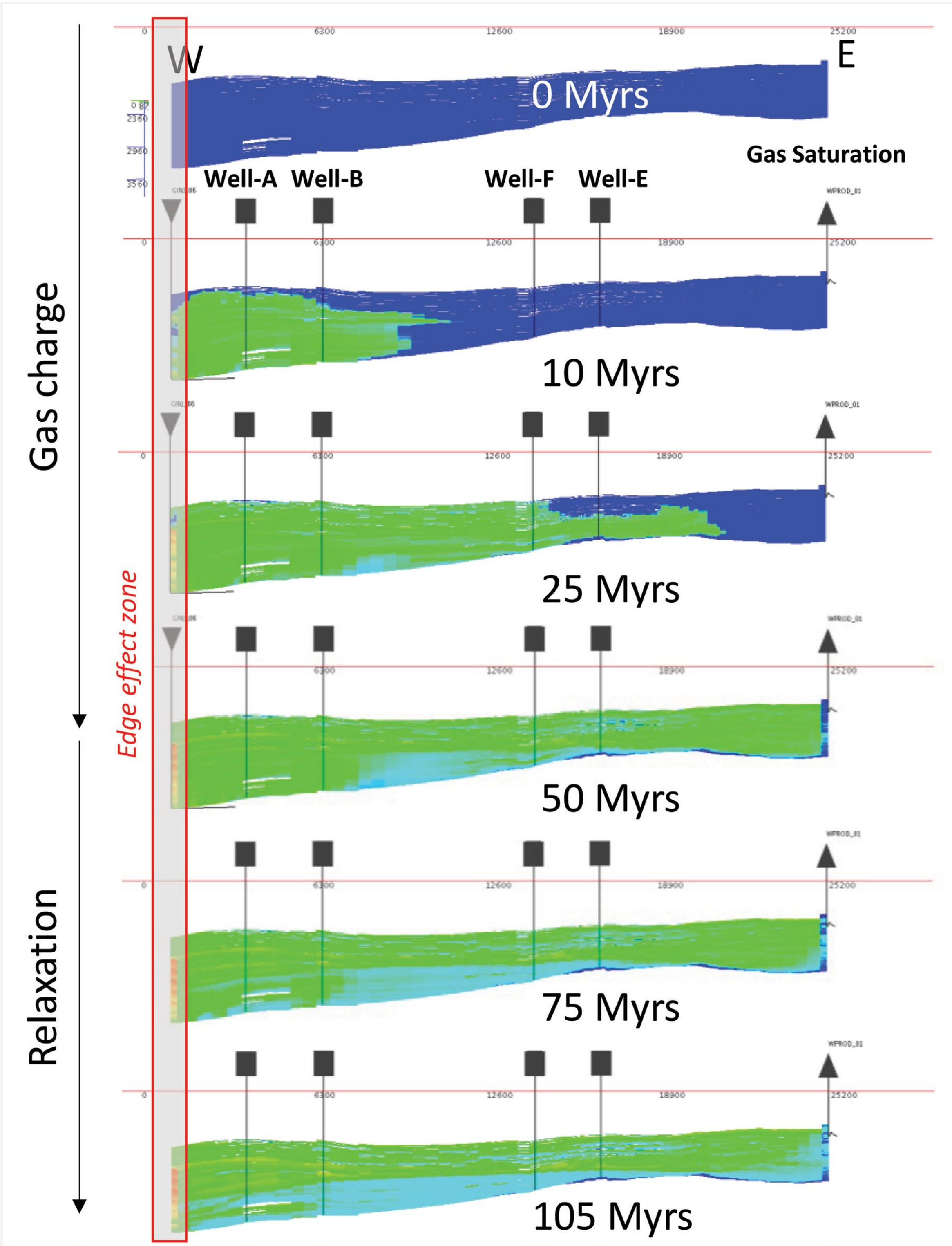

Figure 21. Gas saturation evolution in the W-E model section of the model

Model match and results

The evolution of saturation and pressure grids are presented for Case 3 (as it is referred to in Figure 20), Figure 21 and Figure 23 respectively. One may observe that the model is being charged progressively with gas from 0 to 50 Myrs of simulation time with an irregular forward moving gas front. After 50 Myrs of simulation, the model is completely gas-swept and starts relaxing. Gas saturation in the bottom part of the model tends to decrease as gas is moving upward and eastward. Figure 22 compares simulated water saturation at 65 Myrs with actual water saturation at wells (interpreted Net Sand water saturation). The model shows a qualitatively good match from West to East. In particular, it captures the vertical trend of increasing water saturation in Well-F or Well-C going from SB4 to SB5 and SB6.

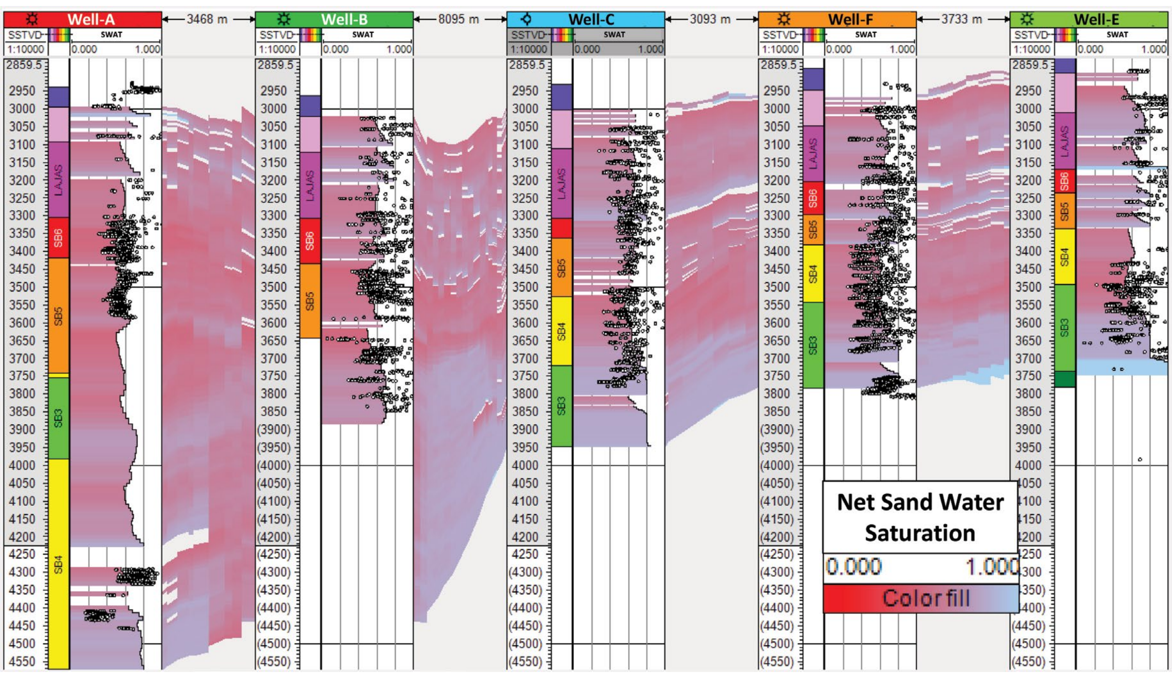

Figure 22. Model water saturation vs log of Net Sand Sw, at matching relaxation time (65Myrs)

As shown in Figure 23, the pressure match is more qualitative. In fact, simulated pressure trends (at 65Myrs) seem more continuous than observed pressures. However, a large vertical variation of simulated pressures can be observed at 20 Myrs in wells Well-F and Well-E. Such a ΔP would occur crossing the forward moving gas front (behaving as a moving baffle at Sg~0.30, corresponding to the kr cross-over). However, the variation of pressure from West to East– 600bars at 65 Myrs in Well-A to 500bars at Well-E (at 3600mSS) –reproduces the observed block-scale pressure gradient.

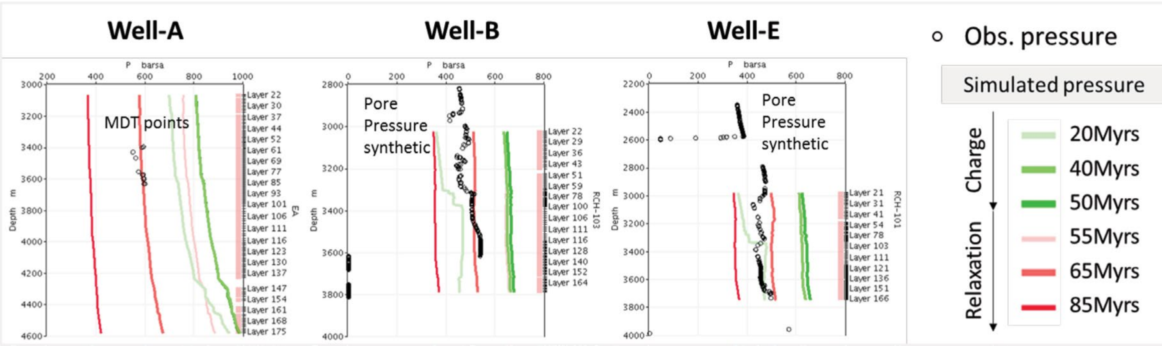

Figure 23. Pressure evolution at wells vs pressure data (best pressure match is obtained at 65Myrs)

In order to locate potential sweet-spots within the simulated distributions of gas saturation, the saturation grids were transformed into Net Hydrocarbon Thickness maps. Figure 24 presents the average and variance maps for matching gas distributions.

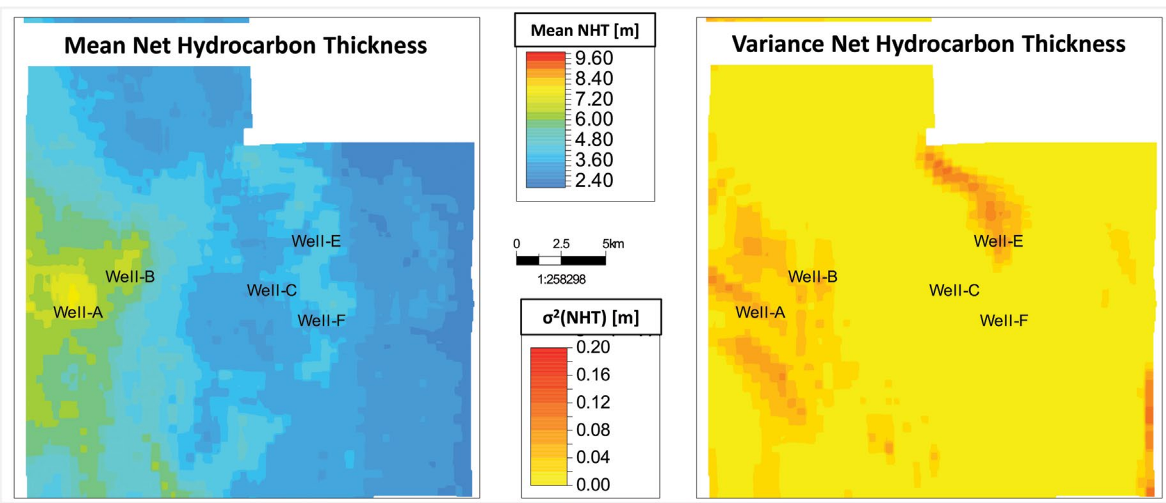

Figure 24. Mean and Variance for Net Hydrocarbon Thickness maps

Mean NHT is described as follows:

$$\overline{NHT} = \sum_{i=1}^{N} \frac{NHT_i}{N} = \sum_{i=1}^{N} \frac{\sum_k (DZ*NTG*\phi*S_g)_k}{N}$$, for N matched grids.

The mean NHT map shows good gas potential in the Well-A and Well-B sector, and going down to the South of the block. As expected, gas potential is higher in the zone of higher over-pressure, to the West of the block, closer to the gas source and with good potential for shale break facies. In particular, the Well-A zone corresponds to the highest potential zone of the simulated sector of the block. It should also be pointed out that even though Well-B is located in the zone of preferential gas accumulation, it shows a gas thickness inferior to Well-A and stays on the "edge" of the identified "sweet-spot". Such an observation supports the observed difference in water production between both wells.

The variance map shows low values. It goes to 0.2m at its highest when good zones have an average net gas thickness of 6 to 8 meters. It means that gas distribution is quite robust to variation on boundaries connections hypotheses.

This model provides results consistent with dynamic observation and in line with the understanding of the migration pattern. But the difference between simulation cases are quite constrained. Further sensitivities (to gas generation pattern, petrophysical properties, modelling of the intrusive volcanic sills, etc.) should be run in order to assess uncertainties related to the identified sweet-spot zones.

CONCLUSIONS

- Tight sands from the Lajas and Punta Rosada formations behave as holding tank for generated gas from the Los Molles source rock in the centre of the Neuquén basin. The resulting over-pressured Basin Centred Gas system was produced in 2 wells of the Aguada San Roque block with high differences in water production.
- Lajas and Punta Rosada gas and water production in over-pressured gas field of the Neuquén basin have been compared to various US analogues and shows a comparable range and scatter of water gas ratio. Lessons learnt from US analogues point out the importance of identifying “sweet-spots” within each play to reach economic developments.
- A phenomenological dynamic model representing gas migration through geological time in the Neuquén basin was built. Beyond capillarity and buoyancy, it provides a representation of viscous forces that are essential in the creation of a BCG system. The simulation results at current time provide a distribution of gas saturations supporting the observed variability of GWR.
- This paper provides an innovative workflow to identify potential sweet-spots within a block. It consists in simulating gas migration within a refined dynamic model at block scale. Even though the timing for gas generation and gas migration is not strictly calibrated, the model still allows the generation gas and pressure distributions that match observed water saturation and pressures at wells.
- Analysis of the simulated distributions of gas saturations yields a map for zones with stronger gas potential. In our case, this zone corresponds to the highest pressures (being located toward the centre of the basin) and sits within the zone of better sand facies.
- The impact of sensitivities to some parameters related to boundary conditions was analysed through a variance map. It shows the robustness of the model to the few uncertain parameters that have been considered. Nevertheless, a proper uncertainty analysis is required to evaluate the potential impact of other major uncertain parameters, mainly related to petro-physical heterogeneities, which may have paramount influence on

the current distribution of gas.

- The gas potential map generated acknowledges that Well-A (tested and produced at low WGR) sits in a zone with higher gas accumulation potential than Well-B (tested with WGR about 10 times higher than Well-A).

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