A NEW PETROLEUM PROVINCE OFFSHORE ARGENTINA?

Erik Imsland Wathne[1], Alberto Sánchez-López[1], Christopher Stadtler[1], Sveinung Wintersto[1], Hans Morten Bjørnseth[1], Tine Lærdal[1]

1: Equinor ASA. eiw@equinor.com, albs@equinor.com, chsta@equinor.com, svwi@equinor.com, hamob@equinor.com, tilar@equinor.com

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RESUMEN

Equinor y sus socios Shell e YPF han iniciado trabajos para perforar un pozo de exploración cuyo objetivo es probar el potencial petrolero del Alto de Colorado, un alto estructural con un gran cierre 4-way, situado en la transición entre la Cuenca del Colorado y la Cuenca Argentina Norte, en profundidades de agua de ~1500 m y a más de 300 km de la costa.

Este pozo representa una oportunidad de exploración frontera y será el primero en ser perforado en esta área desde los años 1990. Su principal objetivo es el prospecto llamado Argerich, situado unos 100-150 km costa afuera de los últimos pozos perforados en la Cuenca del Colorado.

El cierre estructural del Alto de Colorado es considerado un foco para la migración de hidrocarburos tanto desde el interior de la Cuenca del Colorado como desde la exterior Cuenca Argentina Norte.

El análisis de la estratigrafía secuencial de la cuenca ha permitido situar las rocas generadoras, las rocas reservorio y las capas sellantes en su contexto regional, reduciendo los riesgos e incertidumbres asociados a su presencia, todavía no probada. Las principales rocas generadoras que se esperan estén presentes en la zona son de edades Barremieano a Albiano y diferentes modelados indican que podrían estar maduras y expulsando petróleo y gas. Las principales rocas reservorio objetivo de la perforación son reconocibles a partir de geomorfologías observadas en los datos 3D existentes y son interpretadas como depósitos clásticos marinos someros.

El pozo Argerich podría abrir una nueva provincia petrolera aguas afuera en Argentina, con gran potencial en varios prospectos adicionales interpretados en su proximidad.

INTRODUCTION

The CAN_100 license (Fig. 1) was awarded to YPF in 2019 and was re-shaped from the former E1 license. Equinor subsequently farmed in and took over operatorship, with Shell farming into the license in 2021. The current equity split is 35/35/30 on Equinor/YPF/Shell, with Equinor as operator.

The Colorado High located in the central part of the license was recognized by the E1 license holders as a favorable location for exploring for hydrocarbons and was targeted by a 3D seismic

survey already in 2007 (Fig. 2). The survey has been used for re-mapping of prospects and re-processed for final prospect definition and well planning. The high has attracted interest for a long time due to its favorable location at the transition between the inboard Colorado Basin and the outboard Argentina Basin (Fig. 2), being a migration focus for any hydrocarbons expelled from either basin. The Early Cretaceous Barremian to Early Albian is assumed to represent the main interval with deposition of marine source rocks (Fig. 3), a concept that is largely based on studies of the conjugate margin with multiple well penetrations of this time interval. Further encouragement has come from the recent discoveries in Namibia, proving the existence of an outboard South Atlantic petroleum system.

The Colorado High is a large basement high, which due to differential compaction, can be recognized at multiple stratigraphic intervals in the interpreted Cretaceous section as large 4-way closures, where multiple prospects and traps have been defined. The targets for the planned Argerich well are defined within the larger 4-way closure and prospects are also defined based on the interpreted presence of high-quality reservoir. Cretaceous sediments drilled in the Colorado Basin in the 90´s, over 100 km inboard of the Colorado High, are interpreted as dominantly continental. Based on sequence stratigraphic interpretation and geomorphologies from 3D horizon attribute mapping, the main reservoirs in the Argerich prospect are interpreted as shallow marine, representing the transition from continental/marginal marine to marine conditions at the time of deposition. Seals are provided by transgressive marine shales.

The planned frontier exploration well targeting the Argerich prospect on the Colorado High will test the main target with additional upside potential. In addition, the plan is to penetrate the

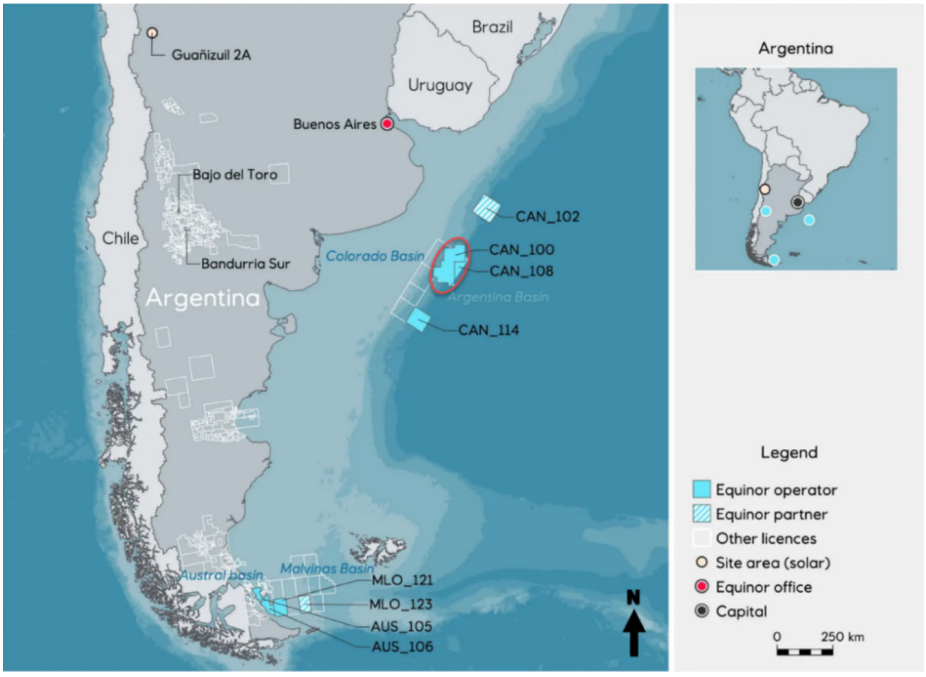

Figure 1. Location of the CAN_100 license at the border between the inboard Colorado Basin and the outboard Argentina Basin.

entire post break-up section and TD in interpreted pre-rift and/or syn-rift deposits, which will provide a full reference and calibration of the succession deposited post South Atlantic break-up.

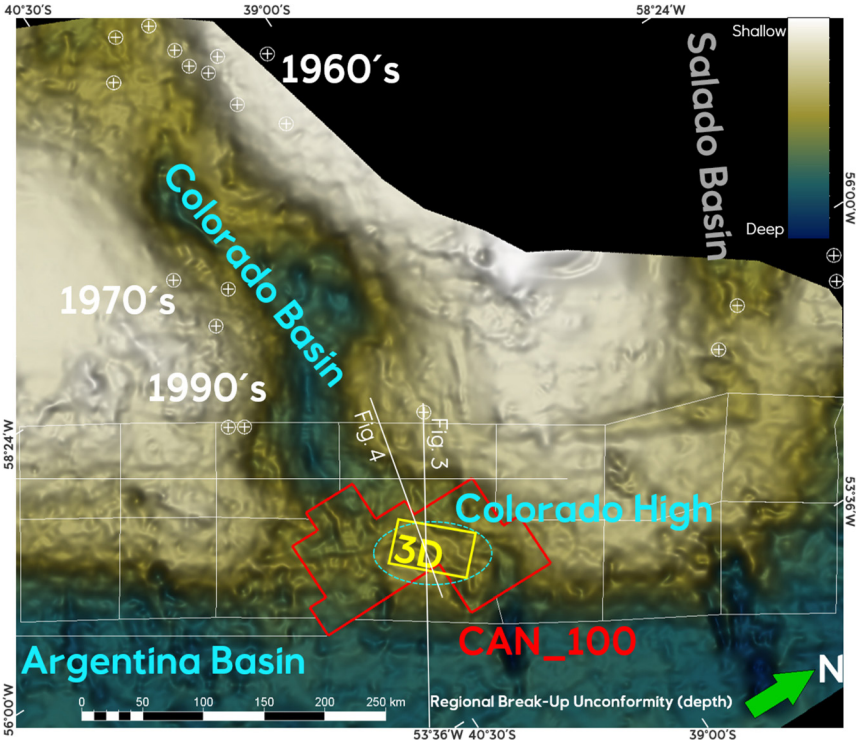

Figure 2. Regional break-up unconformity map in depth outlining the main features of the area and location of the CAN_100 license and existing 3D seismic survey. Note the position of the Colorado High, a basement high that due to differential subsidence/compaction sets up a large 4-way closure (indicated by dotted light blue outline) at the main target level, between the Colorado Basin inboard and the Argentina Basin outboard. Previous exploration efforts further inboard in the Colorado Basin in the 1960´s, 1970´s and 1990's are indicated by well symbols. Approximate locations of figures 3 and 4 indicated with white lines.

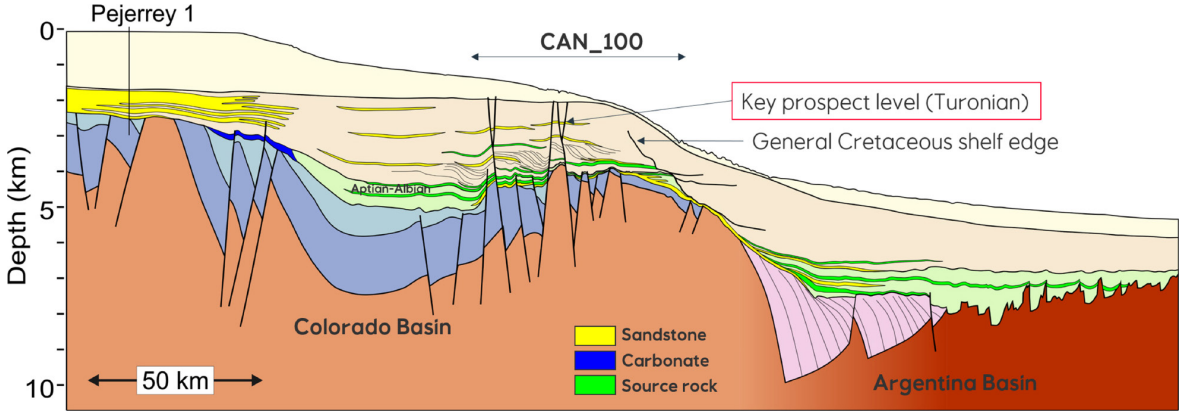

Figure 3. Cross-sectional sketch from the Colorado Basin across the Colorado High to the Argentina Basin, illustrating the main features of the play, with Early Cretaceous source rocks and shallow marine reservoirs corresponding to equivalent continental deposits inboard in the Colorado Basin. Source rocks, if mature, can generate hydrocarbons both in- and outboard, that would likely migrate up and into the strata covering the Colorado High.

GEOLOGICAL REGIONAL CONTEXT

After the Permian-Triassic compressional phase related to the Ventania-Cape Thrust Belt (Pángaro and Ramos 2012), three extensional phases have been described for the Colorado and Salado Basins (Lovecchio *et al.* 2018). Exact ages of the two first phases are controversial and available data to constrain them are limited and uncertain. They have been associated to the Late Triassic to Early Jurassic and to the Early to Late Jurassic respectively. In the first phase, pre-existing Permian-Triassic faults are reactivated. In the second phase extension happens in a N-S to NE-SW direction, forming the main depocenters of the Colorado Basin. The third extensional phase is better constrained and corresponds to the main ENE-WSW opening of the Southern South Atlantic in the Early Cretaceous. It is during this last phase that the Argentina Basin is created at the same time as the Colorado Basin continues to subside. The Colorado High between the two basins is not fully flooded until late Aptian. During the Cretaceous, there is continuous sediment supply from the west and deposition in the Colorado Basin and on the Colorado High, with the shelf edge located just outboard of the Colorado High (Figs. 3 and 4; Bjørnseth *et al.* 2022). Due to continued subsidence both in the inboard Colorado Basin and outboard Argentina Basin, combined with differential compaction, large 4-way closures exist in the Cretaceous section above the Colorado High.

Figure 4 shows a schematic interpretation of seismic reflectors along a line going from the Colorado Basin across the Colorado High. Their continuity is high to the east, where layering is interpreted to be related to marine conditions and deposition of alternating sands and shales. Reflector continuity is low towards the west, where seismic facies are more chaotic, corresponding to the continental sediments encountered in all wells in the region. That pattern changes in the Campanian-Maastrichtian transgressive package, where continuous layering indicates marine conditions over the whole basin. This is confirmed by the presence of marine sediments in wells, calibrated confidently with biostratigraphic data. The white stippled arrow in figure 4 indicate the approximate transition between continental and marine-influenced to fully marine conditions.

Regional seismic stratigraphic interpretation, calibrated to wells, allows us to define six main stratigraphic units within the Cretaceous (Fig. 4). 1) Aptian transgression: immediately after break-up, the basin and big parts of the Colorado High were flooded. Re-working and deposition of transgressive sands is expected to have occurred during that interval, both inboard and outboard of the Colorado High. 2) Aptian regression: the first prograding unit in the Colorado Basin, with low angle clinoforms, suggest that the shoreline rapidly moves from the Colorado Basin towards the Colorado High (red dots linked with the white line in figure 4 show the evolution of the shelf with time). At its top, reflectors indicate a maximum flooding surface (mfs). 3) Albian regression: clear prograding and slightly aggrading clinoforms are observed on the Colorado High. An mfs separates the top of that unit from the overlying one. 4) Cenomanian-Turonian aggrading

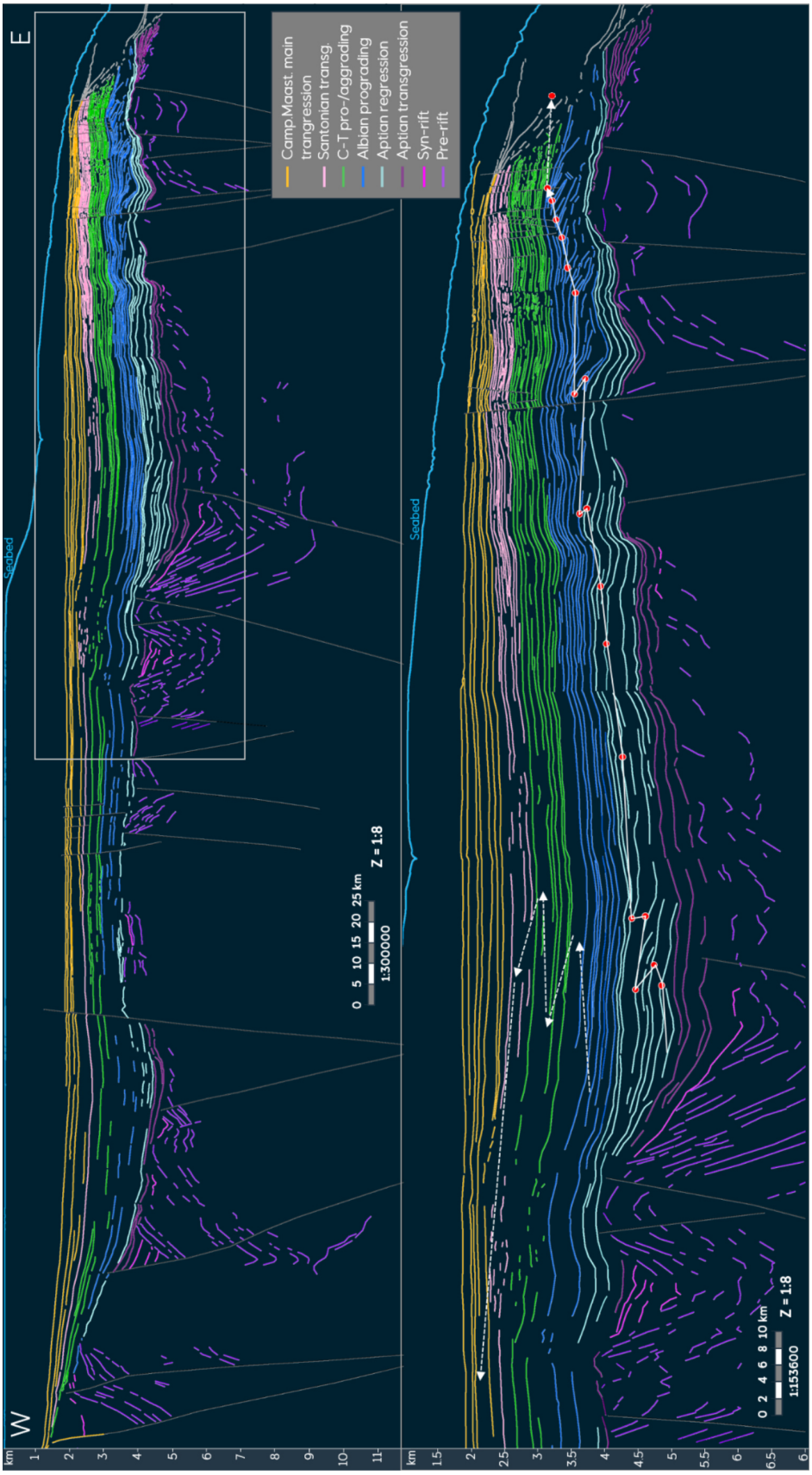

Figure 4. Sketch showing the main faults and reflectors in a regional section (left). A zoom into the grey box is shown to the right. Stratigraphic units have been defined based on stratigraphic and geometric patterns. Evolution of the shelf during the Aptian regression is indicated in red dots linked with a white line. Areas with low density of reflectors show chaotic seismic facies, interpreted as continental deposits, and calibrated by wells; stippled arrows indicate its spatial distribution during the Cretaceous.

sequence: seismic observations across the region show that this sequence is mainly aggrading with minor progradation close to the top of the Turonian. During this period there is continuous deposition of shoreface sands on the Colorado High, and it ends with another regional scale mfs. 5) Santonian transgression: during this period the shoreline is displaced towards the west a few kilometers, with deposition of shoreface sands still on the western flank of the Colorado High. 6) Campanian and Maastrichtian transgression: this main event is described in previous literature and is corroborated by seismic observations, where continuous low amplitude reflectors are interpreted as deep shelfal deposits on top of the Colorado High. Clear indications of deep-water current erosion are also observed in the area.

SOURCE ROCK INTERPRETATION, MODELLING AND MIGRATION

The Cretaceous play is primarily based on hydrocarbon generation and expulsion from Early Cretaceous source rocks, of marine origin and Barremian to Early Albian age. This stratigraphic interval (stratigraphic unit 1 in figure 4 with marine conditions) is not penetrated by wells drilled in the Colorado Basin and the concept is mainly based on studies of the conjugate margin of Africa (Fig. 5).

At the African margin, numerous exploration wells have penetrated source rock intervals in the relevant stratigraphic interval. In addition, source rocks of Barremian to Early Albian age, have been penetrated by the DSDP-361 well on oceanic crust. Recently, the Graff and Venus discoveries by Shell and Total, respectively, are interpreted as sourced by these source rocks, proving the potential for sourcing large hydrocarbon accumulations.

The Barremian to Early Albian interval represents an early phase in the opening of the South Atlantic, with widespread anoxic conditions at a time when the African and South American continents were much closer than at present (Fig. 5). It is reasonable to assume that the conditions were similar across the South Atlantic at this time, hence the same source rocks as documented on the African margin are likely to be present also on the South American margin.

The relevant stratigraphy can be mapped on seismic 2D data and correlated across from the African to the South American margin, with similar seismic expression. Based on temperatures/ heat flow from tectonic modelling (Hinsken *et al.* 2022) and subsequent basin modelling studies, the source rocks are believed to have reached a maturity stage where hydrocarbons have been generated across large areas on the outboard margin of Argentina, as well as in the Colorado Basin, with hydrocarbon expulsion since Cretaceous time.

The Colorado High is regarded as a highly favorable location for migration of expelled hydrocarbons from both the outboard kitchen and the outer parts of the Colorado basin, with faults linking up the source rock interval to mapped reservoirs in the Late Cretaceous (Figs. 3 and 4). In addition, the shallow marine setting across the high in Late Cretaceous can form alternations

of high-quality reservoir rocks and sealing shales that can constitute hydrocarbon traps within the 4-way closures set up by differential compaction above the basement high.

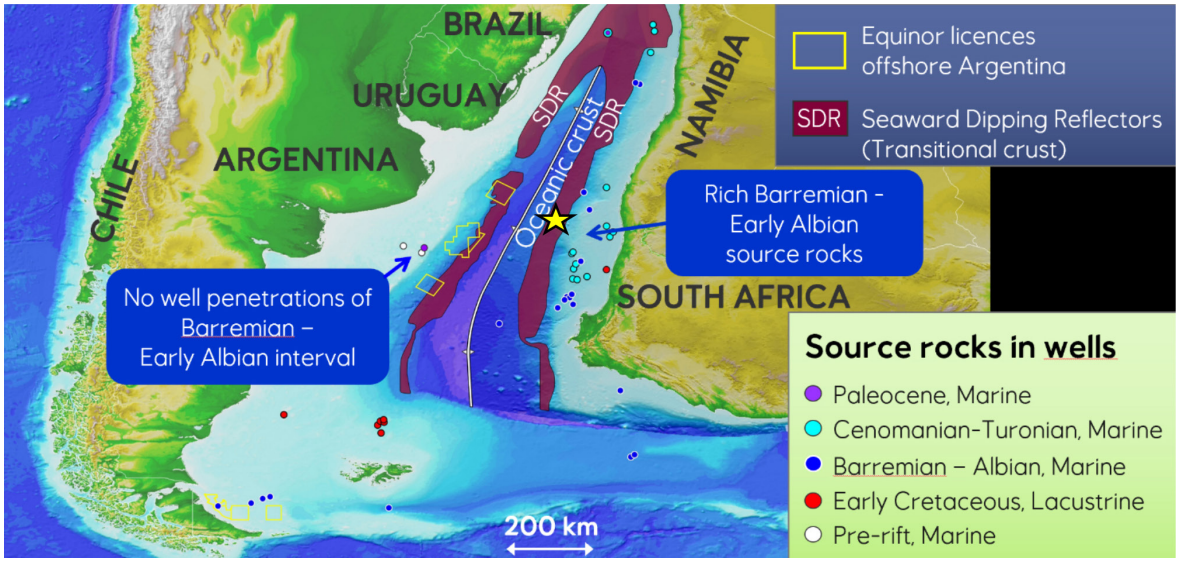

Figure 5. Source rocks are interpreted to be the same on both the South American and South African margins of the South Atlantic, with multiple well penetrations on the African margin and none on the South American margin. In the Early Cretaceous Barremian to Early Albian, the South Atlantic was a narrow basin with anoxic conditions, with South America and Africa much closer than at present. Source rocks have been mapped on seismic and tied to well penetrations on the African margin and correlated seismically to the South American margin. The approximate location of recent Graff and Venus discoveries is indicated by the yellow star.

RESERVOIR INTERPRETATION

With the only wells available more than 100 km´s further West and inboard in the Colorado Basin, the interpretation of reservoir presence and depositional environments is based on large scale stratigraphic interpretation of 2D seismic data tied to the existing wells and complemented with high resolution attribute maps from the area covered by the seismic 3D survey.

The existing wells in the Colorado Basin are interpreted as dominantly continental deposits in the Late Cretaceous, with high net-to-gross sections interpreted as mainly fluvial channel deposits. On larger scale 2D seismic sections (Fig.4), there is a clear change of seismic facies, from more chaotic and weaker seismic reflections in the area with the existing wells to more continuous and stronger seismic reflections in the Colorado High area at the mouth of the Colorado Basin. This is interpreted as an overall change from continental to marine environments.

On 3D seismic data it is also possible to see how this change has shifted back and forth over time in cycles of regression and transgression (Figs. 4 and 6). In the 3D area, it appears as the transition from continental to marine environments was at its most basinward location at Turonian time, which was followed by backstepping of the shoreline towards the end of the Cretaceous (Fig.

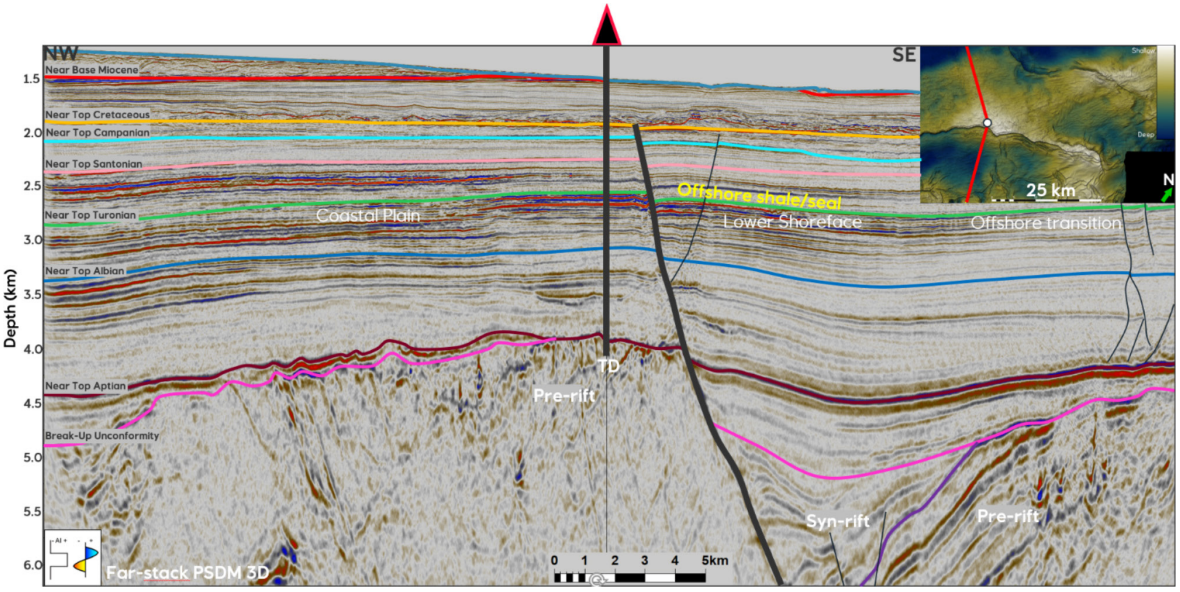

Figure 6. Argerich-1 is planned for 2023 with the main target in the Turonian. In addition, the well is planned to test the entire post break-up section with TD into what is assumed to be pre-rift and/or syn-rift strata. The well is here illustrated on a 3D seismic PSDM far-stack section.

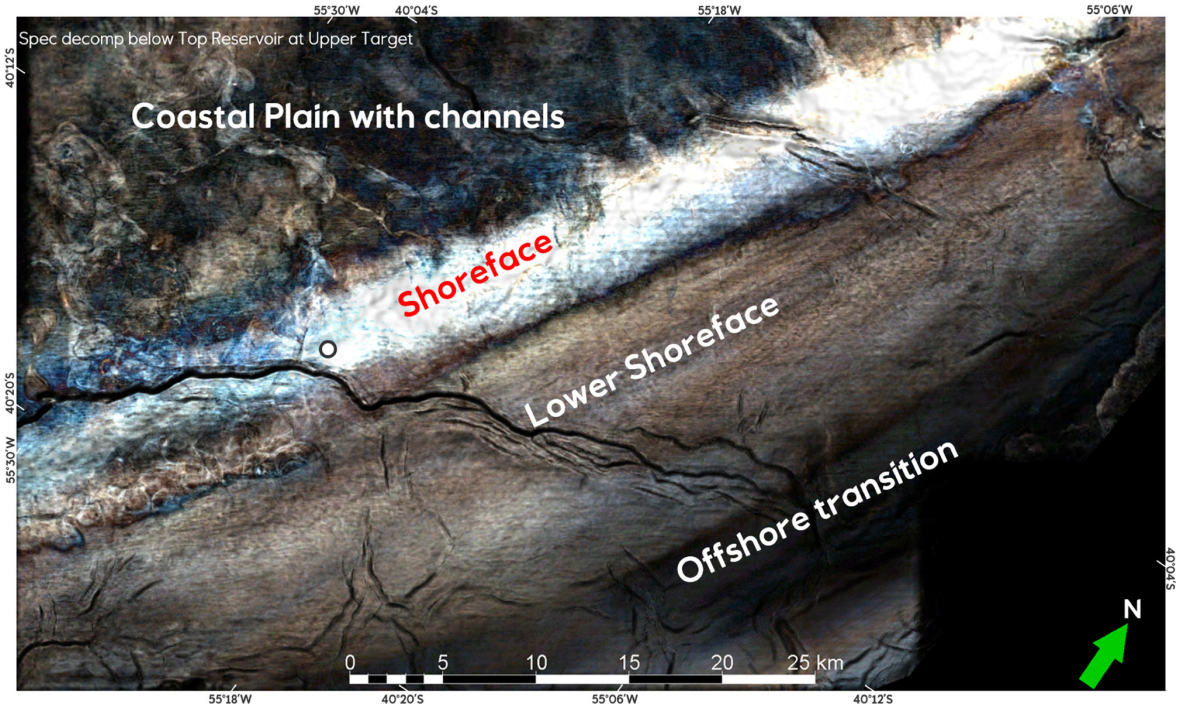

Figure 7. Spectral decomposition map from the Turonian reservoir (planned well indicated by white circle) with interpreted depositional environments. When compared with the structural map in figure 8, the prominent feature in pale colors, interpreted as shoreface deposits, is favorably located across the Argerich and Najdorf structures (see Fig. 8 for reference) and have been used to define the extent of the prospects. Note the presence of channels in the coastal plain that terminate at the shoreface, suggesting the shoreline was wave-dominated without any formation of deltas and significant reworking of sand along the shoreline.

6). 3D seismic attribute maps of horizons in the Turonian allows for the interpretation of coastal plain with channels with an overall SW-NE direction (Fig. 7). The channels appear as both high and low amplitude, interpreted to reflect sand- and mud-filled channels respectively. The channels abruptly end as they reach elongate, NW-SE oriented 5-10 km wide bodies with high amplitudes interpreted as sandy shoreface deposits (Fig. 7). Outboard of these, amplitudes are weaker, but the NW-SE trend is still present. The latter is interpreted as deposits in a lower shoreface to offshore transitional environment, with a mixture of thinner sands and shales. For the interval towards the top of the Turonian, the elongate bodies interpreted as shoreface sands are located just across the crest of the Argerich prospect (Fig. 8). The interval above these is characterized by lower amplitude seismic reflections interpreted as shales deposited during an event of transgression and flooding of the previous shoreline and forming a sealing cap rock to the latter.

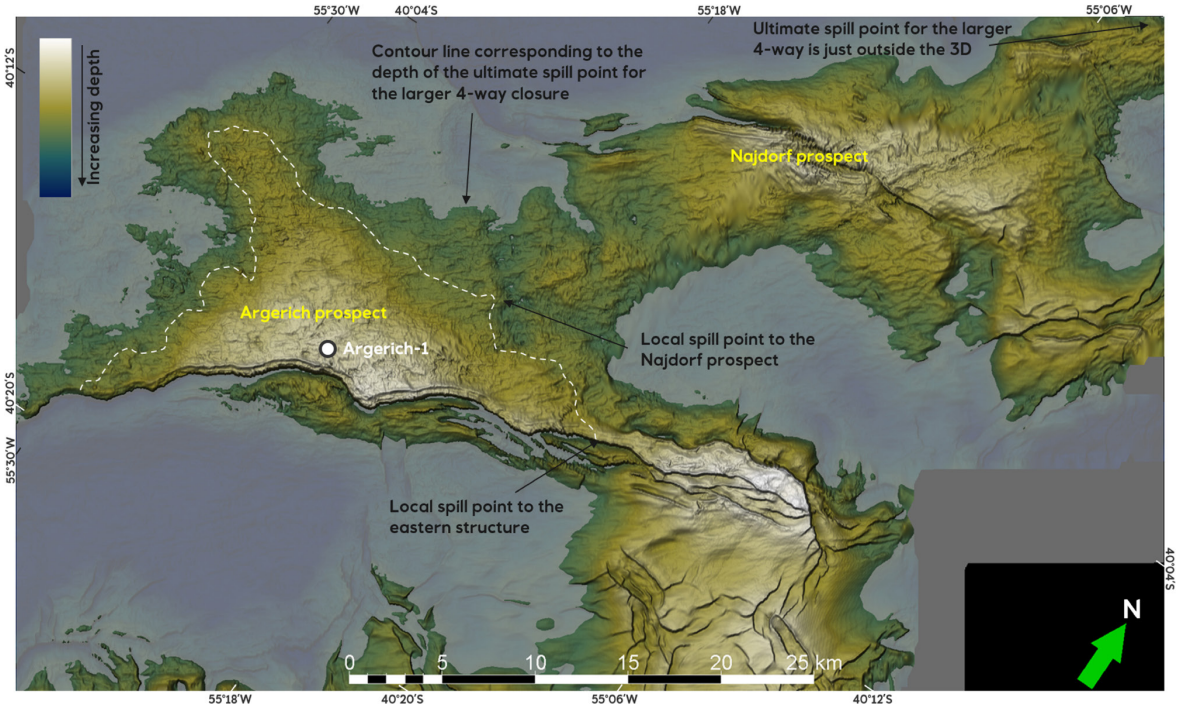

Figure 8. Depth map based on seismic 3D interpretation on the Top Turonian/Top reservoir with the local Argerich 3-way closure indicated by a white stippled line. The ultimate spill point for the larger 4-way closure lies to the NW, just outside the 3D. In a fill-to-spill situation, the Argerich and Najdorf prospects will form one continuous hydrocarbon accumulation within the 4-way closure, which is closing just off the 3D to the North. Additional upside within the closure exists further to the East if reservoir is present.

PLANNED FRONTIER EXPLORATION WELL

The Argerich well will target the elongated high amplitude events/bodies interpreted as sandy shoreface deposits in a 3-way closure against fault, located within the mapped larger 4-way closure spilling towards the northeast (Fig. 7 and 8). Several additional stratigraphic levels will also be

penetrated by the well and represent possible upside potential (Fig. 6).

The well is planned to TD below the break-up unconformity in pre-rift and/or syn-rift deposits to provide a full dated reference section for further evaluation of opportunities spanning the Cretaceous section post break-up.

CONCLUSIONS

A frontier exploration well is planned in the CAN_100 license with a plan to drill the entire post break-up section with TD in pre-rift and/or syn-rift deposits. Based on conjugate studies and basin modelling, Barremian to Early Albian source rocks are interpreted to be present and mainly in an oil mature state both in the outboard Argentinian Basin and the Colorado Basin. The Colorado High at the transition between the two basins is regarded as a favorable location for migration and trapping of hydrocarbons.

Regional sequence stratigraphic interpretation together with 3D seismic geomorphologies provide good confidence for the interpretation of reservoir and source rocks. The well has the potential to prove up in-place volumes exceeding a billion barrels.

If successful, the well can open a new petroleum province offshore Argentina, with significant upside potential within the license and surrounding areas and prove the existence of an effective petroleum system equivalent to that of the African margin represented by the recent Namibian discoveries in Graff and Venus wells.

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