# Syn-rift and pre-rift section in the Colorado Basin, offshore Argentina: An integration of new long offset 2D seismic reflection data with potential fields and vintage seismic refraction data

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**Summary**

The objectives of subsurface hydrocarbon exploration often require integrating a variety of geophysical and geological information. The type and resolution of data can be vast, ranging from detailed examinations of well logs to generalizing broad regions from remotely sensed data. Here, we combine recently acquired state-of-the-art 2D seismic reflection data, vintage seismic refraction data from experiments conducted between 1957 and 1961 (Ewing *et al.*, 1963), and both public and proprietary potential fields data to map the sedimentary and crustal rock layers beneath the Argentine coastal plain.

We used the seismic reflection data to establish the basin framework, including interpreted syn-rift and pre-rift layers. These recent data closely correlate with the older seismic refraction data (Ewing *et al*., 1963), demonstrating the merits of incorporating all relevant information available, even legacy datasets. Regional basin structure and shape were approximated by integrating Moho and basement refractors with basin geometries interpreted from the reflection data into regional 2D gravity models.

**Introduction**

The eastern margin of South America developed following the breakup of Gondwana, encompassing a pre-rift phase in the Upper Paleozoic, rifting in Triassic/Jurassic to Early Cretaceous, and drift from Lower Cretaceous to present-day (Loegering *et al*., 2013). Structures formed during the Paleozoic accretion of Gondwanan terranes and Late Triassic to Early Jurassic extension were reactivated as the present-day passive margin evolved. It is a volcanic margin, characterized by multiple extrusive basaltic complexes manifested on seismic as seaward dipping reflectors (SDRs) (Franke *et al*., 2007); and areas of magmatic underplating have also been identified beneath the margin's crust (Schnabel *et al*., 2008; Autin *et al*., 2016).

The Colorado Basin is the largest of the Mesozoic extensional basins on the northern margin of Argentina. It has a typical rift basin profile filled with Upper Jurassic to Recent syn- and post-rift sediments deposited unconformably on Permian and older pre-rift sediments during rift, sag and drift phases. Rift-fill sediments are predominately sandstones and shales, with minor carbonates and volcanics. Industry drilling began here in the late 1960s, although the first syn-rift section wasn't encountered until the Cruz del Sur well in 1994 (Fryklund *et al*, 1996).

**Data and Methodology**

In 2017-18, TGS acquired over 38,000 km of modern long-offset, long record length 2D seismic reflection data gravity and magnetic data, over large parts of the outboard Colorado, Salado, and Argentina basins along regular survey grids to improve imaging of structural and stratigraphic plays (Ramirez *et al*., 2018) (Figure 1).

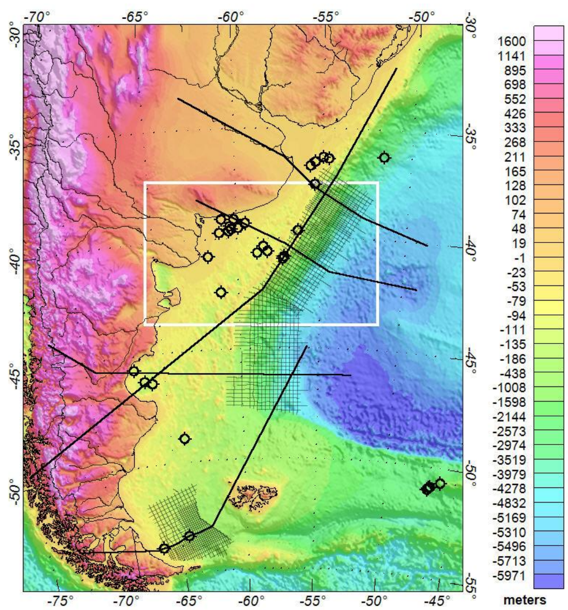


**Figure 1.** Topography, wells, and TGS acquired seismic data over the Argentina Basin from 2017 to 2020, the West Malvinas Basin in 2017-2018 and the Colorado and Salado basins in 2019 (not shown); 2D gravity models (heavy black lines); Figure 2 (white box).

Marine gravity and magnetic data, acquired in tandem with the new reflection seismic, were merged with open-file gravity and magnetic grids (Sandwell *et al*., 2014; Meyer *et al*., 2017). Magnetic anomaly data were used to map M-Series geomagnetic isochrons and the limits of the SDRs. Modeled gravity anomalies, over 2D reflection seismic lines, were tied to basement and Moho refractors and wells that penetrated pre-rift and/or syn-rift rocks. Modeled sedimentary rock densities were determined from RHOB logs measured in five wells: Corona Austral and Estrella (Union Texas), El Delfin (Hunt), Dorado (Amoco), and Pejerrey (Shell) (Figure 2).

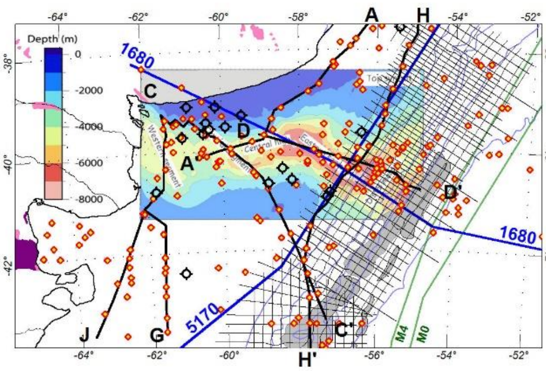


**Figure 2**. Colorado Basin focus area. Interpretation control includes wells (open black circles), TGS regional seismic reflection data (thin black lines), legacy seismic refraction data from published sources (red/yellow diamonds), and Ewing *et al*. (1963) cross sections (heavy black lines); outcropping basement and volcanics (pink and purple polygons respectively), and results from previous studies (Top of Syn-rift map, after Autin *et al*., 2013). 2D gravity models are shown as thick blue lines, Geomagnetic isochrons (green lines, M0 and M4 after Muller *et al*., 1997), seaward dipping reflectors (SDRs are light gray polygons, after Franke *et al.*, 2010), and bathymetry contours (1000 m interval, thin blue lines).

More than 90 seismic refraction profiles through the Argentine coastal plain were used to identify four sedimentary rock layers and two crystalline crustal layers (Ewing *et al*., 1963). That study divided sedimentary rock ages and interval velocities into Pliocene-Miocene (2.05 km/s), Lower Miocene and Upper Cretaceous (2.40 km/s), Lower Cretaceous and Upper Paleozoic (3.65 km/s), and Lower Paleozoic (4.40 km/s) categories. Additional seismic refraction programs were conducted in the region and are also tied to the gravity models (Ludwig *et al*., 1968; Leyden *et al*., 1971; Urien *et al*., 1976; Ludwig *et al*., 1979; Hayes *et al*., 1991).

Five sedimentary rock densities were incorporated into the 2D gravity models: 2.0, 2.3, 2.45 and 2.55 g/cc for drift layers, and 2.65 g/cc for pre-rift and syn-rift layers. Upper crystalline crust densities are 2.7 g/cc for continental rocks, and 2.8 g/cc for oceanic rocks. Lower crystalline crust and upper mantle densities are 2.9 and 3.3 g/cc. SDR layers were assigned the same density as upper oceanic crust (2.8 g/cc).

## Results

Integration of the 2017-18 reflection seismic survey data with publicly available gravity and magnetics data enabled an improved understanding of Colorado Basin structure and its relationship to the adjoining deepwater passive margin Argentina Basin. Major structural features were identified and mapped, including the location and thickness of several large Aptian-aged sub-basins on transitional crust which represent potential source kitchens for hydrocarbons migrating inboard. Excellent correlations were observed between the velocity layers and geologic horizons identified by Ewing *et al.* (1963), and the newly acquired data, where these datasets coincide along the eastern margin of the Colorado Basin.

On a more regional scale, the Continent-Ocean Boundary (COB), the Moho, and a terminal horst Outer High of the Colorado and Salado basins were mapped, along with several large syn- and pre-rift grabens located along the inboard margins of the Outer High. Mapped SDRs near the COB confirm to a great extent the geometry of the SDR wedges as interpreted by Franke *et al.* (2007).

The SDRs correlate well with magnetic anomalies; Hall *et al*. (2018) identified M-series magnetochrons M0 through M11 over the Orange and Cape Basins offshore South Africa. Anomalies M7 and M9 have been identified over its conjugate, offshore Argentina, by Koopman *et al.* (2014).

Our NW-oriented 2D gravity model, 1680, runs subparallel to Ewing *et al*.'s 1963 interpreted cross section D-D', aligned roughly along the strike axis of the Colorado Basin and orthogonal to cross sections A-A' and H-H' (Figure 3), and intersects additional refraction control points (Urien *et al*., 1976; Ludwig *et al*., 1979; Hayes *et al*., 1991). Thickness variations in crystalline crust layers suggest possible high-density magmatic underplating.

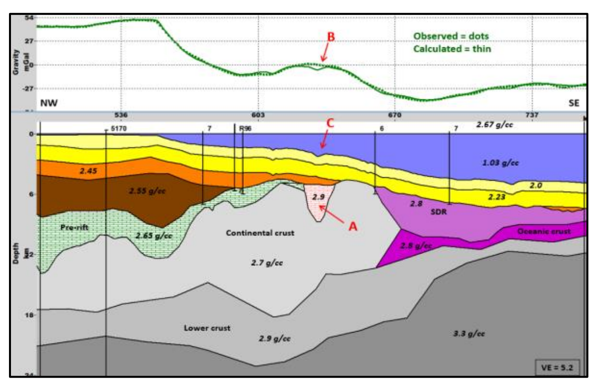


**Figure 3**. 2D gravity Model 1680. Syn- and post-rift clastic-dominated sedimentary rock layers (yellow, orange, and brown) and pre-rift mixed clastics and carbonates (green) overlie continental crust (light gray); yellow post-rift layers overlie SDRs and oceanic crust (purple). Lower crust and mantle rocks are medium and dark gray, respectively. Numbered markers (6 & 7) indicate contoured depths (km) from Autin *et al*. (2013). R9 and 5170 markers identify

intersections with seismic refraction sites (Ludwig *et al*., 1976) and 2D Model 5170.

Our NE-oriented 2D gravity model, 5170, (Figure 4) is subparallel to cross section H-H' interpreted by Ewing *et al*. (1963). From refraction velocities, the authors interpreted a pre- and syn-rift layer with variable thickness draped over basement highs and lows. Similar to the strike model, Model 5170 includes both pre-rift and syn-rift layers which were penetrated by three Union Texas wells: Cruz del Sur, Estrella, and Corona Austral. This model is oriented at a high angle to the Colorado Basin, where the upper crystalline crust thins to about 10 km beneath the rift axis. As with Model 1680, thickness variations in the crystalline crust layers suggest possible high-density magmatic underplating.

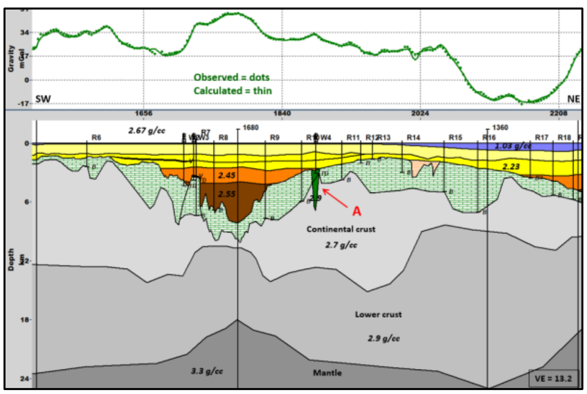


Figure 4. 2D gravity model 5170. See Figure 3 for color scheme. R6-R19 and 1360 and 1680 markers show intersections with seismic refraction sites (Ewing *et al*., 1963; Urien *et al*., 1976) and 2D Models 1360 and 1680, respectively.

## Conclusions

Recently acquired regional, long-offset 2D reflection seismic and high-resolution shipborne gravity and magnetics data help illuminate the internal architecture of the Colorado Basin. Integrating these data with and building on the seminal seismic refraction studies of Ewing *et al*. 1963, we now have a better understanding of the evolution of this complex basin and the relationship to the underlying Gondwanan terranes. The gravity models support the existence of extensive syn-rift and pre-rift sediments inboard of the new seismic data and enable extrapolation of these concepts over the entire northern margin of Argentina

Along with outcrop and exploratory well information, the combined datasets identify the critical elements of a successful hydrocarbon exploration program in a frontier basin, with evidence of source rocks, reservoirs, structural and stratigraphic traps, and seals. Oil and gas shows and geothermally mature syn- and pre-rift source rocks in the Colorado Basin encourage new exploration in this shallow-water extensional basin.

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**Colorado Basin, offshore Argentina**


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