

The hydrocarbon potential of the offshore Talara Basin, Peru

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ABSTRACT. The offshore Talara Basin is the western extension of the hydrocarbon producing onshore fields since the mid-1800s area of Peru and is also located above the subduction zone of the active continental margin of South America. The offshore portion was evaluated using high quality 3D seismic where mapping horizons are all unconformities within the Eocene as well as the unconformities at the top Paleocene and top Cretaceous. Possible source rocks are the Cretaceous black marine shales of the Campanian Redondo Formation, the limestones of the Albian Muerto Formation, and the marine shales of the Paleogene. The primary target offshore is expected to be deep-water turbidites of Paleocene/Eocene age with a depositional source from the northeast from highlands created by the compressional uplift of the Andes. The main seals offshore are expected to be shales of the upper Eocene Lagunitos Formation and shales in the Chacra Formation, which are also seals in the onshore Litoral field. Thermal maturation modeling shows that two hydrocarbon kitchens exist in the offshore portion of the Talara basin, one in the north and another in the south. The probable Cretaceous source rocks reached the onset of maturity (VR=0.63%) at a depth of 3,250 to 3,285 m (10,663-10,778 ft) between 30 and 39 Ma (Late Eocene to Oligocene). Importantly, the Cretaceous source rocks stay within the oil window once they enter it in the late Eocene. Satellite studies show a large offshore present-day oil seep in the southern part of the basin and 3D seismic shows direct hydrocarbon indicators (DHIs) imaged as flat spots and bottom simulating reflectors (BSR). Basin modeling suggests hydrocarbon migration pathways would have been updip (to the east) into the onshore traps and would therefore have first filled the offshore traps along the migration pathway. We conclude that the Talara Basin offshore offers excellent exploration opportunities in a proven productive area where multiple prospects have been mapped.

Keywords: Hydrocarbon potential, Offshore exploration, Talara basin, Peru.

RESUMEN. Potencial de hidrocarburos de la cuenca Talara costa afuera, Perú. La cuenca Talara costa afuera es la extensión occidental de su parte continental que contiene los campos petroleros productores de hidrocarburos desde mediados del siglo XIX en Perú. Esta se encuentra sobre la zona de subducción en el margen activo de los Andes, donde la placa oceánica de Nazca está subduciendo bajo la continental de América del Sur. La porción marina de la cuenca se evaluó utilizando un relevamiento sísmico 3D de alta calidad donde los horizontes de mapeo interpretados son discordancias dentro del Eoceno, así como del Paleoceno superior y el Cretácico Superior. Las posibles rocas generadoras son las lutitas marinas negras del Cretácico de la Formación Redondo (Campaniano), las calizas de la Formación Muerto (Albiano) y las lutitas marinas del Terciario temprano. Se propone que el objetivo principal de la exploración petrolera en alta mar sean las turbiditas de aguas profundas del Paleoceno/Eoceno originadas por aportes desde las tierras altas del noreste,

creadas por la elevación compresiva de los Andes. Se considera que los principales sellos en el sector costa afuera sean lutitas de la Formación Lagunitas del Eoceno superior y las lutitas de la Formación Chacra, que también son sellos en el campo terrestre Litoral. El modelo de maduración térmica muestra que existen dos cocinas de hidrocarburos en la parte costa afuera de la cuenca, una en el norte y otra en el sur. La fuente probable del Cretácico alcanzó el inicio de la madurez (VR=0,63%) a una profundidad de 3.250 a 3.285 m (10.663-10.778 pies) entre 30 y 39 Ma (Eoceno tardío al Oligoceno). Es importante destacar que las rocas generadoras del Cretácico permanecen dentro de la ventana de petróleo al ingresar en el Eoceno tardío. Los estudios satelitales muestran una gran emanación actual de petróleo en alta mar, en la parte sur de la cuenca y la sísmica 3D presenta indicadores directos de hidrocarburos (DHI) en imágenes como puntos planos y reflectores de simulación de fondo (BSR). El modelado de cuencas sugiere que las vías de migración de los hidrocarburos habrían sido ascendentes hacia el este, en dirección a las trampas en tierra y, por lo tanto, habrían llenado primero las trampas en alta mar a lo largo de la vía de migración. Se concluye que la cuenca Talara costa afuera ofrece excelentes oportunidades de exploración en un área productiva probada donde se han identificado múltiples prospectos.

Palabras clave: Potencial de hidrocarburos, Exploración costa afuera, Cuenca Talara, Perú.

1. Introduction

The undrilled deep-water Talara Basin is located along the northern Pacific margin of Peru (Travis *et al.*, 1975). It is the western extension of the Cretaceous and Paleogene-Neogene stratigraphy of the large, traditional reservoirs in the onshore Talara Basin oilfields. Higley (2004) mentioned a production of 1.68 billion barrels of oil in the last approximately 130 years. This basin is also located above the subduction zone of the active margin of South America, where the oceanic Nazca plate is subducting under the continental South American plate (Diniz *et al.*, 2010; Espurt *et al.*, 2018; Lemgruber-Traby *et al.*, 2020).

Current daily production from onshore Eocene sandstone reservoirs is around 15,000 boe from more than 2,600 active wells in an area of 460 km² (Perupetro, 2020¹). Well depths range between 500 and 2,800 m. The average oil gravity is around 33° API (25°-42° range) (Hinoztrosa and Espinoza, 2005) with very low sulphur content. The estimated remaining potential recoverable volume could reach almost 120 MMboe. Several secondary recovery projects have been implemented since 2003, with excellent results.

The western boundary and the unexplored offshore portions of the Talara basin are poorly defined (Figs. 1, 2). The onshore (eastern) margin is bounded by Paleozoic basement exposed in the Amotape Mountains and the southern Silla de Paita. The Amotape Mountains extend at a 60° angle from the Andes and, along with the Tamarindo High, separate the Talara basin from the Lancones basin (Valencia and Uyen, 2002). The southern limit of the onshore Talara basin is the Paita high (Silla de Paita) but there are no obvious equivalent barriers

present in the offshore portion. The basin is bounded to the north by the Dolores-Guayaquil megashar and the Pillars of Zorritos (Kraemer *et al.*, 1999; Higley, 2004).

The Talara basin covers at least 15,000 km², less than half of which is onshore (Figs. 1, 2) (Fildani, 2004). The onshore sedimentary deposits range from Cretaceous to Eocene in age (Fig. 3) and consist of clastic fill that is in excess of 9,000 m thick (Carozzi and Palomino, 1993). Middle-late Eocene strata of the Talara basin record a more complex story with a gradual deepening trend and deposition of deep-water systems. There was periodic extension after the Paleocene when subsidence was controlled by normal faulting allowing arc-related sediment to reach the basin only during periods of subsidence in the forearc region, probably related to plate rearrangement and/or seamounts colliding with the trench (Fildani *et al.*, 2008). This subsidence was filled by siliciclastic sediment from multiple origins, predominantly from the east and the northeast (Fildani, 2004). Limited carbonate facies are restricted to parts of the Cretaceous and Pliocene-Pleistocene sections (Marsaglia and Carozzi, 1991; Carozzi and Palomino, 1993).

The oldest rocks in the region are those of the Amotape Formation (Fig. 3), which is exposed in the Amotape Mountains and consists of deformed Devonian to Permian age low-grade metamorphic rocks (Shepherd and Moberly, 1981). These rocks form an uplifted block along the eastern sides of both the Tumbes and Talara basins and are also reservoirs in the Talara basin (Fildani, 2004). Mesozoic rocks are not well exposed in any part of the basin and the few known outcrops are difficult to access. The rocks of the Cretaceous Muerto Formation unconformably overlie

¹ Perupetro 2020. Statistics. <https://www.perupetro.com.pe/wps/portal/corporativo/PerupetroSite> (Last visit 20/02/2021).

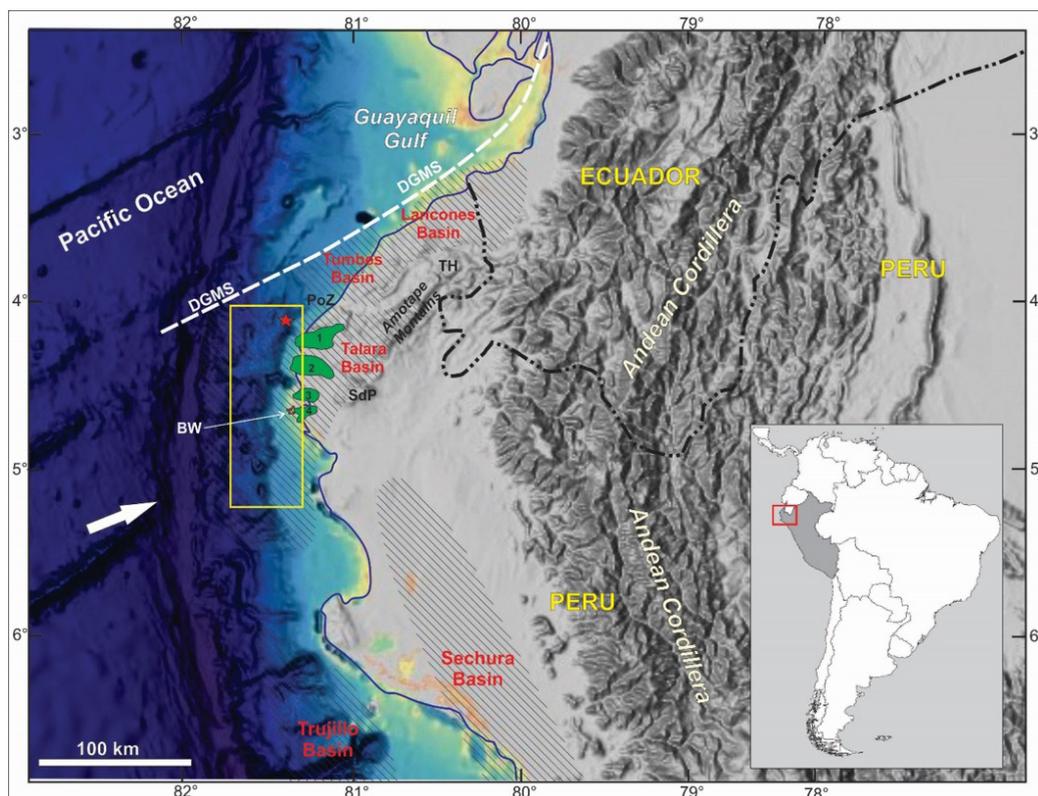


FIG. 1. The location of the Talara Basin, onshore Talara oil fields, Amotape Mountains and other features in northern Peru (**SdP**: Silla de Paita; **PoZ**: Pillar of Zorritos; **TH**: Tamarindo High; **DGMS**: Dolores-Guayaquil mega shear; **BW**: Belco Wells). **1**. Los Organos-Peña Negra oil field; **2**. Lobitos oil field; **3**. Providencia oil field; **4**. Litoral oil field. **White arrow** is the convergence direction of the subducted Nazca plate. **Red star** is the location of Prospect A. (topo-bathymetry from <https://maps.ngdc.noaa.gov/viewers/bathymetry/> (Last visit: 12/06/2021)).

the Amotape Formation and consist of limestone and bituminous marl. The Muerto Formation is overlain by a series of Cretaceous and Paleocene siliciclastic units. Limited data from onshore suggest that the evolution is from a mixed carbonate-siliciclastic environment in the Aptian to a more restricted environment during the Albian for the rocks of the Muerto Formation (Daudt *et al.*, 2010). During the Late Cretaceous (Campanian-Maastrichtian), alluvial fan and fluvial conglomerates and sandstones (*i.e.*, Tablones Formation) were rapidly transgressed by distal shelf shales of the Redondo Formation (Daudt and Scherer, 2006). Various authors have suggested that shales and limestones of the Cretaceous are the petroleum source rocks for the Talara basin, mostly Muerto Formation bituminous marls and the Redondo Formation black shales (Seranne, 1987; Zúñiga-Rivero *et al.*, 1999a, b; Arispe 2001a, b; Gonzales

and Alarcón, 2002; Higley, 2004). Fildani *et al.* (2005) conclude that the main source rocks are not the Upper Cretaceous limestones, marls and black shales, but we believe the negative correlation is due to the fact that no Cretaceous rock samples were analyzed from the offshore Talara basin.

The coastline is marked by a series of raised Pleistocene to Quaternary age marine terraces (Tablazos) composed of transgressive limestone and coquina beds and covering about 60% of the onshore basin (Pedoja *et al.*, 2006). These restrict the usefulness of onshore seismic in exploration (De Vries, 1988; Fildani *et al.*, 2008), but are not present in the surveyed offshore.

Different tectonic models have been proposed for the coastal area of Ecuador and northwest Peru, reflecting the fact that the post-Paleozoic tectonic history of the area is complicated and not simply

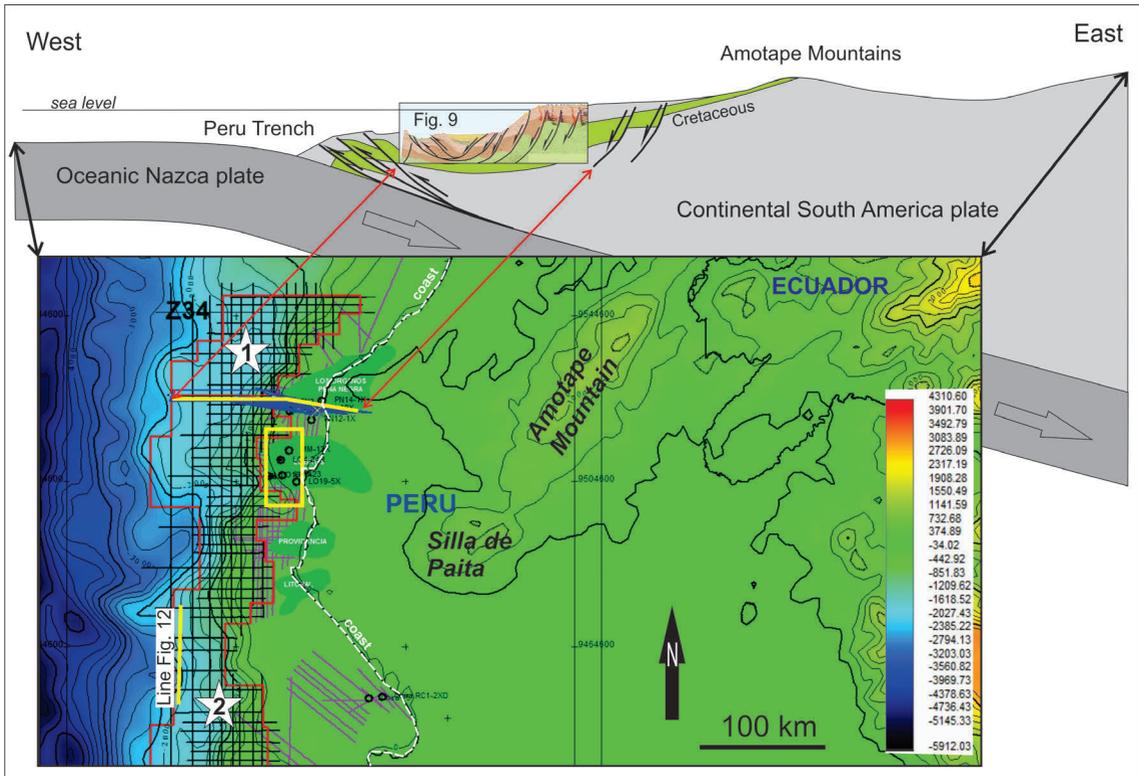


FIG. 2. The regional setting of the Talara Basin offshore portion immediately west of the traditional Talara oil fields, northern Peru. **Yellow lines** indicate the locations of seismic lines shown in figures 9 and 12. Two **white stars** within former Block Z-34 (**red lines**) show the locations of the two modeled pseudowells. **Yellow rectangle** is location of the Belco wells shown in figure 5.

related to subduction (Shepherd and Moberly, 1981; Jaillard *et al.*, 1995; Bourgois *et al.*, 2007). Aizprua *et al.* (2019) propose that the accretion of buoyant oceanic terranes may have had a profound impact on the early margin configuration of SW Ecuador and NW Peru. This led to the development of localized but genetically related forearc depocenters (*sensu* Dickinson, 1995) dominated by a Late Cretaceous (Peruvian Andean phase, Cobbold *et al.*, 2007) deforming outer wedge. This tectonic phase was governed by plate instability followed by re-establishment of the margin by early Eocene (Incaic Andean phase: Cobbold *et al.*, 2007). The resulting margin configuration and the spatial distribution of the different tectonic elements seem to have played a key role into the further Cenozoic (Quechua Andean phase) development of the forearc region. A more detailed account of basin evolution and sedimentary successions can be found in Fildani (2004) and Fildani *et al.* (2005).

This paper documents the petroleum system and exploration potential of the offshore portion of the Talara basin using the extensive knowledge of the onshore portion, and presents some of the prospective areas where success may be likely.

2. Materials and methods

The structural architecture of the former Z-34 block in the offshore area was interpreted using a 3D seismic reflection survey acquired in 2011 and wells provided by Perupetro S.A. Seismic interpretation was conducted using the Kingdom platform (Rossello *et al.*, 2016).

We reconstructed the hydrocarbon generation and migration history in the offshore Talara Basin using the structure maps generated from the 3D seismic survey and integrated available geological and geochemical data into a georeferenced database. A conceptual geological model of the basin, using

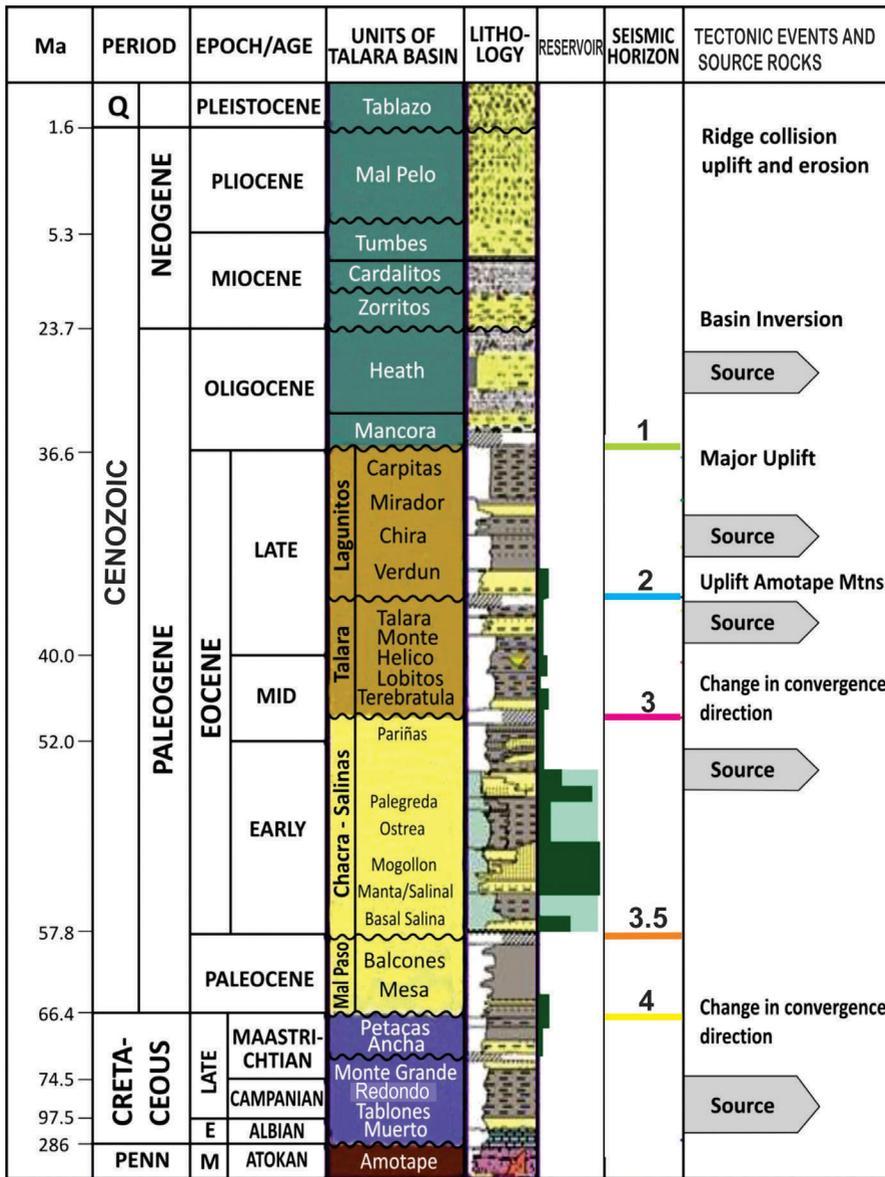


FIG. 3. Stratigraphic column of the Talara basin showing horizons mapped in the offshore part of the basin, main reservoir and source intervals. Seismic mapping horizons (1-4) are all unconformities. Modified from AIPC (no date), GonzalesTorres (1999), Kingston (1994), Kraemer *et al.* (1999), Perupetro (1999), and Seranne (1987). **Light green**: productive section (in **dark green** best reservoir levels). Lithology symbology from http://www.kgs.ku.edu/PRS/Ozark/PROFILE/HELP/DATA_ENTRY/lithology/Lithology-Symbols.html (Last visit: 12/06/2021).

only the major faults, was developed based on the interpretation of the 3D seismic survey calibrated by well data from the shallow marine platform and onshore oil fields. This model was then used to define a physical and temporal input necessary for petroleum system modeling (Magoon and Dow,

1994). Finally, an event chart was constructed showing the critical moments for the petroleum system.

The basin model (Hantschel and Kauerauf, 2009) was constructed using two pseudo wells (Fig. 4), chosen in the northern (Pseudowell 1) and southern

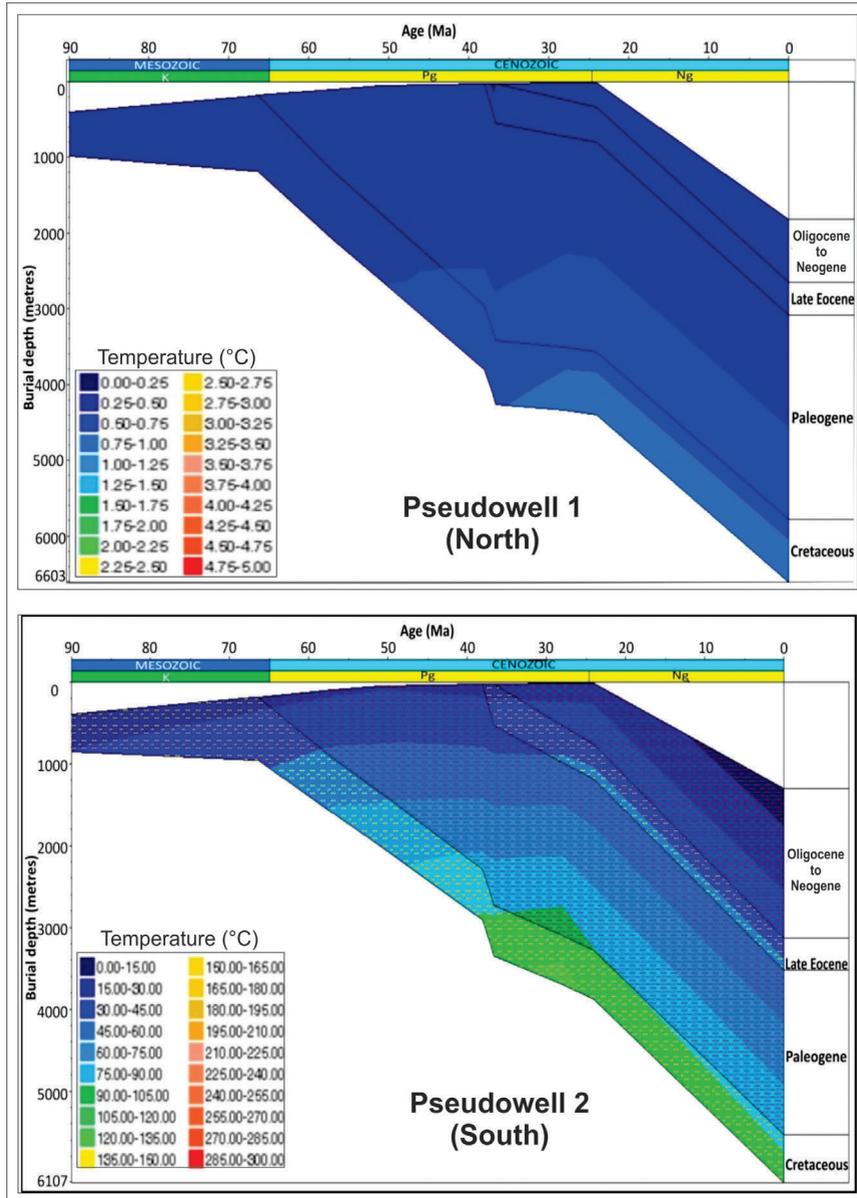


FIG. 4. Basin modelling for the pseudowells (see location in figure 2). This was chosen in the depocenter area of the block. Note that the Cretaceous enters the oil window (onset) at 39 Ma and stays within it until present-day.

(Pseudowell 2) parts of former Block Z-34 where the thickest section of sediments is expected. The onset of maturity in Pseudowell 1 at $V_r=0.63\%$ was determined to be at 3,250 m (10,663 ft) depth bsl at about 39 My (Fig. 4). The onset of maturity at Pseudowell 2 at $V_r=0.62\%$ was determined to be at 3,285 m (10,778 ft) bsl at about 30 My. Both the northern and southern kitchens are in the oil

generation window at the present-day. The maturity at Pseudowell 2 is confirmed by the oil present in the offshore and onshore Paita area in the Paleogene, Cretaceous and Paleozoic age reservoirs in the Talara Basin.

The chronostratigraphy for these pseudowell points was derived from the seismic interpretation and the modelled heat flow used was from the

Perupetro (2005). They derived a heat flow for the present day of 32-37mW/m² with heat flows as high as 35-48mW/m² in the early Eocene which were calibrated to vitrinite reflectance data in various wells. However, it is likely that heat flow is not constant in the basin and may vary considerably from one area to another (Lemgruber-Traby *et al.*, 2020). No sequence is identified which reaches gas maturity in the block.

3. Petroleum system

3.1. Source rocks

The main source rocks in the Talara basin are the Cretaceous (Campanian) black, marine shales of the Redondo Formation (with the Albian limestone of the Muerto Formation) and the marine shales of the Paleogene (Lemgruber-Traby *et al.*, 2020) (Fig. 3). The Muerto Formation contains Type II and Type II-III kerogen and has a Total Organic Carbon (TOC) content of 1-4.5 wt% (Perupetro, 2005).

The Campanian rocks of the Redondo Formation are the most volumetrically significant source rock in thickness and quality (Gonzalez and Alarcon, 2002) and contain Type II and Type II-III kerogen and 1-5.3 wt% TOC. It has excellent potential for hydrocarbon generation with a Hydrocarbon Index (HI) of over 400 mgHC/g TOC (Perupetro, 2005). It was deposited in an area of coastal upwelling and anoxic organic deposition (Pindell and Tabbot, 1995).

The Oligocene rocks of the Heath Formation are also believed to be a major source in the Tumbes and Trujillo Basins, but have been shown by burial history modeling to be immature in the Talara Basin (Lemgruber-Traby *et al.*, 2020). Other minor source rocks are known to be present in the Eocene (Higley, 2004).

3.2. Offshore reservoir rocks

There are more than 40 oil and gas fields in the Talara basin province which produce from up to 12 reservoirs per well (Higley, 2004). The primary reservoirs are the Eocene-age nearshore marine sandstones. The primary target offshore is also expected to be the Eocene-age reservoirs, but their environment of deposition is expected to be deepwater (turbidites) with a source from the northeast to southeast from the highlands created from the compressional uplift of the Andes.

The Paleocene/Eocene sequence is expected to be entirely deepwater clastic (turbiditic) in nature. Eocene reservoirs have been penetrated by wells at the Peña Negra, Lobitos, Providencia and Litoral fields nearby and are known to contain turbidite sandstones (Laverde *et al.*, 2010).

Rock properties of the Eocene Members and Formations are well documented onshore and in the shallow offshore areas (Table 1).

The rock properties of the reservoirs in offshore prospects may be better than those documented onshore because the Eocene turbidites should have better sorting and early migration of hydrocarbons may have preserved higher porosity and permeability values. Some better rock properties in the Pariñas Formation were observed in the Belco NHX-7 well, where up to 25% porosity was encountered (see Fig. 5 for location).

The Basal Salinas sandstones in the northern part of the onshore basin consist mainly of turbidite fans and incised valley fills that prograde to the southwest and northwest (Gonzales Torres, 1999).

An additional reservoir target offshore is the sandstones within the source interval of the Upper Cretaceous Redondo Shale and the Upper Cretaceous Ancha and Petacas Formations (Fig. 3). Four Talara Basin onshore fields produce hydrocarbons from

TABLE 1. AVERAGE ROCK PROPERTIES OF THE MAIN EOCENE RESERVOIR INTERVALS FROM BIANCHI (2002).

Eocene Formation	Porosity	Permeability
Helico (Talara Group)	12-15%	2-5 mD
Pariñas	11-19% (25%)	60-120 mD
Manta (Mogollon)	8-11%	0.15 mD
Basal Salinas Sand	11-16%	14-20 mD

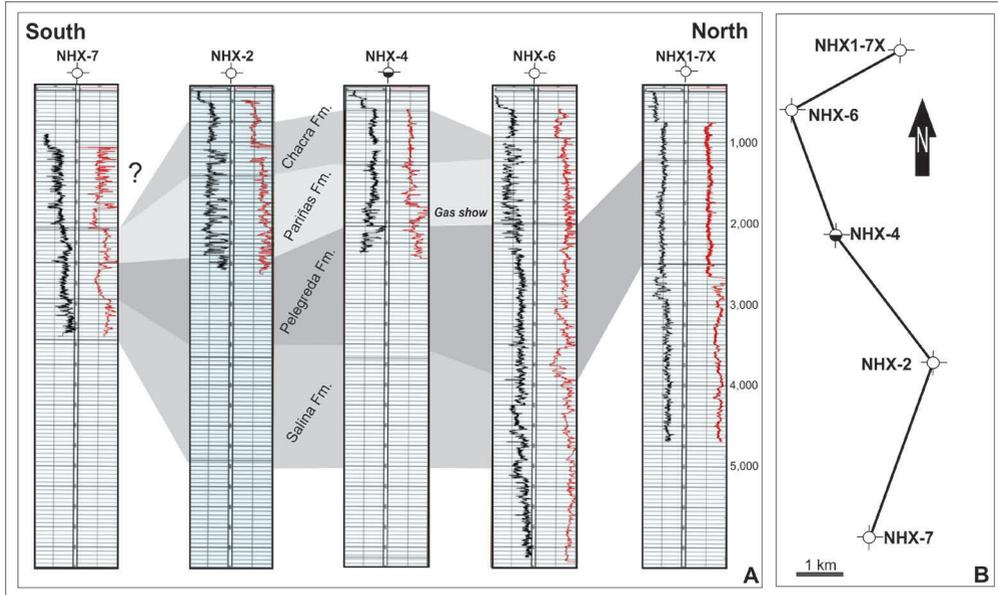


FIG. 5. **A.** Cross-section through five of the six Belco wells drilled in 1984 in shallow water on the eastern margin of Block Z-34 (Depths in feet). Note the gas shows within the Pariñas Formation which corresponds to U/C 3 mapping horizon. **Log header:** Gamma ray shown in black; Resistivity shown in red. **B.** Relative position of these wells (see figure 2 for location).

sandstones within the Cretaceous Redondo Shale and the Ancha and Petacas Formations and also from the basal Mal Paso Group (Fildani *et al.*, 2005).

The Pennsylvanian meta-quartzites and meta-limestones of the Amotape Formation (Fig. 3) can be a commercial reservoir when they are highly fractured (Grosso *et al.*, 2005) and capped by the Cretaceous Redondo Shale. The now abandoned Zorro field produced about 100,000 bbls from the Amotape Formation metamorphic basement (Petroconsultants, 1996). The overlying Muerto, Tablones and Redondo Formations contain probable source rocks and these could be sources for oil in the Amotape reservoirs. When oil is found in the Amotape Formation rocks (Perupetro, 2005) its properties are very similar to the Cretaceous-sourced oils which suggests it was sourced from the same marine shales (Higley, 2004). Four Talara Basin fields produce hydrocarbons from quartzites of the Amotape Formation (Petroconsultants, 1996). Porosities and permeabilities will likely be low in the Amotape Formation.

3.3. Seals

The main seal overlying the early Eocene interval would be the upper Eocene shales of the Talara and

Lagunitos groups (Fig. 3). Shales in the early Eocene Chacra Formation are seals in the onshore Litoral field (Fildani *et al.*, 2005). The Belco wells (Fig. 2) drilled in 1984 encountered the Pariñas Formation rocks (lower Eocene) with freshwater salinities indicating that the seals are intact.

3.4. Hydrocarbon kitchens

Thermal maturation modeling combined with structural mapping has shown that two hydrocarbon kitchens exist in the offshore Talara Basin (one in the north and another in the south (Figs. 2, 4)). The probable Cretaceous source rocks (Muerto and Redondo Formations) reached the onset of maturity (VR=0.63%) at a depth of 3,250 to 3,285 m (10,663-10,778 ft) between 30 and 39 Ma (Late Eocene to Oligocene). Importantly, the Cretaceous source rocks stay within the oil window once they enter it in the late Eocene and appear to stay within that maturity until the present-day.

The events chart (Fig. 6) indicates different potential source rocks in the Cretaceous (Muerto Limestone and Redondo shales) and Paleocene, Eocene and Oligocene Formations, which were deposited into the transition between oceanic and

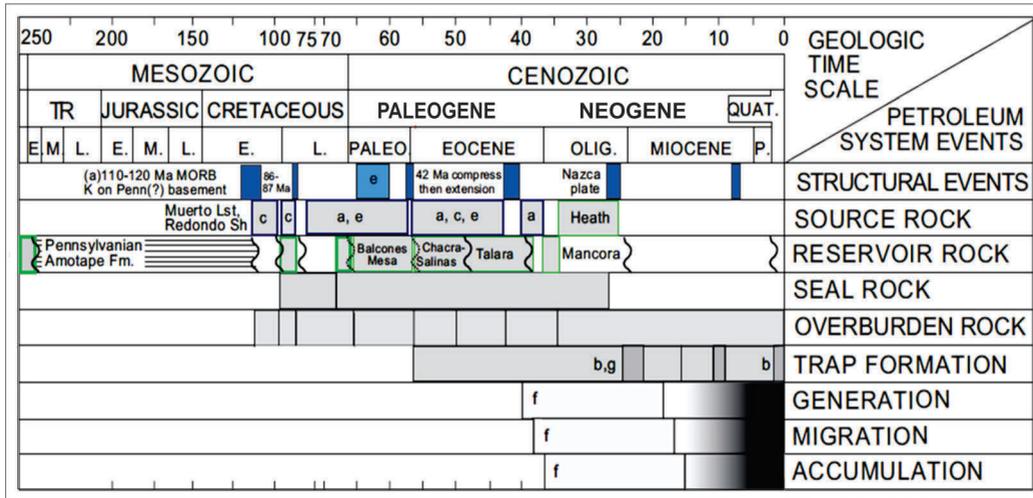


FIG. 6. Petroleum systems event chart of the Talara Basin Province indicating the petroleum system elements (source rock, reservoir, and seal), the timing of hydrocarbon generation, migration and accumulation, and the critical moment (taken from Higley, 2004). Letters **a**: AIPC (no author or date); **b**: Jaillard *et al.* (1995); **c**: Perupetro (1999); **d**: Petroconsultants (1996); **e**: Zúñiga-Rivero *et al.* (1999a, b); **f**: Kingston (1994); **g**: Shepherd and Moberly (1981). **E**: early; **M**: medium; **L**: late; **Olig.**: Oligocene; **P.**: Pliocene; **Quat.**: Quaternary.

continental lithosphere without direct influence of the active subduction. The seal rock ranges from Cretaceous to Oligocene in age and consists mainly of shales. The critical moment, or peak generation, is at 10 Ma.

These two hydrocarbon kitchens are the main locations of oil generation for the onshore and offshore in the Talara Basin. Cumulative oil production from current fields in the Talara Basin amounts to over 1,600 million bbl and a similar estimated amount remains to be discovered and produced. Modeling and source rock potential indicates offshore kitchens where few wells have been drilled in water depths exceed 100 m (328 ft).

3.5. Migration

The onset of migration from the Cretaceous source rocks probably took place in the late Eocene to Oligocene (39-30 Ma), as indicated by our basin modeling studies. Migration was mostly in an updip and easterly direction from the two offshore source kitchens via vertical and sub-vertical faults (Fig. 7). Structural and stratigraphic traps along the migration pathway would have preferentially filled first, before the traps of the onshore fields, such as Peña Negra and Los Organos, were filled.

Migration is still occurring today, as indicated by the sea-surface oil slicks mapped from satellite data (Fig. 8). Present-day oil seeps are shown to be occurring where a large down-to-the-west normal fault is expressed as a scarp on the sea floor (Fig. 7).

4. Reservoir and target/prospect definition

The Talara Basin contains a working petroleum system and has been producing from onshore fields such as Peña Negra, Lobitos, Providencia and Litoral since the mid-1800s. All the elements of the petroleum system are present: source, reservoir, seal and overburden. The components of the petroleum system are also present: the trap formation, generation, migration and accumulation.

The main potential Eocene reservoirs are characterized by alternating marine shales, sandstones, and conglomerates deposited during the early Paleogene. Many of the Eocene sandstone intervals are producing reservoirs onshore (Daudt and Scherer, 2006; Daudt *et al.*, 2011). Normal faulting affected the basin extensively during and after deposition of the basin-fill and created the traps. Offshore mapping horizons are all unconformities within the Eocene as well as the unconformities at the top Paleocene and top Cretaceous (Fig. 3). Correlation from onshore

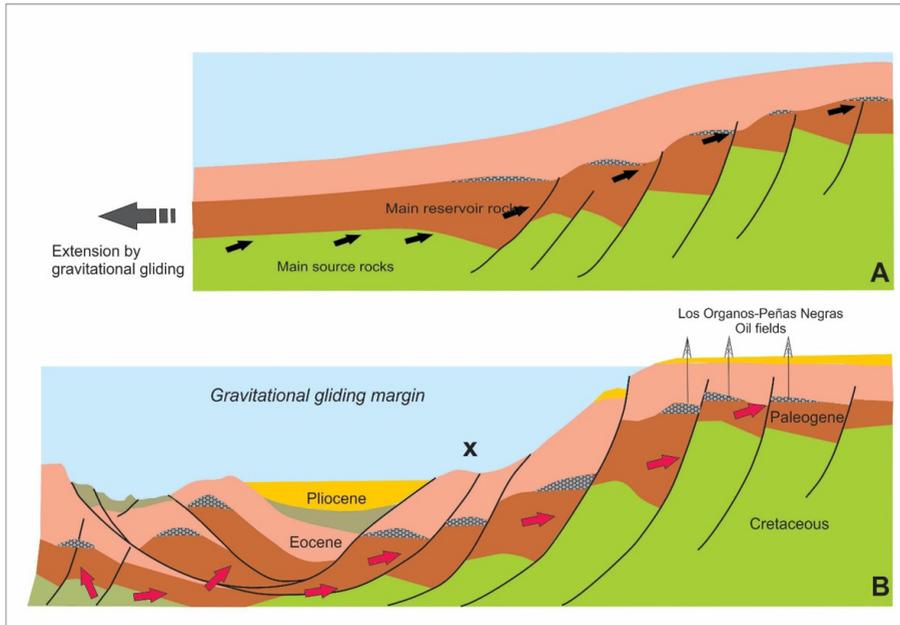


FIG. 7. E-W schematic diagram showing the evolution of the hydrocarbon migration from the offshore source kitchens to the traps in the Talara basin based on the figure 9 seismic lines (see location in figure 2). **A.** Early stage of migration (black arrows: estimated migration routes). **B.** Present-day migration pathway (red arrows), traps shown in gray. Sea floor scarp at **X** is where the present-day oil seep is located.

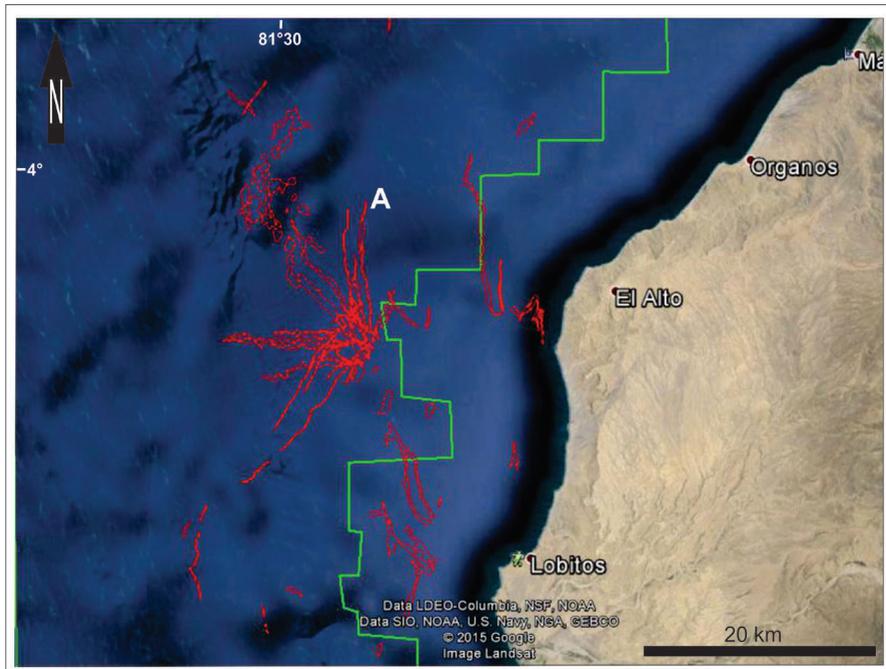


FIG. 8. Map showing radiating pattern based on satellite and radar scenes of present-day oil seeps on the water surface just to the south of Prospect A, showing that migration is occurring at the present-day from a point-source about 15 km south of Prospect A. Green line: eastern border of the former Z-34 Block.

to offshore within the basin is difficult due to the lack of seismic data onshore and a lack of published formation tops and time/depth data (Fig. 9).

Many direct hydrocarbon indicators (DHIs) such as amplitude anomalies (AVO anomaly) and flat spots have been observed in the offshore portion of the Talara Basin. In Prospect A, located immediately west of the onshore Los Organos-Peñas Negras oil fields (Fig. 1) above the main prospective Eocene interval, an AVO anomaly was also observed above the top Eocene U/C 1 horizon (Fig. 10). This anomaly appears on the southwest flank of Prospect A and is about 105 m (345 ft) above the top of the Eocene prospective interval and crosses structural contours, indicating there must be a stratigraphic component to the trap.

At the U/C 1 mapped horizon on the same structure of Prospect A there is an amplitude anomaly immediately below the crest of the structure on Prospect A (Fig. 11). There are also Eocene-Paleocene strong amplitude anomalies between horizons U/C 2 and U/C 3 which appear to onlap the U/C 3 structural

high (Fig. 12). The older amplitudes are evident on the west side of high and do not conform to structure contours, suggesting a stratigraphic trapping element. Flat spots have also been identified at the downdip limits of the amplitude anomalies below U/C 3 and U/C 1 (Fig. 11).

The presence of gas hydrates offshore Peru was postulated by Miller *et al.* (1991) who evaluated 2D seismic data recorded by Shell in deep water offshore Lima and noted the presence of a Bottom Simulating Reflector (BSR). The origin of this gas is probably biogenic since the proposed Cretaceous source rocks are in within the oil window today. The 3D seismic data in former Block Z-34 also shows clear evidence of BSRs in sediments that appear to contain many sandstones of reservoir quality (Fig. 13). Mapping of the BSR and the water bottom on 3D data enabled the thickness of the gas hydrate zone within the sediments to be estimated. Figure 13 shows the gas hydrates to be between 525-579 m (1,722-1,900 ft) thick over Prospect A, based on velocity measurements

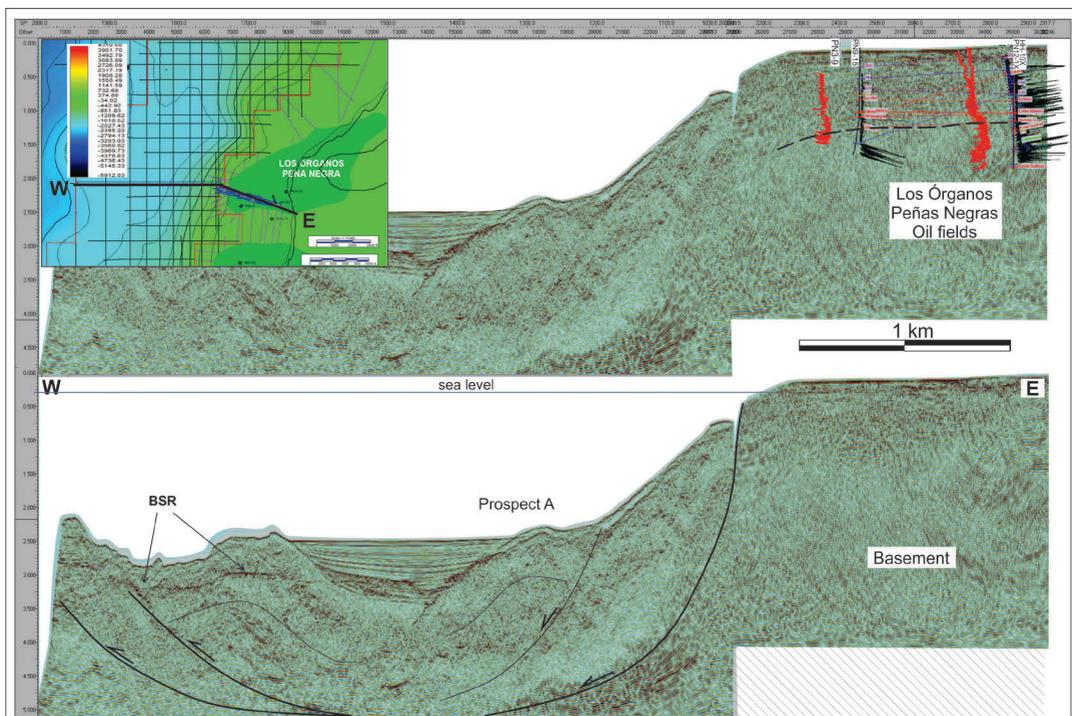


FIG. 9. W-E interpreted (lower) and uninterpreted (upper) cross-sections showing the correlation from onshore producing oil fields to the offshore Talara Basin and the position of the Prospect A. Well logs; Gamma ray in red and resistivity in black (LLD). Insect shows the location of the section. Dashed line is the estimated top of the basement.

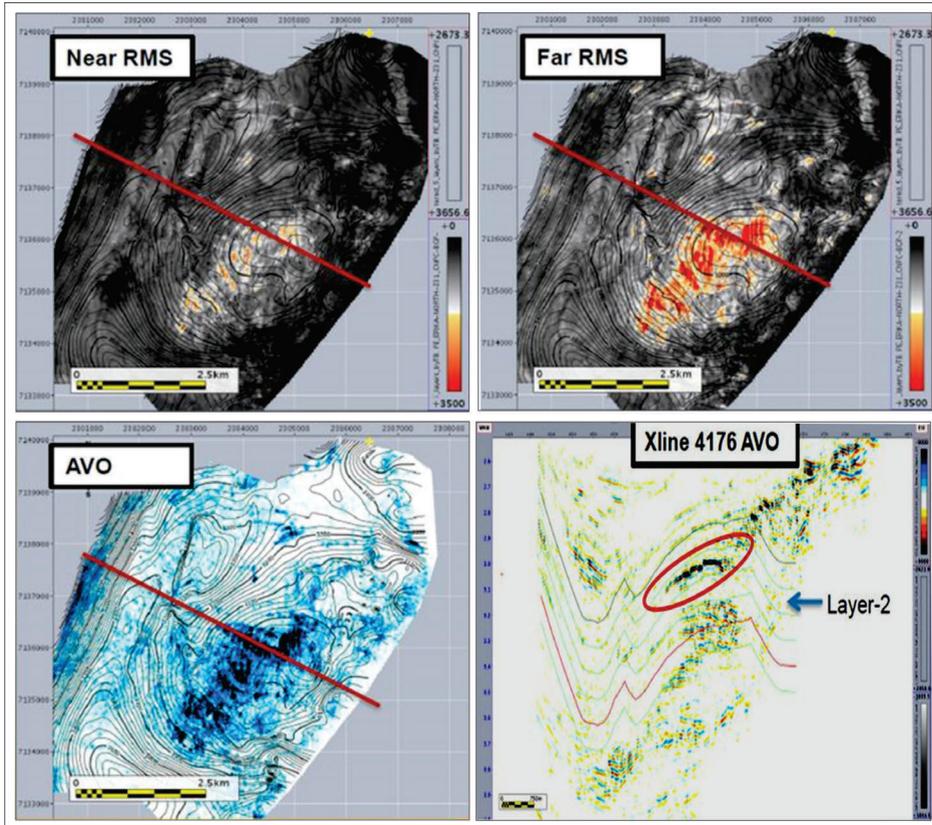


FIG. 10. Near and Far root mean square (RMS) amplitude anomalies on the southwest flank of Prospect A (see figure 1 for location). The anomaly is about 105 m above U/C 1 (top Eocene), in the Oligocene section. It crosses the structural contours, indicating a stratigraphic trapping component. Red line shows the position of the seismic line in figure 11. Red ellipse: strong AVO anomaly.

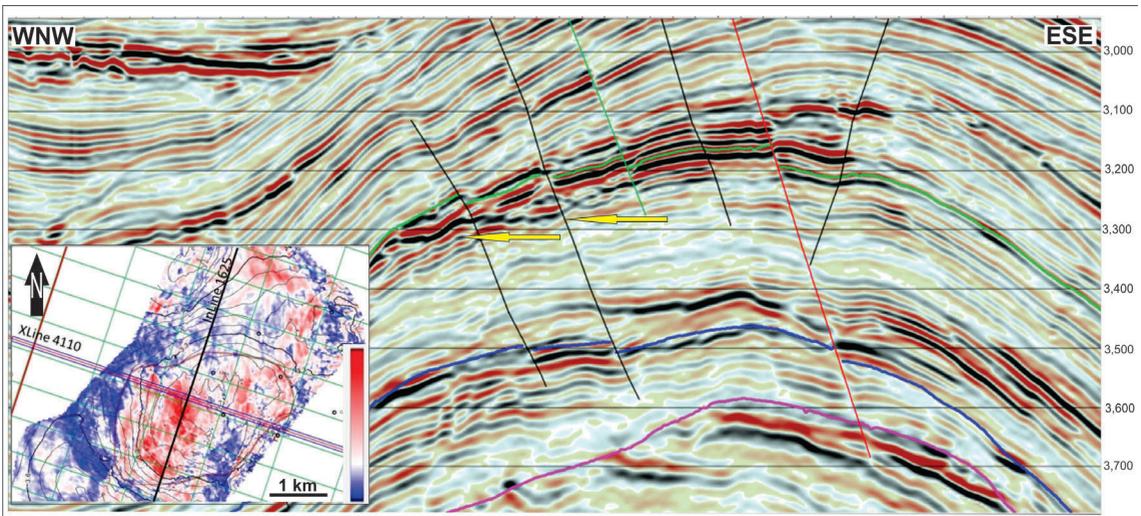


FIG. 11. Flat spots (yellow arrows) at the termination of the amplitude anomalies underlying U/C 1 (green line) in the XLine 4110 (see figure 13) at Prospect A (see location in figure 2). Vertical scale in milliseconds. Inset shows location of this line. Green, red and black are faults.

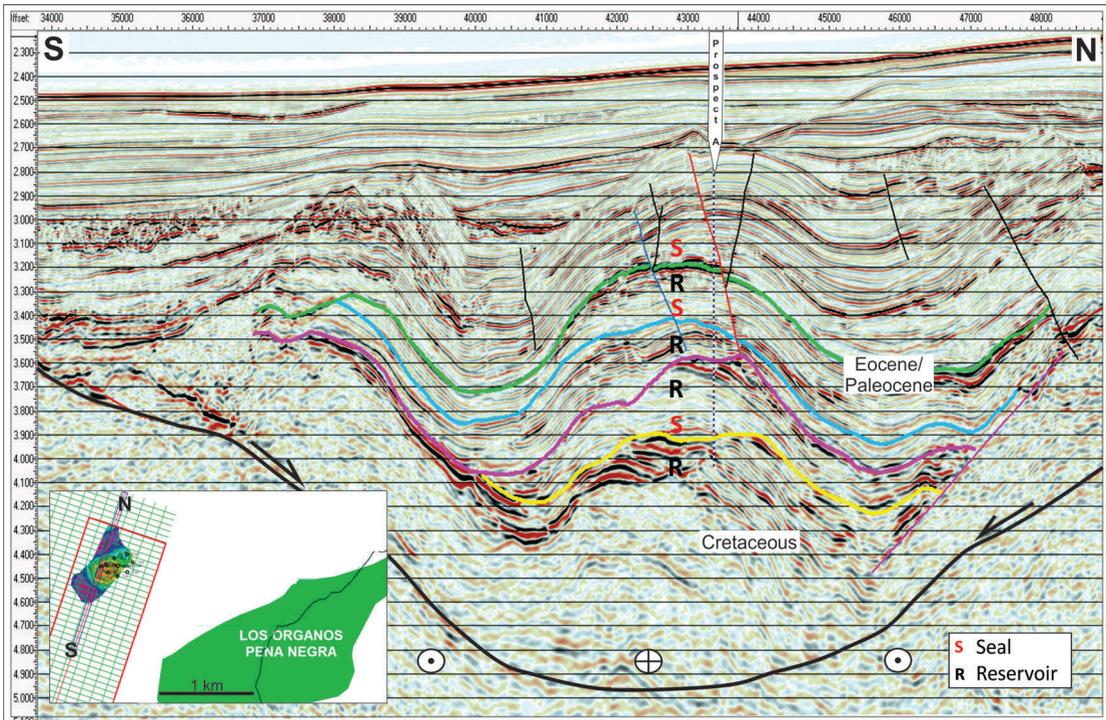


FIG. 12. North-South seismic line 1615 across Prospect A. This line shows the shape of the gravitational gliding toward west of the block, where Prospect A is located. See location in figures 1 and 13. **R**: Reservoir, **S**: Seal (inferred from transparent seismic facies). Yellow line: top Cretaceous; Violet line: U/C3 (top Pariñas Fm.); Blue line: U/C2 (top Talara Fm.); Green line: U/C1 (top Eocene).

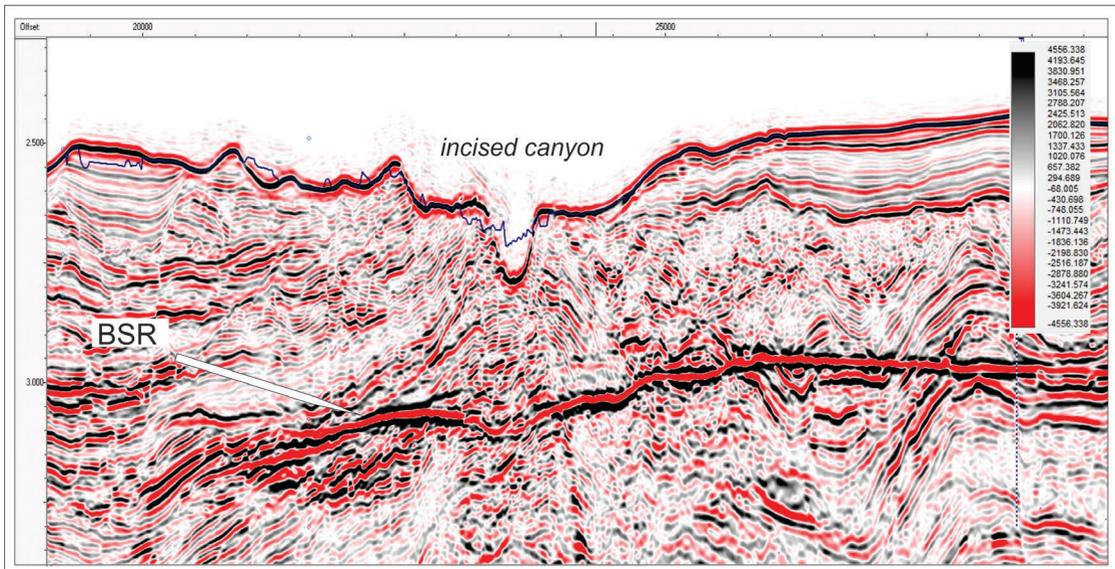


FIG. 13. A typical Bottom Simulating Reflector (BSR) near Prospect A. Seismic line location is shown in figure 2.

from a group of wells with similar stratigraphy in the Gulf of Mexico (Birchwood *et al.*, 2007).

At least six different play types were identified during the mapping of 3D data in the offshore Talara Basin: **1)** Rollover anticline traps with Eocene reservoirs; **2)** Tilted fault block closures with Eocene reservoirs; **3)** Deep-seated anticlinal structures; **4)** Stratigraphic traps with Eocene or Oligocene reservoirs; **5)** Traps below the BSR. At least 23 prospects were identified in the basin.

One of the best prospects is a rollover anticline (Prospect A) located within a mini passive-margin setting, where a large down-to-the-west growth fault is mapped (Figs. 9, 13). Mapping shows that the trap at Prospect A is a structural high where the structure started to form during deposition of the main Eocene reservoir section due to the movement of the large growth fault to the east of the prospect (Fig. 14). The trap is a rollover anticline modified by intra-Eocene unconformities, which were used as the main mapping horizons (Fig. 14). It is located less than 20 km west of the producing Litoral field onshore in a water depth of 1,800 m.

Several unconformities throughout the Eocene reservoir section confirm that the structure started to form in the early Eocene. The four unconformities used in seismic mapping are also shown on figure 3. Three are within the Eocene and one is at the top of the Cretaceous. The structure is present on all mapping horizons down to the top Cretaceous. The main reservoir section is the Eocene Talara Formation, the top of which is at about 39 Ma. Therefore, the reservoir and the trap formed at the ideal time, just before the onset of maturity in the Cretaceous source rocks. Our thermal modeling presented here suggests it is unlikely that the Cretaceous source rocks have entered the gas window.

5. Conclusions

The offshore Talara basin in Peru is an extension of the onshore working petroleum system that has been explored and has produced in excess of 1.68 billion barrels of oil in the last 130 years. During our study of the offshore and based on the interpretation of the 1,100 sq km of marine 3D seismic survey (acquired in 2011) we identified at least 23 prospects

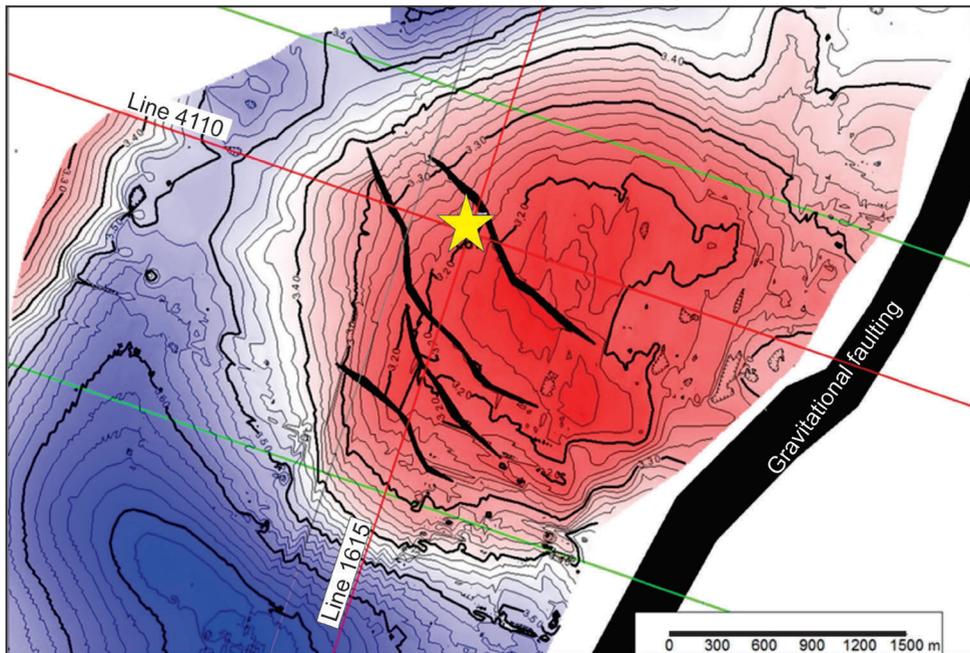


FIG. 14. Structure map on top of U/C 1 at Prospect A (see location in figure 9). Yellow star is the proposed well location. Red lines: seismic lines shown in figures 11 and 14. Green lines: grid of the former Z34 Block. The thick black lines represent the large normal fault, downthrown to the west.

in 6 different plays confirming the offshore Talara Basin offers excellent exploration opportunities. One of the best prospects, Prospect A, is located within a mini passive-margin setting in a water depth of 1,800 m (5,905 ft) and could be tested with a well with a total depth of about 4,200 m (13,700 ft) with a top reservoir section estimated to be at about 2,700 m (8,860 ft).

Potential reservoirs are interpreted to be up to 700 m (2,300 ft) thick with predicted porosities up to 25% due to better sorted sediments and porosity preserved by early hydrocarbon charge. Deeper targets are also thought to be the Upper Cretaceous sandstones in the Redondo Shale, Ancha and Petacas Formations. Another deeper reservoir target might be the fractured low-grade metamorphic rocks of the Amotape Formation, which have produced hydrocarbons in the onshore Talara basin.

The main hydrocarbon source is interpreted to be the Cretaceous (Albian-Campanian) shales, which started generating hydrocarbons at about 39 Ma. The migration pathway was easterly from the two offshore source kitchens and is still occurring today as shown by the sea floor oil seeps. The best prospects are located on the migration pathway between the source kitchens and the Talara Basin onshore oil fields.

The risk of the presence of hydrocarbons in the offshore basin has been reduced due to the presence of amplitude anomalies in structural and combination traps and the identification of multiple flat spots at the downdip limits of these anomalies. The trapping risk has been reduced due to the interpretation of older unconformity traps which would have been present at the time of migration in approximately the Late Eocene to Oligocene.

Despite the fact that the studied area is located on a tectonically active subducting margin, the presence of preserved mini basins on its accretional prism generates an interesting hydrocarbon system to sustain an attractive and underexploited exploration objective.

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