

Mexico's Offshore Gulf of Mexico

A New Look at Its
Untapped Oil Potential

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ABOUT THIS REPORT

Offshore oil and gas in the Gulf of Mexico extends from the United States into Mexico. On one hand, the U.S. has played a highly active role in the development of offshore oil and gas reserves, with production in that area accounting for 17% of total U.S. crude oil production. On the other hand, 90% of Mexico's portion of the Gulf of Mexico province remains unexplored and is thought to have substantial oil and gas potential. This contrast in activity stems largely from the Mexican government delaying until the passing of the energy reform in 2013 to end the monopoly of the state-owned oil company *Petroleos Mexicanos*. This opened the energy sector to private participants for the first time in exploration and production activities. The first bidding rounds for deepwater oil and gas fields in the Perdido Fold Belt and Cuenca Salina were held in 2015. Subsequently, exploratory drilling by private companies on the Mexican side of the Gulf of Mexico increased in recent years, which further revealed that Mexico's favorable geologic characteristics offer substantial untapped offshore oil and gas potential in the Gulf of Mexico. Over the next decade, Mexico's deepwater awarded projects are expected to continue advancing reaching production phase.

Authors Rafael Sandra and Peter Stark bring a wealth of experience and expertise in evaluating the resource potential of geologic basins worldwide. Their paper on the isoOIP model demonstrates how simple and inexpensive decision support tools can continue to contribute to cost effective development of the nation's oil and gas resources.

ABOUT EPRINC

The Energy Policy Research Foundation, Inc. (EPRINC) was founded in 1944 and is a not-for-profit, non-partisan organization that studies energy economics and government policy initiatives with special emphasis on oil, natural gas, and petroleum product markets. EPRINC is routinely called upon to testify before Congress as well to provide briefings for government officials and legislators. Its research and presentations are circulated widely without charge through posts on its website. EPRINC's popular Embassy Series convenes periodic meetings and discussions with the Washington diplomatic community, industry experts, and policy makers on topical issues in energy policy.

EPRINC has been a source of expertise for numerous government studies, and both its chairman and president have participated in major assessments undertaken by the National Petroleum Council. In recent years, EPRINC has undertaken long-term assessments of the economic and strategic implications of the North American petroleum renaissance, reviews of the role of renewable fuels in the transportation sector, and evaluations of the economic contribution of petroleum infrastructure to the national economy. Most recently, EPRINC has been engaged on an assessment of the future of U.S. LNG exports to Asia and the growing importance of Mexico in sustaining the productivity and growth of the North American petroleum production platform.

EPRINC receives undirected research support from the private sector and foundations, and it has undertaken directed research from the U.S. government from both the U.S. Department of Energy and the U.S. Department of Defense. EPRINC publications can be found on its website: www.eprinc.org.

ABOUT THE AUTHORS

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Dr. Sandrea is a life-member of the SPE, and member of the UN Ad Hoc Group of Experts on Fossil Resources – Geneva. He has published over 40 technical papers covering areas such as risk analysis for international upstream petroleum investments; appraisal of global oil and gas reserves — conventional and unconventional; development of algorithms for estimating the production capacity of new oil and gas fields, for estimating the reserves of mature oil & gas fields; global offshore oil reserves potential; assessment of global oil and gas resources, and their potential for enhanced oil recovery — EOR. Together with Dr. Ralph Nielsen, he has published the book: “Dynamics of Petroleum Reservoirs under Gas Injection,” Gulf Publishing, which has been used in petroleum engineering schools worldwide. He recently co-authored the book: “Mexico-History of Oil Exploration,” PennWellBooks.com, Sept. 2018. He is a member of the Penn Energy Research Emissary expert marketplace program: info@emissary.io.

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INTRODUCTION

Mexico's offshore Gulf of Mexico waters have been credited with substantial recoverable reserves and are estimated to have significant undiscovered oil and gas resources. Through 2019, Mexico had discovered almost 54 billion barrels of oil (Bbo) reserves distributed between its two super basins: the prolific southeast basin with 48 Bbo and Tampico-Misantla-Veracruz (TMV) basin with 6 Bbo. Offshore southeast accounts for a huge 34 billion barrels discovered in 130 oil fields including 11 giants (of Mexico's total of 19 oil giants), all in shallow water depths less than 165 meters. The deepwater Trion field in the Perdido Fold Belt area is the exception, with reserves around 270 million barrels (mbo), in water depths of 2,564 meters. Even though most of Mexico's exploration activity since 1975 has targeted offshore prospects, 90% of Mexico's portion of the Gulf of Mexico province remains unexplored and is thought to have substantial untapped oil and gas potential. During 2012, the U.S. Geological Survey estimated that three offshore provinces (Burgos, Tampico-Misantla and the Campeche-Sigsbee Salt Basin) contained 75% of Mexico's undiscovered oil resources (14,295 Bbo) and 70% of its undiscovered gas resources (58.355 Tcf).¹ A year later, Guzman noted that Pemex estimated Mexico's deepwater potential to be 30 Bboe.² More recently, based on Zipf curves, Shann estimated the offshore Sureste Basin alone could have 20 Bboe of undiscovered resources.³

Until now, naturally fractured carbonate reservoirs of Jurassic and Cretaceous age account for almost 97% of Mexico's oil production while Cenozoic sandstones are the predominant gas reservoirs. Mexico has produced a total of 45 billion barrels of oil to date including 26 billion barrels offshore, and has 6.4 billion barrels of remaining reserves. Current production is about 610 million barrels per year, of which 80% is produced offshore.

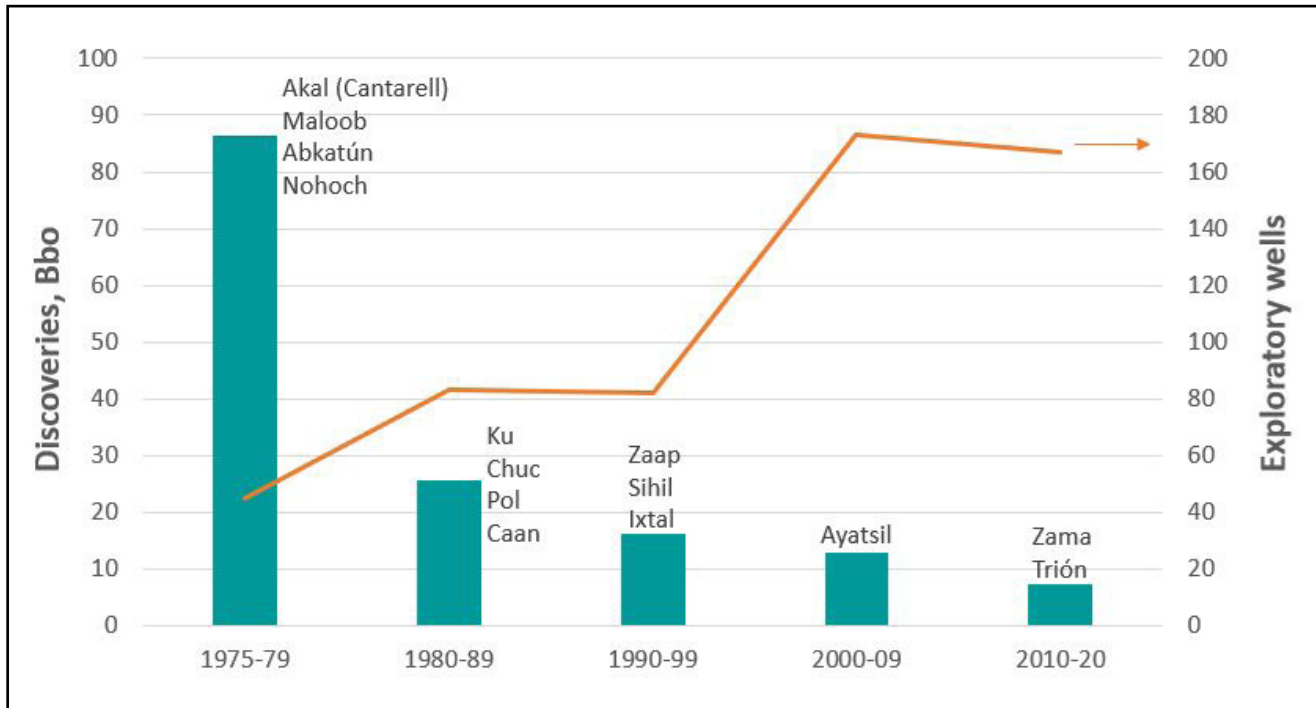
OFFSHORE DISCOVERIES AND EXPLORATORY WELLS

Over the past fifty years, exceptional exploration attributes in the offshore area have made it the preferred choice to boost Mexico's reserves.⁴ While exploration success rate is about 10% for onshore, it is triple that for offshore. In the Sureste basin, the average field size (reserves) is 318 mbo offshore versus 92 mbo onshore; the average size of onshore TMV fields is even lower at 50 mbo per field. On top of that, average discovery size per well offshore is 68 mbo, more than 13 times that of the onshore average. Offshore exploration is correspondingly a high priority and deepwater

Cenozoic prospects are the prime objective for Mexico.

Fig. 1 offers a historical view of discoveries and exploratory wells drilled offshore since production took off in 1975. A constant decline of new discoveries since the 1980s is evident despite the significant increase in the number of exploration wells drilled. Pemex stepped up exploration activities throughout the 2000s following the onset of a high decline rates in Cantarell area production after reaching its peak in 2004.

Figure I
Offshore Discoveries (OIP) and Exploratory Wells Drilled



Source: SENER; Comisión Nacional de Hidrocarburos (CNH)

As illustrated in **Fig. 2**, Mexico’s offshore discovered reserves are concentrated in two prominent clusters: a very large one in the southeast dominated by Mesozoic carbonates of the Sureste basin and the other in the northern Cenozoic Perdido Fold Belt Corridor. In the lightly explored offshore TMV basin, ten discoveries were made in shallow waters (25-55 meters) near its rim. Eight of these on the Tuxpan Platform were in the Cretaceous with an average OIP of 122 mbo. Two others were in the Jurassic: Arenque with an OIP of 1,300 mbo, and Merluza with 24 mbo. The Cenozoic is absent and was not a target in any of the offshore TMV wells.

Following Mexico’s landmark energy bill in 2014, some 50 private companies were awarded licenses to explore 67 blocks (27 deep water and 40 shallow water) in the Gulf’s untapped offshore hydrocarbon resources. Since 2017, private companies drilled a total of 26 exploration wells, all targeting the Cenozoic in the Sureste and Perdido areas; only two wells (Chibu and Max) additionally targeted the Jurassic. In the Perdido area, two

ultra-deepwater wells (Etzil and Trion) were drilled and four more (Xakpun, Ameyali, Xochicalco, and Chimalli) are scheduled to be spudded by year end. In Sureste, two ultra-deepwater wells, two deep water and 19 shallow water wells were drilled; an additional deep water well, Batopilas, is scheduled for 2021.

During this same period, 2017 to mid-2020, Pemex drilled 49 exploratory wells offshore, generally in areas adjoining the licensed blocks and targeting the Cenozoic. Seven wells were drilled in the Perdido area, and the rest are located along the Reforma subbasin trend and in the adjacent Salina subbasin. Previously, in 2011, Pemex had drilled the key deepwater Puskon wildcat well near the margin of the Misantla and Deep Gulf of Mexico provinces. It reached the Cenozoic (Paleocene) at 7,700 meters and was abandoned after reporting only gas shows. So far, the 17 exploratory wells drilled since 2017 by private industry in the area west of Cantarell have discovered five new Cenozoic oil fields, including the giant Zama field and two world-class fields (Amoca and Hokchi).

Pemex also reported two smaller but interesting discoveries near Hokchi that were dry in the Cenozoic but found oil in Mesozoic reservoirs. The

Xikin-1DL found oil in the Jurassic and Suuk-1A found oil in the Cretaceous.

Figure 2
Mexico's Top 100 Offshore Oil Fields



Source: Comisión Nacional de Hidrocarburos (CNH)

Fig. 2 shows recent important dry holes and pending wildcat locations in context with Mexico's top 100 offshore oil fields. The orange and green well-symbols highlight the giant fields and other major producing fields, respectively, while the color white shows the non-commercial or dry holes. The map also shows, for reference purposes, three well-known giant fields discovered onshore: two in the TMV basin (Poza Rica and San Andrés) and one in Sureste (Samaria). Overall, Mexico's onshore accounts for a total of nine giant oil fields discovered to date: seven in Sureste and two in the TMV basins.

In broad terms, Mexico's unexplored mostly deepwater offshore is believed to have substantial untapped oil and gas resources. This study is not a

geologic assessment of Mexico's offshore Gulf, but attempts to redefine its prospective areas following the results of the exploratory drilling activity of the last three years, taking into consideration current technological constraints such as drilling limits with respect to both reservoir and water depths. This information would be helpful in the orientation of new licensing activity, essential at this point to keep investors interested and to sustain efforts to revitalize Mexico's still sluggish oil production.

A spatial volumetric methodology – the iso oil-in-place (isoOIP) model which was field-validated in a recent paper – is used in this paper to identify potential areas of interest in the Perdido Corridor and Sureste basin.⁵ The potential of

Mexico's proven offshore reservoir sections in Cenozoic, Cretaceous, and Jurassic sediments also is considered. Mexico's offshore is unique in that most of the producing fields and exploration drilling sites are clustered in the northernmost and southernmost parts of the Gulf. In between, there are only a few producing fields along the shelf margins and even fewer deepwater exploratory wells. This scenario is particularly fitting for

the isoOIP methodology which can be used to highlight favorable or unfavorable potential OIP volumes nearby to established production such as in the Perdido Corridor and the Sureste basin. The isoOIP methodology also is uniquely suitable to estimate oil-in-place volumes in separate reservoir levels and in areas associated with technological constraints such as ultra-deep waters and deep HPHT reservoirs.

REMAINING UNTAPPED OIL POTENTIAL

Cenozoic Potential

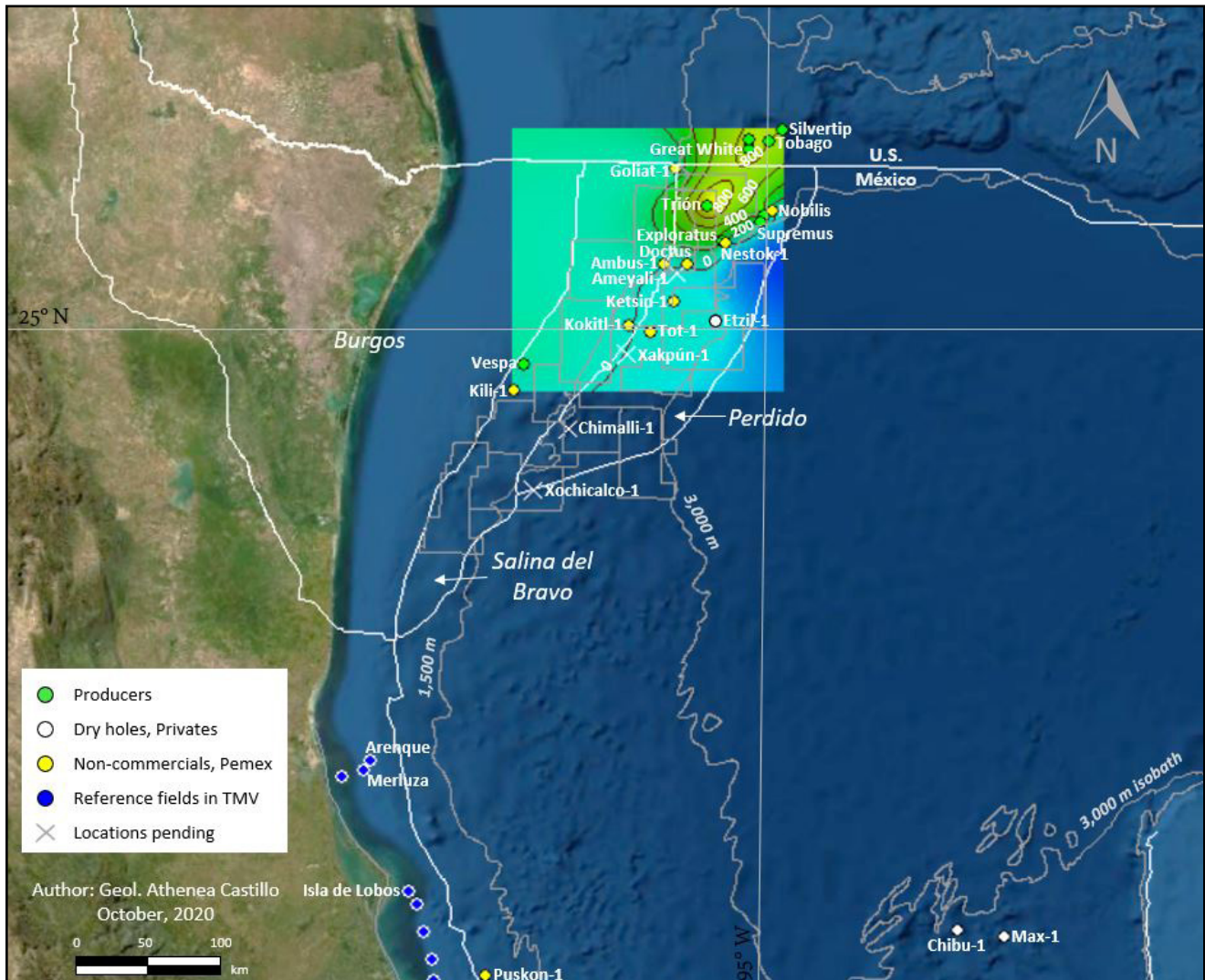
The discussion of Cenozoic potential is divided into two parts, one for the northern Perdido area and the other for the large southern field cluster in the Sureste basin. The sizeable distance (700 kms) between them, with no intermediary control points, was the determining factor for the partition. Overall, the Cenozoic has been penetrated by wells in about 130 oil fields from the Perdido area down to the end of Mexico's oil crescent at Cantarell, along the flank of the Campeche Uplift. On the maps in **Figs. 3** and **4**, the string of fields from Arenque to Morsa along the western margin of the Gulf correspond to the TMV basin. These fields are not included in this study but are shown for reference purposes. The Cenozoic is absent in this area and the fields produce from the Cretaceous and Jurassic. For a more complete regional coverage, 30 major onshore fields at the southern end of the Sureste basin have been included in the analysis.

Perdido Corridor

Fig. 3 shows the isoOIP map for the international Perdido Corridor. Outlines of the existing licensed blocks are included for your reference. The Mexican side of Perdido hosts two undeveloped potential producers including the important Trion field with an OIP of 1,080 mbo. Trion's OIP resources have been confirmed by appraisal drilling, but commerciality of the estimated OIP of 480 mbo at Maximino is uncertain. The latest dry hole drilled by Privates, Etil-1,

amplifies an already southerly diminishing OIP trend along with disappointing results of the Exploratus, Supremus, and Kili-1 (in the neighboring Salina del Bravo sub-basin) exploratory wells drilled previously by Pemex. Since 2017, Pemex has drilled seven exploratory wells with no successes. These Pemex wells are shown in yellow in **Fig. 3**. On the western flank of Perdido, Pemex's recent Goliat-1 well, also a dry hole, raises new concerns about the potential to add significant new resources in Mexico's Perdido Corridor. Fundamental geo-challenges in the Perdido Corridor already require substantial OIP to meet economic thresholds. Many prospects are in ultra-deep water as Cenozoic reservoir depths range from 3,600 to 4,000 meters; abnormal pressures may be encountered. Paleogene reservoirs are tight with low recovery factors; and there is little established infrastructure to facilitate production. But the Perdido Fold Belt's complex structures can host large fields and many exploratory wells may need to be drilled to resolve ultimate commerciality of the play. Of interest, the zero isoOIP contour line on this map almost coincides with the important 3,000 meter isobath. Four wildcats scheduled to be spudded in the coming months near and along the zero OIP contour will provide vital information on the future potential of this important deepwater play. Results from CNOOC's recently (October) drilled Ameyali-1, a 1,345 mbo prospect about 50 km south of Trion, will be closely watched by all stakeholders in Mexico's Perdido Corridor.

Figure 3
Perdido Area Cenozoic IsoOIP — Mexico’s Gulf, mbo



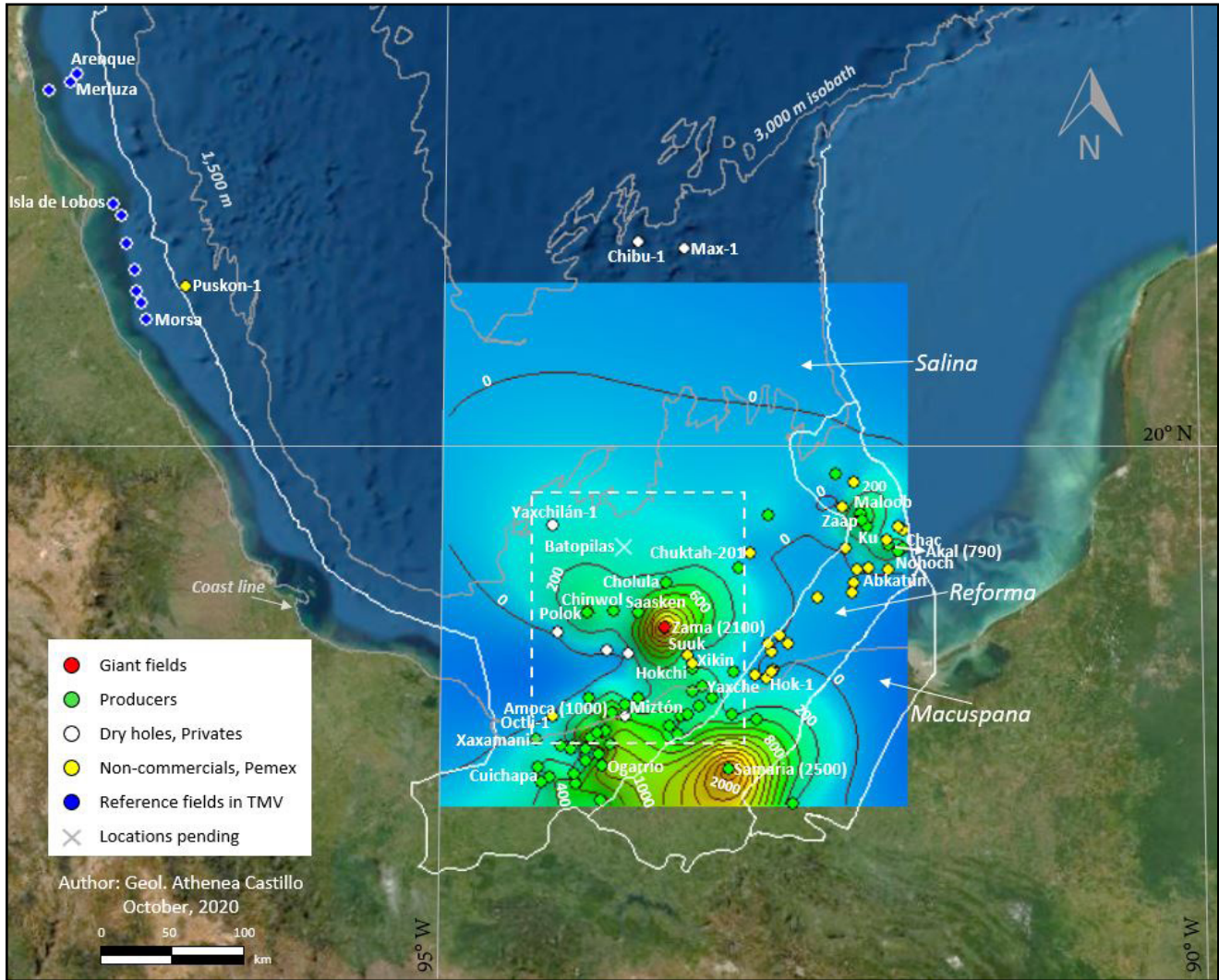
Source: Comisión Nacional de Hidrocarburos (CNH)

Sureste Basin

Let us now turn our attention to the major cluster at the southern end of the Sureste basin as shown in **Fig. 4**. The Cenozoic isoOIP map shows two major fields in this southern offshore cluster: Zama, with an OIP of 2,100 mbo, and Akal with an OIP of 790 mbo. Zama is the only giant oil field discovered among all of Mexico’s Cenozoic

oil producers. The third major field is Samaria, Mexico’s largest onshore giant oil field with vast reserves in the Jurassic. It also contains a huge Cenozoic reservoir with an OIP of 2,500 mbo, but this does not classify as a giant, in reserves terms, because its oil is atypically heavy (10 °API) with a low recovery factor of less than 10%.

Figure 4
Sureste Cenozoic IsoOIP — Mexico’s Gulf, mbo



Source: Comisión Nacional de Hidrocarburos (CNH)

Fresh exploratory drilling, during 2017-2020 in the offshore Sureste basin, conducted in an area of approximately 30,000 square kilometers is highlighted on the map in **Fig. 4**. During this period, nine exploratory wells drilled by Privates led to the discovery of 3.5 Bbo of OIP in five new fields including the giant Zama field and two world-class fields (Amoca and Hokchi). Prior to 2017, eleven exploratory wells resulted in the discovery of 1.3 Bbo OIP but only one of the discoveries, Yaxche, was developed and produced. The potential production capacity associated with the new discoveries is estimated at 250,000 b/d and is expected to go on full production by 2024.

Some start-up production, to the tune of about 15,000 b/d, began in early 2020. Importantly, the new discoveries represent a growth factor of 2.65 compared to past exploration in this offshore area. (Growth factor is the ratio of new discoveries, in this case 3.5 Bbo OIP, to past discovered resources, 1.3 Bbo OIP.) Thanks to new exploration concepts and enhanced technologies, the fresh, post 2016, exploration campaign has achieved a positive step change in the Sureste basin’s offshore Cenozoic reserves and production outlook.

To date, offshore Cenozoic fields in the Sureste basin are credited with 9 Bbo OIP. This represents 70 percent of Mexico’s total offshore Cenozoic OIP

resources. Apart from the obvious success of the 2017-2020 exploration campaign, there is a mix of positive and challenging factors to unlock the Sureste basin's untapped potential in Cenozoic prospects.

Positive factors include:

- Widespread organic-rich Tithonian source rocks.
- Three Miocene sand pulses extend northward across a runoff slope, possibly to the edge of the continental crust.
- Multiple undrilled high relief structures are observed on 3-D seismic.
- Intraformational shales create effective seals.

Challenges include:

- Complex structures with a salt canopy.
- Possible migration losses from deep (7 to 11 kms) source rocks.
- Thermal maturity and heat flow could be impacted by crustal variances.
- Much of the untapped area lies in deep and ultra-deep waters, some areas deeper than 3,000 meters, and is expensive to drill.

IsoOIP contours on the map in **Fig. 4** reflect the interplay of these positive factors and challenges. The zero isoOIP contour line begins north of the shallow water legacy Akal cluster, is anchored to the west by the recently drilled deep water Yaxchilan-1 wildcat and extends toward the western rim of the Sureste basin. This zero contour outlines a broad area north and west of the Zama complex with little potential OIP. Accordingly, the two dry ultra-deepwater wildcats (Chibu-1 and Max-1) located 200 kilometers north of the Zama-Akal cluster emphasize the risks of finding large Cenozoic resources in the northern ultra-deep part of the Salina subbasin.

Nevertheless, results from the pending Batopilas wildcat may tilt the risk pendulum for additional exploratory drilling in deep waters north of the Zama complex. Reentry of the zero isoOIP contour southwest of the Zama complex also indicates that local complexities challenge efforts to expand recent Cenozoic success. Shann illustrates,

for instance, that the high net to gross Miocene sands at 2,600 meters depth at Zama extend at least 60 miles west but these sands were tight or missing to the north at the Yaxchilan-1 wildcat.⁷ Large resources in Pliocene sands have been established at 3,700 meters at the shallow water Amoca field. But these Pliocene sands thin rapidly to the north and the potential for additional resources may be limited.

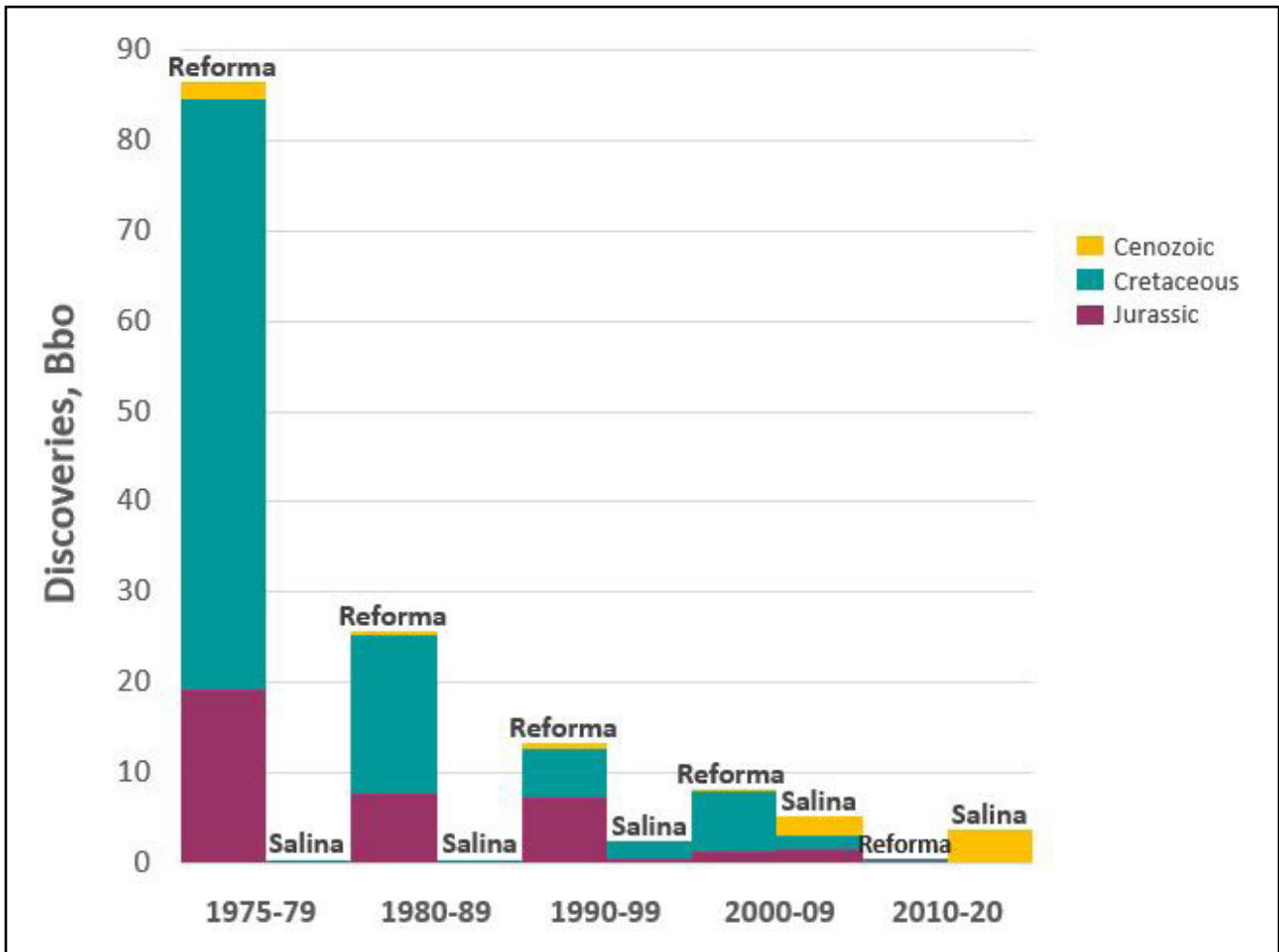
As illustrated by the map of Cenozoic oil fields in **Fig. 4** the distribution of hydrocarbons has been strongly influenced by the geological framework of the Sureste basin. Boundaries for Sureste's three subbasins – Salina del Istmo, Reforma-Akal, and Macuspana – also are shown on the map. Geological influence on Cenozoic production is most evident for the Macuspana subbasin. Although noted for its Cenozoic gas production, Macuspana hosts only one Cenozoic oil field in the project data set. There is little potential to find additional oil resources in Macuspana. The concentrations of Cenozoic oil at the northeast and southwest ends of the Reforma-Akal subbasin are unique. Lighter oil is associated with shallow (700 meters) Cenozoic fields on the large offshore Cantarell structure in the northeast while heavy oil is associated with the giant onshore Samara field in the southwest. There could be modest remaining Cenozoic potential in offshore Reforma but the onshore has been heavily explored in the search for older Mesozoic reservoirs, thus limiting potential for additional Cenozoic oil resources. Post-2016 discoveries substantiate that the moderately-explored offshore Salina del Istmo subbasin has the best potential for future Cenozoic oil discoveries. Based on the OIP model highlighted in **Fig. 4**, the untapped potential of offshore Salina Cenozoic prospects is estimated to be about 2.5 Bbo.

We now expand the story to important older Sureste basin reservoirs. **Fig. 5** shows the time distribution of offshore oil discoveries (OIP) in Cenozoic, Cretaceous, and Jurassic reservoirs in the Salina and Reforma subbasins. Reforma dominates the landscape with 89% of all offshore discoveries (145 Bbo) but has not yielded additional discoveries in the last decade. Initial offshore Salina discoveries were made in the 1990s but overall, this subbasin only accounts for 11 Bbo of discoveries. Salina,

however, is the main focus of all recent offshore exploration efforts that yielded five new fields with 3.5 Bbo OIP in Cenozoic reservoirs. Historically, Cretaceous and Jurassic reservoirs account for most of the Sureste basin’s offshore OIP. Prior to 2010, Reforma’s Cretaceous reservoirs were credited with 97.2 Bbo OIP and its Jurassic reservoirs were credited with 34 Bbo. Also prior to 2010, Salina’s Cretaceous reservoirs were credited with 3 Bbo

OIP and its Jurassic reservoirs were credited with 900 mbo. Salina’s Cretaceous reservoirs were credited with 3 Bbo OIP and its Jurassic reservoirs were credited with 900 mbo. Geological evidence indicates that Salina’s Cretaceous and Jurassic reservoirs could have significant resources. But with little exploratory drilling to date it is a challenge to predict the remaining potential.

Figure 5
Offshore Discoveries (OIP) by Age and Sub-basin



Source: Comisión Nacional de Hidrocarburos (CNH)

Cretaceous Potential

Cretaceous is the crown jewel of Mexico's oil industry. It accounts for 60 % of all oil reserves discovered to date. Interestingly, these vast Cretaceous resources – offshore (OIP 100 Bbo) and onshore (16 Bbo) – all lie clumped up near the southern rim of the Sureste basin as shown in **Fig. 6**. The super-giant Akal field (Cantarell) is the magnetic centerpiece of this huge carbonate accumulation with an OIP of 46 Bbo, almost half of all offshore oil discovered so far! The next largest field is Abkatun with 9 Bbo. In this relatively small area, there are nine giant oil fields, seven offshore and two onshore, which is very impressive.

Elsewhere, in the offshore TMV basin, four fields along the margin of the Tuxpan Platform (the green symbols on the map) are credited with 747 mbo OIP in Cretaceous reservoirs. Smaller, non-commercial, OIP volumes also were identified in three discoveries noted with yellow symbols on the map. About 100 kms north of the Tuxpan Platform the Arenque and Merluza wells failed to find any hydrocarbons in the Cretaceous. TMV exploration to date has not identified new leads to substantial additional Cretaceous oil resources.

The Cretaceous isoOIP map, **Fig 6**, shows the OIP contours over 120 fields including 18 in the onshore Reforma-Akal subbasin. The giant Cretaceous fields are highlighted in orange, other Cretaceous producers are green, recent Pemex dry exploratory wells are yellow, and the X's are recent (2017-2020) exploration wells drilled in the offshore license blocks. All exploratory wells drilled to date in the license blocks targeted the Cenozoic and none penetrated the Cretaceous. Five of the X's were completed as producers and four (Yaxchilan, Ehecatl, Bitol and Alom) were dry and abandoned. Pemex recently drilled the Suuk-1A and Xikin-1DL wells close to the Hokchi field; both were dry in the Cenozoic but were successful in the Cretaceous and Jurassic, respectively. The Suuk discovery is credited with 208 mb OIP in Cretaceous reservoirs.

There is little borehole data to substantiate the potential for offshore Cretaceous reservoirs. But regional geological and geophysical information frames a setting to host significant oil resources in Cretaceous marine carbonates in the Salina del Istmo

subbasin. Most of the positive factors and challenges cited above for Cenozoic oil potential also apply to deeper Cretaceous and Jurassic potential. Importantly, we know that thick, mature, organic-rich Tithonian source rocks underlie most of the offshore Salina subbasin and many high relief structures have not been tested. Among other challenges, drilling depths and costs both increase to tap deeper Cretaceous reservoirs. Cretaceous reservoir depths are at their shallowest in the Akal field (1,700 meters), increasing southwestward to 5,400 meters in the Amoca field. Likewise, reservoir depths also increase northwards of Akal, reaching around 6,000 meters in the Chibu-1 wildcat. Onshore reservoir depths are approximately 5,000 meters in the areas of interest.

Two types of Cretaceous reservoirs could be developed in association with Salina's history of salt intrusions, erosion, uplift, folding, and faulting (Horbury 4). In the first case, salt related carbonate breccias can form in association with upward salt movements that break up overlying marine carbonates. Resulting brecciated carbonate mounds can initiate shallow-water carbonate platforms that, if karsted and additionally brecciated, can develop excellent reservoirs that become preserved in marls and shales as the salt continues its upward movement. In the second case, brittle Lower and Middle Cretaceous micritic carbonates can be fractured in association with Chiapaneco deformation that impacted the Salina subbasin during the Middle to Late Miocene. Fracture development is associated with NW-SE oriented faulted anticlines and is critical to enable economic productivity from these microporous carbonates. These Cretaceous reservoirs could provide substantial secondary reservoirs in high amplitude structures that also are tested for overlying Cenozoic sandstone targets. Availability of Wide Azimuth and 3D seismic to visualize these potential reservoirs below the salt canopy could trigger additional exploration drilling in Salina's offshore license blocks.

The Cretaceous OIP map helps to visualize a baseline for untapped potential that could be associated with prospects in the offshore Salina subbasin. A visual extrapolation of the Cretaceous isoOIP contours in **Fig. 6** indicates significant space for frontier exploration in more than 15,000 sq. kms.

Jurassic Potential

Jurassic is Mexico’s second gem after the Cretaceous. It accounts for one third of all reserves discovered to date. Sureste hosts 65 Bbo of Jurassic OIP, of which 39 Bbo and eleven giant fields lie offshore; 26 Bbo and four giants lie onshore. The TMV basin accounts for another 24 Bbo and two giants, almost all onshore. Fig. 7 shows the isoOIP for the Sureste Jurassic covering 40 offshore and 30 onshore fields. In the recent (2017-2020) exploration program carried out by private industry only two wildcats, Chibu-1 and Max-1, near the northern limit of the basin were drilled targeting the Jurassic. Chibu was drilled in ultra-deep water of 2,760 meters to a final depth of 6,346 meters. Max-1 was drilled in water depths of 2,511 meters to a total depth of 7,100 meters. Unfortunately, both wells were dry and abandoned.

Similar to the Cretaceous, most of the large Jurassic resources discovered to date are in the Reforma-Akal subbasin. Most of the Reforma offshore resources are clustered in the northeastern end of the subbasin and most of the onshore resources are clustered in the southwestern part of the subbasin. Also similar to the Cretaceous, there is little borehole data to substantiate the potential for offshore Jurassic reservoirs in the Salina subbasin. But the seven historic offshore Jurassic discoveries in this subbasin established 2,121 mbo of total OIP. The average Jurassic offshore OIP of 303 mbo is more than twice that of the average OIP for historic offshore Cretaceous fields. The two fields with the largest Jurassic offshore OIP, Xanab with 711 mbo and Yaxche with 533 mbo, are near the coast in shallow water. Pemex’s recent Xikin discovery, with 206 mbo OIP, indicates that favorable Jurassic reservoir conditions extend further offshore but optimum conditions for commercial prospects may be dispersed. Jurassic depositional models indicate that is likely to be the case.

The foundation for the Sureste basin’s petroleum system was laid during the Middle and Upper Jurassic. The foundation was created in three phases:

1. Sureste’s Gulf of Mexico was initiated during the Middle Jurassic by the opening

of a highly restricted shallow saline basin which was first blanketed by Callovian age salt.

2. With onset of more open marine conditions the salt was overlain by cyclical Oxfordian and Kimmeridgian carbonates and oolites were deposited over shoals in shallow water, high energy environments. In the Sureste basin, the shoals were created by early salt movements that resulted in a patch work of small (tens of square kilometers) salt withdrawal basins.
3. Tithonian shales and organic rich mudstone source rocks then buried the carbonates and provided a seal to trap oil and gas in the porous oolitic facies.

This depositional framework with porous oolites and early salt tectonics formed the first phase of the Jurassic petroleum system. The second phase developed 130 million years later when Chiapaneco deformation created the folds and faulted high amplitude structures that are today’s prime exploration targets. Importantly, the injection of hot magnesium rich fluids (along with migrating hydrocarbons) during the Chiapaneco tectonic event further enhanced the oolitic porosity and created the prolific Jurassic reservoirs. The challenge is to identify where the porous Jurassic oolites coincide with features, especially high amplitude folds and faulted anticlines, that can trap large hydrocarbon volumes. Potential Jurassic reservoirs in the high amplitude structures will be reached at around 6000 meters in the unexplored parts of the Salina del Istmo subbasin.

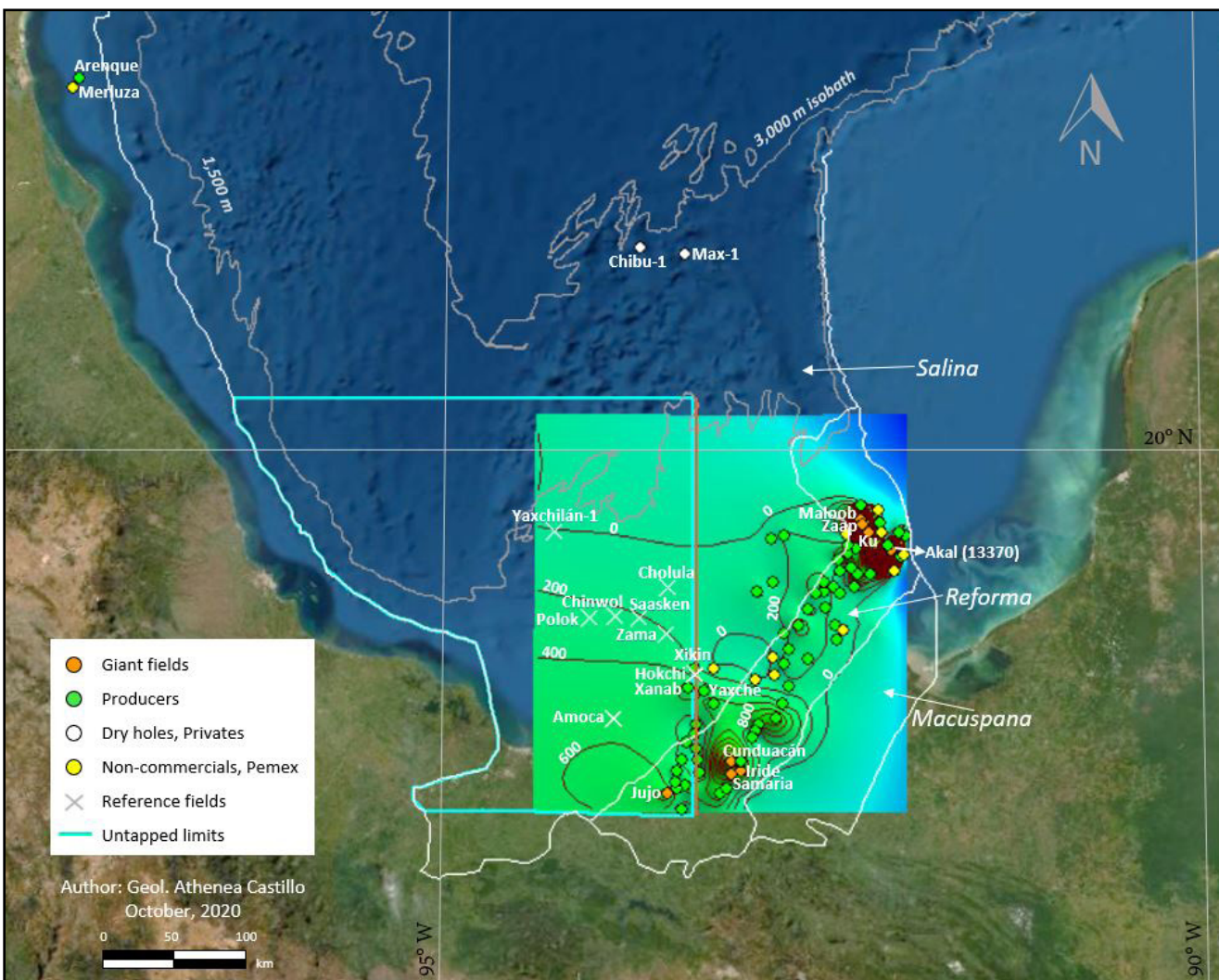
The isoOIP map in Fig. 7 highlights the nearshore area with the best OIP values at the Xanab and Yaxche fields. North of this area the contours outline a broad undrilled area with potential OIP values ranging from 100 mbo to 400 mbo. The zero Jurassic OIP potential at Yaxchilan is inferred from apparent lack of deeper structures on seismic records. The zero only represents the OIP for that prospect. It does not necessarily indicate there is no additional Jurassic potential north of Yaxchilan. To this point, prospective Jurassic carbonates are expected to extend to the

margin of continental crust in the Sureste basin. West of the contoured area, Tithonian source rocks are deeper, more mature and are the source for Cenozoic gas fields in the Catemaco Fold Belt. Additional exploration is vital to anchor OIP values in this large undrilled area with an apparent upside potential for untapped Jurassic oil resources. The X's on the map refer to the locations of existing producing fields in the Cenozoic. Reassessing the

potential to tap deeper Jurassic reservoirs in these established producing structures might provide a jump start to renew exploratory drilling in this area.

The isoOIP map provides an estimate of 3.1 Bbo for the untapped Jurassic offshore potential and an additional 1.3 Bbo for onshore. Both of these numbers, products of legacy data, could be exceeded by explorers armed with latest technologies.

Figure 7
Sureste Jurassic IsoOIP — Mexico's Gulf, mbo

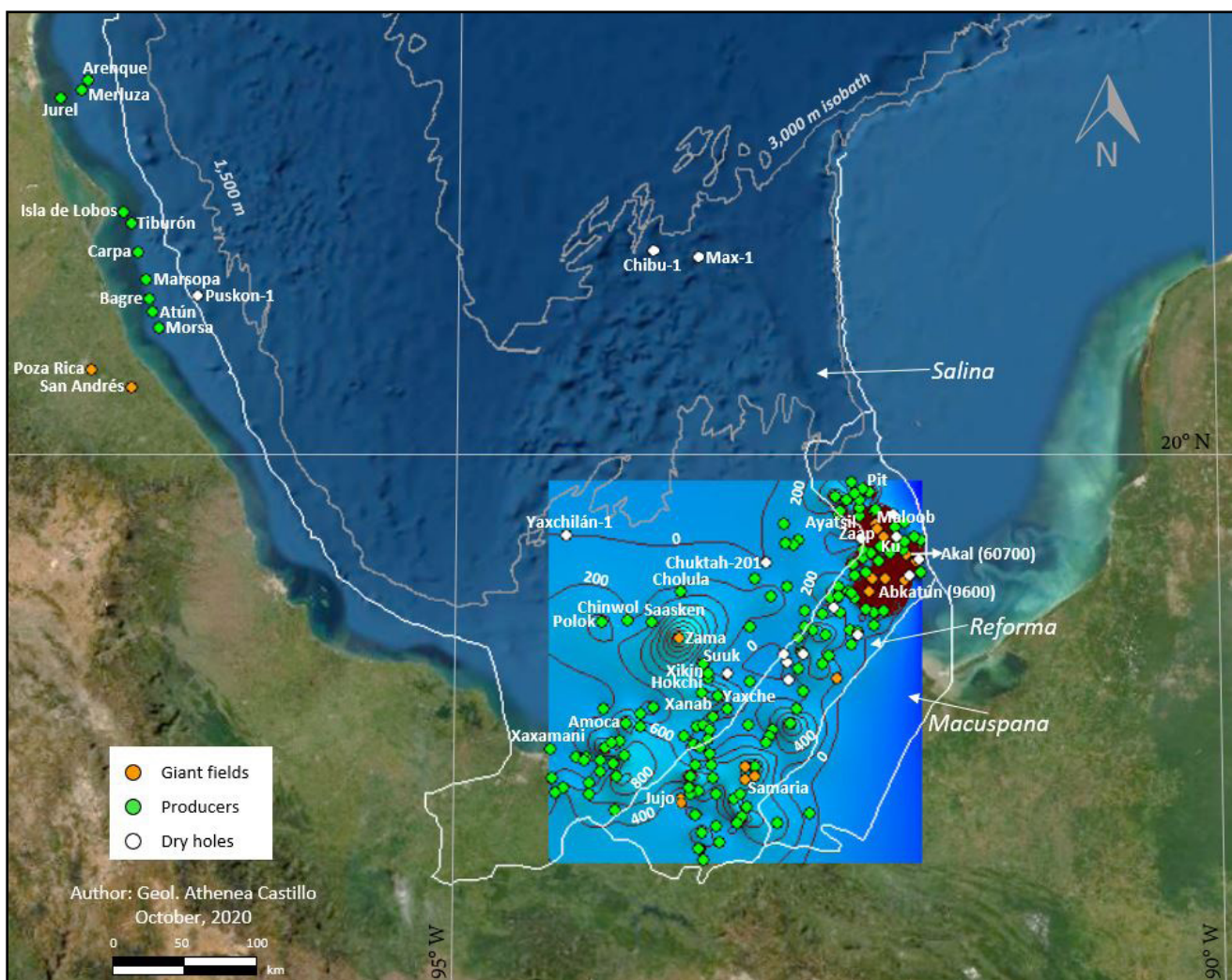


Source: Comisión Nacional de Hidrocarburos (CNH)

At this juncture we have discussed isoOIP maps developed individually for the Cenozoic, Cretaceous and Jurassic reservoirs in Mexico’s offshore Sureste basin. **Fig. 8** introduces a composite isoOIP map display of all three reservoirs. Additionally, it incorporates 30 major onshore fields for a more complete regional coverage. The combined OIP contours certainly enhance the visualization of hydrocarbon potential

in the Sureste basin. Large fields including several giants, mostly in Jurassic and Cretaceous reservoirs, span the mature Reforma-Akal subbasin. Many smaller fields have been established between the large fields but are not posted on this map. Remaining prospects may be in small structures or subtle traps, but the contours indicate that most of this subbasin is prospective for fields with tens of million barrels OIP.

Figure 8
Sureste Composite IsoOIP Map, mbo



Source: Comisión Nacional de Hidrocarburos (CNH)

CONCLUSION

Beginning in 2017, private companies drilled 26 exploratory wells in the newly awarded blocks in Mexico's offshore Gulf. Five more are scheduled to be spudded in the course of 2020. Four wells were drilled in ultra-deep waters, two in deep waters and the remaining seven in shallow waters. All but two of the exploratory wells targeted the Cenozoic; the two exceptions targeted both Cretaceous and Jurassic plays and both were dry and abandoned. Four of the five wildcats about to be spudded are located in the Perdido area and one in the Zama area, all targeting the Cenozoic.

Overall, this recent offshore drilling resulted in the discovery of five new fields with a total of 3.5 Bbo of new oil. The entire program's drilling costs to date are running near \$1billion. All of the wells, dry and producers, have served to better define the prospective areas for future exploration efforts and, in conjunction with a new spatial model, have provided a visual and quantitative estimate of the possible distribution of potential untapped oil volumes in each of Mexico's major Cenozoic, Cretaceous and Jurassic oil producing reservoirs. In this study, the OIP model was used to reassess Mexico's untapped offshore potential in association with post-2016 exploratory drilling by

private companies. All of this recent exploration drilling was confined to the Perdido Fold Belt and the Sureste basin. Based on the OIP model in these two provinces, the remaining estimated untapped offshore OIP is 10.4 Bbo with 2.5 Bbo in the Cenozoic, 4.8 Bbo in the Cretaceous, and 3.1 Bbo in the Jurassic. As a bonus, the model also estimated 3.3 Bbo of additional potential in the onshore Sureste basin.

The OIP estimate is conservative in comparison with prior resource estimates noted in the introduction to this paper but is confined to the untapped potential nearby to recent offshore drilling activity. As such, the OIP model provides a test of reasonableness for the prior estimates. The OIP model also helps to visualize volumes to consider for potential bidders and trends to consider in applying latest technologies to identify prospects spanning the prospective Cenozoic, Cretaceous and Jurassic offshore section. This study highlights the substantial remaining potential in Mexico's Sureste basin. It also provides a case example to stimulate exploration to identify additional commercial fairways in Mexico's unexplored offshore areas.

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ENDNOTES

¹U.S. Geological Survey World Petroleum Resources Project, *Assessment of Undiscovered, Conventional Oil and Gas Resources of Mexico, Guatemala and Belize*, Fact Sheet 2012 – 3069, July 2012.

²Alfredo Guzman, *Petroleum History of Mexico: How It Got to Where It is Today*, AAPG International Conference, Cartagena, Colombia, Sept. 8-11, 2013.

³Mark Shann, *The Sureste Basin of Mexico: Its Framework, Future Oil Exploration Opportunities and Challenges*. Scheduled to be published by the Geological Society London in 2020.

⁴Ivan Sandrea et al, *Mexico, History of Oil Exploration*, PennWell, 2018.

⁵Rafael Sandrea and Peter Stark, *Deepwater Oil Exploration in the Gulf of Mexico – A Spatial Model Provides Clues for Undiscovered Potential*, EPRINC, July 2020. Eprinc.org.

⁶Pemex Annual Reports, *Evaluación de las Reservas de Hidrocarburos*, Jan. 1, 2018, 2019, 2020.

⁷Aruna Mannie, *Mexico's Energy Reform*, GEOExPro, Vol. 17, No. 2, 2020.