Huge Potential Still Waiting in the Gulf of Mexico

The first oil was extracted from the Gulf of Mexico back in 1938. Since then, 30 billion barrels of oil equivalent have been produced from the US Gulf, but the area is still thought to have huge remaining potential, particularly in the deep and ultra-deep waters.

The discovery of oil at Spindletop transformed Houston from a slow-paced frontier town to the metropolitan city it is today.
The Gulf of Mexico basin is a roughly circular structural basin, approximately 1,500 km in diameter, filled with up to 15 km of sediments ranging in age from Late Triassic to Holocene. About 20% of the Gulf lies in more than 3,000m of water, with the deepest part, the Sigsbee Deep, more than 4,000m deep.

Deep Focus

Pre-Stack Depth Migration (PSDM) example from the 80,000 mile DeepFocus 2-D survey. The survey, using 10,000m offsets, was acquired across the deepwater Gulf of Mexico. This example traverses the Port Isabel Fold Belt, clearly showing growth fault extension and related contractional folding of the Port Isabel Fold Belt above a basal detachment. This long-offset seismic data means we can image sediments below the detachment zone to the limit of data at a depth of 20 km.
With 10 new oil and gas discoveries announced in 2005 in the deep water alone, the US Gulf of Mexico continues to play a very prominent role in the ongoing search for global hydrocarbon resources. Since offshore production began, more than 14.6 Bbo (2.3 Bm³) and 164 Tcfg have been recovered from the US part of the Gulf of Mexico, and new plays are continually being tested and proved. According to the US Minerals Management Service (MMS), offshore operations in the Gulf account for a quarter of the U.S. domestic natural gas and one-eighth of the oil produced. Huge technological advances in drilling and production, innovative analytical methods and exciting new techniques for sub-salt imaging mean that interest in the area should continue for many years.

Understanding Tectonic History is Key

The Gulf of Mexico has been a stable tectonic area since the Late Jurassic, but the structures formed at that time are still important to the distribution of hydrocarbons in the area. The present Gulf of Mexico is a result of seafloor spreading which started with the break-up of Pangea in Late Triassic times. Rifting probably continued through Early and Middle Jurassic time with the formation of 'stretched' or 'transitional' continental crust throughout the central part of the basin.

According to Fugro-Robertson's recent report "Petroleum Systems Evaluation of the Gulf of Mexico: Implications from Plate Tectonic Modelling", analysing the distribution of oceanic and continental crust and their associated fault structures is crucial to understanding the hydrocarbon geology of the Gulf of Mexico. This analysis suggests that there was a sudden increase in attenuation of continental crust during the Middle Jurassic, followed by a more stable period in the Late Mid Jurassic. During this period there were a number of shallow marine incursions followed by minor uplift, causing the seas to dry out and widespread evaporite deposition to occur. Co-evolution with this, oceanic crust development was occurring, as the Yucatan Peninsula rotated southwards and separated from the north American continent during the Late Jurassic to earliest Cretaceous (165 Ma to 143 Ma, compare Geological Time Scale, page 12).

The Florida platform to the east of the basin was characterised by aeolian sandstone deposition, up to 1,000m thick, until the Late Jurassic, with marine shales and turbidites being deposited further south and west in the basin. This platform became submerged at the end of the Jurassic, when movement of the Yucatan plate and the further opening of the basin resulted in deepening of marine waters and the deposition of a major source rock over much of the area, including the deposition of the organic rich Smackover Carbonate. In fact, most of the basin was rimmed during the Early Cretaceous by carbonate platforms, while the western flank underwent a compressive deformation episode in the late Cretaceous and early Tertiary.

Throughout the Cenozoic the area has been relatively stable, characterised by central subsidence. This is due in part to sediment loading, with the continental shelf in the Gulf of Mexico prograding seaward as a series of depocentres migrated eastward from the border with Mexico to the present Mississippi River area in the north-central Gulf. This thick Tertiary sequence provides the important overburden critical for maturation and supporting the mobilisation of hydrocarbons.

Salt Plays Crucial Role

Widespread evaporite deposits, up to 3,000m thick, form an important feature of hydrocarbon exploration in the region. They play a crucial role in the depositional and structural history of the northern Gulf of Mexico Basin, and to fully comprehend the development of petroleum systems across the whole area it is necessary to have an understanding of their distribution and movement. Traps are created and destroyed by salt movement, and hydrocarbon maturation and charge is hugely influenced by the local presence of salt. Furthermore, the deposition of reservoirs and seals and the development of mini-basins are controlled by salt movement at
of weakness towards the surface. Although through the surrounding rock along lines viscous material, it moves and flows depth than other rock types. Essentially a

Summary diagram illustrating the relationship between multi-tiered canopies and single tiered canopies across the northern gulf of Mexico (after Mehlhop, 2004)

Salt Movement Initiates Traps
Salt tectonics, sedimentation and growth faulting are intimately related. The initial salt deposition infilled existing topography which had resulted from faulting and volcanics on the basement floor. The thickest salt developed where subsidence was highest during the syn-rift and post-rift phases of basin development.

Salt deposits are divided into autochthonous salt, which is found at the stratigraphic level at which it was deposited, and allochthonous salt, characterised by sheetlike salt bodies which have migrated above the original salt layer. The thickest autochthonous salt, possibly originally as much as 4,000m thick, is Middle Jurassic in age and does not appear to have been deposited uniformly across the basin, instead infilling the existing grabens whilst being thin to absent over adjacent horsts.

Two major evaporite belts can be recognised in the Gulf of Mexico. The first is the Louann Salt, found in the northern part of the Gulf and covering much of the coastal plain and offshore regions of northeastern Mexico, Texas, Louisiana, southern Arkansas, Mississippi, and Florida. The second area is the Southern Gulf of Mexico Campeche Salt Province, which runs along the west and northwest flank of the Yucatan Peninsula. These two areas were originally one, but are now separated by the salt-free Sigbee Abyssal Plain, a deep, relatively structureless area underlain by oceanic crust, formed as the Yucatan pulled away.

Salt is much weaker and less dense at depth than other rock types. Essentially a viscous material, it moves and flows through the surrounding rock along lines of weakness towards the surface. Although

Hydrocarbon Exploration in the US Gulf of Mexico
The presence of oil and gas seeps off the west coast of America pushed the search for hydrocarbons offshore, with the first well being drilled off California in 1896. Onshore discoveries along the coast of the Gulf of Mexico later encouraged offshore exploration in this area, with initial drilling from low lying islands and then from wharfs specially built into the water. The first true offshore discovery in the Gulf was the Creole Field, near Cameron, Louisiana, drilled in 1938 in 4m of water.

Giant Discoveries
After the second World War, there were significant changes in the oil industry, with an end to government controls and a huge surge in public demand for oil and natural gas. This encouraged further exploration in the Gulf of Mexico, and in 1947 the first well drilled out of sight of land started producing 600 bopd 12 miles from the Louisiana coast. By the end of the 1940’s exploration in the Gulf had increased dramatically.

Exploration and production continued rapidly until, by the 1970’s, more than 50% of the discoveries made in the Gulf Coast basins were offshore, with exploration moving further and further from the coast. This brought hydrocarbon exploration into progressively deeper water, pushing the limits of platform technology. By the 1980’s exploratory drilling had reached water depths beyond 2,000m in the western part of the Gulf of Mexico, whilst also moving deeper below the seabed to investigate sub-salt reservoirs.

There was a slight lull in exploration in the Gulf of Mexico in the late 1980’s and early 1990’s, as the major oil companies began to look elsewhere, viewing the Gulf as a mature province with little remaining potential in shallow water. Gradually, however, huge advances in platform and drilling technology allowed oil companies to move further into the unexplored deeper water. At the same time, the development of exploration techniques such as 3D seismic helped locate commercial fields that were missed in earlier exploration efforts.

Deep Water Exploration Boom
By the late 1990’s, a new era began in the US Gulf of Mexico OCS, with intense interest in the oil and natural gas potential of the deep and ultra-deep water areas. The OCS Deep Water Royalty Relief Act of 1995 provided incentives for operators to develop fields in water depths greater than 200m and had a significant impact on deep water activities. It led to a huge expansion in all phases of deep water activity. Oil production from deep water rose over 840% in the last decade, and deep water gas production increased about 1,600% during the same period. In December 2003, for the first time in history, a drilling rig explored for oil and gas in over 3,000m of water.

An exception to this rapid development of the offshore oil industry in the Gulf of Mexico is off the coast of Florida. In 1981 the State of Florida announced a moratorium on new drilling in State waters to protect the fragile environment and unique species of the Florida coastline. This moratorium expires in 2012 but there are already moves afoot within the US House of Representatives and Senate which could result in the lifting of the moratorium and allow drilling up to 100 miles (160 km) from the coast in an area that contains an estimated 5 Tcfg.
Oil industry transformed Houston

As you walk through Houston's hot, busy streets today, it is difficult to visualise this sprawling city as the swampy settlement it first was. Now the fourth largest city in the United States, with an urban population of over two million, it seems incredible that in 1900 Houston had a mere 45,000 inhabitants and was only the 85th largest city in the U.S. This startling development has been spearheaded throughout the last century by the oil industry.

The area now known as Houston began as a marshy, malarial swamp, only inhabited by a small number of Native Americans, and it remained so until the arrival of pirates at the beginning of the 19th century. These Caribbean buccaneers set up short-term settlements on Galveston Island, just south of present day Houston, and their legend lives on in Houston's folklore today.

Texas was under Mexican control until the 1830's, but when the growing number of settlers to the state became disillusioned with the Mexican government, a Texas resistance force was formed and war broke out with Mexico in 1836. After several defeats the Texans eventually emerged victorious and, soon afterwards, a settlement was formed along the Buffalo Bayou, named after the man who had lead Texas to victory, General Sam Houston. The settlement had been established by two brothers, John Kirby Allen and Augustus Chapman Allen, who had bought the land with the intention of making it 'a great centre of government and commerce'. The town soon became the capital of Texas, although it only remained so until 1839.

By 1870 the settlement of Houston had grown to be the third largest city in Texas. It had fast become an important transportation hub for both steamboats and railroads, but remained behind San Antonio and Galveston in size and influence until 1901, when oil was discovered at Spindletop, 90 km north-east of Houston.

Houston has always played a key role in the development of the petroleum industry, with the first geological department devoted to petroleum science being founded in Houston in 1897. However, it was this discovery at Spindletop, and later findings at Humble and Goose Creek in 1905 and 1906, that clearly marked Houston as a centre for the oil industry. Furthermore, it was a catalyst for a large influx of settlers to Houston from the US and beyond, which meant that by the 1930's Houston had become the largest city in Texas.

Further events, like the development of a new port in Houston and NASA choosing it as the site for the Manned Spacecraft Centre, meant that Houston maintained this rapid growth. Including the ever-expanding suburbs, the metropolitan area of Houston is now home to 5.2 million people. However, it is easy to see that it was only after the discovery of oil that Houston began the transformation from a slow-paced frontier town to the metropolitan city it is today.

Tectonic structures due to salt movement are found in more than 60% of the present day slope area of the Gulf of Mexico. These can be very complex formations, including salt rollers and pillows, salt domes or diapirs, salt walls and tongues and turtle structures, with intricate interplay between the autochthonous and allochthonous evaporites and the surrounding rocks. This movement has a significant influence on the reservoir rocks, causing folding, detachment and faulting in the vicinity of the salt structure, thereby changing the rock properties and initiating a huge variety of hydrocarbon traps.

As well as being instrumental in altering the properties of reservoir rocks and in initiating trapping mechanisms, salt has a profound effect on the maturity of hydrocarbons, as it has a high thermal conductivity which retards the maturation of sub-salt source rocks while accelerating that of supra-salt strata. The impermeable nature of salt also means that it forms a barrier to upward migration, creating a seal, although it can serve as pathway for hydrocarbons moving updip along its base.

Well Established Petroleum Systems

After 70 years of exploration, the main producing plays and petroleum systems of the Gulf of Mexico are well known. Almost 99% of total proved reserves in the US Gulf are in Neogene (Miocene, Pliocene, Quaternary) reservoirs, and they are still thought to contain considerable potential.

Source rocks are relatively well understood, with the Late Jurassic (Oxfordian and Tithonian) fine-grained, organic-rich carbonates and shales providing the best regionally extensive sources within the Gulf, including the world famous Smackover Limestone. Cretaceous Albian and Turonian clastics and Eocene shales are also known sources.

In the Gulf of Mexico many exciting plays have already been explored with the most prolific found to date resulting from Miocene-aged high frequency cycles of fluvial or incised valley fill, with deltaic to neritic and deep water submarine fans deposits. These are often associated with salt structures and deformation, both complicating and enhancing prospectivity. Explorationists originally drilled structural
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highs to explore these reservoirs in the early 1980s, but they are now seeking hydrocarbons trapped in ponded turbidite facies in the mini-basins which formed as the salt withdrew due to sediment loading.

Although the known shallow and shelf plays still prove exciting, much of the recent interest in the Gulf of Mexico has been generated by the move into deep and ultra-deep waters.

**New Deep Water Plays**

When the Gulf of Mexico was first explored, it was considered that deep water potential was limited by a lack of sediment supply over large areas into the deep water. Initial seismic analysis and the first deeper wells soon proved that this was not the case. Another early concern was the availability and maturity of source rocks, but modelling successfully demonstrated that probable source rocks, predominantly Cenomanian to Turonian in age, have entered the oil window throughout most of the deep and ultra-deep water province. Maturity modelling shows that most of the hydrocarbons in the vast Sigsbee salt sheet which culminates at the Sigsbee Escarpment are within the oil maturity window, while those found further south are more likely to be condensate.

Production in the deep water has until now been centred on Miocene turbidite sands, deposited relatively recently from the Mississippi delta, with fields up to 500 MMboe being successfully produced. The Cascade discovery proved the existence of an older, Paleogene turbidite sand play more than 560 km down dip from the source deltas in south Texas. Reservoir potential in these well-developed channel sediments is thought to be excellent, with the hydrocarbons accumulating in stratigraphic traps.

Moving into deeper water from this play in the Eastern Gulf of Mexico, salt-cored thrust folds with middle and lower Miocene abyssal plain section draped across them have proved prospective. Two major discoveries in the Mississippi fan thrust and fold belt play, Neptune and Mad Dog, have recently begun producing and are thought to point the way to further finds in these sediments. A number of recent discoveries such as Spiderman and San Jacinto, are in water depths of more than 2,300m.

Foldbelts in ultra-deep water have been found to extend from the deep basin of the western part of the Gulf of Mexico up and under the Sigsbee salt sheet at the continental margin. These include large north-east to south-west trending compressional "box folds" and are characterised by large...
The GGS-Spectrum Big Wave Survey has already highlighted a number of different play types and possible world class exploration opportunities both on the platform and in the deep water areas.

The survey has shown there is a full sedimentary section in the deep waters of the Gulf of Mexico with likely source rocks, trapping mechanisms, age and thermal environment for hydrocarbon accumulations.

In front of the escarpment
- Jurassic horst/graben (buried hill) plays
- Jurassic/Cretaceous plays associated with salt tectonics
- Oligocene and Miocene clastic onlap and draped wedges
- Cretaceous Carbonate fan and detrital plays

On the platform
- Cretaceous Shelf Edge reefs and fans
- Thrombolitic and Patch reefs
- Large regional four way closures
- At depth with clastic reservoirs
prospects, possibly containing reserves of over 1 billion boe each.

Cretaceous carbonates have proved very prolific in the Campeche Basin in Mexico, with fields reporting 100,000 bopd production from single wells. This play is speculated to extend northwards into the US Gulf, possibly as far as Florida, forming a very extensive but very deep target. The reservoirs include rudist and coral reef build-ups and slope carbonate deposits comprised of forereef debris rudstones and shelf-derived grainstones.

The very eastern part of the Gulf of Mexico area is one of the last remaining US petroleum frontier areas, very lightly explored due to the moratorium on exploration in Florida waters since the 1980's. According to a recent seismic survey offshore Florida obtained by GGS-Spectrum, significant volumes of hydrocarbons could be found here in a number of plays. Mesozoic plays include Cretaceous shelf reefs, inner platform reefs and carbonate apron fans, which are created at the foot of the Florida escarpment by the periodic failure of the upper carbonate slope, resulting in the shedding of large volumes of sediment to the basin. There are also deep water prospects associated with rifting and salt tectonics. Younger potential in the Eastern Gulf is represented by clastic plays of Oligocene to Miocene age such as basin floor fans and onlap/drape features.

Deep Water Potential

According to the MMS, the hydrocarbon potential of the deep and ultra-deep water in the Gulf of Mexico could be as high as 46 Bboe (MMS report 2006-022). Although the first deep water field did not start producing until the 1980's, by 1999 the volume of oil production from the deep water had overtaken that of the shelf, and this gap has been growing ever since.

Deep water Gulf of Mexico field discovery sizes have been several times larger than average shallow water field discoveries. The typical deep water field found over the last 10 years is 67 MMboe (proved and unproved reserves), compared to 5 MMboe for the average shallow water field. (The MMS considers hydrocarbon reserves as 'unproved' until it is confirmed that the field will go on production.) Deep water fields also tend to produce at significantly greater production rates, exceeding those of shallow-water wells by more than 1000%. These operations are very expensive, however, and require specialist technical exploration and production equipment, so large discoveries are needed to ensure exploration in the deeper water continues.

Emphasising the fact that exploration is moving ever deeper, there have been 22 discoveries in water depths over 7,000ft (2,134 m), during the last five years, with total announced reserves of 1.8 Bboe.

Recently, the US Government introduced measures to encourage the search for gas in deep water, to offset a decline in shallow water gas production since the mid 1990's. Although the deep water gas production increase has not been as dramatic as that of oil, these tax and financial incentives have resulted in a significant increase in exploration. Additionally, a deep shelf gas play has emerged, partly as a result of investigations into gas formation and porosity preservation in high-temperature and high-pressure reservoirs.

New Frontier Plays

New technologies have been instrumental in opening up another new frontier for the search for gas in deep water. New technologies have been instrumental in opening up another new frontier for the search for gas in deep water. New technologies have been instrumental in opening up another new frontier for the search for gas in deep water. New technologies have been instrumental in opening up another new frontier for the search for gas in deep water. New technologies have been instrumental in opening up another new frontier for the search for gas in deep water.

Over 100 wells have now been drilled sub-salt, the largest of which to date is BP's Thunder Horse (previously Crazy Horse), discovered in 1999 and due to go into production in late 2006. The semi-submersible platform, lying in 1,900m of water, 190 km off the coast of Louisiana, is one of the largest and most complex deep water projects ever undertaken.
Rockall MegaProject West of Britain

- Regional Interpretation Package, including
  - newly reprocessed 2D and 3D seismic data,
  tied to Faroe Shetland Basin MegaSurvey
  - gravity and magnetic data

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play in the Gulf of Mexico, the sub-salt reservoirs. For many years the extensive salt layer was considered ‘economic base- ment’ in the Gulf of Mexico, because the high seismic velocity of salt, contrasting with the relatively slow velocities of the adjacent clastics, meant that the evaporites acted as a barrier to seismic, making it difficult to image the underlying layers. Recent innovations in both seismic acquisition and processing, such as multi-azimuth seismic, mean that salt is no longer a barrier to exploration (see ‘The Sub-Salt Imaging Challenge’, this edition of GeoExpro. Imaging through the salt opens up two areas for exploration. Much of the allochthonous salt is found in laterally extensive thin sheets, masking large areas which have been relatively untouched by salt tec- tonics. Imaging sub-salt means that it is possible to consider the potential beneath, for example, the huge Sigsbee salt sheet, to investigate whether the previously mentioned anticlinal ‘box fold’ structures continue under the salt into shallower waters. In other places the salt forms less extensive structures such as diapirs or tongues, trapping upwardly migrating hydrocarbons. These were previously hidden from conventional seismic and are only now being clearly imaged.

While new approaches to seismic acquisition and processing unlocked the potential of the deep water and sub-salt plays, different technological challenges have had to be met in order to drill and produce successfully from these. New research has lead to technologies such as slimhole drilling, which are necessary to explore and produce ultra-deep water reserves economically. Although expensive to research and develop, these technologies should ultimately help reduce the cost and time necessary to bring ultra-deep water hydro- carbons to the market.

**Mature Basin - Good Potential**
A long period of tectonic stability from the Late Jurassic to the present day has led to the development of excellent source and reservoir rocks. The thick Tertiary sediments form excellent reservoirs while maturing source rocks and initiating salt movement to create traps. These factors have combined together to create a widespread and prolific petroleum province.

The Gulf of Mexico might be considered a mature hydrocarbon basin, with proven reserves in the US Gulf of Mexico OCS estimated to be 18.75 Bbo and 176.8 Tcfg from 1,112 fields (as of December 31, 2002, the last year for which figures have been released from the MMS). The area remains prospective and exciting, however, as new plays have continued to extend the hydrocarbon prospectivity beyond the original boundaries, frequently through the development of innovative technology in both exploration and drilling.

As Fugro-Robertson’s report points out, there are still huge undiscovered resources within the Gulf of Mexico Basin. The study considers that the Miocene and Pliocene clastic plays hold the greatest remaining potential in the US sector, with further possible potential from the Cretaceous and Lower Paleocene carbonates which are so prolific in the Mexican sector. With advances in technology to aid the exploitation of deeply buried reservoirs into increasingly deeper waters of the Gulf, there should be no limit to exploration within the Gulf of Mexico in the foreseeable future.

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