From BAHA to Jack, Evolution of the Lower Tertiary Wilcox Trend In the Deepwater Gulf of Mexico

Dave Meyer, Larry Zarra, and Janet Yun
Chevron North America Exploration and Production
Deepwater Exploration Projects
1500 Louisiana Street, Houston, TX. 77002

ABSTRACT

Since the 1920's, the Lower Tertiary Wilcox Formation (Lower Eocene/Upper Paleocene) has been a significant hydrocarbon resource producing primarily gas from fluvial, deltaic, and shallow marine sandstone reservoirs from southwest Louisiana through south Texas to northeast Mexico. The total estimated recoverable reserves from this present-day onshore trend are approximately 30 trillion cubic feet gas or 5 billion barrels of oil equivalent (bboe). Not until 80 years later, with the drilling of the BAHA 2 well in March 2001, did industry begin to realize the full extent of linkages within the Wilcox depositional systems, from widespread shelf deposits to extensive deepwater turbidite sands. Ensuing drills in deep, offshore United States territorial waters (Perdido Fold Belt of the Alaminos Canyon Area) led to successes at the Trident and Great White prospects, demonstrating the significant potential of the Lower Tertiary Wilcox section more than 250 miles basinward of its onshore depocenter. In 2002, the Cascade discovery well extended the deepwater Wilcox trend another 275 miles east into Walker Ridge and 350 miles down dip from the shelf deltas. Then in 2006, two years after the 2004 Jack discovery, results of the test well were released. The Jack test established flow rates of over 6,000 barrels of oil per day from only 40% of the reservoir, thus confirming the Deepwater Wilcox as a world-class depositional and potential petroleum system. Currently, we estimate that the Wilcox Trend covers over 34,000 mi2 of deepwater in northwest Gulf of Mexico (GoM) and has potential recoverable reserves of 3-15 bboe. If these projections hold, the Deepwater Wilcox could increase proven reserves from GoM deepwaters by 94% to 30 bboe. This would account for a 17% overall increase for the entire GoM basin reserves, which also include the onshore areas (35 bboe) and continental shelf (35 bboe).

THE WILCOX FORMATION AND GULF OF MEXICO PETROLEUM SYSTEM

The Wilcox Formation owes its origin to the Laramide Orogeny, which was a period of mountain building in the western United States responsible for formation of the Rocky Mountains. It is generally believed that collision of the Farallon and North American plates began in the Late Cretaceous, 70 to 80 million years ago (mya), and ended about 35 to 55 mya in the middle to late Lower Tertiary (Paleogene). During this period of mountain building, widespread uplift and erosion led to the development of a tremendous wedge of detrital clastic material. These angular and immature sediments, ranging from quartz and feldspar to volcanic lithics, comprise the fabric of the hydrocarbon-bearing Wilcox sand system, which was deposited roughly between 60 and 52 mya and transcends the Upper Paleocene and Lower Eocene Epochs.

At that time, paleo-drainage systems similar to the present-day Red, Brazos and Rio Grande Rivers were most likely responsible for delivering newly eroded sediments from the western interior United States to paleo-coastal areas (Fig. 1 and cover). At the continental margin, many sediments were deposited in coastal-plain and shallow-water fluviodeltaic environments, while others found their way to deepwater by way of channel-levee systems and ultimately settling in basin-floor fan environments. Proprietary provenance studies indicate very similar rock characteristics for both the onshore Texas sediments and the deepwater GoM turbidites. Also, palynological studies of deepwater Wilcox Formation rock samples found spores unique to Paleogene tree species of the western interior United States.

Onshore, the Wilcox is made up of stacked late lowstand, transgressive, and highstand systems tracts characterized by fluvial, deltaic and shallow water shelf deposits. However, tracing these sediment pathways basinward to the outer shelf and slope of the Wilcox Formation is hampered by a lack of well control, as well as poor quality seismic data resulting from a regionally extensive decollement listric fault system and widespread salt diapers and canopies. Offshore, components of the Wilcox have been observed in nearly two-dozen deepwater wells and document extensive deepwater fan systems. This area of the Wilcox Trend in northwest GoM traverses approximately 400 miles from the Alaminos Canyon Area in the west to the Atwater Valley Area to the east. Although the full extent of the basin floor fan system has yet to be defined, it is interpreted to average about 100 miles in the dip direction, resulting in deepwater fan turbidites covering more than 40,000 mi2 (Fig. 1). This is similar in scale to the Pleistocene-Recent Mississippi Fan system in the eastern GoM.

In its entirety, the Wilcox Trend extends across several structural provinces, including the Perdido Fold Belt in Alaminos Canyon and the Mississippi Fan Fold Belt in Atwater Valley (Fig. 1). There are three main structural/tectonic styles recognized from this west-east transition. In the west, the Perdido Fold Belt consists of several large salt-cored, thrusted, and symmetrical folds of Late Oligocene to Miocene age. Trending northeast-southwest, these folds traverse the boundary between Mexican and U.S. territorial waters (Fig. 2A). In the central portion of the trend within the Keathley Canyon and Walker Ridge areas, structural styles range from relatively low-relief, salt-cored anticlines to salt-withdrawal, three-way salt-truncation

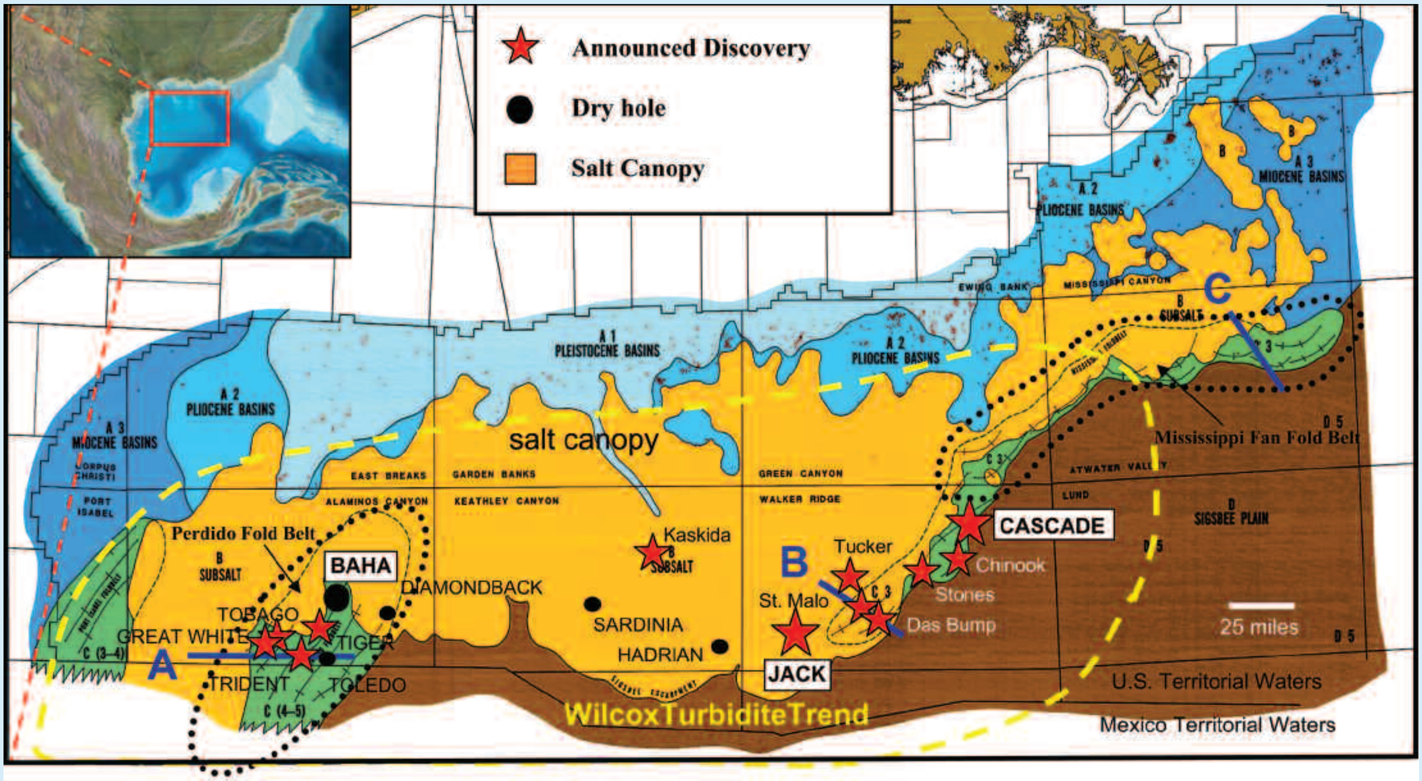

Figure 1. Gulf of Mexico Deepwater Trend Map with key wells, tectonics, salt canopy, and seismic lines.

structures of predominantly Paleocene-Oligocene ages (Fig. 2B). In the East, the Mississippi Fan Fold Belt is characterized by faulted, salt-cored anticlines formed in the Late Miocene during asymmetrical basinward folding and thrusting (Fig. 2C). The complexity of structuring across the Wilcox Trend is further complicated by an extensive salt-canopy system that overlies much of the targeted basin-floor fan turbidites. Salt canopy thicknesses can vary from 5,000' - 20,000' in the area, and with water depths of 5,000' - 10,000', the drill targets are a total of 10,000' to 35,000' below sea level (bsl).

Overall, the GoM petroleum system can be summarized by the stratigraphic column shown in Figure 3, where organic-rich lacustrine to shallow-marine sediments of the Upper Jurassic and deepwater marine carbonates and clastics of the Lower Cretaceous are seen to overlie the Middle Jurassic Louann Salt. This Upper Jurassic to Lower Cretaceous section is the primary source of oil and gas generation in the GoM Basin. The onset of significant deepwater clastic deposition began with formation of the Lower Tertiary Wilcox and has continued with additional pulses during Miocene to Pleistocene lowstands. All key ingredients are now stacked and in place for the 'perfect' petroleum system: 1) a salt substrate that is easily mobilized by gravity, and loading to create structures (folding) that serve as traps for hydrocarbon accumulation; 2) organic-rich rocks that generate oil and gas under the increased pressures and temperatures following deep burial; 3) a porous sandstone reservoir lying directly above the 'oil kitchen'; and 4) a regionally extensive, non-porous shale top seal to prevent leaking of hydrocarbons from the trap. Where present, the Wilcox is the first potential reservoir in this sequence and must be bypassed (non-porous, poor top seal, no trap) to charge younger reservoirs in Miocene to Pleistocene aged rocks.

BAHA AND THE PERDIDO FOLDBELT

In 1996, almost ten years after the original leasing along the Perdido Fold Belt (PFB) in southeast Alaminos Canyon, the consortium of Shell, Texaco, Amoco, and Mobil drilled the "largest remaining undrilled structure in North America" named BAHA. This test was designed to evaluate the fractured shallow-to-deepwater Jurassic-Cretaceous aged carbonates at a total depth of 22,000' in 7,600' of water. However, the wildcat was abandoned at a total depth of 11,208' bsl due to mechanical problems resulting from a very narrow drilling margin within the Eocene formation. This occurs when the fracture gradient of the rock formation and the weight of the drilling fluid, which is used to control and stabilize the borehole, are almost equal. Normally, the drilling fluid is greater than the formation pressure and prevents the well from "blowing out". Although the test well was not a commercial success and did not achieve its primary objective, it did prove a working petroleum system and was able to qualify and hold the lease.

Five years later in 2001, BAHA 2 was drilled on the north flank of the same large anticline approximately 2.5 miles northeast of the original test. This wildcat was in 7,790' of water and drilled to total depth of 19,164' bsl. Again, the primary target was fractured shallow to deepwater carbonates with a secondary target in much higher risk deepwater clastic turbidites of the Oligocene Frio Formation and Eocene/Paleocene Wilcox Formation. The well successfully tested the Cretaceous carbonates, but found them to be non-porous, non-fractured chalks and deepwater micritic limestones. However, the well did encounter a very sandy Lower Tertiary section where the Wilcox-equivalent turbidite sands were logged over a 4,500' gross interval with 12 feet of oil in an Upper Wilcox sand, again proving a working petroleum system (Fig. 3). Although the BAHA structural test was a disappointment, the results of this well had two very profound impacts on the petroleum industry operating

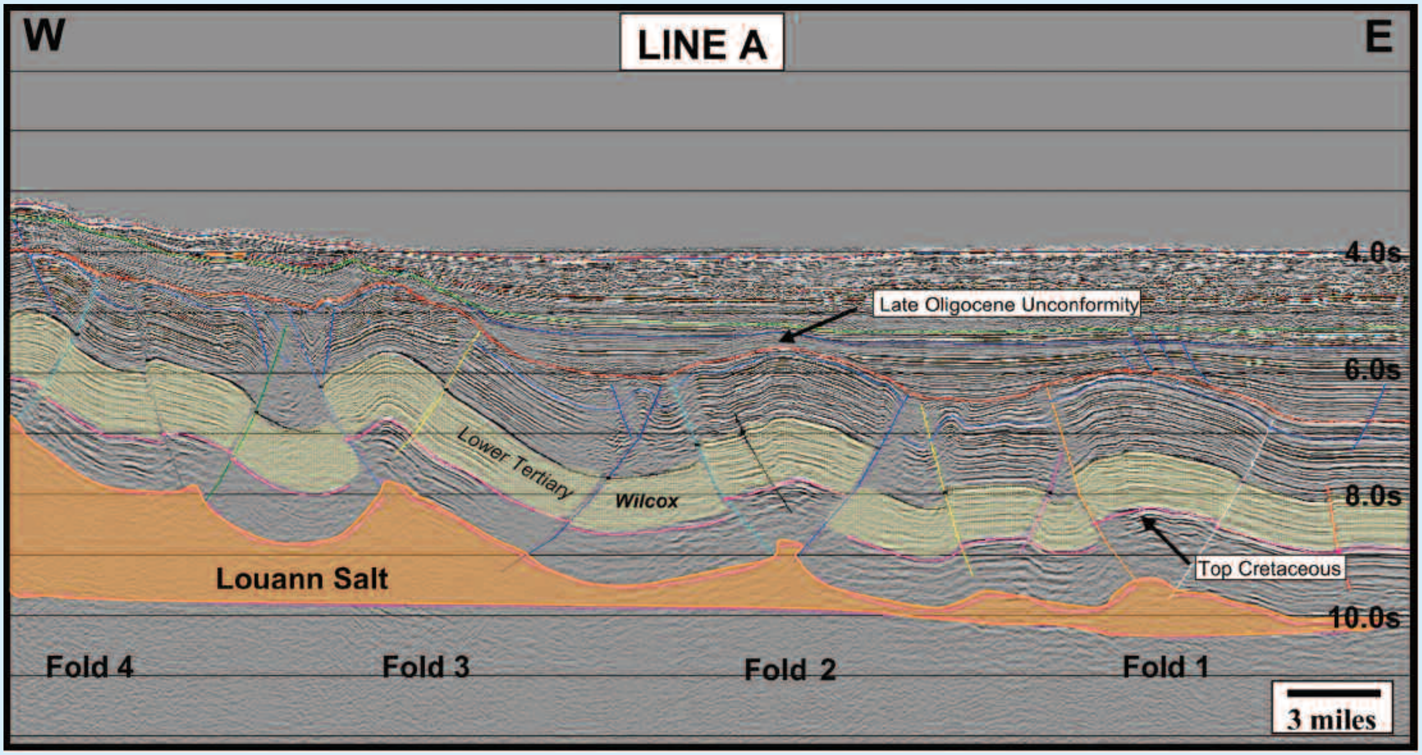

Figure 2a. Thrusted symmetrical box-folds of the Perdido Fold Belt in Alaminos Canyon.

in the area. 1) The massive sand-rich turbidite section of the Wilcox and associated oil show was very encouraging for future exploration, but 2) the final cost to drill the BAHA 2 well was $112MM. If this cost could not be significantly reduced, the associated geological and capital risks would leave this new and exciting trend "dead in the water."

One month after completion of the BAHA 2 well, the Trident wildcat began drilling approximately 30 miles south on an anticlinal closure along the same fold axis

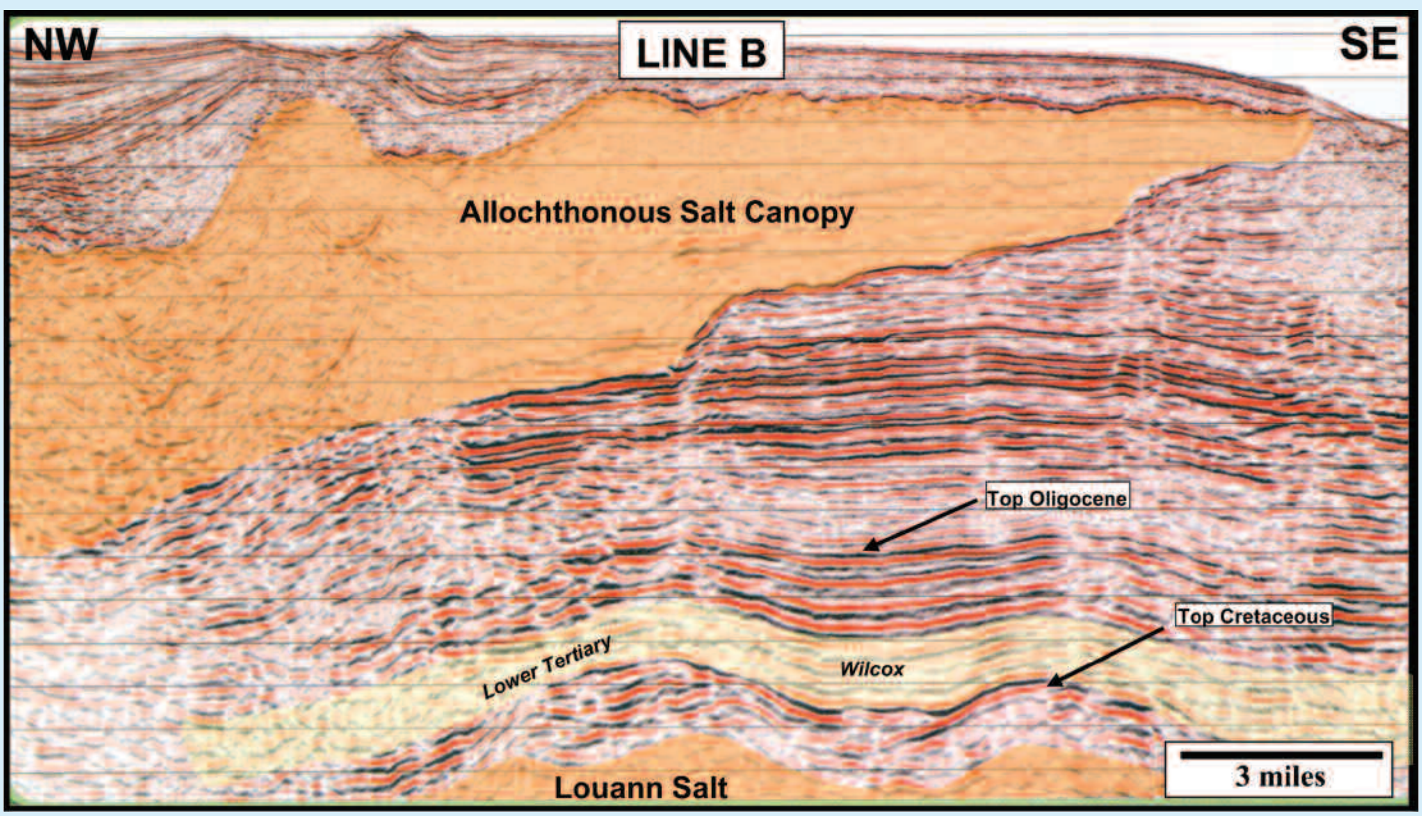

Figure 2b. Relatively low relief salt cored anticlinal structures in Walker Ridge.

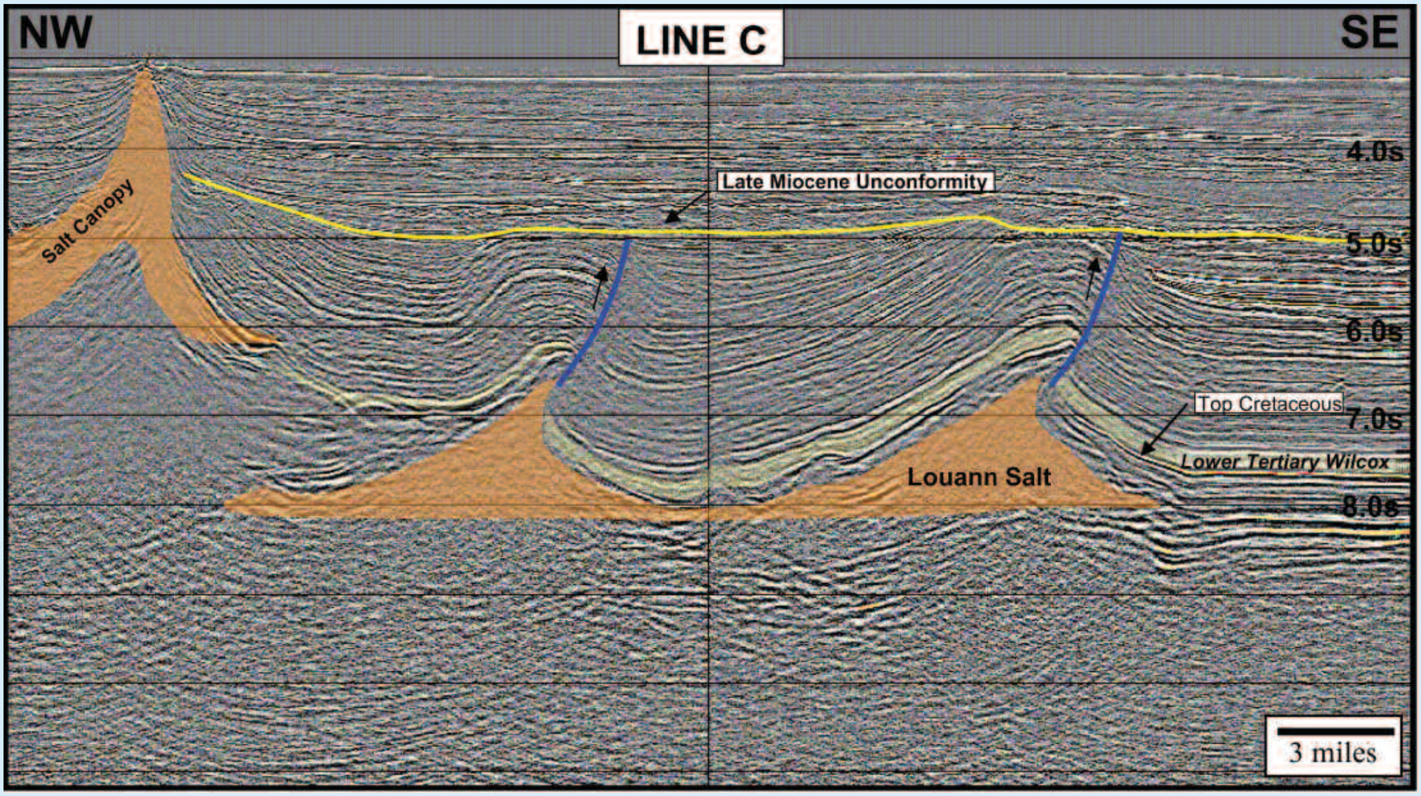

Figure 2c. Asymmetrical thrusts of the Mississippi Fan Fold Belt in Atwater Valley.

(Fig. 4). This well set a world record for water depth of 9,687' and drilled to a total depth of 20,500' bsl. The discovery documented a significant gross hydrocarbon column greater than 300' in the Wilcox section, which was correlative with the BAHA amalgamated sheet sands and channel turbidites, implying a very extensive deepwater fan system. Equally as important as the stratigraphic and depositional implications were the cost improvements. Trident was drilled for $34MM, which was a 70% decrease from the original trend test. The Perdido Fold Belt play was alive and well.

Several Lower Tertiary Wilcox discoveries followed the success of Trident, including the 2002 Great White discovery, Tobago, and Tiger discoveries (Fig.1). After drilling Trident, Great White, and the others that followed, integration of the subsurface data (wireline petrophysical data, formation tests, and core interpretation) with 3D seismic resulted in a much more complex and varied depositional model for the Wilcox section. Initially, many depositional models predicted widespread, laterally extensive sheet sands. However, delineation drilling and high-quality seismic data indicate that the Upper Wilcox section is a mud-rich, channel-levee to amalgamated-channel system at the toe of the slope-to-basin transition (Fig. 4). In contrast, the Lower Wilcox is characterized by sheet to amalgamated-sheet sands deposited in a regionally extensive basin-floor fan system. Generally, this basinward progression of younger strata and waning of the depositional system is believed to track the natural progression of infilling in the Wilcox basin.

CASCADE EXTENDS TREND 300 MILES EAST

In early 2002 while the Great White wildcat was drilling in the PFB, the Cascade well began operations almost 275 miles to the east in the Walker Ridge Area (Fig. 1). This well drilled in 8,140' of water to a total depth of 27,929' bsl, and tested the same Eocene to Paleocene Wilcox section that could be mapped regionally across the GoM with 2D seismic data (Fig. 5). The well found a 1,150' gross hydrocarbon column on the northeast flank of a salt-cored anticline. Regional seismic data indicates a tremendous clastic turbidite wedge that extends and thins from west (PFB) to east (Walker Ridge) (Fig. 5). Although the section is approximately 40% thinner in the Cascade section than in the PFB, it is 50% richer in sand. This trend-extending well was the beginning of a very active exploration program in the east that continues today.

Following the Cascade discovery, six additional wells have been drilled in Walker Ridge: Chinook Deep, St. Malo, Das Bump, Jack, Stones, and Tucker are all discoveries representing a 100% success rate (Fig. 1). This is phenomenal for exploratory wildcats, where a 20% - 33% success rate is normal for the GoM basin. Successful appraisal drilling has occurred on Cascade, St. Malo, and Jack. After two unsuccessful wildcats were drilled in the Keathley Canyon Area during 2004, another significant discovery, Kaskida, was finally made in 2006 (Fig. 1). This was the first of three wildcats to find hydrocarbons in the Keathley Canyon Area, which has now linked the Lower Tertiary Wilcox Trend from Alaminos Canyon in the west, through Keathley Canyon, to Walker Ridge. At present, the Trend has 12 announced discoveries from 17 wildcat tests, which is a 71% success rate.

JACK FLOW TEST

To date, 12 announced discoveries have proven billions of barrels of oil-in-place resource, but moving these volumes to viable, economically recoverable reserves is still a concern. Reservoir parameters of the Wilcox turbidites have remained remarkably consistent from well to well, even among facies associated with different depositional settings; these include leveed channels, channelized fans, and amalgamated sheet

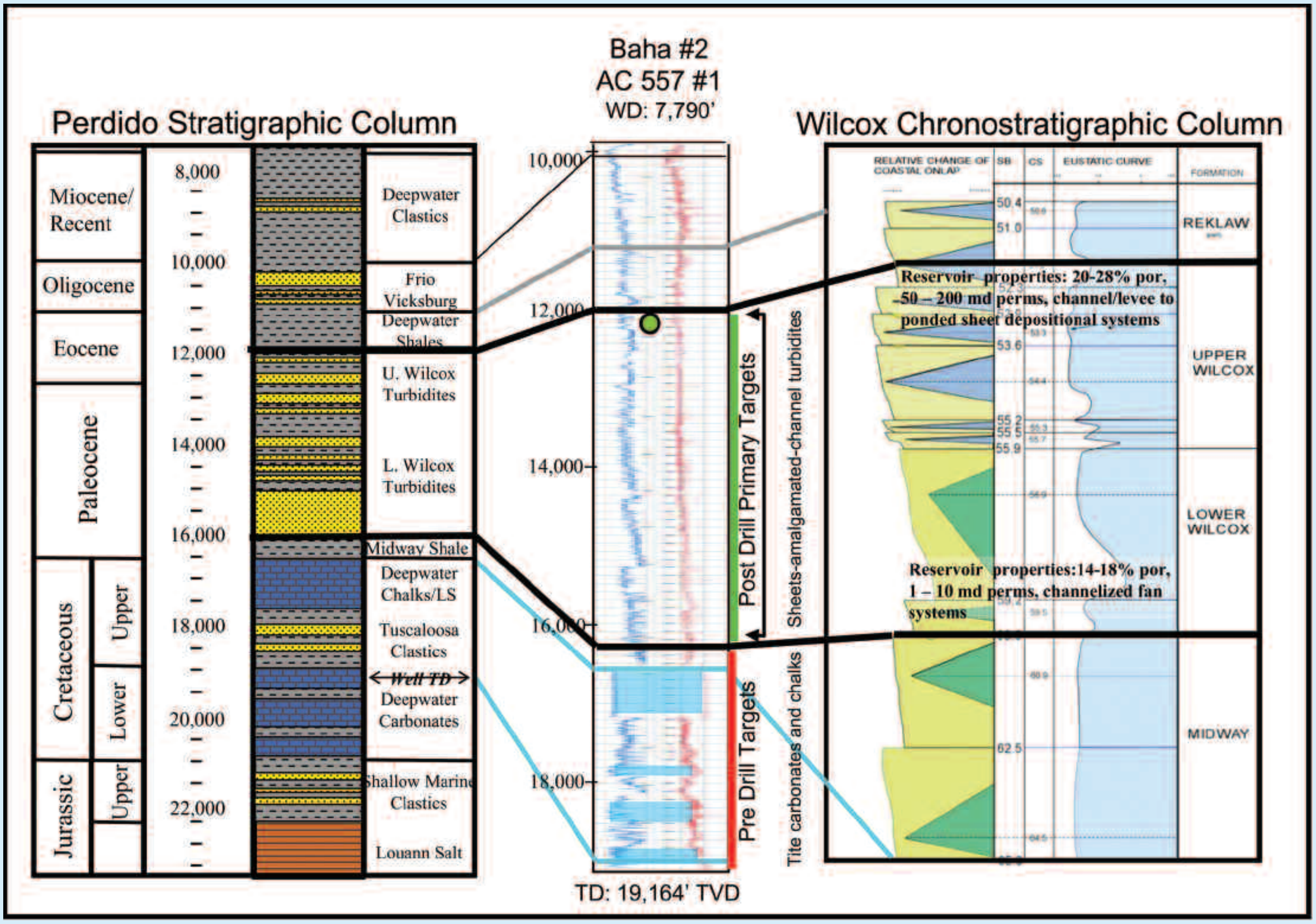

Figure 3. Summary of the BAHA #2 and the significant Wilcox turbidite reservoir section.

sands. However, after four years of drilling with great success, industry remained unsure of the reservoir flow capabilities that are critical for converting this resource base to reserves.

During the first half of 2006, Chevron and its partners, Devon and Statoil, embarked on a record-setting production test of the Jack #2 well drilled in 2005 (Fig.1). This landmark test set more than six world records while conducting the deepest extended-drill-stem test in deepwater GoM history. The Jack well test was in 7,000' of water and greater than 20,000' below the seafloor. During the test, the well sustained a flow rate of more than 6,000 barrels of oil per day with the test representing approximately 40% of the total net pay measured in the well. Typically, a well in the ultra deepwater environment (greater than 5,000') needs to be able to sustain flow rates of 10,000 - 20,000 barrels of oil per day to ensure a reasonable return on capital invested.

The results of the Jack well test were a significant step forward in the process of moving the billions of barrels of oil resource for the Wilcox Trend to billions of barrels of recoverable reserves. However, there remain many technological issues that need to be overcome before the present and future resources become economically viable recoverable reserves. These include the development of reservoir characterization models that integrate oil chemistry properties, reservoir framework and flow capabilities, as well as drilling and completion well design, surface facility infrastructure, and hydrocarbon transportation design.

TREND SUMMARY

The majority of the deepwater Wilcox Trend remains unexplored. Most of the Trend is overlain by a thick salt canopy, which until recently has inhibited exploration due to poor subsalt seismic imaging (Fig. 1). Recent advances in seismic acquisition and processing have improved the ability to interpret subsalt, but the individual sand reservoirs remain below seismic resolution. As a result, much of the depositional model and reservoir characterization of the Wilcox is built upon our current understanding of deepwater clastic depositional systems. Continuing advances in seismic imaging technologies, additional wells, and research in deepwater clastic systems will help refine the Wilcox depositional model and guide new exploration and production.

At present, the 12 announced discoveries have estimated potential reserves of 2.5 bboe, with an average reserve size per prospect of 210 million barrels of oil equivalent. A total of 17 wildcats with a primary Wilcox target have been drilled resulting in a 71% success rate (Fig. 1). There is considerable upside for the trend with a range of 3-15 bboe total reserve potential with a mean of 8 bboe. This year, Petrobras and Devon have announced a projection of first oil in 2009 for Cascade, and Shell and its partners have announced expected first oil for the Great White Complex in Alaminos Canyon at the turn of the decade. Operators of Jack, St. Malo, Stones, and Kaskida have announced appraisal wells during 2006 and 2007 and several others have announced exploration wildcats for 2007.

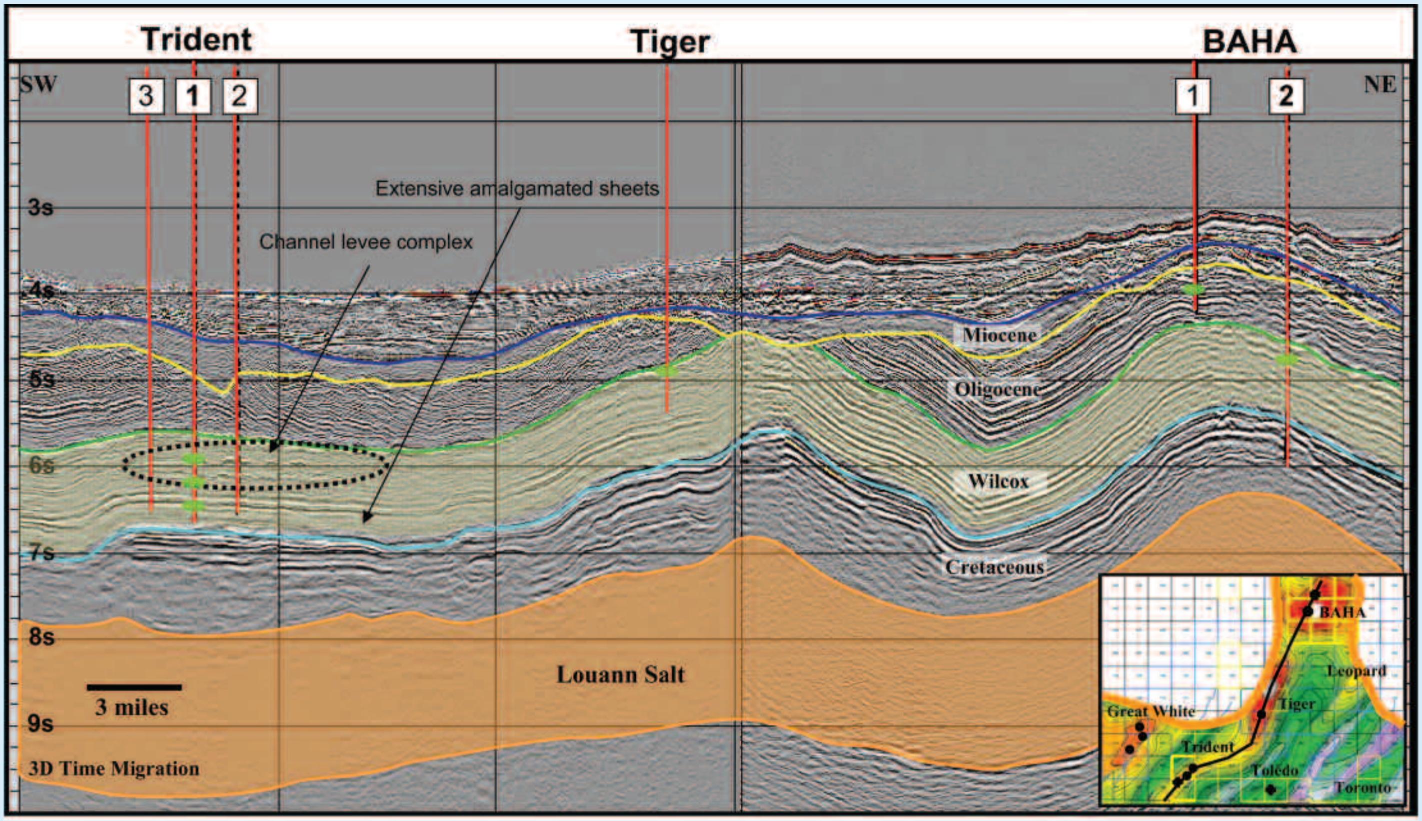

Figure 4. Seismic line tie from BAHA to Trident illustrating seismic character of channel levee systems in the Upper Wilcox and regionally extensive amalgamated sheet sands in the Lower Wilcox. *Oil Accumulation*

ACKNOWLEDGEMENTS

The authors would like to thank Ron Blakey for the paleogeographic reconstruction during late Wilcox time as seen on the front cover, and Fugro, TGS-NOPEC, and WesternGeco for the seismic sections. We also extend a special thanks to all of our internal Chevron teams, ranging from the GoM Deepwater Seismic Processing, Exploration Regional, Maturation, and Appraisal Teams, and ETC Deepwater teams for their input and support.

Accepted July 2007

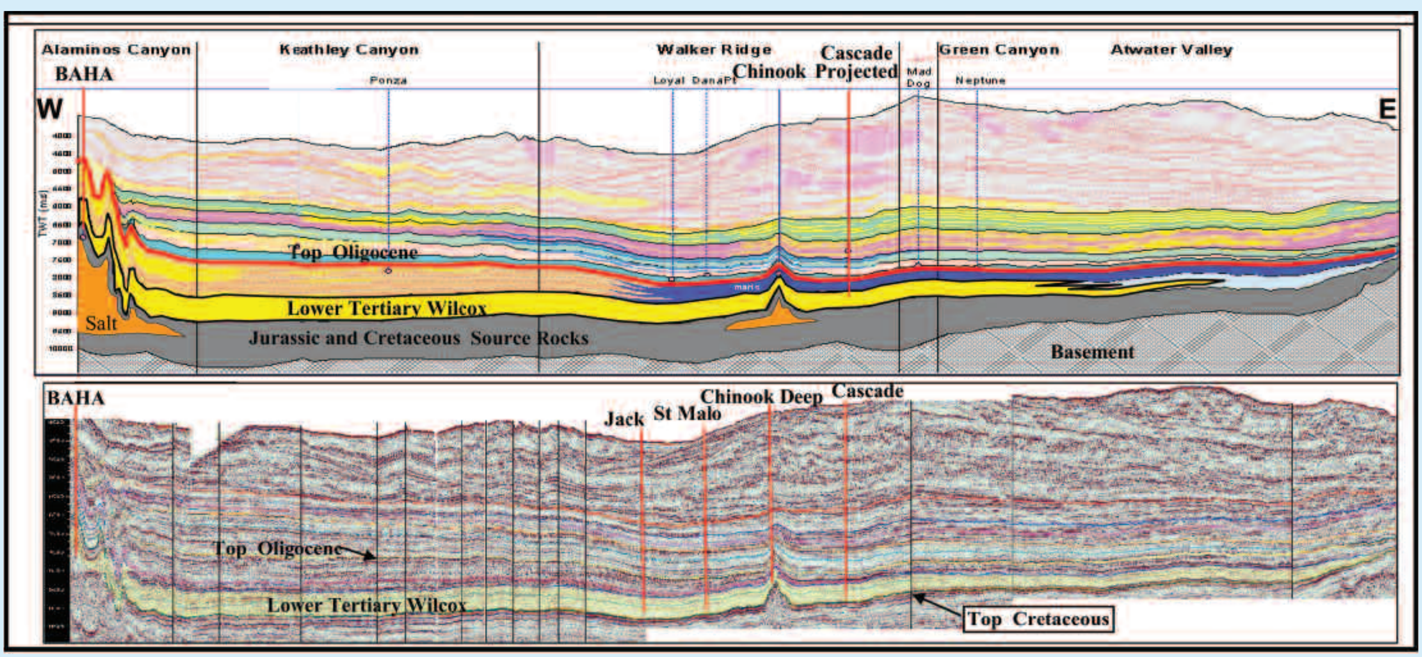

Figure 5. Regional Transect across Alaminos Canyon, Keathley Canyon, Walker Ridge, Green Canyon, and Atwater Valley. The Jack, St. Malo, and Cascade wells are projected into the seismic line.