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Gulf of Mexico's Deepwater Oil Industry Is Built on Pillars of Salt

By PAUL VOOSEN of Greenwire

Not so long ago -- at least, in geological time -- many in the oil game thought the Gulf of Mexico was tapped out.

Financiers called it "the Dead Sea." Nearly a century of production had run its course. Well after deeper well turned up dry, many drilling into thick layers of salt. And where there was salt, most believed, all hope of oil was lost.

Then, 25 years ago, it all began to change.

Exploration geologists discovered that, rather than signaling oil's end, underground salt -- leftovers of repeatedly evaporated seas -- could lead to a horde of new discoveries. And soon, the finds came, with names like Mahogany, Mickey and Tahiti, and the oil majors followed. The salt was obscuring oil, trapping oil or, through its inherently slippery nature, shifting and reordering the Gulf's sedimentary murk.

To understand nearly any deepwater oil find in the Gulf, including BP PLC's runaway Macondo well, requires understanding the salt that provides much of the region's deepest bedrock, geologists say. And, unlike the dull sand and dirt on top of it, carried by various ancestors of the Mississippi River, salt has proven a tricky foundation.

"Do you know the old Bible reference, don't build your house on sand?" said William Galloway, a geologist at the University of Texas at Austin. "Well, building your house on salt goes beyond anything in the biblical expression."

Gulf geology is not only about salt, of course, but scientists' improved take on the rock is one of the best examples of how, for 50 years, the Gulf has served as one of the world's foremost geology labs. Backed by society's endless thirst for oil, geologists have guided drillers to ever deeper and riskier oil reservoirs. But they have also put that money to work, filling in the empty sketch held by most of the vast underground world beneath the ocean floor.

Armed with improved, sonar-like imaging that has begun to reliably sound through salt's uncertain geometries, geologists are discovering oil reserves beneath even foundational salt sheets. (Large recent discoveries off Brazil offer prominent examples.) Not only have these sheets hidden oil, but they have also whisked away the earth's heat, allowing the crude to linger in formations once thought unsuitable.

The global push for salt-hidden oil is only gaining steam, geologists say.

"Salt over the decades has been a difficult rock to seismically image," said Clint Moore, a vice president at ION Geophysical Corp, a seismic technology company. "And we now seem to have solved that problem. And that opens up all kinds of abilities to see the geology of the earth more clearly."

Moore, while at Anadarko Petroleum Corp., was one of the earliest geologists to probe beneath the Gulf's salt, helping discover the Mahogany oil reservoir, the region's first producing subsalt field, after burrowing through 3,825 feet of salt in the early 1990s. The productivity of these salt-based fields could prompt a re-evaluation of peak oil's arrival, he said.

"If the volumes are there, this will be a significant addition to the world's resources," he said.

Of course, there are complications. Deeper wells sit at higher pressures, increasing the risk of blowout. The deepest exploration well, drilled by the ill-fated Deepwater Horizon, is 35,000 feet down, several times the depth of BP's Macondo well. And further oil production will only add to the greenhouse gases humans pour into the atmosphere each year, slowly increasing global temperatures.

Yet despite these caveats, it is hard not to admire the intricate salt formations revealed by, and enabling, the plunge for hydrocarbons. Tongues of salt extend from the Gulf's "mother" sheet, 9 miles below the ocean floor, in intricate plumes and plateaus, hourglass-shaped columns leading to secondary lateral spreads. The plumes have inspired their own exotic terminology -- turtle domes, diapirs, canopies -- and their own geological field, salt tectonics.

"It's an incredible system," said Mark Rowan, a Colorado-based geologist who, as one of the world's leading experts on salt tectonics, frequently consults with the oil industry. "The scale of these [salt formations] is unbelievable," he said, as they often stretch up through 40,000 feet of sediment.

Even BP's Macondo well, though not under salt, owes its existence to the rock, Rowan said. The well is bracketed by nearby salt columns, called diapirs, and its reservoir likely formed by sagging into and then displacing the Gulf's basement salt layer, known as the Louann sheet.

"If you were going to look below Macondo, the Louann level is probably gone," Rowan said. "Where'd it go? It went into those diapirs. ... You basically have these basins sinking into the salt that can create variable traps [for oil]."

Rowan teaches one of the primary courses on salt tectonics, and many of his students are geologists with decades of experience. But the lessons they have learned about salt are often outdated, and once his lessons begin, "their eyes kind of get wide," he said.

Since the late 1980s, he added, "it's been a revolution."

Groundwork

The salt-based revival of the Gulf is a story that begins about 165 million years ago. During the Jurassic period, what is now the Yucatan began to separate from North America -- geologists are uncertain why -- and rolling out between the detaching continents, a shallow proto-Gulf stretched into existence.

This wading pool of a sea formed what is call a restricted basin. Periodically, saltwater rushed in, only to evaporate and leave its salt behind. This cycle repeated for millions of years to build the Louann salt, which can be up to 30,000 feet thick. For much of the Gulf, the Louann became the basement for unending piles of sediment. And it was a shifty basement.

"Very early on, right after the salt was deposited, things started moving," Rowan said.

Salt defies the very connotation of "rock." Over a long enough time, it behaves like a liquid, deforming and viscous. Its sodium-chloride crystal structure is weak, easily pushed around by other rocks, and it keeps a nearly constant density regardless of depth, unlike most sediments, which become progressively packed down. The deeper salt goes, the more slippery and reactive, in comparison, it becomes.

The North American sediment piling onto the Louann, then, soon began to slip and slide toward the Gulf's depressed center. The rock solidified into what looks like a landslide, stretched out at the head and crumpled at the toe. And generally this movement has continued for the past 165 million years, though not uniformly, Rowan said.

This lateral shifting created the opportunity for salt to move vertically, forming columns -- those diapirs -- that plunge upward into sandstone and shale. Previously, geologists had thought the salt would, in impressive fashion, punch through the rock, but research has shown that the salt got growing early, as the sediments compressed, Rowan said.

At times, these diapirs would again flow horizontally, forming canopies over younger sandstone, the compressed remains of past beachfront property that typically hold oil in their pores. The salt diapirs and canopies are impermeable, trapping oil flowing up from its source or directing its path. And the canopies iterate, stretching into second and third columns, occasionally reaching the surface.

"You can see this happening today in the deserts of Iran," Rowan said. "There is salt flowing out onto the desert. It flows. There are basically glaciers of salt."

As mud turned to rock on the salt sheets, it would slowly subside, the salt rushing out and up to further bolster its diapirs. These sediments would form mini-basins, cup-shaped shale or sandstone deposits that riddle the Gulf's northern continental slope. The variable displacement of the sediment -- there is some debate as to whether it is solely caused by gravity -- creates pockets and geology perfect for capturing oil, Rowan said.

"All salt-related deformations, they create structural geometries that give you traps," Rowan said.

While mini-basins have been a foundational structure, the oil discoveries beneath salt canopies really allowed the Gulf to be reborn, especially in areas west of the oil spill.

Connect the salt columns near BP's Macondo well and you would have a similar geology. This latticework of canopies is truly the Gulf's claim to fame, Rowan said.

"The bulk of increased understanding came out of the Gulf of Mexico first," he said.

'Silly Putty' sediment

All of the mini-basins and traps created by the salt would not have made a difference without oil formation, and the reservoirs to fill it. And the Gulf has been the near perfect environment for crude to form throughout its history. The oil has formed -- and been trapped in -- rocks from nearly every era in its history, shaped in large part by salt tectonics.

"It's a jigsaw puzzle with a 5,000-piece scale," Texas' Galloway said.

Since its earliest days, the Gulf of Mexico has lingered in warm temperatures, which allowed riots of ancient, algae-like life to die, drift to the ocean floor and fossilize into oil. Pulses of sand and dirt carried into the sea and onto the salt, borne on vanished rivers. The sediment surges followed the rise of the Rocky Mountains, volcanic eruptions and uplift as the continent slid over a hotspot in the Earth's mantle that, later, created Bermuda.

"There's a tremendous pile of sediment that's really filled in the northern third of the basin," Galloway said, largely over the last tens of millions of years. And this pile has transformed "rather like Silly Putty," he said. "It has no strength at all, so every time you push it, it moves and deforms."

These erosion-based fluxes have continued throughout the Gulf's history, interrupted on occasion by the growth and death of massive reef systems -- and subsequent limestone -- that would put the Bahamas to shame. And while these sedimentary variations are too numerous to recount, one period has been particularly fruitful in past decades, Galloway said.

For 20 million years, ending 5 million years ago, the Appalachians suddenly became active, eroding into the Gulf and filling out its eastern side. Why the erosion began is a mystery, but the rock that formed during this period, known as the Miocene, has proved to have excellent storage and flow potential for oil. BP's Macondo well is such a reservoir, Galloway said, and its blowout shows how prolific these Miocene rocks can be.

When petroleum geologists talk about oil reservoirs like Macondo, they are typically talking about sandstone, the porous rocks formed out of sandy deposits that were once river deltas and barrier islands. And several decades ago, many geologists resisted the notion that cohesive sand formations could flow into deep water, the Miocene sandstone industry now enthusiastically taps.

"The geological and exploration fraternity has always tended to underestimate the Gulf of Mexico," Galloway said. "Even 20 years ago, it did not appreciate how much sediment moved in deepwater settings. ... If you were conservative, you'd say, 'We could go out there in deep water, but we won't find sand.'"

Dry holes

The best scientists, however, knew there would be sand, said Paul Weimer, a geologist at the University of Colorado at Boulder.

The sand, researchers had found, billows out in snake-like flows deep into the basin, fans that at shallower waters had long been targets. But the Gulf was not in fashion then, and the economics did not work without several large discoveries to justify investment, Weimer said.

"What will happen is, companies blow hot and cold on various sedimentary basins," he said. In the 1980s, regions like the North Sea were hot. Still, geologists knew the sandstone was out there in the Gulf of Mexico, Weimer said, though "a lot of dry holes were drilled in the process."

One of those dry holes was guided by ION's Moore, in 1985, who was then working for Diamond Shamrock. The firm had drilled down 8,800 feet only to discover that it was churning through salt. Back then, when salt of any substantial amount was hit, it was assumed to run all the way down to mother salt -- time to abandon the well. But the crew recalibrated its seismic sensor and decided to dig deeper, and soon enough, the salt ended.

And beneath it?

"There was a huge thickness of reservoir sand, over 1,000 feet of clean, porous sandstone," Moore said. This is sexy rock if you are a petroleum geologist. And while it held no oil, it was a perfect candidate to hold it. This model reservoir opened eyes, he said, and was one of the first finds to start people thinking about deeper fields in the Gulf of Mexico.

Before the big subsalt push could really begin, however, there were many technical challenges to overcome. Drilling through salt takes fine control of the synthetic mud used to control a well, and the transition from salt back to shale requires a large, and perfectly timed, increase in mud weight, Rowan said.

"When you drill through salt, you find high pressures," he said.

Avoiding or overcoming these pockets has not been easy and has required significant upgrades in the computer algorithms used to process seismic imaging, the sound-based sensors long used to discover oil. Sound travels through rock at differing velocities and zips through salt with particular haste. The canopies that stretch out from the Louann can be particularly tricky.

"It plays greater havoc with the seismic waves and [their] processing and makes it difficult to image the petroleum-bearing structures below and around it," Moore said.

Oil companies have been using algorithms to improve seismics for decades, but the relentless progression of computing power now allows firms to conduct time-lapse imagery that includes salt-wary velocity models. And firms like Moore's can now process seismics that are not based on single-reflection models, accommodating angles of reflection. Oil can be seen directly beneath the salt, rather than inferred.

The global salt push is just beginning, with many companies looking to duplicate the success seen in the Gulf of Mexico and Brazil, where massive reserves were found beneath a "mother" salt sheet. Those sheets and their diapirs have provided safe haven for crude, which would have otherwise been overcooked by the planet's heat, rendering it useless or inaccessible, Rowan said.

"The earth is like a refinery," Moore added. "With more temperature and pressure, more of the heavier hydrocarbons are cooked away. But the thick salt above the reservoir allows the oil to survive."

It remains to be seen how much the Earth's atmosphere can tolerate more oil combustion, and how the government will regulate deepwater drilling in the Gulf's future. But despite its long history, the Gulf and its salt-shaped structures will continue to produce finds for another generation, Moore said.

"There are decades of exploration left in the Gulf of Mexico," he said.

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