

## Appendix B

# Offshore Oil and Gas Recovery Technology

The success of offshore exploration and production during the past four decades can be attributed, in large part, to technological advances. Innovative technologies, such as new offshore production systems, three-dimensional (3-D) seismic surveys, and improved drilling and completion techniques, have improved the economics of offshore activities and enabled development to occur in deeper, more remote environments. This appendix describes the major developments in exploration, drilling, completion, and production technology. It also briefly discusses subsalt deposits, which comprise an additional area of promising application for the new technologies. Since 85 percent of the continental shelf in the Gulf of Mexico is covered by salt deposits, the potential for hydrocarbon development may be quite large.

## Production Systems

Progress in offshore technology is exemplified by advances in production platforms, which provide a base for operations, drilling, and then production, if necessary.<sup>1</sup> For many years, the standard method for offshore development was to utilize a fixed structure based on the sea bottom, such as an artificial island or man-made platform. Use of this approach in ever-deeper waters is hindered by technical difficulties and economic disadvantages that grow dramatically with water depth.

The industry has advanced far beyond the 100-by-300-foot platform secured on a foundation of timber piles that served as the base of the first offshore discovery well drilled in the Gulf of Mexico in 1938.<sup>2</sup> At present, there are seven

general types of offshore platforms, as described by the Minerals Management Service.<sup>3</sup>

- A *Fixed Platform* (FP) consists of a jacket (a tall vertical section made of tubular steel members supported by piles driven into the seabed) with a deck placed on top (Figure B1). The deck provides space for crew quarters, drilling rigs, and production facilities. The fixed platform is economically feasible for installation in water depths up to about 1,650 feet. An example of a fixed platform is the Shell's Bullwinkle in Green Canyon block 65 installed in mid 1988. This is the world's tallest platform. It became the largest production platform when its capacity was increased to handle production from the Troika prospect in Green Canyon Block 244, which began production in late 1997.
- A *Compliant Tower* (CT) consists of a narrow, flexible tower and a piled foundation that can support a conventional deck for drilling and production operations. Unlike the fixed platform, the compliant tower withstands large lateral forces by sustaining significant lateral deflections, and is usually used in water depths between 1,500 and 3,000 feet. An example of compliant tower use is the Lena field produced by Exxon in 1983.
- A *Seastar* is a floating mini-tension leg platform of relatively low cost developed for production of smaller deep-water reserves that would be uneconomic to produce using more conventional deep-water production systems. It can also be used as a utility, satellite, or early production platform for larger deep-water discoveries. Seastar platforms can be used in water depths ranging from 600 to 3,500 feet. British Borneo is planning to install the world's first Seastar in the Gulf of Mexico in the Ewing Bank area at a water depth of 1,700 feet. British Borneo refers to this prospect as Morpeth.

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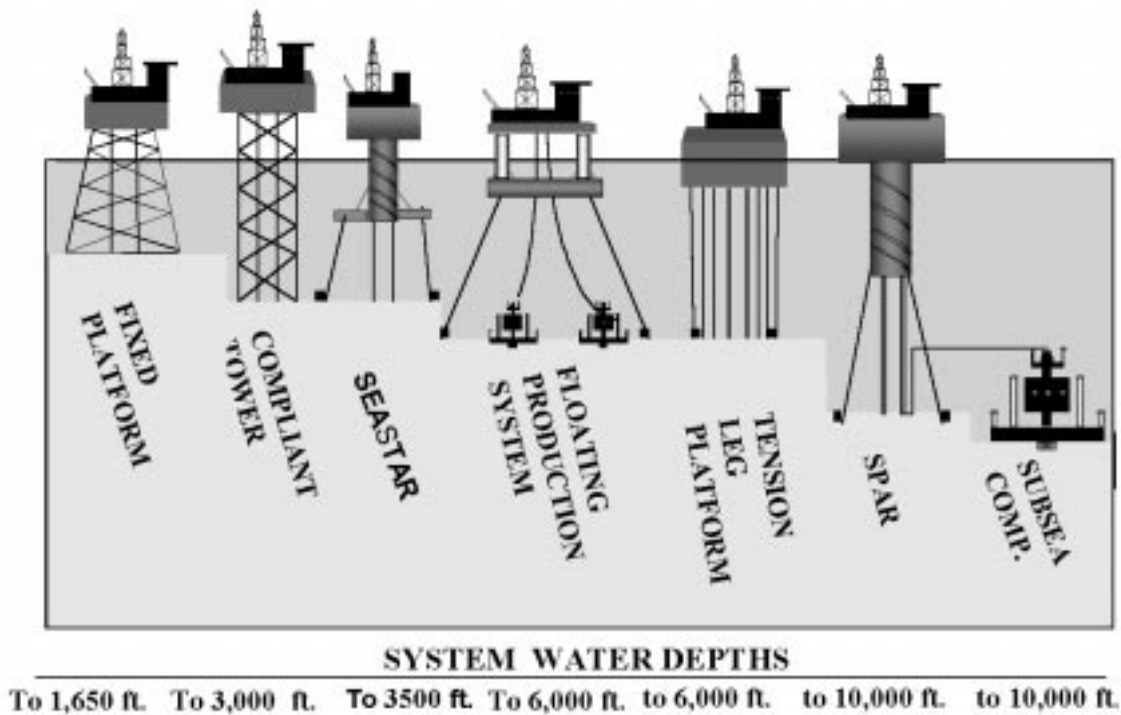
<sup>1</sup>Recent projects in very deep water, such as Shell's Mensa have been developed with subsea completions that are "tied back" to an existing production platform in shallower water. This cost-reduction technique obviates the on-site production platform, the expense of which grows rapidly with water depth.

<sup>2</sup>This occurred at the Creole Field in 14 feet of water, located about 1.5 miles from the Louisiana coast. "U.S. Offshore Milestones," Minerals Management Service (December 1997), available on the MMS website, <<http://www.mms.gov>>.

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<sup>3</sup>Energy Information Administration, Office of Oil and Gas, adapted from "Deepwater Development Systems in the Gulf of Mexico: Basic Options," Minerals Management Service, <[www.gomr.mms.gov/homepg/offshore/deepwatr/options.html](http://www.gomr.mms.gov/homepg/offshore/deepwatr/options.html)>.

**Figure B1. Offshore Production Systems**



Source: Energy Information Administration, Office of Oil and Gas. Adapted from Minerals Management Service, "Deepwater Development Systems in the Gulf of Mexico: Basic Options," <[www.gomr.mms.gov/homepg/offshore/deepwater/options.html](http://www.gomr.mms.gov/homepg/offshore/deepwater/options.html)>.

- A *Floating Production System* (FPS) consists of a semi-submersible that has drilling and production equipment. It has wire rope and chain connections to an anchor, or it can be dynamically positioned using rotating thrusters. Wellheads are on the ocean floor and connected to the surface deck with production risers designed to accommodate platform motion. The FPS can be used in water depths from 600 to 6,000 feet.
- A *Tension Leg Platform* (TLP) consists of a floating structure held in place by vertical, tensioned tendons connected to the sea floor by pile-secured templates. Tensioned tendons provide for use of the TLP in a broad water depth range and for limited vertical motion. TLPs are available for use in water depths up to about 6,000 feet. An example of a TLP is Shell's Ursa platform, anticipated to begin production in 1999. Ursa is the second largest find in the Gulf of Mexico. This platform will be installed in 4,000 feet of water, will have the depth record for a drilling and production platform, and will be the largest structure in the Gulf of Mexico.
- A *Spar Platform* consists of a large-diameter single vertical cylinder supporting a deck. It has a typical fixed platform topside (surface deck with drilling and production equipment), three types of risers (production, drilling, and export), and a hull moored using a taut catenary system of 6 to 20 lines anchored into the sea floor. Spars are available in water depths up to 3,000 feet, although existing technology can extend this to about 10,000 feet. Spar is not an acronym but refers to the analogy of a spar on a ship. In September 1996, Oryx Energy installed the first Spar production platform in the Gulf in 1,930 feet of water in Viosca knoll Block 826. This is a 770-foot-long, 70-foot-diameter cylindrical structure anchored vertically to the sea floor.
- A *Subsea System* ranges from a single subsea well producing to a nearby platform to multiple wells producing through a manifold and pipeline system to a distant production facility. These systems are being applied in water depths of at least 7,000 feet or more. A prime example of a subsea system development is Shell's Mensa field located in Mississippi Canyon Blocks 686, 687, 730 and 731. This field started

producing in July 1997 in 5,376 feet of water, shattering the then depth-record for production. Consisting of a subsea completion system, the field is tied back through a 12-inch flowline to the shallow water platform West Delta 143. The 68-mile tieback has the world record for the longest tieback distance to a platform.

## Seismic Technology

The search for hydrocarbons relies heavily on the use of seismic technology, which is based on reading data initiated from energy sources, such as explosions, air guns (offshore use), vibrator trucks, or well sources. These sources produce waves that pass through the subsurface and are recorded at strategically placed geophones or hydrophones. In the offshore, these seismic responses are usually read from streamers towed behind modern seismic vessels, recorded, and processed later by computers that analyze the data.

The earliest seismic surveys, during the 1920s, were analog recorded and produced two-dimensional (2-D) analyses. Digital recording was introduced in the 1960s, and then, as computer technology burgeoned, so did geophysical signal processing. During the past 30 years, computer-intensive techniques have evolved.

Geophysicists began experimental three-dimensional (3-D) seismic survey work in the 1970s. Commercial 3-D seismology began in the early 1980s on a limited basis. Recent innovations that were essential to the development of 3-D seismology are satellite positioning, new processing algorithms, and the interpretative workstation.<sup>4</sup> The 3-D seismic technology has been a critical component in Gulf of Mexico activity. According to Texaco, in 1989 only 5 percent of the wells drilled in the Gulf of Mexico were based on 3-D seismic surveys. In 1996, nearly 80 percent of the wells drilled were based on 3-D seismic.<sup>5</sup>

New mechanical techniques being used today, and currently being considered for wider application, include increasing the numbers and lengths of streamers, using remotely operated vehicles (ROV) to set geophones or hydrophones on the sea floor, and running forward and backward passes over subsalt prospects.

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<sup>4</sup>Energy Information Administration, "Three-Dimensional Seismology: A New Perspective," *Natural Gas Monthly*, DOE/EIA-0130(92/12) (Washington, DC, December 1992).

<sup>5</sup>"U.S. E&P Surge Hinges on Technology, Not Oil Prices," editorial in the *Oil and Gas Journal* (January 13, 1997), p. 42.

New processing techniques are prestacked 3-D depth migration, interpretation of multiple 3-D surveys in different times (4-D seismic), and reservoir characterization of horizons. These methods are allowed by the rapid increase of computer processing power. Before 1990, the processing of seismic survey data consumed the largest processors for weeks. With the introduction of massive parallel processors (MPP), the processing time has been reduced from weeks to only days. The increase in processing power has also allowed more sophistication in analysis and processing.

Because of developments in seismic data acquisition and development, the industry has realized that the presence of salt in an exploratory hole may indicate the presence of hydrocarbon deposits below the salt in sedimentary deposits. Progress in 3-D and 4-D seismic interpretation, along with the additional computer advancements to process these data, have opened possibilities in new subsalt structure development (more detail on subsalt activity is available in the last section of this appendix).

Advances in seismic technology have not only improved the industry's results in exploration, but also have increased productivity and lowered costs per unit output. The improved information provided by the new seismic techniques lead to improved well placement, which increases well flow and ultimate recovery. Further, the fewer dry holes incurred in project development enhance project profitability by avoiding additional costs and the time lost drilling dry holes.

## Drilling Technology

Drilling is the most essential activity in oil and gas recovery. Once a prospect has been identified, it is only through the actual penetration of the formation by the drill bit that the presence of recoverable hydrocarbons is confirmed. The challenging conditions that confront drilling in deep water necessitate specialized equipment. The number of drilling rigs qualified for deep-water operations are limited. Five rigs capable of drilling in up to 2,500 feet of water were operating in 1995. By 1996, nine were in operation and additional rigs were being upgraded for operations in deep water. Because this set of equipment has expanded more slowly than the demand for drilling services, deep-water day rates are increasing rapidly and are at the highest levels in 20 years. According to C. Russell Luigs, Global Marine Inc. Chairman and CEO, "Compared

to a year ago our rig fleet average day rate has increased about 50 percent.”<sup>6</sup>

Drilling rigs that use such new technology as top-drive drilling and proposed dual derricks are reducing drilling and completion times. In light of the limited number of vessels available for drilling deep-water wells and the resulting increasing drilling rates for such equipment, shorter operating times are a key advantage expected from dual rig derricks.<sup>7</sup>

In addition to creating drilling rigs that can operate at great water depths, new drilling techniques have evolved, which increase productivity and lower unit costs. The evolution of directional and horizontal drilling to penetrate multiple diverse pay targets is a prime example of technological advancement applied in the offshore. The industry now has the ability to reduce costs by using fewer wells to penetrate producing reservoirs at their optimum locations. Horizontal completions within the formation also extend the reach of each well through hydrocarbon-bearing rock, thus increasing the flow rates compared with those from simple vertical completions. These advancements can be attributed to several developments. For example, the evolution of retrievable whipstocks allows the driller to exit the cased wells without losing potential production from the existing wellbores. Also, top drive systems allow the driller to keep the bit in the sidetracked hole, and mud motor enhancements permit drilling up to 60 degrees per 100-foot-radius holes without articulated systems. In addition, pay zone steering systems are capable of staying within pay zone boundaries.<sup>8</sup>

New innovations in drilling also include multilateral and multibranch wells. A multilateral well has more than one horizontal (or near horizontal) lateral drilled from a single site and connected to a single wellbore. A multibranch well has more than one branch drilled from a single site and connected to a single wellbore. Although not as pervasive in the offshore as in the onshore because of the necessity of pressure-sealed systems, multilateral and multibranch wells are expected to be more important factors in future offshore development.

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<sup>6</sup> Sheila Popov, “The Tide Has Turned in the Gulf of Mexico,” *Hart’s Petroleum Engineer International* (October 1997), pp. 25-35.

<sup>7</sup> Michael J.K. Craig and Stephen T. Hyde, “Deepwater Gulf of Mexico more profitable than previously thought,” *Oil and Gas Journal* (March 10, 1997), pp. 41-50.

<sup>8</sup> “Multilateral-Well Completion-System Advances,” editorial in the *Journal of Petroleum Technology* (July 1997), pp. 693-699.

## Completion Technology

The average rate of production from deep-water wells has increased as completion technology, tubing size, and production facility efficiencies have advanced. Less expensive and more productive wells can be achieved with extended reach, horizontal and multilateral wells. Higher rate completions are possible using larger tubing (5-inch or more) and high-rate gravel packs. Initial rates from Shell’s Auger Platform were about 12,000 barrels of oil per day per well. These flow rates, while very impressive, have been eclipsed by a well at BP’s Troika project on Green Canyon Block 244, which produced 31,000 barrels of oil on January 4, 1998.<sup>9</sup>

Another area of development for completion technology involves subsea well completions that are connected by pipeline to a platform that may be miles away. The use of previously installed platform infrastructure as central producing and processing centers for new fields allows oil and gas recovery from fields that would be uneconomic if their development required their own platform and facilities. Old platforms above and on the continental slope have extended their useful life by processing deep water fields. A prime example of this innovation is the Mensa field, which gathers gas at a local manifold and then ships the gas by pipeline to the West Delta 143 platform 68 miles up the continental shelf.

## Other Technology

The exploitation of deep water deposits has benefitted from technological development directed at virtually all aspects of operation. Profitability is enhanced with any new equipment or innovation that either increases productivity, lowers costs, improves reliability, or accelerates project development (hence increasing the present value of expected returns). In addition to the major developments already discussed, other areas of interest for technological improvement include more reliable oil subsea systems (which include diverless remotely operated vehicle systems), bundled pipeline installations of 5 miles or more that can be towed to locations, improved pipeline connections to floating and subsea completions, composite materials used in valving, and other construction materials.

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<sup>9</sup> Minerals Management Service, “Gulf of Mexico Deepwater Continues to Shine As America’s New Frontier,” <[www.gomr.mms.gov/homepg/whatsnew/newsreal/980305.html](http://www.gomr.mms.gov/homepg/whatsnew/newsreal/980305.html)>.

The advantages of adopting improved technology in deep water projects are seen in a number of ways. For example, well flow rates for the Ursa project are 150 percent more than those for the Auger project just a few years earlier. The economic advantages from these developments are substantial as the unit capital costs were almost halved between the two projects. The incidence of dry holes incurred in exploration also has declined with direct reduction in project costs. The number of successful wells as a fraction of total wells has increased dramatically, which reflects the benefits of improvements in 3-D seismic and other techniques. Lastly, aggressive innovation has improved project development by accelerating the process from initial stages to the point of first production. Rapid development requires not only improvements in project management, but also better processes to allow construction of new facilities designed for the particular location in a timely fashion. Project development time had ranged up to 5 years for all offshore projects previously. More recent field development has been conducted in much less time, with the period from discovery to first production ranging between 6 and 18 months.<sup>10</sup> Experience with deep-water construction and operations has enabled development to proceed much faster, with time from discovery to production declining from 10 years to just over 2 years by 1996 (Chapter 4, Figure 35). Accelerated development enhances project economics significantly by reducing the carrying cost of early capital investment, and by increasing the present value of the revenue stream. Design improvements between the Auger and Mars projects allowed Shell to cut the construction period to 9 months with a saving of \$120 million.<sup>11</sup>

## Subsalt Deposits

Technology has provided access to areas that were either technically or economically inaccessible owing to major challenges, such as deposits located in very deep water or located below salt formations. While the major additions to production and reserves in the Gulf of Mexico have occurred in deep waters, work in refining the discovery and recovery of oil and gas deposits in subsalt formations must be noted as another promising area of potential supplies.

Eighty-five percent of the continental shelf in the Gulf of Mexico, including both shallow- and deep-water areas, is covered by salt deposits, which comprises an extensive area

for potential hydrocarbon development. Phillips Petroleum achieved the first subsalt commercial development in the Gulf of Mexico with its Mahogany platform. This platform, which was set in August 1996, showed that commercial prospects could be found below salt (in this case below a 4,000 foot salt sheet).

The subsalt accumulations can be found in structural traps below salt sheets or sills. The first fields under salt were found by directional wells drilling below salt overhangs extending out from salt domes. Experience in field development close to salt-covered areas indicated that not all salt features were simple dome-shaped features or solid sheets. Often the salt structure was the result of flows from salt deposits that extended horizontally over sedimentary rocks that could contain oil. The salt then acts as an impermeable barrier that entraps the hydrocarbons in accumulations that may be commercially viable prospects.

The identification of structures below salt sheets was the first problem to overcome in the development of subsalt prospects, as the salt layers pose great difficulty in geophysical analysis. The unclear results did not provide strong support for investing in expensive exploratory drilling. The advent of high-speed parallel processing, pre- and post-stack processing techniques and 3-D grid design helped potential reservoir resolution and identification of prospects.

Industry activity in subsalt prospect development has been encouraged also by improvements in drilling and casing techniques in salt formations. Drilling through and below salt columns presents unique challenges to the drilling and completion of wells. The drilling of these wells requires special planning and techniques. Special strings of casing strategically placed are paramount to successful drilling and producing wells.

The highly sophisticated technology available to firms for offshore operations does not necessarily assure success in their endeavors, and the subsalt prospects illustrate this point. The initial enthusiasm after the Mahogany project was followed by a string of disappointments in the pursuit of subsalt prospects. After a relative lull in activity industry-wide, Anadarko announced a major subsalt discovery in shallow water that should contain at least 140 million barrels of oil equivalent (BOE), with reasonable potential of exceeding 200 million BOE.<sup>12</sup> Successes of this magnitude should rekindle interest in meeting the challenge posed by salt formations.

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<sup>10</sup>"New Ideas, Companies Invigorate Gulf," *The American Oil & Gas Reporter* (June 1996), p. 68.

<sup>11</sup>Minerals Management Service, *Deepwater in the Gulf of Mexico: America's New Frontier*, OCS Report MMS 97-0004 (February 1997).

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<sup>12</sup>Anadarko announces big subsalt discovery," *Oilgram News* (July 30, 1998), p. 1.

Subsalt development has also been slowed because the majority of prospects have been leased or recovery from the subsalt is delayed by production activities elsewhere on a given lease. Subsalt operations apparently will be more a

factor in the future as flows from leases presently dedicated to other production decline and the leases approach the end of their lease terms, which will promote additional development to assure continuation of lease rights.