DEEPWATER PETROLEUM EXPLORATION & PRODUCTION
A NONTECHNICAL GUIDE | 2nd Edition

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Foreword

Forewarned is forearmed.

—Miguel De Cervantes (1547–1616)
Don Quixote

We needed to hurry up and write this second edition. As with any foray into a new frontier, history and innovation have been happening almost every day since our first edition's publication date.

As in the first edition, our first two chapters bring you from the first geologic toe-in-the-water in California more than 100 years ago to stepping off the Outer Continental Shelf of the Gulf of Mexico into thousands of feet of water, as well as the plunge into the Campos Basin off the coast of Brazil. That journey is just the prelude to understanding present and even future deepwater operations.

To complete the setting, this edition adds a new complete chapter on geology and geophysics. To pull this off, we asked four accomplished scientists in the field, Stephen Sears, Fred Keller, Tim Garfield, and Mike Forrest, all with decades of experience with large exploration and production (E&P) organizations, to contribute chapter 3.

The processes for exploring, developing, and producing petroleum in the deepwater are about the same as for the shelf or, really, the onshore. From the outside, just four steps take place—explore, appraise, develop, and produce. From the inside, each of these processes takes many more steps, depending on how closely we look. And we look closer in chapters 4 through 13, even more closely than in the first edition. We examine in detail the engineering and scientific schemes that companies use in the deepwater, dealing especially with how they differ from shallower operations and the onshore. We have added other new chapters on the drilling rigs and service vessels used in the deepwater.

A theme underlies this book: how the upstream industry and companies learned their way into the deepwater. The first two chapters almost dwell on it. At the end of chapters 4, 5, 10, 11, and 13, case studies of prominent companies show how they climbed their own learning curves to success. Chapter 14 finishes off the theme by dubbing deepwater the "third wave."

We assumed something about your knowledge of E&P operations—onshore and offshore. Because you bought this book, which has the word "nontechnical" in the title, we treat each subject as if you have but a modicum of background. You should find almost everything easy to understand. If you need more depth, our publisher, PennWell, has a few other books, such as Raymond and Leffler's *Oil and Gas Production in Nontechnical Language* and Norm Hyne's *Nontechnical Guide to Petroleum Geology, Exploration, Drilling, and Production* to help you out.

This book is a collaborative effort of three industry veterans with more than 125 years experience in the industry. Despite that exhaustive and exhausting record, we needed the invaluable input from a throng of other industry experts and former colleagues. We have to recognize some of the many we consulted: Howard Shatto, Bruce Collipp, Mike Forrest, Jim Day, Dick Frisbie, John Huff, Ken Arnold, Doug Peart, George Rodenbusch, Alex van den Berg, Don Jacobsen, Harold Bross, Susan Lorimer, Jim Seaver, Bob Helmkamp, Franz Kopp, Dean Taylor, Mike Talbot, Joe Netherland, Bradley Beitler, Ken Dupal, Rich Smith, and Paul Wieg. Without their help, we could not have satisfied our own standards for a quality product. Still, we interpreted all they said and are therefore responsible for the way we presented it.

Introduction

My reaction when Rich Pattarozzi told me he was working on a nontechnical book about the development and production of oil and natural gas in deepwater has not changed: "At last. Without doubt, our industry needs this book. I could not be more enthusiastic about its content."

Going into the deepwater demands so much of so many that few individuals can grasp all of the intricate details and technical challenges that have to be overcome. I believe these three authors are unsurpassed in their ability to tell the story from start to finish in an understandable fashion.

Rich Pattarozzi, the talented senior executive at Shell Exploration and Production who created our deepwater organization, provided the dynamic leadership to take Shell where no oil and gas company had been. For Rich, technical and economic challenges were never roadblocks. They were merely opportunities for creativity and innovation that brought out the best in Shell's staff. Gordon Sterling pioneered many of the technical breakthroughs required to take our company on its incredible journey. Never afraid to question conventional engineering paradigms, he encouraged and nurtured the new and often radical approaches necessary to break through the technical barriers that inevitably occurred along the way. And finally, there is Bill Leffler, a long-time planner and strategic thinker at Shell, who has a gift of communicating through the written word. Despite his nontechnical background, Bill is able to transform complicated concepts into clear and concise words that are understandable for the expert and for the layperson.

While this book is all about the oil and gas companies' operations in deepwater, no doubt it will find a home on the desks and bookshelves of many non–oil company readers. Our industry has been most fortunate to have the thousands of dedicated service and supply personnel whose help and innovation in their area of expertise have made this deepwater story possible. Some of the key sectors that have made significant contributions are fabrication and construction, marine transportation, offshore drilling, producing systems, and oil and gas pipelines. Through this incredible journey, a vital partnership between the oil and gas operators and the service and supply industry has developed along the lines so evident in the more than 150-year history of the oil and gas industry.

I recommend this book to you, not only for its readability, but also for the story that it tells. It is the saga of thousands of men and women, working individually and together, both technical and business professionals, people who have accepted a challenge and created the systems that enable our industry to do what the naysayers said could not be done—to produce oil and gas in water depths 5,000 to 10,000 feet—safely, economically, and in an environmentally sound way.

Jack E. Little, President and CEO (retired)
Shell Oil Company
October 18, 2010

the Gulf of Mexico. Still, they worked in only 16 feet of water. They used a conventional design for their facility except for steel pilings under the area of the platform that supported the derrick, a concession to their concern about stability during harsh weather. Alas, their effort yielded no oil either.

Superior Approaches

The next year, Superior took another leap, technically, economically, and geographically. They moved 18 miles from the Louisiana coast, still in only 20 feet of water. They judged the pile-supported platform in their Creole field too expensive to build in the new, more remote site. Instead they had the J. Ray McDermott Company construct a steel tubular structure in an onshore yard and barged the prefabricated units to the site. Horizontal and diagonal members linked the tubulars like huge Tinker Toys. (See fig. 1–4.) With these innovative steps, Superior shortened installation time, improved structural integrity, reduced costs, improved safety conditions around installation, and, to the contractors' delight, created a new industry sector, prefabrication.

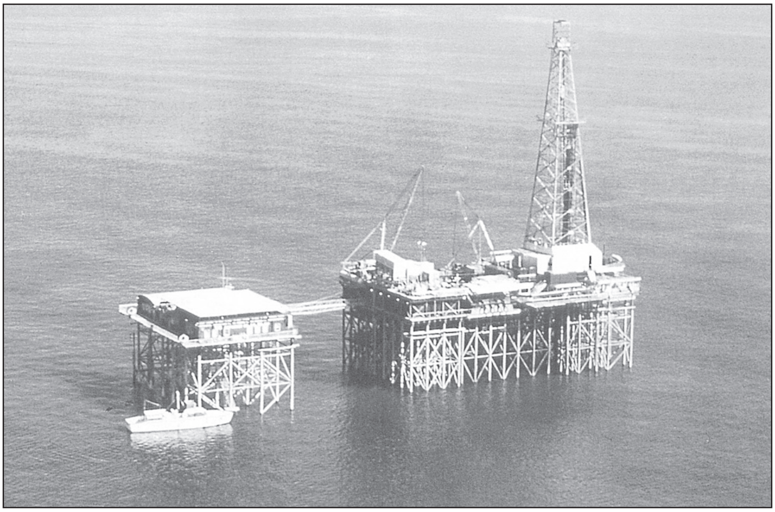

Fig. 1–4. Superior's prefabricated template platform. (Courtesy McDermott International, Inc.)

the Continental Shelf (table 2–1). Conoco, Shell, British Petroleum, Exxon, and Oryx (who ultimately disappeared into Kerr-McGee, who was absorbed by Anadarko) pioneered exploration success in the new province.

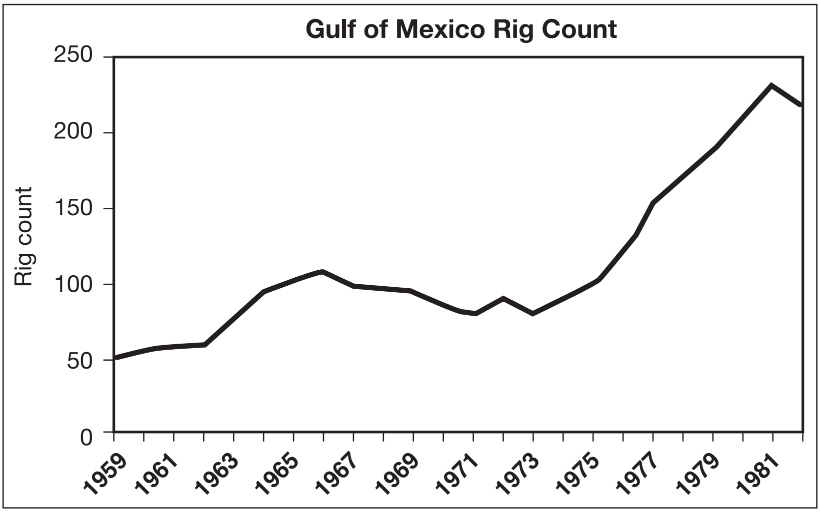

Fig. 2–1. Rig count in the Gulf of Mexico, 1959–1982

Table 2–1. Significant deepwater discoveries in the 1980s

Field	Volume Million barrels	Depth in feet	Company	Year
Joliet	65	1724	Conoco	1981
Pompano	163	1436	BP	1981
Tahoe	71	1391	Shell	1984
Popeye	85	2065	Shell/BP/ Mobil	1985
Ram-Powell	379	3243	Shell/Amoco/ Exxon	1985
Mensa	116	5276	Shell	1986
Auger	386	2260	Shell	1986
Neptune/Thor	108	1864	Oryx/Exxon	1987
Mars	538	2960	Shell/BP	1988

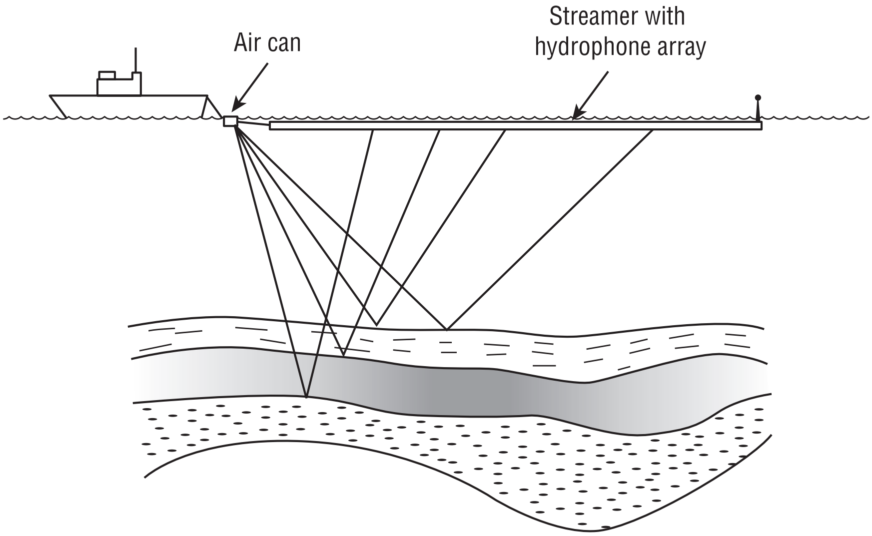

Fig. 3–14. Offshore seismic acquisition

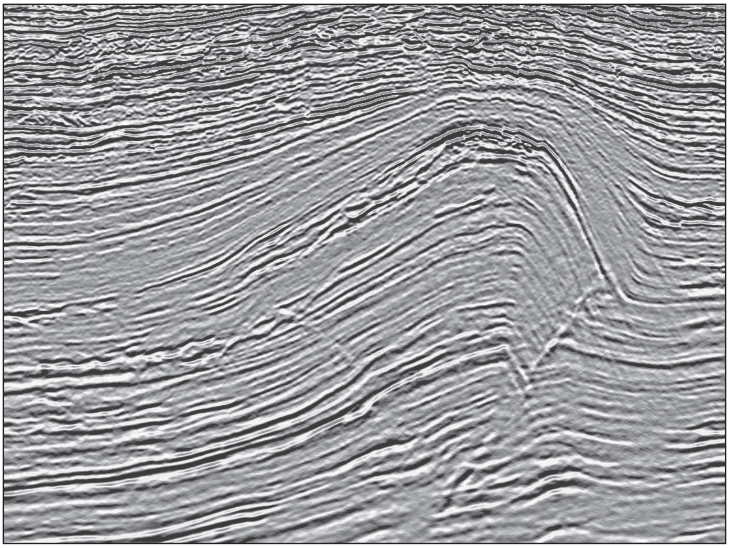

Fig. 3–15. A 2-D seismic display of a hanging wall anticline with direct hydrocarbon indicator (DHI), West Niger Delta. (Courtesy Veritas DGC.)

Not all leaps landed on two feet. Petrobras tried installing "dry chambers" at eight subsea installations, i.e., dry trees encapsulated in a pressurized chamber on the sea floor. The high cost of the surface vessel and risky intervention techniques led them to abandon the idea and convert the wells to wet tree technology.

Subsea processing had its conception in Brazil with the installation of a sea floor manifold in 1982. Later Petrobras would install electric subsea pumping, and in 2010 sea floor separation and water reinjection.

By the late 1970s Petrobras was beginning to take full advantage of the world's accumulated subsurface knowledge: tectonic plate movement theory, especially the drift of South America away from Africa and the resulting rift, understanding the role of rivers and turbidite sedimentation, and the latest seismic reflection technology.

In 1984 Petrobras made its first real deepwater discovery, Albacore (150–1,100 meters of water), followed by Marlim (781 meters) in 1986 and Marlim Sul (1,709 meters) in 1987. These depths challenged existing development technology. Petrobras had mastered subsea completion and production to floating vessels, but only to about 400 meters. The company began its ambitious program, Deepwater Systems Technology Innovation Program (in Portuguese its acronym is PROCAP), in 1986, aimed at significantly reducing its offshore costs to make fields economical, as well as enabling itself to move into 1,000 meters of water and beyond. By 2006 it had thirty-three offshore fields being produced, though over 600 subsea trees to twenty-three floating and thirteen fixed platforms and the Roncador field had just been completed in 1,886 meters. Also that year Petrobras produced enough oil to make Brazil petroleum self-sufficient. Granted, the national program turning biomaterial into gasoline and diesel fuel helped, but crude oil production had risen to 2.3 million barrels per day.

The supergiant Tupi discovery in 2006 in the Santos Basin to the south demonstrated the need for even newer technologies. Tupi damage to the drilling sequence. The well will have to be re-entered; the pressure will have to be overcome; the severed drill pipe will have to be removed. All this can add costly days to the drilling operation.

Drilling crews test the BOP system on rigorous schedules to ensure that it always functions. Company policies and local government agencies determine the frequency and testing procedures.

Evaluating the Well

After the drill bit reaches the target depth (TD), the bit and the drill pipe are pulled, and the drilling engineer and his team evaluate the well. A drill stem test (see box below) may evaluate the flow rates of hydrocarbons from the zones not yet covered by casing. Integrating this data with the logs and other tests leads to the completion decision. The drilling vessel can stand by while this decision is being mulled, or the well can be "temporarily abandoned" by placing cement plugs in the well bore and then disconnecting at the BOP. The vessel then moves on to another assignment.

Drillstem Test

"A procedure to determine the productive capacity, pressure, permeability, or extent (or a combination of these) of a hydrocarbon reservoir. While several different proprietary hardware sets are available to accomplish this, the common idea is to isolate the zone of interest with temporary packers. Next, one or more valves are opened to produce the reservoir fluids through the drill pipe and allow the well to flow for a time. Finally, the operator kills the well, closes the valves, removes the packers and trips the tools out of the hole. Depending on the requirements and goals for the test, it may be of short (one hour or less) or long (several days or weeks) duration and there might be more than one flow period and pressure buildup period." (From "Schlumberger Glossary of Oilfield Terms" at www.glossary.oilfield.slb.com/.)