Joseph A. Tainter & Tadeusz W. Patzek

DRILLING DOWN

The Gulf Oil Debacle and Our Energy Dilemma

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In memory of Anne O'Rourke

– JAT

For my wife, Joanna, and my children, Lucas, Sophie, and Julie

–TWP

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Chapter 1

Introduction

We begin this book during the Fourth of July weekend, 75 days after the Deepwater Horizon exploded, burst into flames, and sank, killing 11 men. In the wake of this accident came the worst environmental disaster in U.S. history. The starting date of our writing is significant because this is a weekend when normally thousands of people would descend on the beaches and restaurants of the Gulf Coast. The Gulf is a place of great bounty. A couple of hours with some traps produces enough blue crabs to make a cauldron of gumbo that can feed a family and guests for days. Order crayfish ("crawdads") at the right season and your table will be piled high with them. All of this, and the livelihoods that depend on it, is now lost over large areas.

Because of how tightly connected our economy and society are, it is not hard to foresee many of the consequences. As the owners of boats, restaurants, and motels lose business, they lay off employees and pay less tax. The suppliers with whom they do business suffer the same in connections that extend across the country and across the oceans. Oil on a beach means local restaurants serve less beef from Kansas, fewer chickens from Arkansas, and fewer vegetables from California. Those restaurants order fewer serving plates from overseas, and motels order fewer sheets, and less detergent to wash the sheets. Employees laid off will not be buying new cars or wide-screen televisions, eating out, or replacing a washing machine. Church donations are already down. With reduced taxes, state and local governments will hire fewer teachers or police officers. Such connections could be traced on and on. BP, the company that leased the Deepwater Horizon, has stated that it will pay

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all claims, but there are limits to that commitment. Can a vegetable grower in California expect compensation for fewer shipments to Gulf Coast restaurants? What about a vegetable farmer in Mexico, or a fruit grower in Chile? Can a seafood restaurant in Albuquerque or Denver expect compensation because shrimp and oysters from the Gulf are scarcer and more expensive? For that matter, what about companies such as Zatarain's, which produces spices for New Orleans cuisine, or Café du Monde, a local coffee shop and producer of a special coffee blend? At some point people, businesses, and governments hurt by the spill will have to absorb their losses.

There are also losses that cannot be counted in money, and these may be far more tragic. A few years ago, a colleague in economics, George Peterson of the U.S. Forest Service's Rocky Mountain Research Station, was asked to help determine compensation for damages from the *Exxon Valdez* oil spill in southeast Alaska. There, as in the Gulf, people accustomed to a life of fishing suddenly lost their livelihoods. The surprise was to discover that these people could not be adequately compensated with any amount of money. People had lost a way of life that gave meaning and value. How do you compensate people who have lost their sense of worth, their identity? Quite simply, you cannot. As it was in the Alaska spill, so it is in the Gulf. Money may be necessary, but it cannot compensate for what has been lost. And knowing the people of the Gulf, we are certain that they do not want to spend years living off payments from BP.

Then there is the natural ecosystem itself, the marshes and beaches, the fish, birds, and mammals, and the once-blue water. Beaches can be cleaned, but you cannot restore a complex system. Nature must do that, and will, but the process may take decades. This is the most important restoration of all. All else in the Gulf – businesses, jobs, taxes, church donations, a way of life – depend on this natural system.

A great deal has been written about the Gulf spill in articles, books, and online. Much of this, however, repeats the obvious observations about our dependence on oil, energy independence, the desirability of clean energy, and the failures of regulation. Although we do not downplay the importance of these matters, such points are already known. Within the Gulf tragedy there are deeper lessons about energy, about our society, about how we came to be both so complex and so dependent on fossil fuels, and about what this means for our future. It is clear that the Gulf tragedy and its aftermath constitute a period in time when important lessons can be drawn and learned, and a moment when we will be open to introspection about oil and a society that requires such great quantities of this nonrenewable resource. The late anthropologist Leslie White once noted that a bomber flying over Europe during

World War II consumed more energy in a single flight than had been consumed by all the people of Europe during the Paleolithic, or Old Stone Age, who existed entirely by hunting and gathering wild foods. White estimated that such societies could produce only about 1/20 horsepower per person, an amount that today would not suffice for even a fleeting moment of industrial life. Our societies today need such vast amounts of energy that we provide it by mining stocks of solar energy accumulated eons ago, and converted into coal, natural gas, and petroleum. Without these stocks we could not live as we do.

Is it realistic to think that we can simply rely forever on today's energy sources? Groups such as the Association for the Study of Peak Oil and Gas (ASPO) warn that we will soon reach a point known as "peak oil." When this point is reached, oil production cannot be increased, even when there is plentiful oil in the ground. In fact, once production starts to decline, each year thereafter the world will need to get by on less oil than the year before. The date of reaching peak oil is controversial. The U.S. Army once predicted that it would be 2005, and some analysts – including one of the authors – think that indeed we reached it then. If so, the effects have been masked by the current recession and the development of previously unreachable oil deposits, such as in deep water. The simple answer is that we do not know exactly if peak oil has been reached, nor how long global oil production would hover at a level close to the peak. The only certainty is that the global peak of oil production is closer each day.

The Roman poet Juvenal wrote that "a good person is as rare as a Black Swan." Until 1697, when black swans were found in Australia, they were thought not to exist. All swans observed by Europeans had been white. The term has come to mean something that has never been observed, and is considered either impossible or highly unlikely. As explained by Nassim Nicholas Taleb, nothing in the past convinces us that a black swan can exist. Was the Gulf spill a Black Swan, something that was highly unlikely to happen? Nothing like it had occurred in America's waters, not even the *Exxon Valdez* spill. Most people, and clearly the regulatory authorities, thought that such a catastrophe could not happen. Yet there have actually been several times when we averted such spills because the blowout preventer, which failed in the Deepwater Horizon case, did work. Such events point to a systemic problem, and suggest that the spill was in fact likely given sufficient opportunities and time.

There is, however, still a sense in which the Black Swan metaphor is useful here. One important aspect of Black Swan events is that they give us an opportunity to see the world in a new light, to discard outdated assumptions and question what we have thought. Our society rarely thinks about our energy supply, or how that supply brings food to our tables, clothing and consumer goods to stores, loans for cars and houses, and taxes for the government. Even donations to churches depend ultimately on petroleum. Our ignorance of energy has been like the one-time ignorance of Europeans about swans. Economists treat energy as a commodity, no different from bananas or iPods, to be produced and sold in relation to market demand. Peak oil, and the resulting imperative to drill deeper and more remotely to find new oil, not only gives us the opportunity to look at the assumptions in our lives, but also the larger societal processes that result from what we call the energy–complexity spiral.

Toward the end of World War II, Vannevar Bush, director of the wartime Office of Scientific Research and Development, submitted a report to President Truman entitled *Science, the Endless Frontier*. President Roosevelt had requested the report because of the great contribution of science to the war effort. In the report, Bush wrote that

> Advances in science will…bring higher standards of living, will lead to the prevention or cure of diseases, will promote conservation of our limited national resources, and will assure means of defense against aggression.

Nearly 65 years later, Secretary of Energy Steven Chu voiced nearly the same optimism. "Scientific and technological discovery and innovation," he testified before Congress in 2009, "are the major engines of increasing productivity and are indispensable to ensuring economic growth, job creation, and rising incomes for American families in the technologically driven twenty-first century." Both statements reflect an enduring facet of American life: our optimism that technology will solve today's problems and provide a better future. The Deepwater Horizon was an expression of that optimism and, until it exploded and sank, it might have given comfort that the optimism was warranted.

Yet the Deepwater Horizon shows both the strengths and the weaknesses of our reliance on technology. Humans have been using petroleum products for 5,000 years, and in that time we have exploited the most accessible sources, those easiest to find and bring into production. As we exhaust the easiest sources, we turn to deposits that are less accessible and costlier to obtain. In the early 1930s, the Texas Co., later Texaco (now Chevron) developed the first mobile steel barges for drilling in the brackish coastal areas of the Gulf of Mexico. In 1937, Pure Oil (now Chevron) and its partner Superior Oil (now ExxonMobil) used a fixed platform to develop a field in 14 feet of water one mile offshore of Cameron Parish, Louisiana. In 1946, Magnolia Petroleum (now ExxonMobil) drilled at a site 18 miles off the coast, erecting a platform in 18 feet of water off Saint Mary Parish, Louisiana. The Macondo Well was the technological descendent of these, and many other, early offshore wells.

There is a systematic pattern that links our demand for oil to the complexity of the technology we use to find and produce petroleum, our economic and energy return on energy production, the complexity of our society, and our ability to maintain the way of life to which we are accustomed. It takes energy to get energy, to find, extract, refine, and distribute it. The difference between what we spend and what we get back is called net energy. It is also known at Energy Returned on Energy Invested (EROEI), a term that will be even more prominent in the future. As the petroleum we extract comes from reserves that are more and more inaccessible – a mile underwater in the case of the Deepwater Horizon – the net energy declines. While EROEI declines, the technology that we develop to find and extract petroleum grows increasingly complex and costly. It takes more energy to get energy, and to develop and run petroleum technology. Deep-sea exploration rigs are among the most complex technologies that we have developed, and they are correspondingly costly. The Deepwater Horizon cost about $1,000,000,000 to build in 2001, and $500,000 a day to operate. For the past 100 years, abundant and inexpensive energy has fueled tremendous growth in the size and complexity of our societies, and in the numbers of people that the earth supports. This energy–complexity spiral means that we need greater amounts of energy just to stay even, let alone continue to grow. At the same time, our way of life and the ordinary challenges of living generate problems that require additional complexity and energy to solve. This added complexity is not just in the technological sphere, but also in our institutions, our activities, and our daily lives. The energy–complexity spiral occurs because abundant energy stimulates and requires more complexity, and complexity in turn requires still more energy.

Over the last few centuries, this spiral has moved ever upward. The question we must confront is: how much longer will this pattern continue? The spiral moves upward today in the face of greater and greater resistance, that resistance being the increasing difficulty of getting oil. The Gulf disaster forces us to confront this dilemma. It makes us see how costly it can be to pursue petroleum that is ever more remote, and to ask whether we can plan on a future that requires still more oil. The tragedy in the Gulf shows that although we need oil for our way of life, oil can also ruin that way of life directly or through our inability to manage the growing risks associated with complexity in all areas from technology to business operations to government oversight. In undertaking to write this book, then, our purposes are twofold: first to explain the Gulf disaster, the energy–complexity spiral, and how they are necessarily connected; and second to encourage all consumers of energy to consider whether this spiral is sustainable, and what it will mean for us if it is not.

Chapter 2

The Significance of Oil in the Gulf of Mexico

It was 9:15 p.m. on April 20, 2010, and the captain of the Deepwater Horizon was entertaining heavyweights from British Petroleum (BP) and Transocean, by showing off the computers and software at his disposal. After the Captain welcomed his visitors on the bridge, Yancy Keplinger, one of two dynamic-positioning officers, began a tour while the second officer, Andrea Fleytas, was at the desk station. The officers explained how the rig's thrusters kept the Deepwater Horizon in place above the well, showed off the radars and current meters, and offered to let the visitors try their hands at the rig's dynamic-positioning video simulator. One of the visitors, a man named Winslow, watched as the crew programmed-in 70-knot winds and 30-foot seas, and hypothetically put two of the rig's six thrusters out of commission. Then they set the simulator to manual mode and let another visitor work the hand controls to maintain the rig's location. While Keplinger was advising about how much thrust to use, Winslow decided to grab a quick cup of coffee and a smoke. He walked down to the rig's smoking area, poured some coffee, and lit his cigarette.[1]

Most readers will be familiar and comfortable with this narrative. There was nothing extraordinary about it, as thousands of similar scenes of human–computer and human–machinery interactions play out every day in industrial, medical, military, banking, security, or TV news settings. Everything seemed to be under control, with the computers in charge, and their sensors humming. The people assigned to watch these computers, and

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[1] All of these events are documented in the President's Commission Report, Chap. 1, p. 7.

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act on their advice, were content and getting ready to go to sleep. This is who we have become, and this is the environment in which most of us exist.

Suddenly, all hell broke loose, and it became clear that the people watching the computer screens did not understand what the computers were telling them. It took just a few seconds for their false sense of security to go up in the same flames that consumed the Deepwater Horizon in two days.

Although the outcome was extraordinary, the circumstances were not. Thousands of computer screens and messages are misinterpreted or misunderstood every day, but only occasionally does a mine cave in, a nuclear reactor melt down, a well blow out, a plane crash, a refinery explode, or soldiers die from friendly fire as a result. Each time we are reassured that the incidents were isolated and could have been avoided if people were just more thoughtful, better trained, or better supervised, managed, and regulated. Is this sense of security justified, a sort of divide-and-conquer mentality where isolated events appear small and amenable to familiar solutions, or are these events the result of societal processes over which we have little control?

Why would a company like BP build such a monument to technology and ingenuity as the Macondo well in the first place? Why was it necessary to drill for oil one mile beneath the surface of the Gulf of Mexico? Hubris among top management may have minimized the perception of risk, but well-informed employees throughout the organization understood the perils as well as the benefits of deep offshore operations. You may think that the need and motivation for these operations are obvious, but any rationale for drilling in these inhospitable environments must take into account the amount of oil (or energy in some form) that is needed to build and maintain an offshore drilling rig such as the Deepwater Horizon, extract the oil, and transport, store, and bring the precious liquid to market. In other words, large offshore platforms are built and operated using vast quantities of energy in order to find and recover even more. The cost is still higher when you consider the complex management and regulatory structures needed to complement the technology, however poorly you may feel that the responsible people performed in the case of the Deepwater Horizon.

Let us begin with fundamentals. First we need to know how much recoverable oil is waiting for us down there, how this amount of oil measures up against demand and total oil use in the United States, and how big the energy profit is after so much energy is expended in exploration, drilling, recovery, refining, and transportation to your local gas station or power plant. In other words, do the benefits outweigh the risks, for whom, and for how long?

We also need to know something about energy itself. Everybody talks about energy, but do we really understand its omnipresent role in society?

How does our insatiable appetite for energy fuel the growth of technological and organizational complexity, with all of their attendant benefits and costs? In this book, you will learn the technological and organizational factors that led to the disastrous oil spill in the Gulf. We call these factors the proximate causes. You will also see how energy and complexity can enter a positive feedback loop and spiral out of control in human societies, which makes catastrophes on local and regional scales increasingly likely, and can even threaten the future of our civilization.

How Important Is Oil Production in the Gulf?

Oil production in the Gulf of Mexico is considered vital to meeting U.S. energy needs, and thus world energy requirements. We present here some data on the Gulf oil reservoirs that we know about, those we expect are yet to be discovered, and those that we think exist but will always be too small to exploit because the potential economic or energy profit is too small. Oil or gas reserves are the quantities of crude oil or natural gas (total hydrocarbons) we are sure can be recovered profitably from known accumulations of hydrocarbons. The concept of reserves implies that oil companies can use "off-the-shelf" technology to get at the hydrocarbons. In other words, to count as reserves, the hydrocarbons must be discovered, commercially recoverable, and still remaining. Usually, only 1/3–1/2 of the oil and 3/4 of the gas in place can be recovered economically.

To estimate oil and gas reserves in the Gulf (see Fig. 2.1), we first have to define the physical extent of the oil-producing areas in what is known as the Outer Continental Shelf (OCS). In the U.S. Interior Department's lingo, OCS consists of the submerged lands, subsoil, and seabed lying between the seaward extent of the states' jurisdiction and the seaward extent of federal jurisdiction. The continental shelf is the gently sloping undersea plain between a continent and the deep ocean. The U.S. OCS has been divided into four leasing regions, one of which is the Gulf of Mexico (GOM) OCS Region.

In 1953, Congress designated the Secretary of the Interior to administer mineral exploration and development of the entire OCS through the Outer Continental Shelf Lands Act (OCSLA). The OCSLA was amended in 1978 directing the secretary to:

- Conserve the Nation's natural resources.
- Develop natural gas and oil reserves in an orderly and timely manner.
- Meet the energy needs of the country.

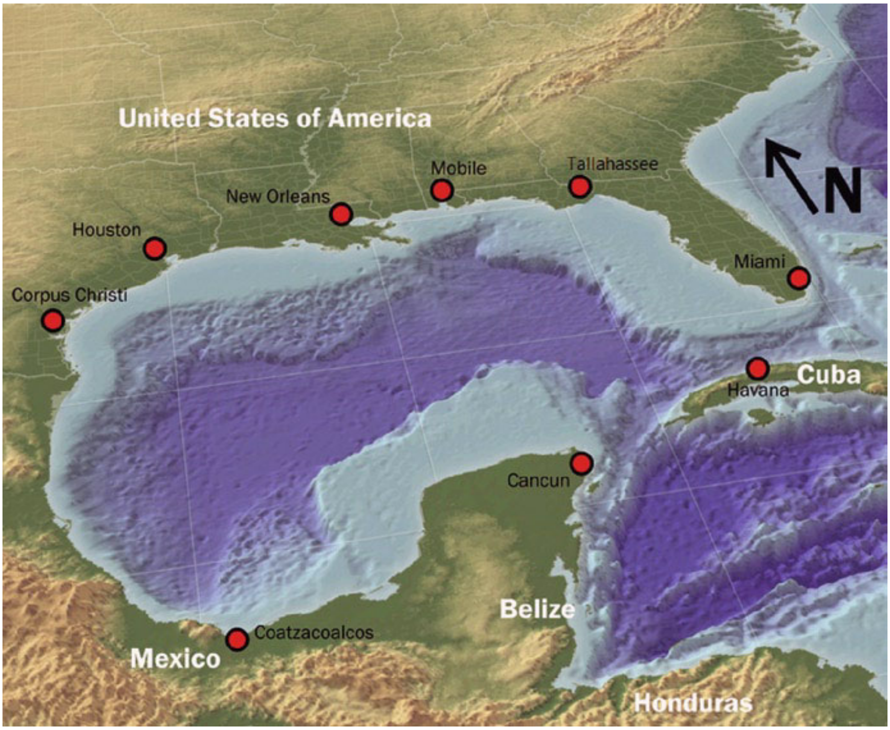

Fig. 2.1 The continental shelf of the Gulf of Mexico is topographically diverse, and includes slopes, escarpments, knolls, basins, and submarine canyons. Ocean water enters from the Yucatan channel and exits from the straits of Florida, creating the loop current associated with the upwelling and the high level of nutrient flow of this large marine ecosystem. Large quantities of freshwater are delivered from rivers in the United States and Mexico. The Gulf of Mexico is North America's most productive sea. Its shallow waters, especially river estuaries, teem with marine life. The region of the Mississippi River outflow sustains the highest level of marine life in the Gulf of Mexico. Chemical water pollution, coastal erosion, and overfishing are major threats to the health of this most important marine ecosystem in North and Central America. The Gulf of Mexico region is also a major oil and gas province that delivered 1.5 million barrels of oil per day for the United States in 2009. (Sources: NOAA, Minerals Management Service (MMS))

- Protect the human, marine, and coastal environments.
- Receive a fair and equitable return on the resources of the OCS.

State jurisdiction is defined as follows.

- Texas and the Gulf coast of Florida are extended three marine leagues (approximately nine nautical miles) seaward from the baseline from which the breadth of the territorial sea is measured.

- Louisiana is extended three imperial nautical miles (imperial nautical mile = 6,080.2 feet) seaward of the baseline from which the breadth of the territorial sea is measured.
- All other states' seaward limits are extended three nautical miles (approximately 3.3 statute miles) seaward of the baseline from which the breadth of the territorial seaward is measured.

As you can see, Texas got a much better deal than all other states, but Texas is bigger and – some people think – better. For our purposes, suffice it to say that federal jurisdiction is defined under accepted principles of international law. Thus, the GOM OCS covers an area of over 600,000 square kilometers, a little less than the area of Texas and twice the size of Poland.

As Figs. 2.2 and 2.3 show, most of the large oil and gas fields were discovered more than 30 years ago and the future "reserve" growth will have little effect on the ultimate hydrocarbon recovery from the Gulf's OCS. The sizes of reservoirs are important for understanding ultimate oil recovery from the GOM. It turns out[2] that over the entire range of reservoir sizes, hydrocarbon reservoirs follow a "parabolic-fractal" law that says there is an increasing proportion of the smaller reservoirs relative to the larger ones. In other words, the reservoir size drops off faster than a simple power law would predict. Leaving aside the mathematics of fractals, if this law of reservoir sizes holds true, our current estimate of ultimate oil recovery in the Gulf might prove to be highly accurate, because most, if not all, of the largest oilfields have already been discovered, and the smaller ones will not add much new oil to the total regardless of how many new oilfields are discovered. On the other hand, the probability of finding another very large reservoir (a new "king," "viceroy," or at least an "elephant") is much higher than a normal or "Gaussian" probability distribution would predict. We can refer to this possibility as "fractal optimism."

Finding new oil in the deep Gulf of Mexico has not been easy. Historically, "dry holes," wells that never produced commercial hydrocarbons, have been numerous. In water depths greater than 1,000 feet (305 meters), 1,677 dry hole wells were drilled, with 331 dry hole wells in water depth greater than 5,000 feet (1,520 meters). To put the last number in perspective, 72% of all wells drilled in water depths greater than 5,000 feet were dry holes! The BP Macondo well was an exploration well that definitely was a success of sorts.

[2] Jean Laherrère, Distribution of field sizes in a petroleum system: Parabolic-fractal, lognormal, or stretched exponential?, *Marine and Petroleum Geology*, **17** (2000), 539–546.

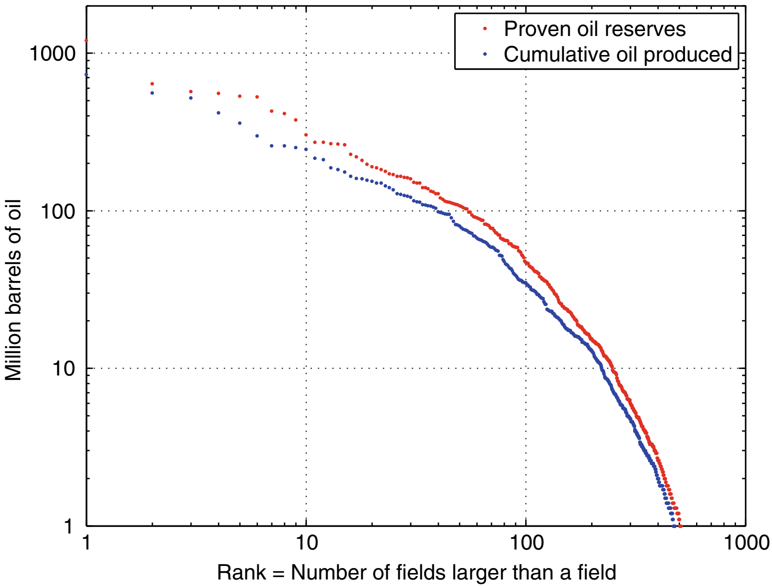

Fig. 2.2 This is the complete ranking of oil deposit volumes in the Gulf of Mexico reported to the Minerals Management Service by 2006, the latest complete statistic. The cutoff for production is one million barrels of cumulative oil produced. Thus the nonproducing oil reservoirs are excluded from the lower curve. The upper curve ranks the "proven oil reserves," (the oil we can produce for sure) with a cutoff of one million barrels of oil as well. The upper curve has 32 more points (oil fields) than the lower one, and the same ranks do not correspond to the same reservoirs. The plot has the logarithmic *x*-and *y*-axes. A simple power law, Rank×Volume^a = Constant, would be "fractal" and plot as a straight line of log Volume versus log Rank, just like this plot. The fact that both curves bend down means that reservoir size decreases faster than a simple fractal would predict. Such a distribution is a "parabolic-fractal" or a "stretched exponential." Note that the reservoir volumes do not follow a bell curve, and their distribution is not Gaussian. Mother Nature operates very differently from finance and statistics that use the Gaussian distributions *ad nauseam*, whether they are justified or not. The largest reservoirs are discovered and produced first, therefore adding new discoveries of small reservoirs is unlikely to change significantly how much oil will be ultimately produced from the Gulf of Mexico. Since 2006, however, there have been several major new discoveries by Shell and others. It is hoped these discoveries will add to the reservoir volume in the largest fields, where it counts the most

Since 1995, the overall fraction of dry holes in the Gulf of Mexico was close to 25% of all wells drilled.

The U.S. federal government has kept records of oil and gas production in the Gulf of Mexico since 1947. According to the Minerals Management Service, between January 1947 and September 2010, 46,221 wells were

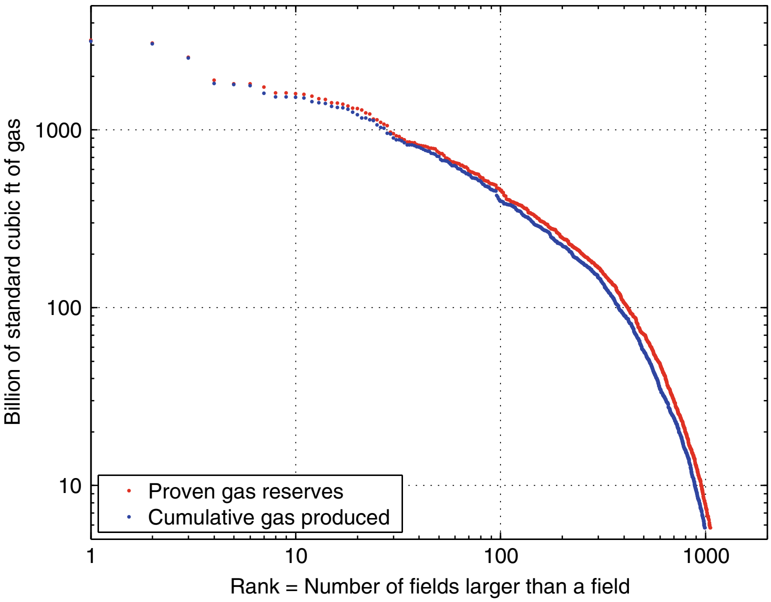

Fig. 2.3 This is the complete ranking of gas deposit volumes in the Gulf of Mexico reported to MMS by 2006, the latest complete statistic. The cutoff for production is 5.8 billion standard cubic feet of cumulative gas produced. Upon combustion, this volume of gas generates the same heat as roughly one million barrels of oil (one barrel of oil is energy-equivalent to 5,800 standard cubic feet of natural gas). The nonproducing gas reservoirs are excluded from the *lower curve*. The *upper curve* ranks the "proven gas reserves," also with a cutoff of 5.8 billion standard cubic feet of gas, equivalent in energy to one million barrels of oil. There are 62 more points on the *upper curve* than on the *lower* one, the same ranks do not correspond to the same reservoirs, and the seeming coincidence of the two curves is an optical illusion. Note that with the same lower cutoff, there are twice as many gas deposits as oil deposits, reflecting the dominance of natural gas in the Gulf. Also note the rapid proliferation of the ever smaller gas reservoirs (*the curves bend down very steeply*)

drilled in shallow Gulf water at depths of up to 1,000 feet (305 meters), and 19,888 wells are still producing. Some 3,500 platforms were activated in the shallow GOM. Between January 1975 and September 2010, 3,757 wells were drilled in deep GOM, and 1,077 wells are still producing in water depths greater than 1,000 feet (305 meters). Forty-seven platforms were activated in the deep Gulf. In water depths greater than 5,000 feet (1,524 meters), 645 wells were drilled and 115 are still producing from ten platforms. Thus, over the last 60 years, some 60,000 wells were drilled in the GOM and produced from 3,550 platforms, which is a gigantic investment

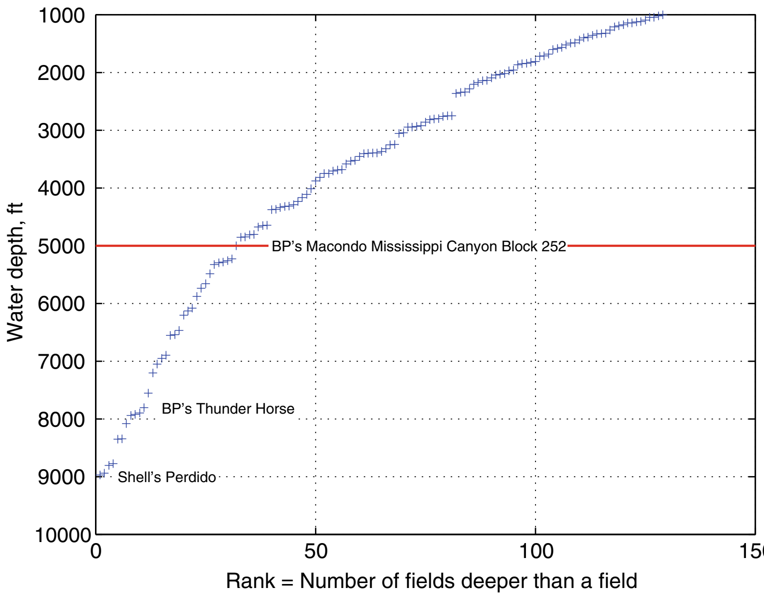

Fig. 2.4 The majority of oil production in the Gulf of Mexico comes from platforms in water deeper than 1,000 feet. There were 129 oil and gas deposits (*reservoirs*) reported by the Minerals Management Service in 2006 in water depths greater that 1,000 feet, 29 of them in water depths greater than 5,000 feet. Note that the water depth of BP's Macondo well is really 5,067 − 75 = 4,992 feet below the water surface. Its depth was measured from the derrick floor of the Deepwater Horizon rig, 75 feet above the sea. Some 1,073 wells are producing in water depths greater than 1,000 feet, 115 of them in water depths greater than 5,000 feet

of material and human resources. Figure 2.4 summarizes the distribution of known oil and gas deposits in the Gulf of Mexico in water depths greater than 1,000 feet.

The rates of oil production from the shallow (less than 1,000 feet deep) and deep (above 1,000 feet of depth, and mostly above 4,000 feet) Gulf water are shown in Fig. 2.5. The shallow water production peaked in 1973, and the deepwater production might have peaked in 2009. Our forecast is based solely on the historical production and its future decline; when completely new oilfields are brought online, our estimate may go up. The cumulative oil produced from the deepwater Gulf is shown in Fig. 2.6. The industry forecasts up to nine billion barrels of ultimate production from the deepwater Gulf, whereas Patzek forecasts only eight billion barrels. Either way, the total oil produced from the deep Gulf water will be less than the 11 billion barrels of oil already produced from the Prudhoe Bay field in Alaska, with another