Chapter 4
An Overview of the Geologic Origins of Hydrocarbons and Production Trends in the Gulf of Mexico

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Abstract The Gulf of Mexico (GoM) region is one of the most important hydrocarbon-producing sedimentary basins in the world. Triassic rifting leads to formation of this small ocean basin characterized by the accumulation of thick salt deposits followed by a thick succession of continental- and marine-derived deposits that combined to generate and trap abundant hydrocarbons. This chapter presents a very brief overview of factors related to hydrocarbon accumulation and production trends in US waters. The offshore GoM has been producing from shelf to deep water for the past ~70 years. Ultra-deep-water drilling was reached in the late 1980s and progressed to depths near 3000 m by the 2000s. Although the extraction of the GoM's oil and natural gas is in its mature phase, studies indicate that oil and gas reserves are significant and that the GoM will be producing for many decades into the future.

Keywords Gulf of Mexico · Geologic history · Hydrocarbons · Production trends

4.1 Introduction

The Gulf of Mexico (GoM) is one of the most important hydrocarbon-producing sedimentary basins in the world—both *onshore* and *offshore*. Oil and gas primarily accumulate in sedimentary rocks that have been deposited when continents have been covered with seawater along the margins of continents or in small ocean basins such as the GoM. There are no economically viable oil and gas accumulations out in the middle of the Earth's large oceans where deep-sea sediments cover the oceanic crust. So, a first-order requirement for significant oil and gas accumulations is that a thick stratigraphic succession of sediments, eventually lithifying into sedimentary rocks, is deposited in some structurally defined basin. The GoM sedimentary basin has been defined by structural features in the Earth's crust, mostly faults, such that the basin's margins extend on land into Georgia, Alabama, Mississippi,

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Louisiana, Arkansas (almost into Oklahoma), Texas, and much of eastern Mexico including the Yucatan/Campeche carbonate platform and all of the Florida Platform. Some key sedimentary basins have been completely filled with evaporites, muds, siliciclastic sands, and carbonate/biogenic deposits to the point where oil and gas can be extracted from beneath dry land and from beneath the seafloor offshore.

Source rocks for oil and gas, reservoir rocks with porosity for storage, and structure or seals to trap the hydrocarbons all are abundant in the GoM.

The *onshore* portion of the GoM basin has produced and continues to produce an enormous amount of oil and natural gas. For the purpose of this paper, we consider only the *offshore* component, which is the seaward extension of geologic formations and structures that are contiguous beneath the coastline out beneath the continental shelf and deep water of the slope and basin floor. Offshore oil drilling is divided into three components by depth: (1) *shelf* out to 125 m depth, (2) *deep water* from 225 to 1500 m depth, and (3) *ultra- deep water* >1,500 m depth. The deepest part of the modern Gulf of Mexico, the Sigsbee Plain (Sigsbee Deep 2018), is estimated to be ~3750–4384 m deep and is underlain by oceanic crust (Fig. 4.1). The offshore GoM

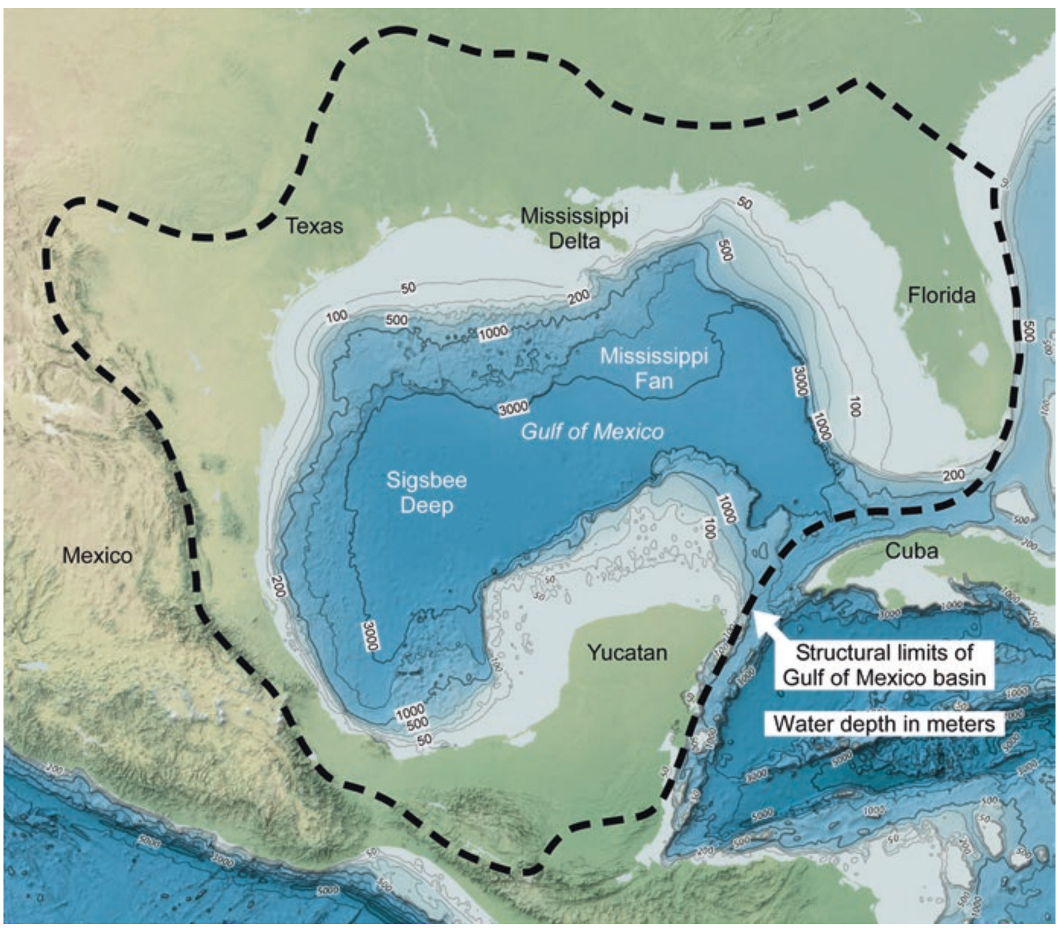

Fig. 4.1 Bathymetry of the Gulf of Mexico reveals the irregular seafloor caused by salt structures in the north and south and the wide flat carbonate platforms in the east and southeastern Gulf. Approximate structural limits of the Gulf of Mexico basin from Salvador (1991a). Background imagery from https://noaa.maps.arcgis.com/home/webmap/viewer.html is a combination of GEBCO_2014 30 arc-second global bathymetry with Natural Earth 2 landscape

has been producing from shelf to deep water for the past ~73 years, with drilling in ultra-deep-water depths since the late 1980s (BOEM 2017).

The deepest water well site is presently in a little over 3000 m water depth. The US offshore seabed subject to US federal jurisdiction portion of the GoM is referred to by the industry and the federal government (Bureau of Ocean Energy Management—BOEM) as the Outer Continental Shelf (OCS). From a geological perspective, this is a misleading term as most of the GoM hydrocarbon exploration and extraction is not on the continental shelf but on the slope and out into the deep basin. However, it is all considered to be federal OCS. In this chapter we will present a brief review of the geologic history and depositional architecture of one of the most geologically complex, and hydrocarbon-rich, sedimentary basins in the world.

4.2 Evolution of Gulf of Mexico

The GoM began to form in the Late Triassic about 225–200 million years ago (mya) by rifting and breaking up of the Pangaean megacontinent (cojoined North America, South America, and Africa) (Fig. 4.2). Phases of rifting and crustal thinning led to significant extension of continental basement crust forming numerous fault-defined arches and basins. The accompanying regional subsidence created the broader structural dimensions of the entire GoM sedimentary basin as North America (Laurasia) pulled apart from South America/Africa (Gondwana). The overall boundaries of the GoM basin extended far inland beyond the present-day coastline.

Early basin deposition included continental red beds and nonmarine sediments (rivers, lakes, eolian sand dunes) which were followed by evaporites in Middle to Late Jurassic time. As extension and subsidence continued, the GoM basin began

Fig. 4.2 Geologic time scale for events discussed in this paper. Epoch boundary ages after Walker et al. (2018)

ERA	PERIOD	EPOCH	AGE (Ma)
			0
CENOZOIC	QUATERNARY	HOLOCENE	0.012
		PLEISTOCENE	2.58
	TERTIARY	PLIOCENE	5.333
		MIOCENE	23.03
		OLIGOCENE	33.9
		EOCENE	56
		PALEOCENE	66
MESOZOIC	CRETACEOUS	LATE	100.5
		EARLY	145
	JURASSIC	LATE	163.5
		MIDDLE	174.1
		EARLY	201.3
	TRIASSIC	LATE	237
		MIDDLE	247.2
		EARLY	251.9

flooding with seawater entering through gaps connecting it to the global ocean, specifically the Pacific. Due to multiple sea-level changes, restricted connections to the open ocean, and tectonic motions, the seawater became trapped and ensuing evaporation created brines which precipitated evaporite minerals, primarily halite or salt (NaCl). Evaporite deposits covered much of the basement topography, with an estimated 4 km of original salt thickness accumulating in the Texas to Louisiana slope area in a relatively short time period from ~167–165 mya (Salvador 1991b; Weimer et al. 2017).

Eventually, probably by 160 mya, normal salinity marine waters entered through permanent and fully opened connections to the global ocean thus shutting down evaporite deposition. Continued rifting and seafloor spreading extending to the end of Jurassic time led to seafloor spreading producing oceanic crust. This led to the separation of the salt deposits forming two primary hydrocarbon provinces in the GoM – the Louann Salt in the northern GoM and Campeche Salt in the southern GoM off Mexico (Fig. 4.3). The remobilization of these early salt deposits has played a key role in the structural development and entrapment of hydrocarbons in the GoM. However, possibly due to the combined and simultaneous effects of

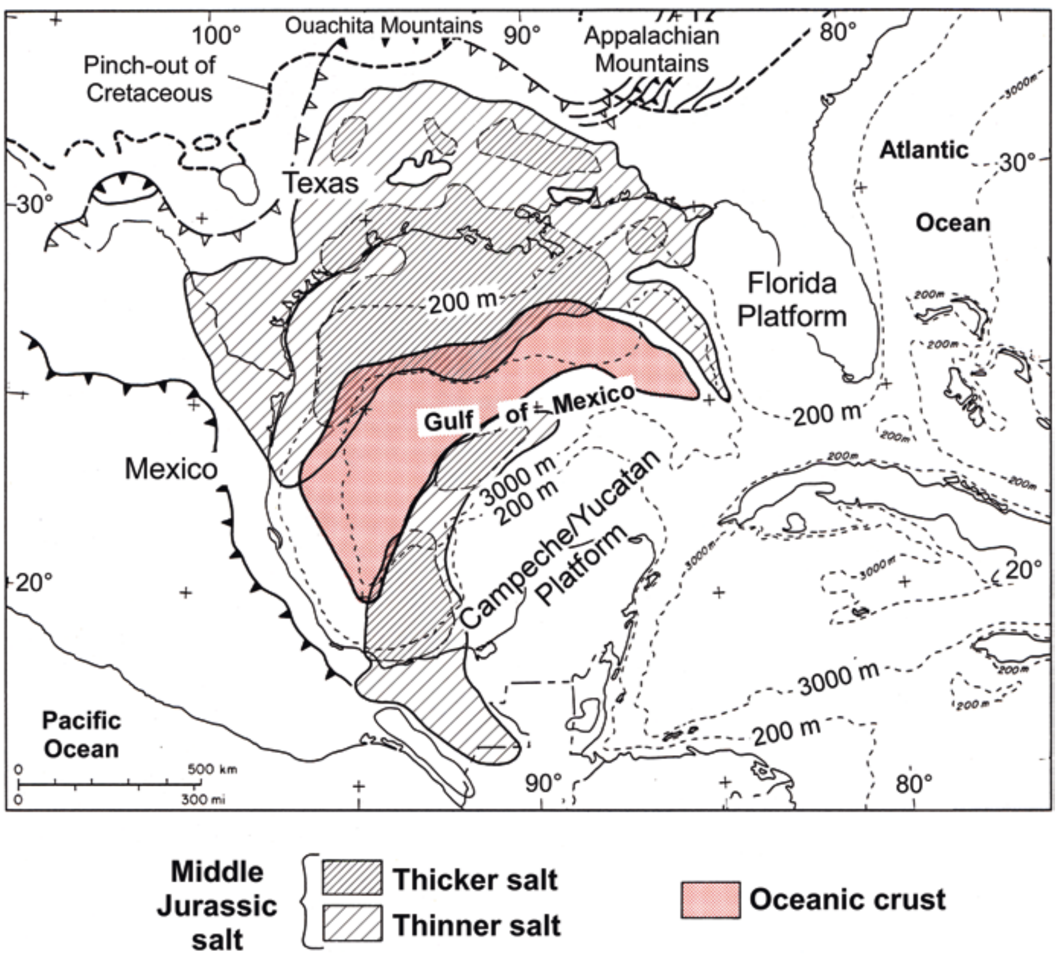

Fig. 4.3 Distribution of salt provinces and oceanic crust. (From Salvador 1991c)

restricted, physical circulation within the GoM and global oceanic anoxic events (OAE), significant amount of organic matter was deposited within the muds that were now being shed off the surrounding land mass. These organic-rich muds were deposited from ~160 to 145 mya from the Late Jurassic into the very Early Cretaceous when global OAEs were becoming prominent, global temperatures were increasing, sea level was rising, and the Earth was entering its greenhouse phase. Along with extensive Late Jurassic tidal flat deposits that produced lipid-rich algal organics, these early deposits contributed much of the primary source rocks that ultimately provided the hydrocarbons in the GoM.

The Late Jurassic transition to more open marine conditions also saw formation of two large carbonate platforms that framed the southern and eastern margins of the GoM. Significant growth of these shallow-water carbonate platforms in the Early Cretaceous formed the thick foundations of the Yucatan/Campeche Platform and the Peninsular Florida Platform—neither of which have become significant hydrocarbon-producing areas. Meanwhile, siliciclastic sediment (non-carbonate sand and mud) was delivered to the Gulf basin largely progressing from north to south and west to east. Following the Laramide orogeny (Laramide Orogeny 2018) in the Late Cretaceous (beginning ~70–80 ma), a massive influx and progradation of clastic sediment entered the northern GoM extending through the Cenozoic. Up to 20 km of sediments eventually accumulated on top of the Louann Salt and the organic-rich source beds which progressively loaded and remobilized the early salt deposits, creating complex subsurface structures that play a major role in trapping hydrocarbon accumulations targeted by oil and gas exploration. Throughout time, sea-level fluctuations have also acted to influence sedimentary facies distribution and stacking patterns of source rocks, reservoirs (e.g., sandstones), and seals (e.g., shales), including drowning of the GoM Early Cretaceous carbonate platforms.

The massive sedimentary influx had six major effects. First, it introduced sands into deep water as submarine fans, which became key reservoir rocks into which hydrocarbons would eventually flow and accumulate. Second, as the weight (lithostatic load) of the sedimentary overburden on top of the Louann increased, the salt started to flow plastically both vertically and laterally. These allochthonous salt systems continually evolve, imparting a multitude of diapiric structures and tectonic processes that reshaped the internal three-dimensional structure and geometries of the sedimentary section (Rowan 2017). This deformation of the 4 km of salt formed a huge number of enormously complex structures that resulted in trapping migrating oil and gas (Fig. 4.4). Third, the high sedimentation rate caused differential compaction creating extensive faulting (listric or growth faults) that also created an enormous number of traps. Fourth, as the sedimentary cover thickened, the lithostatic loading caused increased subsidence in the basin thus subjecting the source rocks to increased temperature and pressure. Thermal maturation resulted in the transformation from organic matter to crude oil and natural gas. Fifth, units of impermeable fine-grained sedimentary units formed seals completing the trapping ability of various structures. Sixth, the rapid sedimentation rate and compaction created widespread overpressurization common to many of the oil and gas accumulations in

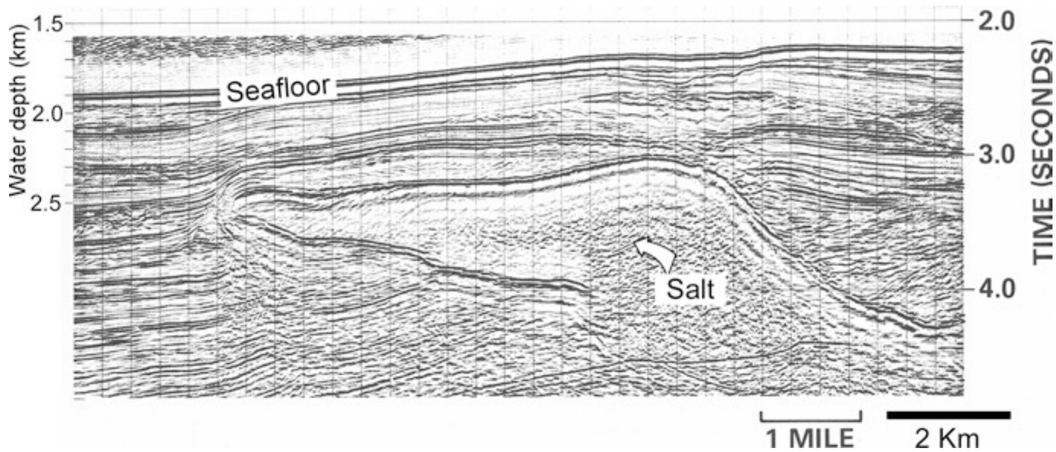

Fig. 4.4 Seismic section showing example of a salt sheet that intruded shallower sediment. Salt can migrate vertically and horizontally, trapping hydrocarbons in underlying and adjacent strata. (Source: Nelson (1991))

the northern GoM. Overpressurization of oil and natural gas accumulations poses a huge hazard during drilling and extraction operations.

Notable features of the present-day GoM include the wide carbonate platform ramps of the Florida and Yucatan shelf margins, Campeche-Sigsbee Knolls in the south, the Mexican Ridges along the western margin, a wide Texas-Louisiana continental shelf and slope across the northern Gulf which is flanked by the Sigsbee Escarpment (formed by horizontal subsurface salt extrusion), and the Mississippi Fan system (Buffler 1991) (Fig. 4.5). Some Early Cretaceous carbonate buildups that extend around the western and northern Gulf margins have been buried by the clastic influx from the west and north and are mostly far inland (USA) or beneath the present coastline (Mexico) (Nehring 1991). The shallow-water Florida and Campeche carbonate banks were drowned in the mid-Cretaceous, transitioning to deep-water environments of carbonate and Tertiary siliciclastic sediment accumulation (Worzel and Bryant 1973; Mitchum 1978).

4.3 Basic Ingredients Required to Generate Oil/Gas Accumulations

Simply stated, there are five primary ingredients that must be present in any sedimentary basin to form a hydrocarbon megaprovince. They are (1) a rich and abundant source of organic matter, commonly called *source rocks*; (2) *thermal maturity* (heat) to transform the organic matter into crude oil and natural gas; (3) *migration* through porous and permeable rocks—*reservoir rocks*; (4) multiple features such as folds, faults, or salt structures (diapirs and pillows) or an up-dip decrease in reservoir rock permeability to *trap* the migrating hydrocarbons; and (5) overlying or surrounding impermeable rocks forming part of the trap called *seals* such that the hydrocarbons cannot escape.

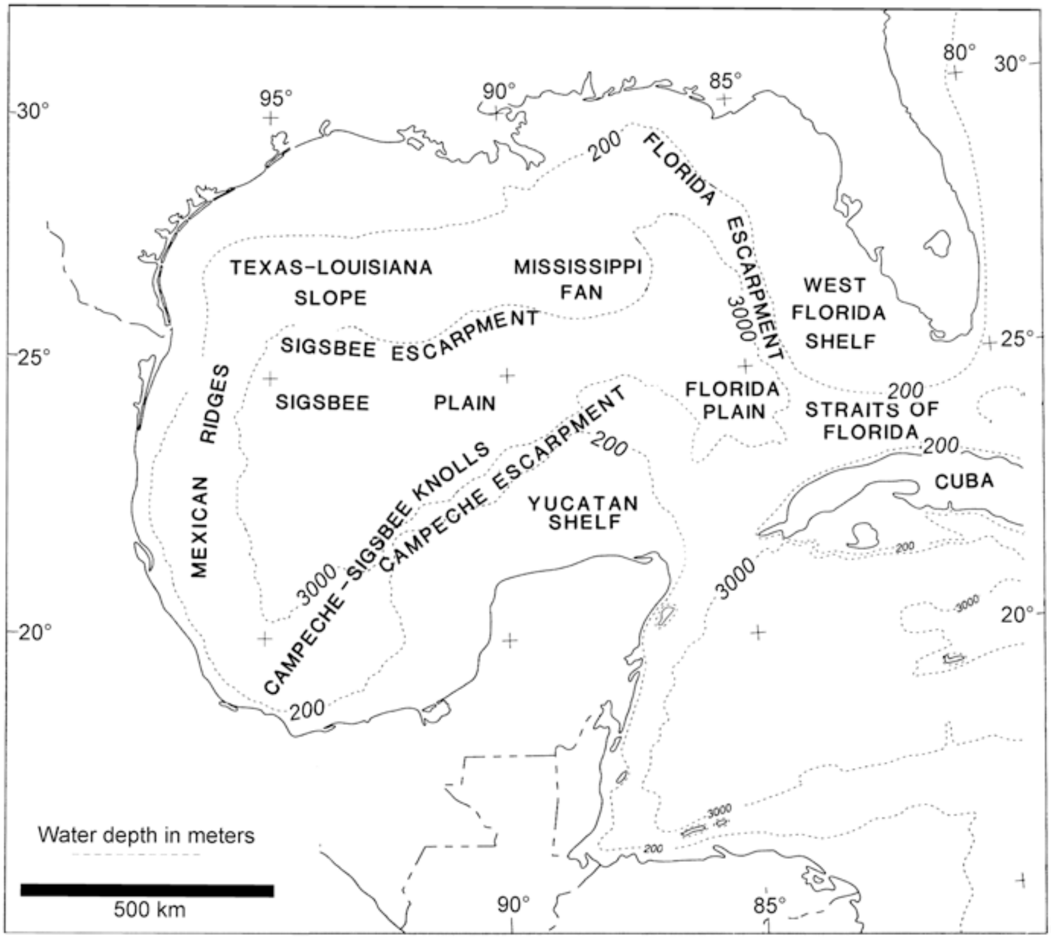

Fig. 4.5 Geographic features in the GoM. (Source: Buffler (1991))

A *source rock* is capable of generating great quantities of hydrocarbons of economic significance (Brooks et al. 1987). Since most hydrocarbon accumulations are associated with marine sedimentary rocks, the source of the organic matter comes from the primary productivity of the Earth's past oceans and marginal marine environments. Some source rocks do form in lacustrine or nonmarine deltaic environments. The total organic carbon (TOC) is the primary measurement and the quality of the organic matter indicated by the presence of key organic molecules.

In the marine environment, remains of planktonic organisms and bacteria, preserved under anoxic conditions, constitute the organic matter to be converted later to crude oil and gas through thermal maturation. Upwelling environments, whereby nutrients from deeper water are brought to the surface where light can drive photosynthesis, are primary organic matter production sites. Ultimately, sufficient organic matter has to sink, escape the biologic pump (recycling of sinking organic matter back to the surface), reach the seafloor along with inorganic muds, and become buried and lithified with time thus forming an organic-rich shale source rock. Overall, source rocks in general average 1.8–2.2% TOC. An average shale has 0.8% TOC. In stark comparison, source rocks in the GoM range reach up to 15%

TOC (Jacques and Clegg 2002). So, organic enrichment of the initially deposited marine muds is one of the primary reasons the GoM is one of the world's hydrocarbon megaprovinces.

Thermal maturation, also called thermal cracking, is the temperature and time required to convert buried organic matter to crude oil (kerogen, a commonly mentioned term, is a very early phase of crude oil). Crude oil is an unrefined liquid hydrocarbon composed of many hundreds of organic compounds. With burial, the TOC-rich shales experience increased heat as part of the evolving geothermal gradient, the rate at which temperature increases with respect to increasing depth in the Earth's interior. Obviously, the geothermal gradient can vary enormously depending upon geologic setting. But, away from plate tectonic boundaries, heat increases at depth at ~25–30 °C/km worldwide (Geothermal Gradient n.d.).

There are temperature ranges or windows where crude oil and gas will form, for oil, 60–120 °C, and for natural gas, 100–200 °C. For crude oil, if the ambient temperature is raised above 130 °C for even a short period of time, natural gas will begin to form (Hyne 2001). The transformation from organic matter to crude oil and natural gas takes place on multi-million-year time scales. In general, oil is most commonly found at subseafloor depths ~3 km. At subseafloor depths >5 km, mostly natural gas is found as the ambient temperature is too high for oil to remain stable.

Migration through *reservoir rocks* occurs as newly formed oil, and gas are created during thermal maturation along with burial and compaction. Faults and fractures within the relatively impermeable source rocks allow the hydrocarbons to seep upward into overlying more permeable sedimentary rocks (sandstones or limestones). These overlying sedimentary units were deposited later under different conditions than were the source rocks. These more porous and permeable units, also called *carrier beds*, provide the conduit for the hydrocarbons eventually to be trapped on the upward journey or to reach the seafloor forming seeps. The Mississippi River system includes both source and reservoir rocks extending from deltas to deep-water submarine fan. Oil and gas are less dense than the seawater that was trapped interstitially as sediments were deposited. This upward flow of the oil and gas is a fundamental process in the hydrocarbon development of a sedimentary basin (Hyne 2001).

Traps and *seals* prevent oil and gas from migrating further upward in a reservoir rock. As a result the hydrocarbons begin to accumulate commonly resulting in an economically viable extraction site. Traps may be anticlinal folds whose closure captures upwardly migrating fluids. Traps may be faults whereby hydrocarbon migration is blocked by the immediate juxtaposition of much lower permeable rocks immediately on the other side of the fault. Upwardly migrating fluids in reservoir rocks will be stopped by completely impermeable evaporites (mostly salt, NaCl, in the GoM) in vertical, diapiric structures or by laterally decreasing permeability in the reservoir rock (pinch out) ultimately becoming impermeable, forming a stratigraphic trap. Where impermeable, non-fractured, or non-faulted strata overlie reservoir rocks, a seal is created preventing further possible upward fluid migration. In the northern Gulf, traps and seals are constantly evolving in response to ongoing sediment loading and salt movement, reflected by hundreds of hydrocarbon seeps across the continental slope.

Finally, the natural gas may become overpressurized posing serious problems during extraction. In areas of high sedimentation rates and rapid burial, the pore pressure of the trapped gas increases (oil, being a liquid, cannot be compressed). If the gas cannot escape due to the efficiency of the trap, its pressure increases more dramatically than surrounding areas where pore fluids can escape at a rate that is in equilibrium with the sedimentation rate. If an overpressurized trap is penetrated by drilling, a blowout could occur—hence the universal need for blowout preventers on the seafloor surrounding each drill string, particularly in the GoM (Mello and Karner 1996).

4.4 Exploration and Production Trends

About 40 years after oil was discovered in east Texas in the early 1900s (famous discovery named Spindletop near Beaumont in 1901), the first offshore drilling rigs ventured into a few meters of water just off the coast. By 1947, a consortium led by Kerr-McGee successfully completed the first well off Louisiana out of sight of land via a drilling ship. Since then, more than 7000 drilling platforms have been constructed (and about 5000 have been removed) in the northern GoM making this offshore portion of the basin to be one of the largest hydrocarbon megaprovinces in the world (BOEM 2018). By 1987, the offshore GoM had produced 222.5 billion of barrels of oil equivalent (BOE; unit of energy released burning 1 barrel oil or 5620 ft^3 natural gas), which amounted to 9% of the world's oil and 11% of the world's natural gas. A hydrocarbon megaprovince at that time was defined as a basin that had produced >100 billion BOE. Only the Arabian/Iranian province had produced more (Nehring 1991). Today, the GoM in US-controlled waters has "technically recoverable resources of over 48 billion barrels of oil and 141 trillion ft^3 of gas" (Lease Sale 250 2018). This amounts to approximately 68 billion BOE. Seemingly, the GoM has produced much more BOE in the past than is known technically recoverable in the future. More recently (2015/2016), the offshore GoM generated ~18% of the total US crude oil (GoM, 1.6 million barrels/day; total US, 8.9 million barrels/day—late 2017/early 2018 data) and 5% of the total US natural gas. Additionally, 45% of the entire US oil and 51% of the US natural gas production is refined and processed along the northern GoM coastline.

The offshore GoM has been producing from shelf to deep water for the past ~70 years. Ultra-deep-water drilling was reached in the late 1980s and progressed to depths near 3000 m by the 2000s (Fig. 4.6). Maximum water depths have hovered around 3000 m for the past 15 years. Since 2005, activity on the shelf and upper slope has declined, while deep water activity has remained strong except for a drilling moratorium in 2010 following the *Deepwater Horizon* oil spill. A drop off in drilling activity in water depths shallower than ~800 m could indicate a depletion of remaining resources in the more accessible mid-water depths and mostly located off Texas (Fig. 4.7). However, deep water GoM oil and gas production as a percentage of total US OCS production shows continuing growth (Fig. 4.8). This record for

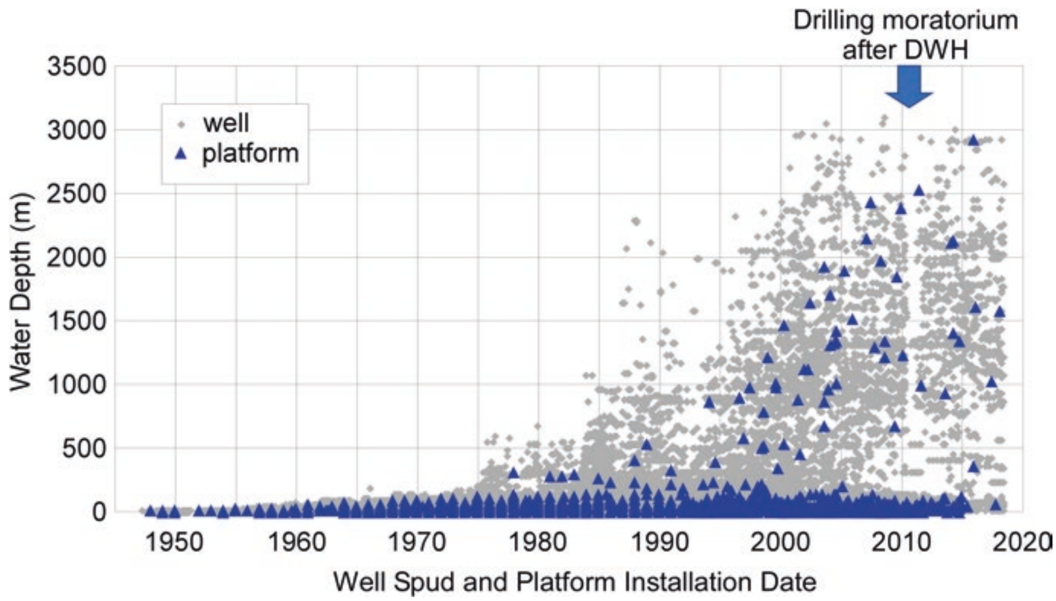

Fig. 4.6 Plot of well spud dates and platform installations versus water depth for US GoM from 1947 to 2018. Data from the BSEE web site in August 2018. Total number of wells is 53,238. Total number of platforms is 1964. Note the persistent trend into deep water. The deepest platform to date was installed January 2016 in 2914 meters water depth. Note the hiatus in drilling activity due to a drilling moratorium following the Deepwater Horizon oil spill in 2010. (Source: BSEE, Deepwater Natural Gas and Oil Qualified Fields. https://www.data.bsee.gov/Leasing/OffshoreStatsbyWD/Default.aspx)

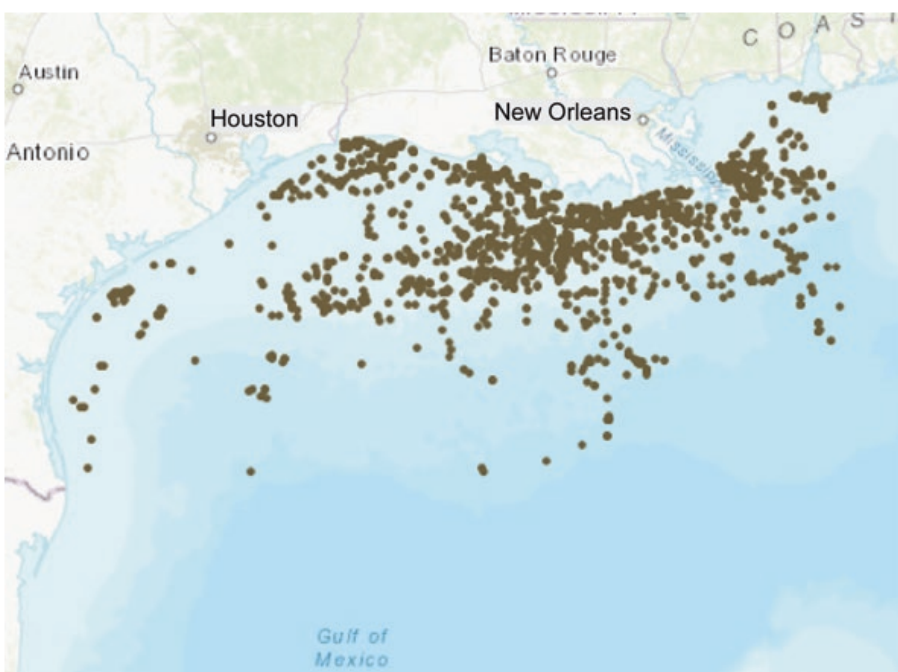

Fig. 4.7 Active oil and gas platforms in federal waters in November 2018. (Source: https://www.eia.gov/special/gulf_of_mexico/index.php)

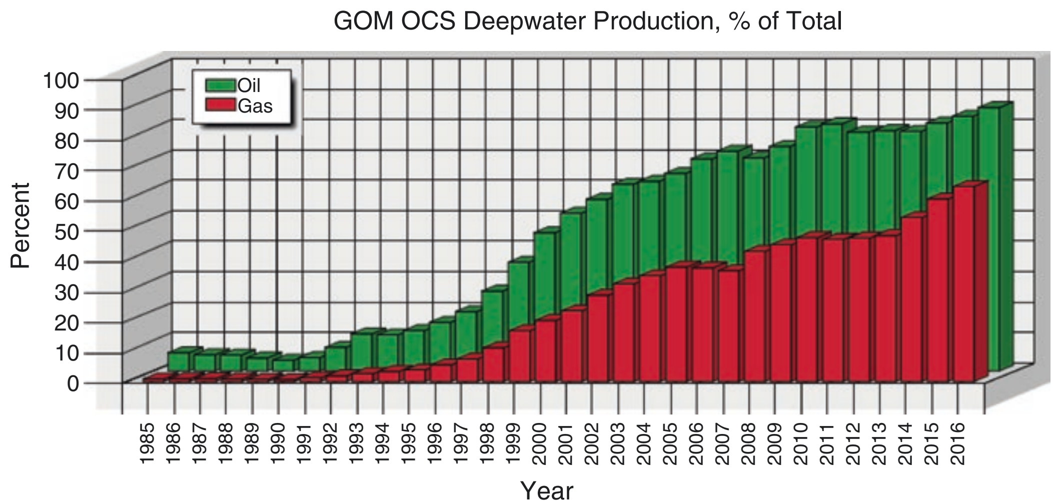

Fig. 4.8 Plot showing deep-water production as a % of all GoM OCS production. The share of production from deep water continues to increase. (Source: https://www.data.bsee.gov/Production/ProductionData/Summary.aspx)

well spudding is one measure of future trends, with production of discovered reserves following many years into the future (Fig. 4.6). Additionally, there is the remote possibility of hydrocarbon extraction east of the Florida moratorium line at some point in the future. And, of course, our neighbors, Mexico and Cuba, have conducted hydrocarbon exploration. PEMEX, the Mexican national oil company, has produced significant oil and gas in their own offshore exclusive economic zone (Pemex.com 2018). The Cubans have yet to do so, although oil and gas are produced in that country onshore along the northern coast (Hemlock 2017).

4.5 Where Is the Industry Headed Next and Why?

A review characterizing play areas based on geologic setting is provided in a recent BOEM report (BOEM 2017). This report lists some 12 assessment areas for Cenozoic strata and 13 Mesozoic play areas. Significant areas of potential that are the least explored are in the deep Gulf or within the eastern planning region that includes much of the west Florida offshore area currently under a drilling moratorium until 2022. Salt-influenced traps will continue to be important throughout the northern GoM slope region where extensive clastic deposition within slope basins and the Mississippi Fan created a thick section for reservoir accumulations (Fig. 4.9). Cenozoic strata will continue to be important targets that have trapped hydrocarbons migrating from deeper source rocks in association with faulting and salt deformation. In ultra-deepwater, some untapped areas of interest could include the Buried Hill play area (Fig. 4.10), an undrilled area that has characteristics similar to productive plays elsewhere in the world that include Jurassic to Cretaceous siliciclastics and carbonates intermixed with early rift blocks forming structural traps.

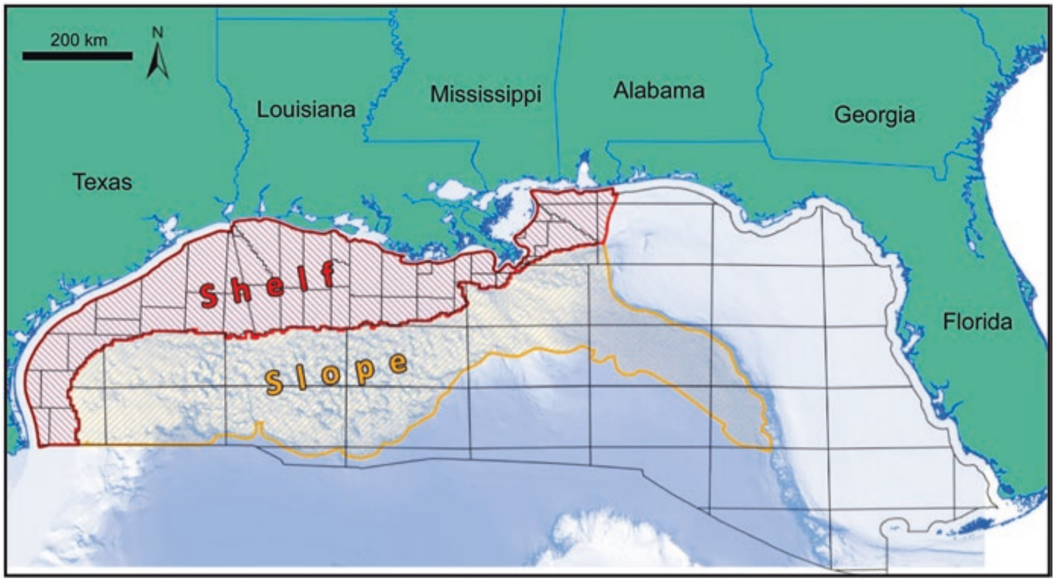

Fig. 4.9 Thick Cenozoic shelf and slope deposits extend into deep water. (From BOEM (2017))

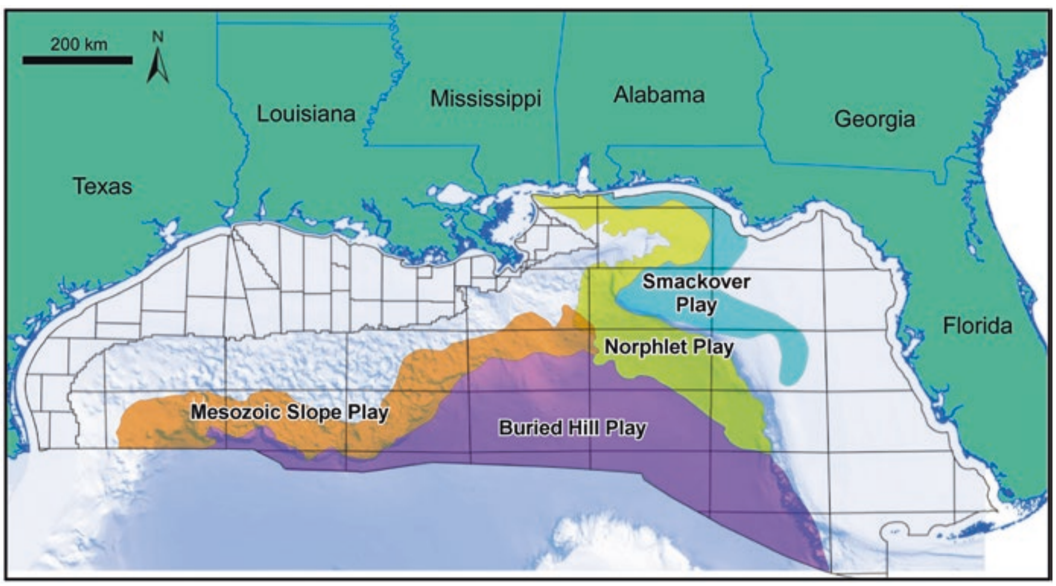

Fig. 4.10 Selected deepwater plays illustrating potential future exploration targets. (Modified from BOEM (2017))

In addition, the Jurassic Norphlet play area hosting important sandstone reservoirs and overlying Smackover known for source rocks as well as reservoirs is also promising. A recent Norphlet discovery in the northeastern GoM announced by Shell in early 2018 is an indicator of this future potential (OGJ editor 2018). The other unknown potential lies in the eastern planning region off west Florida which is currently under a drilling moratorium until 2022.

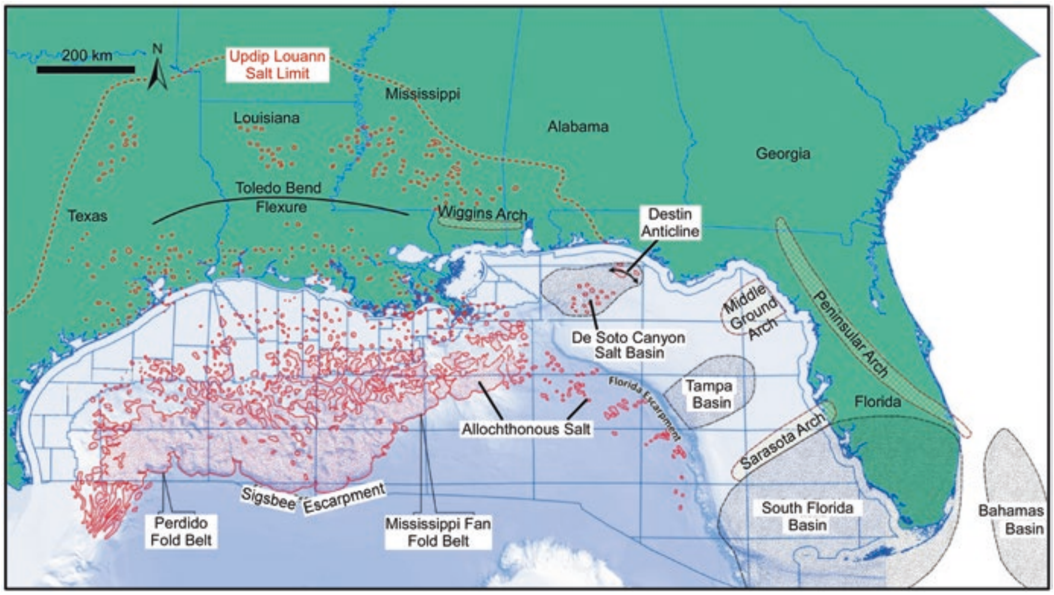

Fig. 4.11 Distribution of salt structures in northern GoM and potential basins of interest for hydrocarbons on the west Florida shelf. (From BOEM (2017))

Three important basins beneath the west Florida shelf and slope include the De Soto Canyon/Destin Dome area off the panhandle with known gas reserves, the Tampa Basin holding substantial Mesozoic to Cenozoic deposits, and the South Florida Basin that has been producing onshore for decades (Fig. 4.11). As always, salt structures along the base of the Florida Escarpment in deep water indicate potential structures for reserves. Exploration activity in Mexican waters is substantially less than the US waters, but similar factors are important.

4.6 Online Resources for Up-to-Date Information

Many statistics presented in this chapter are time sensitive and subject to change. Several online resources are easily accessible to provide up-to-date information on US oil and gas exploration activity.

1. Bureau of Ocean Energy Management (BOEM) – "manages development of US Outer Continental Shelf energy and mineral resources." Among other things, BOEM supports environmental assessment studies and manages lease sales (https://www.boem.gov).
2. Bureau of Safety and Environmental Enforcement (BSEE) – provides regulatory oversight and enforcement (https://www.bsee.gov). A particularly useful page for up-to-date data is at https://www.data.bsee.gov/Main/Default.aspx.
3. US Energy Information Administration (EIA) – provides data for statistics and analysis for all US energy resources (https://www.eia.gov).

4.7 Conclusions

Globally, offshore oil production amounts to ~30% of all the oil extracted. As such the GoM offshore produces ~6% of all the world's oil. The only other offshore basins that are about as productive as the GoM are off Norway, Angola, and Brazil. The rest of the global offshore production comes from many, much smaller basins. This very brief and simplified summary of the geologic history of the GoM reveals that the ingredients needed to produce a hydrocarbon megaprovince were all created in abundance within the past 200 my. The industry continues to explore ultra-deepwater sites as well as to continue to examine more challenging sites heretofore unexplored in shallower water. Additionally, there is the remote possibility of hydrocarbon extraction east of the Florida Moratorium line at some point in the future. Although the extraction of the GoM's oil and natural gas is in its mature phase, studies indicate that oil and gas reserves are significant (28–137 billion BOE in the northern GoM, Weimer et al. 2017) and that the GoM will be producing for many decades into the future.

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References

BOEM (2018) https://www.data.boem.gov/Platform/PlatformStructures/Default.aspx

Brooks J, Cornford C, Archer R (1987) The role of hydrocarbon source rocks in petroleum exploration. In: Brooks J, Fleet AJ (eds) Marine petroleum source rocks, Geological Society Special Publication No. 26. Geological Society, London, pp 17–46

Buffler RT (1991) Seismic stratigraphy of the deep Gulf of Mexico basin and adjacent margins. In: Salvador A (ed) The geology of North America, vol J, The Gulf of Mexico Basin. The Geological Society of America, Boulder, pp 353–387

Bureau of Ocean Energy Management (2017) Assessment of technically and economically recoverable hydrocarbon resources of the Gulf of Mexico outer continental shelf as of January 1, 2014. Outer continental shelf report BOEM 2017-005, 44 p

Geothermal Gradient (n.d.) In Schlumberger Oilfield Glossary online. Retrieved from https://www.glossary.oilfield.slb.com/Terms/g/geothermal_gradient.aspx

Hemlock D (2017) Inside Cuba's plan to boost domestic oil production. CUBATRADE digital magazine. http://www.cubatrademagazine.com/inside-cuban-plan-boost-domestic-oil-production/. Accessed Oct 2018

Hyne NJ (2001) Nontechnical guide to petroleum geology, exploration, drilling, and production, 2nd edn. PenWell Corporation, Tulsa, 598 p

Jacques J, Clegg H (2002) Gulf of Mexico Late Jurassic source rock prediction. Offshore Mag 62(10). https://www.offshore-mag.com/articles/print/volume-62/issue-10/news/gulf-of-mexico-late-jurassic-source-rock-prediction.html. Accessed Oct 2018

Laramide Orogeny (2018) Wikipedia https://en.wikipedia.org/wiki/Laramide_orogeny. Accessed Oct 2018

Lease Sale 250 (2018) Bureau of Ocean Energy Management. www.boem.gov/sale-250. Accessed Oct 2018

Mello UT, Karner GD (1996) Development of sediment overpressure and its effect on thermal maturation: application to the Gulf of Mexico basin. AAPG Bull 80(9):1367–1396

Mitchum RM (1978) Seismic stratigraphic investigation of West Florida slope. In: Bouma AH Moore GT and M. Coleman M (eds) Framework, facies, and oil-trapping characteristics of the upper continental margin: AAPG Studies in Geology No. 7, pp 193–223

Nehring R (1991) Oil and gas resources. In: Salvador A (ed) The geology of North America, vol J, The Gulf of Mexico Basin. The Geological Society of America, Boulder, pp 445–494

Nelson TH (1991) Salt tectonics and listric-normal faulting. In: Salvador A (ed) The geology of North America, vol J, The Gulf of Mexico Basin. The Geological Society of America, Boulder, pp 73–89

OGJ editors (2018) Shell makes sixth discovery in Norphlet deepwater play. Oil Gas J. https://www.ogj.com/articles/2018/05/shell-makes-sixth-discovery-in-norphlet-deepwater-play.html. Accessed Aug 2018

Pemex.com (2018) Petróleos Mexicanos http://www.pemex.com/en/investors/publications/Paginas/default.aspx. Accessed Oct 2018

Rowan MG (2017) An overview of allochthonous salt tectonics. In: Permo-Triassic Salt Provinces of Europe, North Africa and the Atlantic Margins. Elsevier Inc. https://doi.org/10.1016/B978-0-12-809417-4.00005-7. Accessed Sept 2018

Salvador A (1991a) Introduction. In: Salvador A (ed) The Geology of North America, vol. J, The Gulf of Mexico Basin. The Geological Society of America, Boulder, Colorado, pp 1–12

Salvador A (1991b) Triassic-Jurassic. In: Salvador A (ed) The geology of North America, vol J, The Gulf of Mexico Basin. The Geological Society of America, Boulder, pp 131–180

Salvador A (1991c) Origin and development of the Gulf of Mexico basin. In: Salvador A (ed) The geology of North America, vol J, The Gulf of Mexico Basin. Boulder, The Geological Society of America, pp 389–444

Sigsbee Deep (2018) Wikipedia. https://en.wikipedia.org/wiki/Sigsbee_Deep. Accessed Oct 2018

Walker JD, Geissman JW, Bowring SA, Babcock LE (2018) Geologic Time Scale v. 5.0: Geological Society of America. https://doi.org/10.1130/2018.CTS005R3C. https://www.geosociety.org/documents/gsa/timescale. Accessed Sept 2018

Weimer P, Bouroullec R, Adson J, Cossey SPJ (2017) An overview of the petroleum systems of the northern deep-water Gulf of Mexico. Am Assoc Pet Geo Bull 101(7):941–993

Worzel JL, Bryant WR (1973) Regional aspects of deep sea drilling in the Gulf of Mexico leg 10. In: Worzel B et al (eds) Initial reports of the deep sea drilling project, v.10. U.S. Government Printing Office, Washington, DC, pp 737–748. https://doi.org/10.2973/dsdp.proc.10.129.1973. Accessed Oct 2018