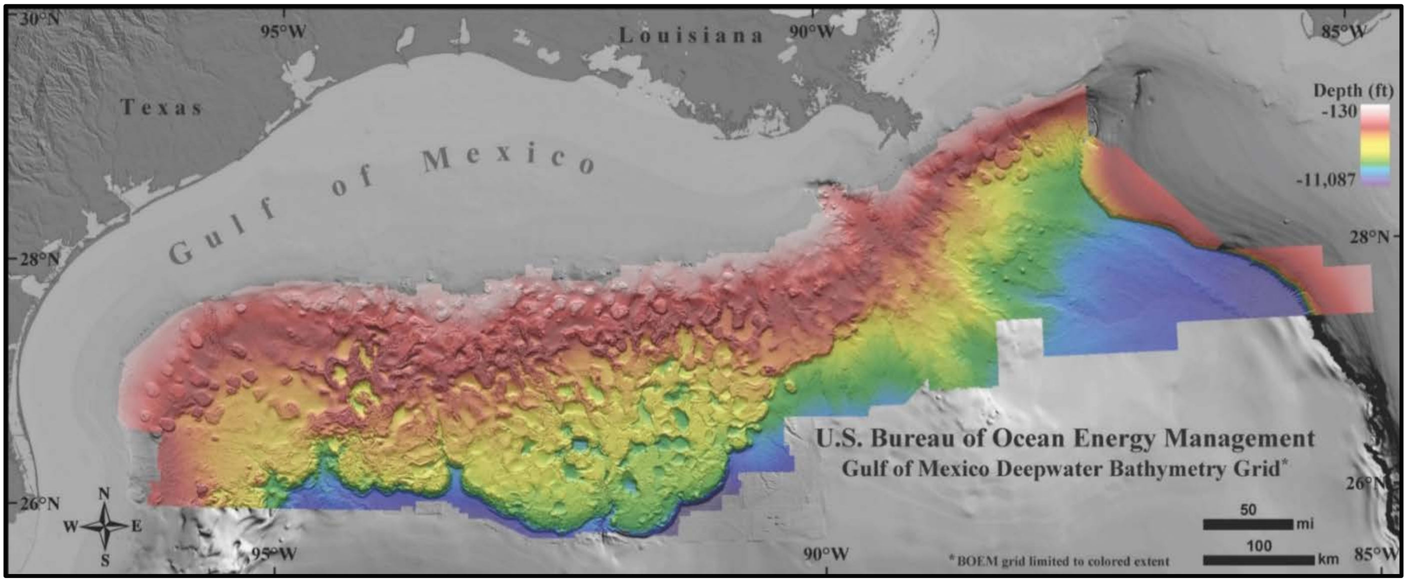
OCS Report
BOEM 2021-005

Deepwater Gulf of Mexico

December 31, 2019



U.S. Department of the Interior
Bureau of Ocean Energy Management
Gulf of Mexico Office

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ON THE COVER—BOEM's high-resolution bathymetry map of the deepwater Gulf of Mexico (Kramer and Shedd, 2017). From the 3D seismic inventory available to BOEM, seismic surveys that were either old enough for public release or for which BOEM sought and obtained permission from owners were used. The bathymetry map is a mosaic of more than 100 of the best 3D time-domain surveys in water depths from 40 to 3,379 m (131 to 11,086 ft). The prominent water bottom reflector is typically well imaged in deep water. The original acquisition resolution of the 3D data (as fine as 149 m^2; 1,600 ft^2) produced approximately 1.4 billion datapoints (pixels). BOEM uses high-resolution bathymetric data during evaluations of shallow drilling hazards and to identify areas of biologic sensitivity. BOEM's map is available for academic, industry, and other Federal agency applications on BOEM's website (USDOI, BOEM, 2017a).

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A MESSAGE FROM THE REGIONAL DIRECTOR

The Gulf of Mexico is one of the world's prolific hydrocarbon basins, with decades of production history. It is the primary offshore source of hydrocarbons for the United States, generating approximately 98 percent of all offshore oil and natural gas production, with deep water representing most of that total. The year 2019 was a record year for American offshore oil production, at 596.9 million barrels, or 15 percent of domestic oil production, and $5.7 billion in direct revenues to the government, and nearly all of that production came from deep water.

Revenues received from Outer Continental Shelf (OCS) leases are directed to the newly created National Parks and Public Land Legacy Restoration Fund, as well as the U.S. Treasury, the Land and Water Conservation Fund, the Historic Preservation Fund, and individual Gulf Coast States (i.e., Texas, Louisiana, Mississippi, and Alabama). The states use these funds to support coastal conservation and restoration projects, hurricane protection programs, and activities to implement marine, coastal, or conservation management plans.

This publication's release marks BOEM's Gulf of Mexico Office’s 11th report and highlights oil and gas in the deepwater Gulf of Mexico, the last being published in 2016. We have expanded the report to focus on resource potential and include environmental and study information as well. The report also details activities related to leasing, seismic, well data, geology, reserves, and production.

The Gulf of Mexico is the cornerstone of the OCS, and the development of its resources is essential to our national security. The continuation of safe and reliable oil and gas from the Gulf of Mexico is crucial for America's economy and energy portfolio. As I look forward to the Gulf of Mexico's future, I am very pleased to present this report.

Michael A. Celata
Director, Gulf of Mexico Office, Bureau of Ocean Energy Management

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ABBREVIATIONS AND ACRONYMS

$	United States dollars
>	greater than
≥	greater than or equal to
<	less than
°F	degrees Fahrenheit
2D	2-dimensional
3D	3-dimensional
4D	4-dimensional (time lapse)
AC	Alaminos Canyon
APD	application for permit to drill
ASV	autonomous surface vessel
AT	Atwater Valley
Av	average
BBOE	billion barrels of oil equivalent
BiOp	Biological Opinion
BOE	barrels of oil equivalent
BOEM	Bureau of Ocean Energy Management
BOPD	barrels of oil per day
BSEE	Bureau of Safety and Environmental Enforcement
CAA	Clean Air Act
CFR	Code of Federal Regulations
CPA	Central Planning Area
CR	contingent resources
CTP	compliant tower platform
DC	De Soto Canyon
DNA	Determination of NEPA Adequacy
DOCD	Development Operations Coordination Document
DOI	Department of the Interior
DPP	development and production plan
EA	environmental assessment
E&D	exploration and development
EB	East Breaks
EIA	Energy Information Agency
EIS	environmental impact statement
EP	exploration plan
EPA	Eastern Planning Area
ESA	Endangered Species Act
EW	Ewing Bank
Expon.	exponential
FAZ	full azimuth
ft	feet
FP	fixed platform
FPSO	floating production, storage, and offloading facility
FPU	floating production unit
FWI	full-waveform inversion
FWS	Fish and Wildlife Service
G&G	geological and geophysical
GB	Garden Banks
GC	Green Canyon
GOM	Gulf of Mexico
HYCOM	Hybrid Coordinate Ocean Model
IPF	impact-producing factor
ITR	incidental take regulation
K	thousand
KC	Keathley Canyon
LOA	Letters of Authorization
LL	Lloyd Ridge
LP	Office of Leasing and Plans
m	meters
Ma	millions of years
Max	maximum
MAZ	multi azimuth
MC	Mississippi Canyon
mD	millidarcy
mi	miles
Mid	middle
Min	minimum
MMBOE	million barrels of oil equivalent
MMCFD	million cubic feet of gas per day
MMPA	Marine Mammal Protection Act
mTLP	mini-tension leg platform
N	north or number
NAAQS	National Ambient Air Quality Standards
NAZ	narrow azimuth
NEPA	National Environmental Policy Ac
NIS	Norwegian International Ship
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
OBC	ocean-bottom cable
OBN	ocean-bottom node
OCS	Outer Continental Shelf
OCSLA	Outer Continental Shelf Lands Act

OSRA	Oil Spill Risk Analysis
PGS	Petroleum Geo-Services
PDP	developed producing
POE	plan of exploration
PSBF	potentially sensitive biological features
psi	pounds per square inch
psia	pounds per square inch absolute
RAM4D	rapid autonomous marine 4D
RE	Office of Resource Evaluation
RJD	reserves justified for development
ROD	Record of Decision
ROV	remotely operated vehicle
SE	Sigsbee Escarpment
Secretary	Secretary of the Interior
semi	semisubmersible platform
spar	single point anchor reservoir platform
spec	specification
Std. Dev.	standard deviation
TLP	tension leg platform
TPS	tuned pulse source
TVDSS	true vertical depth subsea
TVDT	true vertical depth thickness
U.K.	United Kingdom
U.S.	United States
USD	United States dollars
USDOC	United States Department of Commerce
USDOE	United States Department of Energy
USDOI	United States Department of the Interior
USEPA	United States Environmental Protection Agency
UTRR	undiscovered technically recoverable resources
VK	Viosca Knoll
WAZ	wide azimuth
WPA	Western Planning Area
WR	Walker Ridge

ABOUT THIS REPORT

The Bureau of Ocean Energy Management (BOEM) is a bureau in the United States Department of the Interior (DOI) that manages the offshore energy resources of the Outer Continental Shelf (OCS). BOEM's functions are carried out by personnel located at the Bureau's Headquarters and regional Alaska, Gulf of Mexico, and Pacific OCS Offices. BOEM's New Orleans Office (Gulf of Mexico OCS region) is responsible for the United States' (U.S.) portion of Gulf of Mexico (GOM) waters; therefore, the acronym GOM used throughout this report refers only to U.S. Federal waters. The OCS is divided into several types of administrative geographical units, including three planning areas—the Western, Central, and Eastern Planning Areas (WPA, CPA, and EPA, respectively)—and numerous protraction areas (**Figure 1**). Each protraction area is further divided into blocks approximately 9 square miles in area.

A variety of criteria can be used to define deep water. The threshold separating shallow water and deep water can range from 656 to 1,500 feet (ft), or 200 to 457 meters (m). For purposes of this report, deep water is defined as water depths greater than or equal to 1,000 ft (305 m). Ultra-deepwater also is difficult to define precisely; for this report, it is defined as water depths greater than or equal to 5,000 ft (1,524 m). Many of the data presented herein are subdivided according to the water-depth categories of 1,000, 2,500, 5,000, and 7,500 ft (305, 762, 1,524, and 2,286 m). The bathymetric contour lines presented on several maps in this report are for reference only; they are not to be used for absolute depth measurements.

Most information in this report is gleaned from data as of the end of December 2019, except where noted. Crude oil and condensate are reported jointly as oil; associated and non-associated gas are reported jointly as gas. Oil volumes are reported as stock tank barrels and gas as standard cubic feet. Oil-equivalent gas is a volume of gas (associated and/or non-associated) expressed in terms of its energy equivalence to oil (i.e., 5,620 cubic feet of gas per barrel of oil) and is reported in barrels. The combined volume of oil and oil-equivalent gas is referred to as barrels of oil equivalent (BOE) and is reported in barrels.

It is important to note that the total number of fields, as defined by BOEM criteria, and the total number of operator-designated projects may not be the same. A field name is assigned to a lease or a group of leases by BOEM so that oil and natural gas resources, reserves, and production can be allocated on the basis of the unique geologic feature that contains the hydrocarbon accumulation(s). The field's identifying block number corresponds to the first lease qualified by BOEM as capable of production or the block where the primary structure is located. Therefore, more than one operator-designated project may be included in a single BOEM-designated field. Additionally, because BOEM-qualified leases can be placed in either new or preexisting fields as defined in the OCS Operations Field Directory, discoveries on newer leases can be placed into much older fields.

THE OFFICE OF RESOURCE EVALUATION

The Office of Resource Evaluation (RE) in BOEM's New Orleans Office contributed the Seismic Data, Well Data, Geologic Trends, Reserves and Resources, and Production sections for this report. RE provides independent geologic analysis both pre-lease with fair market value determination, and post-lease with reserves inventory, resource assessment, and conservation of resources. RE also, working with the Office of Leasing and Plans, provides worst-case discharge verification for proposed wells. The RE program office also coordinates geological and geophysical (G&G) data acquisition and analysis, and G&G regulatory reviews of plans and permits, as well as providing development and support for the National Program.

THE OFFICE OF LEASING AND PLANS

The Office of Leasing and Plans (LP) contributed to the Leasing section of this report. The work of LP is highly specialized, national in scope with international implications, and unique to BOEM in its regulation of OCS offshore oil, gas, and sulfur leasing. The work of LP is accomplished through pre-sale, sale, and post-sale activities associated with the offshore mineral leasing program in the Gulf of Mexico and Atlantic OCS planning areas, including development of the National Program for leasing. The LP program office plans and executes Gulf of Mexico and Atlantic OCS lease sales according to the National Program for leasing. As part of the leasing activities, LP issues new company qualifications and leases, maintains official lease records, and approves changes in lease and company ownership and operatorship. In order to ensure that lessees and operators comply with all financial and performance obligations arising from a lease, grant, or permit and applicable regulations, LP administers the financial assurance program. The financial assurance program includes bonding to cover the level of activity on property and facility abandonment and site clearance, as well as the Oil Spill Financial Responsibility Program, which is designed to ensure that designated applicants for covered offshore facilities have the financial resources necessary to pay for cleanup and damages that could be caused by oil discharges. Post-sale activities include in-depth technical reviews and approvals of OCS exploration and development plans submitted by operators and the granting of rights-of-use and easement. Creation and maintenance of data related to lease ownership/operatorship, financial assurance, and exploration and development is conducted in LP, as well as creation and maintenance of maps and visuals supporting pre-sale, sale, and post-sale activities and environmental assessments.

THE OFFICE OF ENVIRONMENT

The Office of Environment (OE) contributed to the environmental resources and environmental studies sections of this report. OE carries out the environmental policies of DOI in accordance with the National Environmental Policy Act (NEPA) and the Outer Continental Shelf Lands Act (OCSLA; 43 U.S.C. §§ 1301-1356), as amended, with regard to oil and gas in the Gulf of Mexico and Atlantic OCS and other mineral (salt and sulfur) extraction operations, as well as renewable energy activities and alternate use of existing oil and gas structures in the Gulf of Mexico OCS. As a part of its leasing responsibilities, OE develops or evaluates post-lease, operation-specific NEPA documents and reviews environmental documents required by the lease; performs environmental investigations to assess the effects of OCS oil- and gas-related activities and/or compliance by operators with environmental requirements; and applies unique measures to mitigate potential environmental impacts of proposed activities. OE also consults with other Federal agencies regarding issues related to the following:

- Endangered Species Act (16 U.S.C. §§ 1531 *et seq*.);
- Magnuson-Stevens Fishery Conservation and Management Act (essential fish habitat; 16 U.S.C §§ 1801 *et seq*.);
- National Historic Preservation Act (16 U.S.C. §§ 1531 *et seq*.);
- Oil Pollution Act (33 U.S.C. § 2701); and
- Marine Mammal Protection Act (16 U.S.C. §§ 1361-1423).

The OE coordinates with coastal states to assure both pre-lease and post-lease compliance under the Coastal Zone Management Act (16 U.S.C. §§ 1451 §§ *et seq*.) and develops, negotiates, and supervises all environmental studies in the Gulf of Mexico and oil- and gas-related studies in the Atlantic OCS planning areas. As a part of the National Historic Preservation Act, OE reviews all permitted seafloor-disturbing actions for compliance with Section 106 of the Act.

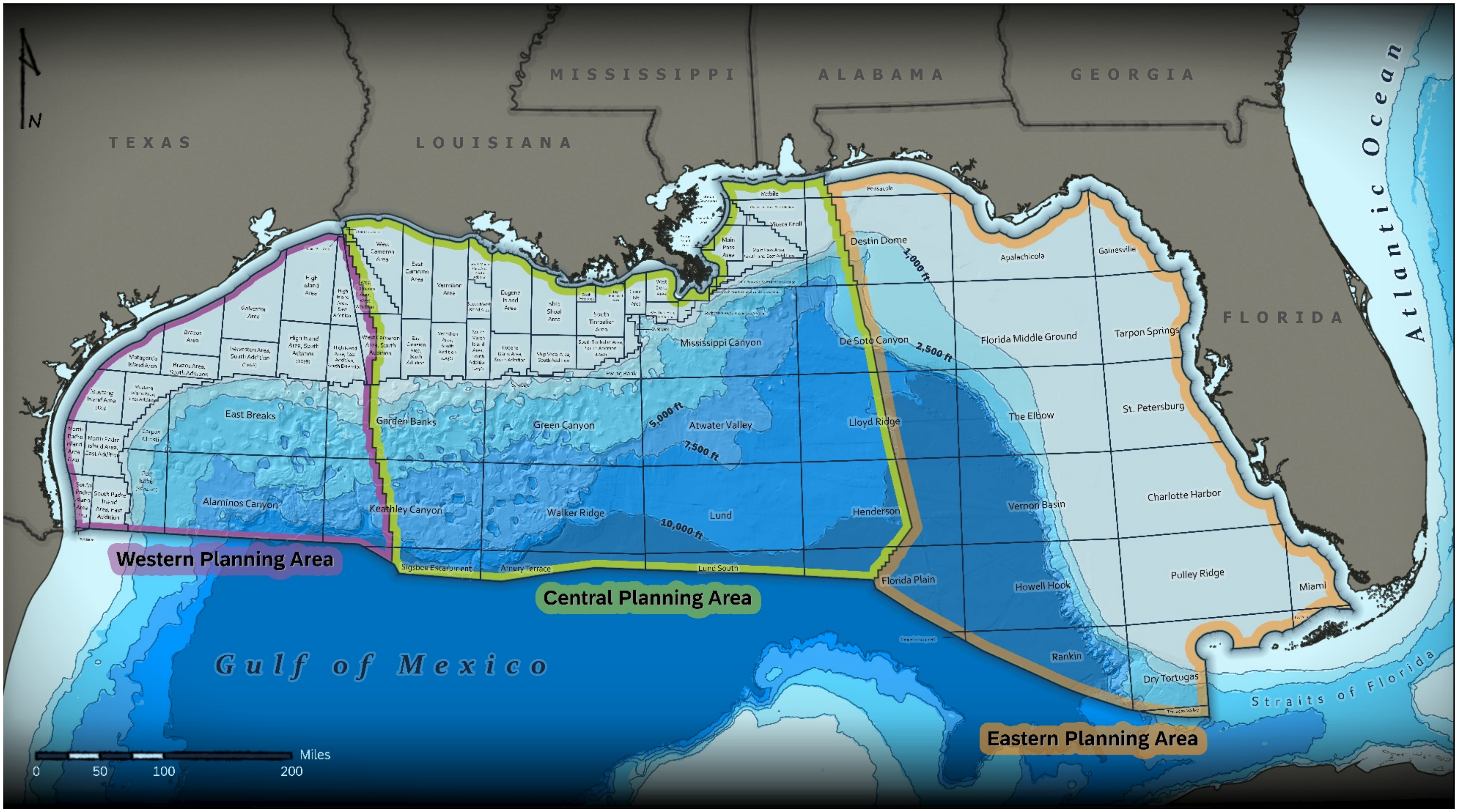


Figure 1. Base map illustrating planning areas, protraction areas, and water-depth categories referred to in this report.

ABOUT THE GULF OF MEXICO BASIN

The Gulf of Mexico (GOM) is a small ocean basin with a water-surface area of more than 1.5 million square kilometers (371 million acres) (**Figure 2**). The greatest water depth is approximately 3,700 m (roughly 12,000 ft). It is almost completely surrounded by land, opening to the Atlantic Ocean through the Straits of Florida and to the Caribbean Sea through the Yucatan Channel. The physical oceanography of GOM waters deeper than 3,281 ft (1,000 m) can be approximated as a 2-layer system, with an upper layer that is dominated by the Loop Current and associated anticyclonic eddies (Welsh et al., 2009; Inoue et al., 2008) and a lower layer that has near uniform currents (Welsh et al., 2009; Inoue et al., 2008). Sea-surface temperatures are determined by the interaction of the atmosphere and ocean over seasonal cycles through the mixing of Loop Current water and associated eddies and by the upwelling and mixing of waters along the shelf (Muller Karger et al., 2015). Salinity is strongly influenced by freshwater inputs from rivers, especially the Mississippi and Atchafalaya Rivers, and by the Loop Current that transports warm, high salinity water in from the Caribbean Sea.

In the GOM, the continental shelf extends seaward from the shoreline to about the 200-m (656-ft) water depth and is characterized by a gentle slope of a few meters per kilometer (less than 1 degree). The shelf is wide off Florida and Texas, but it is narrower where the Mississippi River delta has extended seawards to near the shelf edge. The continental slope extends from the shelf edge to the Sigsbee and Florida Escarpments in about 2,000- to 3,000-m (6,562- to 9,843-ft) water depth. The topography of the slope is irregular and characterized by canyons, troughs, and salt structures. The gradient on the slope is normally 1-2 degrees, while the gradient of the Florida Escarpment may reach 45 degrees in some places. The Mississippi Fan has a gentle incline, with slopes of 4 m (13 ft) or less per kilometer (21 ft or less per mile), with the lower Mississippi Fan having an even flatter slope at 1 m (3 ft) or less per kilometer (5 ft or less per mile). The Sigsbee and Florida abyssal plains (ocean floor) are basically horizontal physiographic subprovinces and are surrounded by features with higher topography. Approximately 41 percent of the GOM is continental slope (200-3,000 m [656-9,843 ft]), and 24 percent is abyssal plain (3,000+ m [9,843 ft]). The deepest area is located within the Sigsbee Deep abyssal plain (3,800 m [12,467 ft]) (Darnell, 2015). BOEM currently has a mature and active OCS oil and gas program in the GOM and has analyzed the potential environmental impacts from OCS oil- and gas-related activity for over 40 years.

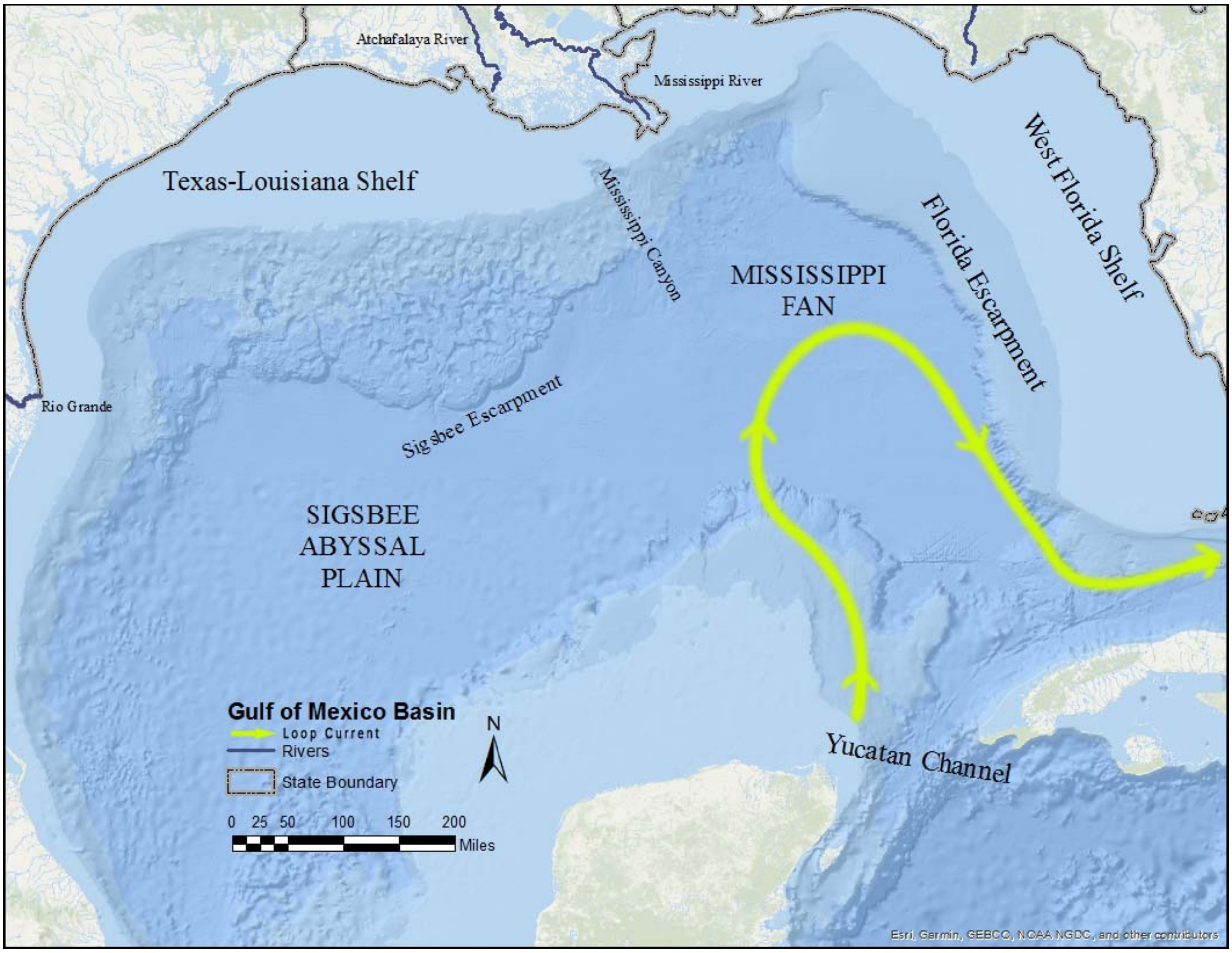


Figure 2. Features of the Gulf of Mexico Basin.

DEEPWATER HISTORY

Following is a summary of notable oil- and gas-related events that have occurred in the northern U.S. GOM, with emphasis on emphasizing deepwater activities.

1947	• The first well out of sight of land was drilled in Ship Shoal Block 32 about 12 miles off the Louisiana coast in approximately 19 feet of water, marking the birth of the true “offshore” oil and gas industry.
1953	• The Submerged Lands Act was passed, giving states the right to lease blocks for offshore drilling up to 3 to 9 nautical miles from the coast. • The Outer Continental Shelf Lands Act was passed, giving the Department of the Interior the authority to issue leases beyond State jurisdiction.
1960s	• A series of turbidite probe studies by a number of universities and industrial companies confirmed an exploration play in deep water.
1975	• The first deepwater well was drilled in Mississippi Canyon Block 194 in 1,022 feet of water, resulting in the Cognac discovery.
1978	• The first production facility in deep water was installed at the Cognac Field utilizing a fixed platform.
1979	• The first production from deep water began from the Cognac Field.

1983	• The first compliant tower in deep water was installed in Mississippi Canyon Block 280 at the Lena Field in 1,000 feet of water. • Areawide leasing was implemented, based on a 5-year leasing plan for Federal waters, which expanded the area available for leasing and quickened the pace of lease sales.
1988	• The first subsea completion in deep water occurred in Ewing Bank Block 999 at the Green Canyon 29 Field in 1,462 feet of water.
1989	• The first tension leg platform was installed in Green Canyon Block 184 at the Jolliet Field in 1,760 feet of water.
1990	• The first subsalt discovery in deep water was drilled in Mississippi Canyon Block 211 at the Mica Field in 4,356 feet of water.
1995	• The Deep Water Royalty Relief Act was passed, eliminating royalty payments (up to specified volumes) on new deepwater leases issued from 1996 to 2000 and allowed different levels of relief for leases issued before and after these dates.
1996	• The first deepwater well to encounter Wilcox-equivalent, Lower Tertiary sediments was drilled in Alaminos Canyon Block 600 at the BAHA prospect in 7,620 feet of water, proving a new exploration play in the ultra-deepwater.
1999	• Deepwater oil production overtook that of shallow water.

2002	• The first Spar platform was installed in Viosca Knoll Block 826 at the Neptune Field in 1,930 feet of water.
2003	• The first semisubmersible platform was installed in Mississippi Canyon Block 474 in 6,340 feet of water. Named the Na Kika Hub, the production platform collects gas from six fields.
2005	• Hurricanes Katrina and Rita left destructive paths, curtailing almost all oil and gas production from the Gulf of Mexico.
2006	• The first commercial, wide-azimuth seismic survey was acquired in deep water.
2007	• The Independence Hub was installed in Mississippi Canyon Block 920 in 7,920 feet of water, claiming the world water-depth record for a semisubmersible platform. The Hub hosted production from 11 fields. The last producing well went offline in 2015.
2009	• The first Mobile Offshore Production Unit was installed in Green Canyon Block 237 in 2,200 feet of water. The ship-shaped floater acts as a hub for the Boris and Phoenix Fields. • The Perdido Hub was installed in Alaminos Canyon Block 857 in 7,817 feet of water, claiming the world water-depth record for a Spar platform. The Hub hosts production from three discoveries.

2010	• The first production from the deepwater Lower Tertiary (Wilcox) Play began from the Great White Field (Alaminos Canyon 857). Production is collected at the Perdido Hub Spar platform. • The Macondo discovery blowout and explosion aboard the *Deepwater Horizon* drilling rig caused oil to flow into the Gulf of Mexico for 87 days before the well was sealed. A 6-month moratorium on all deepwater drilling on the Outer Continental Shelf was declared shortly thereafter.
2011	• The first floating production, storage, and offloading (FPSO) facility was utilized in Walker Ridge Block 249 in 8,300 feet of water. The FPSO acts as a hub for the Cascade and Chinook Fields. • The Bureau of Ocean Energy Management was created when the Minerals Management Service was divided into three independent entities.
2014	• The largest (based on displacement) semisubmersible platform was installed at Walker Ridge Block 718 in approximately 6,950 feet of water. The platform hosts production from the Jack and St. Malo Fields.
2016	• The Turritella FPSO was installed in Walker Ridge Block 551 in 9,560 feet of water, claiming the world water-depth record for an FPSO. The hub hosts production from the Stones Field.
2018	• The first production facilty to collect oil from the deepwater Upper Jurassic Norphlet Formation Play was installed in Mississippi Canyon Block 437. It holds the current water-depth record for a semisubmersible platform in 7,400 feet of water.
2019	• The first production from the deepwater Upper Jurassic Norphlet Formation Play began from the Appomattox and Vicksburg "A" Fields, marking the first high-temperature development in deep water. • Chevron sanctioned the first deepwater high-pressure development for the Lower Tertiary Anchor Field (Green Canyon 807) in approximately 5,180 feet of water. High-pressure technologies capable of handling 20,000 pound per square inch will be used for the project. Production will be collected by a semisubmersible platform.

LEASING

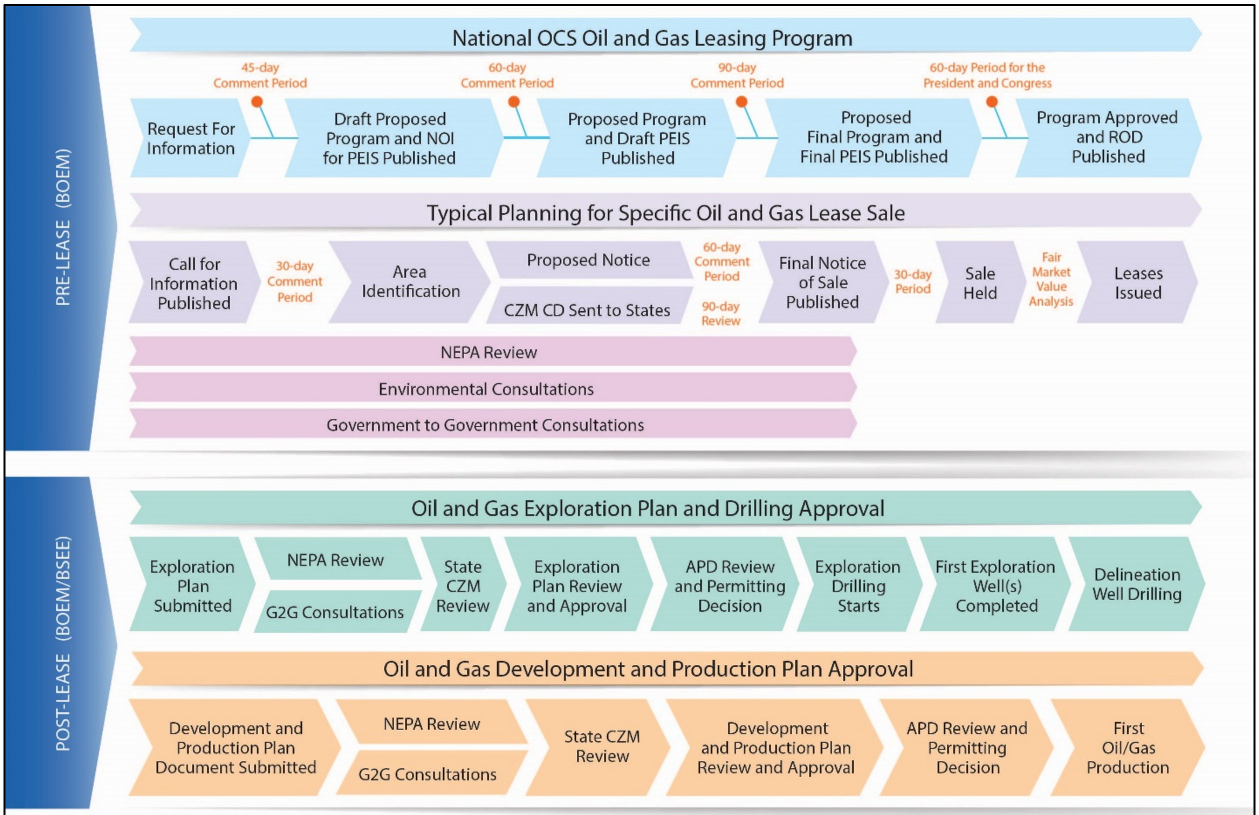
NATIONAL OCS OIL AND GAS LEASING PROGRAM

Section 18 of the OCSLA (43 U.S.C. § 1344) requires the Secretary of the Interior (Secretary) to prepare, maintain, and periodically revise a new nationwide OCS oil and gas leasing program (referred to as the National OCS Program). The National OCS Program must address, as precisely as possible, the size, timing, and location of leasing activity for the 5-year period following its approval (43 U.S.C. § 1344(a)). Additionally, Section 18(a) of the OCSLA requires the Secretary to consider economic, social, and environmental values and the potential impact of activities on the marine, coastal, and human environments. The Secretary must identify a schedule of lease sales that balances the potentials for environmental damage, the discovery of oil and gas, and adverse impact on the coastal zone (43 U.S.C. § 1344(a)(3)). The National OCS Program also must provide for the receipt of fair market value by the Federal Government for land leased and rights conveyed.

When approved, the leasing program consists of scheduled lease sales for a 5-year period, along with policies pertaining to the size and location of lease sales and the receipt of fair market value. The purpose of a schedule is to increase the predictability of lease sales in order to facilitate planning by industry, Federal agencies, the affected states, and the general public. The schedule indicates the timing and location of lease sales and shows the presale steps in the process that lead to a competitive sealed bid auction for a specific OCS area. To facilitate the scheduling of and preparation for lease sales in the National OCS Program, the OCS is divided into 26 administrative geographical units called planning areas. The Gulf of Mexico region contains the Western, Central, and Eastern Planning Areas (**Figure 1**). The 2017-2022 National OCS Program approved the region-wide lease sale approach combining the WPA, CPA, and EPA's unleased acreage not subject to moratorium or otherwise unavailable.

In preparing a new National OCS Program, the Secretary (through BOEM) solicits comments from coastal State governors and localities, tribal governments, the public, the oil and natural gas industry, environmental groups, and affected Federal agencies. BOEM requests comments at the start of the process of developing a new National OCS Program and following the issuance of each of the first two program proposals: (1) the draft proposed program with a 60-day comment period; and (2) the proposed program with a 90-day comment period. The third and last version, the proposed final program, is prepared with a 60-day notification period following submission to the President and Congress. After 60 days, if Congress does not object, the Secretary may approve the program.

In addition to the steps required by Section 18 of the OCSLA, the Secretary must comply with the requirements of NEPA. In the context of BOEM's multiple-stage oil and gas leasing program, the obligation to fully comply with NEPA does not mature until the lease sale stage (*Center for Biological Diversity v. Department of the Interior*, 563 F.3d 466 [D.C. Cir. 2009]; *Center for Sustainable Economy v. Jewell*, 779 F.3d 588 [D.C. Cir. 2015]). However, exercising its discretion, BOEM has typically prepared a Programmatic Environmental Impact Statement (EIS) concurrently with the development of each National OCS Program. The analyses in this Programmatic EIS focus on high-level impacts at the national and regional scale (rather than impacts of individual lease sales or project-specific actions). To determine the size, timing, and location of lease sales to be included in a National OCS Program, the Secretary will consider the analyses in the Proposed Program as well as the Programmatic EIS. BOEM also completes environmental reviews at subsequent stages of the OCSLA process as outlined in **Figure 3**. Prior to holding an individual oil and gas lease sale, BOEM must ensure that all necessary reviews and/or opportunities for public input have taken place under the OCSLA, Coastal Zone Management Act, and NEPA.



Key: APD = Application for Permit to Drill; BOEM = Bureau of Ocean Energy Management; BSEE = Bureau of Safety and Environment Enforcement; CD = Consistency Determination; CZM = Coastal Zone Management; EA = Environmental Assessment; EIS = Environmental Impact Statement; G2G = Government to Government; NEPA = National Environmental Policy Act; NOI = Notice of Intent; OCS = Outer Continental Shelf; PEIS = Programmatic Environmental Impact Statement; ROD = Record of Decision.

Figure 3. BOEM's OCS oil and gas leasing, exploration, and development process.

For the GOM region, a Multisale EIS is typically prepared, which tiers from the National OCS Program EIS. This Multisale EIS analyzes the potential impacts of a "typical" region-wide lease sale (e.g., GOM Region-wide Lease Sale 256) on the marine, coastal, and human environments. Once published, this Multisale EIS serves as the programmatic NEPA analysis for each of the proposed GOM region-wide lease sales in the National OCS Program. Following the 30-day review period for the Final Multisale EIS, BOEM issues a Record of Decision (ROD) for the first proposed GOM lease sale of the National OCS Program. The ROD must be published at least 30 days prior to holding the actual lease sale.

For subsequent lease sales in a program, a Determination of NEPA Adequacy (DNA) specific to each individual lease sale is usually prepared. The DNA for each lease sale identifies and determines whether new information or circumstances bearing on a proposed lease sale or its impacts triggers BOEM's obligation to supplement the Multisale EIS. If additional NEPA review is warranted based on the DNA, BOEM prepares an environmental assessment or EIS prior to issuing a Record of Decision or holding the lease sale. If additional supplementation is not triggered, the Multisale EIS and the DNA, which summarizes the Multisale EIS conclusions and any pertinent new information, are used to support a ROD for that proposed lease sale. This NEPA review process (i.e., DNA) is repeated for each subsequent GOM lease sale in the National OCS Program. This process, however, would not apply to any proposed lease sales in the area of the EPA currently under congressional moratoria or for any other GOM lease sales that would consider areas outside of those that have been historically offered for leasing in previous programs (e.g., blocks within transboundary areas). Consultation is conducted with the states during this process, and consistency with each affected State's Coastal Zone Management program is determined before the lease sale is held.

The entire National OCS Program development process usually takes approximately 2½ to 3+ years to complete. **Figure 3** above shows the major OCSLA and NEPA steps in the process for approving a National OCS Program and for subsequent activities following approval of a National OCS Program. BOEM is currently operating under the OCS Oil and Gas Leasing Program for 2017-2022. This National OCS Program proposes 10 oil and gas region-wide lease sales in the GOM. As directed in Executive Order 13795 (April 28, 2017) and Secretarial Order 3350 (May 1, 2017), BOEM is initiating a process to develop the next National OCS Oil and Gas Program. Detailed schedule information is available at https://www.boem.gov/oil-gas-energy/leasing/2017-2022-lease-sale-schedule. More information on the National OCS Oil and Gas Program can be found on BOEM's website at https://www.boem.gov/national-ocs-oil-and-gas-leasing-program.

LEASING ACTIVITY

Since publication of the last deepwater report, which contained leasing activity through March 2016, there have been eight lease sales held in the Gulf of Mexico between August 2016 and March 2020. In March 2017, CPA Lease Sale 247 was the last planning area-specific lease sale held. Beginning with Lease Sale 249, in accordance with the National OCS Program, the lease sales became region-wide in scope containing available blocks in the WPA, CPA and EPA. The eight lease sales discussed in this report received bids totaling $1,379,459,256 with $1,213,610,054 in high bids. BOEM received 1,148 bids from 49 companies on 1,018 blocks comprising 5,669,998 acres offshore Alabama, Louisiana, Mississippi, and Texas. The total of blocks receiving bids statistics includes each time a bid was received on a block during this time period; therefore, some blocks are counted multiple times.

These eight lease sales ultimately resulted in the award of 954 leases. BOEM rejected high bids totaling $55,829,474 on 56 blocks as insufficient for fair market value. Eight additional blocks were forfeited when the company(s) failed to execute the leases. The accepted high bids for all lease sales totaled $1,156,187,358 with $1,119,949,233 in water depths 1,000 ft or deeper, accounting for approximately 97 percent of the accepted high bids. (This figure includes the 1/5 bonus forfeited on the 8 blocks resulting in no lease.)

Approximately 82 percent of the blocks receiving bids were in water depths 1,000 ft or deeper, and approximately 18 percent of the blocks receiving bids were in water depths less than 1,000 ft. The block in the deepest water that received a bid was Alaminos Canyon Block 600 at 10,978 ft. The highest bid received on a block was $25,919,784, which was submitted by Hess Corporation for Mississippi Canyon Block 338.

INDIVIDUAL LEASE SALE STATISTICS

WPA Lease Sale 248

Held on August 24, 2016, in New Orleans, bids for WPA Lease Sale 248 totaled $18,067,020. This was the 12th lease sale scheduled in the 2012-2017 National OCS Program. BOEM received 24 bids from three companies on 24 blocks comprising 138,240 acres offshore Texas (**Figure 4**).

All of the blocks (100%) receiving bids were in water depths 1,000 ft or deeper. The block in the deepest water that received a bid was East Breaks Block 785 at 5,171 ft. The highest bid received on a block was $1,124,000, which was submitted by Exxon Mobil Corporation for East Breaks Block 590.

WPA Lease Sale 248 ultimately resulted in the award of 24 leases. BOEM did not reject any high bids. The accepted high bids for the lease sale totaled $18,067,020.

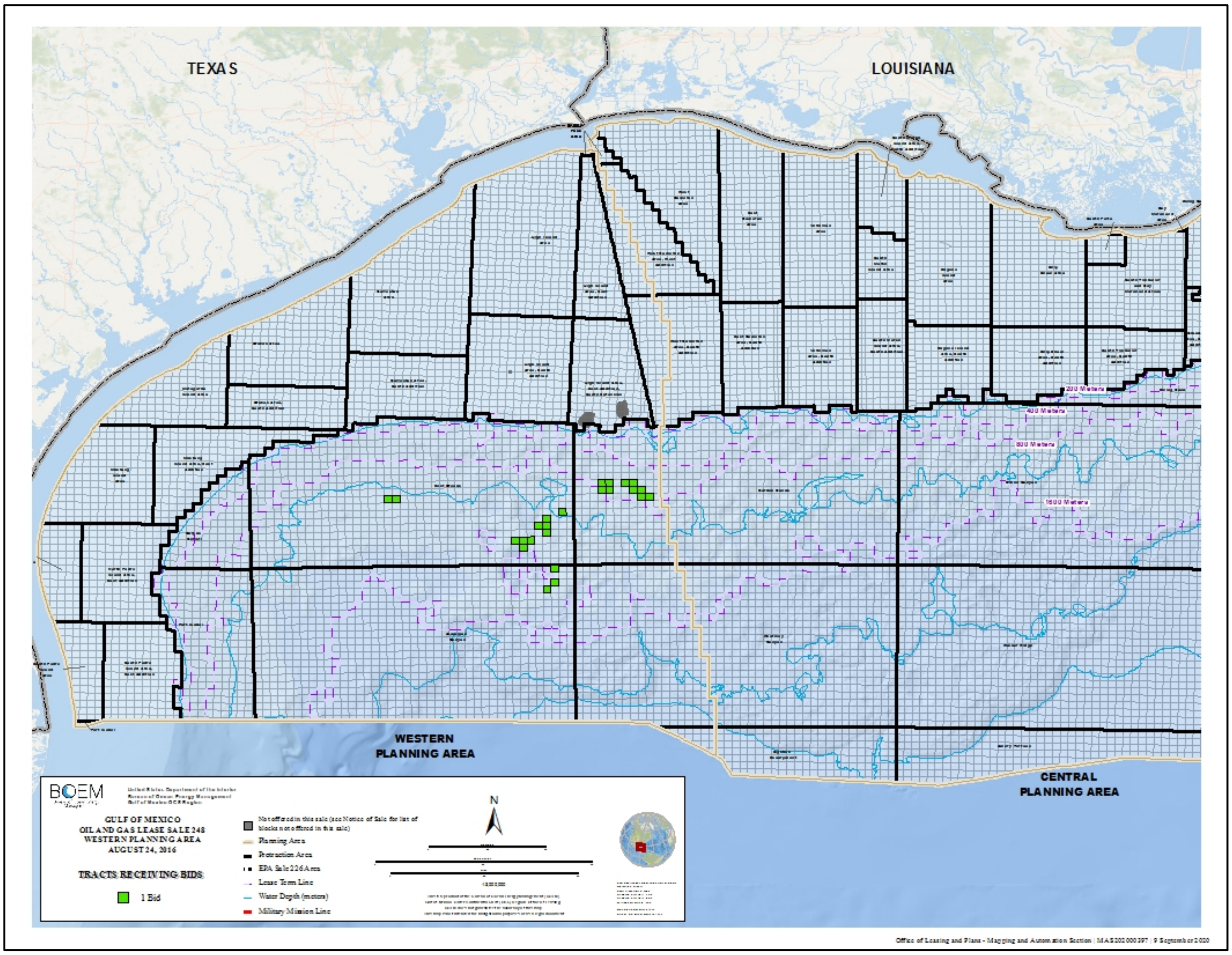


Figure 4. WPA Lease Sale 248 geographic bid distribution.

CPA Lease Sale 247

Held on March 22, 2017, in New Orleans, bids for CPA Lease Sale 247 totaled $315,303,884 with $274,797,434 in high bids. This was the 14th lease sale scheduled in the 2012-2017 National Program. BOEM received 189 bids from 28 companies on 163 blocks comprising 913,542 acres offshore Alabama, Louisiana, Mississippi, and Texas (**Figure 5**).

Approximately 84 percent of the blocks receiving bids were in water depths 1,000 ft or deeper, and approximately 16 percent of the blocks receiving bids were in water depths less than 1,000 ft. The block in the deepest water that received a bid was Walker Ridge Block 595 at 9,895 ft. The highest bid received on a block was $24,056,719, which was submitted by Shell Offshore Inc. for Atwater Valley Block 64.

CPA Lease Sale 247 ultimately resulted in the award of 148 leases. BOEM rejected high bids totaling $10,848,507 on 10 blocks as insufficient for fair market value. Five additional blocks resulted in no lease when the company failed to execute the lease. The accepted high bids for the lease sale totaled $263,398,527 with $259,424,958 in water depths 1,000 ft or deeper, accounting for approximately 98 percent of the accepted high bids

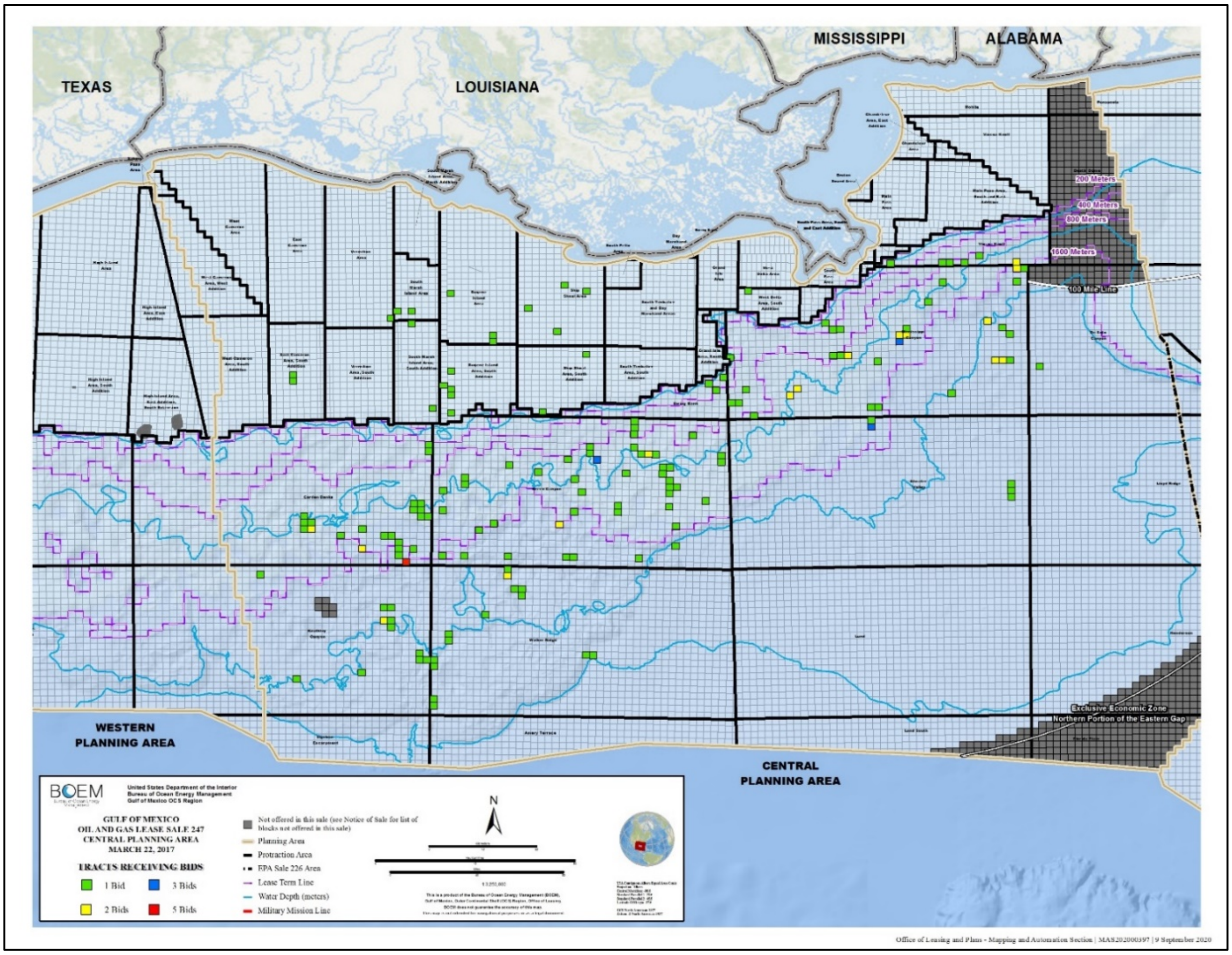


Figure 5. CPA Lease Sale 247 geographic bid distribution.

GOM Region-wide Lease Sale 249

Held on August 16, 2017, in New Orleans, bids for GOM Region-wide Lease Sale 249 totaled $137,006,181 with $121,143,055 in high bids. This was the first region-wide lease sale scheduled in the 2017-2022 National OCS Program. BOEM received 99 bids from 27 companies on 90 blocks comprising 508,096 acres offshore Alabama, Louisiana, Mississippi, and Texas (**Figure 6**).

Approximately 86 percent of the blocks receiving bids were in water depths 1,000 ft or deeper, and approximately 14 percent of the blocks receiving bids were in water depths less than 1,000 ft. The block in the deepest water that received a bid was Alaminos Canyon Block 858 at 9,767 ft. The highest bid received on a block was $12,100,717, which was submitted by TOTAL E&P USA, INC. for Garden Banks Block 1003.

GOM Region-wide Lease Sale 249 ultimately resulted in the award of 81 leases. BOEM rejected high bids totaling $9,294,188 on seven blocks as insufficient for fair market value. Two additional blocks resulted in no lease when the company failed to execute the lease. The accepted high bids for the lease sale totaled $110,878,164 with $108,157,341.60 in water depths 1,000 ft or deeper, accounting for approximately 98 percent of the accepted high bids.

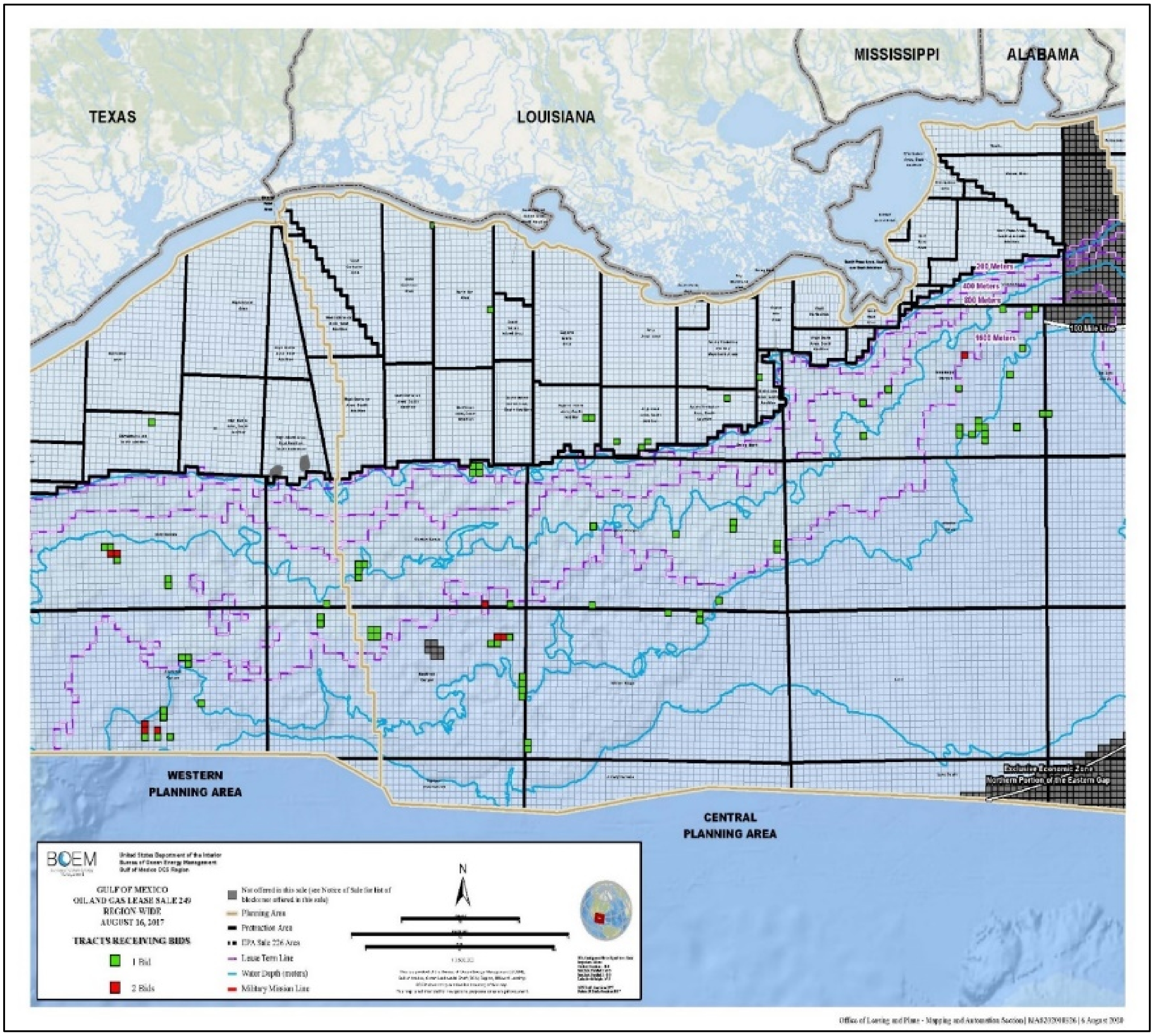


Figure 6. GOM Region-wide Lease Sale 249 geographic bid distribution.

GOM Region-wide Lease Sale 250

Held on March 21, 2018, in New Orleans, bids for GOM Region-wide Lease Sale 250 totaled $139,122,383 with $124,763,581 in high bids. This was the second region-wide lease sale scheduled in the 2017-2022 National OCS Program. BOEM received 159 bids from 33 companies on 148 blocks comprising 815,404 acres offshore Alabama, Louisiana, Mississippi, and Texas (**Figure 7**).

Approximately 70 percent of the blocks receiving bids were in water depths 1,000 ft or deeper, and approximately 30 percent of the blocks receiving bids were in water depths less than 1,000 ft. The block in the deepest water that received a bid was Lloyd Ridge Block 628 at 9,613 ft. The highest bid received on a block was $7,000,728, which was submitted by TOTAL E&P USA, INC. for Mississippi Canyon Block 697.

GOM Region-wide Lease Sale 250 ultimately resulted in the award of 139 leases. BOEM rejected high bids totaling $9,434,442 on nine blocks as insufficient for fair market value. The accepted high bids for the lease sale totaled $115,329,139 with $106,429,055 in water depths 1,000 ft or deeper, accounting for approximately 92 percent of the accepted high bids.

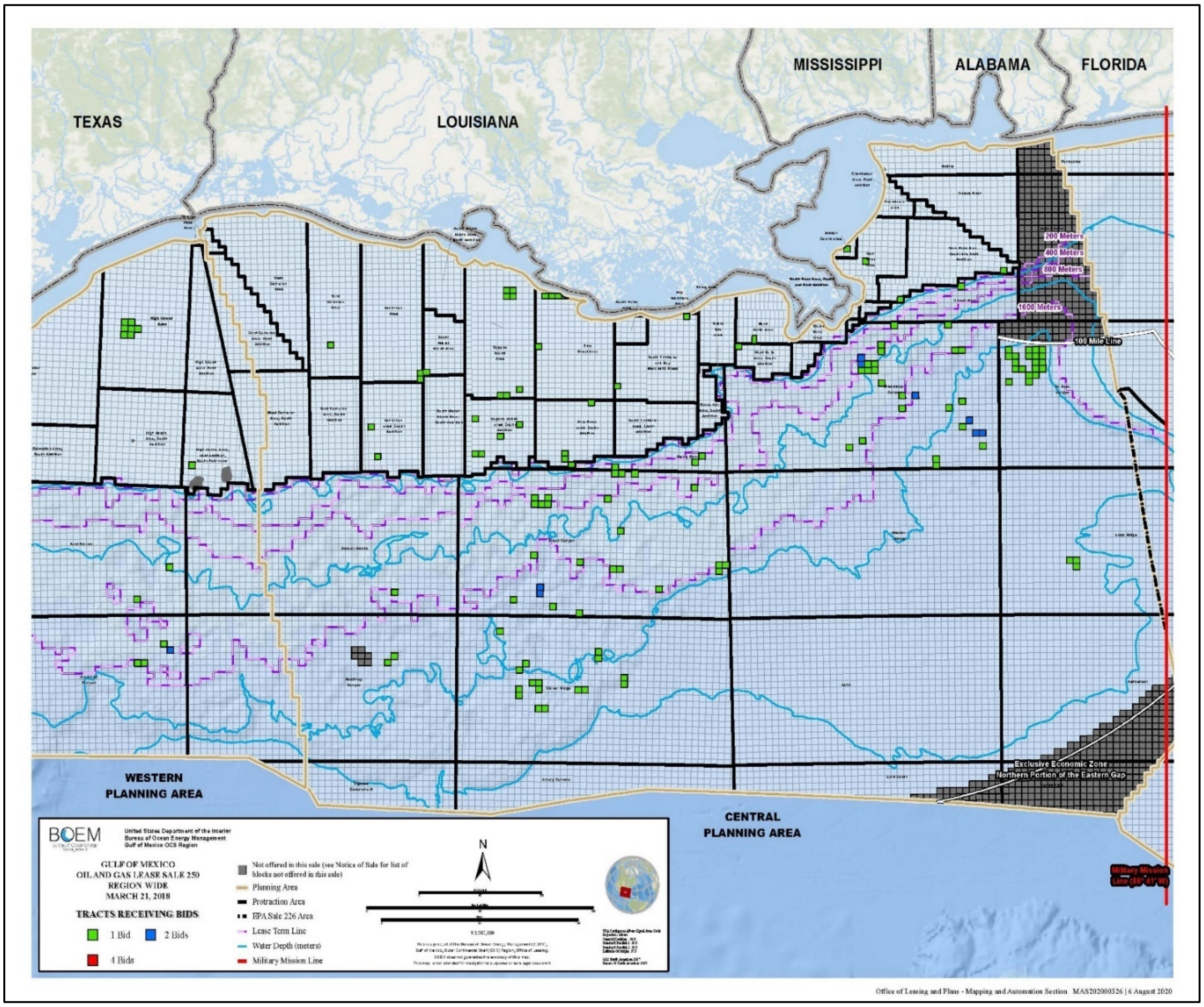


Figure 7. GOM Region-wide Lease Sale 250 geographic bid distribution.

GOM Region-wide Lease Sale 251

Held on August 15, 2018, in New Orleans, bids for GOM Region-wide Lease Sale 251 totaled $202,667,923 with $178,069,406 in high bids. This was the third region-wide lease sale scheduled in the 2017-2022 National OCS Program. BOEM received 171 bids from 29 companies on 144 blocks comprising 801,289 acres offshore Alabama, Louisiana, Mississippi, and Texas (**Figure 8**).

Approximately 77 percent of the blocks receiving bids were in water depths 1,000 ft or deeper, and approximately 23 percent of the blocks receiving bids were in water depths less than 1,000 ft. The block in the deepest water that received a bid was Lloyd Ridge Block 239 at 9,921 ft. The highest bid received on a block was $25,919,784, which was submitted by Hess Corporation for Mississippi Canyon Block 338.

GOM Region-wide Lease Sale 251 ultimately resulted in the award of 141 leases. BOEM rejected high bids totaling $2,579,942 on three blocks as insufficient for fair market value. The accepted high bids for the lease sale totaled $175,489,464 with $165,592,814 in water depths 1,000 ft or deeper, accounting for approximately 94 percent of the accepted high bids.

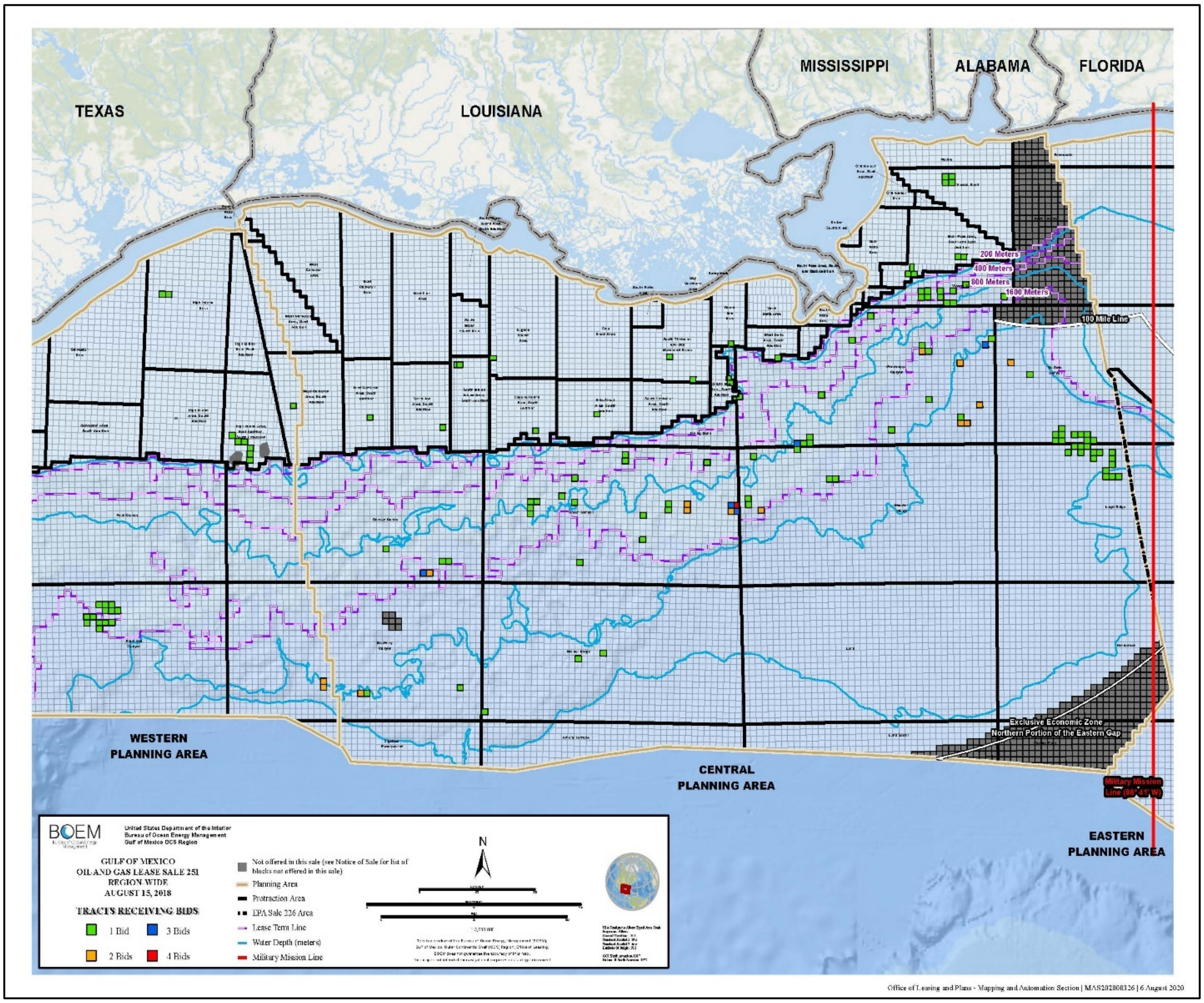


Figure 8. GOM Region-wide Lease Sale 251 geographic bid distribution.

GOM Region-wide Lease Sale 252

Held on March 20, 2019, in New Orleans, bids for GOM Region-wide Lease Sale 252 totaled $283,782,480 with $244,299,344 in high bids. This was the fourth region-wide lease sale scheduled in the 2017-2022 National OCS Program. BOEM received 257 bids from 30 companies on 227 blocks comprising 1,261,134 acres offshore Alabama, Louisiana, Mississippi, and Texas (**Figure 9**).

Approximately 84 percent of the blocks receiving bids were in water depths 1,000 ft or deeper, and approximately 16 percent of the blocks receiving bids were in water depths less than 1,000 ft. The block in the deepest water that received a bid was Lloyd Ridge Block 456 at 10,020 ft. The highest bid received on a block was $24,495,776, which was submitted by Equinor Gulf of Mexico LLC for Mississippi Canyon Block 801.

GOM Region-wide Lease Sale 252 ultimately resulted in the award of 211 leases. BOEM rejected high bids totaling $12,437,161 on 15 blocks as insufficient for fair market value. One additional block resulted in no lease when the company failed to execute the lease. The accepted high bids for the lease sale totaled $231,790,063 with $225,202,228 in water depths 1,000 ft or deeper, accounting for approximately 97 percent of the accepted high bids.

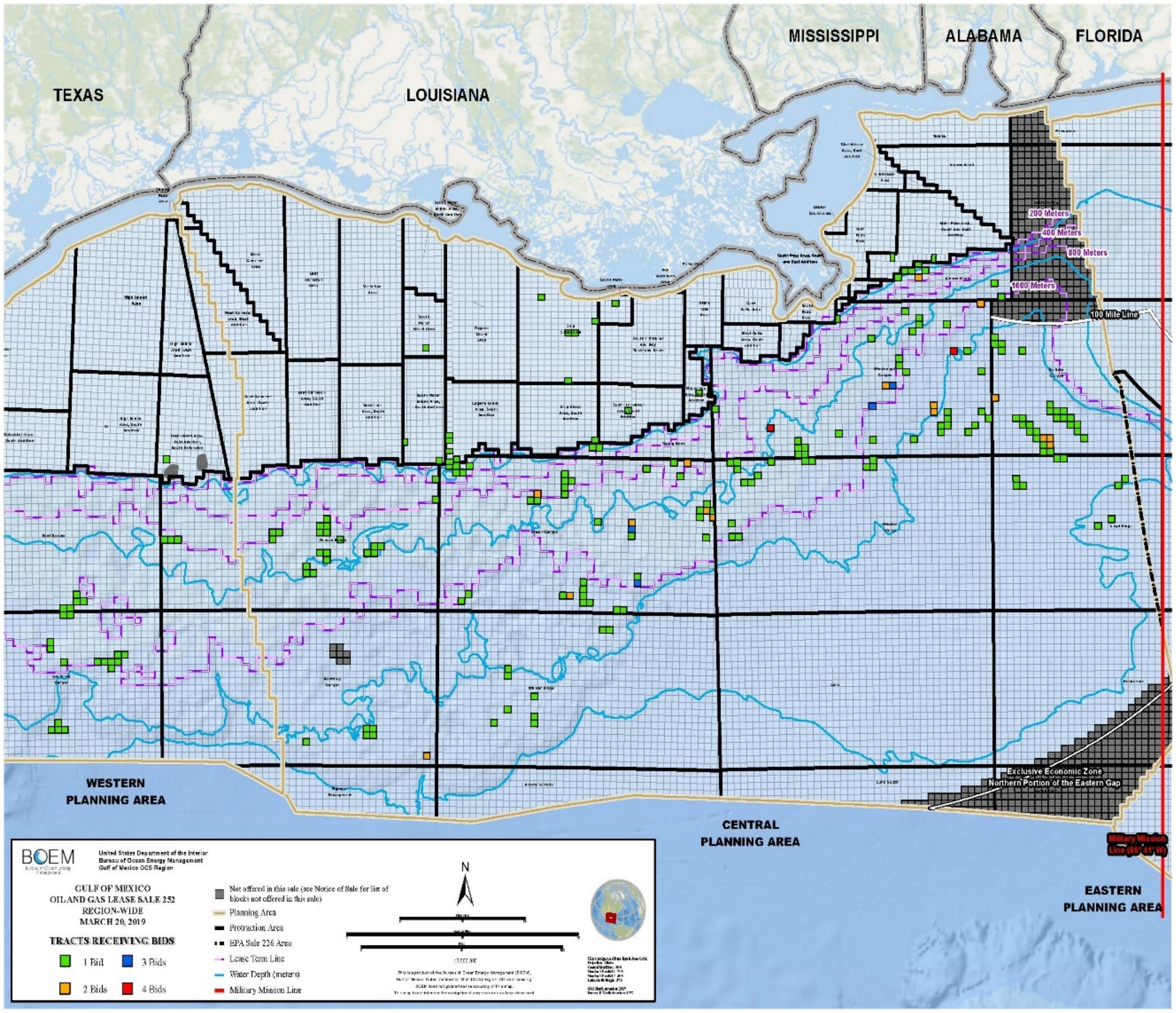


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Figure 9. GOM Region-wide Lease Sale 252 geographic bid distribution.

GOM Region-wide Lease Sale 253

Held on August 21, 2019, in New Orleans, bids for GOM Region-wide Lease Sale 253 totaled $174,922,200 with $159,386,761 in high bids. This was the fifth region-wide lease sale scheduled in the 2017-2022 National OCS Program. BOEM received 165 bids from 27 companies on 151 blocks comprising 835,007 acres offshore Alabama, Louisiana, Mississippi, and Texas (**Figure 10**).

Approximately 85 percent of the blocks receiving bids were in water depths 1,000 ft or deeper, and approximately 15 percent of the blocks receiving bids were in water depths less than 1,000 ft. The block in the deepest water that received a bid was Lloyd Ridge Block 149 at 9,774 ft. The highest bid received on a block was $22,510,319, which was submitted by BHP Billiton Petroleum (Deepwater) Inc. for Green Canyon Block 124.

GOM Region-wide Lease Sale 253 ultimately resulted in the award of 147 leases. BOEM rejected high bids totaling $4,392,234 on four blocks as insufficient for fair market value. The accepted high bids for the lease sale totaled $154,994,527 with $151,736,702 in water depths 1,000 ft or deeper, accounting for approximately 98 percent of the accepted high bids.

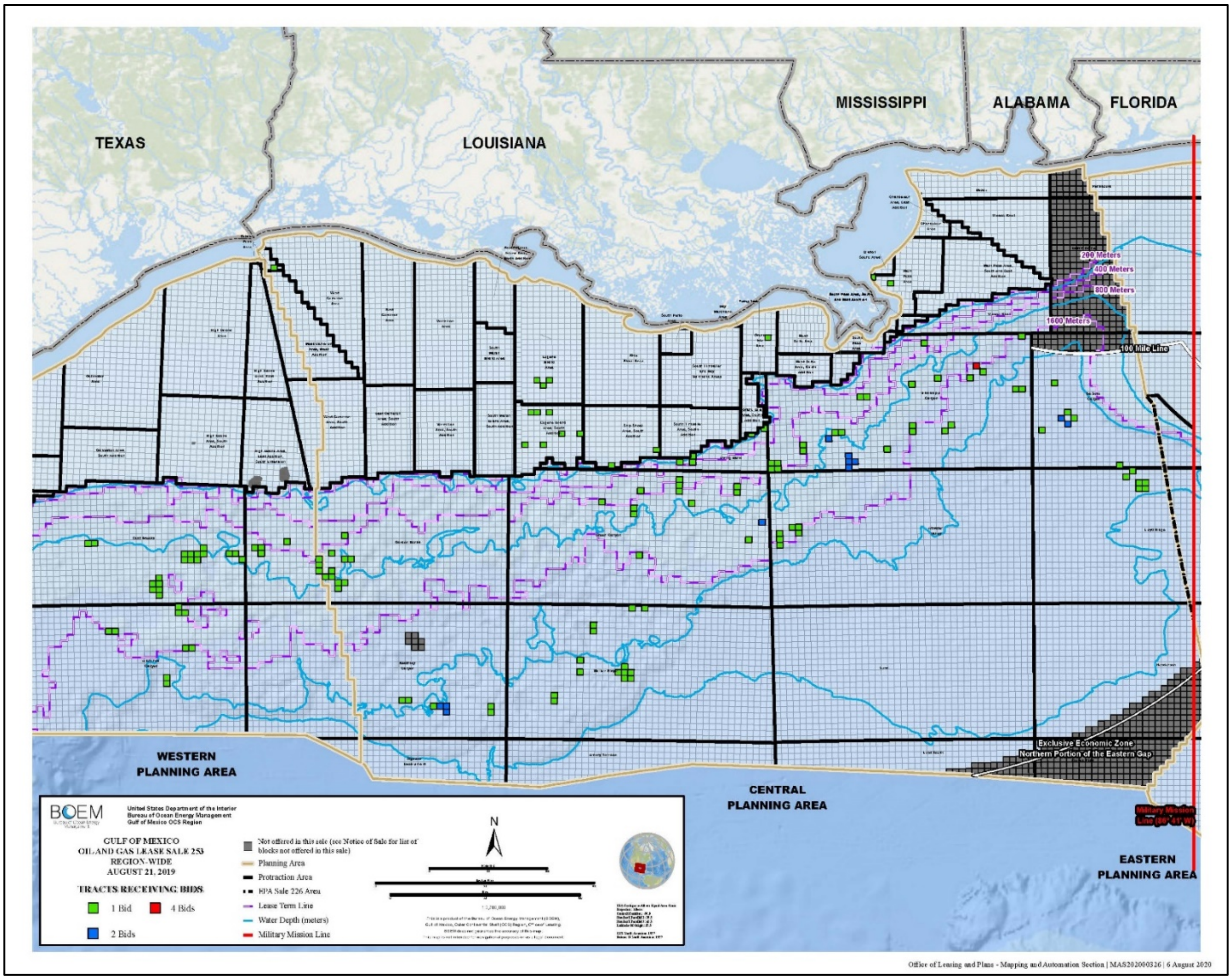

Figure 10. GOM Region-wide Lease Sale 253 geographic bid distribution.

GOM Region-wide Lease Sale 254

Held on March 18, 2020, in New Orleans, bids for GOM Region-wide Lease Sale 254 totaled $108,587,185 with $93,083,453 in high bids. This was the sixth region-wide lease sale scheduled in the 2017-2022 National OCS Program. BOEM received 84 bids from 22 companies on 71 blocks comprising 397,286 acres offshore Alabama, Louisiana, Mississippi, and Texas (**Figure 11**).

Approximately 92 percent of the blocks receiving bids were in water depths 1,000 ft or deeper, and approximately 8 percent of the blocks receiving bids were in water depths less than 1,000 ft. The block in the deepest water that received a bid was Alaminos Canyon Block 600 at 10,978 ft. The highest bid received on a block was $11,114,050, which was submitted by BHP Billiton Petroleum (Deepwater) Inc. for Green Canyon Block 80.

GOM Region-wide Lease Sale 254 ultimately resulted in the award of 63 leases. BOEM rejected high bids totaling $6,843,000 on eight blocks as insufficient for fair market value. The accepted high bids for the lease sale totaled $86,240,453 with $85,339,114 in water depths 1,000 ft or deeper, accounting for approximately 99 percent of the accepted high bids.

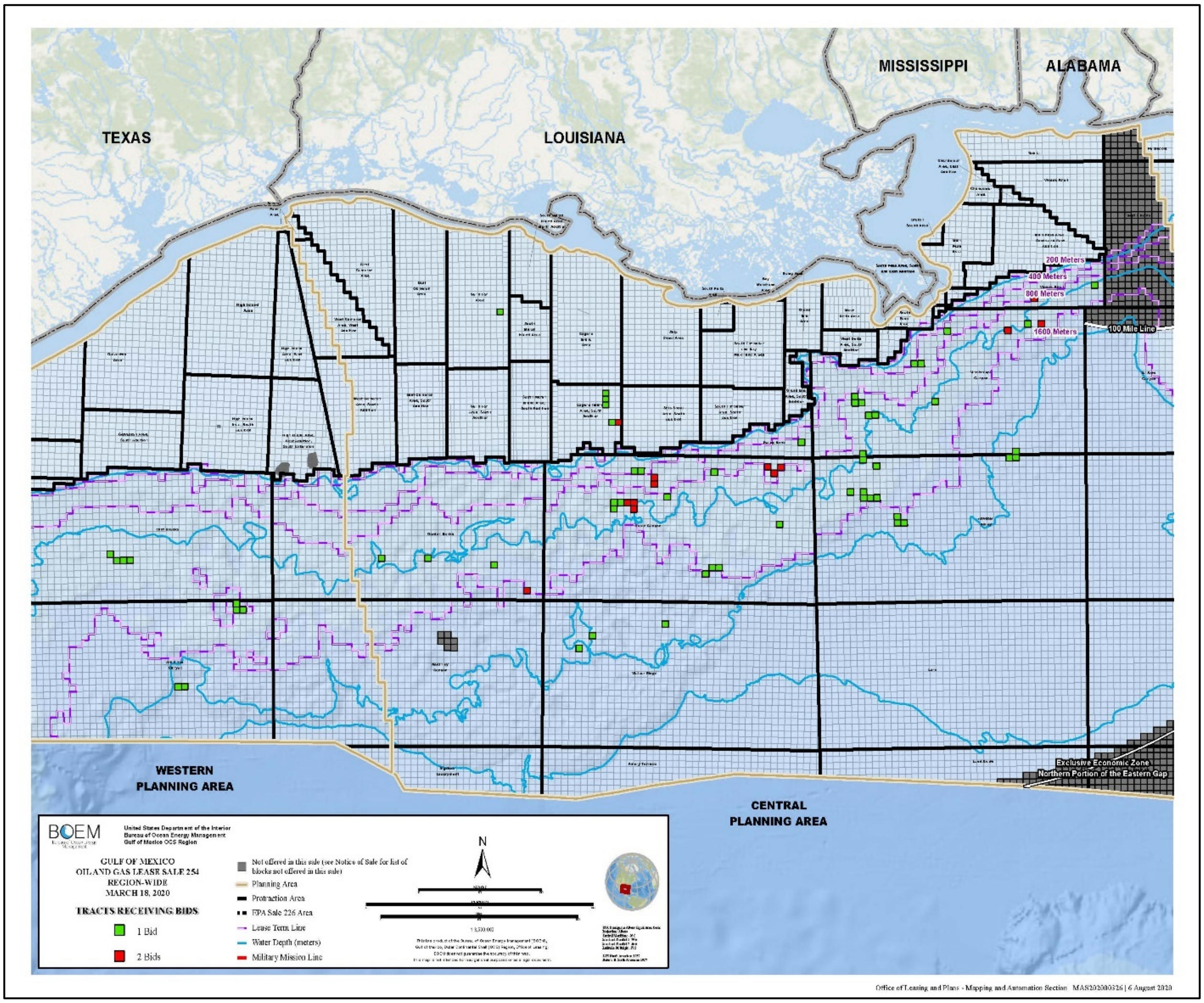

Figure 11. GOM Region-wide Lease Sale 254 geographic bid distribution.

LEASING TRENDS

This section presents a series of graphs showing leasing data and Cushing, OK WTI Spot prices of oil in dollars per barrel from the U.S. Energy Information Administration (EIA). Analysis of leasing trends data shows a relationship between oil prices and the number of bids received in a given year, a relationship between oil prices and blocks receiving bids in a lease sale, and a relationship between oil prices and the sum of high bids received in a lease sale.

Figure 12 shows the relationship between the commodity price for oil and the number of bids that BOEM received by year. In the 7 years prior to 2008 bidding activity follows the steady increase in the price of oil. The recession of 2008 resulted in the sharp decline in the price of oil. The drop in the price of oil correlates to a decrease in the number of bids received; however, price alone cannot fully explain the decrease. Contributing factors include the transition from offshore to onshore unconventional exploration (i.e., fracking), the maturation some major fields located in the GOM shallow water, and a reduction in competition among companies placing bids. While the price of oil trends upward between 2009 and 2014, the number of bids received does not. This is a departure from the 2000 to 2008 trend where the number of bids increases with the price of oil. This variability is likely due in part to the Macondo oil spill. The number of bids received decreases in 2014 following the steep decline in the price of oil. This is likely a result of industry economic decisions based on the threshold for a play to be profitable. The price of oil increases each year from 2016 to 2019; the number of bids again increases. The following figures show the contribution of leasing on the shelf from 2000 to 2008 and the emergence of deepwater leasing.

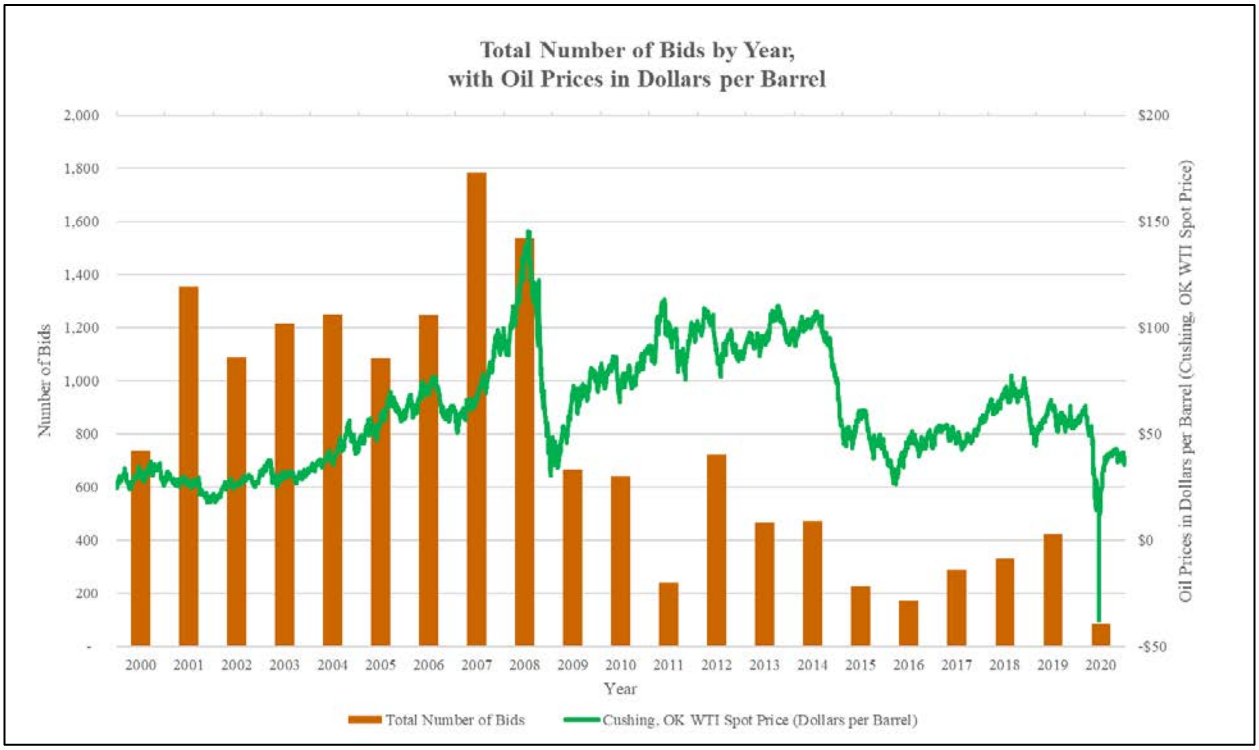

Figure 12. Total number of bids by year, with oil prices in dollars per barrel, 2000–March 18, 2020, with Cushing, OK WTI Spot Price in dollars per barrel (daily) from the U.S. Energy Information Administration.

The same general relationship can be seen between blocks receiving bids and the price of oil in the Gulf of Mexico (**Figure 13**). Significantly more blocks received bids in both shallow and deep water between 2000 (CPA Lease Sale 175) and 2008 (EPA Lease Sale 224) as the price of oil increased. Also in 2017, just as with total bids by year, there appears to be an uptick in the number of blocks receiving bids following CPA Lease Sale 247 (**Figure 13**).

Interest in shallow-water blocks has decreased over time. CPA Lease Sale 247 and the GOM region-wide lease sales show a high interest in deepwater blocks (**Figures 13 and 14**). Nearly all blocks receiving bids in GOM Region-wide Lease Sale 254 were found in deep water (**Figures 13 and 14**). The sum of high bids by lease sale shows a general relationship with oil prices (**Figure 15**) similar to what is seen in **Figures 12-14**.

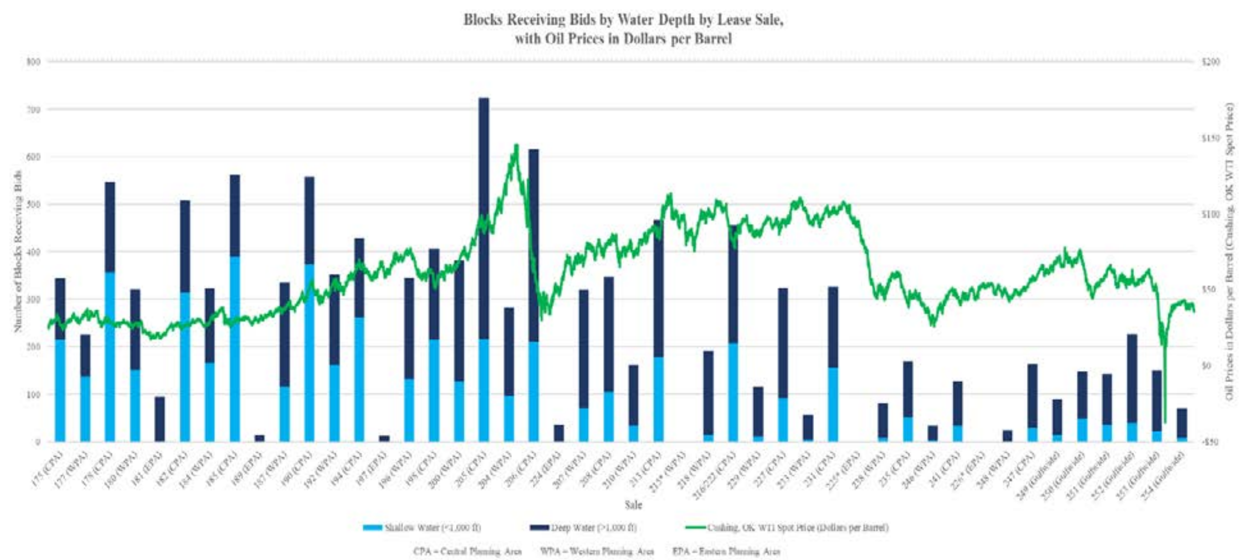

Figure 13. Blocks receiving bids by water depth by lease sale, with Cushing, OK WTI Spot Price in dollars per barrel (daily) from the U.S. Energy Information Administration.

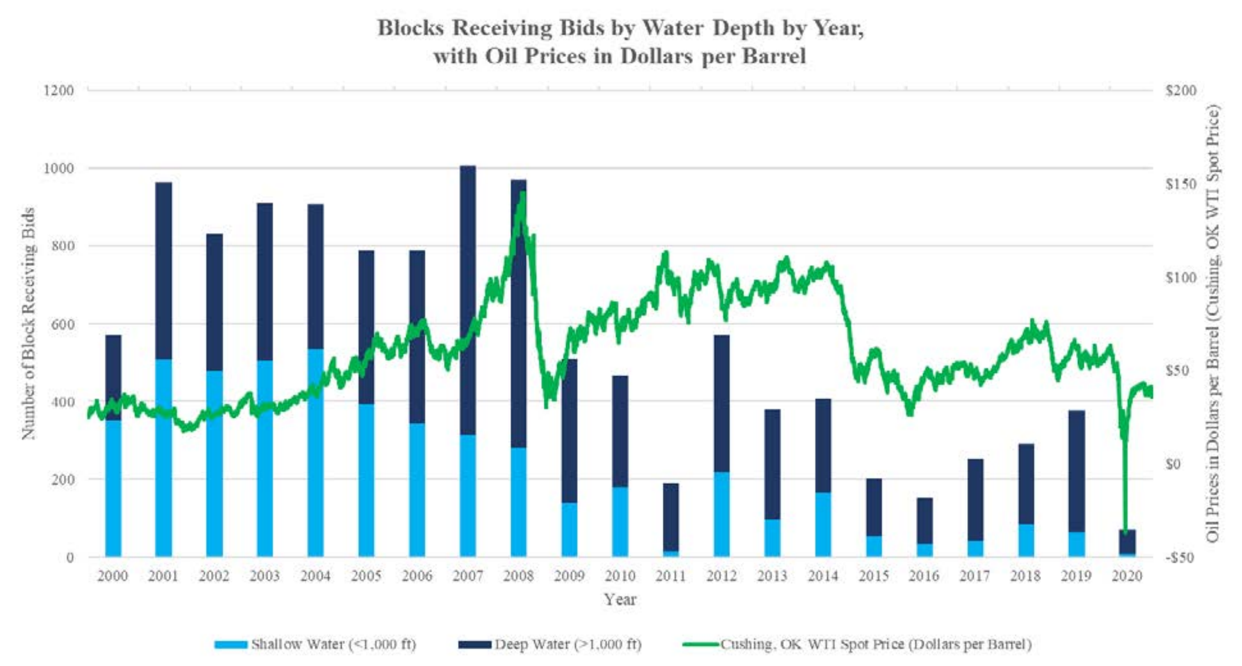

Figure 14. Blocks receiving bids by water depth by year, with Cushing, OK WTI Spot Price in dollars per barrel (daily) from the U.S. Energy Information Administration.

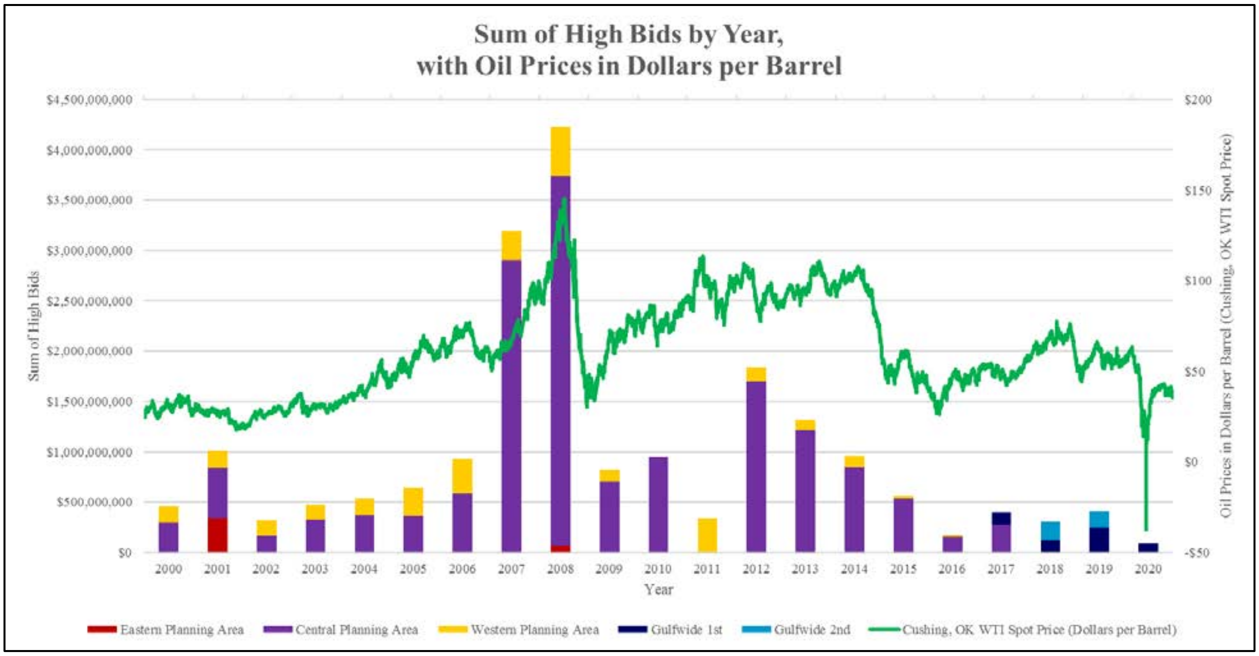

Figure 15. Sum of high bids by year showing individual lease sales, with Cushing, OK WTI Spot Price in dollars per barrel (daily) from the U.S. Energy Information Administration.

ACTIVE LEASES

Figures 16-19 depict all active leases in the GOM by water-depth ranges at the end of calendar year 2019. **Figure 15** shows the approximate number of active leases for each water-depth interval in deep water from 2016 to 2019. **Figure 17** compares the number of active leases in shallow water and deep water over the same time period. Active leases in shallow water have been in continuous decline since 2004 (not shown on **Figure 17**), while the number of active leases in deep water has only slightly decreased over the last 5 years. The number of active leases in deep water continue to greatly exceed the number of active leases in shallow water. For 2019, the total number of active leases in water depths of 1,000 ft or greater was 1,681, a slight increase over 2018, constituting 65 percent of all active leases in that year (**Figure 18**). The greatest number of active leases in deep water are located in water depths of 2,500 to 4,999 ft (**Figure 16**).

Figure 19 displays the geographic distribution of active leases following the two region-wide lease sales held in 2019. The limited number of active leases in the EPA is related to leasing restrictions. Note that some active leases are associated with more than one block; therefore, the map contains more highlighted blocks than the number of active leases. Additionally, lease status (i.e., active, expired, terminated, or relinquished) can change daily, so the active leases depicted in **Figure 19** is an approximation.

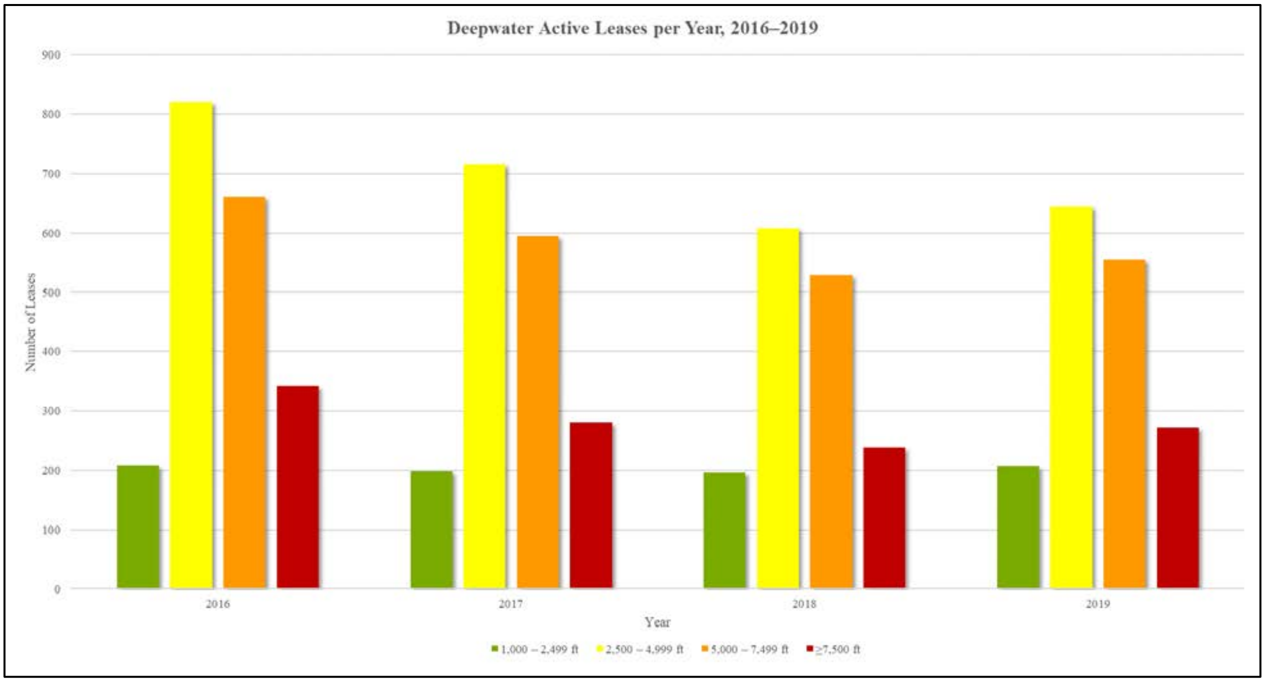

Figure 16. Number of active leases for each deepwater interval at the end of each year.

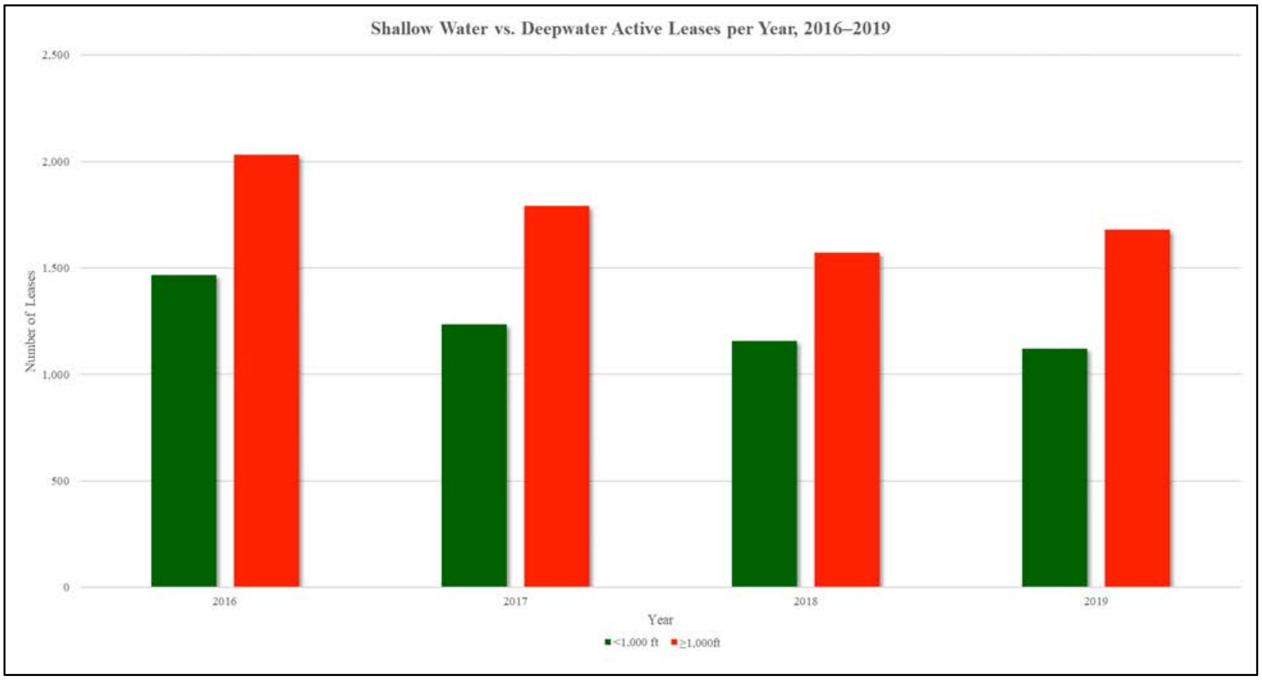

Figure 17. Number of deepwater and shallow-water active leases at the end of each year.

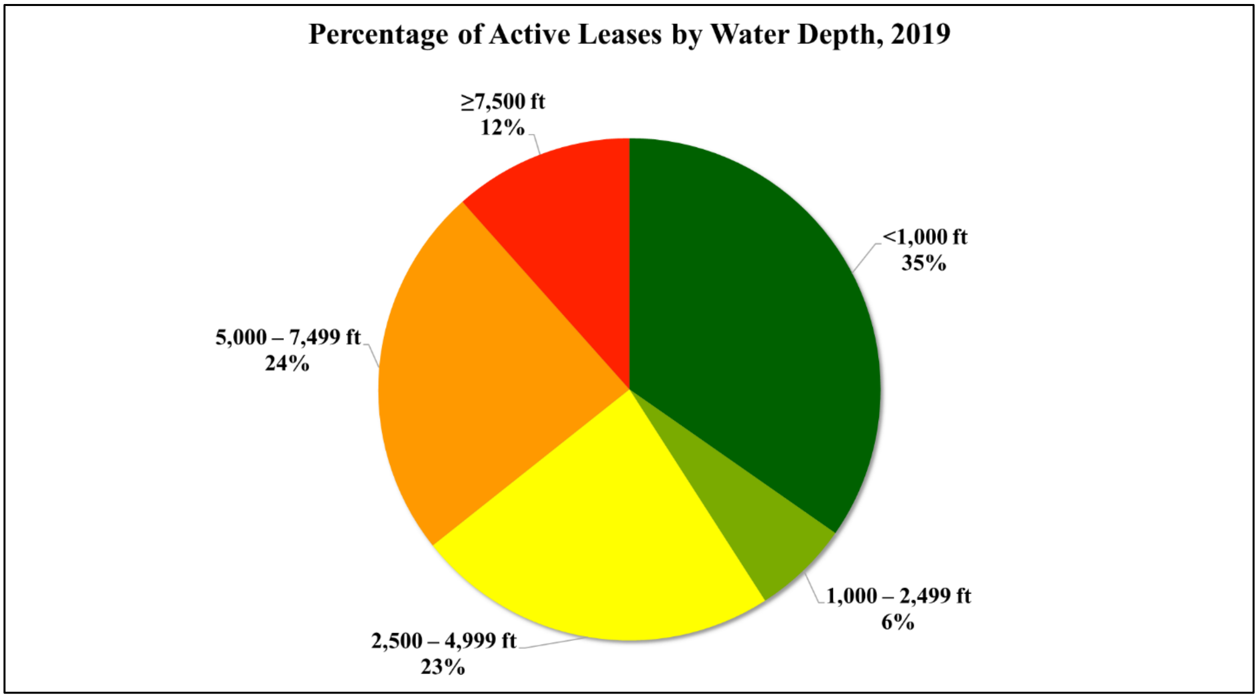

Figure 18. Active leases at the end of 2019 by water-depth categories.

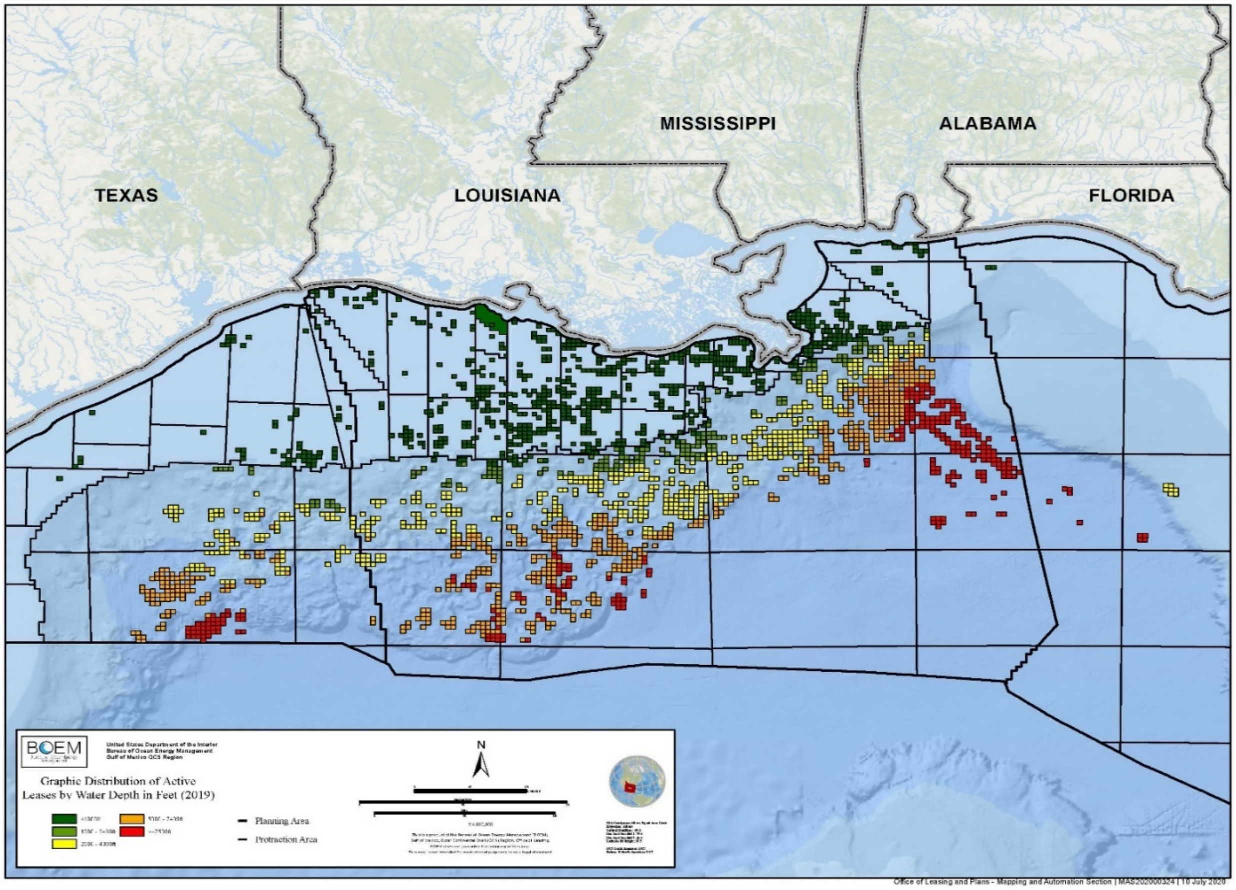

Figure 19. Geographic distribution of active leases by water depth.

COMPANY BIDDING ACTIVITY

The number of companies bidding in the the last 20 years tracks closely with the number of bids received and the number of tracts receiving bids. **Figure 20** shows the trend and numbers of companies bidding, the number of bids received, and the tracts receiving bids. Generally, as the number of companies participating in a given lease sale increases, so do the number of tracts receiving bids and the number of bids received. Since 2016, it is notable that the majority of companies are generally bidding in deep water, which is depicted in **Figure 21**. A list of companies that participated in the lease sales covered in this report are listed in **Table 1**.

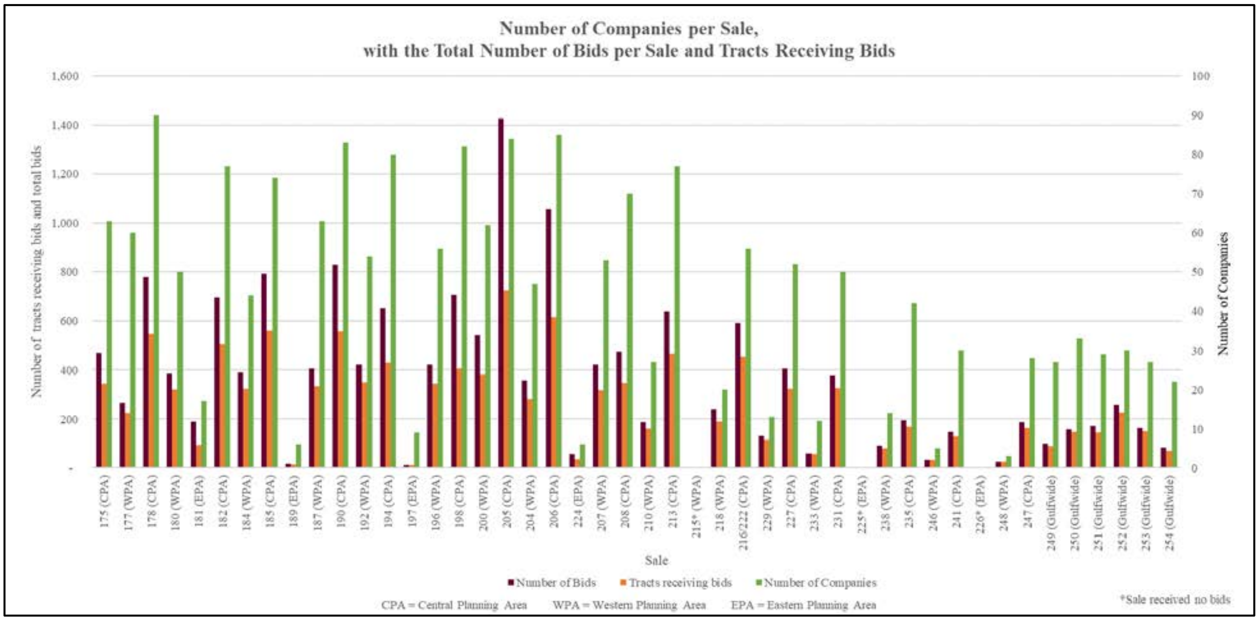

Figure 20. Number of companies participating, bids received, and tracts receiving bids in each lease sale from 2000 (CPA Lease Sale 175) to 2020 (GOM Region-wide Lease Sale 254).

Figure 21. Number of companies participating in lease sales.

Table 1. Companies participating in lease sales from 2016 through March 2020

Companies Participating in Lease Sales from 2016 through March 2020	
Anadarko Petroleum Corporation	GulfSlope Energy, Inc.
Anadarko US Offshore LLC	Hess Corporation
Apache Deepwater LLC	Houston Energy, L.P.
Apache Shelf Exploration LLC	Juneau Oil & Gas, LLC
Arena Energy, LLC	Kosmos Energy Gulf of Mexico Operations, LLC
Beacon Offshore Energy Exploration LLC	LLOG Bluewater Holdings, L.L.C.
BHP Billiton Petroleum (Deepwater) Inc.	LLOG Exploration Offshore, L.L.C.
BP Exploration & Production Inc.	Montecito Offshore L.L.C.
Byron Energy Inc.	Murphy Exploration & Production Company - USA
Cantium, LLC	Noble Energy, Inc.
Castex Offshore, Inc.	Peregrine Oil & Gas II, LLC
Chevron U.S.A. Inc.	Red Willow Offshore, LLC
CL&F Offshore LLC	Renaissance Offshore, LLC
Cobalt International Energy, L.P.	Repsol E&P USA Inc.
Cretaceous LLC	Reserves Management, L.C.
CSL Exploration, LP	Ridgewood Energy Corporation
Dorado Deep GP, LLC	SDB Offshore Energy, LLC
Ecopetrol America LLC	Shell Offshore Inc.
EnVen Energy Ventures, LLC	Talos Energy Offshore LLC
Equinor Gulf of Mexico LLC	Talos Resources LLC
Exxon Mobil Corporation	TOPCO OFFSHORE, LLC
Fieldwood Energy LLC	TOTAL E&P USA, INC.
Fieldwood Energy Offshore LLC	Venari Offshore LLC
Focus Exploration, LLC	W & T Energy VI, LLC
Freeport-McMoRan Exploration & Production LLC	W & T Offshore, Inc.
GOME 1271 LLC	Walter Oil & Gas Corporation

Major vs Non-Major bidders and Joint bidding trends in can be seen in **Figures 22 and 23** for GOM lease sales. For the purposes of this report, a "Major," is defined by the Herold Financial Dictionary as the six to eight companies that oil analysts use to talk about the world's biggest publicly owned gas and oil corporations. These companies are also known as Big Oil Super Majors, super-majors, oil majors, or big oil. The Major companies in this section of the report are BP Exploration & Production Inc., Chevron U.S.A. Inc., Union Oil Company of California, ConocoPhillips Company, Exxon Mobil Corporation, Shell Offshore Inc., and TOTAL E&P USA, INC. All bidding activity includes successful, unsuccessful, joint, and single bidding, unless otherwise specified.

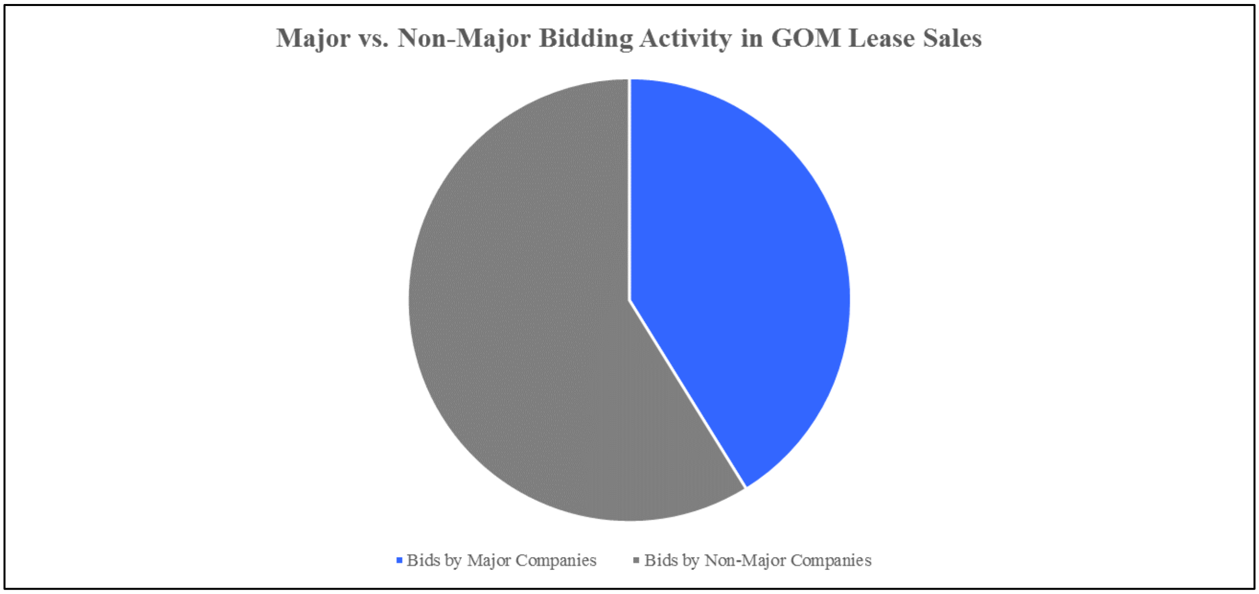

Figure 22. Pie chart showing major and non-major companies bidding activity for GOM Region-wide Lease Sales 247, 248, 249, 250, 251, 252, 253, and 254.

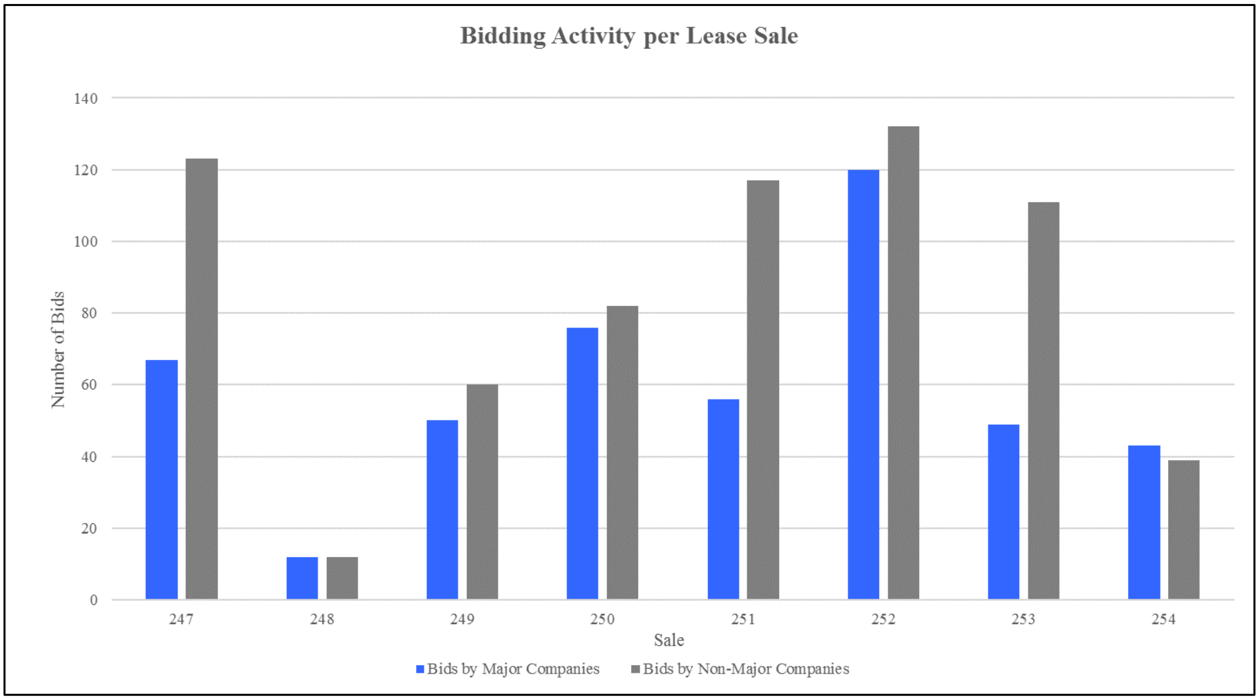

Figure 23. Bidding activity per lease sale with bids by major companies and non-major companies.

Deepwater bids for **Figures 24 and 25** are determined by block water depths less than 1,000 ft and water depths greater than 1,000 ft, respectively. Since 2016, the major companies have only bid in deep water.

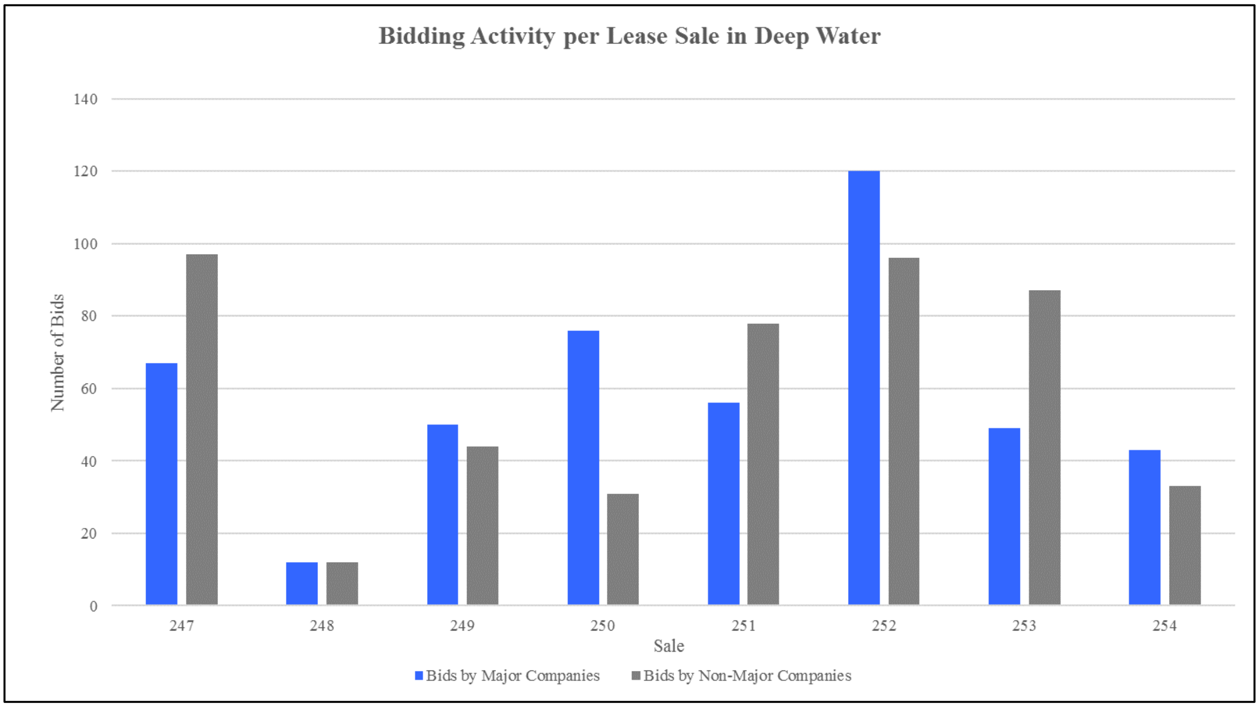

Figure 24. Bidding activity per lease sale in deep water with bids by major companies and non-major companies.

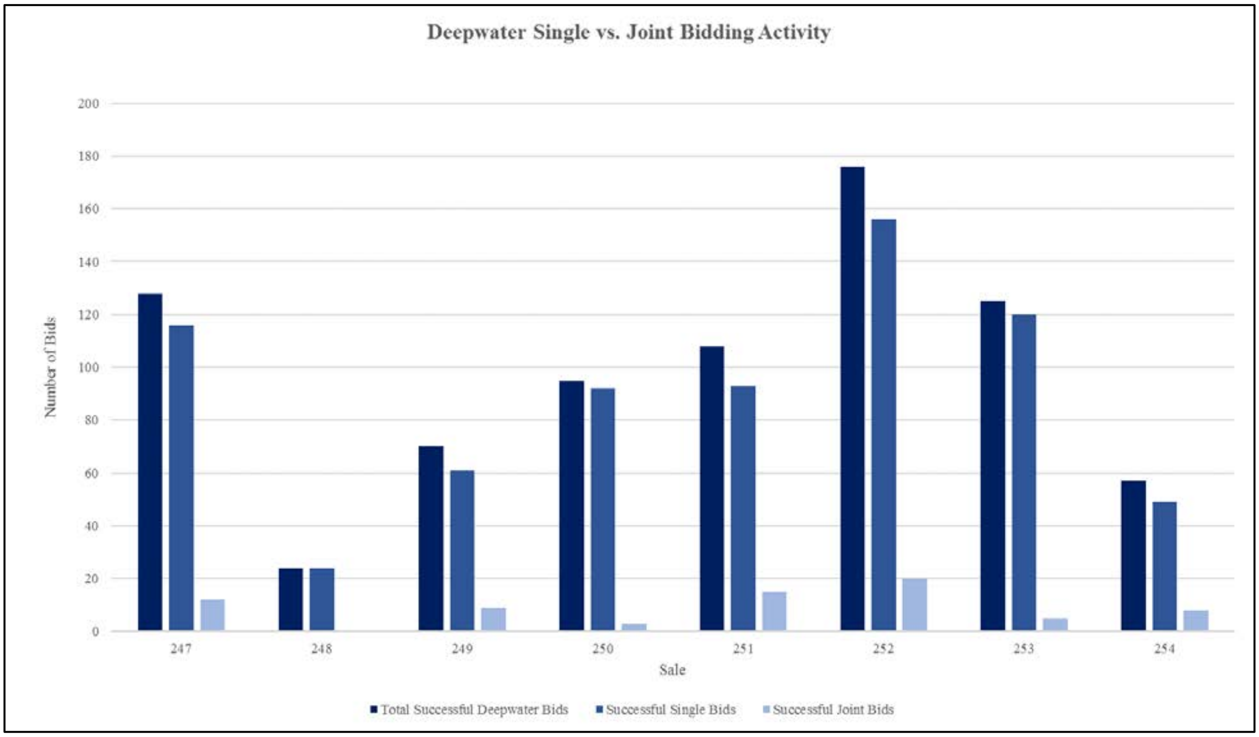

Figure 25. Successful single and joint bidding activity in deep water.

A “lease not-issued” is a high bid that was acceptable to BOEM; however, the high bidder(s) chose not to execute the lease and forfeited the 1/5 bonus deposit. Leases not-issued are depicted in **Figures 26 and 27**.

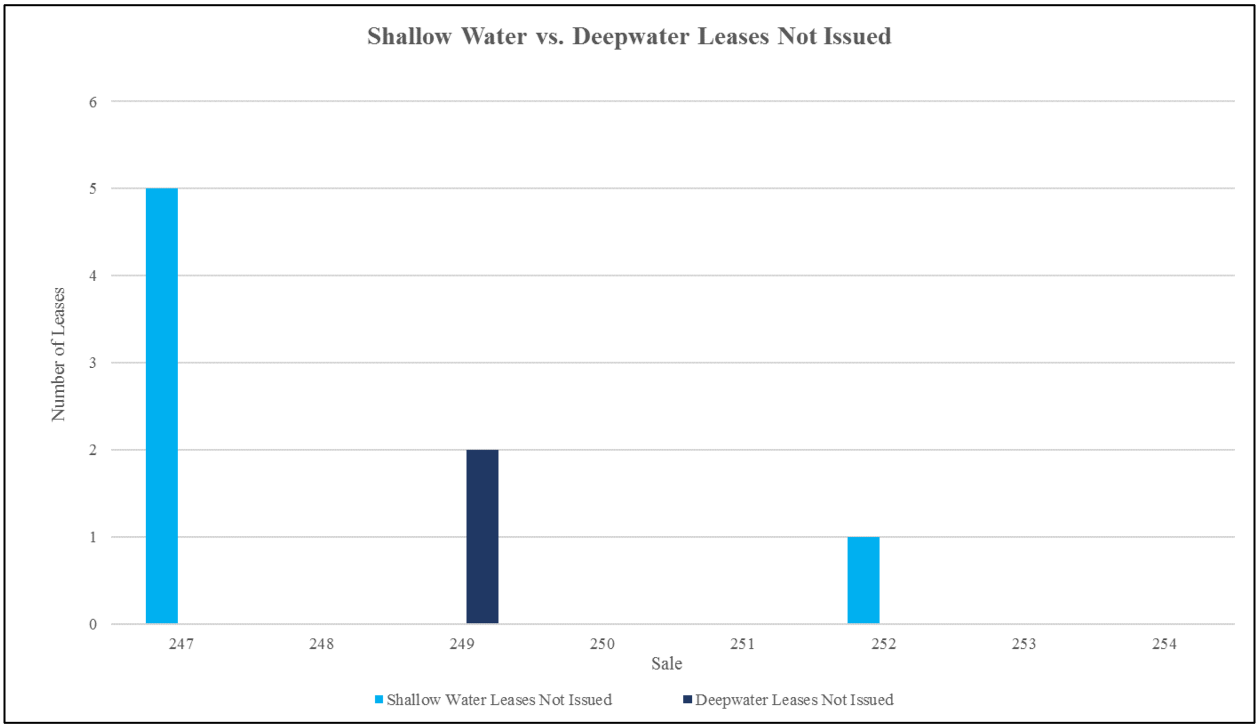

Figure 26. Leases not issued in shallow water and deep water.

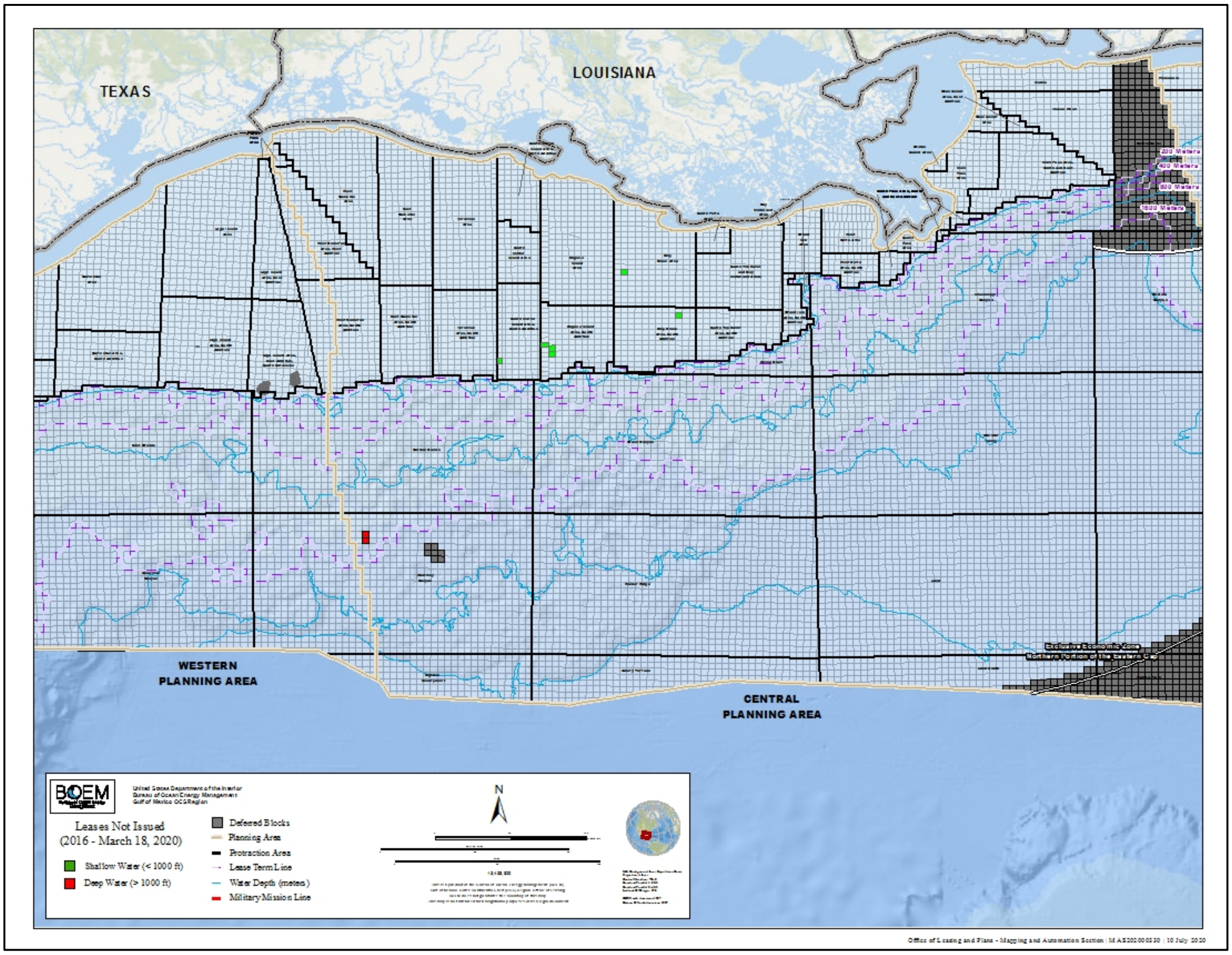

Figure 27. Map showing leases not issued from 2016 through March 18, 2020, in shallow water and deep water.

FAIR MARKET VALUE

The OCSLA grants the Secretary the authority to issue leases in the OCS. Section 18(a)(4) of the OCSLA states that "Leasing activities shall be conducted to assure receipt of fair market value for the lands leased and the rights conveyed by the Federal Government." Lessees pay bonuses, rentals, and royalties reflecting the value of the rights to explore and potentially develop and produce OCS oil and gas resources. BOEM sets minimum bid levels, rental rates, and royalty rates for individual lease sales based on its assessment of market and resource conditions as the lease sale approaches.

Since 1983, BOEM has used a two-phase, post-lease sale bid evaluation process to meet the fair market value requirement. Under its bid adequacy procedures, BOEM reviews all high bids received and evaluates all blocks using either tract-specific bidding factors or detailed tract-specific analytical factors to ensure that fair market value is received for each OCS lease issued. This bid adequacy process relies on both evidence of market competition and in-house estimates of tract value. In addition to the lease fiscal terms and bid adequacy process, BOEM establishes terms and conditions to assure diligent development of leases and environmentally compliant and safe operations. Any bid that does not represent fair market value is rejected. As shown in Figure 28, BOEM rejected a total of $400,126,888 in high bids from 1996, the first year that leases were issued under the Royality Relief Act, through March 2020. The rejected blocks subsequently received $1,345,710,170 in high bids, with an overall gain of $945,583,283. The $945,583,283 gain in rejects highlight the importance of the fair market value process in OCS resource management. Of this total, BOEM rejected $344,155,130 in high bids on deepwater blocks as shown in **Figure 28**. The rejected blocks subsequently received $1,193,083,621 from deepwater blocks, with an overall gain of $848,928,491 in deep water. Since 2016, 54 of the 56 bids rejected were in deep water (**Figures 29 and 30**).

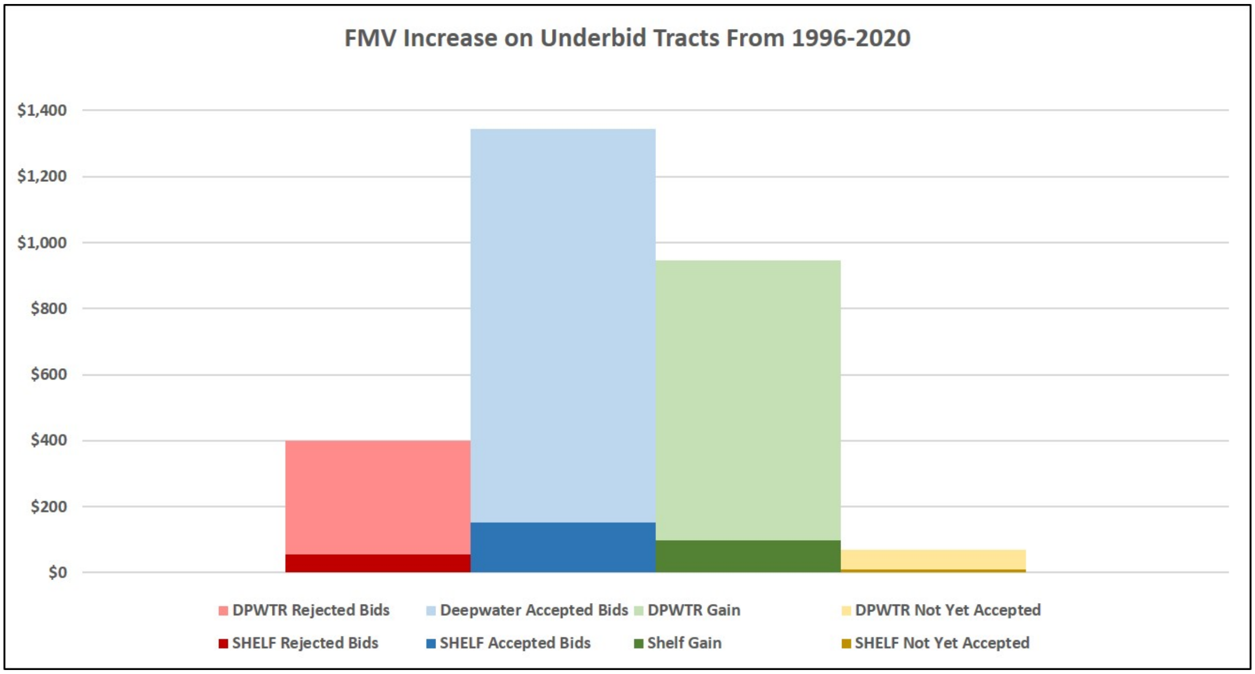

Figure 28. FMV (fair market value) increase on underbid tracts from 1996-2020.
Values adjusted for inflation to 2020. Rejected Bids are bids that were rejected during the lease sales. Accepted Bids are rejected bids that were rejected and subsequently rebid on and accepted. Gains is the difference from the rejected bid amount and accepted bid amount. Not Yet Accepted is the rejected bids that have yet to be leased after being rejected.

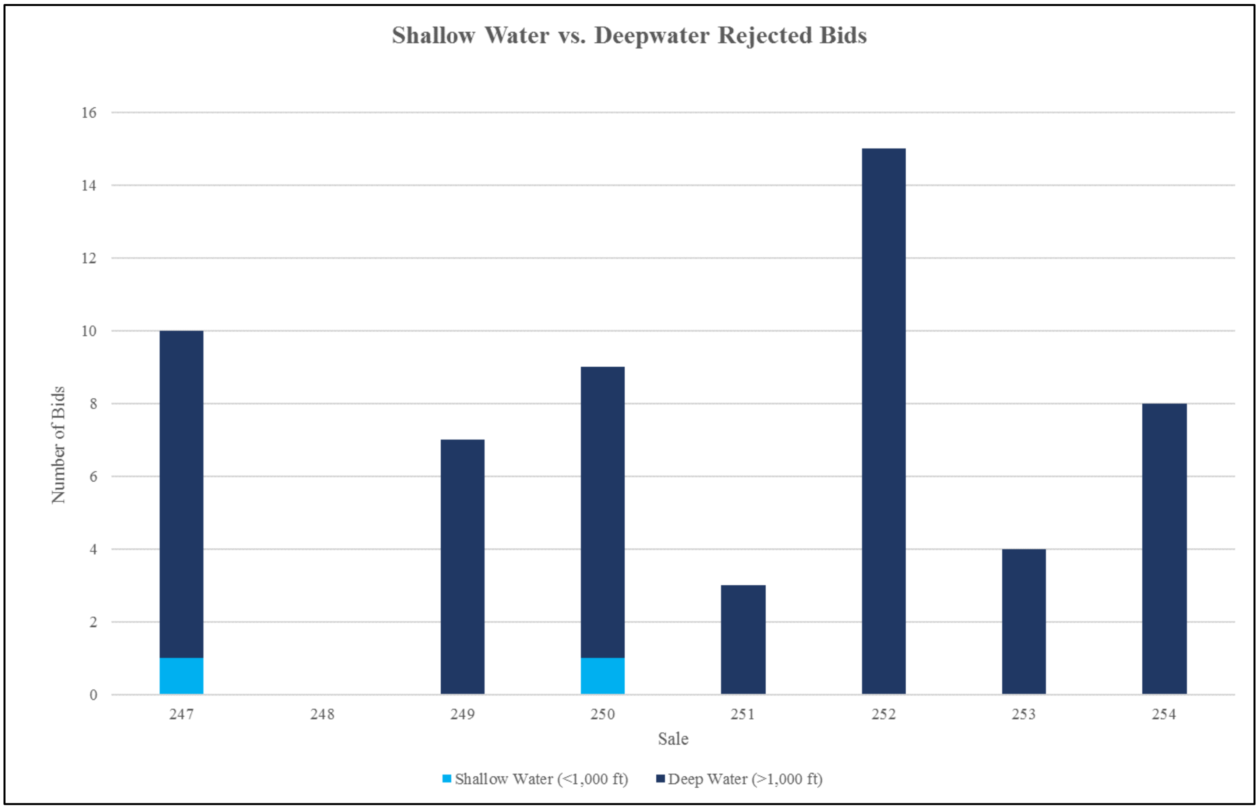

Figure 29. Number of rejected bids in shallow water and deep water.

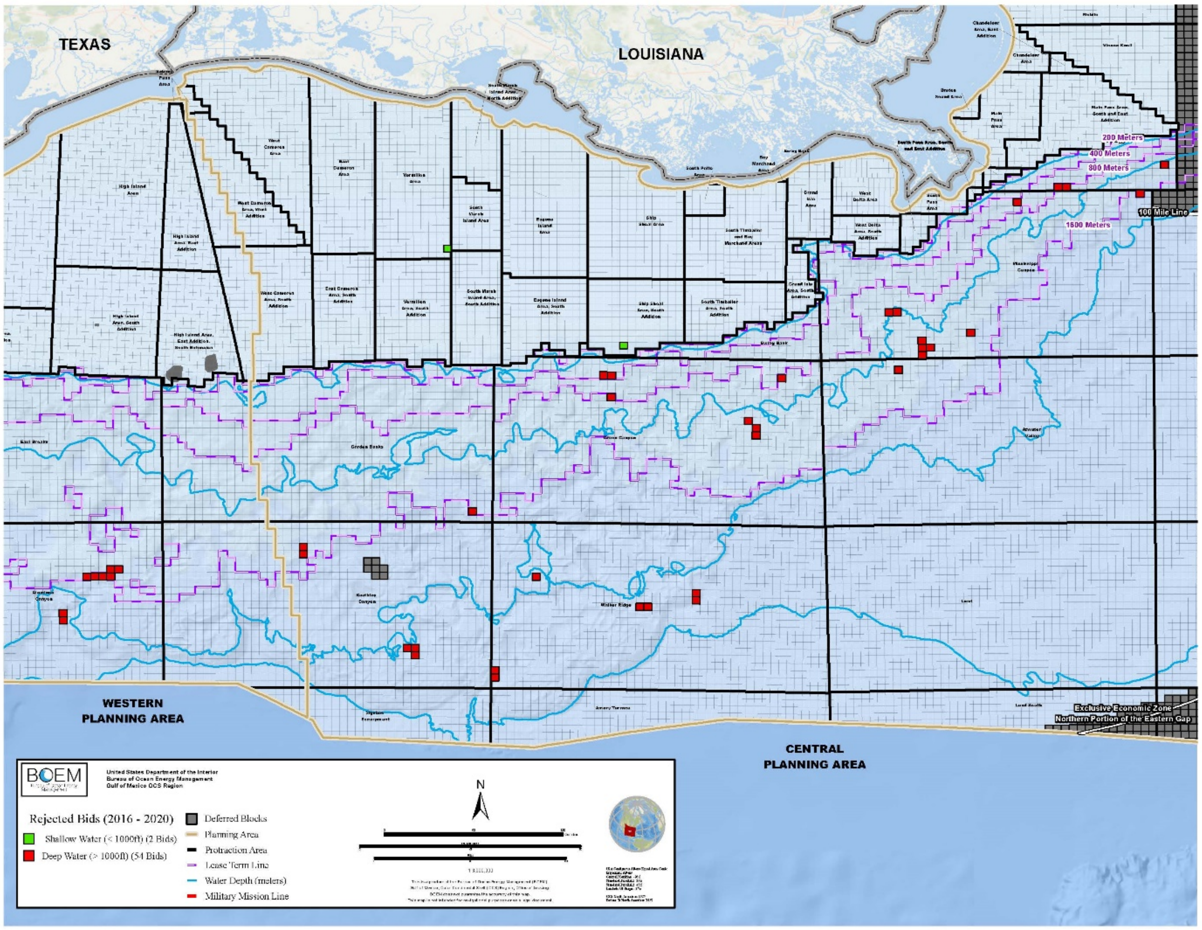

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Figure 30. Map showing rejected bids from 2016 to 2020 in shallow water and deep water.

LEASING ACTIVITY

All leasing activity (exploration and development drilling, installation of platforms and pipelines, etc.) must be included in an approved plan. Although the order of plan submission and drilling activities can vary with projects, operators generally proceed as shown below.

- File an EP
- Drill exploratory wells
- File a Conceptual Plan
- File a DOCD
- Install production facilities
- Drill development wells
- Begin first production

Plans Introduction

Before a lessee or their designated operator may begin exploration or development activities on a lease, they must submit a plan to BOEM's Office of Leasing and Plans. There are three types of BOEM plans: exploration plans; development operations and coordination documents; and development and production plans. Lessees and operators may submit plans in the form of initial, revised, and supplemental plans. Plans may cover multiple leases and may include multiple platforms and wells.

Plan Review Process

The BOEM New Orleans Office's Plans Section receives and coordinates the reviews of plans. During the plan review process, many Subject Matter Experts within BOEM and the Bureau of Safety and Environmental Enforcement (BSEE) conduct reviews of proposed activities to ensure operators will not:

- violate applicable Federal laws and regulations,
- unreasonably interfere with other uses of the area or interfere with or endanger operations on other leases,
- result in pollution,
- create hazardous or unsafe conditions, or
- disturb any site, structure, or object of historical or archaeological significance.

In addition to reviews conducted by BOEM and BSEE, the plan may be reviewed by other Federal agencies, State governments, and the general public. For example, the Plans Section may send copies of a plan to State Coastal Zone Management offices and place the plan on the regulations.gov website for public comment. The Plans Section is responsible for coordinating these reviews and ensuring that they are completed within regulatory timeframes.

Exploration Plans, Development Operations Coordination Documents, Plans of Exploration, and Development and Production Plans

An exploration plan (EP) must be submitted prior to conducting exploration activities. An EP may cover activities such as exploratory drilling, installing temporary caissons and well protectors, and certain geological and geophysical exploration or development activities. The EPs have taken the place of Plans of Exploration (POE), which are no longer used.

Prior to conducting development and production activities in the western GOM, the lessee or designated operator must submit a development operations coordination document (DOCD). A DOCD may cover activities such as development drilling, installing platforms and subsea production infrastructure, and installing lease term pipelines.

If the lessee or designated operator plans to conduct development and production activities in any OCS area other than the western GOM, they must first submit a development and production plan (DPP).

This report covers EPs and DOCDs for activities to be performed in the WPA and CPA. It excludes DPPs as well as EPs submitted for exploration activities in the Alaska, Atlantic, and Pacific regions. The data for this report were compiled by querying BOEM's internal corporate database of plan sites. It includes both well and platform sites. Only plans with at least one site in a water depth of 1,000 ft or more were included in the dataset. Because plans may cover multiple wells and platforms across multiple blocks at varying water depths, the query filtered for the deepest site associated with each plan. The plans included in the dataset were received between January 1, 2000, and March 18, 2020 (GOM Region-wide Lease Sale 254). All data are presented by calendar year. **Figure 31** shows the location of plans submitted by year.

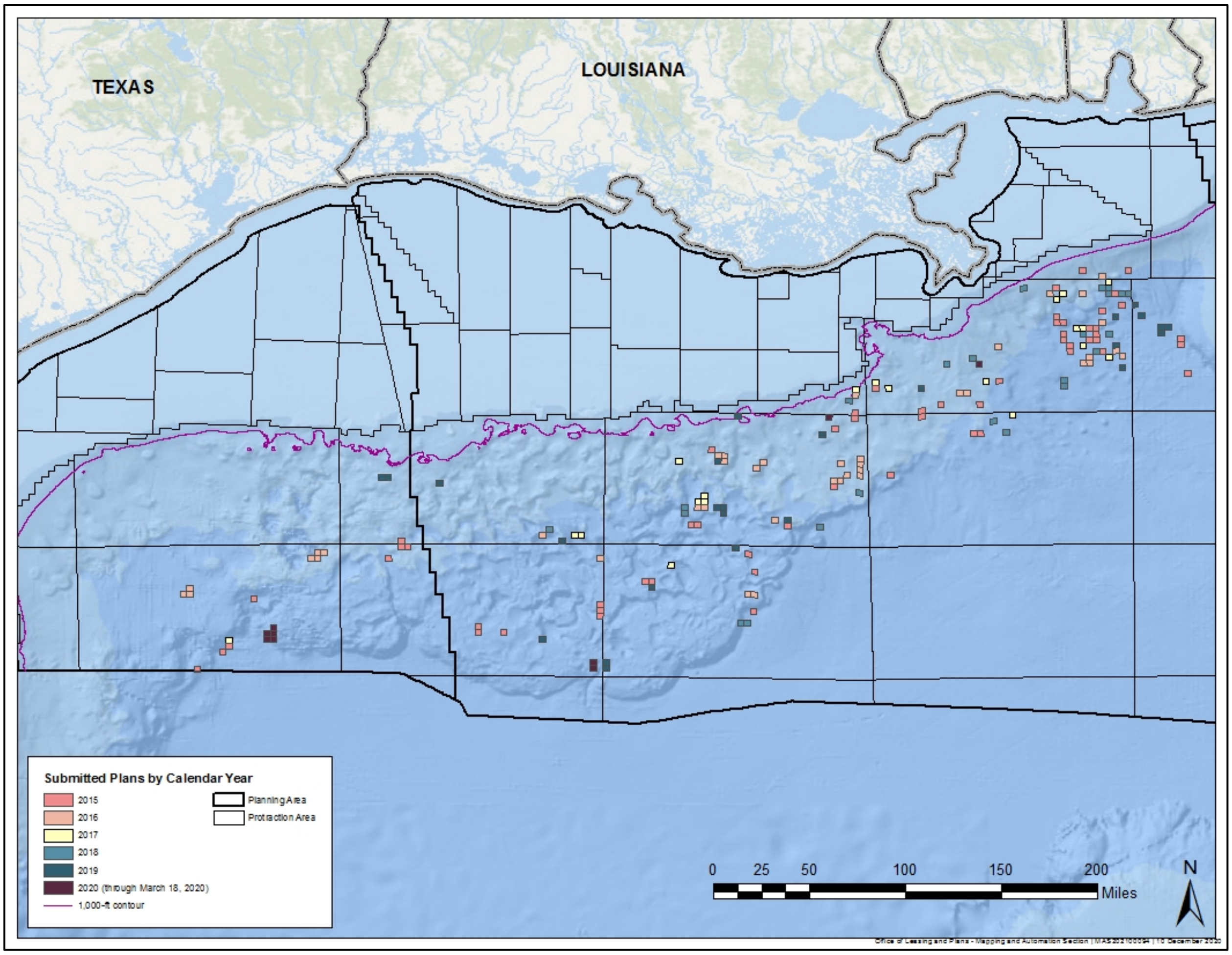

Figure 31. Plans submitted by calendar year.

Figure 32 shows the number of deepwater EPs, DOCDs, and POEs that have been received in the past.

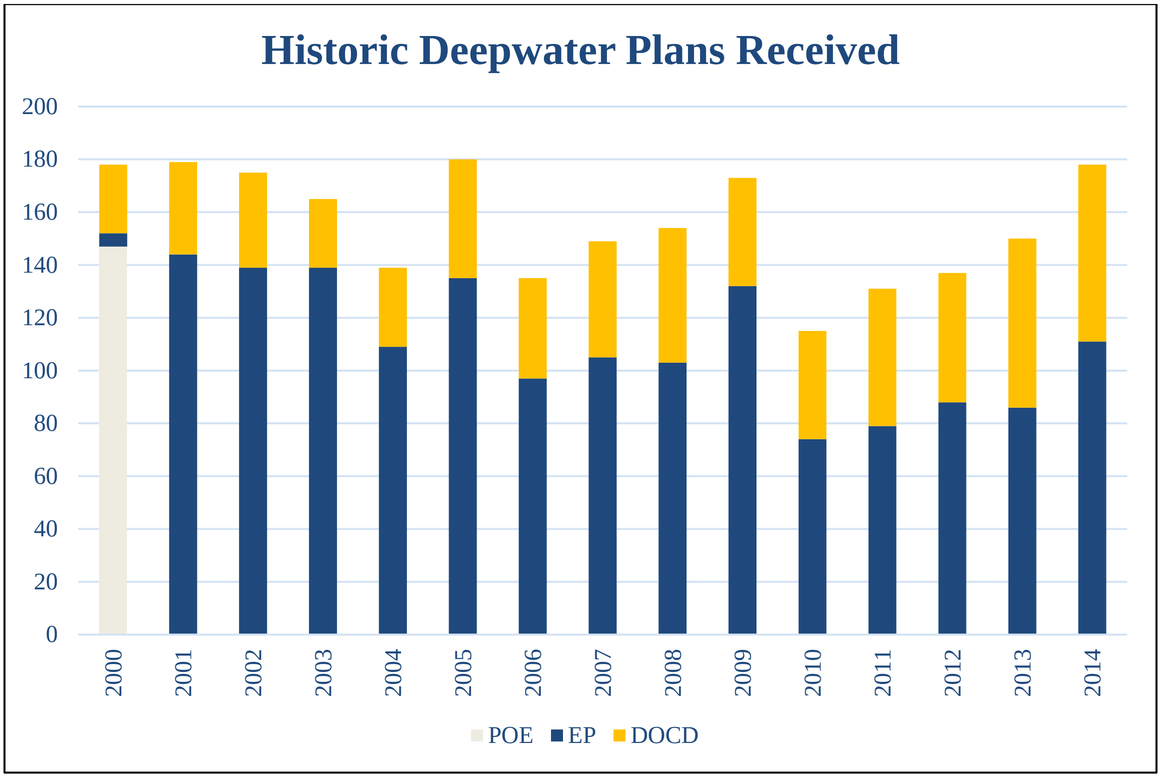

Figure 32. Historic deepwater plans received by year.

The plan review process was revised after the *Deepwater Horizon* oil spill. Guidance published in December 2010 regarding required NEPA review and worst-case discharge calculations necessitated the revision of nearly all deepwater plans that had been previously approved. Generally, deepwater plans that were approved prior to 2011 are no longer valid and may not be used for drilling activities without first submitting revisions.

Figure 33 shows the total number of DOCDs and EPs received each year for activities proposed in water depths greater than 1,000 ft in the last 5 years. Note that the data for 2020 includes only plans that were received through March 18, 2020 (GOM Region-wide Lease Sale 254).

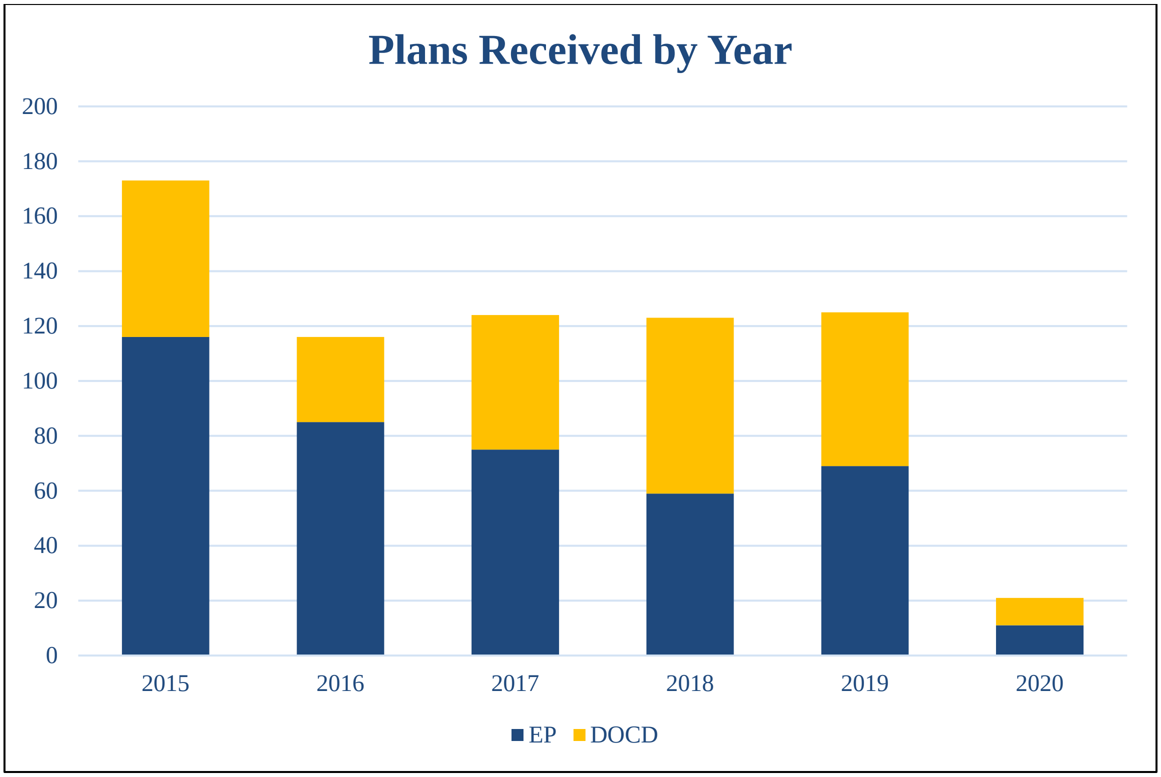

Figure 33. Total number of DOCDs and EPs (includes initial, revised and supplemental) received by year in water depths greater than 1,000 ft.

Figures 34 and 35 provides a breakdown of the plans received by water depth in feet. Note that the data for 2020 includes only plans that were received through March 18, 2020 (GOM Region-wide Lease Sale 254).

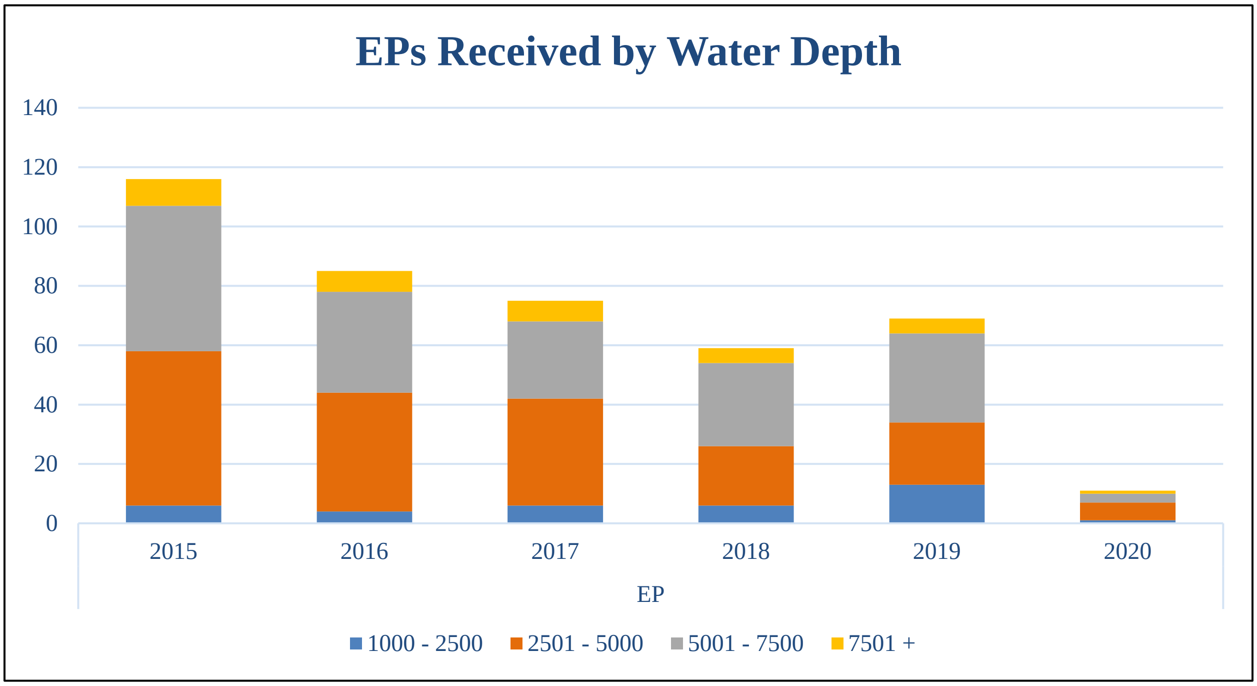

Figure 34. EPs received by water depth.

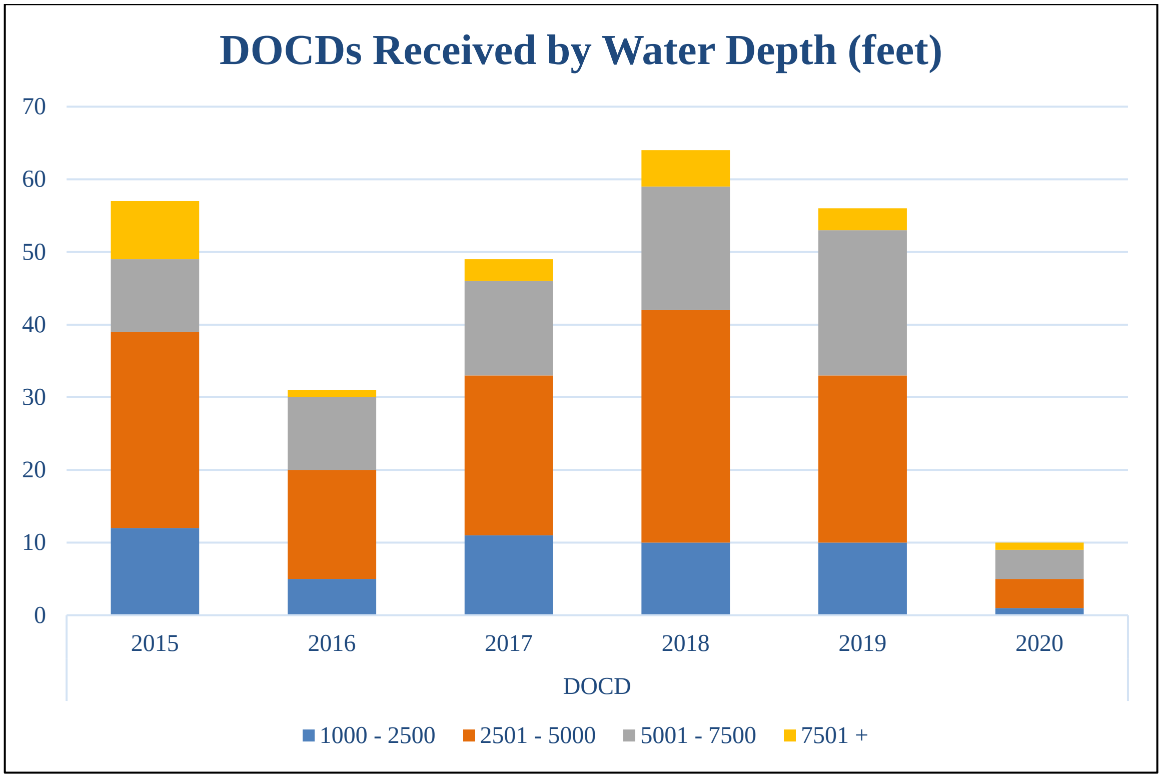

Figure 35. DOCDs received by water depth.

Initial, Revised, and Supplemental Plans

The first plan submitted for proposed operations on a new lease is an initial plan. Initial EPs and DOCDs must contain all the items required by regulations at 30 CFR §§ 550.211 (EPs) and 550.241 (DOCDs).

Once the Initial plan has been approved by BOEM, lessees and operators may alter the proposed operations by revising or supplementing the approved plan. For example, an operator may submit a revised plan to alter the proposed drilling schedule or change the target location of an approved well. An operator may submit a supplemental plan to conduct other activities not proposed in their initial plan, such as drilling additional wells.

Figures 36 and 37 provide breakdowns of plans received historically by type, i.e., Initial (N), Revised (R), and Supplemental (S). Note that POEs were phased out and the Plans Section began receiving EPs in 2000.

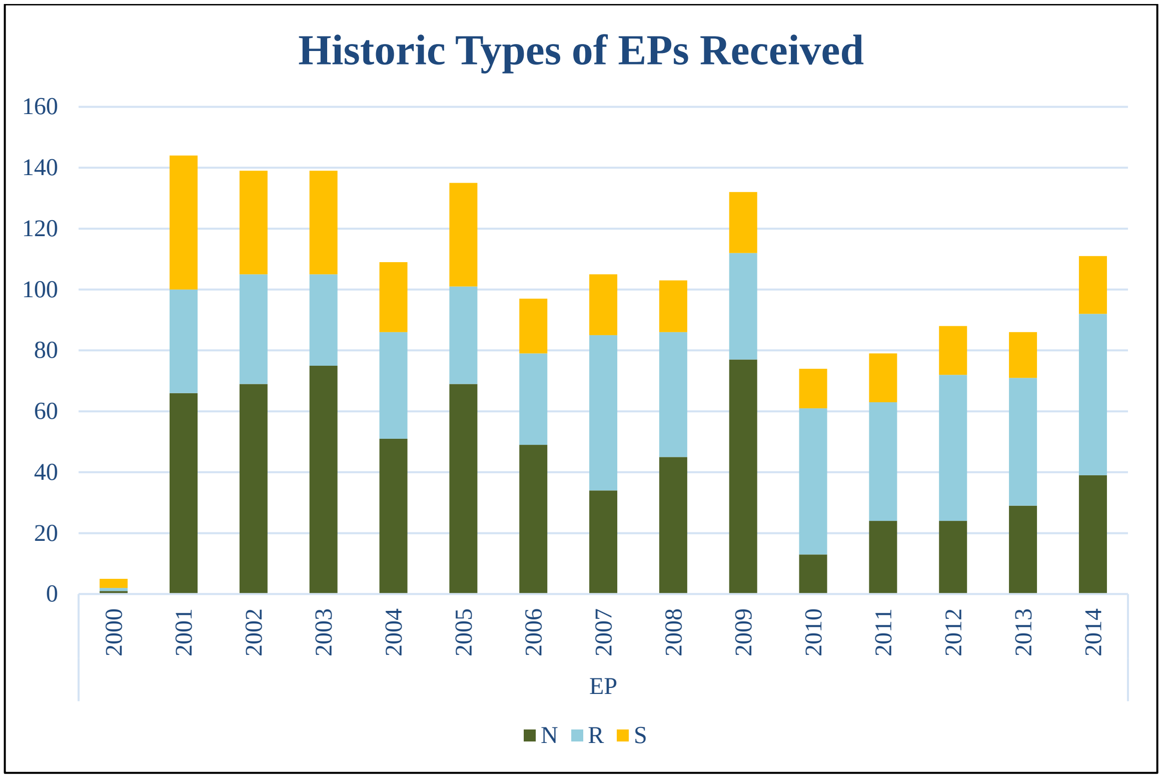

Figure 36. Historic types of EPs received by year.

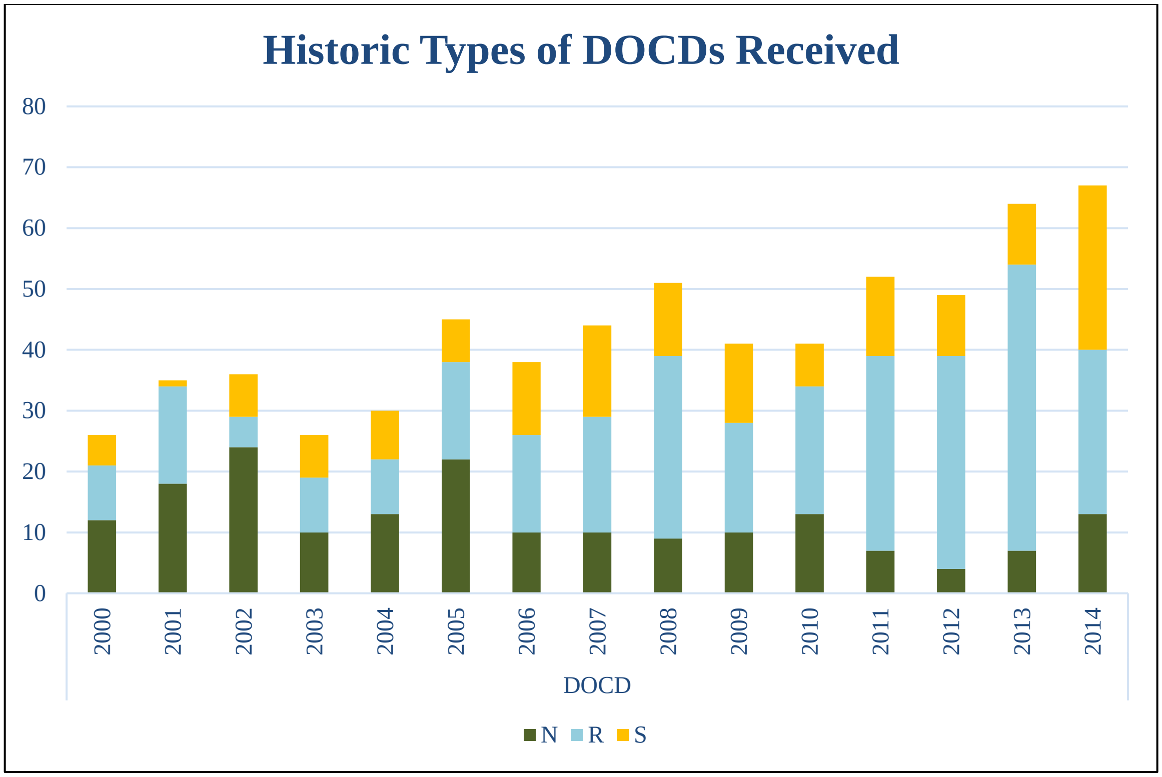

Figure 37. Historic types of DOCDs received by year.

As noted above, guidance published in December 2010 regarding required NEPA review and worst-case discharge calculations necessitated the revision of nearly all deepwater plans that had previously been approved. For that reason, there was a significant increase in the number of revised EPs and DOCDs received and reviewed in the following 3 years.

Figures 38 and 39 provide a breakdown of plans received in the last 5 years by type, Initial (N), Revised (R), and Supplemental (S). Note that the data for fiscal year 2020 includes only plans that were received through March 18, 2020 (GOM Region-wide Lease Sale 254).

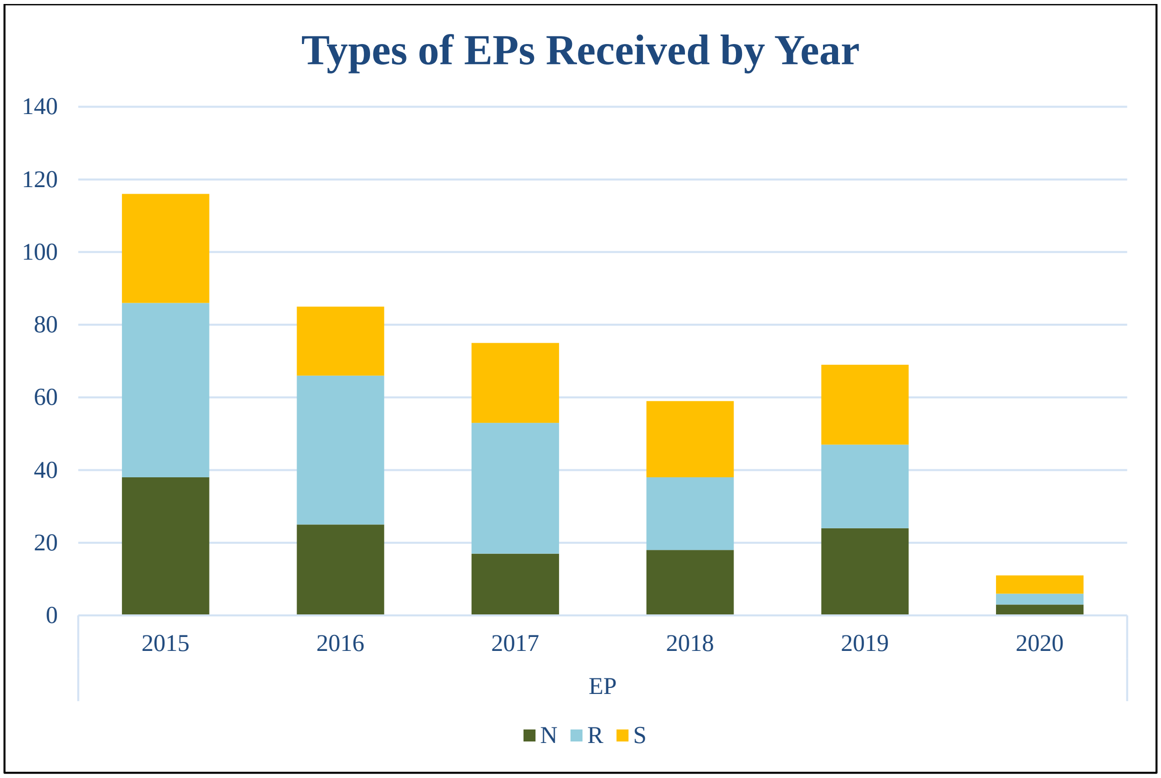

Figure 38. Types of EPs received by year.

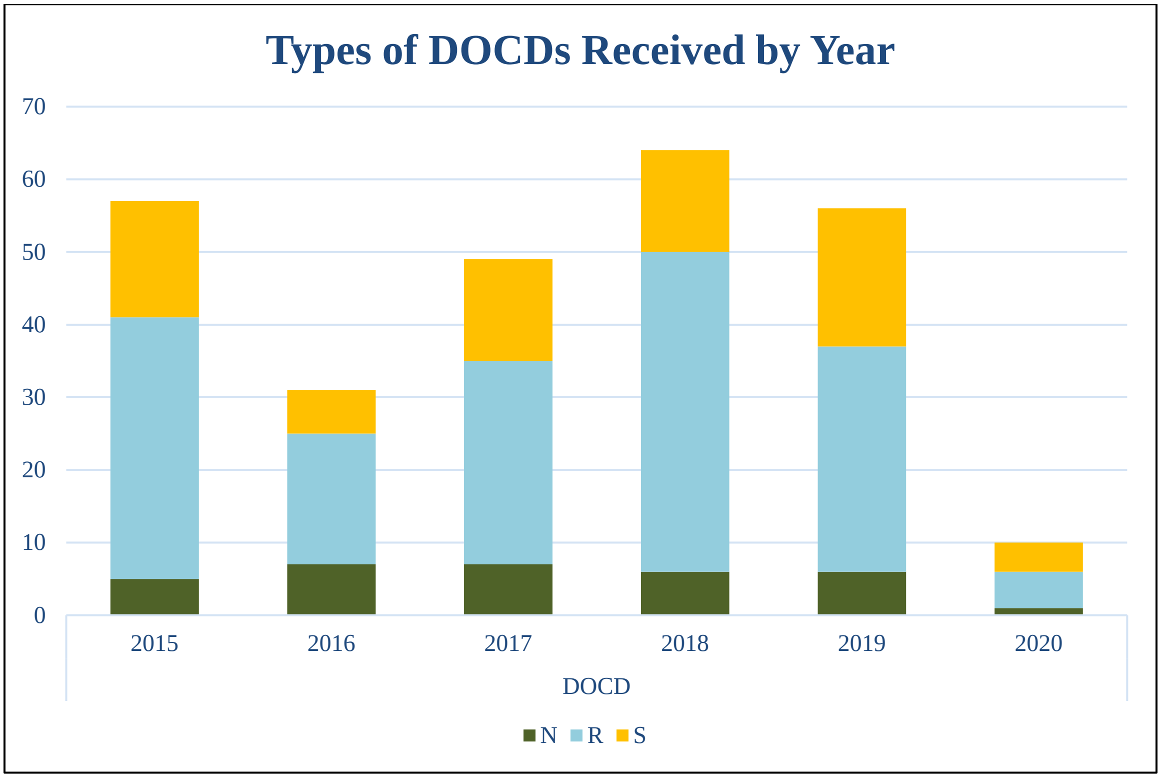

Figure 39. Types of DOCDs received by year.

Deepwater EP submittal trended downwards in the years 2015 through 2018 and rose slightly in 2019. By second quarter 2020, the Plans Section had received roughly one-quarter the number of EPs received in 2019. This general downward trend in deepwater EP submittal may continue.

Although DOCDs were down in 2019, generally there is a consistent submittal of initial DOCDs. Overall, DOCD submittal increased from 2016 through 2018. By second quarter 2020, the Plans Section had received roughly one fifth the number of DOCDs received in 2019. The Plans Section is predicted to receive a similar number of DOCDs in 2020 as it did in 2019. Revised DOCDs make up the bulk of submissions each year. Revised DOCDs are commonly submitted to update air emissions information to account for schedule changes of future operations.

Drilling Activities

Once a plan has been approved by BOEM's Office of Leasing and Plans, the operator may apply to drill proposed wells. Applications for Permits to Drill (APDs) are reviewed and approved by BSEE's District Offices. The APD must include the control number of the plan in which the proposed well was reviewed by BOEM.

New wells may be proposed in both EPs and DOCDs. Information regarding a proposed well that was reviewed under an initial EP or DOCD may be revised or supplemented in subsequent plans. Therefore, an APD may reference any type of plan. If additional information is needed by BSEE's District Office, it will require the operator to submit a revised or supplemental EP or DOCD. Once that revised or supplemental EP or DOCD is approved, BSEE's District Office will update the APD to reference the new plan, even if the APD has already been approved.

For example, a deepwater well may be proposed in an initial EP. Sometime later, but before applying for an APD to drill the well, the operator may submit a supplemental EP to update details about the proposed well and propose additional wells. The operator may then reference this supplemental EP in its APD to drill the well. As a condition of approval, BSEE's District Office may require the operator to submit a revised EP to provide additional information about the well. The APD will then be updated to reference the revised EP, even if the well has already been drilled.

Figures 40 and 41 compare the number of deepwater plans received in the last 5 years with the number of those plans that are referenced in approved APDs. Note that the data for year 2020 includes only plans that were received through March 18, 2020 (GOM Region-wide Lease Sale 254).

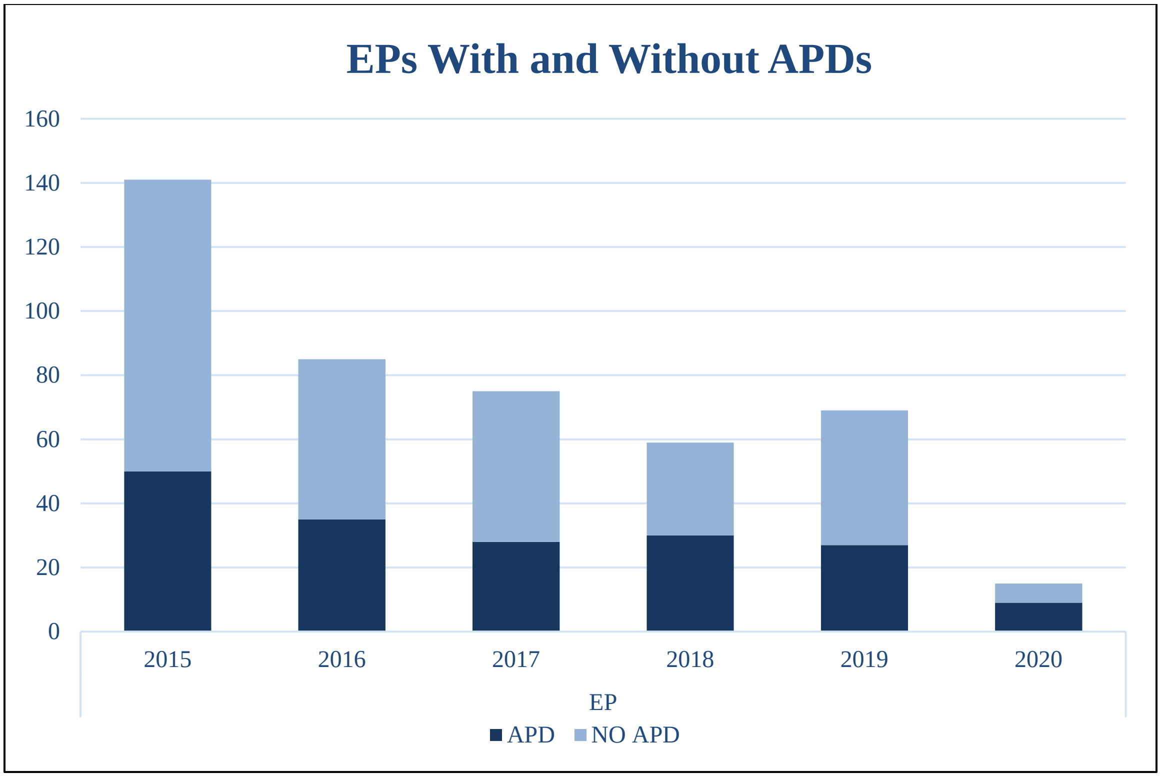

Figure 40. EPs referenced in approved APDs and EPs not referenced in approved APDs.

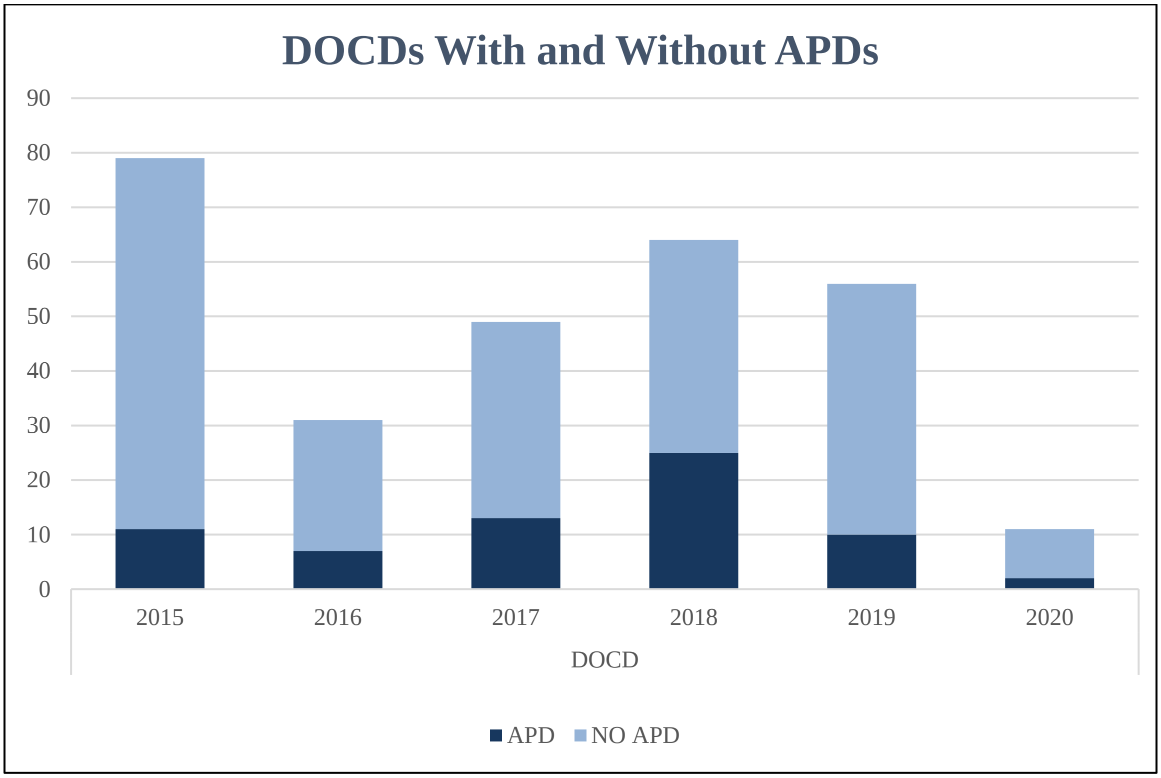

Figure 41. DOCDs referenced in approved APDs and DOCDs not referenced in approved APDs.

Due to the nature of the plan review process, BOEM's Office of Leasing and Plans receives, reviews, and approves many plans that may never be referenced in future drilling permits. Another way to examine drilling activity is to compare the leases that were included in Initial EPs to leases with approved APDs. **Figure 42** provides a comparison of the number of leases that have appeared in Initial EPs in the last 5 years to the number of those leases that have approved APDs. Note that the data for year 2020 include only plans that were received through March 18, 2020 (GOM Region-wide Lease Sale 254).

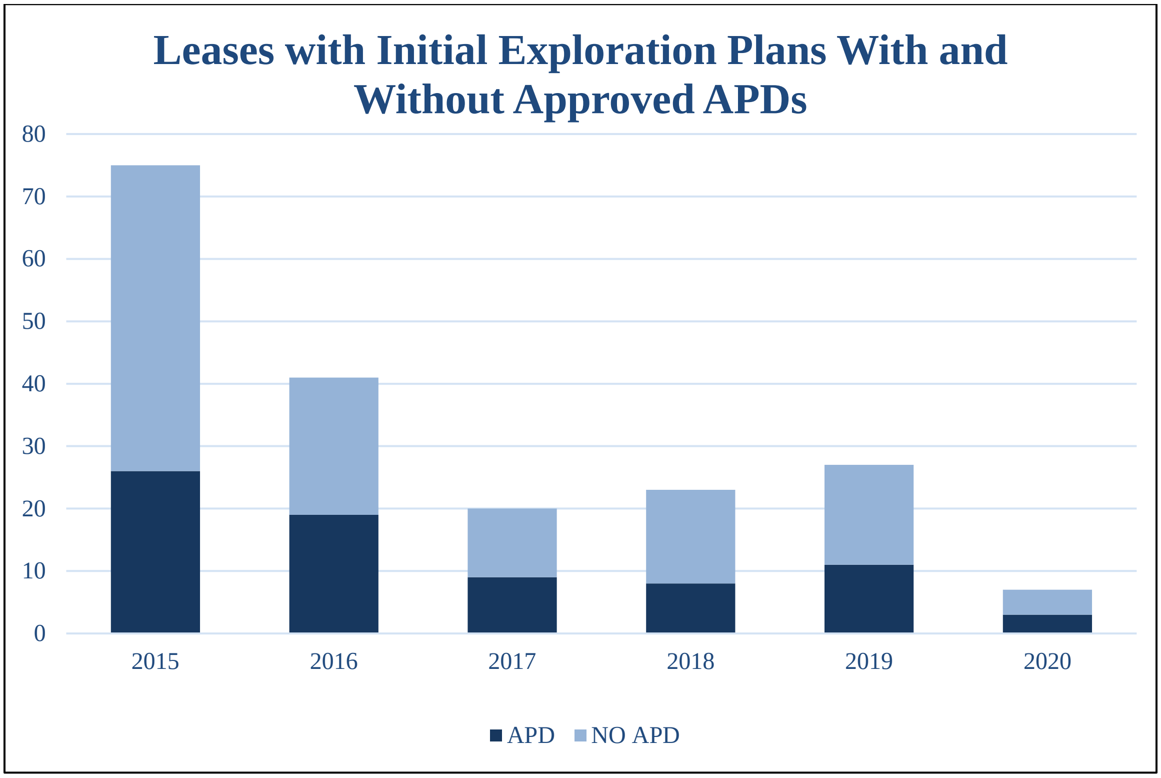

Figure 42. Leases with initial exploration plan with and without approved APDs.

As shown in **Figure 42**, the number of leases that appeared in new exploration plans declined from 2015 to 2017 and increased from 2017 to 2019. The Plans Section is predicted to approve a similar number of plans in 2020 as were approved in 2019. Compared to the decline in new exploration plans, the number of leases with new drilling permits has remained relatively steady over the same time period, declining slightly between 2015 and 2017 before rising again in 2019. The share of leases with approved exploration plans that later receive approved drilling permits has also increased since 2015. This may indicate that operators have altered their expectations regarding how many new wells will be drilled in upcoming years.

In any given year of the leases that appear in Initial EPs, less than half may ultimately be drilled. Often, wells are included in plans as potential relief wells to be drilled only in the event of a blowout. Additionally, wells proposed in approved Initial EPs may be drilled months or years after the Initial EP has been approved. The time between plan approval and APD approval ranges from 1 day to several years. **Figure 43** provides the average time from Initial EP approval to APD approval each fiscal year. Note that the data for 2020 include only plans that were received through March 18, 2020 (GOM Region-wide Lease Sale 254).

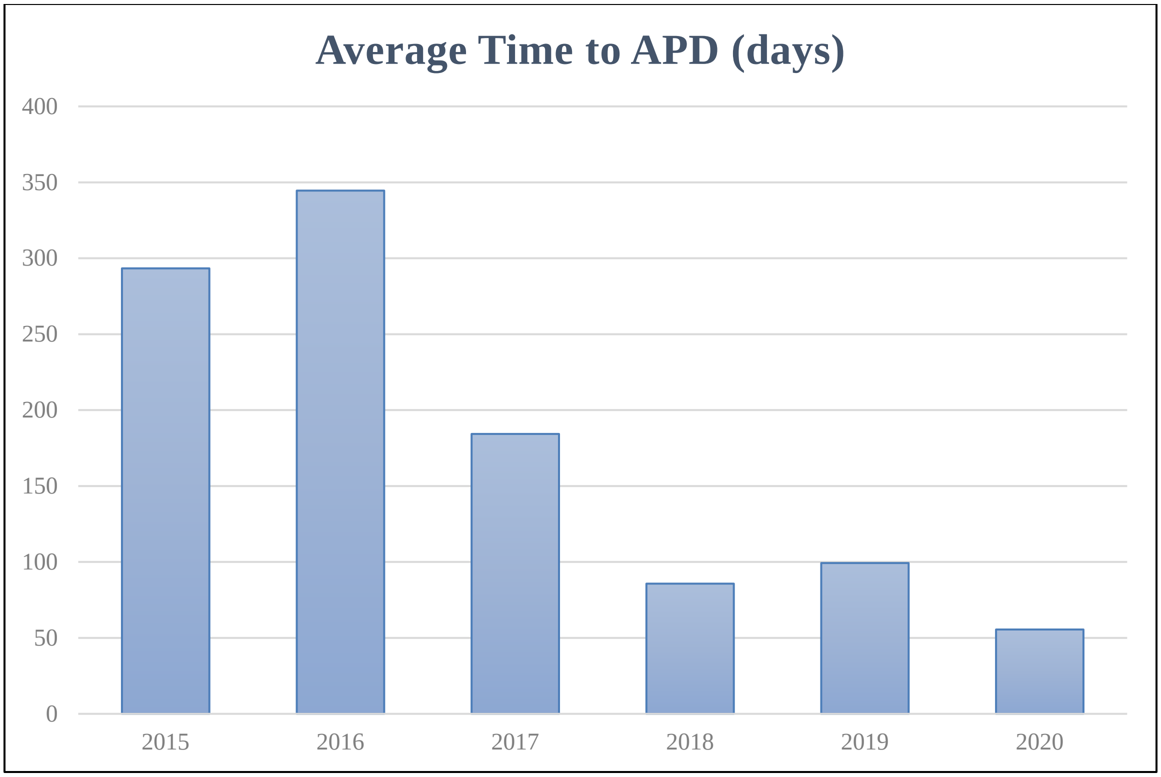

Figure 43. Average time to APD (days).

The average time between approving an Initial EP to approving an APD to drill the first well on the lease was reduced drastically in recent years. This may be explained by changes in BOEM's financial assurance policy. BOEM NTL No. 2015-N04, "General Financial Assurance," requires operators to provide general financial assurance before activities approved in a plan could commence. After the NTL was published, some operators hesitated to submit APDs while BOEM determined how wells that had been proposed, but not yet drilled, would be assessed for required financial assurance. By 2018, BOEM's policy of assessing wells at the time an APD was submitted had been established, and several operators submitted APDs for plans that had been approved more than a year previously.

LEASE RELINQUISHMENT ACTIVITY

Lease relinquishments are a component of newly available blocks, i.e., any block that was either relinquished, terminated, or expired in the time period between lease sales, and is one tool used by BOEM to predict potential bidding activity. **Figures 44 and 45** show leases that were relinquished prior to their expiration date from 2016 to March 18, 2020. Note that lease terms vary according to water depth. The large number of relinquishments in 2016 can be partially attributed to Conoco Phillips Company relinquishing 232 leases and BP Exploration & Production Inc. relinquishing 143 leases. Conoco Phillips Company publicly stated in 2016 that it would not be continuing deepwater drilling in Gulf of Mexico as part of a money-saving strategy to reduce deepwater exploration (Offshore Energy, 2016). The factors that play a role in the variability of bids received also contributes to the number of leases being relinquished. These factors include the price of oil, the transition from offshore to onshore unconventional exploration, and the price thresholds at which an individual play is economic to pursue. There is a decline in the relinquishments following the record number in 2016. This is in part due to less active leases available to be relinquished as so many were relinquished in 2016.

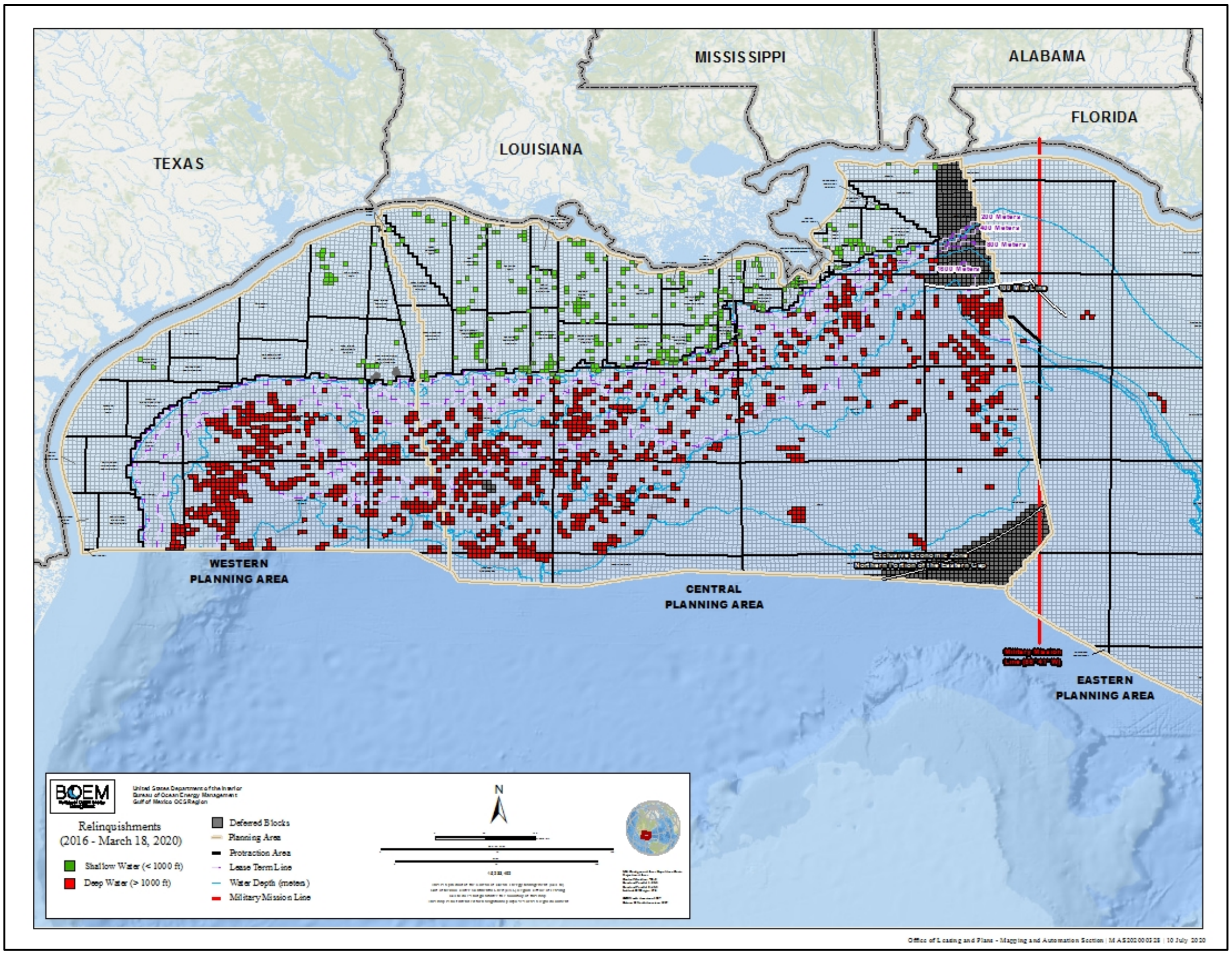

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Figure 44. Map showing relinquishments from 2016 to March 18, 2020, in shallow water and deep water.

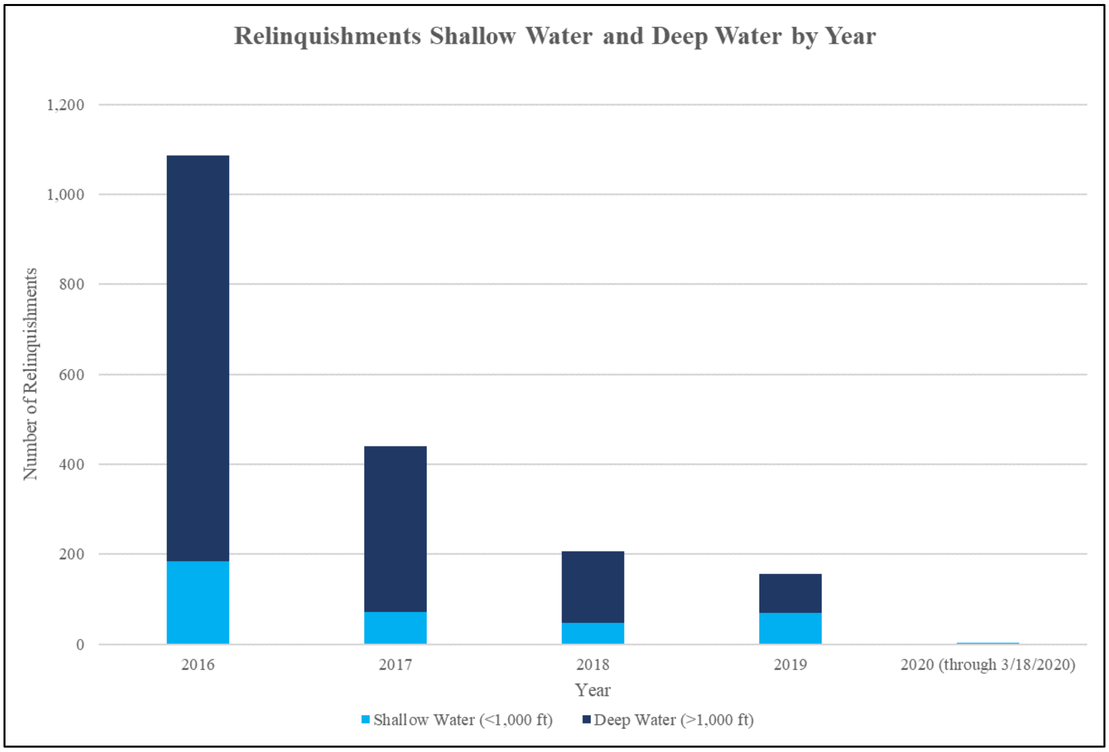


Figure 45. Relinquishments by year from 2016 to 2020 in shallow water and deep water.

LEASE OWNERSHIP

Lease ownership can be acquired through a lease sale or via assignment of Record Title Interest or Operating Rights Interest. **Figure 46** shows assignments of record title interest for 2016 through March 18, 2020, in shallow water and deep water. In 2016, Conoco Phillips Company transferred all interest in 70 assignments of record title interest, which is an indicator of the company's money-saving strategy to reduce deepwater exploration as noted above. **Figure 47** shows assignments of operating rights interest for 2016 through March 18, 2020, in shallow water and deep water.

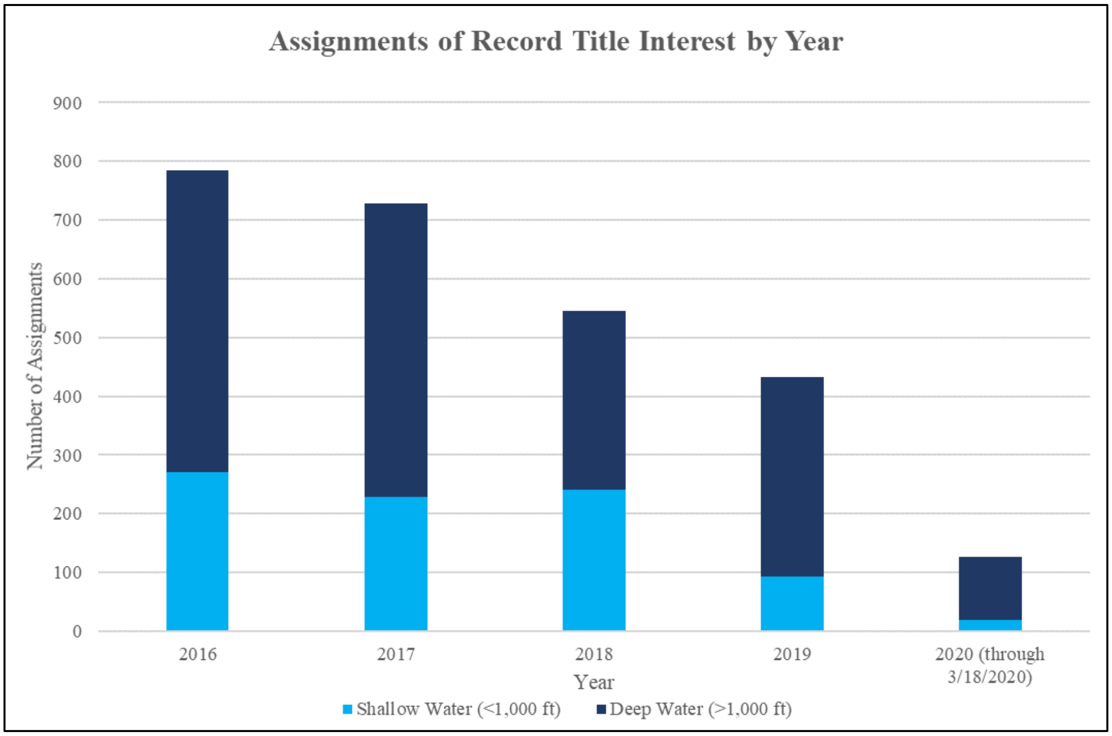


Figure 46. Assignments of record title interest by year from 2016 through March 18, 2020, in shallow water and deep water.

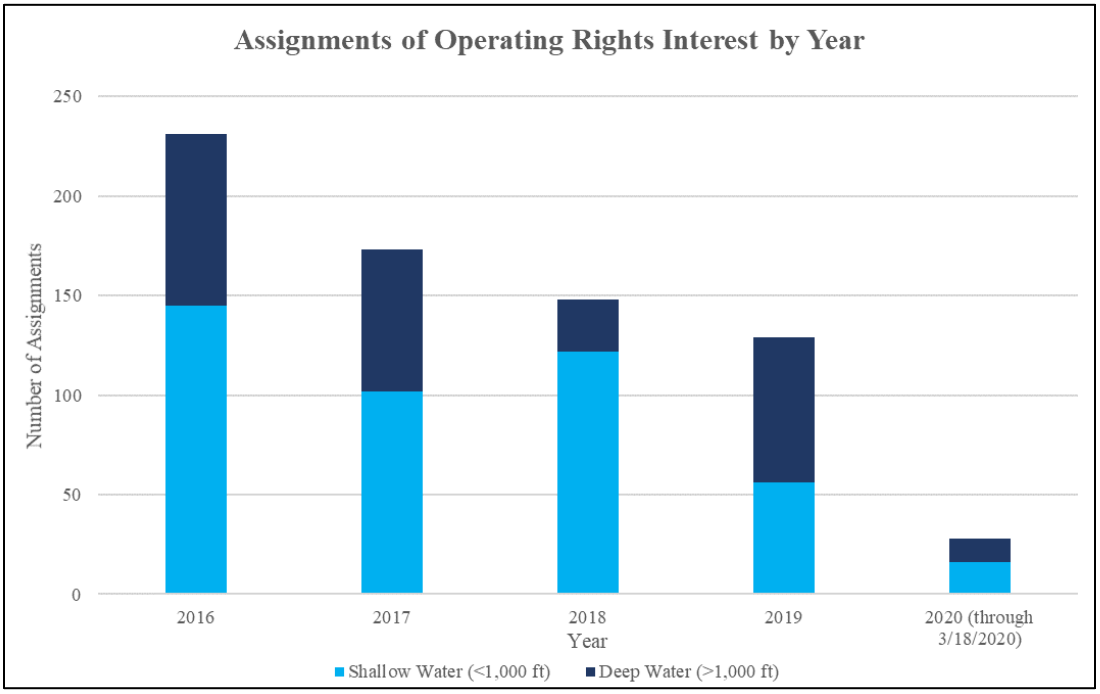


Figure 47. Assignments of operating rights interest by year from 2016 through March 18, 2020, in shallow water and deep water.

BUSINESS LANDSCAPE

Characteristics of the companies doing business on the OCS have changed over the years, with large/major companies transferring sunset properties to small companies while pursuing new discoveries in the deepwater Gulf of Mexico. As a steward of OCS resources, BOEM manages a variety of financial and physical risks associated with OCS oil- and gas-related activities. Some of these risks are intrinsically related to financial assurance and loss prevention to the U.S. Government and the American taxpayer; for example, a company becomes financially insolvent and the U.S. Government and the American taxpayer are forced to pay for decommissioning a facility. Since 2009, there have been 35 bankruptcies of corporations with OCS oil- and gas-related activities of approximately $7.5 billion in total decommissioning liability. This $7.5 billion includes properties with co-lessees and predecessors, and properties held by companies that successfully emerged from a Chapter 11 reorganization bankruptcy. **Figure 48** shows the bankruptcies of lease owners and operators and the associated properties in which they have record title interest. It is clear from that figure that most of the lessees and operators who filed for bankruptcy are in shallow water.

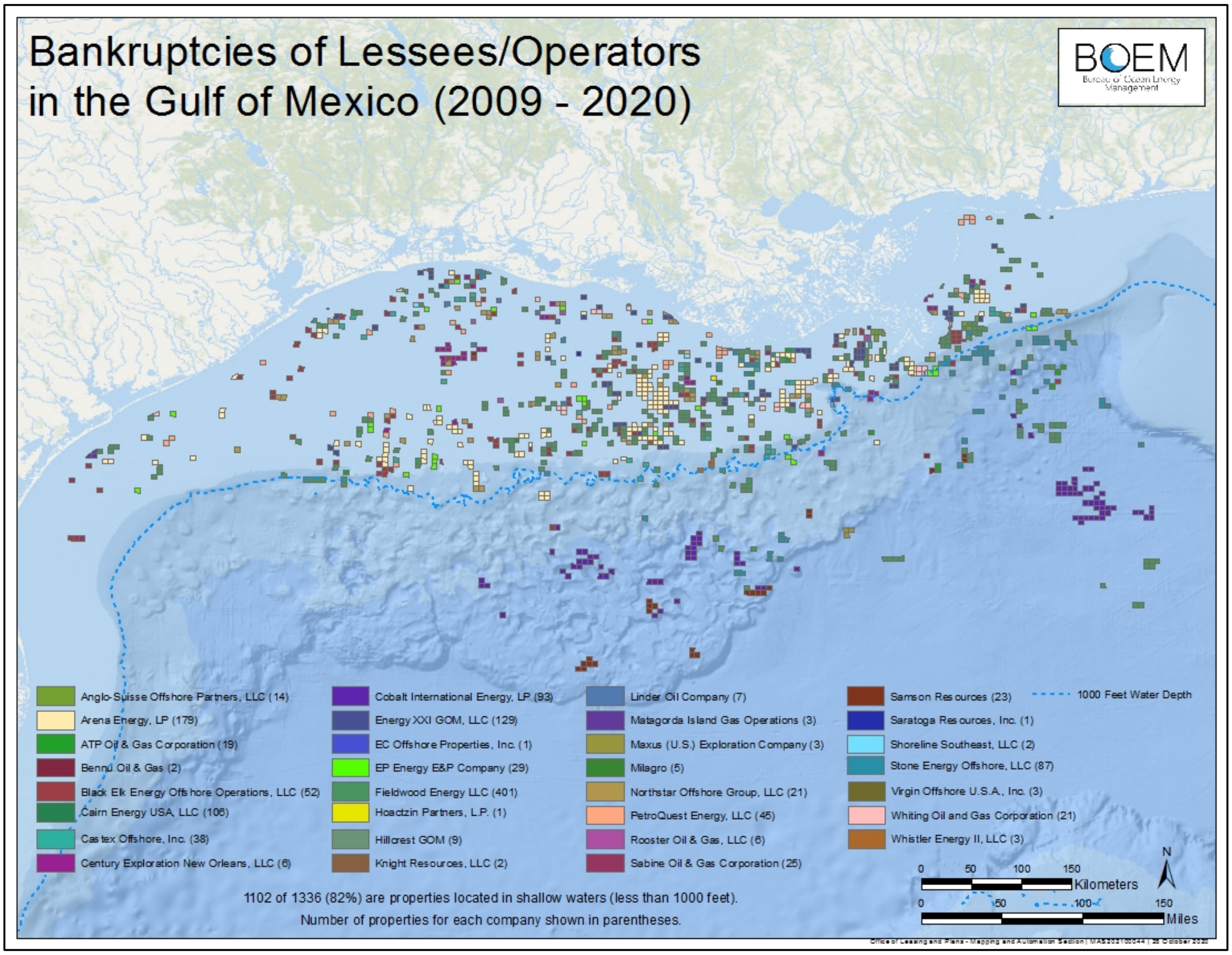


Figure 48. Bankruptcies of lessees/operators in the Gulf of Mexico, 2009-2020.

SEISMIC DATA

INTRODUCTION

The Office of Resource Evaluation in BOEM's New Orleans Office has a statutory responsibility for issuing geophysical permits for seismic surveying and geological permits for shallow drilling or coring. This responsibility is defined in Section 11 of the Outer Continental Shelf Lands Act and supporting regulations (30 CFR part 551).

The GOM has been a crucible for 3-dimensional (3D) seismic acquisition advancements, spurred on by the need for better subsalt imaging capability and larger ships equipped to tow many airgun and streamer arrays. Array lengths have doubled in length during the last decade from 3 to more than 7 miles (mi) to achieve greater subsurface visualization. Legacy 3D surveys in the GOM tend to be narrow azimuth (NAZ) (1 vessel towing airgun(s) and 1-3 streamers) (**Figure 49**). Over the last decade NAZ has been slowly displaced by wide -azimuth (WAZ) acquisition (a survey acquired with 2 or more source vessels) and multi- and full azimuth (MAZ, FAZ) (a survey acquired in 2 or more directions by a single vessel) (**Figure 49**).

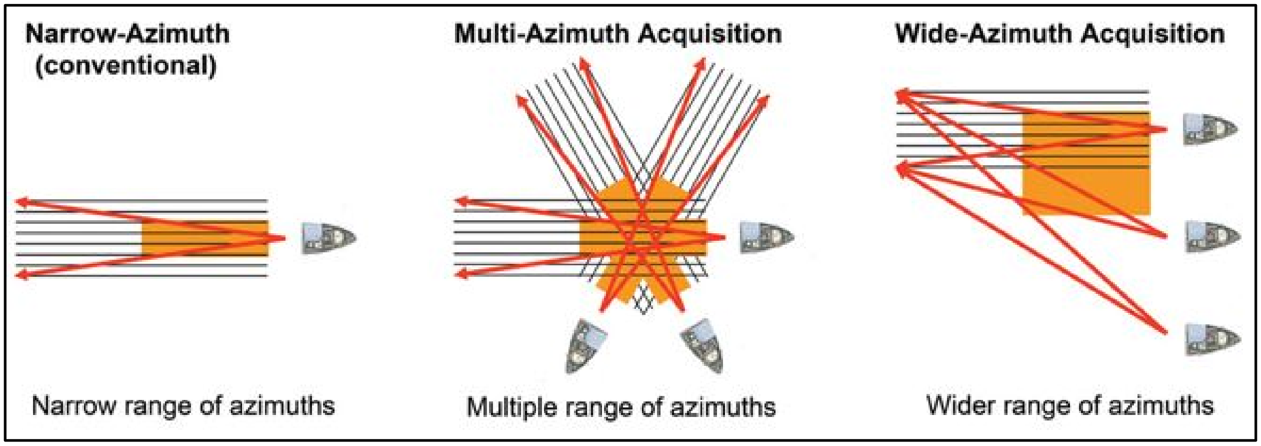


Figure 49. Schematic comparison of narrow-azimuth, multi-azimuth, and wide-azimuth streamer acquisition. Wide-azimuth survey type has the largest footprint requiring more than one vessel. Multi-azimuth uses one vessel that traverses two or more shooting directions (from Rekdal and Long, 2006).

INFLUENCES ON GOM SEISMIC ACTIVITY

As the farthest upstream aspect of the oil and gas industry, seismic acquisition is a leading indicator for planned exploration and development (E&D) activity. Seismic acquisition typically involves multi-year lead times ahead of E&D drilling. Oil price is dependent on the actions of all countries producing oil. Imbalance between supply and demand tracks to the production decisions of the countries possessing the resource (Slav, 2020). There have been two periods of contraction and two periods of expansion since 2006. The first contraction occurred after the Great Recession in 2009. Another period of contraction occurred 2015-2017 when Saudi Arabia first attempted to surge oil production and apply downward price pressure to reacquire market share from higher cost U.S. shale oil production. The expansions occurred 2007-2008 during the speculative real estate bubble before the Great Recession, and 2010-2014 following the *Deepwater Horizon* oil spill.

In the first quarter of 2020 the twin stressors of COVID-19 and yet another attempt to surge oil production by Saudi Arabia and Russia (OPEC+) to recapture market share from U.S. oil shale induced a demand collapse of approximately 30 percent (French and Moise, 2020). The daily price of West Texas intermediate crude reached historic lows of less than $20 per barrel in April 2020, and a startling flash crash on April 20, 2020, to -$37.63 caused by future oil contract trading for May that ran up against inventory buildup (Bloomberg News, 2020). In July, oil prices had rebounded above $40 per barrel (USDOE, EIA, 2020). Oil prices may gain support from an OPEC+ production agreement reached in April 2020 (Krauss, 2020); however, all indications are that 2020-2021 will be a very uncertain time for the seismic acquisition business. Analysts forecast a 50 percent drop in revenue for the seismic business in 2020 (Offshore, 2020), an environment that could lead seismic companies that are heavily leveraged toward bankruptcy or distressed asset sales, such as CGG's June 2017 Chapters 11 and 15 restructuring.

There has been substantial merger and acquisition activity in the seismic business over the last 5 years that has resulted in a more consolidated industry with reduced acquisition capacity. Seismic data are delivered to E&D operators through either a proprietary or multi-client business model. For proprietary business, the E&D company contracts a seismic service company to acquire and process data on its behalf. For multi-client business the seismic operator retains ownership and control of the data and can license it to multiple parties. The E&D operators often prefer multi-client over proprietary because the cost is substantially lower. Typically, one or more clients will commit to licensing the data before acquisition begins, a practice called "pre-funding". "Late sales" refer to licenses sold after data acquisition is underway or complete.

The 2018 exit of WesternGeco/Schlumberger from seismic acquisition indicated a market that was bifurcating (Duey, 2018), a trend that has accelerated in recent years. CGG exited marine seismic acquisition in early 2020 (Pai, 2020). Operators are now distinguishing themselves either as vessel providers or software/services and data processing companies. TGS, for example, subcontracts their seismic acquisition and owns no vessels. The business model of the integrated seismic operator that acquires and processes data for purpose-contracted or speculative multi-client licensing has been mostly abandoned (Beaubouef, 2020). The vessel providers bear the brunt of financial pain in contracting markets because they own the hard assets and the fixed costs that accompany them. In comparison, the overhead for software services and data processing companies is substantially lower.

The seismic data collected in the GOM over the last 5 years is shown by year in **Table 2** and **Figure 50**. This period coincided with a significant contraction from 2015 through 2017 that resulted from Saudi Arabia's supply surge against U.S. shale oil production. The contraction led to retrenchment from 2018 through 2019 as E&D operators sought to adjust their development plans while excess hydrocarbon supply was slowly wrung from the market.

TECHNOLOGY DEPLOYMENTS

As operator consolidation and uncertainty pervade the seismic market, there have been changes in seismic hardware, acquisition technique, and data processing that are greatly improving the quality of seismic imaging. Marine seismic acquisition can be separated into towed-streamer and stationary receiver acquisition. Stationary receiver acquisition is performed with ocean-bottom cable (OBC) or node (OBN) systems. Since BP permanently installed the first 4-component OBC system in the Valhall Field, Norway (Moldovenau, 2006), 4-dimensional (4D, time lapse) seismic acquisition has become an important field management tool for optimizing reservoir depletion. The technique is based on repetitive 3D surveys over a reservoir's productive life using the same OBC or OBN locations.

A paradigm shift has taken place over the last 10 years in the 4D seismic arena with acquisition technologies that decouple source and receiver equipment and allow repeat positioning of both shot and receivers to within meters. New instrumentation will soon be available to OBN seismic operators. A current downside of OBN deployment is that remotely operated vehicles (ROVs) are needed to place nodes on the seafloor. To carry out a repeat survey, ROVs relocate each node to swap in a new node with fresh batteries. Node relocation can be a problem because of low visibility, turbidity caused by the ROV's thrusters, or if nodes settled into a muddy seafloor. Robotic nodes are under development by a consortium of Saudi Aramco, CGG, and Seabed GeoSolutions (Jacobs, 2014). The goal of RoboNode™ is to eliminate the need for ROV intervention for placing and relocating nodes by equipping each node with a launch and recovery system for each node to self-deploy and self-recover. Removing the operational down time caused by ROV breakdown or maintenance delays should lower costs.

Table 2. Seismic activity in the GOM from 2015 through 2019.

Year	Permit #	Permittee	Contractor	Survey Type	Data Type	Exclusive or Speculative
2015	L15-007	BP	FairfieldNodal	4D-OBN	FAZ	Exclusive
2015	L15-037	Shell	FairfieldNodal	4D-OBN	FAZ	Exclusive
2015	L15-039	FairfieldNodal	FairfieldNodal	3D-OBN	FAZ	Speculative
2015	L15-053	WesternGeco	WesternGeco	COIL	FAZ	Speculative
2015	T15-015	Shell	FairfieldNodal	4D-OBN	FAZ	Exclusive
2016	L16-011	WesternGeco	WesternGeco	COIL	FAZ	Speculative
2016	T16-004	Shell	NCS Subsea	3D Hi-Res	NAZ	Exclusive
2017	L17-011	BP	FairfieldNodal	4D-OBN	FAZ	Exclusive
2017	L17-022	WesternGeco	WesternGeco	3D-OBN	FAZ	Exclusive
2017	L17-029	Hess	FairfieldNodal	3D-OBN	FAZ	Exclusive
2017	L17-032	TGS	Polarcus	3D	NAZ	Speculative
2017	T17-003	Shell	Sound Oceanics	3D-Hi-Res	NAZ	Exclusive
2017	T17-004	CGG	CGG	3D	WAZ	Speculative
2018	L18-009	Shell	Seabed GeoSolutions	4D-OBN	FAZ	Exclusive
2018	T18-008	Shell	Seabed GeoSolutions	4D-OBN	FAZ	Exclusive
2018	T18-010	BHP	FairfieldNodal	3D-OBN	FAZ	Exclusive
2018	L18-013	Shell	Seabed GeoSolutions	4D-OBN	FAZ	Exclusive
2018	L18-017	TGS	Fairfield Geotechnologies	3D-OBN	FAZ	Speculative
2018	L18-018	Anadarko	Fairfield Geotechnologies	3D-OBN	FAZ	Exclusive
2018	L18-019	BP	Fairfield Geotechnologies	4D-OBN	FAZ	Exclusive
2019	L19-007	Total	Oceaneering	3D-Hi-Res	NAZ	Exclusive
2019	L19-008	CGG	Seabed GeoSolutions	3D-OBN	FAZ	Speculative
2019	L19-012	Chevron	Seabed GeoSolutions	4D-OBN	FAZ	Exclusive
2019	L19-014	BHP	MagSeis Fairfield	3D-OBN	FAZ	Exclusive
2019	L19-020	Shell	NCS Subsea	3D-Hi-Res	NAZ	Exclusive
2019	L19-026	WesternGeco	Shearwater	3D-OBN	FAZ	Speculative
2019	L19-034	Anadarko	MagSeis Fairfield	3D-OBN	FAZ	Exclusive
2019	L19-039	BP	MagSeis Fairfield	4D-OBN	FAZ	Exclusive
2019	L19-045	Chevron	Seabed GeoSolutions	4D-OBN	FAZ	Exclusive
2019	T19-008	Shell	NCS Subsea	3D-Hi-Res	NAZ	Exclusive

NAZ - Narrow Azimuth
WAZ - Wide Azimuth
FAZ - Full Azimuth

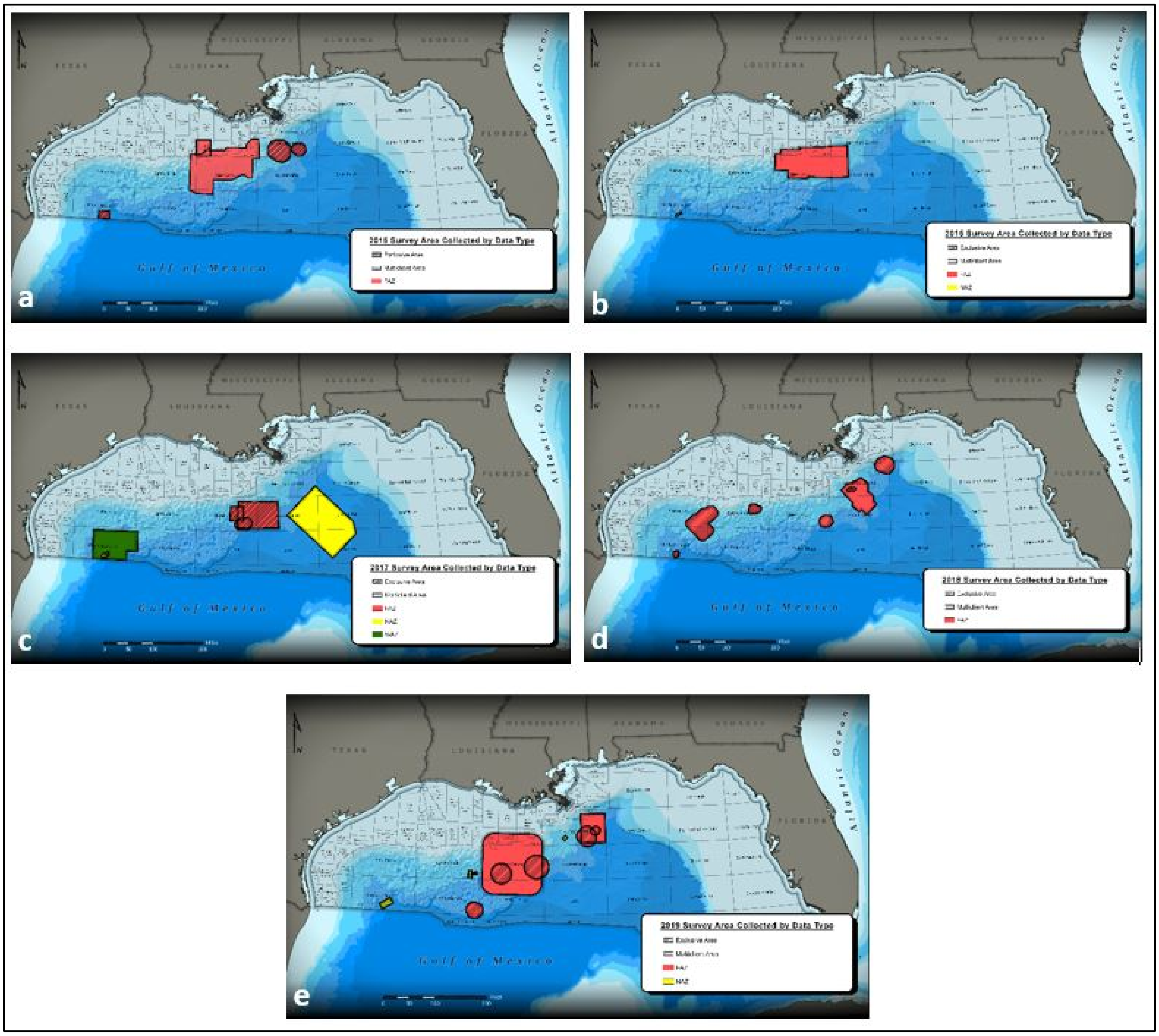


Figure 50. Seismic data types permitted by BOEM from 2015 through 2019; 2a = 2015, 2b = 2016, 2c = 2017, 2d = 2018, 2e = 2019. Exclusive and speculative surveys are identified.

The trend over the past decade in towed streamer acquisition has been to increase the streamer length and the number of streamers towed. Prior to 2000, most surveys were acquired with streamers shorter than 5,000 m (3.1 mi). In the last 5 years, an increasing number of surveys have used streamer lengths between 6,000 m (3.7 mi) and 12,000 m (7.4 mi) (Moldovenau, 2006). Additions to the worldwide seismic fleet since 2,000 were stimulated in parallel with increased deployments of WAZ seismic surveys. So-called "complex azimuth" surveys like WAZ improve signal-to-noise ratio and definition of subsalt geology. The WAZ surveys have a larger footprint that requires larger vessels capable of towing longer streamer lines and airgun arrays.

Increased streamer length paralleled improvements in managing long arrays when WesternGeco's deployed their Q-Marine™ seismic acquisition, a system since adopted by most operators. Q-Marine uses gel-filled streamers and can deliver seismic data with improved signal-to-noise ratio, greater bandwidth, reliable amplitudes due to calibrated sources and sensors, accurate positioning of the receivers along the streamers, and steerable and repeatable positioning (Moldovenau, 2006). Steerable streamers are necessary to keep them parallel while surveying and provide more accurate positioning for 4D reservoir management.

Fluid-filled (obsolete, but still in use), gel-filled, and solid streamers are used for marine seismic acquisition. A streamer system containing a liquid that gels into a solid was introduced in 1997 (Moldovenau, 2006). This system was designed to reduce the signal-to-noise ratio that is aggravated in rough sea states (Rekdal and Long, 2006); however, the service life of this system is short. Solid streamers filled with a flexible polymer foam that is even less sensitive to sea noise are now used by most seismic operators. Systems known generically as "broadband seismic" augment solid streamers with extra sensors ("multisensory") and are designed to further improve seismic resolution and signal to noise ratios. PGS introduced multisensory technology as GeoStreamer™ in 2007. Other seismic operators subsequently introduced their own proprietary systems: Sentinel MS™ (Sercel) and IsoMetrix™ (WesternGeco/Schlumberger) (Dondurur, 2018).

Coil 3D surveys are a technique developed by WesternGeco as a type of WAZ providing full-azimuth coverage. Coil surveys are acquired by one or more vessels sailing in a circular path while towing selfsteering streamers and an airgun array (**Figure 51**). When transit of one circle is complete, the vessel moves to a second circle separated by a fixed distance from the first. This pattern is repeated until the survey area is covered (Buia et al., 2008). The first feasibility test of the "coil shooting" technique in the GOM was carried out in Green Canyon in 2007. Comparison was made with another WAZ dataset shot with parallel sail lines over the same area with the same velocity model. With their Q-Marine™ streamer configuration, WesternGeco was able to show coil shooting to image as well or better than the WAZ survey obtained with parallel sail lines.

One of the drivers for the development of marine vibroseis is that seismic airguns can harm or disturb some marine mammals when operating in proximity to them. In recent years seismic operators have pursued technologies to reduce the higher frequencies from the source while retaining the ability to image the subsurface. Tuned pulse source is a pneumatic signal designed to operate using low-pressure air. Compared to airguns, a tuned pulse source has a much stronger low-frequency and reduced high-frequency content (Ronen and Chelminski, 2017).

A marine vibroseis source generates significantly lower sound pressure levels than seismic airguns and omits the higher frequencies that may disturb cetaceans. In February 2015, the Geokinetics AquaVib™ was tested in South Timbalier during the acquisition of a production 3D OBC survey (Pramik et al., 2015). Initial processing of the AquaVib field tests showed that this marine vibrator system can achieve comparable data quality to traditional airgun sources.

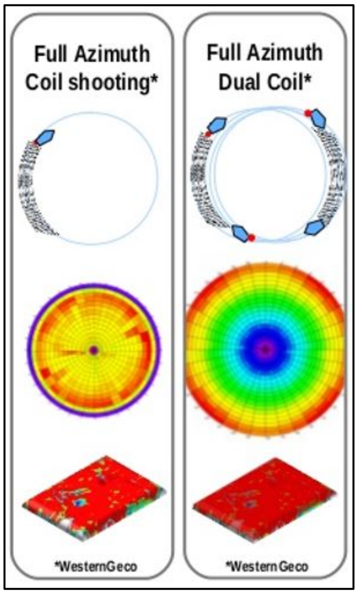


Figure 51. WesternGeco developed the coil acquisition technique. Colors correspond to the number of traces recorded for each offset-azimuth combination. Cooler colors indicate a lower number of traces, whereas warmer colors indicate a higher number of traces. (Image courtesy of WesternGeco.)

Beginning in 2007 and continuing into 2015, BP designed, built, and field tested Wolfspar™, a full-scale, ultra-low-frequency seismic source optimized for full-waveform inversion (FWI). Unlike airguns or marine vibrators, Wolfspar can tailor its output precisely to the needs of the geoprocessing algorithm preferred for velocity model building (Dellinger et al., 2016). In late 2017, BP acquired 1,000 kilometers of source lines over the deepwater, subsalt Mad Dog (Green Canyon 826) Field using Wolfspar (Dellinger et al., 2019). This OBN survey (permit L17-011) used the low-frequency Wolfspar source and two airguns, simultaneously, and was the first industry test designed primarily for building velocity models in areas of complex geology. In 2019, BP used Wolfspar to add 1 billion barrels of oil at the Thunder Horse (Mississippi Canyon 778) Field (permit L19-039) and 400 million barrels at the Atlantis Field (Green Canyon 743) (permit L18-019) (Research and Markets, 2020).

The FWI is considered the most promising data-driven tool to automatically build velocity models by iteratively minimizing the difference between recorded data and modeled synthetic data (Wang et al., 2019). Other variants of FWI seek to use diving and reflected wave paths, so-called Joint FWI (Zhou et al., 2015).

For decades the standard practice for salt-model building has been to use tomography, imaging by cross sections, combined with shallow diving waves (from source downward into sediments) to first build the best possible sediment velocity model. Next, a sediment-flood migration applies the sediment velocity model to the entire thickness of geologic section to define a top-of-salt interpretation, followed by a salt-flood migration that applies salt velocity to define a base-of-salt interpretation. This procedure is not only labor intensive and time consuming but also prone to misinterpretation because an interpreter must pick the base-of-salt, which is often ambiguous. The final velocity model is only as good as the base-of-salt interpretation.

A breakthrough success of FWI salt velocity updating came from Shen et al. (2017) and Michell et al. (2017) in which FWI corrected misinterpretations of salt structures to greatly improve subsalt imaging at BP's Atlantis Field in Green Canyon. There is great interest in time-lapse FWI, an iterative 4D reservoir management approach that minimizes seismic artifacts introduced by inaccurate starting velocity models and data having poor signal-to-noise ratio. Time-lapse FWI is proving successful for salt and near-salt velocity updates for the challenging geological environments typical of the GOM (Hicks, 2016) with both towed streamer and fixed bottom (OBN) datasets.

LS3 Harris is a U.K.-based company specializing in the development of autonomous surface vessels (ASV). Together with Shell, LS3 Harris seeks to further develop their C-Worker class of ASV to include an unmanned seismic source vessel as part of its rapid autonomous marine 4D (RAM4D) concept. RAM4D anticipates a single, small, surface vessel towing a small seismic source (250-500 in^3) for 4D surveys. The unmanned vessel operates for up to 10 days without escort and following pre-charted shot points (Chalenski et al., 2017). The use of ASVs for small-footprint, repetitive 3D surveys anticipates significant cost savings by eliminating large manned vessels. C-Worker class vessels are about 20 ft long and suitable for containerized storage onshore. By down-scaling survey footprint, airgun size, and personnel, the operational costs of 4D surveys may be reduced by a factor of 10 (Chalenski et al., 2017). Upcoming trials for RAM4D are taking place in the GOM and include an extended sea endurance test, followed by full operational testing in Broussard, Louisiana, to culminate in an offshore seismic survey on the OCS.

LEVEL OF GULF OF MEXICO SEISMIC ACTIVITY

Twelve seismic operators have carried out surveys in the GOM between 2015 through 2019 (**Table 2**). Upon inspection the prevalence of 4D and OBN is shown. The OBN surveys are the dominant seismic output in the GOM with 10 3D OBN and 11 4D OBN surveys among the 30 surveys conducted from 2015 through 2019. **Table 2** also shows that NAZ seismic data type is largely becoming a legacy technology displaced by different types of FAZ data types. OBN surveying is dominated by Fairfield (FairfieldNodal and MagSeis Fairfield), with WesternGeco and Seabed GeoSolutions as minor players.

BOEM examined IHS Markit's SeismicBase database (a proprietary database to which BOEM subscribes), from 2006 to 2019 for activity trends in the GOM, and within the worldwide seismic fleet. IHS Markit's SeismicBase relies on operator self-reporting of their vessel locations and activities. Ninetyone seismic vessels operated in the GOM between 2006 and 2019 under the flags of several countries (**Figure 52**). Most seismic vessels were Bahama- or Panama-flagged (42%), with vessels flagged NIS, Norway, Cyprus, and United States collectively representing 38 percent of the GOM fleet. **Figure 52** also shows Norwegian vessels operating in the GOM have the greatest range in age from 12 to 55 years old.

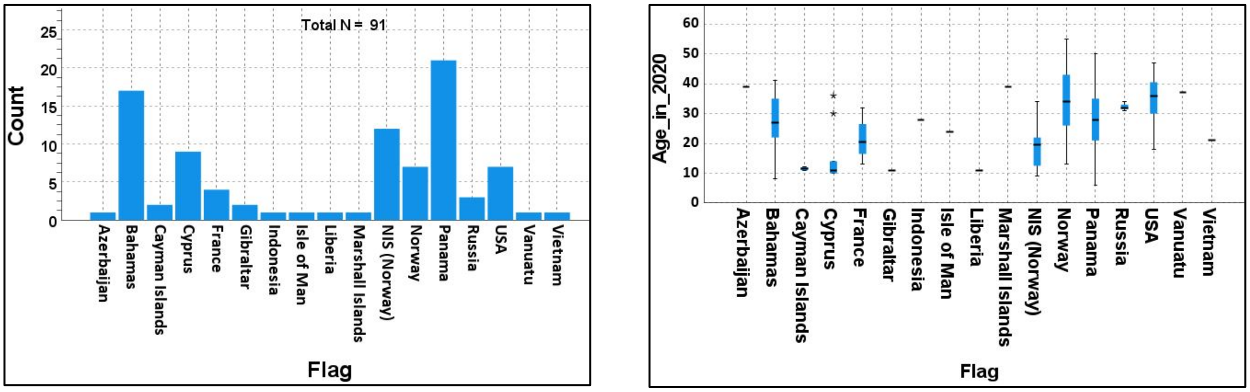


Figure 52. Flags for 91 seismic vessels that operated in the Gulf of Mexico between 2006 and 2019 (left), and their age in 2020 (right) (from IHS Markit's SeismicBase database).

Figure 53 shows an average age of approximately 25 years for seismic vessels operating in the GOM between 2006 and 2019. Ages for seismic vessels taken from IHS Markit's SeismicBase skew older because SeismicBase reports original construction dates, but the dates for the common practice of refitting, rebuilding, and conversions is not unless individual vessels are researched. A 2015 analysis of the worldwide seismic fleet by Carnegie Investment Bank (Westgaard, 2015) reported that vessels built after 2005 constitute approximately 70 percent of currently active vessels and that approximately 23 percent of the worldwide fleet were older than 15 years.

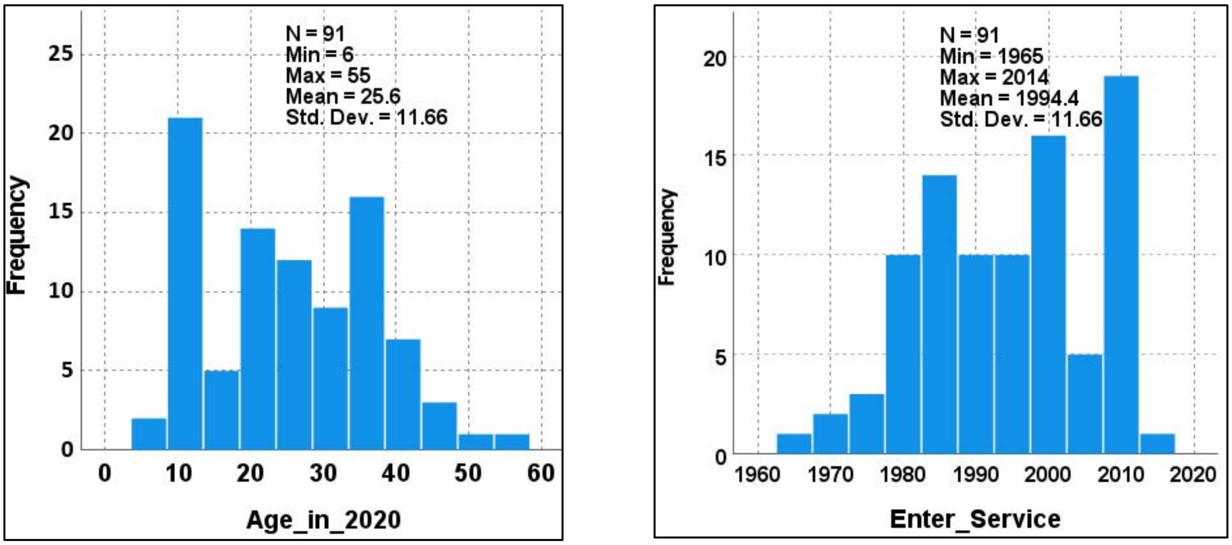


Figure 53. Age range of the 91 seismic vessels operating in the Gulf of Mexico between 2006 and 2019 (left), and the year they entered service (right) (from IHS Markit's SeismicBase database).

Gulf of Mexico Seismic Activity vs Oil Price

The price of oil affects the level of seismic acquisition in the GOM. **Figure 54** shows the relationship between oil price and total vessel activity in the GOM between 2006 and 2019 from IHS Markit's SeismicBase. There are nine survey types and vessel activities reported in IHS Markit's SeismicBase that describe what vessels are doing in the GOM, for example, "inshore" (tripping in or out of a GOM shore base). Total vessel activity in **Figure 54** is a roll up of the nine survey types or vessel activity. The effect of steep changes in oil price as a stimulus or suppressant of vessel activity in GOM appears to have a lag time of approximately 1-1.5 years.

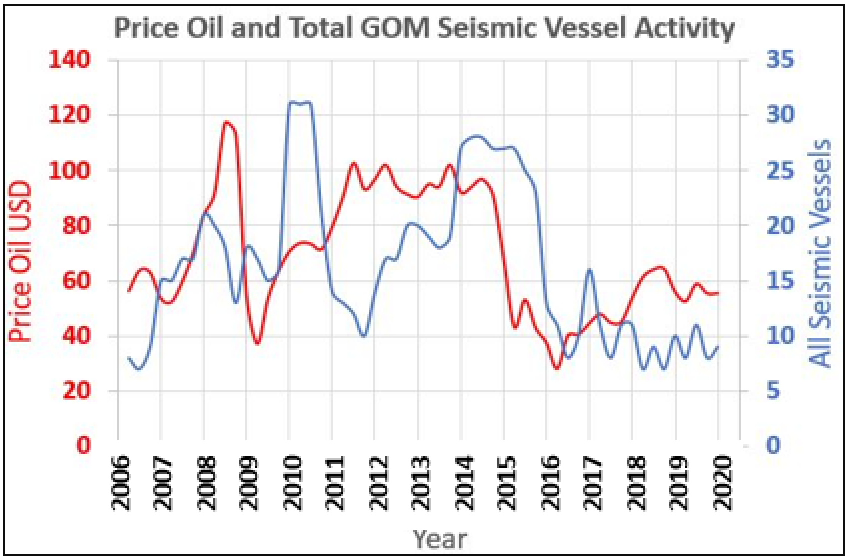


Figure 54. Graph showing the relationship between oil price and total vessel activity in the Gulf of Mexico between 2006 and 2019 (vessel activity from IHS Markit's SeismicBase). Oil price and vessel activity are averaged by quarter. Oil price data average by month is from the Energy Information Agency (USDOE, EIA, 2020).

VESSEL CONTRACT RATES

The contracted rates for seismic vessels are an important part of the business, but hard data are elusive for competitive reasons. Rates would be expected to show variation based on contracting or expanding oil price environments. Each quarter IHS Markit's SeismicBase analysts include a roll up of contract vessel rates in United States dollars (USD) for the worldwide fleet. A low-end and a high-end rate range is based on vessel specification (spec) level. Lower spec vessels are those with low tool deployment capability or flexibility. Higher spec vessels tend to be larger and have high tool deployment capability or flexibility. The age of the vessel also factors into contract rate variability, with newer or rebuilt vessels commanding higher rates. The vessel types reported in IHS Markit's SeismicBase are 2-dimensional (2D) and 3D, which is a coarse generalization for vessel types supporting seismic acquisition. IHS Markit's SeismicBase assesses 2D survey vessels at low and high spec levels and 3D survey vessels at low, medium, high, and very high spec levels.

BOEM modified and averaged IHS Markit's SeismicBase's reporting categories and retained their low--end and high-end contract rate range to compile **Figure 55**. For 2D vessels BOEM averaged the low- and high-spec ranges for the low-end and high-end rate ranges. For 3D vessels BOEM averaged low, medium, high, and very high spec ranges for the low-end and high-end rate ranges. **Figure 56** shows another contract rate compilation (Westgaard, 2015) for the period 2006-2016 based on the worldwide fleet. **Figures 55 and 56** identify the run up to the Great Recession from 2008 to 2009, the expansive/stable oil price environment between 2010 and 2014, and the contracting price environment after Saudi Arabia first surged oil production in 2015 to suppress U.S. oil shale production.

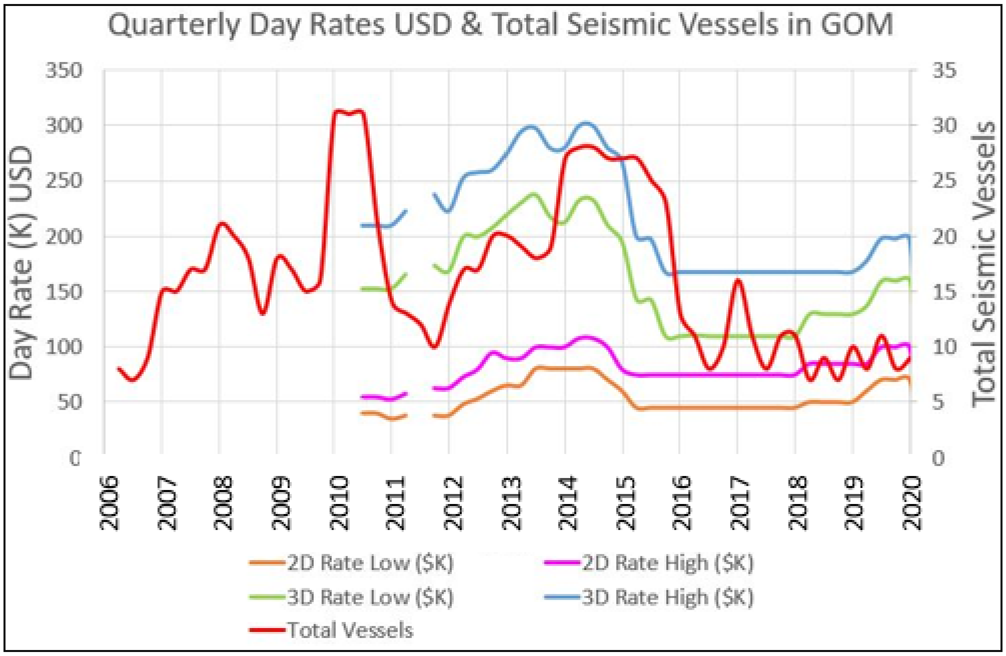


Figure 55. BOEM assessment of seismic vessel contract rates applicable to the worldwide seismic fleet for 2D and 3D seismic capability in relation to total seismic vessel activity in the Gulf of Mexico, both averaged by quarter (prepared from data in IHS Markit's SeismicBase).

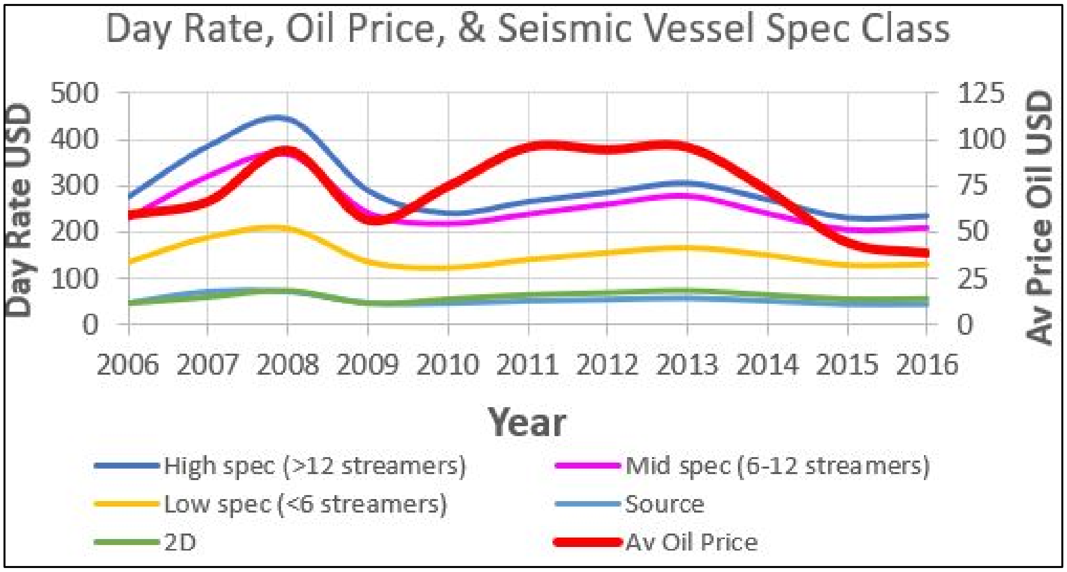


Figure 56. Day rates (KUSD), oil price (USD), and vessel specification classes from the worldwide fleet for 2006 to 2016, with estimates provided for 2015 and 2016 (prepared from data in Westgaard, 2015).

CONCLUSIONS

The GOM is considered a super basin (Addison, 2020; Brown, 2020). Deployment of 4D OBN and FAZ/WAZ will continue to drive innovation for seismic acquisition in this vibrant and mature hydrocarbon province. The use of OBN and 4D shown in **Table 2** indicates how these survey data types reflect the trends one would expect in a mature super basin; that being a growing emphasis on seismic used for the management of producing fields. The imaging challenges of subsalt plays has effectively displaced 3D NAZ data type by coil, FAZ, and WAZ data types. All are seismic data types designed to deliver more subsurface datapoints for any subsurface location.

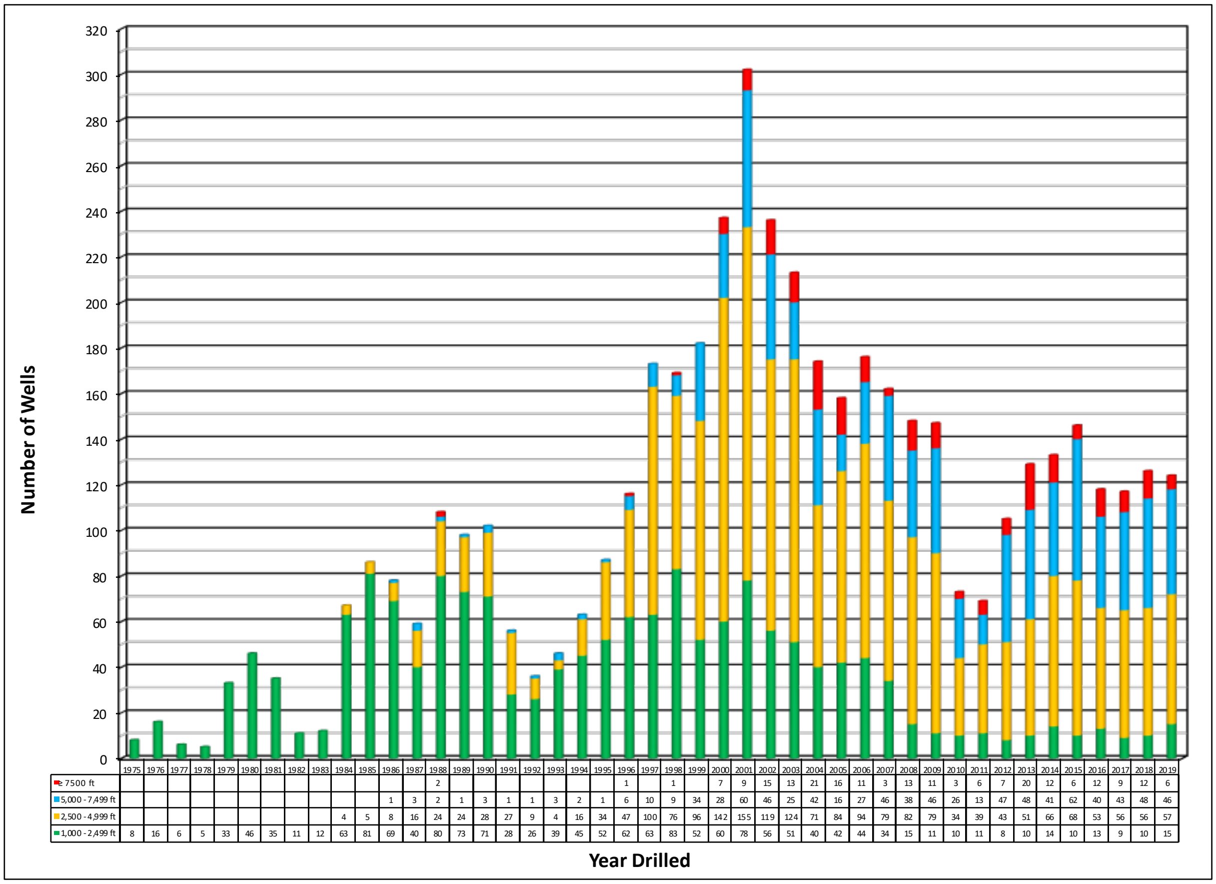
The supply and demand imbalances that have been introduced by COVID-19 lockdowns, behavior modifications, and oil demand collapse in the first quarter of 2020 are intertwined, yet distinct. It will take time to rebalance supply and demand in the global market. While the depth and duration of the pandemic shock is uncertain, some analysts expect it to be short-lived (Arezki and Nguyen, 2020).

Contract vessel rates for different seismic vessel classes show variation based on collapsing/contracting and expanding/stable oil price environments. Oil price drops can be sudden in response to economic cycles and geopolitical events that upset the balance of supply and demand. Recovery from a stressed oil price environment and transitioning to a stable or expansive environment tends to be more gradual in comparison. There is a lag time of 1-1.5 years between a price-induced stimulus, up or down, and a vessel deployment response.

The canvass of seismic vessel contract rates shows a looser relationship. During the expansive-to-stable oil price period between 2011 and 2014, the response of seismic vessel contract rates and total vessels deployed in the GOM involved an approximately 2-year lead period between contracts for vessels and realized vessel deployments. During the contracting oil price period following Saudi Arabia’s first attempt to surge oil production in 2015, the response of seismic vessel day rate and total vessels deployed in the GOM involved an approximate 1-year lag period between contracts expiring and ramp down of vessel deployments. The lead and lag times show that it is easier for seismic operators to react to a contracting price environment by cold-stacking their vessels than to anticipate when and for how long an expanding or stable price environment may lie before them.

WELL DATA

The first well drilled in the GOM in water depths of 1,000 ft or greater reached total depth in 1975 as part of the Cognac (Mississippi Canyon 194) Field. Through 2014, more than 4,100 wells have been drilled in the deepwater GOM. This number includes original wellbores, sidetracks, and bypasses. **Figure 57** shows the year these wells reached total depth, categorized by water-depth intervals. The depressed drilling numbers in 2010 and 2011 are caused by the repercussions of the BP Macondo blowout in 2009. From 2012 on, the number of wells drilled has remained strong at between 100 and 140 wells per year.



	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
🟥 ≥ 7500 ft														2	
🟦 5,000 - 7,499 ft												1	3	2	1
🟨 2,500 - 4,999 ft										4	5	8	16	24	24
🟩 1,000 - 2,499 ft	8	16	6	5	33	46	35	11	12	63	81	69	40	80	73

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
🟥 ≥ 7500 ft							1		1		7	9	15	13	21
🟦 5,000 - 7,499 ft	3	1	1	3	2	1	6	10	9	34	28	60	46	25	42
🟨 2,500 - 4,999 ft	28	27	9	4	16	34	47	100	76	96	142	155	119	124	71
🟩 1,000 - 2,499 ft	71	28	26	39	45	52	62	63	83	52	60	78	56	51	40

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
🟥 ≥ 7500 ft	16	11	3	13	11	3	6	7	20	12	6	12	9	12	6
🟦 5,000 - 7,499 ft	16	27	46	38	46	26	13	47	48	41	62	40	43	48	46
🟨 2,500 - 4,999 ft	84	94	79	82	79	34	39	43	51	66	68	53	56	56	57
🟩 1,000 - 2,499 ft	42	44	34	15	11	10	11	8	10	14	10	13	9	10	15

Figure 57. Number of deepwater wells drilled by water depth.

DRILLING AND WATER DEPTHS

The maximum drilling depth in deep water has continually increased over time, reaching true vertical subsea depths (TVDSS) of more than 35,000 ft in 2009 (**Figure 58**). In August 2013, a well operated by Cobalt at the Ardennes prospect in Green Canyon Block 896 was drilled to a record depth of 35,935 ft TVDSS. The well targeted Miocene and Lower Tertiary objectives but found no commercial hydrocarbons. The increase in drilling depths with time may be attributed to several factors, including enhanced rig capabilities, deeper exploration targets, and the general trend toward greater water depths, as can be seen in **Figure 59**. In August 2008, a well operated by Murphy at the unsuccessful Manhattan prospect in Lloyd Ridge Block 511 set a GOM water-depth drilling record of 10,141 ft. More information about each well drilled can be found in **Tables 3 and 4**. Due to the proprietary nature of the well data, total well depths cannot be shown for the year 2019.

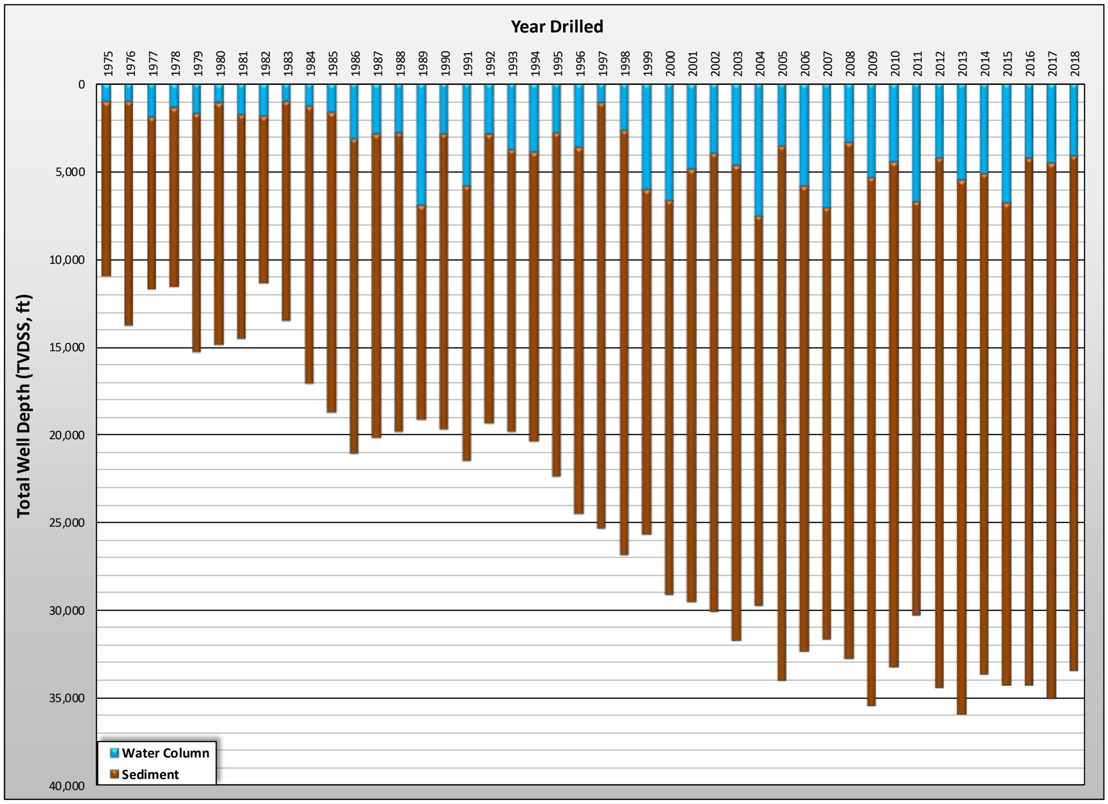


Figure 58. Well-depth drilling records by year.

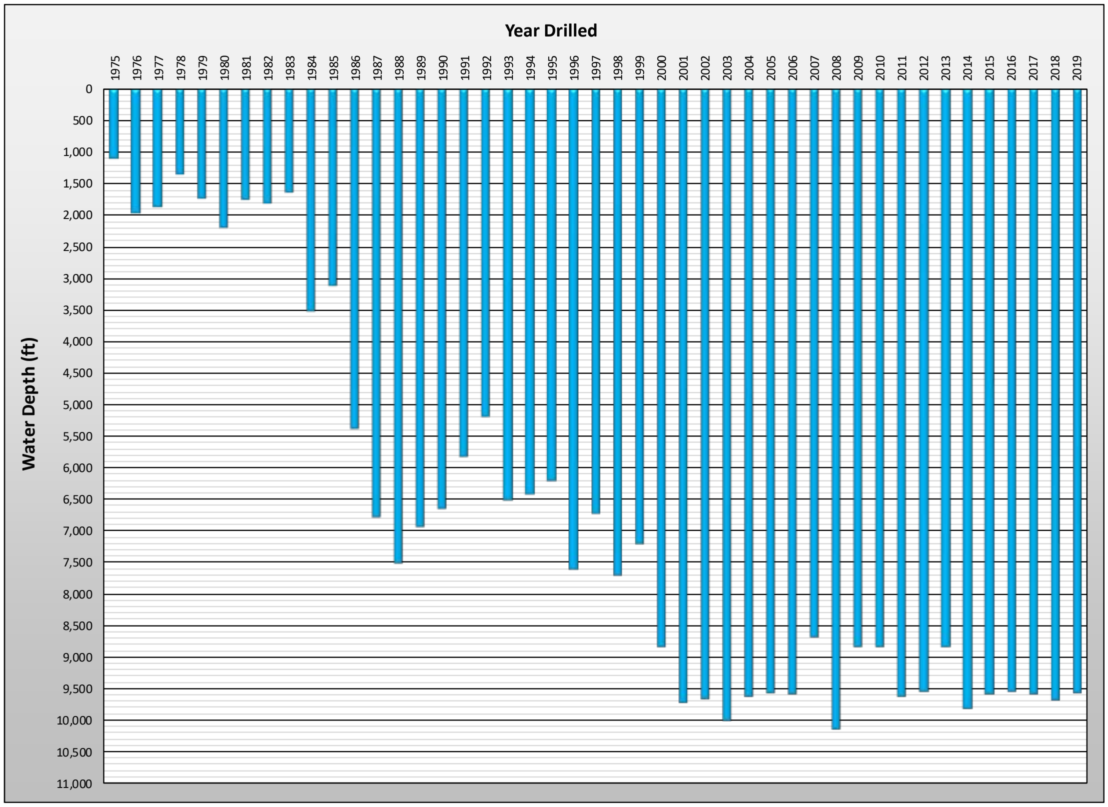


Figure 59. Water-depth drilling records by year.

Table 3. Well-depth drilling records by year.

Year	Total Well Depth (TVDSS, ft)	Total Well Depth (TVDSS, m)	Bottom Hole Area	Bottom Hole Block	BOEM Field Nickname
1975	11,033	3,363	MC	194	Cognac
1976	13,846	4,220	MC	194	Cognac
1977	11,783	3,591	MC	112	
1978	11,587	3,532	VK	906	
1979	15,358	4,681	MC	282	
1980	14,929	4,550	VK	863	
1981	14,544	4,433	MC	28	Pompano
1982	11,419	3,481	GC	184	Jolliet
1983	13,562	4,134	GC	136	Shasta
1984	17,108	5,215	GC	66	Bullwinkle
1985	18,774	5,722	GC	152	Marathon
1986	21,116	6,436	GC	301	
1987	20,228	6,165	GB	470	Auger
1988	19,848	6,050	GB	426	Auger
1989	19,150	5,837	MC	522	Fourier
1990	19,705	6,006	GB	426	Auger
1991	21,504	6,554	KC	255	
1992	19,374	5,905	GB	470	Auger
1993	19,881	6,060	MC	809	Mars-Ursa
1994	20,413	6,222	MC	935	Europa
1995	22,403	6,828	MC	718	Pluto
1996	24,565	7,487	GB	602	Macaroni
1997	25,360	7,730	GC	142	
1998	26,906	8,201	GB	386	Llano
1999	25,719	7,839	MC	778	Thunder Horse
2000	29,153	8,886	WR	456	
2001	29,595	9,021	MC	727	Tubular Bells
2002	30,123	9,181	GC	640	Tahiti/Caesar/Tonga
2003	31,732	9,672	GC	727	Tahiti/Caesar/Tonga
2004	29,757	9,070	WR	724	Das Bump
2005	34,067	10,384	GC	512	Stampede
2006	32,400	9,876	KC	292	Kaskida
2007	31,713	9,666	WR	627	Julia
2008	32,796	9,996	GC	468	Stampede
2009	35,501	10,821	GC	945	
2010	33,297	10,149	GC	817	
2011	30,287	9,231	KC	736	Moccasin
2012	34,412	10,489	GB	959	North Platte
2013	35,935	10,953	GC	896	
2014	33,667	10,262	GC	807	Anchor
2015	34,335	10,465	WR	225	
2016	34,337	10,466	GB	998	
2017	35,034	10,678	GB	959	North Platte
2018	33,462	10,199	GC	392	

Table 4. Water-depth drilling records by year.

Year	Water Depth (ft)	Water Depth (m)	Bottom Hole Area	Bottom Hole Block	BOEM Field Nickname
1975	1,121	342	MC	68	
1976	1,986	605	MC	113	
1977	1,895	578	MC	112	
1978	1,363	415	VK	906	
1979	1,747	532	MC	282	
1980	2,211	674	MC	198	
1981	1,775	541	MC	28	Pompano
1982	1,835	559	GC	184	Jolliet
1983	1,657	505	GC	184	Jolliet
1984	3,534	1,077	MC	852	
1985	3,135	956	GC	254	Allegheny
1986	5,400	1,646	MC	731	Mensa
1987	6,794	2,071	AT	471	
1988	7,520	2,292	MC	657	Coulomb
1989	6,950	2,118	MC	522	Fourier
1990	6,660	2,030	MC	952	
1991	5,834	1,778	KC	255	
1992	5,195	1,583	MC	84	King/Horn Mt.
1993	6,530	1,990	DC	133	King's Peak
1994	6,420	1,957	MC	217	King's Peak
1995	6,220	1,896	AT	575	Neptune
1996	7,620	2,323	AC	600	BAHA
1997	6,740	2,054	DC	177	King's Peak
1998	7,716	2,352	AT	118	
1999	7,209	2,197	MC	348	Camden Hills
2000	8,845	2,696	WR	425	Chinook
2001	9,727	2,965	AC	903	Trident
2002	9,672	2,948	AC	947	Trident
2003	10,011	3,051	AC	951	
2004	9,627	2,934	AC	859	Tobago
2005	9,576	2,919	WR	508	Stones
2006	9,586	2,922	WR	508	Stones
2007	8,694	2,650	AC	731	
2008	10,141	3,091	LL	511	
2009	8,850	2,697	WR	469	Chinook
2010	8,850	2,697	WR	469	Chinook
2011	9,627	2,934	AC	859	Tobago
2012	9,553	2,912	WR	507	Stones
2013	8,843	2,695	WR	425	Chinook
2014	9,819	2,993	LL	411	
2015	9,585	2,922	WR	508	Stones
2016	9,552	2,911	WR	508	Stones
2017	9,587	2,922	WR	464	Stones
2018	9,681	2,951	WR	595	
2019	9,565	2,915	WR	508	Stones

GEOLOGIC TRENDS

OVERVIEW

Rocks in the northern U.S. Gulf of Mexico OCS Basin range in age from Triassic to Pleistocene and cover a wide range of depositional environments, including subaerial red beds and aeolian dunes, marine carbonate platforms and reefs, and deltaic and deep-sea fan deposits. Generalized to the Series level, **Table 5** depicts the ages of rock formations discussed herein. The discovered resource base (reserves plus contingent resources) in the northern GOM totals over 67 billion barrels of oil equivalent (BBOE). The geologic plays located in shallow water (<1,000 ft) have been thoroughly explored and exploited for over 70 years. These shallow-water plays account for discovered resources of nearly 45 BBOE. The first discovery in deep water (>1,000 ft) occurred in 1975 with Shell's Cognac (Mississippi Canyon 194) Field in Pliocene rocks. Together, the Pleistocene, Pliocene, and Miocene Trends in deep water contribute nearly 19 BBOE to the discovered resources in the northern GOM.

Table 5. Geologic timescale of the northern GOM Basin.

Age (Ma)	Erathem	System	Series	Formation
0.0117	Cenozoic	Quaternary	Pleistocene	
2.588		Neogene	Pliocene	
5.333			Miocene	
2.303		Lower Tertiary (Paleogene)	Oligocene	Frio
33.9			Eocene	Wilcox
56.0			Paleocene	
66.0	Mesozoic	Cretaceous	Upper	Tuscaloosa
100.5			Lower	
145.0		Jurassic	Upper	Smackover Norphlet
163.5			Middle	Louann Salt
174.1			Lower	
201.3		Triassic		
252.17				

With time, discoveries progressed farther into deeper waters and older sediments. The oldest Cenozoic rocks in the deepwater GOM, referred to collectively as the Lower Tertiary Trend (Wilcox and Frio rocks, **Table 5**), have been an active exploration target for around 20 years. Located from the East Breaks/Alaminos Canyon to Green Canyon/Walker Ridge Areas, many of the trend's oil discoveries are trapped in large compressional folds, some of which lie in water depths of more than 9,000 ft. This trend has contributed nearly 3 BBOE to the GOM's discovered resource base.

Mesozoic rocks in the deepwater GOM have been an active exploration target in the Upper Jurassic Norphlet Formation (**Table 5**) Trend for 17 years. Current discoveries in this trend are located in the eastern Mississippi Canyon and western De Soto Canyon Areas in over 7,000 ft of water. Characterized by oil trapped in aeolian dunes within tectonic detachment rafts, these discoveries account for nearly 1 BBOE so far.

Along with the deepwater Lower Tertiary and Norphlet Trends, other conceptual plays in the northern GOM that may be future exploration targets include (1) the Upper Cretaceous Tuscaloosa Formation (**Table 5**) Slope Play, primarily located in the Mississippi Canyon Area; (2) the Expanded Middle to early Upper Jurassic Play, primarily located in the extreme southwest De Soto Canyon and north Lloyd Ridge Areas; and (3) the Triassic to Middle Jurassic Pre-Salt or Equivalent Play, identified in the northeastern GOM extending from the De Soto Canyon/Lloyd Ridge Areas east across the Florida Platform. These are among 30 total plays to be assessed for undiscovered resources in BOEM's 2021 GOM Resource Assessment (in progress).

PLEISTOCENE-PLIOCENE-MIOCENE TREND

In the deepwater GOM, hydrocarbons are often trapped on the flanks of minibasins situated above and below tabular salt bodies. These minibasins formed as a result of ongoing salt withdrawal and migration, as depositional depressions on top of salt canopies filled with Miocene, Pliocene, and Pleistocene sediments (**Table 5**). Notably, some deepwater discoveries associated with minibasins are found in what is known as a "turtle" structure, which forms when salt entirely evacuates from its source due to sediment loading and the synclinal flanks of the minibasin collapse leaving an inverted sediment pile anticline. Numerous other discoveries are found beneath extensive salt canopies associated with compressional fold belts.

Many of these deepwater discoveries have a range of hydrocarbon-bearing pool ages. The following discussion classifies each BOEM-designated oil and gas field according to the sediment age that most of the hydrocarbons are trapped in by volume. In the deepwater GOM, there are a total of 249 fields that are Pleistocene, Pliocene, and Miocene in age. Of these, 54 contain hydrocarbons that are trapped predominantly in Pleistocene pools. These fields have discovery dates ranging from 1975 through 2009, and nearly two-thirds of the fields are now expired. With a production history beginning in 1988, a total of 34 fields have produced, and approximately half are still online. Large (>50 million barrels of oil equivalent [MMBOE]) Pleistocene discoveries that are not depleted include Hoover (Alaminos Canyon 25), Gunnison (Garden Banks 668), Jolliet (Green Canyon 184), and Magnolia (Garden Banks 783).

Of the 249 deepwater fields, 70 contain hydrocarbons trapped predominantly in Pliocene pools. These fields have discovery dates ranging from 1975 through 2014, and just over half of the fields are now expired. With a production history beginning in 1979, a total of 52 fields have produced, and nearly two-thirds are still online. Large (>250 MMBOE) Pliocene discoveries that are not depleted include Auger (Garden Banks 426), Cognac (Mississippi Canyon 194), Troika (Green Canyon 244), and Lucius (Keathley Canyon 875). Other Pliocene fields, such as Hopkins (Green Canyon 627) was discovered in December 2014, while Hadrian South (Keathley Canyon 964) produced from 2015 into 2018. Lucius, the large subsalt Pliocene discovery, began production in January 2015.

The remaining 125 fields are predominantly Miocene. These fields have discovery dates ranging from 1981 through 2018, and just under half of those fields are now expired. With a production history beginning in 1994, a total of 90 fields have produced, and nearly two-thirds are still online. Large (>250 MMBOE) Miocene discoveries that are not depleted include the Mars-Ursa (Mississippi Canyon 807) geologic complex, which is trapped along the flanks of a large minibasin; Atlantis (Green Canyon 743) and Mad Dog (Green Canyon 826), which are associated with compressional fold belts; and Thunder Horse (Mississippi Canyon 778), which is a turtle structure. Nearly three-fourths of all deepwater fields with discovery dates from 2015 through 2018 are Miocene.

Estimated volumes and the spatial distribution of the 34 Pleistocene-dominant fields, 52 Pliocene-dominant fields, and 92 Miocene-dominant fields in deep water that are classified as proved reserves or reserves justified for development are shown in **Figure 60**. The sizes are for the whole field, but each field is classified by the dominant sediment age in which the hydrocarbons are trapped by volume. The map implies nothing about production or remaining reserves. Except for Hoover, all Pleistocene-dominant fields are less than 100 MMBOE. Volumetric estimates put 21 Pliocene-dominant fields greater than 50 MMBOE, with 4 of those topping 250 MMBOE. Of the Miocene-dominant fields, 39 contain greater than 50 MMBOE, with 12 of those greater than 250 MMBOE.

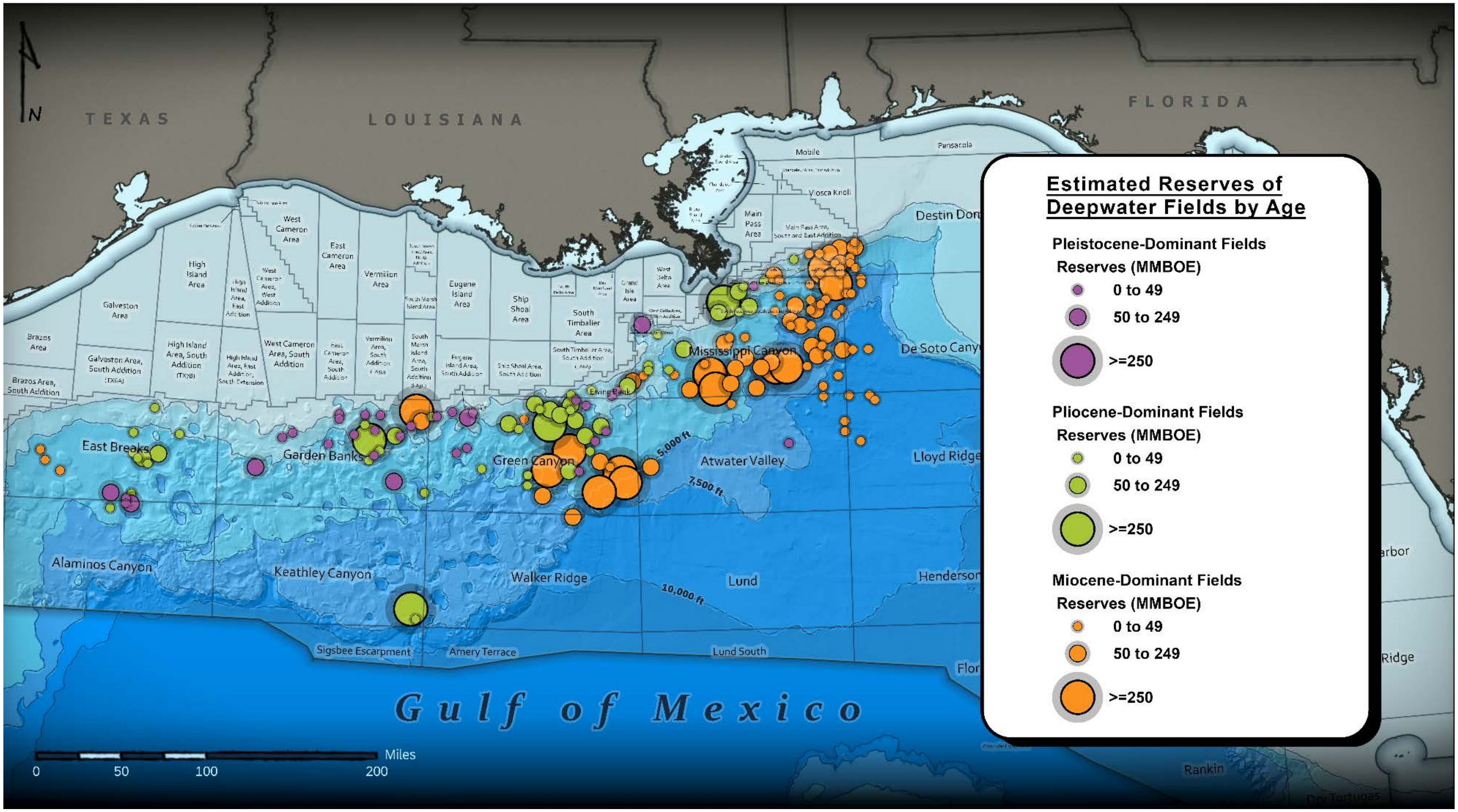


Figure 60. Total proved field volumes classified by dominant reservoir age.

LOWER TERTIARY TREND

The Lower Tertiary Trend in the deepwater GOM has emerged as one of the world's leading exploration plays due to significant discoveries from the Alaminos Canyon to Walker Ridge Areas. However, long before the 1996 BAHA well in Alaminos Canyon confirmed the presence of Wilcox-equivalent, Lower Tertiary rocks in the deepwater GOM, the Lower Tertiary play was explored onshore. Lower Tertiary rocks can be found exposed in onshore outcrops across all the Gulf Coast States. Onshore, the Oligocene Frio Formation and Paleocene to Eocene members of the Wilcox Group have a long history of drilling and production. These onshore reservoirs are situated in areas containing predominantly deltaic to shallow-marine sediments, with the paleo-shelf margins located onshore across the northern GOM. Large Lower Tertiary paleocanyons, which could have channeled sediments from the shelf to the deep water, occur from onshore Texas to Louisiana. A northward-thinning Lower Tertiary wedge across the modern abyssal plain in the Walker Ridge, Atwater Valley, and Lund Areas also suggests a southern source, possibly from the Yucatan or Cuba.

The aforementioned first well to penetrate Wilcox-equivalent, Lower Tertiary rocks in the deepwater GOM occurred in 1996 in Alaminos Canyon Block 600. Four of the world's largest companies at the time—Texaco, Amoco, Shell, and Mobil—proceeded to drill a giant anticlinal structure they dubbed BAHA (an acronym representing the first letter of each company's name for the prospect). In a then record-setting 7,620 ft of water, the well logged 15 ft of oil in the Eocene and was dubbed a dry hole. Even though technical difficulties forced drilling to stop before the target depth (Mesozoic fractured carbonates), the value of the well lies in the fact that it encountered thick sands in an area where none were expected. It took 5 years for the companies to integrate the well data with seismic data before the BAHA #2 well reached total depth in Alaminos Canyon Block 557. It too was commercially unsuccessful, but the well confirmed the extensive and continual nature of the thick Lower Tertiary sands, referred to as the "Whopper Sand." The well also demonstrated that, because of the very deep waters, deep reservoirs, and unexpected pressure regimes, the cost of drilling a well in this environment was enormous. Therefore, to be economic in these conditions, true discoveries would have to be large.

Over the past 20 years, the majority of wells in this deepwater trend have targeted Wilcox-equivalent (Upper Paleocene to Lower Eocene, **Table 5**) basinal turbidite systems. However, a few exploration wells in the Alaminos Canyon Area have encountered discoveries in onshore Frio-equivalent (Oligocene, **Table 5**) rocks also (e.g., Great White–Alaminos Canyon Block 857 and Silvertip–Alaminos Canyon Block 815). Significant portions of the trend are beneath salt canopies and are associated with large compressional fold belts at the basinward limit of a balanced and linked, complex system in which updip sedimentary loading and gravity-driven collapse associated with extension are accommodated by the extrusion of salt canopies and downdip contraction (Rowan et al., 2000). The timing of fold development varies across the trend, generally becoming younger to the east. Structural styles/exploration targets include 4-way closures, 3-way closures against salt, and turtle structures. Primary exploration risks include the timing of hydrocarbon expulsion and migration, reservoir quality, and an effective seal mechanism.

A total of 72 exploratory Lower Tertiary prospects have been drilled in the deepwater GOM, 53 in the WPA and 19 in the CPA. In **Table 6**, these prospects are classified solely by the Lower Tertiary section that the well tested, not any other aged section the well encountered. The classifications are defined as listed below.

- Oil Discovery (Producing) – the prospect is currently producing from the Lower Tertiary.
- Oil Discovery – the prospect has a well that penetrates the Lower Tertiary section and would meet the requirements defined by 30 CFR § 550.116 to qualify as producible, and the lease is still active.

- Non-Commercial Oil – the prospect has a well that penetrates the Lower Tertiary section and would qualify as producible under the guidelines defined by 30 CFR § 550.116, but the lease in which the well was drilled has been either relinquished, terminated, or expired.
- Dry Hole – the prospect does not have a well in which the Lower Tertiary section penetrated would meet the requirements defined by 30 CFR § 550.116 to qualify as producible.
- Announced Oil Discovery – the only information that BOEM can disclose about the prospect is from a publicly released industry statement.

Figure 61 shows the spatial distribution and results of the exploratory Lower Tertiary prospects as defined above. Lower Tertiary discoveries estimated to contain greater than 100 MMBOE of recoverable resources include Buckskin (Keathley Canyon Block 872), Anchor (Green Canyon Block 807), Great White (Alaminos Canyon Block 857), St. Malo (Walker Ridge Block 678), Jack (Walker Ridge Block 759), Tiber (Keathley Canyon Block 102), Shenandoah (Walker Ridge Block 52), Whale (Alaminos Canyon Block 772), and North Platte (Garden Banks Block 959). The 2014 Leon oil discovery in Keathley Canyon Block 642 has an announced net oil thickness of 500 ft, and an agreement has been reached to drill a delineation well.

Of the 72 prospects drilled to date, 21 are classified as oil discoveries, resulting in a 29 percent success rate of Lower Tertiary prospects drilled (**Figure 62**). The years 2019 and 2020 only represent operator-announced discoveries, not all Lower Tertiary prospects drilled, due to the proprietary nature of the well data. Recent Lower Tertiary operator-announced discoveries include Monument (Walker Ridge Block 272), in which Equinor announced approximately 200 ft of net oil pay, with a total well depth of 33,348 ft. Shell also announced the Blacktip discovery (Alaminos Canyon Block 380), which encountered more than 400 ft of net oil pay, with good reservoir and fluid characteristics.

The production history of the Lower Tertiary Trend began in 2009 with the installation of the Perdido Regional Host spar in Alaminos Canyon Block 857 in 7,835 ft of water, a world water-depth record for a spar. The spar hosts production from the Great White (Alaminos Canyon 857) and Tobago/Silvertip (Alaminos Canyon 859) Fields. First production at the facility occurred in 2010. The installation of the northern GOM’s first floating production, storage, and offloading (FPSO) facility occurred in 2011 at Walker Ridge Block 249 in approximately 8,300 ft of water. The FPSO began collecting production from the Cascade (Walker Ridge 206) and Chinook (Walker Ridge 469) Fields in 2012. The largest (based on displacement) semisubmersible production platform in the GOM was installed in early 2014 at Walker Ridge Block 718 in approximately 6,950 ft of water. The semisubmersible hosts production from the Jack (Walker Ridge 759) and St. Malo (Walker Ridge 678) Fields. Production from these fields began in late 2014. In September 2016, the Stones (Walker Ridge 508) Field started production in Walker Ridge Block 551 featuring the use of the northern GOM’s second FPSO. This FPSO was installed in approximately 9,560 ft of water, setting the world water-depth record for a production facility. Other production startups from deepwater GOM Lower Tertiary rocks include the Julia (Walker Ridge 627) Field in March of 2016 as a subsea tieback to the Jack/St. Malo semisubmersible, as well as the Buckskin (Keathley Canyon 827) Field in June 2019 as a subsea tieback to the Lucius Spar located in Keathley Canyon Block 875.

Table 6. Deepwater Lower Tertiary publicly released well information.

Planning Area	Year	Prospect Name	Location	Lease	Operator	Partner(s)	Lower Tertiary Section Result
WPA	1996	BAHA	AC Block 600	G08580	Shell	Chevron, Amoco, Mobil, Texaco	Dry Hole
WPA	2001	BAHA-2	AC Block 557	G08272	Shell	Chevron, Amoco, Mobil, Texaco	Dry Hole
CPA	2001	Ponza	KC Block 774	G21441	Union	Devon, Statoil	Dry Hole
WPA	2001	Trident	AC Block 903	G20876	Union	Devon, Chevron, Eni Petroleum, StatoilHydro	Non-Commercial Oil
CPA	2002	Cascade	WR Block 206	G16965	Murphy	No Partner	Oil Discovery (Producing, 2012)
WPA	2002	Great White	AC Block 857	G17565	Shell	BP, Chevron	Oil Discovery (Producing, 2010)
CPA	2003	Chinook	WR Block 469	G16997	Murphy	No Partner	Oil Discovery (Producing, 2012)
CPA	2003	Tahiti	GC Block 727	G16783	Anadarko	Equinor, Chevron	Dry Hole
WPA	2003	Toledo	AC Block 951	G20885	Chevron	Devon, Nippon, Maxus	Non-Commercial Oil
CPA	2003	St. Malo	WR Block 678	G21245	Union	Equinor, Chevron, Exxon, Eni Petroleum	Oil Discovery (Producing, 2014)
WPA	2004	Silvertip	AC Block 815	G19409	Shell	Chevron	Oil Discovery (Producing, 2010)
CPA	2004	Hadrian	KC Block 919	G21447	Exxon, Anadarko	MP Gulf of Mexico LLC, Eni Petroleum	Non-Commercial Oil
WPA	2004	Tiger	AC Block 818	G20863	Chevron	Statoil, Repsol, Nippon	Non-Commercial Oil
CPA	2004	Jack	WR Block 759	G17016	Chevron	Equinor, TEP Jack	Oil Discovery (Producing, 2014)
WPA	2004	Tobago	AC Block 859	G20871	Shell	Union. Chevron, CNOOC Petroleum	Oil Discovery (Producing, 2011)
CPA	2004	Das Bump	WR Block 724	G17011	BP	Petrobras	Non-Commercial Oil
CPA	2004	Sardinia	KC Block 681	G20949	StatoilHydro	No Partner	Dry Hole
WPA	2005	Diamondback	AC Block 739	G19390	BP	Shell, Amerada Hess	Non-Commercial Oil
CPA	2005	Mad Dog South	GC Block 826	G09982	BP	BHP Billiton, Union Oil	Non-Commercial Oil
CPA	2005	Shenzi	GC Block 653	G20084	BHP Billinton	Hess, Repsol	Dry Hole
CPA	2005	Stones	WR Block 508	G17001	Shell	No Partner	Oil Discovery (Producing, 2016)
CPA	2005	Big Foot	WR Block 29	G16942	Cheveron	Equinor, Marubeni	Non-Commercial Oil
CPA	2006	Mission Deep	GC Block 955	G20114	Anadarko	Kerr-McGee, Devon	Dry Hole
CPA	2006	Kaskida	KC Block 292	G25792	BP	No Partner	Oil Discovery
CPA	2006	Tucker	WR Block 544	G17003	BP	Statoil	Non-Commercial Oil
WPA	2007	North Brontosaurus	AC Block 731	G19386	Chevron	Exxon, Statoil, Nippon, Repsol	Dry Hole
CPA	2007	Julia	WR Block 627	G20361	Exxon	Statoil	Oil Discovery (Producing, 2016)
CPA	2007	Cortez Bank	KC Block 244	G19530	BP	Devon	Non-Commercial Oil
CPA	2007	Hal	WR Block 848	G20403	Statoil	No Partner	Non-Commercial Oil
CPA	2007	Atlas	WR Block 155	G18649	Kerr-McGee	Repsol E&P	Non-Commercial Oil
CPA	2008	Damascus	WR Block 581	G25257	Chevron	Devon, Maersk	Dry Hole
CPA	2008	Chuck	WR Block 278	G18675	Devon	Conoco Philips, Exxon, Maersk	Non-Commercial Oil
CPA	2008	Green Bay	WR Block 372	G18701	Anadarko	Statoil, Devon, Conoco Philips, Nippon	Dry Hole
CPA	2008	Buckskin	KC Block 872	G25823	LLOG	Buckstone Development, Repsol E&P, Beacon Offshore, Navitas Buckskin	Oil Discovery (Producing, 2019)
CPA	2009	Shenandoah	WR Block 52	G25232	LLOG	ShenHai, Beacon Offshore	Oil Discovery
CPA	2009	Lewis	WR Block 316	G25246	Chevron	Exxon, Maersk, Hess	Dry Hole
CPA	2009	Salida	GB Block 988	G25696	Freeport-MacMoRan	Plains	Dry Hole
CPA	2009	Rickenbacker	KC Block 470	G22360	Anadarko	Conoco Philips, Plains, StatoilHydro, Woodside Energy	Dry Hole
CPA	2009	Turtle Lake	GC Block 847	G23000	Chevron	Hess, Anadarko, Maersk	Dry Hole
CPA	2009	Bass	KC Block 596	G19600	Devon	Conoco Philips	Dry Hole
CPA	2009	Northwood	GC Block 945	G32547	Freeport-MacMoRan	Plains, Maersk, Maxus	Dry Hole
WPA	2009	Tiber	KC Block 102	G25782	BP	No Partner	Oil Discovery
CPA	2011	Logan	WR Block 969	G26419	Statoil	Ecopetrol, Perobras, OOGC	Non-Commercial Oil
WPA	2011	Cobra	AC Block 810	G31199	Statoil	Ecopetrol, OOGC	Dry Hole
CPA	2011	Moccasin	KC Block 736	G22367	Chevron	Samson Offshore	Non-Commercial Oil
CPA	2012	Bioko	KC Block 698	G33343	Statoil	Shell, Conoco Philips	Dry Hole
CPA	2012	North Platte	GB Block 959	G30876	Total E&P	Equinor	Oil Discovery
CPA	2013	Coronado	WR Block 98	G21841	Anadarko	Conoco Philips, Venari	Oil Discovery
WPA	2013	Gila	KC Block 93	G25780	Chevron	BP, Conoco Philips	Non-Commercial Oil
CPA	2013	Ardennes	GC Block 896	G31765	Cobalt	Total E&P	Dry Hole
CPA	2013	Aegean	KC Block 163	G32606	Cobalt	Total E&P	Dry Hole
CPA	2013	Phobos	SE Block 39	G27779	Anadarko	No Partner	Non-Commercial Oil
CPA	2013	Yucatan North	WR Block 95	G31943	Anadarko	Shell, Nexen, INPEX, Cobalt	Non-Commercial Oil
WPA	2014	Nansen Deep	EB Block 645	G32822	Anadarko	Kerr-McGee, Marubeni	Non-Commercial Oil
WPA	2014	Oceanographer	GB Block 973	G32911	Chevron	Maersk. Samson	Dry Hole
CPA	2014	Leon	KC Block 642	G33335	LLOG	Repsol, Beacon Offshore	Oil Discovery
CPA	2014	Anchor	GC Block 807	G31752	Cheveron	Total E&P, TEP Anchor	Oil Discovery
CPA	2014	K2	GC Block 562	G11075	Anadarko	Ecopetrol, Eni Petroleum, Conoco Philips, JX Nippon	Dry Hole
CPA	2014	Guadalupe	KC Block 10	G27698	BP	No Partner	Oil Discovery
CPA	2015	Key Largo	WR Block 578	G33379	Marathon	Repsol	Dry Hole
CPA	2015	Sweetwater	KC Block 414	G26748	Chevron	BP, Nexen, Venari	Non-Commercial Oil
CPA	2015	Solomon	WR Block 225	G32668	Murphy	Venari	Dry Hole
CPA	2015	Sicily	KC Block 814	G25810	Union	Hess, Nexen	Non-Commercial Oil
WPA	2016	Melmar	AC Block 475	G35137	Hess	No Partner	Non-Commercial Oil
CPA	2016	Dawn Marie	GB Block 998	G31688	Chevron	Shell	Dry Hole
CPA	2016	Goodfellow	KC Block 129	G30924	Cobalt	Total E&P	Dry Hole
WPA	2016	Gibson	KC Block 96	G33531	Chevron	BP	Non-Commercial Oil
WPA	2017	Whale	AC Block 772	G35153	Shell	Chevron	Oil Discovery
CPA	2017	Ipanema	WR Block 376	G33375	Shell	No Partner	Non-Commercial Oil
CPA	2018	Stones SW	WR Block 595	G36088	Shell	No Partner	Dry Hole
WPA	2019	Blacktip	AC Block 380	G32954	Shell	Chevron, Equinor, Repsol E&P	Announced Oil Discovery
CPA	2020	Monument	WR Block 272	G35081	Equinor	Progress Resources, Repsol E&P	Announced Oil Discovery

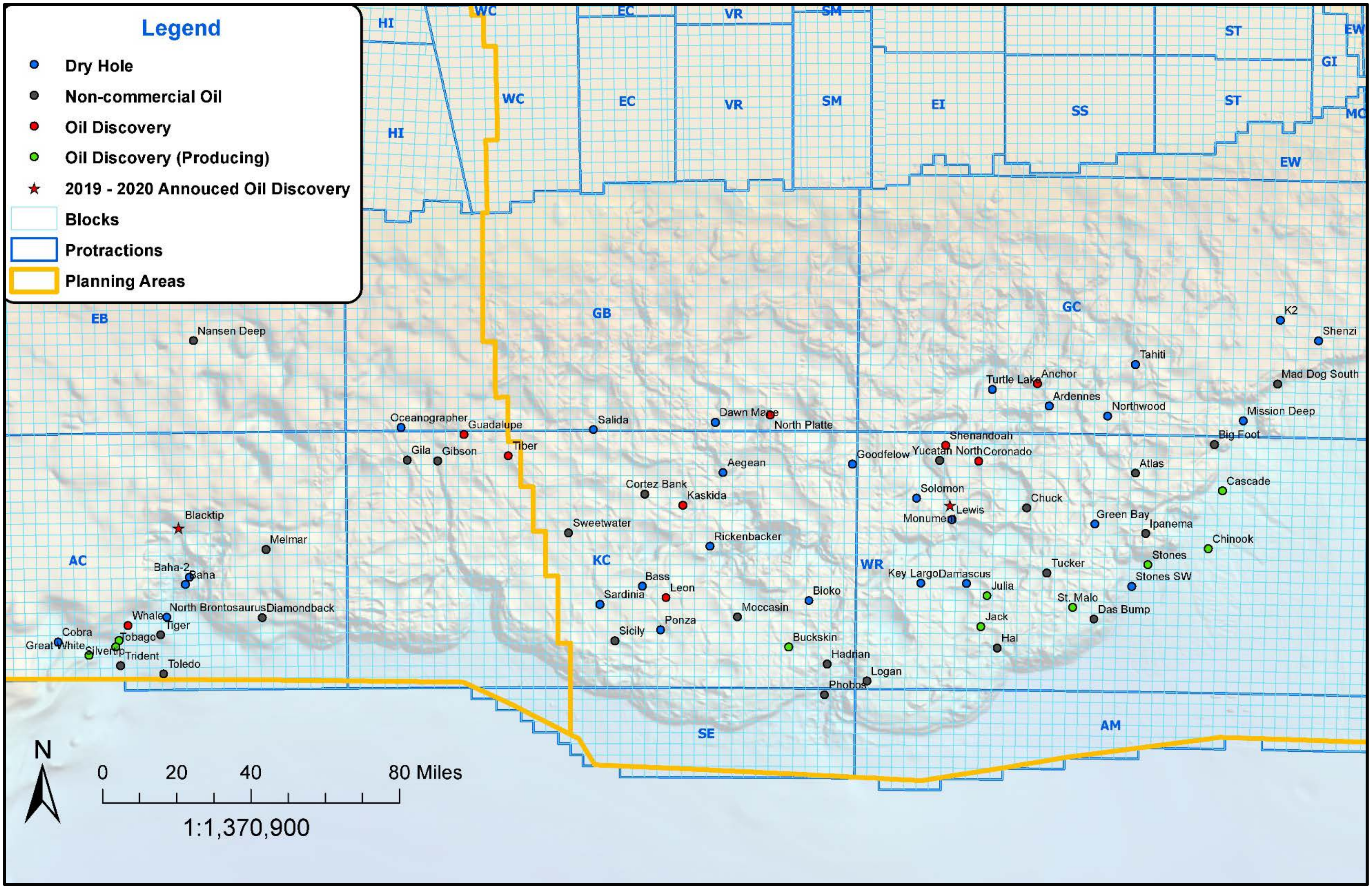


Figure 61. Deepwater Lower Tertiary Trend.

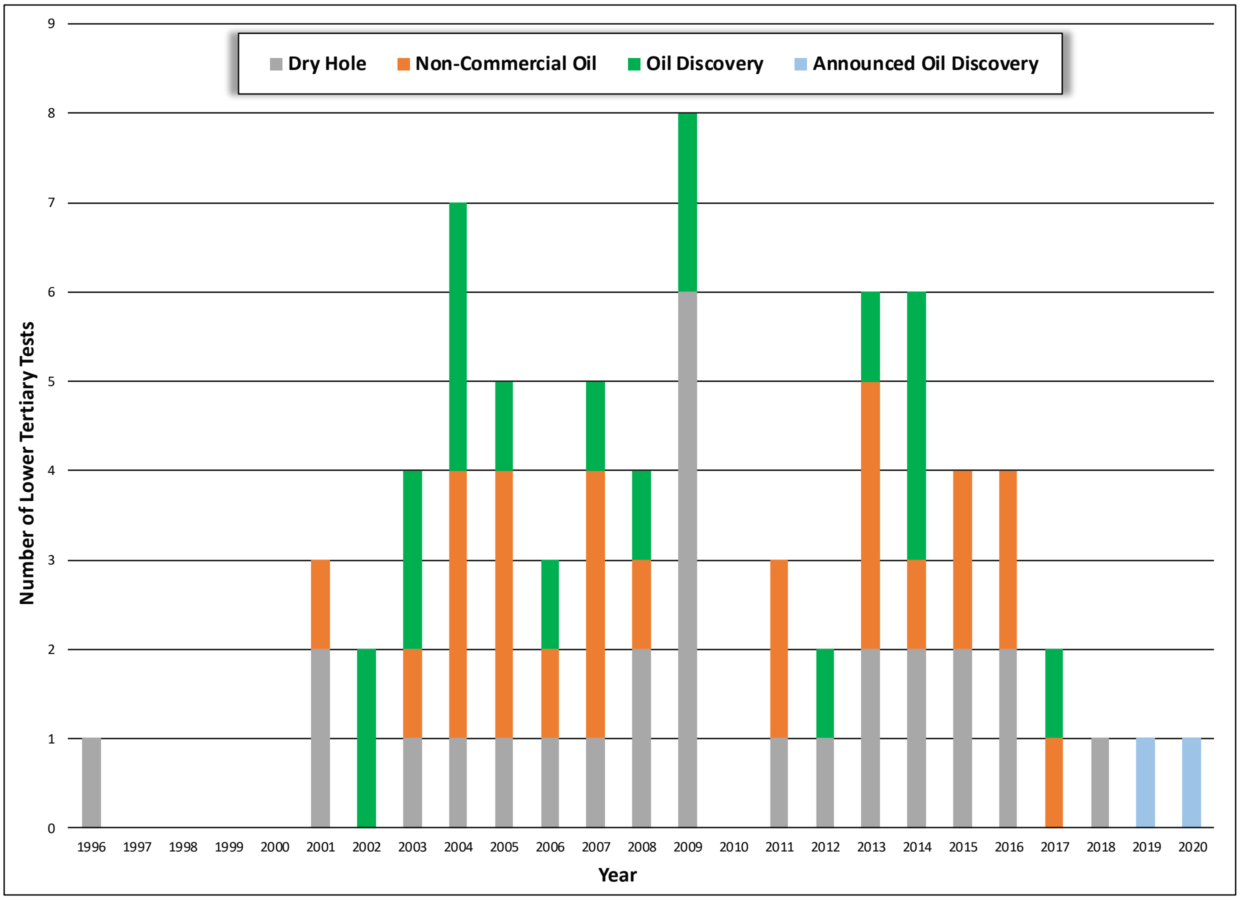


Figure 62. Number of deepwater Lower Tertiary well tests.

UPPER JURASSIC NORPHLET TREND

An active exploration trend for 17 years in the deepwater Mesozoic has been the Upper Jurassic Norphlet Aeolian Dune Play (**Table 5**). The onset of the deepwater portion of the Norphlet Play was initiated in 2003 by Shell Offshore and Nexen Petroleum with the drilling of their Shiloh prospect in De Soto Canyon Block 269 (Lease Sale 181). The well encountered approximately 100 ft of oil column within the aeolian Norphlet section of the Upper Jurassic. The drilling of this single well was a proof-of-concept for this play by proving the presence of hydrocarbon source rock (Smackover, **Table 5**), reservoir rock (Norphlet), and vertical and horizontal seals (also Smackover). A working petroleum system had been established. The operator has since reclassified Shiloh as a “non-commercial” discovery.

Shiloh, along with the Vicksburg “B” well (De Soto Canyon Block 353) drilled in 2007, extended the Norphlet Play from the natural gas producing shallow-water play in the Mobile Bay/Destin Dome areas, southward into the oil prone, deepwater (>7,200 ft) protractions of Mississippi Canyon and De Soto Canyon.

Oil industry majors and larger independents have been the most active participants in acquiring available lease blocks in the eastern part of the CPA and western portion of the EPA. Primary protractions of interest include De Soto Canyon, Lloyd Ridge, and Mississippi Canyon, where the primary reservoir is aeolian dune sands. Nineteen CPA, EPA, and GOM areawide lease sales have been held since the drilling of the Shiloh well in 2003, with 451 blocks (2,597,760 acres) leased. Bonus bids accepted for the blocks have totaled $1,134,357,166 (**Table 7**).

Table 7. Deepwater Norphlet lease sale information.

Lease Sale	Date	Planning Area	Number of Blocks Receiving Bids	Total of High Bids	Participating Companies
Sale 197	March 2005	EPA	12	$6,974,531	Anadarko Petroleum, Devon Energy, Dominion Exploration and Production, Helis Oil and Gas, Houston Energy, Newfield Exploration, Petrobras America, Red Willow Offshore, Spinnaker Exploration
Sale 205	October 2007	CPA	96	$418,728,078	Anadarko Exploration and Production, Eni Petroleum US, Hess Corporation, KNOC USA, LLOG Exploration Offshore, Marathon Oil, Mariner Energy, Murphy Exploration and Production, Nexen Petroleum Offshore, Petrobras America, Shell Offshore, Stephens Production, Stone Energy
Sale 224	March 2008	EPA	36	$64,713,213	BHP Billiton, Eni Petroleum US, BP Exploration and Production
Sale 208	March 2009	CPA	13	$6,476,545	Anadarko Petroleum, Shell Offshore
Sale 213	March 2010	CPA	8	$9,662,605	BHP Billiton, Murphy Exploration and Production, Shell Offshore, Statoil Gulf Properties
Sale 216/222	June 2012	CPA	54	$85,101,084	Anadarko US Offshore, BHP Billiton, BP Exploration and Production, Chevron USA, Ecopetrol America, LLOG Exploration Offshore, Murphy Exploration and Production, Nexen Petroleum, Nobel Energy, Shell Offshore, Statoil Gulf of Mexico, Stone Energy
Sale 227	March 2013	CPA	59	$179,459,461	Anadarko US Offshore, Apache Deepwater, BHP Billiton, Chevron USA, Ecopetrol America, Eni Petroleum, LLOG Bluewater Holding, Murphy Exploration and Production, Repsol Exploration, Shell Offshore, Stone Energy, Venari Offshore
Sale 225	March 2014	EPA	0	$0	
Sale 231	March 2014	CPA	66	$161,113,401	BP Exploration & Production, BHP Billiton, Chevron USA, Cobalt International, Ecopetrol America, Murphy Exploration & Production, Noble Energy, Ridgewood Energy, Shell Offshore, Statoil Gulf of Mexico, Total Exploration & Production USA, Venari Offshore
Sale 235	March 2015	CPA	6	$4,884,029	Cobalt Int'l Energy, Shell Offshore, Total Exploration and Production USA
Sale 226	March 2016	EPA	0	$0	
Sale 241	March 2016	CPA	6	$28,807,716	Chevron USA, Exxon/Mobil, Shell Offshore
Sale 247	March 2017	CPA	10	$12,761,540	Shell Offshore, Total Exploration & Production, Exxon/Mobil, Chevron USA
Sale 249	August 2017	CPA	3	$2,728,058	Anadarko US Offshore, Shell Offshore
Sale 250	March 2018	CPA	11	$23,292,534	BP Exploration & Production, Total Exploration & Production USA, Chevron USA, Deep Gulf Energy
Sale 251	August 2018	CPA	40	$88,794,510	Exxon/Mobil, Anadarko US Offshore, BP Exploration & Production, Total Exploration & Production USA, Chevron USA, Talos Energy, Kosmos Energy
Sale 252	March 2019	CPA	15	$29,120,148	BP Exploration & Production, Total Exploration & Production USA, Anadarko US Offshore, Shell Offshore
Sale 253	August 2019	CPA	13	$10,009,823	Shell Offshore, BP Exploration & Production, Chevron USA
Sale 254	March 2020	CPA	3	$1,729,890	BP Exploration & Production

A total of 31 exploratory/delineation wells have been drilled to test/evaluate the Norphlet section of the Upper Jurassic in deep water through mid-2018, resulting in potentially seven commercial discoveries (**Figure 63** and **Table 8**).

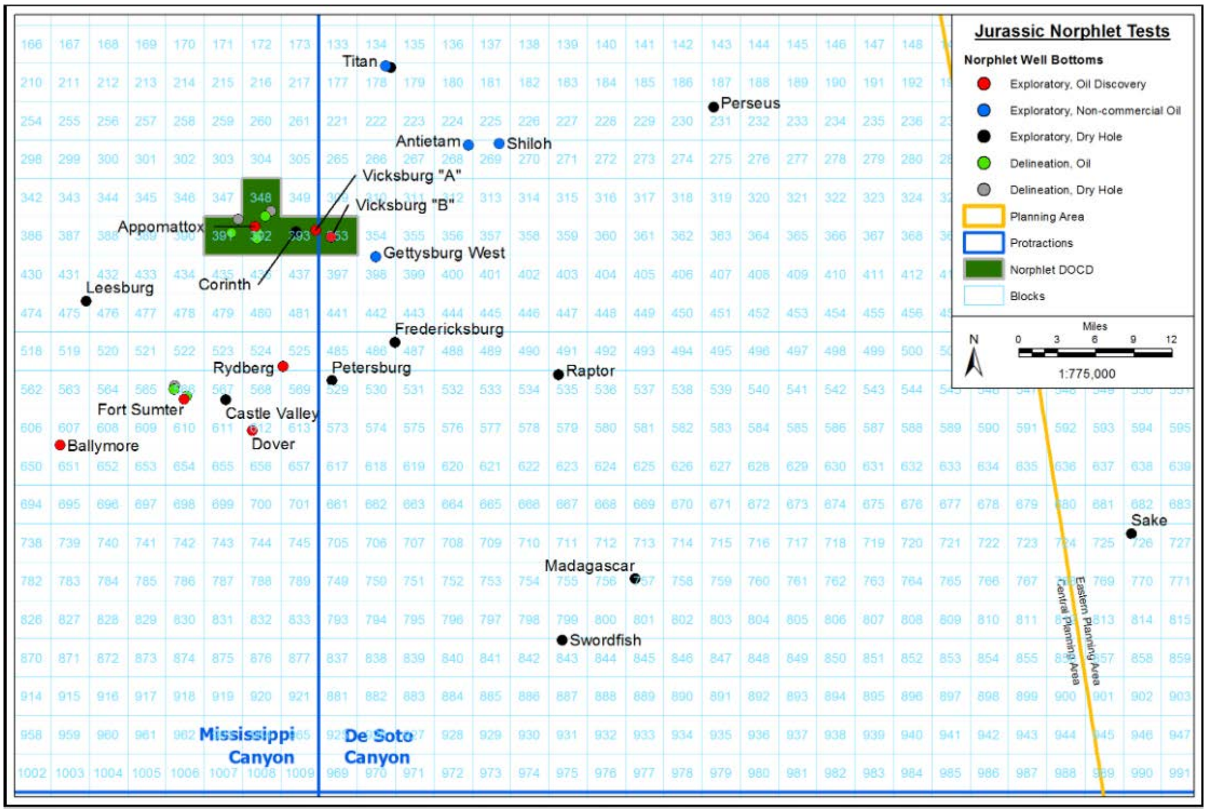


Figure 63. Deepwater Norphlet Trend.

Table 8. Deepwater Norphlet publicly released well information.

Planning Area	Year	Prospect Name	Location	Lease	Type of Well	Number of Wells	Operator	Partner(s)	Norphlet Section Result
CPA	2003	Shiloh	DC Block 269	G23502	Exploratory	1	Shell	Nexen	Non-Commercial Oil
CPA	2007	Vicksburg "B"	DC Block 353	G25852	Exploratory	1	Shell	Nexen	Oil Discovery
CPA	2008	Fredericksburg	DC Block 486	G25855	Exploratory	1	Shell	Nexen, Plains	Dry Hole
CPA	2009	Appomattox	MC Block 392	G26253	Exploratory	1	Shell	Nexen	Oil Discovery
CPA	2009	Appomattox	MC Block 392	G26253	Delineation	3/1 lost	Shell	Nexen	2 Wells Oil
CPA	2009	Antietam	DC Block 268	G23501	Exploratory	3/2 lost	Shell	Nexen	Non-Commercial Oil
CPA	2011	Appomattox	MC Block 348	G19939	Delineation	2	Shell	Nexen	1 Well Oil/1 Well Dry
CPA	2012	Appomattox	MC Block 391	G26252	Delineation	2	Shell	Nexen	1 Well Oil/1 Well Dry
CPA	2013	Raptor	DC Block 535	G23520	Exploratory	1	Anadarko	BHP	Dry Hole*
CPA	2013	Madagascar	DC Block 757	G31570	Exploratory	1	Marathon	Murphy, Ecopetrol	Dry Hole
CPA	2013	Swordfish	DC Block 843	G23540	Exploratory	1	Shell	Nexen, Eni	Dry Hole
CPA	2013	Petersburg	DC Block 529	G23517	Exploratory	1	Shell	Nexen	Dry Hole
CPA	2013	Vicksburg "A"	MC Block 393	G26254	Exploratory	1	Shell	Nexen	Oil Discovery
CPA	2013	Corinth	MC Block 393	G26254	Exploratory	2/1 lost	Shell	Nexen	Dry Hole
EPA	2013	Sake	DC Block 726	G32014	Exploratory	2/1 lost	BHP	Statoil	Dry Hole
CPA	2014	Rydberg	MC Block 525	G31507	Exploratory	2/1 lost	Shell	Nexen, Ecopetrol	Oil Discovery
CPA	2014	Titan	DC Block 178	G25850	Exploratory	3/1 lost	Murphy	Ecopetrol, Venari	Non-Commercial Oil
CPA	2014	Perseus	DC Block 231	G33780	Exploratory	1	Statoil	BHP, Marathon	Dry Hole
CPA	2014	Gettysburg West	DC Block 398	G25854	Exploratory	1	Shell	Nexen	Non-Commercial Oil
CPA	2016	Leesburg	MC Block 475	G35335	Exploratory	1	Shell	Chevron, Venari	Dry Hole
CPA	2016	Fort Sumter	MC Block 566	G08831	Exploratory	1	Shell	No Partner	Oil Discovery
CPA	2016	Fort Sumter	MC Block 566	G08831	Delineation	3	Shell	No Partner	2 Wells Oil/1 Well Dry
CPA	2017	Castle Valley	MC Block 567	G33744	Exploratory	2/1 lost	Shell	No Partner	Dry Hole**
CPA	2018	Ballymore	MC Block 607	G34451	Exploratory	3/2 lost	Chevron	Total	Oil Discovery
CPA	2018	Dover	MC Block 612	G33166	Exploratory	2/1 lost	Shell	No Partner	Oil Discovery

*The Raptor well did penetrate 150 ft of oil in the younger Jurassic Haynesville section (non-commercial).

**The Castle Valley well, programmed to test the Norphlet, stopped drilling and plugged and abandoned the well above the Norphlet objective.

In the CPA through mid-2018, 41 wellbores have been drilled, of which 22 are classified as exploratory, 9 are categorized as delineation, and the remaining 10 were lost due to mechanical problems or shallow-water flow. All of these wells are located in northwest De Soto Canyon and northeast Mississippi Canyon. Water depths in this area are in excess of 7,000 feet. Average drilling footage for the wellbores reaching total depth is approximately 25,000 ft, with overall drilling times of 100 to 150 days per well. In the EPA, two wells have been drilled, with one classified as exploratory and the other lost due to shallow-water flow problems. The borehole is located on the Florida Escarpment in block 726 of south-central De Soto Canyon. The wellbore is located in 3,575 ft of water and was drilled to 18,365 ft. Drilling time was 44 days.

There are two companies who have announced significant Norphlet oil discoveries. Shell Offshore, via press releases, has announced several significant deepwater discoveries associated with the Jurassic Norphlet play as follows: Appomattox (Mississippi Canyon Block 392), Vicksburg "A" (Mississippi Canyon Block 393), Rydberg (Mississippi Canyon Block 525), Fort Sumter (Mississippi Canyon Block 566), and Dover (Mississippi Canyon Block 612). Chevron released a press release for their discovery at Ballymore (Mississippi Canyon Block 607). All are located in northeast Mississippi Canyon (**Figure 64**). These wells penetrated significant oil-bearing Norphlet sand intervals at depths in excess of 24,000 ft. Through mid-2018, Shell, as operator, along with its partner, has drilled delineation wells at Appomattox and Fort Sumter.

Shell has estimated the discovered resources associated with Appomattox/Vicksburg "A" to be approximately 650 MMBOE. Their development operations coordination document (DOCD) indicates a subsea production system featuring 6 drill centers, 15 producing wells, and 5 water injection wells tied back to a semisubmersible platform located on Mississippi Canyon Block 437. The date of first production for the project was May 2019.

Shell has assessed the Norphlet aeolian reservoir and its associated oil characteristics. Whole core examination, along with the analysis of associated well logs, established a dune type change in the aeolian deposits from the individual seif (longitudinal) and star dune setting in the north to an area with barchan (horned) dunes in a coalesced erg environment in the south (**Figure 64**) (Godo et al., 2011). In addition to two sequences of barchanoid dunes (both sinuous and straight-crested forms), these core and log analyses also identified three additional large-scale depositional intervals: (1) interbedded lacustrine mudrocks; (2) stacked aeolian sheets and/or sheetflood facies; and (3) mixed coastal sand sheets with some waterlain sabkha facies (Godo et al., 2011).

The structure of each Norphlet prospect is contained within and controlled by tectonic rafts that detached along the Florida Escarpment and translated basinward by gravity gliding on the autochthonous Louann Salt in the late Jurassic to early Cretaceous (Pilcher et al., 2014). A common Norphlet well log response is illustrated in **Figure 65** with the Appomattox discovery in Mississippi Canyon Block 392. The Norphlet section, deposited on the Louann Salt, consists of clean, blocky, medium- to fine-grained aeolian dune deposits. Some wells drilled to date also contain a Norphlet fluvial section consisting of alternating shale and channel sand beds. Porosities, permeabilities, and net-to-gross intervals all decrease toward the east as fluvial interaction increases away from the well-developed dune field to the west (**Figures 66 and 67**). The Norphlet section is overlain by the Smackover Formation, which is a carbonate-rich section that acts as both the seal and hydrocarbon source for Norphlet reservoirs. In the contacts between the Smackover and the top of the Norphlet, both abrupt and gradational have been observed.

Primary play risks identified to date within the deepwater area include the presence of a reservoir, reservoir quality, and hydrocarbon properties, including the presence of asphaltenes, which can restrict hydrocarbon flow. Additional risks include timing (trap creation relative to hydrocarbon generation and expulsion) and trap seal (vertical and horizontal) for hydrocarbon preservation.

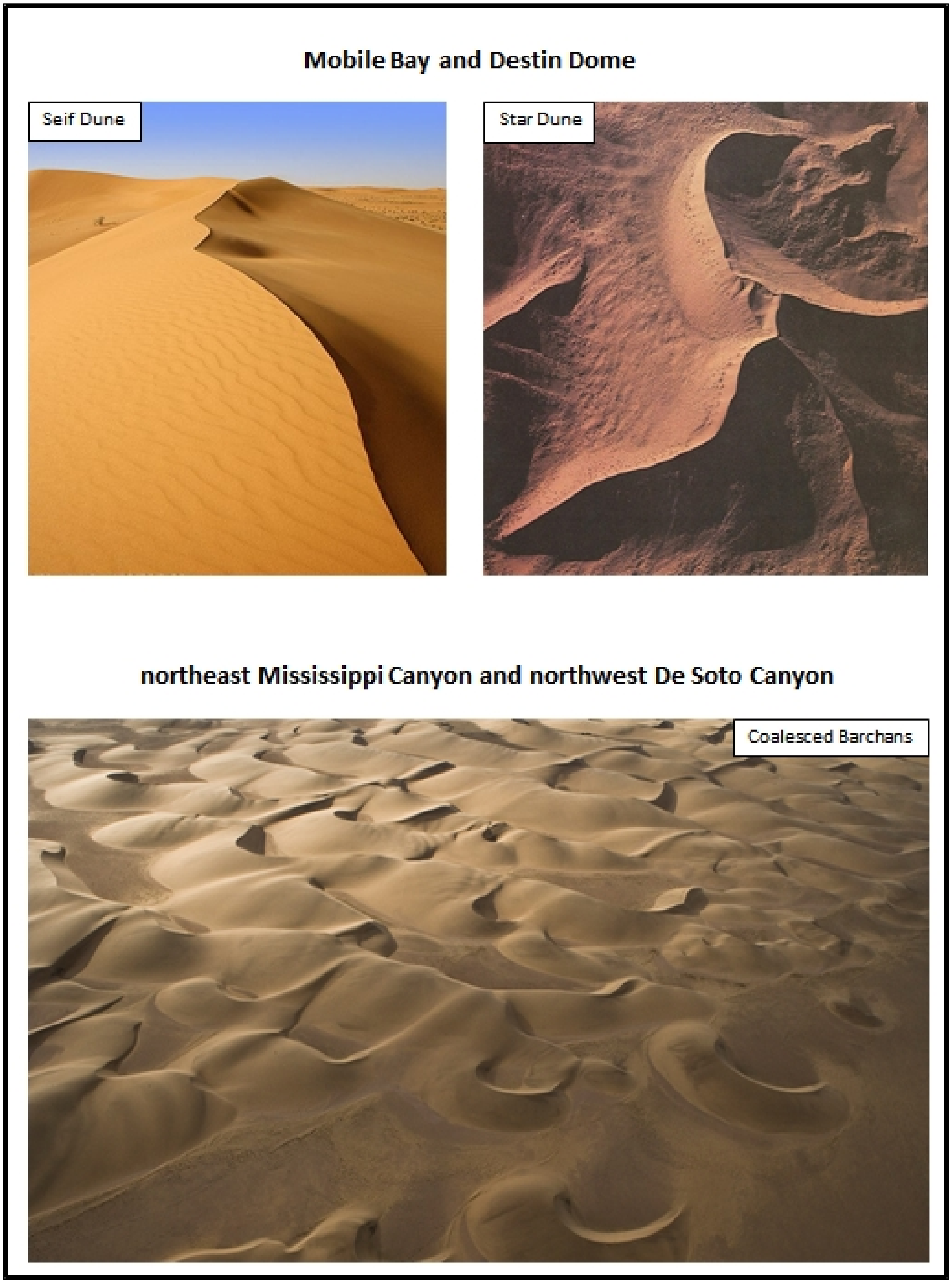


Figure 64. Aeolian dune type change from shallow-water to deepwater Norphlet.

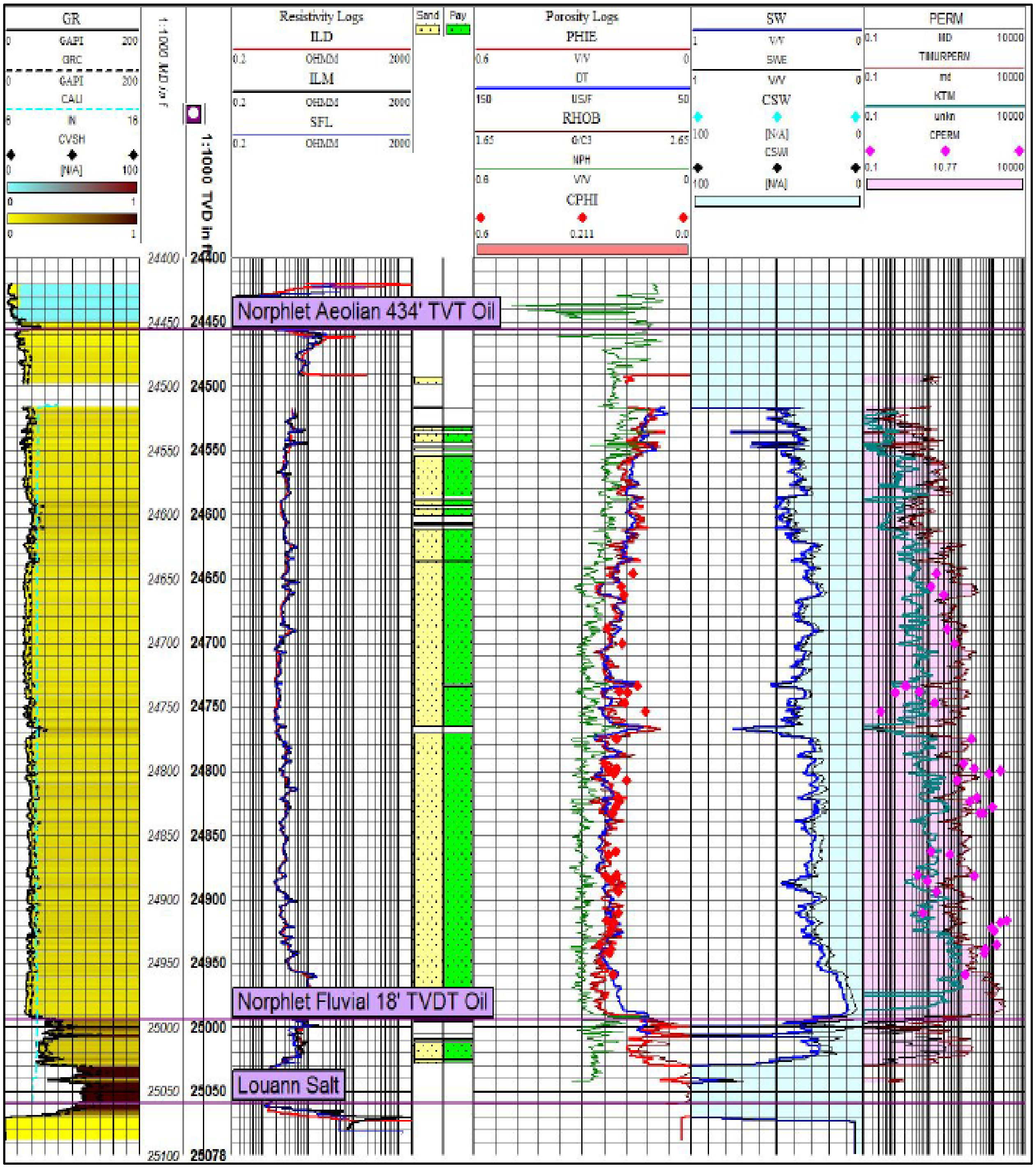


Figure 65. Norphlet well log response in the Appomattox discovery in Mississippi Canyon Block 392.

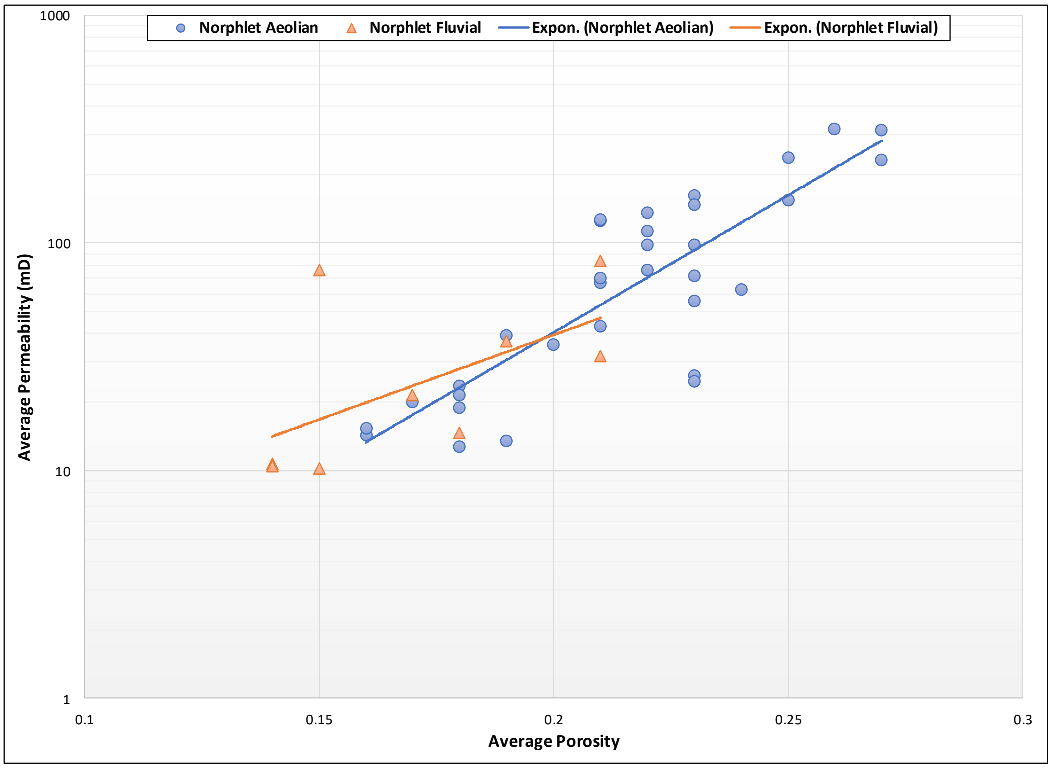


Figure 66. Porosity and permeability crossplot by Norphlet facies.

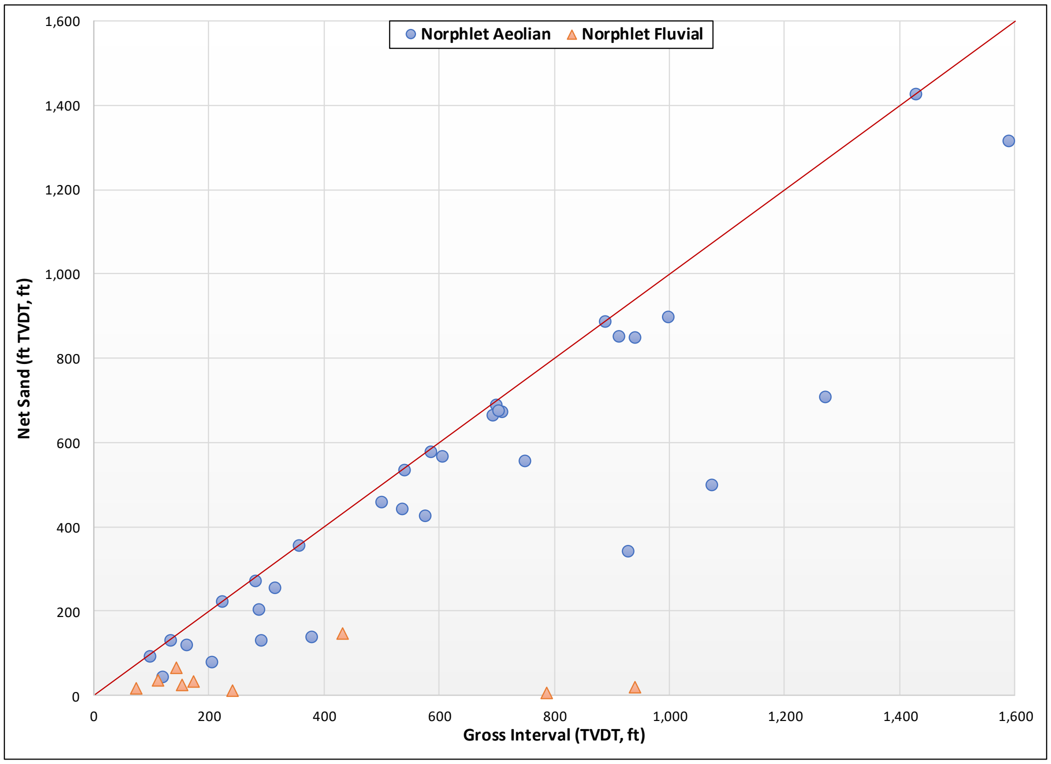


Figure 67. Net sand to gross interval crossplot by Norphlet facies.

DEEPWATER WILCOX AND NORPHLET COMPARISONS

Some Wilcox (Lower Eocene-Upper Paleocene) and Norphlet (Upper Jurassic) reservoirs in the deepwater GOM are characterized by either high pressure or high temperature. When comparing the Wilcox and Norphlet, three distinct pressure and temperature trends are observed.

1) Wilcox reservoirs located within Alaminos Canyon are associated with lower temperatures and pressures.
2) Wilcox reservoirs located outside Alaminos Canyon are associated with higher pressures.
3) Deepwater Norphlet reservoirs are associated with higher temperatures.

Figure 68 illustrates the depth to the top of the Wilcox Formation (Lower Eocene) and the depth to the top of the Norphlet Formation, within each respective trend. The top of the Wilcox Formation in the WPA's Alaminos Canyon associated with the Perdido Fold Belt is generally encountered at a depth much shallower than the rest of the deepwater Wilcox Trend. Depths are less than 20,000 ft, with an average depth of approximately 14,000 ft. The top of the Wilcox Formation located in the WPA and CPA outside of Alaminos Canyon is generally much deeper (25,000 to 35,000 ft). Both water depth up to 10,000 ft as well as the presence of a thick (5,000 to 20,000 ft) complicated salt canopy system overlying much of the targeted sediments contribute to the deeper target depths. The depth to the top of the deepwater Norphlet Formation ranges from 21,000 to 28,000 ft, with an average depth of 25,000 ft.

Pressure and temperature generally increase with depth. **Figure 69** shows the distribution of pressures associated with the top of the Wilcox and Norphlet Formations. These pressures are estimated reservoir pressures at depth. They were calculated based on formation depth and an adjusted drill mud weight to compensate for drilling slightly overbalanced. The Bureau of Safety and Environmental Enforcement (BSEE) identifies a high-pressure environment within a well when at least one of the following conditions is met:

1) the well completion equipment or well control equipment is assigned a pressure rating greater than 15,000 pounds per square inch absolute (psia) and
2) the maximum anticipated surface pressure or shut-in tubing pressure is greater than 15,000 psia on the seafloor for a well with a subsea wellhead or at the surface for a well with a surface wellhead (USDOI, BSEE, 2019).

While **Figure 69** does not depict the pressure at the wellhead, it does identify that the deeper Wilcox Formation outside of the Perdido Fold Belt area has higher reservoir pressures associated with it. The result of its much shallower depth, the Wilcox Formation in the Alaminos Canyon Area exhibits the lowest of the pressures. The pressure versus depth crossplot in **Figure 70** also illustrates the differences in pressure between the Wilcox Formation located within Alaminos Canyon, the Wilcox Formation outside of Alaminos Canyon, and the deepwater Norphlet Formation. Because many of the Wilcox reservoirs are typically 20,000+ psi and 30,000+ ft deep, advancements and continuing improvements in high-pressure drilling technology have had to occur in order to explore and develop this geologic trend economically. In December 2019, Chevron Corporation announced the sanctioning of its Anchor (Green Canyon Block 807) project. It marks industry's first deepwater, high-pressure (20,000 psi) development to achieve a final investment decision.

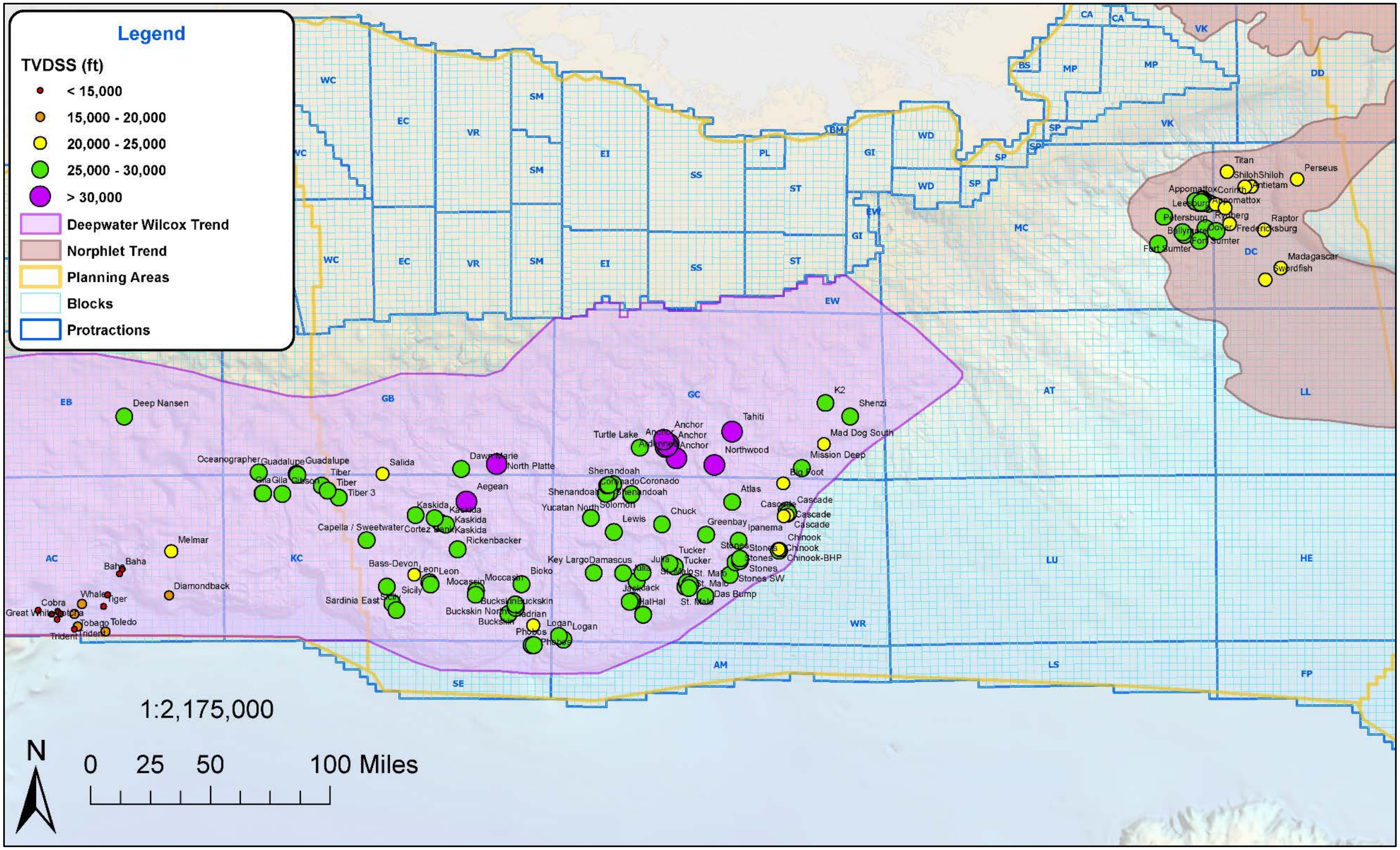


Figure 68. Depth to top of the Wilcox and Norphlet Formations.

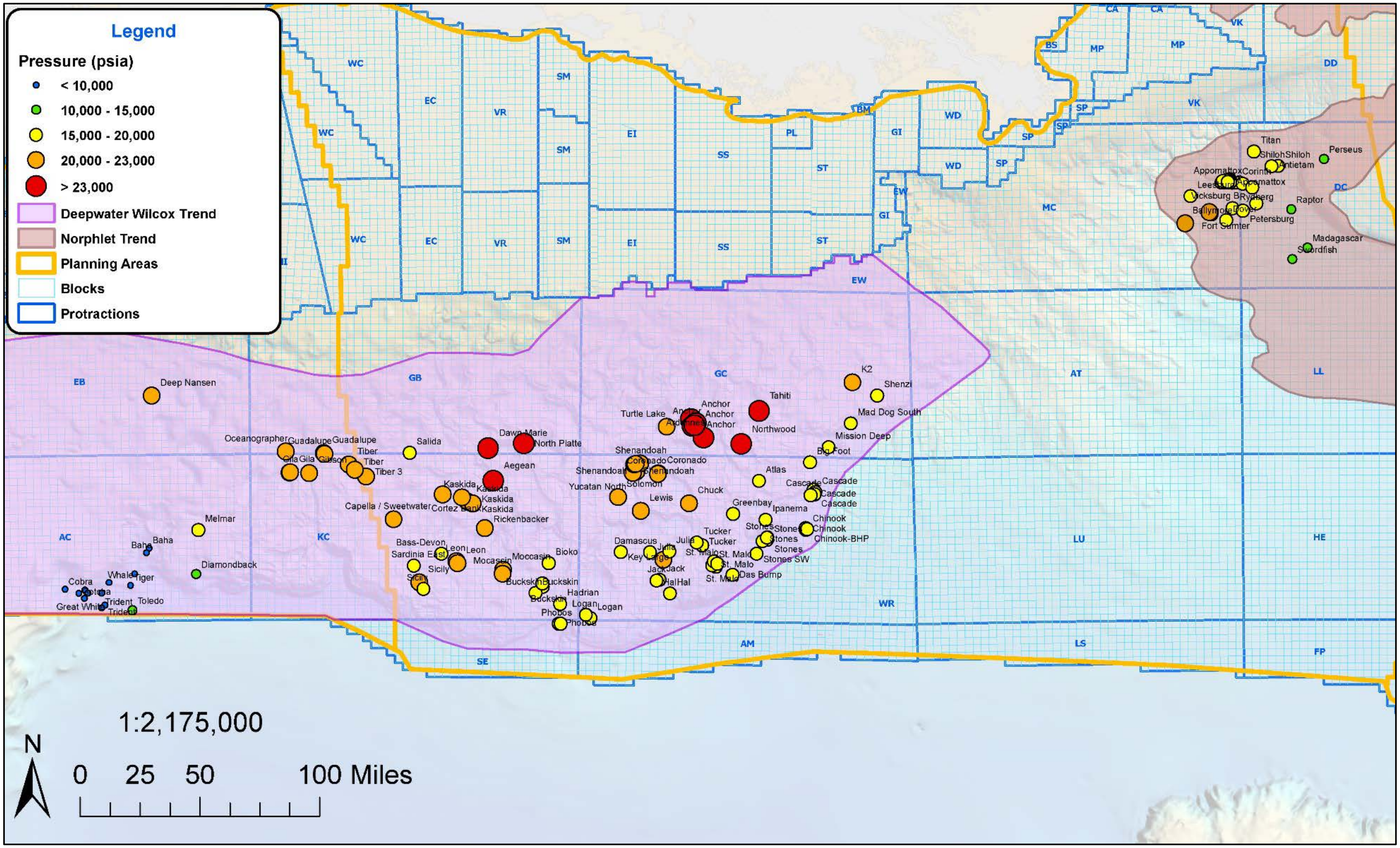


Figure 69. Geographic distribution of formation pressures at the top of the Wilcox and Norphlet Formations.

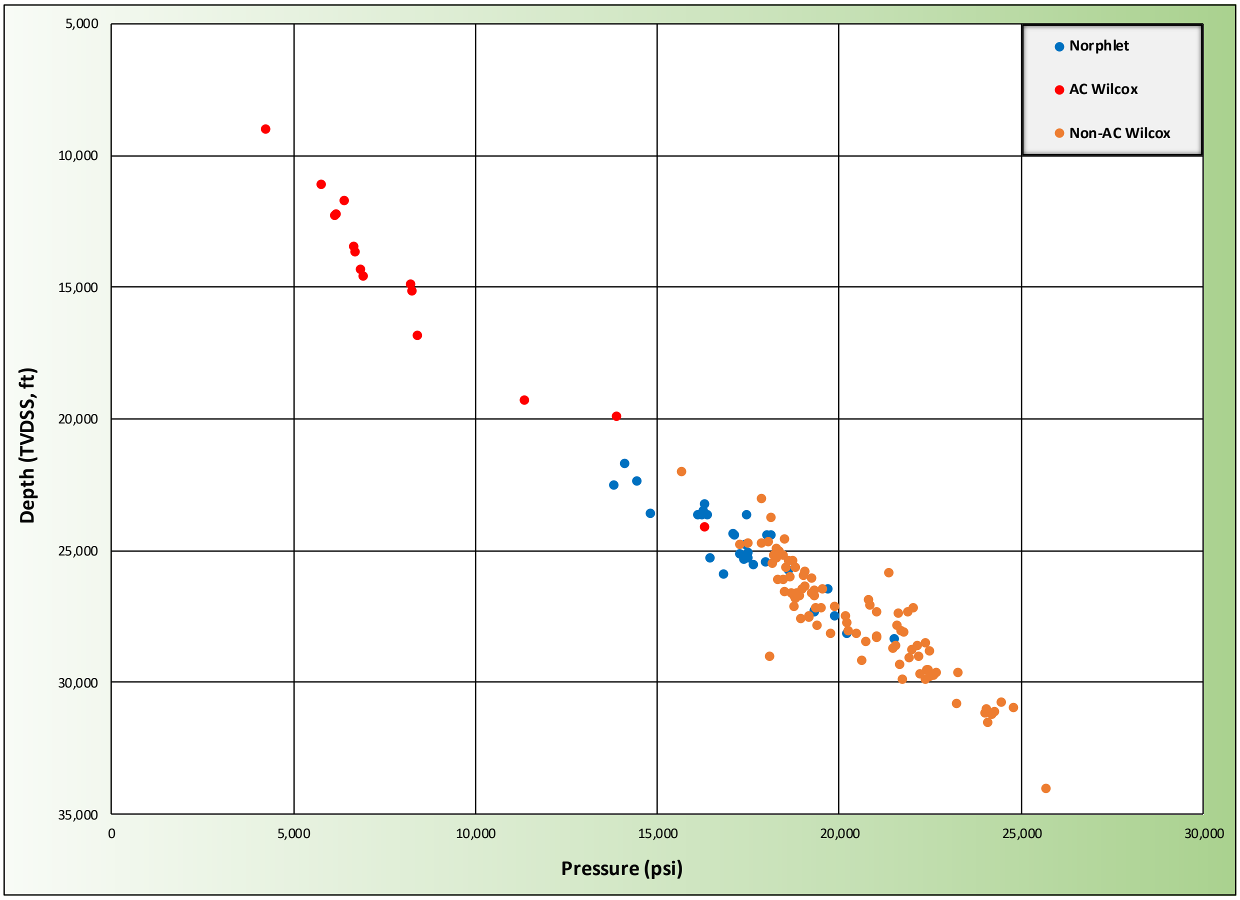


Figure 70. Formation pressures by depth at the top of the Wilcox and Norphlet Formations.

Figure 71 shows the distribution of temperatures associated with the top of the Wilcox and Norphlet Formations. These estimated top of formation temperatures are derived from wireline log bottom-hole temperatures where available. BSEE identifies a high-temperature environment within a well when at least one of the following conditions is met:

1) the well completion equipment or well control equipment is assigned a temperature rating greater than 350 degrees Fahrenheit and
2) the flowing temperature is equal to or greater than 350 degrees Fahrenheit on the seafloor for a well with a subsea wellhead or at the surface for a well with a surface wellhead (USDOI, BSEE, 2019).

While **Figure 71** does not depict the temperature at the wellhead; it does demonstrate the higher reservoir temperatures associated with the deepwater Norphlet Formation. The temperature versus depth crossplot in **Figure 72** illustrates the differences in temperature between the Wilcox Formation located within Alaminos Canyon, the Wilcox Formation outside of Alaminos Canyon, and the deepwater Norphlet Formation. Even though many of the non-Alaminos Canyon Wilcox reservoirs are deeper than the Norphlet reservoirs, they are lower in temperature due to thick overlying salt canopies. Shell's deepwater Norphlet Appomattox (Mississippi Canyon Block 392) project was the first high-temperature project to gain BSEE's approval and to begin production in May 2019.

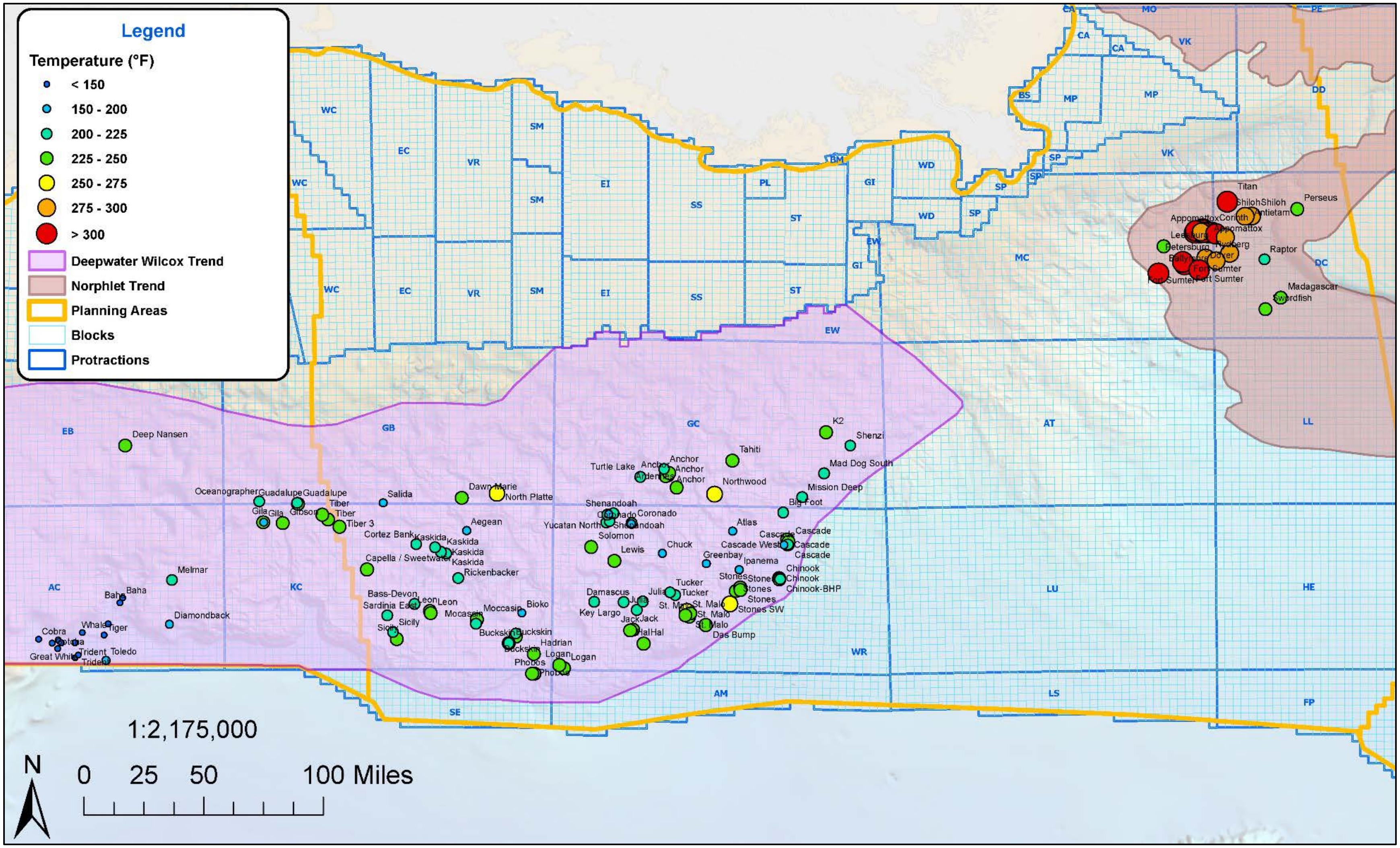


Figure 71. Geographic distribution of formation temperatures at the top of the Wilcox and Norphlet Formations.

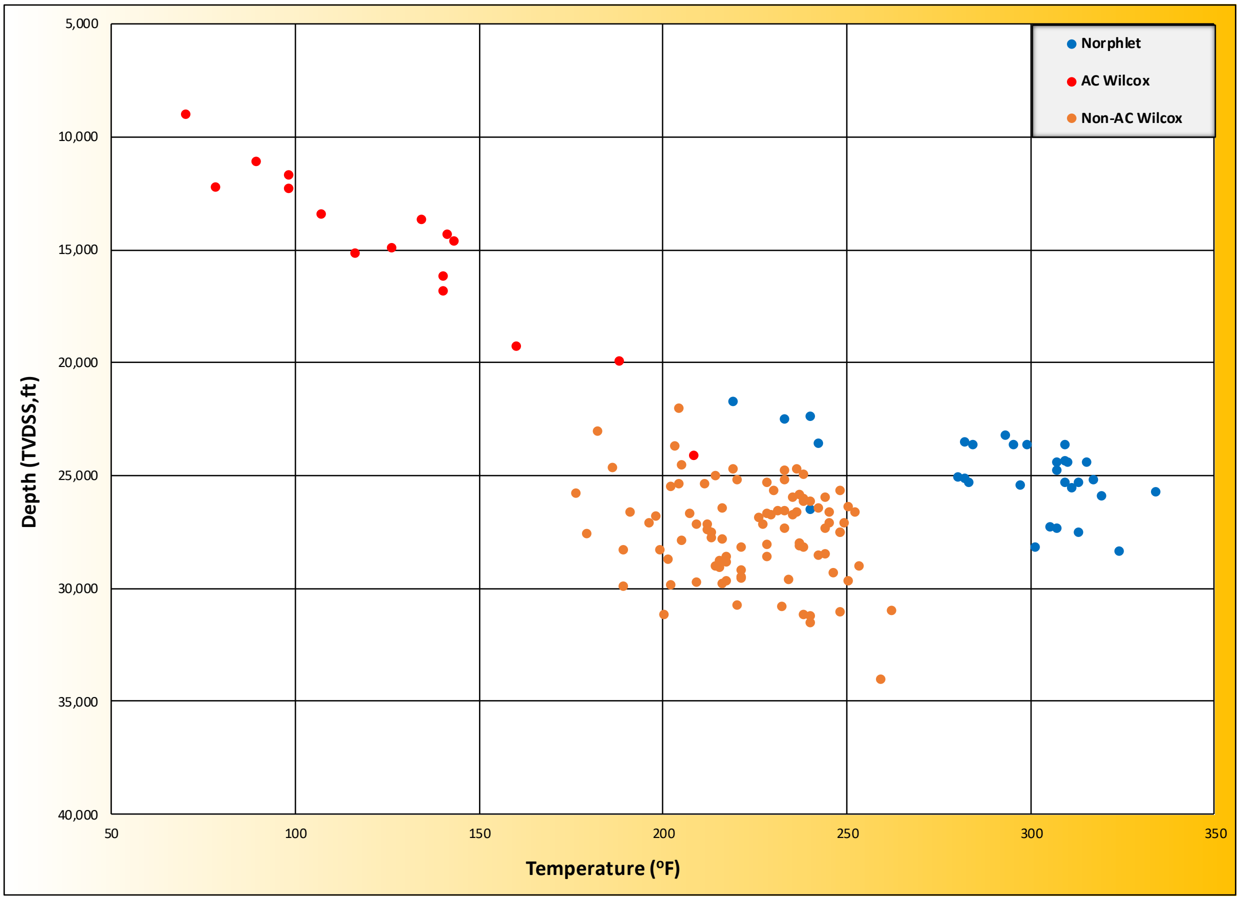


Figure 72. Formation temperatures by depth at the top of the Wilcox and Norphlet Formations.

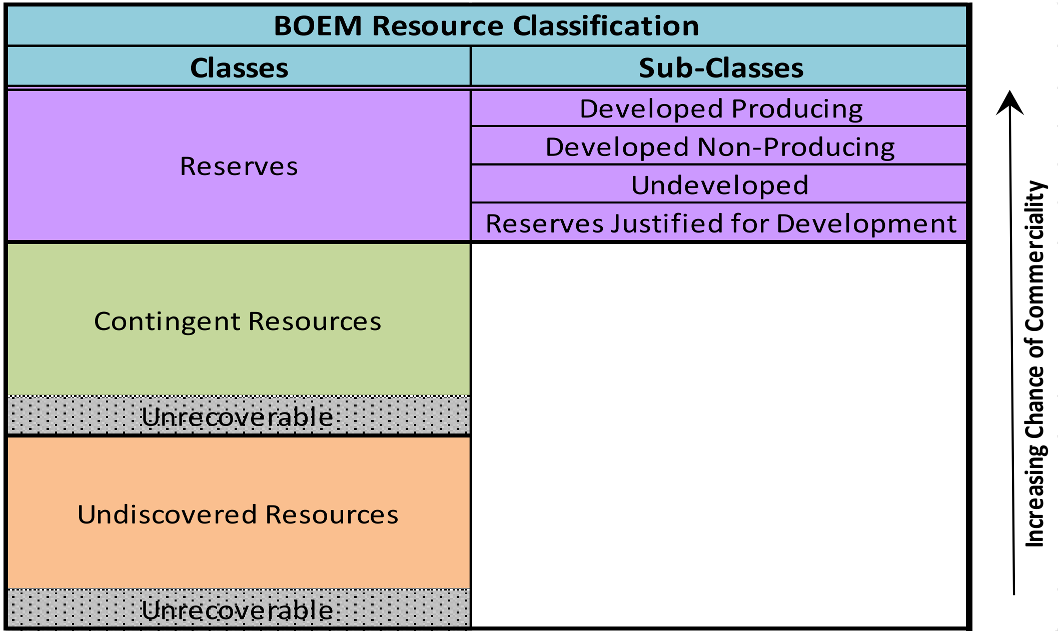
RESERVES AND RESOURCES

CLASSIFICATION

Table 9 shows the system of resource classification used by BOEM. Once a successful exploratory well is drilled, the process that BOEM uses to move its resource estimates to reserves generally proceeds as stated below.

- At the point in time a discovery is made, the identified accumulation of hydrocarbons is classified as Contingent Resources, since a development project has not yet been identified.
- When the lessee makes a formal commitment to develop and produce the accumulation, it is classified as Reserves Justified for Development.
- During the period when infrastructure is being constructed and installed, the accumulation is classified as Undeveloped Reserves.
- After the equipment is in place and production of the accumulation has begun, the status becomes Developed Producing Reserves.
- Fields that are depleted or have expired, relinquished, or terminated without production are classified as Developed Non-Producing.

Table 9. BOEM resource classification. Modified from Burgess et al. (2020a).



BOEM Resource Classification	
Classes	**Sub-Classes**
Reserves	Developed Producing
	Developed Non-Producing
	Undeveloped
	Reserves Justified for Development
Contingent Resources	
Unrecoverable	
Undiscovered Resources	
Unrecoverable	

RESERVES INVENTORY

Volumes of original reserves and cumulative production for the Gulf of Mexico OCS are published annually by BOEM. As of the end of 2019, BOEM's reserves inventory contains volumetric estimates of 61,825 MMBOE (Burgess et al., 2020b), with 18,048 MMBOE coming from deepwater fields (**Figure 73**). Reportable contingent resources increase BOEM volumes by 5,450 MMBOE (**Figure 73**), with 79 percent of those resources in resources in deep water. Contingent resources can be found in oil and gas fields where the lessee has not made a formal commitment to develop the project; in leases that have not yet qualified and have not been placed in a field; and in fields that expired, relinquished, or terminated without production. The 5,450 MMBOE contingent-resource value does not represent all of the contingent resources in the GOM, as newer discoveries, and other discoveries that never reached a development commitment, may not have a BOEM-volume estimate. As new drilling and development occur, additional hydrocarbon volumes may become reportable.

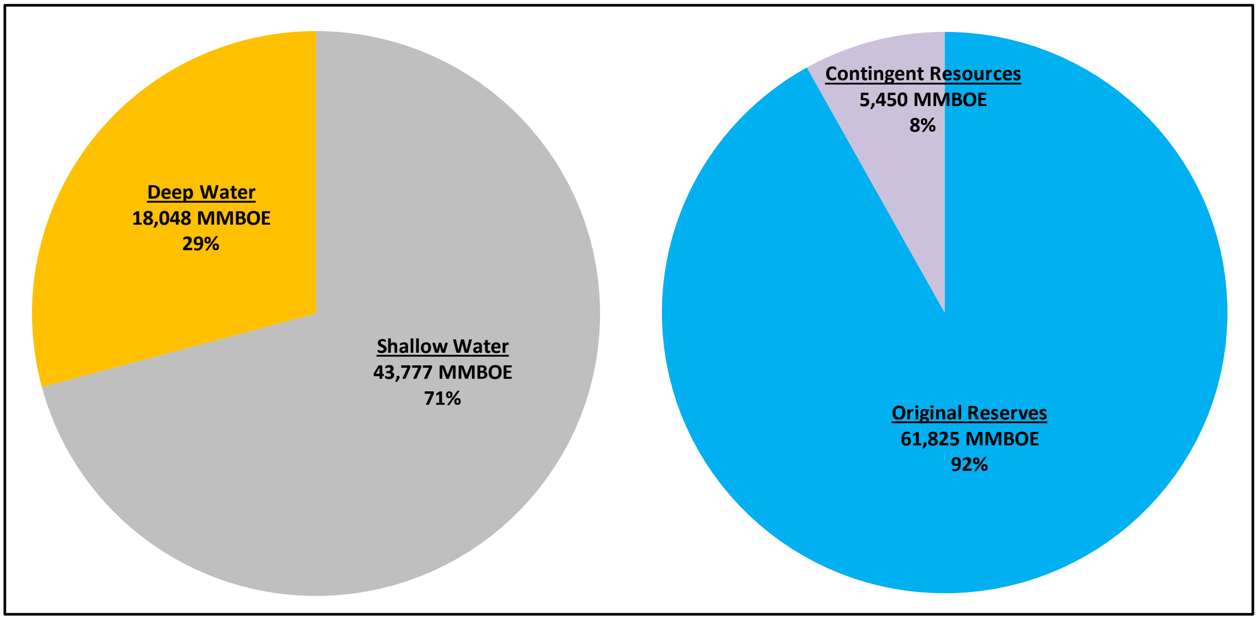


Figure 73. BOEM original reserves by water depth (left) and contingent resources (right).

The number of BOEM-designated fields in deep water by discovery year is shown in **Figure 74**. There were 293 deepwater fields classified as reserves or contingent resources at the end of 2019.

Figure 74 displays BOEM estimates of the reserves portion of **Table 9** assigned by field discovery year and delineated by water-depth categories. Over the past 45 years, reserves inventory contributions from discoveries in shallow water (<1,000 ft) have generally become less significant, as the modern-day shelf plays are very mature and heavily explored. Deepwater contributions to the reserves inventory began in 1975 with the discovery of the Cognac (Mississippi Canyon 194) Field in 1,022 ft of water. In 1989, the discovery of the Mars-Ursa (Mississippi Canyon 807 and Mississippi Canyon 809) geologic complex in an average water depth of 3,340 ft added substantial volumes. Lower Tertiary discoveries in ultra-deepwater (>5,000 ft) began contributing to the reserves inventory in 2002, with the discovery of the Great White (Alaminos Canyon 857) and Cascade (Walker Ridge 206) Fields. Additionally, **Figure 75** does not include volumetric estimates from the contingent resources portion of **Table 9**. The volumetric estimates for a discovery remain as contingent resources until an operator commits to a development project. For example, development options are being evaluated for the 2017 Lower Tertiary Whale discovery (Alaminos Canyon Block 772) in approximately 8,626 ft of water. Therefore, until a final investment decision is reached, the discovery remains a BOEM contingent resource.

Figure 76 illustrates the locations and estimated sizes of 189 fields in deep water with proved reserves or reserves justified for development. The fields have a wide geographic distribution and range in geologic age from Pleistocene through Jurassic. Over the last 6 years, BOEM has recognized 28 new deepwater fields (**Figure 77**). Most of these fields are classified as contingent resources, as there has not yet been a development commitment by the operator (**Table 10**).

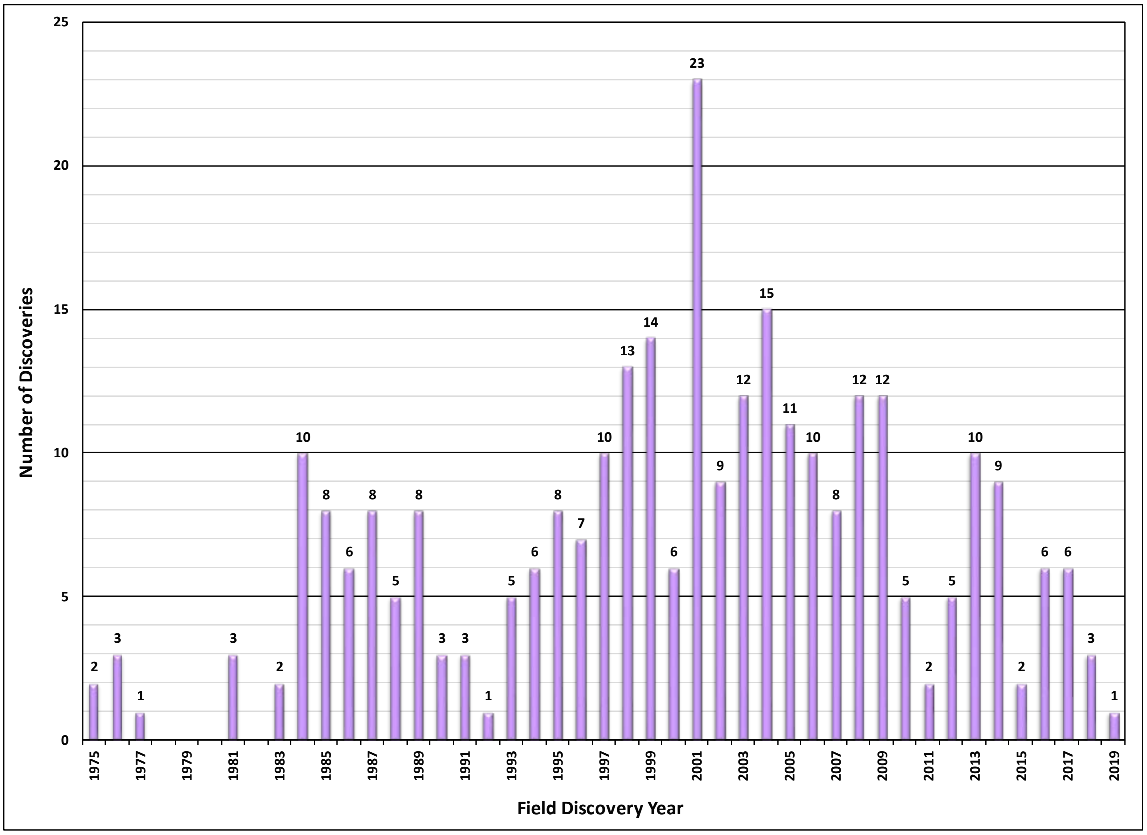


Figure 74. Number of BOEM-designated fields in deep water by discovery year through 2019.

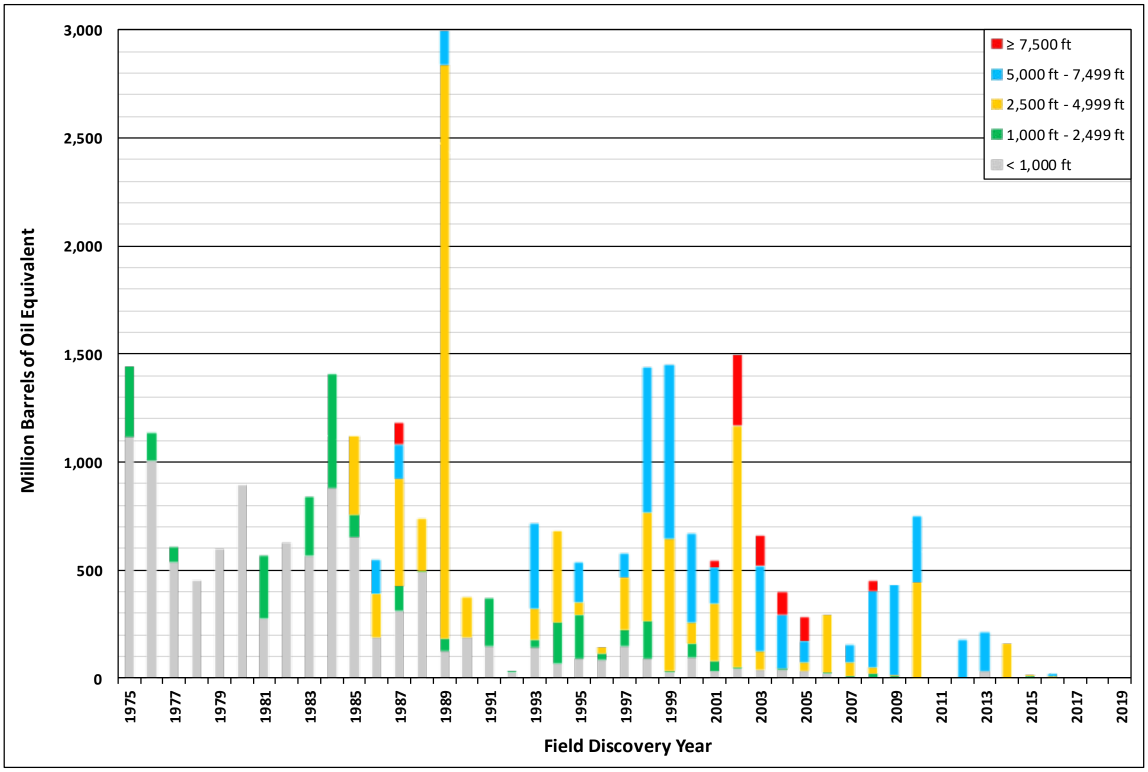


Figure 75. Field reserves by discovery year for each deepwater category.

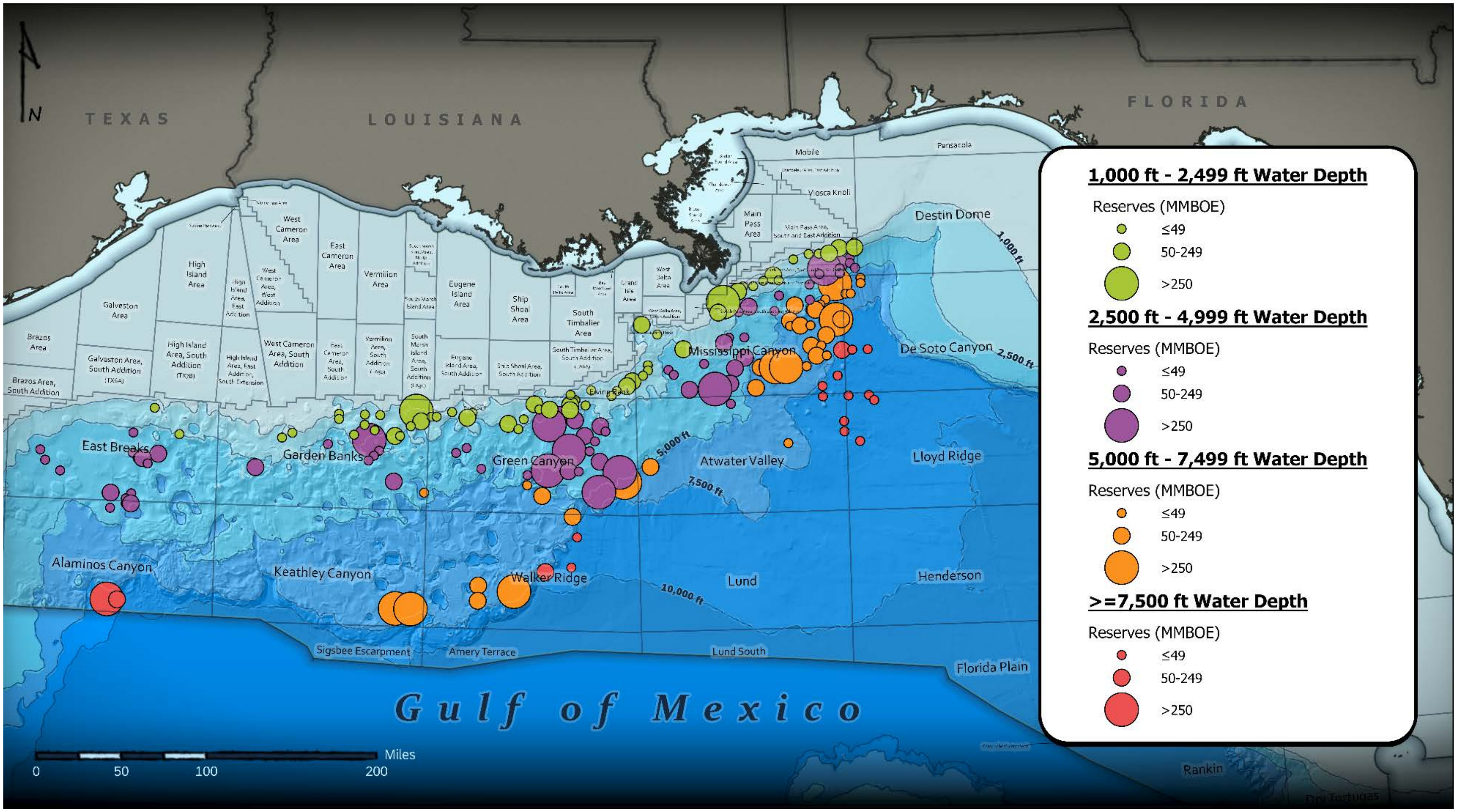


Figure 76. Estimated reserves of deepwater fields.

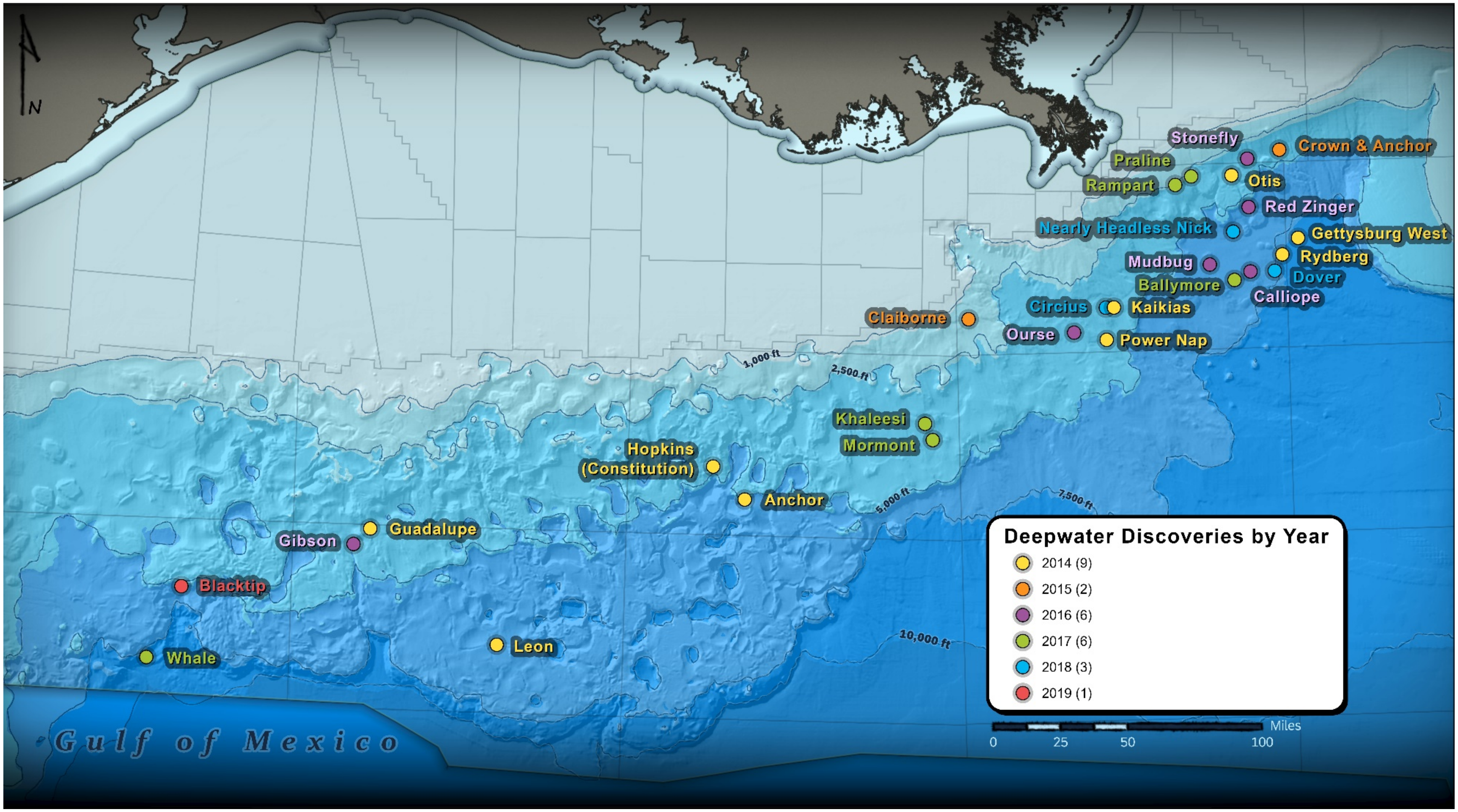


Figure 77. Deepwater fields discovered in the years 2014-2019.

Table 10. 2014-2019 deepwater field discoveries.

Field or Block	Nickname	Water Depth (average in ft)	Water Depth (average in m)	Reservoir Age	Discovery Date	First Production Date	Expiration Date	BOEM Resource Classification
MC525	Rydberg	7,421	2,262	Upper Jurassic	03-Jun-14			CR
MC079	Otis	3,861	1,177	Miocene	28-Jul-14	01-Apr-16		PDP
KC010	Guadalupe	3,910	1,192	Lower Tertiary	14-Aug-14			CR
MC768	Kaikias	4,479	1,365	Miocene	23-Aug-14	01-May-18		PDP
KC642	Leon	6,154	1,876	Lower Tertiary	30-Sep-14			CR
GC807	Anchor	5,037	1,535	Lower Tertiary	01-Nov-14			CR
DC398	Gettysburg West	7,579	2,310	Upper Jurassic	28-Nov-14		01-Jun-15	CR
GC627	Hopkins (Constitution)	4,385	1,337	Pliocene	01-Dec-14	01-Jan-19		PDP
MC Block 943	Power Nap	4,208	1,283	Miocene	14-Dec-14			CR
VK959	Crown & Anchor	4,254	1,297	Miocene	20-May-15	01-Jun-18		PDP
MC794	Claiborne	1,433	437	Miocene	08-Dec-15	01-Dec-18		PDP
MC560	Mudbug	6,237	1,901	Miocene	27-Apr-16			CR
MC895	Ourse	3,743	1,141	Miocene	04-May-16			CR
KC096	Gibson	4,835	1,474	Lower Tertiary	16-May-16		01-Nov-19	CR
MC257	Red Zinger	5,848	1,782	Miocene	28-Aug-16	01-Dec-18		PDP
VK999	Stonefly	4,116	1,255	Miocene	22-Sep-16	01-Dec-19		PDP
MC609	Calliope	6,822	2,079	Miocene	23-Oct-16			RJD
GC389	Khaleesi	3,552	1,083	Miocene	21-Jan-17			CR
AC Block 772	Whale	8,626	2,629	Lower Tertiary	23-Feb-17			CR
GC478	Mormont	3,774	1,150	Miocene	31-Mar-17			CR
MC074	Praline	2,644	806	Miocene	14-May-17			CR
MC116	Rampart	2,667	813	Miocene	15-Aug-17		01-Sep-18	CR
MC651	Ballymore	6,540	1,993	Upper Jurassic	16-Dec-17			CR
MC Block 767	Circius	4,070	1,241	Miocene	17-Mar-18			CR
MC612	Dover	7,372	2,247	Upper Jurassic	30-Apr-18			CR
MC387	Nearly Headless Nick	6,592	2,009	Miocene	30-Aug-18			CR
AC Block 380	Blacktip	6,210	1,893	Lower Tertiary	22-Apr-19			CR

CR - Contingent Resources
PDP - Developed Producing
RJD - Reserves Justified for Development

RESOURCE ASSESSMENT

BOEM provides estimates of the undiscovered resources (**Table 9**) approximately every 5 years. In each assessment, the undiscovered resources located outside of known oil and gas fields are modeled using discovered resources from each GOM field. Discovered resources are original reserves (remaining reserves plus cumulative production) and contingent resources. The latest assessment (in progress) is performed primarily using discovered resources as of the end of 2019.

The undiscovered resources resulting from the assessment are categorized as undiscovered technically recoverable resources (UTRR) that may be produced as a consequence of natural pressure, artificial lift, pressure maintenance, or other secondary recovery methods. The assessment does not include (1) quantities of hydrocarbon resources that could be recovered by enhanced recovery techniques, (2) gas in geopressured brines, (3) natural gas hydrates, or (4) oil and natural gas that may be present in insufficient quantities or quality to be produced by conventional recovery techniques. Herein, UTRR is reported at the mean percentile level—the average or expected value.

Figure 78 presents discovered resources and preliminary results for UTRR values in water depths less than and greater than the approximate modern-day continental shelf-slope break (656 ft or 200 m). The highly-explored plays on the shelf generally contain most of the discovered resources (~66%). The entire Gulf of Mexico OCS is assessed to contain a total UTRR value of nearly 40 BBOE. Of this total, with nearly 34 BBOE, plays beyond the shelf-slope break are assessed to contain by far the most undiscovered resources (~86%). For example, the Lower Tertiary (Wilcox) Play contains numerous discoveries in deepwater that are associated with large compressional folds, while discoveries in the deepwater Upper Jurassic Norphlet Aeolian Dune Play are contained within tectonic detachment rafts.

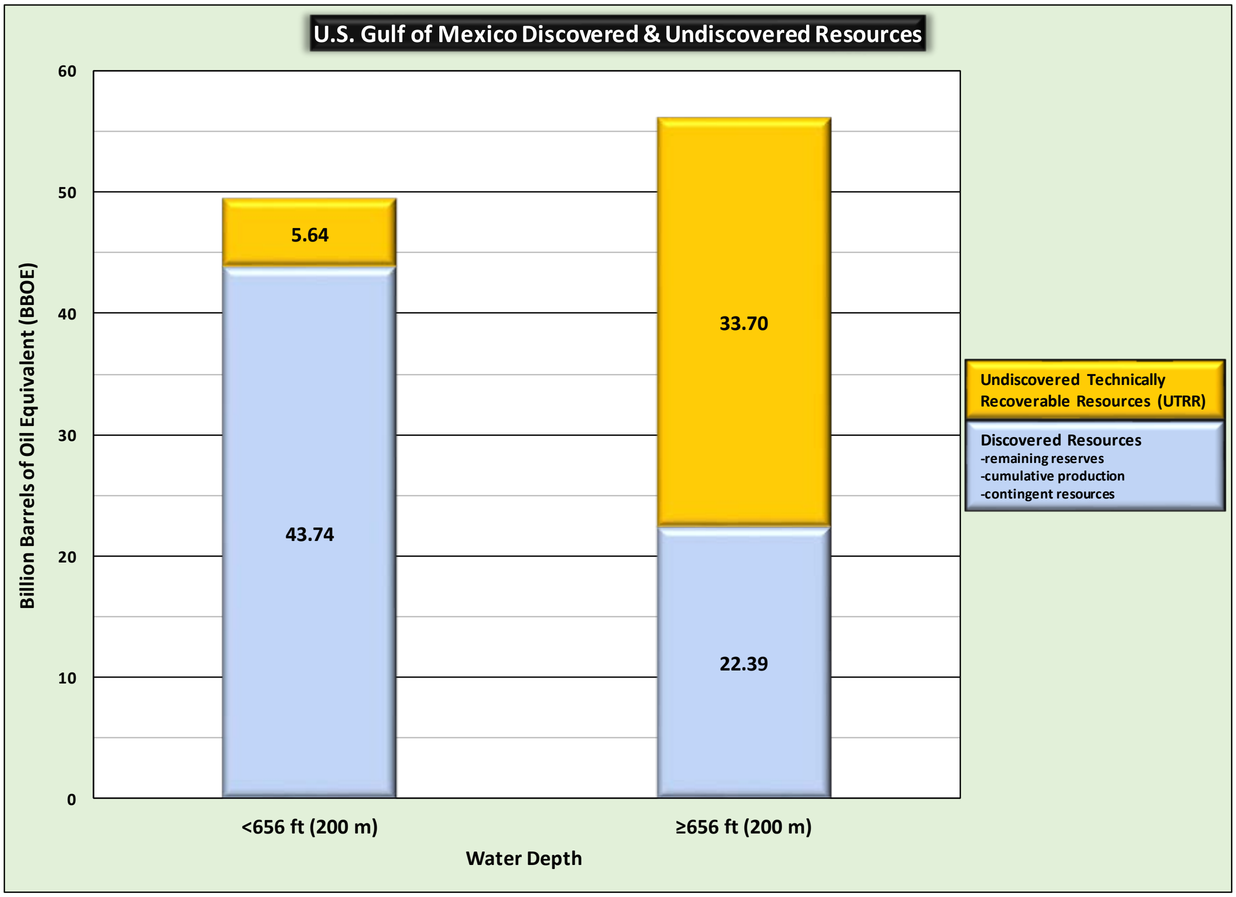


Figure 78. Discovered and undiscovered resources by water depth.

PRODUCTION

FACILITIES

Just as leasing, drilling, and discoveries progressed into deeper waters with time, so did production. Development strategies vary for deep water, depending on reserve size, proximity to infrastructure, operating considerations (such as well interventions), economic considerations, water depth, and an operator's interest in establishing a production hub for the area. An operator has a choice of numerous platform types (**Figure 79**).

- Fixed Platform (FP) – a fixed, not floating, structure.
- Compliant Tower Platform (CTP) –a fixed, not floating, structure with mooring guidewires to constrain motion.
- Tension Leg Platform (TLP) – a 4-column, tendon-founded, floating structure.
- Mini Tension Leg Platform (mTLP) – a 3-column, tendon-founded, floating structure.
- Single Point Anchor Reservoir Platform (Spar) – a can-shaped hull, mooring/pile-founded, floating structure.
- Semisubmersible Platform (Semi) – a mooring/pile-founded, 4-column, floating structure.
- Floating Production Unit (FPU) – a ship-shaped, buoy-connected, mobile offshore production unit.
- Floating Production, Storage, and Offloading Facility (FPSO) – a ship-shaped, buoy-connected, mooring-founded, floating structure.

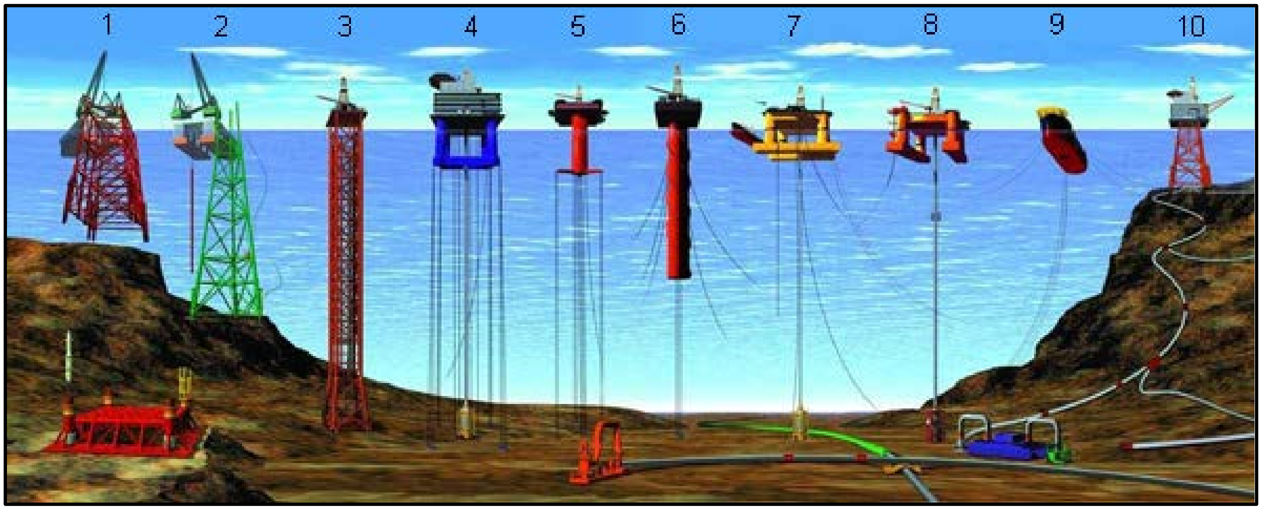


Figure 79. Types of deepwater production facilities (1, 2 – fixed platforms; 3 – compliant tower platform; 4, 5 – tension leg and mini tension leg platforms; 6 – spar; 7, 8 – semisubmersible platforms; 9 – floating production, storage, and offloading facility; and 10 – subsea completion and tieback to a host facility). (Image courtesy of the National Oceanic and Atmospheric Administration.)

The type of facility that an operator chooses depends on numerous factors, including payload, drilling/intervention capabilities, dry tree and/or wet tree capability, water depth rating, motion characteristics, seafloor topography, constructability, and fabrication time, among others. The challenge is to select the platform type and capabilities that fit the reservoir depletion plan and site characteristics while satisfying commercial and strategic objectives.

Some discoveries in the deepwater GOM are too small to be economically developed as stand-alone projects. In these instances, an operator may decide to use subsea technology to control and produce the wells, "tying back" to existing production facilities. These facilities may be located many miles away from the actual wells. Subsea systems are capable of producing hydrocarbons from reservoirs covering the entire range of water depths that industry is exploring. They range in complexity from a single subsea well producing to a nearby fixed platform, tension leg platform (TLP), or floating production facility (e.g., semisubmersible) to multiple wells producing through a manifold and pipeline system to a distant production facility. Subsea systems have been, and will continue to be, a key component in the development of deepwater discoveries. Subsea systems generally consist of multiple pieces of equipment located on the seafloor; this equipment allows the production of hydrocarbons in water depths that would normally preclude installing conventional fixed or bottom-founded platforms. The economics of deepwater development have improved by connecting multiple subsea projects to a single production facility.

Figure 80 shows water-depth applications for the production facilities by installation year in the deepwater GOM through 2019. Fixed and compliant tower platforms have been utilized in water depths less than 2,000 ft, as they are extensions of shallow-water technology. Tension leg platforms have been historically utilized in water depths of less than 5,000 ft in the GOM. However, in early 2019, the Big Foot development in Walker Ridge Block 29 utilized an extended-TLP design in 5,185 ft of water to become the deepest installed TLP.

Semisubmersibles and spars can be utilized in a wide range of water depths, including ultra-deepwater (>5,000 ft). Installed in mid-2018, the deepest GOM application of a semisubmersible platform is in 7,400 ft of water in Mississippi Canyon Block 437. This semisubmersible acts as a hub for Shell's Upper Jurassic Norphlet discoveries in the area. The Perdido Hub in Alaminos Canyon Block 857 operates in the deepest water for a spar in the GOM. At 7,835 ft, the spar collects production from the Lower Tertiary Trend in the area.

Ship-shaped production platforms are utilized where no permanent production infrastructure exists and are advantageous in inclement weather as they can be temporarily disconnected from the production streams and sailed to safe harbor. The FPSO utilized for the Lower Tertiary Stones development is the deepest water-depth application of any production platform in the GOM at 9,560 ft in Walker Ridge Block 551.

Table 11 provides details for the 58 deepwater production facilities in the GOM. Seventeen of the facilities have the capacity to collect more than 100,000 barrels of oil per day (BOPD). Five of those are rated for more than 200,000 BOPD, including the Mississippi Canyon Block 437 semisubmersible (**Figure 81**). Installed in 2018, the semisubmersible is the most-recent installed platform, and of all nine semisubmersibles, it operates in the deepest water at 7,400 ft. This platform was installed to collect production from the Upper Jurassic Norphlet Formation Trend, marking the first high-temperature development in the deepwater GOM.

In the last 6 years, there have been production startups from 32 deepwater fields (**Figure 82**). Five of those fields produce from the Lower Tertiary Trend, and two represent first production from the aforementioned Norphlet Formation (**Table 12**).

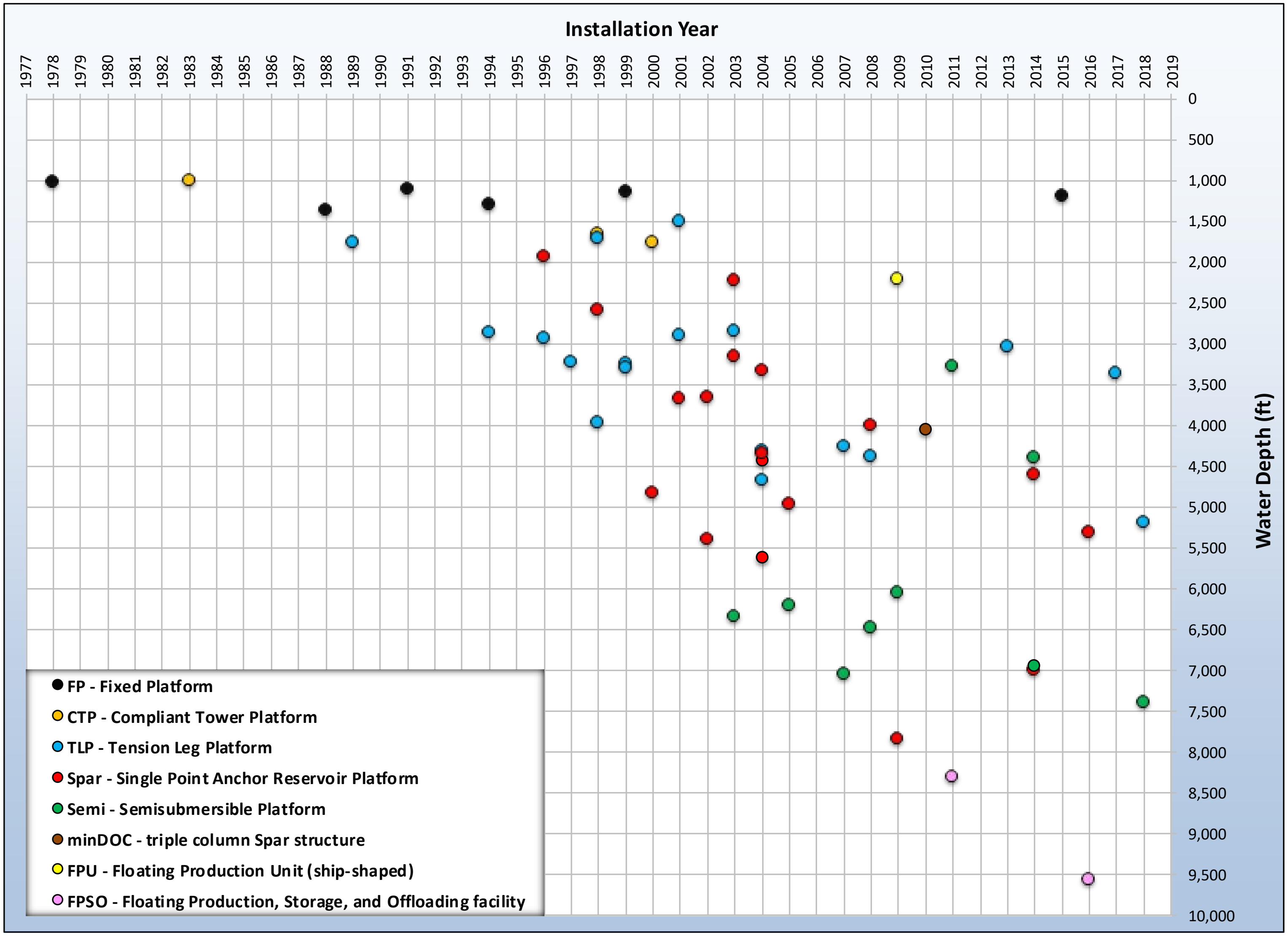


Figure 80. Installation dates and water depths for the various types of production facilities utilized in the GOM.

Table 11. Production facilities utilized in the GOM.

Area	Block	Water Depth (ft)	Water Depth (m)	Type	Installation Date	Capacity (BOPD)	Capacity (MMCFD)	Project
MC	194	1,023	312	FP	01-Jan-78	28,000	357	Cognac
MC	280	1,000	305	CTP	01-Jan-83	20,000	50	Lena*
GC	65	1,353	412	FP	01-Jan-88	200,000	306	Bullwinkle
GC	184	1,760	536	TLP	01-Jan-89	20,000	50	Jolliet
MC	109	1,100	335	FP	01-Jan-91	20,000	30	Amberjack
GB	426	2,860	872	TLP	05-Feb-94	105,000	250	Auger
VK	989	1,290	393	FP	19-Aug-94	60,000	90	Pompano
MC	807	2,933	894	TLP	18-Jul-96	100,000	110	Mars A
VK	826	1,930	588	Spar	19-Nov-96	26,000	35	Neptune (VK)
VK	956	3,216	980	TLP	21-May-97	314,000	70	Ram Powell
GB	260	1,648	502	CTP	31-May-98	50,000	150	Balpate
GC	205	2,590	789	Spar	21-Jul-98	30,000	60	Genesis
EW	921	1,700	518	mTLP	10-Aug-98	38,500	42	Morpeth
MC	809	3,970	1,210	TLP	28-Dec-98	150,000	400	Ursa
VK	915	3,236	986	TLP	27-Jul-99	40,000	40	Marlin
GC	254	3,294	1,004	mTLP	19-Aug-99	25,000	45	Allegheny
VK	823	1,130	344	FP	17-Sep-99	15,000	120	Virgo
AC	25	4,825	1,471	Spar	25-Apr-00	65,000	225	Hoover
VK	786	1,754	535	CTP	28-Apr-00	60,000	48	Petronius
GC	158	2,900	884	TLP	20-Jun-01	120,000	150	Brutus
EW	1003	1,500	457	TLP	18-Jul-01	50,000	80	Prince
EB	602	3,675	1,120	Spar	10-Nov-01	40,000	200	Nansen
EB	643	3,650	1,113	Spar	28-Apr-02	40,000	20	Boomvang
MC	127	5,400	1,646	Spar	29-Jun-02	65,000	60	Horn Mountain
MC	474	6,340	1,932	Semi	02-Aug-03	110,000	425	Na Kika Hub
MC	243	2,850	869	mTLP	03-Aug-03	35,000	55	Matterhorn
MC	582	2,223	678	Spar	08-Aug-03	40,000	110	Medusa
GB	668	3,150	960	Spar	09-Dec-03	40,000	200	Gunnison
GC	608	4,300	1,311	TLP	24-Jan-04	100,000	250	Marco Polo
MC	773	5,610	1,710	Spar	19-Feb-04	60,000	60	Devil's Tower
GC	645	4,340	1,323	Spar	03-Jun-04	113,000	142	Holstein
GC	782	4,420	1,347	Spar	30-Jul-04	80,000	40	Mad Dog
GC	338	3,330	1,015	Spar	02-Aug-04	60,000	110	Front Runner
GB	783	4,670	1,423	TLP	05-Aug-04	50,000	150	Magnolia
MC	778	6,200	1,890	Semi	01-Apr-05	250,000	200	Thunder Horse
GC	680	4,970	1,515	Spar	27-Dec-05	84,000	200	Constitution
GC	787	7,050	2,149	Semi	16-Jan-07	200,000	180	Atlantis
GC	613	4,250	1,295	mTLP	16-Oct-07	50,000	50	Neptune (AT)
MC	650	6,480	1,975	Semi	18-Apr-08	60,000	44	Blind Faith
GC	641	4,000	1,219	Spar	08-Aug-08	155,000	146	Tahiti
GC	653	4,375	1,334	TLP	25-Aug-08	100,000	50	Shenzi
GC	237	2,200	671	FPU**	11-Jun-09	45,000	80	Phoenix
MC	736	6,050	1,844	Semi	07-Aug-09	60,000	70	Thunder Hawk
AC	857	7,835	2,388	Spar	12-Nov-09	100,000	200	Perdido Hub
MC	941	4,050	1,234	minDOC	06-Mar-10	25,000	50	Telemark/Mirage/Morgus
WR	249	8,300	2,530	FPSO	30-Jun-11	80,000	16	Cascade/Chinook
MC	547	3,280	1,000	Semi	12-Jul-11	60,000	150	Who Dat
MC	807	3,028	923	TLP	30-Jul-13	100,000	150	Mars B
WR	718	6,950	2,118	Semi	05-Jan-14	170,000	79	Jack/St. Malo
MC	724	4,600	1,402	Spar	09-Mar-14	60,000	135	Tubular Bells
KC	875	7,000	2,134	Spar	17-Mar-14	80,000	150	Lucius
MC	254	4,400	1,341	Semi	08-Oct-14	80,000	200	Delta House Hub
EW	834	1,186	361	FP	25-Nov-15	30,000	60	Coelacanth
WR	551	9,560	2,914	FPSO	01-Jan-16	60,000	15	Stones
GC	860	5,300	1,615	Spar	07-Jan-16	80,000	80	Heidelberg
GC	468	3,360	1,024	TLP	29-May-17	80,000	60	Stampede
WR	29	5,185	1,580	TLP	19-Feb-18	75,000	26	Big Foot
MC	437	7,400	2,256	Semi	07-Jun-18	200,000	140	Appomattox/Vicksburg "A"

*The Lena Compliant Tower Platform is in the process of being decommisioned.

**Ship-Shaped Mobile Offshore Production Unit

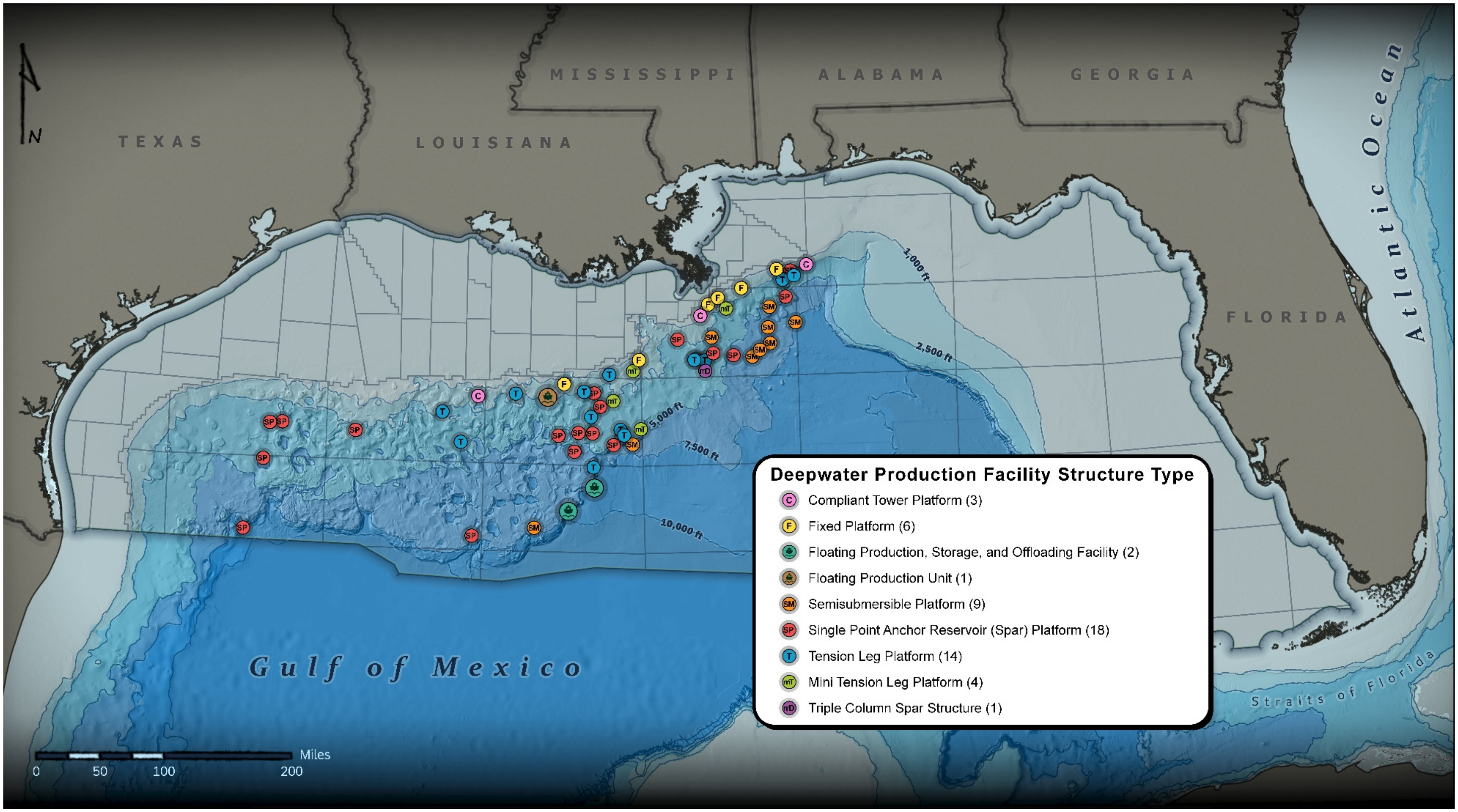


Figure 81. Geographic distribution of deepwater production facilities through 2019.

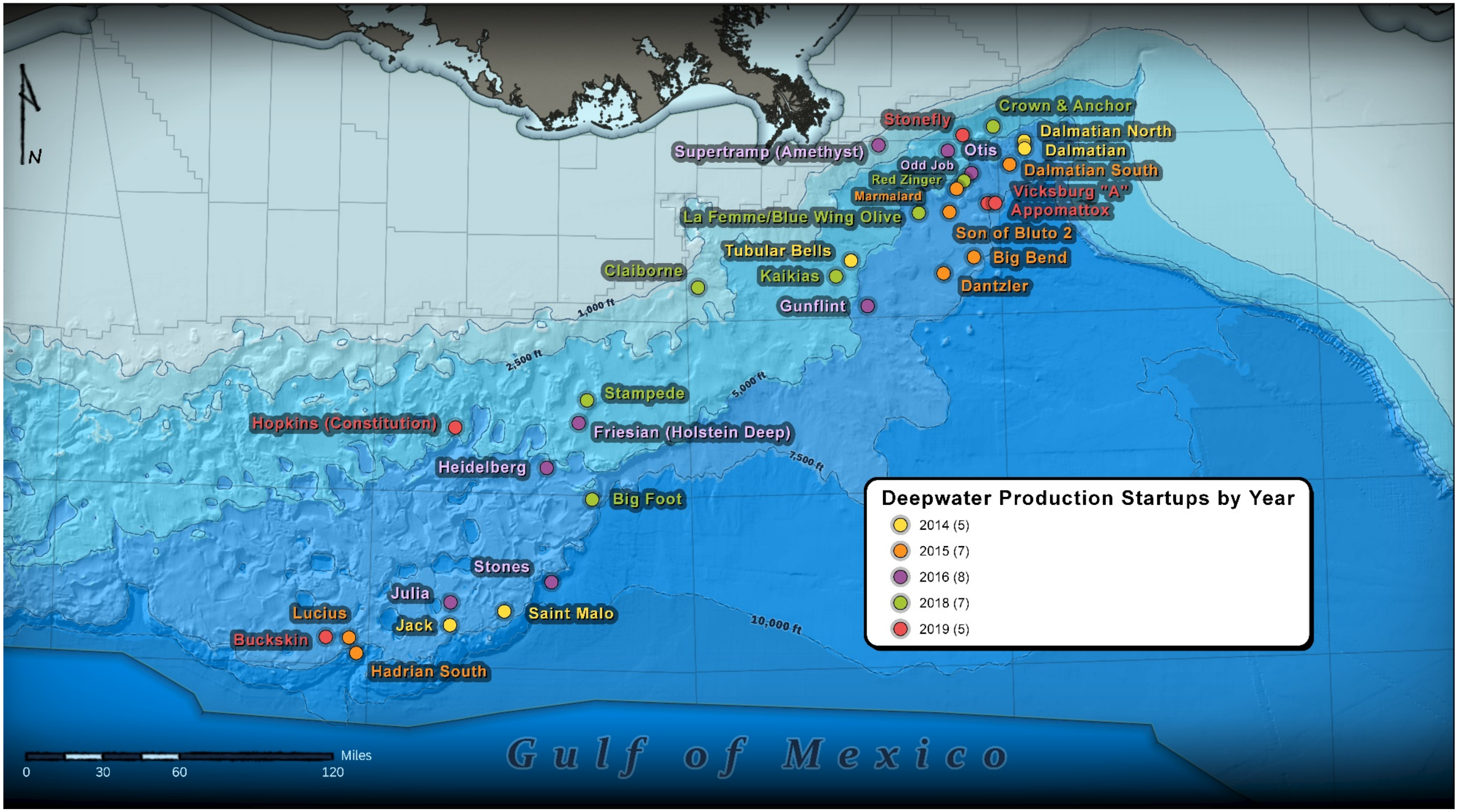


Figure 82. Deepwater fields starting production in the years 2014-2019.

Table 12. 2014-2019 deepwater field production startups.

Field	Nickname	Water Depth (average in ft)	Water Depth (average in m)	Reservoir Age	Discovery Date	First Production Date	Expiration Date	Production Host
DC048	Dalmatian	5,876	1,791	Miocene	29-Sep-08	01-Apr-14	01-Jan-17	VK Block 786 Petronius CTP
DC004	Dalmatian North	5,823	1,775	Miocene	30-Apr-10	01-Jun-14		VK Block 786 Petronius CTP
MC682	Tubular Bells	4,490	1,369	Miocene	17-Oct-03	01-Nov-14		MC Block 724 Gulfstar 1 Spar
WR678	Saint Malo	6,953	2,119	Lower Tertiary	13-Oct-03	01-Dec-14		WR Block 718 Jack/St. Malo Semi
WR759	Jack	6,967	2,124	Lower Tertiary	09-Jul-04	01-Dec-14		WR Block 718 Jack/St. Malo Semi
KC875	Lucius	7,106	2,166	Pliocene, Miocene	23-Jan-10	01-Jan-15		KC Block 875 Lucius Spar
KC964	Hadrian South	7,623	2,323	Pliocene	21-Sep-08	01-Mar-15	01-Oct-18	KC Block 875 Lucius Spar
MC300	Marmalard	5,978	1,822	Miocene	03-May-12	01-Apr-15		MC Block 254 Delta House Hub Semi
MC431	Son of Bluto 2	6,426	1,959	Miocene	14-Mar-12	01-Aug-15		MC Block 254 Delta House Hub Semi
MC698	Big Bend	7,221	2,201	Miocene	15-Nov-12	01-Oct-15		MC Block 736 Thunder Hawk Semi
MC782	Dantzler	6,575	2,004	Miocene	20-Nov-13	01-Nov-15		MC Block 736 Thunder Hawk Semi
DC134	Dalmatian South	6,318	1,926	Miocene	27-Sep-12	01-Dec-15		VK Block 786 Petronius CTP
MC026	Supertramp (Amethyst)	1,193	364	Pliocene	27-May-94	01-Jan-16	01-May-17	VK Block 989 Pompano FP
GC859	Heidelberg	5,327	1,624	Miocene	23-Jan-09	01-Jan-16		GC Block 860 Spar
GC599	Friesian (Holstein Deep)	3,857	1,176	Miocene	08-Oct-06	01-Apr-16		GC Block 645 Spar
WR627	Julia	7,135	2,175	Lower Tertiary	07-Apr-07	01-Apr-16		WR Block 718 Jack/St. Malo Semi
MC079	Otis	3,861	1,177	Miocene	28-Jul-14	01-Apr-16		MC Block 254 Delta House Hub Semi
MC948	Gunflint	6,083	1,854	Miocene	15-Aug-08	01-Jul-16		MC Block 724 Gulfstar 1 Spar
WR508	Stones	9,252	2,820	Lower Tertiary	10-Mar-05	01-Sep-16		WR Block 551 FPSO
MC214	Odd Job	5,892	1,796	Miocene	17-Sep-13	01-Oct-16		MC Block 254 Delta House Hub Semi
GC468	Stampede	3,527	1,075	Miocene	24-Jun-06	01-Jan-18		GC Block 468 TLP
MC768	Kaikias	4,479	1,365	Miocene	23-Aug-14	01-May-18		MC Block 809 Ursa TLP
VK959	Crown & Anchor	4,254	1,297	Miocene	20-May-15	01-Jun-18		VK Block 915 Marlin TLP
MC427	La Femme/Blue Wing Olive	5,778	1,761	Miocene	02-Dec-04	01-Nov-18		MC Block 254 Delta House Hub Semi
WR029	Big Foot	5,436	1,657	Miocene	02-Dec-05	01-Nov-18		WR Block 29 TLP
MC794	Claiborne	1,433	437	Miocene	08-Dec-15	01-Dec-18		EW Block 834 Coelacanth FP
MC257	Red Zinger	5,848	1,782	Miocene	28-Aug-16	01-Dec-18		MC Block 254 Delta House Hub Semi
GC627	Hopkins (Constitution)	4,385	1,337	Pliocene	01-Dec-14	01-Jan-19		GC Block 680 Spar
MC392	Appomattox	7,221	2,201	Upper Jurassic	21-Dec-09	01-May-19		MC Block 437 Semi
MC393	Vicksburg "A"	7,411	2,259	Upper Jurassic	17-May-13	01-May-19		MC Block 437 Semi
KC872	Buckskin	6,608	2,014	Lower Tertiary	25-Nov-08	01-Jun-19		KC Block 875 Lucius Spar
VK999	Stonefly	4,116	1,255	Miocene	22-Sep-16	01-Dec-19		VK Block 956 Ram Powell TLP

VOLUMES

Figure 83 illustrates the relevance of the GOM to the Nation's energy supply. The GOM supplied 15.5 percent of the Nation's domestic oil and 3.0 percent of the Nation's domestic natural gas production in 2019. For the GOM specifically, 91 percent of the oil production and 70 percent of the natural gas production in 2019 were from wells in deep water.

Table 13 shows the 20 most prolific producing fields in the GOM for the year 2019. The top three producers averaged over 100,000 BOE per day. Half of the fields produce from ultra-deepwater (≥5,000 ft), with production from four of those fields—St. Malo, Great White, Jack, and Stones—coming from the Lower Tertiary Trend.

Figure 84 compares shallow-water and deepwater oil and gas production, respectively, since production from the GOM began. Oil production from shallow water dominated until production from numerous, large deepwater discoveries ramped up beginning in the mid-1990s. Beginning in the year 1999, more oil has been produced from the deepwater areas of the GOM than from shallow waters. Current oil production volumes from the deep water are at historic high levels. Beginning in 2014, oil volumes have increased by an average of almost 45 million barrels per year. Natural gas production from the GOM has always been dominantly from shallow waters. This production has steeply declined, however, beginning in the late-1990s. In fact, natural gas production has declined so much that for the first time ever, natural gas production from deep water is higher than that from shallow water beginning in 2014.

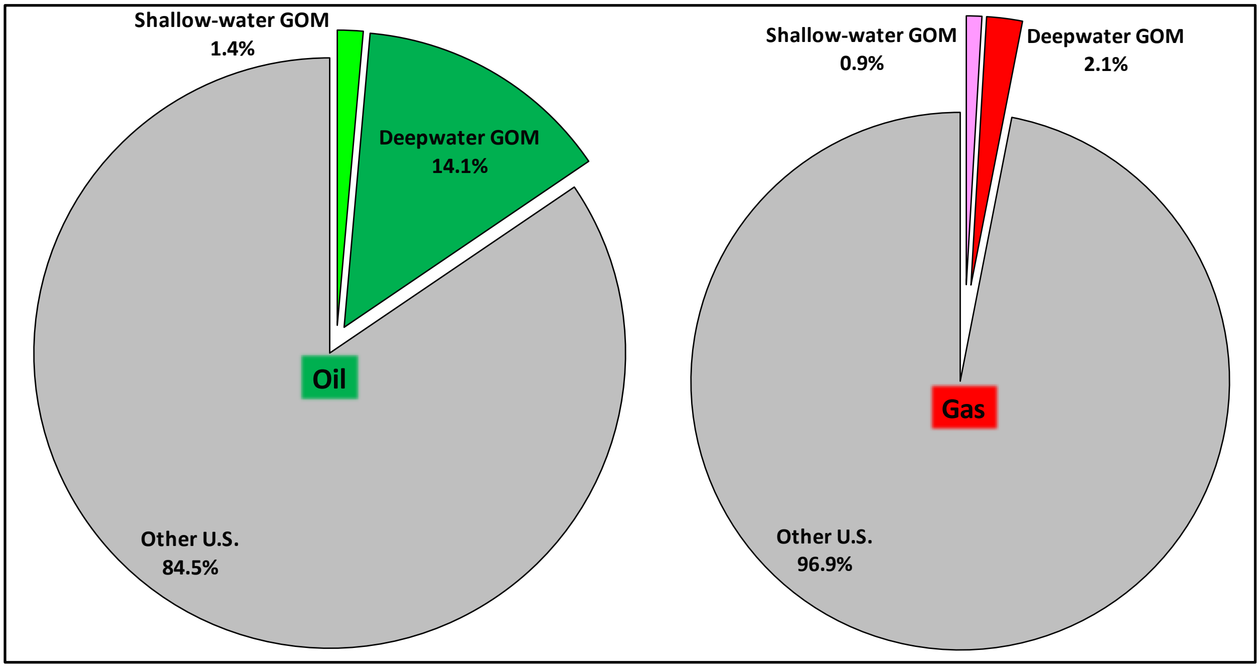
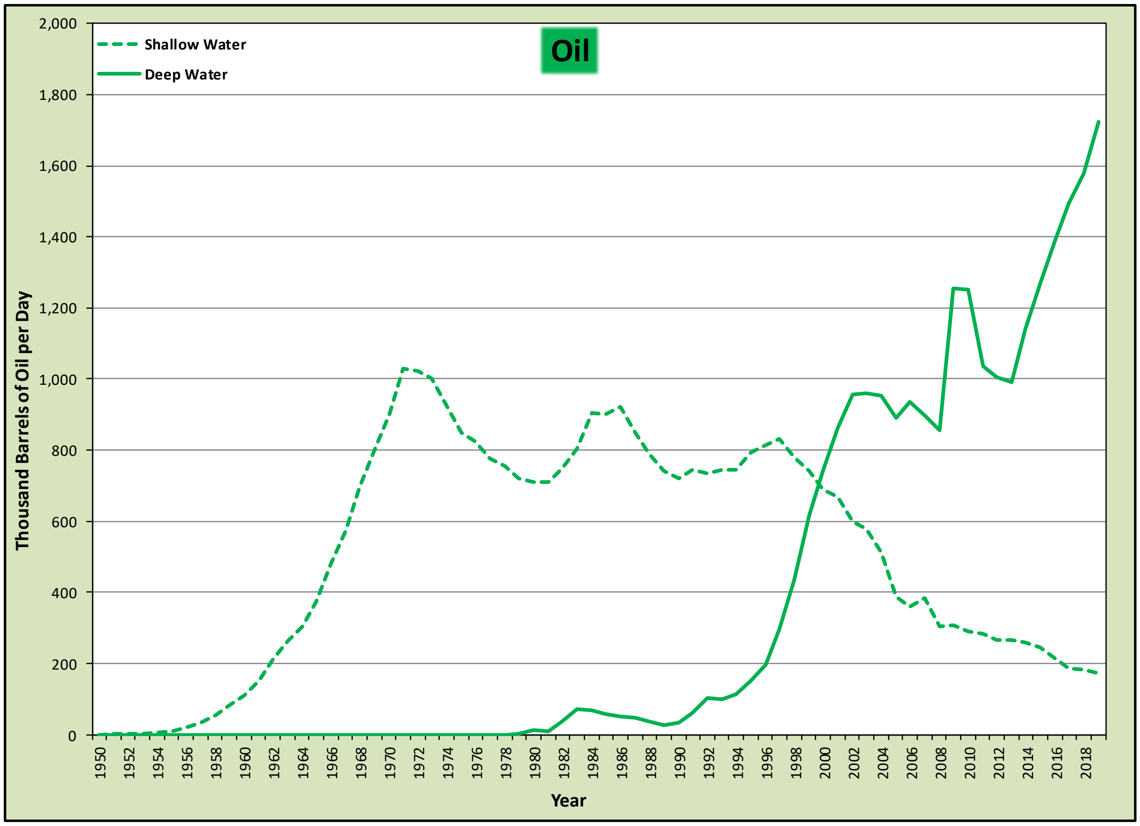


Figure 83. Estimated U.S. oil and natural gas production in 2019.

Table 13. Top 20 producing fields in 2019.

Field	Project Name	Water Depth (ft)	Water Depth (m)	2019 Production (BOE)	2019 Average Daily Production (BOE/Day)	Production Facility
MC807	Mars-Ursa	3,340	1,018	93,213,489	255,379	MC Blocks 807 and 809 TLPs
GC640	Tahiti/Caesar/Tonga	4,337	1,322	64,296,741	176,155	GC Block 641 Spar/Subsea
GC743	Atlantis	6,331	1,930	39,568,964	108,408	GC Block 787 Semi
WR678	St. Malo	6,953	2,119	34,745,139	95,192	WR Block 718 Semi
MC778	Thunder Horse	6,095	1,858	31,785,602	87,084	MC Block 778 Semi
AC857	Great White	7,921	2,414	27,714,438	75,930	AC Block 857 Perdido Hub Spar
GC826	Mad Dog	4,864	1,483	24,179,297	66,245	GC Block 782 Spar
MC776	North Thunder Horse	5,672	1,729	24,137,613	66,130	Subsea to Thunder Horse Semi
MC084	Horn Mountain/King	5,315	1,620	19,853,198	54,392	MC Block 127 Spar/Subsea
GC654	Shenzi	4,303	1,312	18,104,356	49,601	GC Block 653 TLP
WR759	Jack	6,967	2,124	17,766,183	48,674	WR Block 718 Semi
MC768	Kaikias	4,479	1,365	16,987,323	46,541	Subsea to Ursa TLP
GB426	Auger	2,845	867	16,267,923	44,570	GB Block 426 TLP
GB171	Salsa	1,206	368	13,625,868	37,331	GB Block 172 FP
GB387	Llano	2,338	713	13,303,736	36,449	Subsea to Auger TLP
KC875	Lucius	7,106	2,166	13,132,107	35,978	KC Block 875 Spar
MC300	Marmalard	5,978	1,822	12,713,649	34,832	MC Block 254 Delta House Hub Semi
MC546	Longhorn	2,542	775	11,833,933	32,422	Subsea to MC Block 365 FP (Corral)
WR508	Stones	9,252	2,820	11,705,589	32,070	WR Block 551 FPSO
GC468	Stampede	3,527	1,075	11,425,281	31,302	GC Block 468 TLP



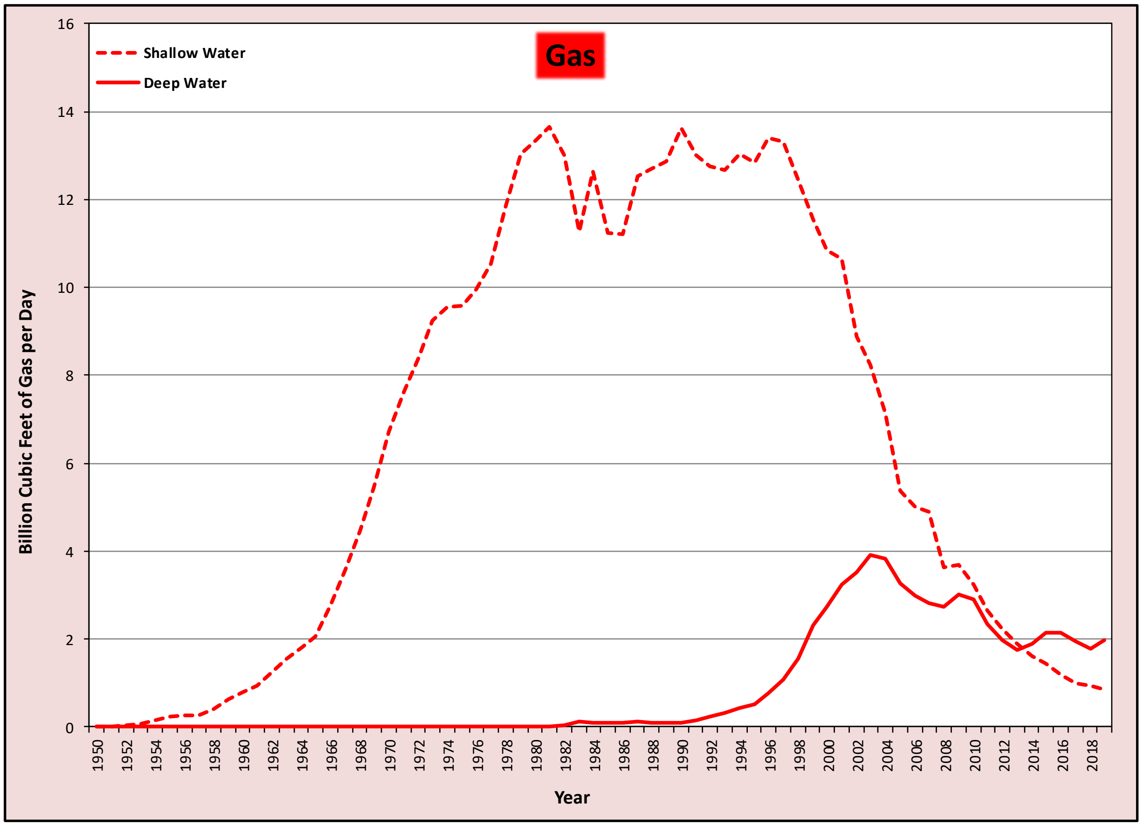


Figure 84. Comparison of average annual shallow-water and deepwater oil and natural gas production.

ENVIRONMENTAL STEWARDSHIP

To ensure that environmental protection is a primary consideration in our decisions, BOEM focuses on two core components that constantly engage with and inform each other: environmental assessment and environmental science. Environmental assessment includes identifying the environmental resources and evaluating the impacts of BOEM's proposed actions and activities. The involvement of the public and Federal, State, and Tribal governments during the assessment process aids in the identification policy, regulatory, and cultural practices that may be affected by OCS oil- and gas-related and non-OCS oil- and gas-related activities. Gulf of Mexico scientists research and prepare extensive environmental documents that describe and characterize the environmental setting for the GOM region. This information is used in the preparation of environmental impact assessments and in conducting consultations with other agencies charged with protecting various resources (**Figure 85**).

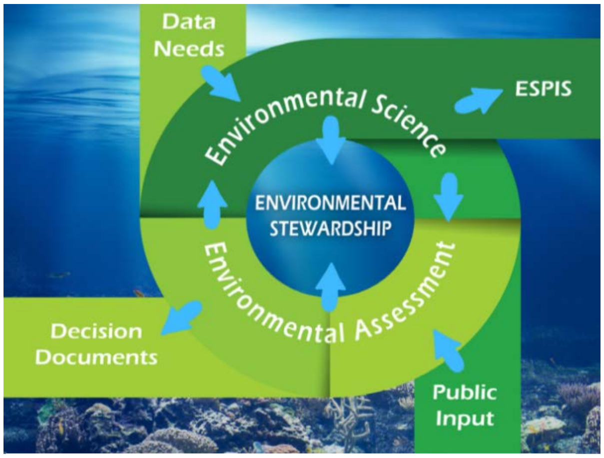


Figure 85. Interaction between studies and assessment activities.

Environmental science includes developing, conducting, and overseeing world-class scientific research to inform policy decisions. BOEM manages pioneering and ongoing research studies in the Atlantic and Pacific Oceans, Gulf of Mexico, and offshore Alaska. Gulf of Mexico scientists are managing critical research projects and publish environmental studies on topics including marine biology, archaeology, physical oceanography, air quality, socioeconomics, and fates and effects. The following sections provide an overview of the environmental setting and resources in the deepwater areas of the GOM, commonly applied lease stipulations and mitigations to reduce potential impacts, and describes current and relevant environmental studies.

ENVIRONMENTAL RESOURCES

By evaluating past environmental impact analyses, public input, studies, and other peer-reviewed literature, BOEM's subject-matter experts identified impact-producing factors (IPFs) associated with oil and gas-related activities in deep water. These IPFs can be grouped into the following generalized "issue" categories:

An impact-producing factor (IPF) is the outcome or result of any proposed activities with the potential to positively or negatively affect physical, biological, cultural, and/or socioeconomic resources.

- **air emissions and pollution** associated with offshore and onshore activity. The activities associated with OCS oil and gas leasing that could potentially affect air quality include (1) use of G&G survey vessels, (2) use of drilling and production and associated vessels, (3) use of support helicopters, (4) pipelaying operations, (5) flaring and venting, and (6) decommissioning of facilities and pipelines. Routine emission of air pollutants occur during exploration, development, production, installation, and decommissioning activities.
- **discharges and wastes** associated with offshore activity (i.e., drilling muds, produced waters, well treatment fluids, bilge, ballast, etc.). Routine wastes and discharges are permitted or regulated by BOEM, BSEE, and/or other Federal and State agencies. Water pollution associated

with OCS oil- and gas-related activities in the GOM is permitted by the U.S. Environmental Protection Agency (USEPA) through the National Pollutant Discharge Elimination System (NPDES) general permits in support of the Clean Water Act.

- **bottom disturbance** associated with drilling, infrastructure emplacement, removal, and G&G data collection activities;
- **noise** from G&G surveys, ship and aircraft traffic, drilling and production operations, trenching, construction, and decommissioning;
- **lighting and visual impacts** of the physical presence of infrastructure and vessel and aircraft traffic;
- **offshore habitat modification/space use** associated with infrastructure emplacement and removal and multiple-use areas on the seabed, in the water column, at the sea surface, or in the airspace; and
- **accidental events** that include oil spills, chemical spills, pipeline failures, losses of well control, accidental air emissions, hydrogen sulfide and sulfurous petroleum releases, trash and debris, spill response associated with unintended releases, and collisions and strikes.

Environmental resources potentially affected by deepwater OCS oil- and gas-related activities include air quality, water quality, benthic and pelagic communities, fish and invertebrates, birds, sea turtles, and marine mammals. Thought not reasonably foreseeable, should there be a catastrophic discharge event, numerous coastal resources could also be affected by the spill-response activities. BOEM has analyzed the potential effects of a lowprobability catastrophic event, as requested by the Council on Environmental Quality pursuant to its regulation at 40 CFR § 1502.22.

Air Quality

Air quality is the degree to which the ambient air is free of pollution.

Responsibility for air quality in the GOM is shared between BOEM and the USEPA. In 1990, Section 328 of the Clean Air Act (CAA) Amendments directed the USEPA to regulate air pollution along the U.S. Gulf Coast off the State of Florida, eastward of 87°30' W. longitude. The CAA Amendments of 1990 also require the USEPA to set the National Ambient Air Quality Standards (NAAQS) for six common air pollutants of concern called criteria air pollutants. Meanwhile under the OCSLA, the U.S. Department of the Interior (USDOI) (delegated to BOEM) has air quality responsibility for the Gulf of Mexico OCS westward of 87°30' W. longitude, where OCS oil- and gas-related activities are well established. On May 14, 2020, the USDOI and BOEM announced a final rule to update air quality regulations for applicable BOEM activities in the CPA and WPA. The final rule ensures that BOEM's Air Quality Regulatory Program remains in compliance with the OCSLA requirements, ensuring BOEM uses up-to-date air quality standards (i.e., NAAQS) and benchmarks consistent with those already established by the USEPA.

Air pollution occurs when pollutants (e.g., gases and particles) are emitted into the atmosphere. Deepwater OCS oil- and gas-related activities that could potentially affect air quality include (1) G&G survey vessels; (2) drilling, production, and pipelaying operations; (3) support vessels and helicopters; (4) pipelaying operations; (5) flaring and venting; and (6) and accidental releases. Emissions from these activities occur during exploration, development, production, installation, and decommissioning activities. The potential impacts of these factors are analyzed in BOEM's environmental reviews for both pre-lease and post-lease activities.

Circulation patterns, geography, time of day, season, and other variables influence the transport and/or chemical transformation of pollutants and overall air quality of a region. Given these challenges and uncertainties inherent with delineating what effects are directly correlated to specific sources, air quality is generally assessed cumulatively (i.e., all OCS sources including those not associated with oil and gas development). BOEM conducts and incorporates regional-scale studies into its oil and gas leasing environmental impact assessments to broadly estimate the potential incremental and cumulative air quality effects associated with oil and gas leasing, including those from deepwater activities. BOEM also uses this information to assess site-specific impacts of deepwater activities during post-lease reviews by using emission exemption threshold formula screening methods to determine whether a proposed source would cause or contribute to a violation of the NAAQS.

In accordance with the CAA Amendments, only areas within State boundaries are designated as either unclassifiable/attainment or nonattainment status. Gulf of Mexico OCS waters are not designated areas for the NAAQS since there are no regulatory provisions under the CAA or OCSLA; however, OCS oil and gas exploration, development, and production sources are analyzed to ensure they do not significantly affect the air quality of any state. Most criteria air pollutants along the Gulf Coast are below the NAAQS; however, ozone and sulfur dioxide are still a concern in nonattainment areas.

Water Quality

__Water quality__ can be defined as a measure of the suitability of water for a particular use based on selected physical, chemical, and biological characteristics.

Water quality relates to the condition or environmental health of a waterbody, reflecting its chemical, physical, and biological integrity, as well as its interrelationship with human health and ecosystem functions. Primary indicators of water quality in coastal and offshore environments include temperature, salinity, dissolved oxygen, chlorophyll content, nutrients and other trace constituents (e.g., metals), potential of hydrogen (pH), oxidation reduction potential (Eh), pathogens, optical properties (i.e., clarity, turbidity, and dissolved and suspended matter), and contaminant concentrations (i.e., heavy metals and hydrocarbons). These indicators, and water quality in general, are influenced primarily by (1) the configuration of the basin, including influx of water from the Caribbean Sea and the output of water through the Straits of Florida; and (2) runoff from the land masses, which controls the quantity and quality of freshwater input. With increasing distance from shore, oceanic circulation patterns play an increasingly large role in dispersing and diluting anthropogenic contaminants and thus determining water quality.

In deep water, the primary oil- and gas-related IPF to water quality is discharges and wastes. Discharges can transport trace metals, hydrocarbons, and other suspended materials within several acres around the drilling location; however, they are regulated by the USEPA and must comply with NPDES permit requirements. BOEM's *Gulf of Mexico OCS Regulatory Framework* technical report discusses the Clean Water Act and NPDES permitting in greater detail (USDOI, BOEM, 2020).

Other potential IPFs that can occur in deep water are air emissions, bottom disturbances, and unintended spills. The potential impacts of these factors are analyzed in BOEM's environmental reviews. Water quality of the deep GOM may also be closely tied to sediment quality, and the two can affect each other, though research is limited. Discharges from ongoing and future OCS oil- and gas-related activities will likely continue and remain an influence on water quality. Other factors not connected to deepwater oil and gas development—such as urbanization, mining, ocean acidification, eutrophication (excess nutrients in the water), and hypoxia—are expected to continue to degrade water quality within all GOM planning areas.

Biological Resources and Habitats

For biological communities and habitat, the definition of shallow water versus deep water is dependent upon local hydrography, sediment load, light penetration, organisms present, and community structure. In general, deepwater is defined as greater than 300 m (980 ft) water depth.

Phytoplankton, photosynthetic, and typically unicellular organisms produce the bulk of organic matter in the GOM large marine ecosystem. Primary productivity varies in the GOM, from eutrophic coastal and estuarine waters to the oligotrophic deep ocean. Production is much lower in the surface waters over the deep GOM basin.

The increasing concentration of greenhouse gases in the atmosphere is advancing planet-wide physical, chemical, and biological changes and substantially impacting the GOM and elsewhere. Broadly, possible impacts include temperature and rainfall changes, rising sea levels, and changes to ocean conditions, such as ocean circulation patterns and storm frequency (IPCC, 2014). These changes may affect marine GOM ecosystems by increasing the vertical stratification of the water column, shifting prey distribution, impacting competition, and generally impacting species' ranges (Learmonth et al., 2006). Such modifications could result in ecosystem regime shifts as the productivity of the regional ecosystem undergoes various downstream changes related to nutrient inputs and coastal ocean processes (Doney et al., 2012).

Benthic Communities and Habitats

Benthic fauna inhabit the seafloor throughout the GOM at all water depths (**Figure 86**). Documented benthic ecosystems in the GOM include muddy softbottom; oyster reefs; coral and sponge dominant banks (e.g., the Flower Garden Banks); hydrocarbon seeps along the continental margin; and marine canyons, escarpments, and seamounts on the abyssal plain (Briones, 2004). Most GOM hardbottom benthic communities are diverse and characterized by high species richness and low abundance, while softbottom communities are characterized by low species richness and high abundance. Within the photic zone, naturally occurring geological (e.g., exposed bedrock) or biogenic (e.g., authigenic carbonate relict reef) seafloor with measurable vertical relief serves as important habitat for a wide variety of sessile and mobile marine organisms in the GOM.

Topographic features or banks are hardbottom habitats with high biomass, diversity, and abundance. These include the mid-shelf and shelf-edge banks (e.g., the East and West Flower Garden Banks), South Texas banks, the Alabama Pinnacle Trend, and Florida Middle Grounds. Encrusting algae and sessile invertebrates such as corals, sponges, sea fans, sea whips, hydroids, anemones, ascidians, and bryozoans may recruit to and colonize these hard substrates, creating "live bottom" (Cummings et al., 1962). Corals and large sponges function as structural architects by adding complexity to the benthic habitat. These complex structures provide shelter to small fish and invertebrates, which in turn provide food for larger fishes, including many that form important commercial fisheries (Fraser and Sedberry, 2008; Szedlmayer and Lee, 2004; Gallaway et al., 2009; Johnston et al., 2015; Nash et al., 2013).

Hardbottom substrate is found throughout the deep waters of the GOM and is comprised of either exposed bedrock or relict authigenic carbonate coral reef (Brooks et al., 2016). Both hard- and soft-bodied corals colonize deepwater substrate. Associated sessile and mobile benthic megafauna include sponges, anemones, echinoderms, crustaceans, and demersal fishes. Field data suggest that the extent of deepwater, hardbottom habitat is large and that diversity of corals and sponges is high (Boland et al., 2017).

Cold seeps are areas of the ocean floor where high concentrations of oil or reduced chemicals are expelled, forming hydrocarbon or gas plumes. Hydrocarbon seep ecosystems support over 330 chemosynthetic communities in the GOM, typically at water depths greater than 300 m (984 ft) (Roberts et al., 1990 and 2010). Chemosynthetic fauna in the GOM include chemoautotrophic bacteria, vestimentiferan tubeworms, mussels, epibenthic clams, and burrowing clams (MacDonald et al., 1990).

The IPF categories potentially affecting benthic communities in deep water are noise, discharges and wastes, bottom disturbance, lighting and visual impacts, offshore habitat modification/space use, and accidental events. The potential impacts of these factors are analyzed in BOEM's environmental reviews.

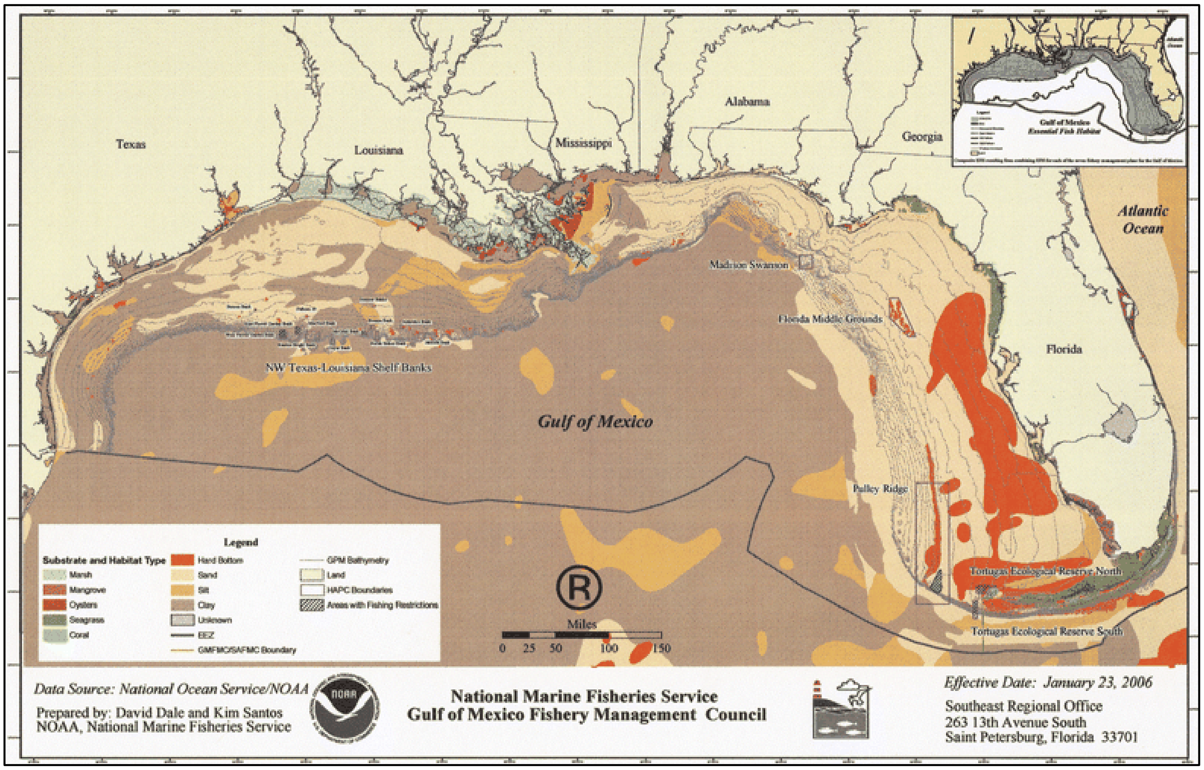


Figure 86. Benthic habitat distribution in the Gulf of Mexico (Rowe, 2017 [modified from Gulf of Mexico Fishery Management Council, 2004 and 2005]). This figure is licensed under the terms of the Creative Commons Attribution-Noncommercial 2.5 International License (http://creativecommons.org/licenses/by-nc/2.5/).

Pelagic Communities and Habitats

Pelagic communities include all swimming and floating organisms that reside in the water column. Pelagic habitats encompass the entire water column from the water's surface to the greatest depths (excluding the seafloor). The relationships of pelagic communities to pelagic habitat are complex and frequently tied to physical and chemical attributes that can vary seasonally and annually. Some pelagic habitats are more static and less susceptible to large-scale variations, such as the deep-sea meso-, bathy, and abyssopelagic zones. The pelagic zone is divided into two provinces: neritic and oceanic (**Figure 87**). There is a lack of natural structural habitat due to the oceanic province's depths and distance from shore. However, *Sargassum* (*S. natans* and *S. fluitans*) is a unique floating habitat comprised of brown macroalgae that free-float in generally large mats.

The uppermost habitat zone in the oceanic province is the epipelagic zone. This zone is entirely within the photic zone, allowing for photosynthesis by phytoplankton (e.g., diatoms) and other primary producers (e.g., autotrophic dinoflagellates). Oceanic epipelagic waters are generally nutrient poor (Webb, 2019). Consequently, primary producers in this oceanic province rely heavily on atmospheric deposition of nutrients, such as soil dust from deserts and other terrestrial habitats (Jickells and Moore, 2015).

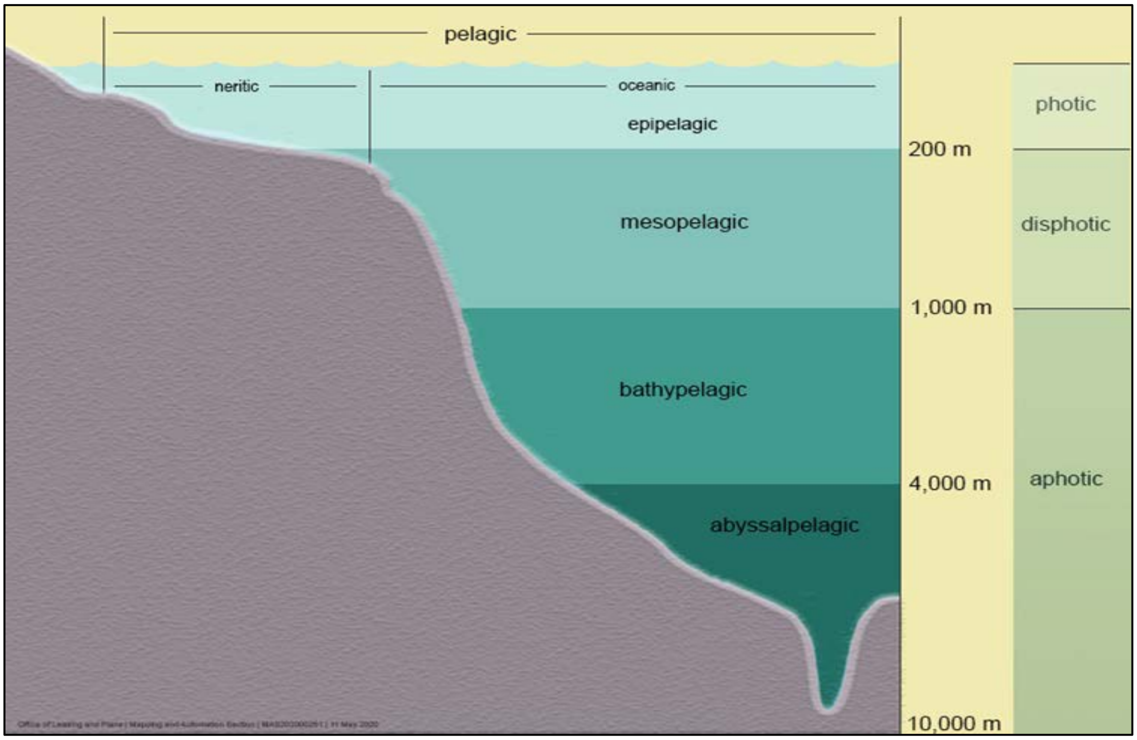


Figure 87. Oceanic province habitat zones and light zones of the Gulf of Mexico with corresponding depth levels.

Deep-sea pelagic habitat zones are defined here as those deeper than 200 m (656 ft). Deep-sea zones are some of the most stable environments in the ocean because of their vast depths, which may contribute to increased susceptibility to anthropogenic disturbances (Food and Agriculture Organization of the United Nations, 2009 and 2020; Ashford et al., 2019). The deep-sea pelagic realm represents approximately 91 percent of the GOM's total volume and contains enormous taxonomical and functional diversity (Sutton et al., 2020).

The IPF categories potentially affecting pelagic communities in deep water are air emissions and pollution, discharges and wastes, bottom disturbance, noise, lighting and visual impacts, offshore habitat modification/space use, and accidental events. The potential impacts of these factors are analyzed in BOEM's environmental reviews. Fish and invertebrates, diving seabirds, marine mammals, and sea turtles, fish occupying pelagic habitats are discussed in their respective sections below.

Fish and Invertebrates and Commercial and Recreational Fisheries

The GOM has a taxonomically and ecologically diverse assemblage of fish and invertebrates, including 1,541 fish species in 736 genera, 237 families, and 45 orders and 13,000 invertebrate species in 46 phyla (Felder and Camp, 2009). There were $927 million in finfish and shellfish landings in the GOM in 2016, which comprised 17.1 percent of total U.S. landings revenues (USDOC, NMFS, 2016). Some of the most economically important commercial fisheries are white shrimp, brown shrimp, eastern oysters, Gulf menhaden, blue crab, red grouper, red snapper, and tunas. Recreational fishing in the GOM is also an important industry, including red snapper, king mackerel, spotted seatrout, red drum, Atlantic croaker, sand seatrout, Spanish mackerel, and black drum. The number of described species for both GOM fish and invertebrates continues to increase over time due to ongoing exploration of deep-sea ecosystems. Many of these tropical fishes and invertebrates, along with other endemic species, are year-round residents in the northern GOM. Other large, pelagic species found in the northern GOM (e.g., whale sharks, giant manta ray, and bluefin tuna) occur seasonally and are highly migratory. Several fish and invertebrate species occurring in the coastal and marine habitats of the GOM are listed as threatened or endangered under the Endangered Species Act (ESA). Threatened species include the Gulf sturgeon, Nassau grouper, oceanic whitetip shark, giant manta ray, and several species of coral.

Fish and invertebrates in the GOM can vary spatiotemporally due to ontogenetic (i.e., development from egg to adult) shifts in habitat use. For others, habitat shifts are predominantly food-driven, resulting in vertical migrations through the water column in search of prey — a behavior commonly observed in deep-sea fish and invertebrates (Hopkins and Baird, 1985; Flock and Hopkins, 1992; Salvanes and Kristofferson, 2001). For highly migratory species, seasonal shifts in habitat use are correlated to reproduction and food availability. Less mobile species can include those attached to or primarily living in the benthos as adults and juveniles (e.g., sponges, corals, oysters, and tilefish), and their larval stages are the only time when these animals are highly mobile.

The GOM also includes deep-sea meso-, bathy-, and abyssopelagic habitats and their associated species of fishes and invertebrates. Many organisms living within the meso- and bathypelagic zone exhibit diel vertical migration behaviors. Conversely, species like swordfish and oceanic marine mammals (i.e., dolphins and toothed whales) dive to these habitats during the day to feed on deep-sea cephalopods (e.g., squids and octopus) and fish (e.g., lanternfish). Knowledge of abyssopelagic assemblages and community structure in the GOM is very limited.

The IPF categories potentially affecting fish and invertebrates in deep water are noise, discharges and wastes, bottom disturbance, lighting and visual impacts, offshore habitat modification/space use, and accidental events. The potential impacts of these factors are analyzed in BOEM's environmental reviews.

Birds

Birds from six distinct taxonomic and ecological groups are represented within the marine and coastal habitats in the GOM region (USDOI, FWS, 2013). Seven ESA-listed bird species (i.e., Cape Sable seaside sparrow, Mississippi sandhill crane, piping plover, rufa red knot, roseate tern, whooping crane, and wood stork) are distributed across the GOM region, either year-round or migratory, with a strong seasonal component. These species are considered and analyzed in consultations with the U.S. Fish and Wildlife Service (FWS). Other listed species also occur in the coastal GOM but rely more on terrestrial habitats or are not commonly documented in the deepwater northern GOM.

Both residential and migratory bird species are found in the GOM. Migratory birds are any species that migrate and live or reproduce in multiple, separate places at least once during their annual life cycle. Many passerines, or songbirds, breed and winter within the Gulf Coast States and can be found in the coastal area and offshore during the trans-Gulf migration in the fall and spring. Other bird species live primarily offshore, except during their breeding season (Duncan and Harvard, 1980), relying on offshore waters for food and rest at stop-over sites.

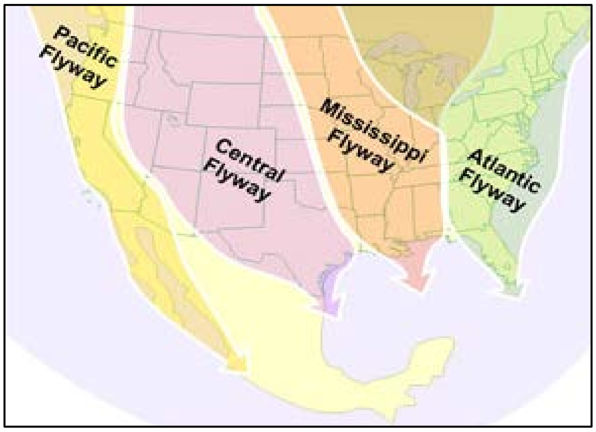


Figure 88. North American migratory birds follow migratory routes, or "flyways" (USDOI, FWS, 2013).

The GOM is an essential area for migratory birds, as three of the four major flyways (**Figure 88**) occur within the GOM. Hundreds of millions of migratory birds use these flyways, many of whom converge within the northern GOM (Russell, 2005). Roughly 40 percent of all North American migrating birds use the Mississippi Flyway (USDOI, FWS, 2013). During this highly energetic period, stop-over sites are critical to migratory birds. These areas provide resting and feeding opportunities (Brown et al., 2001, McWilliams and Karasov, 2005). Adequate stop over sites allow migratory birds to arrive in good health (Helmers, 1992).

Species abundance in the GOM varies seasonally due to migration and breeding timings. Abundance can also be driven by mesoscale features (Ribic et al., 1997; Bost et al., 2009; Scales et al., 2014). Seabirds produce few offspring but invest high amounts of parental care. As such, seabird population levels can be impacted by natural climate cycles (Paleczny, 2012) and anthropogenic activities. Nutritional conditions of prey are essential to seabird reproductive success and population dynamics as well (Lamb, 2016).

The IPF categories potentially affecting birds in deep water are noise, discharges and wastes, lighting and visual impacts, OCS habitat modification/ space use, and accidental events. The potential impacts of these factors are analyzed in BOEM's environmental reviews.

Marine Mammals

The GOM marine mammal community is diverse and distributed throughout the northern GOM waters, including members of the taxonomic order Cetacea and suborders Mysticeti (i.e., baleen whales) and Odontoceti (i.e., toothed whales), as well as the order Sirenia (i.e., manatee). Twenty-one species of cetaceans and one species of Sirenia regularly occur in the GOM and are identified in the NMFS Stock Assessment Reports (Hayes et al., 2018 and 2019). Habitat-based cetacean density models are found in Roberts et al. (2016). Two cetacean species, the sperm whale, and the GOM Bryde's whale, regularly occur in the GOM and are listed as endangered under the ESA. The West Indian manatee is listed as threatened under the ESA and has designated critical habitat in northeastern Florida (*Federal Register*, 1976). Further, 19 of the 20 toothed cetaceans (including beaked whales and dolphins) that regularly occur in the GOM are not ESA-listed. The Marine Mammal Protection Act (MMPA) protects all marine mammals, ESA-listed or not.

Most marine mammal distributions vary across the northern GOM with little known about each species' breeding and calving grounds or general patterns of movement. Several species (e.g., the GOM Bryde's whale, sperm whale, and bottlenose dolphin) have presumed year-round resident populations in the GOM (Van Parijs, 2015). The distribution and abundance of cetaceans within the northern GOM is strongly influenced by various mesoscale oceanographic circulation patterns. These patterns are primarily driven by river discharge (primarily the Mississippi River), wind stress, and the Loop Current and its derived circulation phenomena. Marine mammals may focus their foraging efforts on these abundant nutrientrich prey locations to improve overall feeding efficiency and reduce overall energy costs (Bailey and Thompson, 2010). In addition, marine mammals may forage under *Sargassum* mats due to the abundance of small fishes that typically assemble there (Casazza and Ross, 2008; Dooley, 1972). Other than factors influencing feeding behaviors, very little is known generally about other factors that may influence marine mammal distribution in the northern GOM.

Marine mammals can detect acoustic pressure, and different mammalian families have distinct hearing capabilities (**Figure 89**). Marine mammals produce sounds for a variety of natural behaviors over a range of acoustic frequencies (Richardson et al., 1995). Some cetaceans have sophisticated mechanisms for beamforming and sound localization, which they utilize for hunting prey. Fully aquatic mammals (e.g., cetaceans and sirenians) have additional adaptations. Toothed whales use higher frequency echolocation clicks to navigate and track prey, as well as a variety of whistle types during social interactions (Richardson et al., 1995). Baleen whales produce low-frequency reproductive and social calls that can travel great distances, even across ocean basins (Clark and Gagnon, 2004).

The IPF categories potentially affecting marine mammals in deep water are noise and accidental events (which includes vessel strikes). The potential impacts of these factors are analyzed in BOEM's environmental reviews.

Section 7(a)(2) of the ESA requires Federal agencies to ensure their actions are not likely to jeopardize the continued existence of endangered or threatened species or adversely modify or destroy their designated critical habitat. In GOM deep water, all ESA-listed species are under NMFS' jurisdiction, and BOEM must consult with NMFS when authorizing oil- and gas-related activities. This includes all listed marine mammals, sea turtles, fish, corals, and other invertebrates. On March 13, 2020, NMFS released the *Programmatic Biological Opinion on the Federally Regulated Oil and Gas Program Activities in the Gulf of Mexico* (USDOC, NOAA, 2020). The Biological Opinion (BiOp) covers all activities associated with the oil and gas program in the WPA, CPA and a small portion of the EPA that is not under moratorium. The BiOp outlines the terms and conditions and reasonable and prudent measures that are applied to prelease and post-lease plan and permit applications. The BiOp also includes a Reasonable and Prudent Alternative to avoid jeopardizing the continued existence of the GOM Bryde's whale, which has very low population numbers and is particularly vulnerable to vessel strikes.

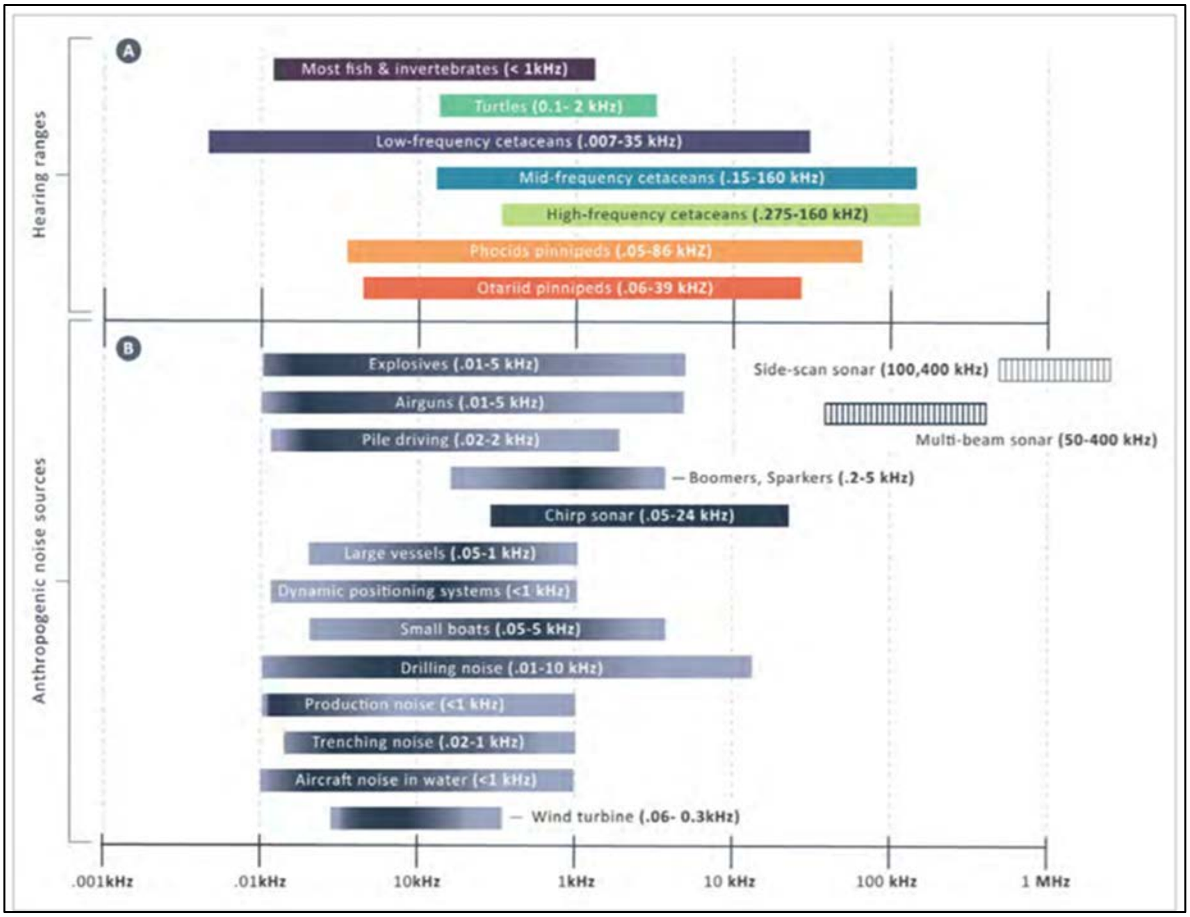


Figure 89. (A) Approximate hearing ranges of marine species and (B) frequency ranges of various anthropogenic sources. These ranges represent approximately 90% of the acoustic energy, and color shading roughly corresponds to the dominant energy band of each source. Dashed lines represent broadband sonars to depict the multi-frequency nature of these sounds. The frequency axis of both plots shows kHz in a logarithmic scale. Sources: Popper et al., 2014; Richardson et al., 1995; and USDOC, NMFS, 2016a.

Sea Turtles

Five ESA-listed sea turtles occur in the GOM, including the loggerhead turtle, green turtle, hawksbill turtle, Kemp's ridley turtle, and leatherback turtle. The Northwest Atlantic Ocean Distinct Population Segment of loggerhead turtle and the North Atlantic Distinct Population Segment of green turtle are ESAlisted as threatened (*Federal Register*, 2014). Hawksbill turtles, Kemp's ridley turtles, leatherback turtles (proposed threatened as Northwest Atlantic Distinct Population Segment), and breeding populations of green sea turtles in Florida are ESA-listed as endangered. Floating *Sargassum* patches in the CPA and WPA are federally designated under the ESA as critical habitat for loggerhead turtles. The FWS and NMFS share jurisdiction for sea turtles. The FWS has responsibility for monitoring and managing sea turtles on beaches, and NMFS has jurisdiction for sea turtles in the marine environment.

All five sea turtle species are all highly migratory. Important marine habitats for sea turtles in the Gulf of Mexico OCS include nesting beaches, barrier islands, estuaries and embayments, nearshore hard substrate areas, and the Gulf Stream (Valverde and Holzwart, 2017). These species rely on coastal and pelagic waters for foraging needs (Bjorndal, 1997; Collard, 1990; Fritts et al., 1983a and 1983b; Godley et al., 2008; USDOC, NMFS and USDOI, FWS, 2015). *Sargassum* mats provide food and protection from predation for juvenile sea turtles (Casazza and Ross, 2008; Dooley, 1972). Loggerhead, green, Kemp's ridley, and hawksbill hatchling sea turtles are thought to find *Sargassum* rafts when seeking frontal zones, then utilizing the habitat as foraging grounds and protection during their pelagic “lost years” (Carr, 1987; Coston-Clements et al., 1991; Witherington et al., 2012; Putman and Mansfield, 2015). Most sea turtle species move geographically, either seasonally or between nesting activities.

The IPF categories potentially affecting sea turtles in deep water are noise, lighting and visual impacts, OCS habitat modification/space use, and accidental events (which includes vessel strikes). The potential impacts of these factors are analyzed in BOEM’s environmental reviews.

Environmental Stipulations and Mitigations

Measures to minimize potential impacts are an integral part of the OCS Program. Post-lease mitigating measures have been implemented for over 40 years in the Gulf of Mexico region, as they relate to OCS plans, as well as pipelines (installation and decommissioning), structure removal, and G&G applications. These mitigating measures have been amended over time to address changes in regulations, new technology, and new methods of operation. Many of these mitigating measures have been adopted as lease stipulations and incorporated into regulations and/or guidelines governing OCS oil- and gas-related exploration, development, and production activities. These measures are implemented through lease stipulations, operating regulations, and project-specific requirements or approval conditions. Mitigating measures address concerns such as endangered and threatened species, geologic and manmade hazards, military warning and ordnance disposal areas, archaeological sites, air quality, oil-spill response planning, chemosynthetic communities, artificial reefs, operations in hydrogen sulfide-prone areas, and shunting drill effluents in the vicinity of biologically sensitive features.

Mitigations are commonly applied at the lease sale stage as lease stipulations to OCS oil and gas leases as a result of any given lease sale. For each proposed lease sale in the GOM, BOEM considers potential lease stipulations developed from numerous scoping efforts for the ongoing National OCS Oil and Gas Program, as well as from lease stipulations applied in previous lease sales. Stipulations are attached to OCS oil and gas leases and are legally binding.

Frequently applied lease stipulations for Gulf of Mexico OCS oil and gas lease sales are listed below.

Stipulation No. 1 – Military Areas

Stipulation No. 2 – Evacuation

Stipulation No. 3 – Coordination

Stipulation No. 4 – Protected Species

Stipulation No. 5 –Topographic Features

Stipulation No. 6 – United Nations Convention on the Law of the Sea Royalty Payment

Stipulation No. 7 – Agreement between the United States of America and the United Mexican States Concerning Transboundary Hydrocarbon Reservoirs in the Gulf of Mexico

Stipulation No. 8 – Live Bottom

Stipulation No. 9 – Blocks South of Baldwin County, Alabama

Stipulation No. 10 – Restrictions due to Rights-of-Use and Easements for Floating Production Facilities

Any stipulations or mitigation requirements to be included in a lease sale are described in the Record of Decision for that lease sale. More information on stipulations applied to past lease sales are available by navigating to BOEM's website at https://www.boem.gov/oil-gas-energy/leasing/2017-2022-lease-sale-schedule and selecting the Final Notice of Sale Package for any given lease sale.

Mitigating measures are an integral part of BOEM's program to ensure that post-lease operations are always conducted in an environmentally sound manner (with an emphasis on minimizing any adverse impact of routine operations on the environment). For example, post-activity surveys are carried out to ensure that a site has been cleared of potential snags to commercial fishing gear, and pre-activity surveys seek to avoid archaeological sites and biologically sensitive areas such as pinnacles, topographic features, and chemosynthetic communities. All plans for OCS oil- and gas-related activities (e.g., exploration and development plans, pipeline applications, geological and geophysical activities, and structure-removal applications) go through rigorous BOEM review and approval to ensure compliance with established laws and regulations. Existing mitigating measures (i.e., measures already established or agreed to by earlier authorization[s], such as through lease stipulations) must be incorporated and documented in plans submitted to BOEM. Operational compliance with the mitigating measures is enforced by BSEE.

Additionally, some BOEM-identified mitigating measures are incorporated into OCS operations through cooperative agreements or efforts with industry and State and Federal agencies. These mitigating measures include NMFS' Observer Program to protect marine mammals and sea turtles during explosive structure removals, labeling operational supplies to track possible sources of debris or equipment loss, and development of methods of pipeline landfall to eliminate impacts to beaches or wetlands.

Since many of site-specific mitigations are recurring, BOEM has developed a list of "standard" or commonly applied mitigations. Standard mitigation text is revised as often as is necessary (e.g., to reflect changes in regulatory citations, agency/personnel contact numbers, and internal policy). Site-specific mitigation "categories" include the following: air quality; archaeological resources; marine minerals; artificial reef material; chemosynthetic communities; Flower Garden Banks; topographic features; hard bottoms/pinnacles; military warning areas and Eglin Water Test Areas; hydrogen sulfide; drilling hazards; remotely operated vehicle surveys; geophysical survey reviews; and general safety concerns. Site-specific mitigation "types" include the following: advisories; conditions of approval; hazard survey reviews; inspection requirements; notifications; post-approval submittals; and safety precautions. In addition to standard mitigations, BOEM may also apply nonrecurring mitigating measures that are developed on a case-by-case basis for a site-specific activity proposal.

Following a lease sale, an applicant seeks approvals to develop its lease by preparing and submitting OCS plans. The OCS plans are reviewed by BOEM and, if required based on site-specific environmental reviews, BOEM may assign conditions of approval. The conditions of approval become part of the approved post-lease authorization and include environmental protections, requirements that maintain conformance with law, the requirements of other agencies having jurisdiction, and/or safety precautions.

Some examples of BOEM's conditions of approval include the following:

- other approvals prerequisite to BOEM's approval (e.g., the Coastal Zone Management Act);
- safety precautions (e.g., hydrogen sulfide present);
- post-approval submittals (e.g., surveys and interpretive reports, post-activity anchor plats);
- inspection requirements (e.g., pipeline pressure testing);
- pre-deployment notifications (e.g., U.S. Department of Defense use restrictions and Military Warning Areas); and
- reduce or avoid environmental impacts on resources identified in NEPA or other laws (e.g., the National Historic Preservation Act and National Marine Sanctuaries).

BOEM revises applicable mitigations as needed to adaptively manage the evaluation of mitigation compliance and effectiveness. A primary focus of this effort is requirements for postapproval submittal of information within a specified timeframe or after a triggering event (e.g., end of operations reports for plans, construction reports for pipelines, and removal reports for structure removals).

ENVIRONMENTAL STUDIES

Section 20 of the OCSLA directs BOEM to study and consider potential impacts to the coastal, marine, and human environments when making decisions on how to effectively promote energy independence, environmental protection, and economic development. As such, the Environmental Studies Program (ESP) was initiated in 1973 and has since provided more than $1.2 billion to date for research. The Environmental Studies Section, in BOEM's New Orleans Office, plans, implements, and manages the Environmental Studies Program for the Gulf of Mexico region. The studies program helps BOEM obtain the best available data and information about environmental resources, including those in deepwater environments, ensuring that coastal, marine, and human environmental impacts are adequately considered in the decision-making process. BOEM incorporates findings from the ESP into its environmental reviews and NEPA documents. Study results also inform the development and application of mitigation measures, which are used to avoid, minimize, and monitor the impacts of energy and mineral resource development on the OCS.

Ongoing interaction between studies and assessment activities helps BOEM prioritize and target specific information needs, fill knowledge gaps in time for future decisions, and maintain our high level of commitment to environmental stewardship. Information regarding BOEM's past and ongoing studies can be found in BOEM's Environmental Studies Program Information System (ESPIS), an online searchable database available at https://marinecadastre.gov/espis/#/. The following selection of Gulf-wide or deepwater studies were published between 2014 and 2019, informing decisions that affect GOM deepwater activities.

Risk Analysis Studies

A Study to Improve Oil-Spill Risk Analysis in the Gulf of Mexico: A Multi-Model Approach

Prior to holding a lease sale, BOEM analyzes the environmental impact of potential spills resulting from oil and gas operations in the Gulf of Mexico OCS. High-resolution gridded surface current and wind products in the GOM are needed to drive the oil-spill trajectory model, which estimates the probability of potential oil-spill contact with various environmental resources. Currently, BOEM's Oil Spill Risk Analysis (OSRA) model relies on the surface currents generated by one of the GOM's circulation models. This deterministic approach can be improved by incorporating multiple datasets to account for the uncertainty associated with surface winds models.

The study conducted ensembled OSRA model runs that include different sets of surface currents simulated by two well-validated Gulf of Mexico ocean circulation models and their corresponding wind forces (**Figure 90**). Model solutions were statistically analyzed to better understand the uncertainty of the probablility of oil-spill contact with environmental resources in order to increase the accuracy of the oil-spill risk analysis in projected areas of OCS operations. The method developed for this study could be employed in other OCS regions.

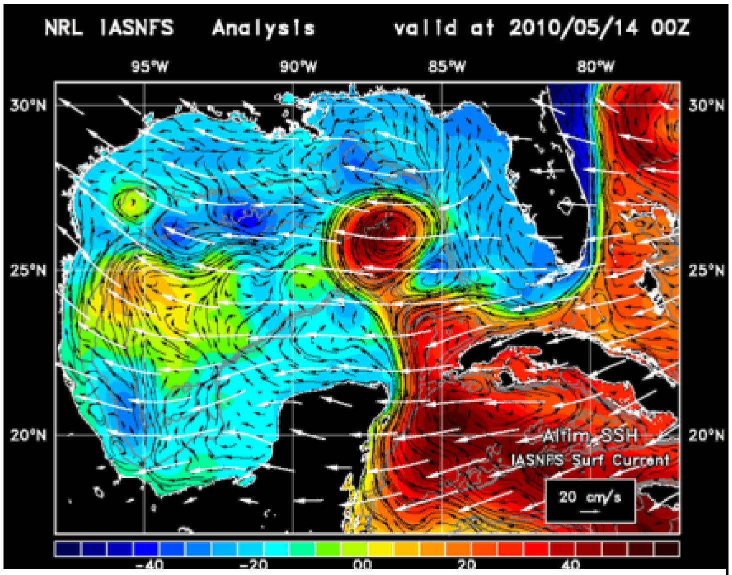


Figure 90. IASNFS reanalysis current at surface (black vectors) and NOGAPS 10-m wind (white vectors) superimposed over satellite altimeter SSH (in colors).

Remote Sensing Assessment of Surface Oil Transport and Fate During Spills in the Gulf of Mexico

Remote-sensing products, as well as ocean circulation models, provide important information about the oceanographic processes that influence the trajectory and spread of surface oil during a spill. Hydrodynamic models and imagery are used by government agencies during a spill response to map the spill's extent and describe how oceanographic processes determine spill movement. BOEM also needs this information to inform our oil-spill risk analyses and assessments of potential environmental impacts. Satellite imagery and other overflight data inform on spill extent while remote-sensing data can be used to estimate oil location and thickness.

BOEM funded this study to fill gaps in our understanding of the mechanisms controlling surface oil movement during spills, particularly at small spatial scales. The impact of the various physical and chemical processes on spill transport depends on the type of oil involved or released, as well as current oceanographic conditions. The Loop Current and its eddies play a significant role in the movement of surface oil in the eastern GOM. During the past spill events in the GOM, substantial remote sensing, overflight, and in-situ measurements were collected. The study analyzed these previous observations in greater detail along with the current state of knowledge on oceanographic processes to better quantify wind and ocean current influence on spill movement.

One of the objectives of this study was to characterize surface oil distributions through remote-sensing techniques. After identifying sensing functional techniques, the study developed an oil transport and weathering model and physical forcing fields for analyzing surface oil distributions. Applying the sensing techniques to the model, this study described the effects of oceanographic and wind forcing on the transport and character of oil, and identified different mixing processes that influence surface oil transport.

Biological Studies

Investigations of Chemosynthetic Communities on the Lower Continental Slope of the Gulf of Mexico

Over the last 25 years, cold-seep and hydrothermal vent communities have been studied at moderate depths in the GOM, along with the geology, geochemistry, and microbiology that supports their survival.

The most intensively studied and most understood of any deep-sea, cold-seep communities in the world are in water depths less than 1,000 m on the upper Louisiana slope of the GOM. Pervious studies have obtained a better understanding of the basic biology of the dominant animals and their life histories, as well as the processes that lead to the development of coral communities on carbonates created during periods of active hydrocarbon seepage. In addition, new organisms have been discovered, such as the ice worms associated with methane ice and the mussels that live near brine pools.

Although several GOM hydrocarbon seep sites located below 1,000 m have been visited by scientists, only a single site has been more intensively investigated. Located in Alaminos Canyon, the site lies at a depth of 2,200 m and has lush communities of biota, including tubeworms and mussels similar to the more well-known shallower sites (**Figure 91**). However, the underlying geology and almost all of the species present at Alaminos Canyon are different in part due to higher levels of methane and lower levels of oxygen in the deeper water sites as compared to shallower sites. Preliminary studies indicate that the structure of the communities associated with the tubeworms and mussels is also quite different, with higher tubeworm diversity found in shallower sites while higher mussel diversity was observed in deeper sites.

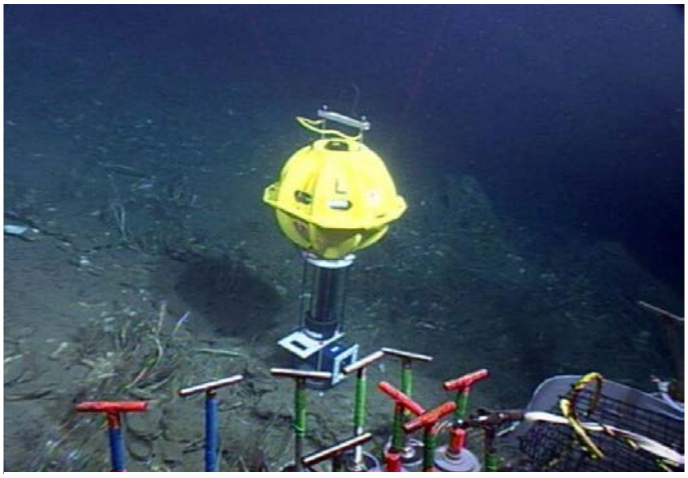


Figure 91. Rotary camera "Louie" deployed in seep community of tube worms and mussels.

The primary objective of the study was to discover and characterize seafloor communities associated with hydrocarbon seeps and on hard ground in the deep GOM. Information about these communities informed BOEM's development and delineation of appropriate avoidance zones to ensure that they are not impacted or damaged by conventional energy-related, seafloor-disturbing activities conducted in their vicinity.

Deepwater Reconnaissance of Potentially Sensitive Biological Features Surrounding Shelf-Edge Topographic Banks in the Northern Gulf of Mexico

Potentially sensitive biological features (PSBFs) are hardbottom habitats supporting diverse biological communities at or near the continental shelf edge. The PSBFs enhance habitat complexity by providing hard substrate that supports larval settlement of floral and faunal species, as well as food and refuge. These habitats, in turn, attract other benthic and demersal fauna, which increases biodiversity. The relationship between habitat complexity and species diversity of deeper communities is not well known nor are the geographic patterns between diversity and relief. One hypothesis suggested that the relationship between species diversity and hardbottom relief could serve as a proxy for community species diversity. BOEM funded this study to determine if this was the case and if predictions of the locations of areas with high biodiversity could be improved. The physical relief, geographic patterns in relief, and possible processes explaining PSBF formation were examined. Fourteen banks in the GOM were surveyed (maximum depth 247 m) over a west to east range of 215 km (28.338° N, -93.688° W to 27.821° N, 92.004° W). The biodiversity and geographic patterns of sessile, epibenthic communities on the PSBFs were also examined and found that communities vary in their environments and are potentially exposed to disturbance from OCS oil- and gas-related activities and fishing. Study results are used by BOEM to inform analyses of the potential impacts of conventional energy development on PSBFs and their benthic communities, as well as to develop mitigation measures to reduce those impacts.

Physical Sciences Studies

Lagrangian Study of the Deep Circulation in the Gulf of Mexico

Instabilities of the Loop Current, which enters the GOM through the Yucatan Channel and exits through the Straits of Florida, influences deep circulation. When the northward extension of the Loop Current towards the Mississippi Delta becomes unstable and separates, a large warm anticyclone known as a Loop Current eddy (diameter ~200-400 km) forms. The eddy translates across the western basin until it interacts with the Mexican slope and the mesoscale upperlayer eddy field. Large amounts of kinetic energy are transferred to the lower layer (below ~1,000 m) by baroclinic instabilities. Deepwater currents can influence the dispersion of water mass properties as well as pollutants such as oil spills.

BOEM funded the study to increase knowledge and understanding of the deep circulations in the GOM. A Lagrangian approach incorporated a deep Ranging and Fixing of Sound (RAFOS) and seven autonomous profiling (APEX) floats, which were deployed to collect observation data through the deep GOM without regard to national boundaries. The study also investigated the connections between upper- and lower-layer circulation processes. Information from the study is used by BOEM to better understand deepwater currents in the GOM; in environmental analyses and an understanding of the trajectory, fates, and effects of spill events; and in planning for potential future spill-response efforts.

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The Department of the Interior Mission

The Department of the Interior protects and manages the Nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors the Nation's trust responsibilities or special commitments to American Indians, Alaska Natives, and affiliated Island Communities.

The Bureau of Ocean Energy Management Mission

The Bureau of Ocean Energy Management (BOEM) is responsible for managing development of U.S. Outer Continental Shelf energy and mineral resources in an environmentally and economically responsible way.