BOEM
Bureau of Ocean Energy Management

General Information

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Types of Geological and Geophysical Surveys and Equipment

Geological and geophysical (G&G) surveys provide information used by government and industry to evaluate the potential for offshore oil, gas, methane hydrate resources, non-energy/marine mineral resources, and geologic hazards. The Bureau of Ocean Energy Management (BOEM) uses this information to fulfill its statutory responsibilities to ensure safe operations, support environmental impact analyses, protect benthic resources through avoidance measures, meet listed species' consultation requirements, ensure fair market value for leases, make royalty relief determinations, conserve oil and gas resources, and perform other statutory responsibilities.

The G&G surveys are conducted within our oceans and waters to:

(1) obtain data for hydrocarbon (oil, gas, and sulphur) exploration and production,
(2) locate and monitor marine mineral resources,
(3) aid in locating sites for alternative energy structures and pipelines,
(4) identify possible manmade, seafloor, or geologic hazards, and
(5) locate potential archaeological and benthic resources.

In general, G&G surveys are typically classified into the following categories by equipment type and survey technique:

- Hydrocarbon Exploration and Development Deep-Penetration Seismic;
- High-Resolution Geophysical (HRG) Seismic;
- Electromagnetic, Magnetic, Gravity, and Remote Sensing; and
- Geological Testing (Bottom Sampling and Drilling/Coring).

Geophysical Surveys

Hydrocarbon Exploration and Development Deep-Penetration and HRG Surveys

Deep-penetration seismic exploration and development surveys are conducted to obtain data on geological formations from the sediment near-surface to several thousand meters deep (below the sediment surface). A survey vessel or vessels tow a low-frequency acoustic source or sources (usually high-pressure airgun or airgun arrays), sending an acoustic signal that penetrates several thousand feet into the earth's subsurface and is then reflected to surface receivers. These receivers can either be towed in the water column or placed on the ocean bottom. These airguns generate air bubbles that expand and contract in the water column, and the resultant noise levels are generally in the 225-260 decibel range for airgun arrays. The resultant information, which is then processed by exclusive algorithms, enables industry to define strata and geologic structures/hazards and to accurately assess potential hydrocarbon reservoirs. This enables industry to optimally locate exploration and development wells in an effort to maximize extraction and production from a reservoir.

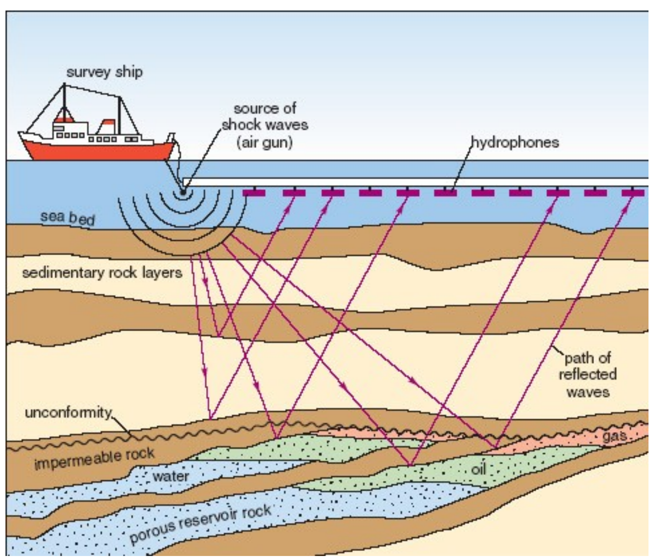

Photo 1. Basic Application of Seismic Data Acquisition in a Marine Setting (USEPA, 2011).

State-of-the-art computer mapping systems use seismic data sets generated by the following seismic survey types:

Photo 2. Typical Marine Seismic Survey Vessel and Towed Array Configuration and Seafloor Imaging Data (USDOI, BOEM, 2013).

- **Two-Dimensional (2D) Surveys**: The 2D acquisition involves a single vessel towing a single acoustic array. The receivers are either towed behind the vessel on a long cable (streamer) or placed on the ocean bottom (cables or nodes). The resultant data set is a planar representation of the subsurface. The 2D dataset can generally be acquired for identifying regional structural geology and/or linking known productive areas over large geographic areas to similar geological features.
- **Three-Dimensional (3D) Surveys**: The 3D acquisition involes one or several acoustic source vessels towing multiple receiver cables (or cable/nodal receivers configured on the ocean bottom) to acquire a 3D volume of data. The 3D seismic data have enabled industry to identify, with greater precision, where the most economical prospects may be located. The 3D technology is also used to identify previously overlooked hydrocarbon-bearing zones and new productive horizons. However, because 3D modeling requires much denser data coverage (i.e., closer line spacing) than 2D seismic surveys, areas already covered using 2D techniques may be resurveyed. Variations of 3D surveys include the following:
  1. **Four-Dimensional (4D) Surveys**: The 4D surveys are time-lapse 3D surveys that are repeated over producing fields to characterize production reservoirs. The 4D surveys are used predominantly as a reservoir monitoring tool to observe reservoir changes over time.
  2. **Wide Azimuth (WAZ)/Coil Multi-Vessel Surveys**: In single-vessel 3D surveys, only a limited subset of the reflected wave field can be recorded because of the narrow range of source-receiver azimuths. Wide, rich, and multi-azimuth acquisition configurations involve multiple vessels operating concurrently in a variety of source vessel-to-acquisitional vessel geometries. Several source vessels (usually 2-4) are used in coordination with single or dual receiver vessels. Coil surveys[1] are a further refinement of the WAZ acquisition of subsalt data. These surveys can consist of a single source/receiver arrangement or a multi-vessel operation with multiple sources, with seismic data being acquired while the vessels follow a circular to spiral path. This method was initially developed as a single-vessel alternative to WAZ surveys but has evolved into a multi-vessel technology.
- **Nodes and Ocean Bottom Cable Surveys**: Ocean bottom cable surveys were originally designed to enable seismic surveys in congested areas such as producing fields with their many platforms and production facilities. These surveys have been found to be useful for obtaining, repeatable 4D data and four-component (4C) data (seismic pressure, as well as vertical and two horizontal motions of the water bottom, or seafloor), yielding more information about the fluids and rock characteristics in the subsurface. Autonomous nodes, cabled nodes, and ocean bottom cable surveys require the use of multiple ships (usually 2 ships for cable layout/pickup, 1 ship for recording, 1 ship for shooting, and 2 smaller utility boats). New technology has also allowed for autonomous receiving units (nodes) to be deployed by remotely operated vehicles. A particular node or cable can lay on the bottom anywhere from 2 hours to several days, depending on operation conditions. In some cases, nodes or cables may be left on the bottom for future 4D (time-lapse) surveys.
- **Vertical Cable Surveys**: Vertical cable surveys, although now uncommon, are similar to ocean bottom cable surveys in that the receivers are deployed and then acoustic data are output by a source vessel. The receivers are located at several locations along a vertical cable that is anchored to the ocean bottom. These surveys can be conducted in water depths up to about 2,500 meters (m) (8,200 feet [ft]). Cables may be left in place for hours or days, depending on the size of the survey area and operating conditions. The dual airgun array is the same as normally used in 3D streamer surveys.
- **Vertical Seismic Profile (VSP) Surveys**: These surveys are used to obtain wellbore information about the nature of the seismic signal, as well as more information about the geology surrounding the vertical array of sensors. Vertical seismic profiling is a technique carried out by placing sensors down a well borehole before production tubing is placed in the wellbore, during development and production phases, or when a well is abandoned. Seismic airgun sources used in VSP surveys are the same as those used in conventional seismic airgun surveys.

[1] Coil surveys are a proprietary acquisitional technique developed by WesternGeco (Schlumberger).

Active Acoustic Source HRG Seismic Surveys and Equipment

These seafloor- to shallow-focused subbottom penetration surveys are used to identify potential:

- benthic biological communities/habitats,
- archaeological resources,
- seafloor bathymetry,
- geological hazards,
- seafloor engineering, and
- marine minerals.

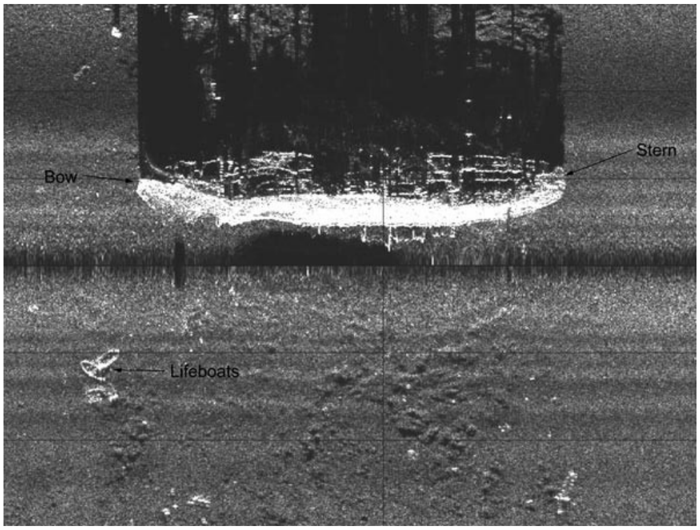

Photo 3. A Sidescan-Sonar Image of the Passenger Freighter *Robert E. Lee,* Collected by the HUGIN 3000 AUV in 2001 (USDOC, NOAA, 2013).

The high-frequency acoustic signal is reflected from sediments near the seafloor surface to several kilometers or more below the seafloor. Such high-resolution data may be used for initial site evaluation for a drilling rig or renewable energy structure emplacement and for platform or pipeline design and emplacement. The HRG surveys are also used for the identification of marine minerals or potential sand resources for coastal restoration. High-resolution site survey data obtained at greater depths below the seafloor can also be used for exploration purposes. High-resolution site surveys collect data using a variety of acoustic signal sources.

Some examples of equipment used in HRG seismic surveys include:

Photo 4. Sidescan Sonar Equipment (dual-frequency system) (USDOI, GS, 2013).

Sidescan Sonar: Like other sonars, a sidescan transmits sound energy and then receives and processes the return signal (echo) that has reflected off the seafloor or other objects. Sidescan sonar is a specialized system for detecting objects on the seafloor and mapping seafloor geomorphology, benthic habitats, and surficial sedimentary texture. Sidescan sonar typically consists of three basic components: towfish; transmission cable; and topside processing unit. In a sidescan sonar, the transmitted energy is formed into the shape of a fan that sweeps the seafloor from directly under the towfish to either side, typically to a distance of 100 m (328 ft) or wider. The strength of the return echo is continuously recorded, creating an image of the seafloor. For example, objects that protrude from the bottom create a light area (strong return) and shadows from these objects are dark areas (little or no return) as in Photo 3 above, or vice versa, depending on operator preference (USDOC, NOAA, 2013).

Deep-Tow Sidescan Sonar: Deep-tow, sidescan-sonar surveys are conducted in the Gulf of Mexico primarily for engineering studies involving the placement of production facilities and pipelines. The surveys provide information about seafloor topography and help to identify the presence of sand flows, hydrates, seeps, and potential hard-bottom areas. Operations are conducted from ships towing data communications cables up to 7 kilometers (km) (4.35 miles [mi]) long. This allows operations in water depths up to 3,000 m (9,843 ft) deep. Close to the end of the cable is a 30-45 m (98-148 ft) long section of chain to keep the sensor package (fish) tracking at approximately 25-30 m (82-98 ft) above the bottom. The chain drags along the seafloor, cutting a trench approximately 10 centimeters (cm) wide by 15 cm deep (4 inches [in] wide by 6 in deep). Also included in the sensor package is a pinger for subbottom profiling.

Boomers: The boomer is a broad-band sound source operating in the 3.5-hertz (Hz) to 10-kilohertz (kHz) range. By sending electrical energy from the power supply through wire coils, two spring-loaded plates in the boomer transducer are electrically charged causing plates to repel, thus generating an acoustic pulse. This system is commonly mounted on a sled and towed behind a boat. Dependent on subsurface material types, resolution of the boomer system ranges from 0.5-1 m (1.5-3 ft), with penetration depths ranging from 25-50 m (82-164 ft). The reflected signal is received by a towed hydrophone streamer (USDOI, GS, 2013).

Photo 5. Example of a Representative Boomer Plate System (Applied Acoustic Engineering Ltd., 2011, in USDOI, BOEM, 2012).

Chirp Subbottom Profilers: Chirp systems enable high-resolution mapping of relatively shallow deposits. Chirp systems emit a "swept" frequency signal, meaning that the transmitted signal is emitted over a period of time and over a set range of frequencies (ranging from 3.5-200 kHz). This repeatable (transmitted) waveform can be varied in terms of pulse length, frequency bandwidth, and phase/amplitude. The sonar head is mounted at the bottom of the ship's hull, with the central axes of both transducers oriented directly downward or towed at a constant elevation above the seafloor. Newer chirp systems are able to penetrate to comparable levels as the boomer, yet yield extraordinary detail or resolution of the section. Penetration depths range from about 3 m (10 ft) in coarse sand to about 200 m (656 ft) in finer grained sediments, depending on the frequency range of the outgoing signal and the system employed.

Sparkers: The sparker is an acoustic sound source that generates an electrical arc that momentarily vaporizes water between positive and negative leads. The collapsing bubbles produce a broad band (50 Hz - 4 kHz) omnidirectional pulse that can penetrate several hundred meters into the subsurface. Hydrophone arrays towed nearby receive the return signals. It can operate only in salt water. The sparker system (operated at 50-4,000 Hz) generally yields greater penetration than the boomer or chirp systems, with resolution on the order of a few meters.

Magnetic, Gravity, and Remote Sensing Surveys

Other types of survey activities that provide data on hydrocarbon resources and/or geohazards include controlled source electromagnetic surveys, magnetotelluric surveys, several aerial remote-sensing methods (e.g., radar imaging and aeromagnetic surveys), gravity surveys, and gravity gradiometric surveys.

Electromagnetic Surveys: Electromagnetic surveys are used to help delineate potential oil and gas reservoirs. There are two practical electromagnetic techniques applicable to marine surveys. Both the magnetotelluric (MT) and controlled source electromagnetic (CSEM) methods have been primarily applied in the marine environment in a research mode.

In the MT technique, no electrical currents are induced into the earth, but the receiver device detects the natural electrical and magnetic fields present in the earth. Ships are used to deploy and retrieve the receivers with data loggers. Also attached to the receivers are four arms protruding out from each side of the box with an electrode on each end. These arms are about 20 m (65 ft) long and made of 5-cm (2-in) plastic polyvinyl chloride (PVC) pipe. Inside the recording box is a magnetometer and a long-term data logger, which allows the box to remain on the water bottom for days at a time. The receiver is retrieved by using an acoustic pinger that releases the anchor from the recording box, which then floats to the surface.

In the CSEM technique, two cables (joined together with the second cable a few hundred feet longer than the first) are towed around by a ship. Attached to the end of each cable is a bi- or di-pole, which is a metal cylinder about 3 m (9.8 ft) long and 0.3 m (1 ft) in diameter. At regular intervals, an electrical signal at very low frequencies is input through the cables and into the seafloor. These electrical signals are detected by previously deployed receivers 2-10 km (1.2-6.2 mi) away from the source and arranged in a line or profile. The receiver boxes are attached to degradable concrete blocks like those used in the MT technique. Inside the receiver boxes are recording devices that allow for recording for a few days. When the recording is finished, an acoustic pinger releases the recording box from the anchor, and the recording box floats to the surface for retrieval.

Radar Imaging: Radar imaging by satellite is currently used to detect oil slicks on the sea surface. This is possible because, when the oil molecules reach the sea surface, they form a thin layer that dampens the ocean surface capillary waves. The detection of oil slicks requires quiet water conditions and consequently is limited by sea state as well as satellite position and frequency of coverage. The resolution of the radar images ranges from 8-100 m (26-328 ft) with a swath width range of 50-500 km (31-310 mi). The radar satellite is in a near polar orbit at an altitude of 798 km (495 mi). The cycle time for a duplicate orbit is 24 days, but a common spot on the earth can be revisited every 5 days and surveyed with different viewing parameters. BOEM does not permit or approve radar imaging surveys.

Aeromagnetic Surveys: Aeromagnetic surveys are conducted in the Gulf of Mexico to map for deep crustal structure, salt-related structure, and intra-sedimentary anomalies. The surveys are flown by fixed wing aircraft, with flight lines on the order of 400 km (250 mi) long at a height of 75-150 m (246-492 ft) above the sea surface and flown at speeds of about 220 kilometers per hour (758 miles per hour). Flight line spacing ranges from 500-800 m (1,640-2,625 ft) apart with cross lines. The earth's magnetic field is measured by either a proton precision or cesium vapor magnetometer mounted in a "stinger" projection from the tail of the aircraft. On occasion, two magnetometers are used to measure not only the total magnetic field but also the vertical gradient of the field. Magnetometers also can be towed behind a ship. This usually is in conjunction with a seismic survey, but it can be run as a separate survey.

Marine Magnetic Surveys: Marine magnetic surveys measure the earth's magnetic field for the purpose of determining structure and sedimentary properties of subsurface horizons. These surveys are usually conducted in conjunction with a seismic survey, allowing the navigation information to be used for both surveys. The development of low-power digital sensors has allowed the sensor package to be towed behind the seismic source array, which has greatly improved the operational efficiency of magnetic surveys. The sensor is towed behind one of the subarrays of the seismic source array at distances of 50, 100, or 150 m (164, 328, or 492 ft) (behind the array), although a 100 m (328 ft) distance is the most common. The sensor is towed at a depth of 3 m (10 ft) and makes use of depth devices mounted on the cable to maintain a constant depth.

Gravity Surveys: Marine gravity data can be collected with instruments on the seafloor, in boreholes, in ships, helicopters, or in planes. Most collection points are on ships. Marine gravity meters have, in some cases, been housed in a ship while it is conducting a seismic survey. However, the preferred method has been to use dedicated ships in order to acquire more precise data. With the advent of global positioning system (GPS) navigation and larger, more stable seismic ships, it is now possible to achieve the same order of accuracy with meters placed in seismic ships as in dedicated ships. Data grids for gravity surveys range from 1.6 km x 8 km (1 mi x 5 mi) to 9.7 km x 32 km (6 mi x 20 mi). Gravity data may also be collected using helicopters or planes.

Gravity Gradiometry: Measuring the earth's gravity gradient is now possible with the release of Department of Defense technology. The instrument is housed in a box located in the center of a survey ship. In shallow water, the ship sails a 0.25 km x 1 km (0.15 mi x 0.6 mi) grid, and in deep water, a 1 km by 2 km (0.6 mi x 1.25 mi) grid is used. Typically, a 20-block area is selected for survey, and this can be completed in about 2 days. These surveys are now conducted using planes as well.

Geological Surveys

Photo 6. Bottom Coring Samples (USDOI, BOEM, 2013).

Geological and geochemical sampling is conducted to obtain samples of the seafloor for physical and/or chemical analyses. Physical analyses are used in engineering studies or geotechnical evaluations for placement of structures such as renewable energy facilities, platforms and pipelines, and marine minerals resource evaluation and prospecting. Chemical analyses (surface geochemical prospecting) are based on the premise that upward migrated petroleum from deep source rocks and reservoirs can be detected in near-surface sediments and are used to evaluate exploration potential. Sometimes a program of bottom sampling and shallow coring is conducted simultaneously using a small marine drilling vessel (USDOI, GS, 1976). Other sampling techniques using towed hydrocarbon "sniffers" are rarely used.

Bottom Sampling

This method is used for retrieving soil samples from the seabed surface. The information obtained can be used for a number of applications including the following:

- bulk sampling for seabed minerals;
- marine aggregate prospecting;
- environmental sampling;
- pre-dredge investigations; and
- ground truth for morphological mapping and geophysical surveys.

Grab Samplers: Grab samplers are one of the most common methods of retrieving sediment samples or biological samples from the seabed. A grab sampler is a device that collects a sample of the topmost layers of the seabed and benthic biota by bringing two steel shells together and cutting a bite from the soil. A typical hydraulic grab sampler will weigh about half a tonne and can operate in water depths down to 200 m (656 ft). Typical sampling rates are between three and four grabs per hour.

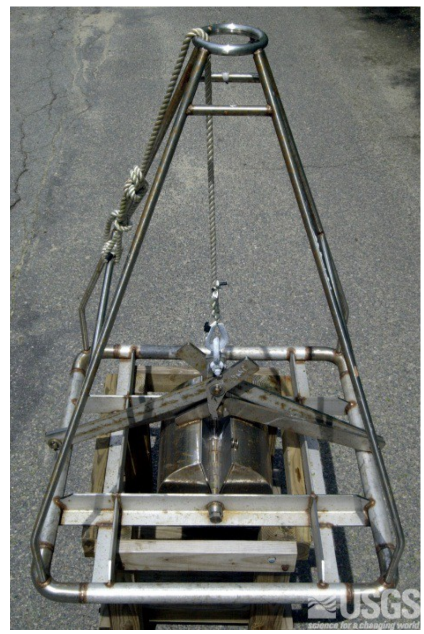

Photo 7. Close Up of Van Veen Sediment Grab Sampler (USDOI, GS, 2013).

Coring

Coring applications can be used to investigate seafloor soils for purposes of[2]

- dredging and inshore engineering;
- offshore oil and gas engineering;
- route surveys for pipelines and cables; and
- providing soil type control for geophysical surveys.

Piston Core: The typical piston core is a 6 m (20 ft) long, 7.5 cm (3 in) diameter pipe with a 910 kilogram (2,000 pound) core weight. In gravity coring, wire is paid out from the coring winch at a fairly fast speed, allowing the corer to hit the bottom with a force proportional to the weight of the corer and the speed at which it is deployed. Penetration into the bottom is limited by the sediment type, friction of the sediment on the outside and inside walls of the core barrel, and the resistance of the water exiting the top of the core barrel. In contrast, a piston corer uses a "free fall" of the coring rig to achieve a greater initial force on impact and a sliding piston inside the core barrel to reduce inside wall friction with the sediment and to assist in the evacuation of displaced water from the top of the corer. The core barrel dimensions are

[2] Source: ISSMGE, 2005.

generally a 6 m (20 ft) long by 7.6 cm (3 in) internal diameter by a 9 cm (3.5 in) outer diameter. Coring at lengths greater than 6 m (20 ft) is possible but not common.

Vibracores: Vibracorers are used wherever soil conditions are unsuited to gravity corers or where greater penetration of the seabed is necessary. Vibracoring generally uses a 7 cm (2.8 in) diameter core barrel mounted on a platform or tripod support assembly and can penetrate sediments in the upper 15 m (50 ft). To penetrate dense sands and gravels, or to reach deeper into stiff clays, the corer's barrel is vibrated, facilitating its penetration into the soil (ISSMGE, 2005). A typical vibracore survey will obtain 15-25 cores, approximately 6 m (20 ft) deep in a 1-square mile (640 acre or 259 hectare) area.

Box Cores: Box corers are used to recover relatively undisturbed block samples of seabed in soft, cohesive sediments. The box corer is a very simple device that envelops an area of seabed then seals the base of its box to retain the sample from further disturbance during recovery. The standard box corer consists of a steel frame incorporating the sample box surmounted by a 200-300 kilogram (441-661 pound) mass. When activated by a self-release trigger system, the box is closed at the bottom by a swivelling base. The total mass of a box corer is in the order of 1.5 metric tons (3,307 pounds) and the sample volume is about 25-30 litres (6.6-8 gallons) (ISSMGE, 2005).

Other Methods

Shallow Borings: Shallow coring is done by conventional rotary drilling equipment from a drilling barge or boat. Penetration is usually limited to the recovery of several meters of consolidated rock.

Heat Flow Measurements: Another tool in limited use in deepwater exploration is a heat flow probe. This technique, used primarily in academic circles as a research tool, provides geochemical and geological information that aids in understanding regional-scale hydrodynamics and the potential for occurrence of hydrocarbons. Heat flow measurements are conducted with a device that looks much like a piston corer. The device measures both temperature gradient and thermal conductivity *in situ* over subbottom depth intervals of up to 6 m (20 ft). The footprint and impact on the sediments is almost identical to that of piston or gravity coring.

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