Analysis of Seismic Methods Used for Subsea Hydrocarbon Exploration

Birin, Ivan; Maglić, Lovro

Source / Izvornik: **Pomorski zbornik, 2020, 58, 77 - 89**

Journal article, Published version
Rad u časopisu, Objavljena verzija rada (izdavačev PDF)

https://doi.org/10.18048/2020.58.05.

ISSN 0554-6397
UDK: 004.032.26
Review article
Received: 15th February 2020

Ivan Birin
E-mail: ivanbirin@hotmail.com
Lovro Maglić
E-mail: maglic@pfri.hr
University of Rijeka, Faculty of Maritime Studies, Studentska 2, 51000 Rijeka, Croatia

Analysis of Seismic Methods Used for Subsea Hydrocarbon Exploration

Abstract

Subsea hydrocarbon exploration comprises detection and estimation of shape, depth, volume and other physical properties of hydrocarbon fields within the Earth's subsurface layers. Marine seismic survey is a process that generally includes sending seismic waves into seabed and recording the intensity and travel time of reflected seismic waves to determine the subsurface features of the Earth. Different methods, equipment and techniques are used to conduct a survey, from sea surface seismic arrays to seabed local seismic station networks. In this paper different widely used seismic methods are presented, together with their advantages and drawbacks. Furthermore, new methods that are being developed and tested for future approach to more advanced and efficient seismic exploration are presented.

Keywords: subsea exploration, seismic array, subsea survey, hydrocarbon exploration

1. Introduction

Hydrocarbons naturally occur as oil, natural gas and gas condensate. Generally, the continental deposits of hydrocarbons are rather thoroughly examined, based on the available technological solutions and their capabilities. On the other hand, water surface, hence the seabed as well, occupies approximately 70% of the Earth's surface, still provides numerous opportunities for subsea hydrocarbon fields discoveries. Many states and oil companies largely invest in subsea exploration to find new large hydrocarbon reserves for exploitation. In general, the complete process of oil exploitation from the seabed is a very complex and expensive process that includes several steps: exploration (detection and quantitative estimation of a potential hydrocarbon field), exploration drilling and qualitative testing, filed exploitation and finally decommissioning. As mentioned, the exploration can be divided into two steps: non-invasive (detection) and invasive (drilling) [11]. Non-invasive methods are gravimetry, magnetometry and seismic measurements. An invasive method is exploratory drilling with specialized drill ships or platforms (predominantly jack-up or semisubmersible platforms). Seismic exploratory methods are one of many activities in the sea that highly influence marine fauna, marine mammals in particular. Seismic waves generated in the water column negatively influence fish and mammals, especially those species that use sound for location and communication [8].

The objective of this paper is to present and analyze the non-invasive seismic methods used for hydrocarbon exploration. Seismic methods, which are nowadays commercially used, vary significantly and include: towed streamers method (1), as the predominant commercial method, ocean bottom seafloor cable method (2), permanent buried seismic installation (3) and vertical seismic profiling (4) (Figure 1). All marine seismic methods include a source (S) of seismic (shock) waves used to obtain a profile of the seafloor. Each seismic method can be further divided based on the receiver system geometry, measurement density on a certain area and sensor types [12].

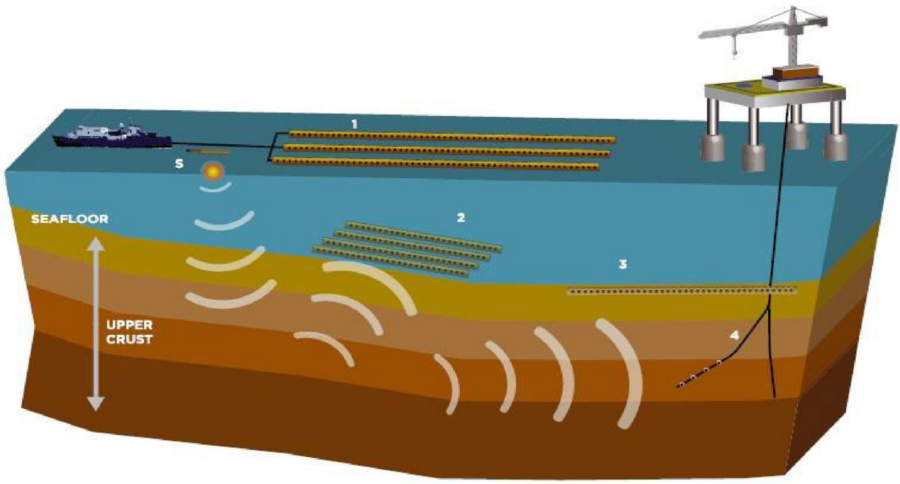

Figure 1 - Methods of seismic exploration [12]

All commercially used seismic methods as well as novel methods being developed are presented and analyzed in the following text.

2. Towed streamers method

Two main elements of this method are specialized seismic ships and seismic gear (seismic array), which is deployed and towed on the sea surface by a seismic ship. Seismic ships are usually 75 to 90 meters long, with crew size ranging between 30 and 80 members (Figure 2). During seismic operations, these ships navigate with speed of approximately 5 knots following the exact predetermined survey plan (scheme) [5]. Seismic operations are weather (wave) sensitive, meaning that if the waves are higher than 3 meters the operations are typically stopped and the seismic array is secured on the ship [5, 12].

There are two principal approaches to seismic surveying using this method: two-dimensional (2D) and three-dimensional (3D) exploration (Figure 3) [7]. 2D is a basic and less expensive method that uses a simple seismic array i.e. only one streamer. The data acquired represents a 2D view of the seafloor section (length and depth). 2D survey usually precedes the 3D or 4D survey.

Figure 2 - Seismic ship Ramfrom Titan [4]

3D surveying is a more complex and efficient method of seismic surveying that involves a more sophisticated approach using a complex seismic array i.e. several streamers at the same time. The data acquired represents a 3D view of the seafloor section (length, width and depth) [7]. There is an even more sophisticated and efficient approach - a four-dimensional (4D) exploration or time lapse survey. In general, 4D exploration represents multiple surveys of the same area and high-density data acquisition and comparison. Such data comparison provides an understanding of the subsea reservoir behavior as well as the historical changes (fluid or gas movements, pore pressure changes, temperature changes, changes in layer thickness, etc.), and helps to predict its future conditions [1, 11].

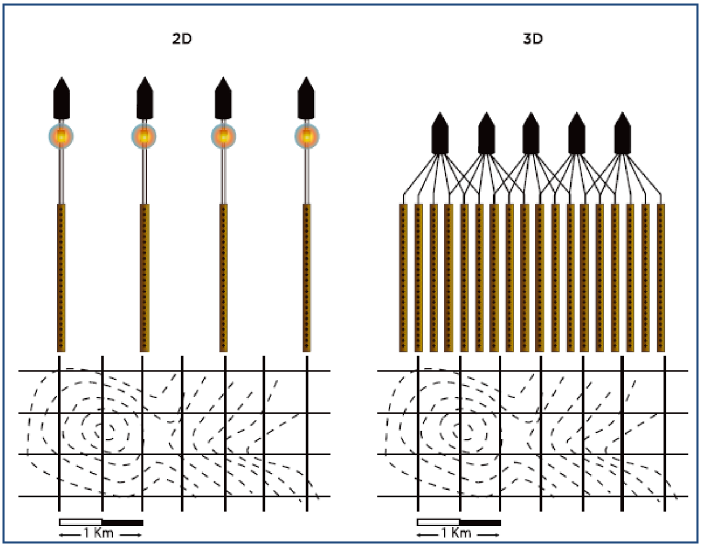

Figure 3 - Towed streamers - 2D and 3D survey [12]

A modern seismic ship can conduct any of the abovementioned approaches. The main elements of a seismic array typically include air-guns (source of shock waves), long streamers (cables) equipped with hydrophones (sensors receiving reflected shock waves) and auxiliary equipment like paravanes, different floaters and tail buoys (Figure 4) [2, 4].

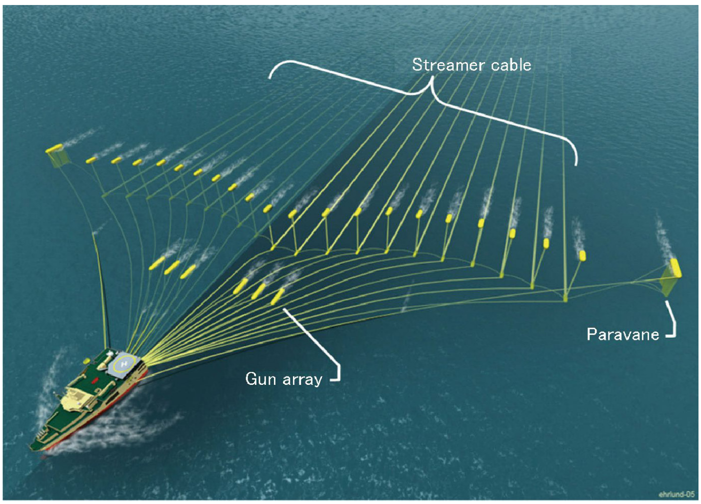

Figure 4 - Towed seismic streamers - a typical array [4]

Air guns are used to generate and release shock or compression waves towards the seabed (Figure 5). In this method a shock wave is actually a very strong sound wave. Air guns can be stacked in one row or placed in multiple rows. Each row forms a string. Air gun strings are usually 15 to 30 meters long and 20 meters wide. An air gun comprises two high-pressure air chambers: an upper control chamber and a discharge chamber. High-pressure air is typically supplied to the upper control chamber at 2000 to 2500 psi from the compressor onboard the seismic vessel via an air hose. Then, it bleeds into the lower firing chamber through an orifice in the shank of the shuttle. The air gun is actuated by sending an electrical pulse to the solenoid valve, which then opens, allowing the high-pressure air to flow to the underside of the triggering piston. High-pressure air in the lower (firing) chamber is discharged into the surrounding water through air gun ports. The air from these ports forms a bubble, which oscillates according to the operating pressure, the intended depth of operation and the volume of air discharged into the water. The shuttle is forced back down to its original position by the high-pressure air in the control chamber, so that once the discharge chamber is fully charged with high-pressure air, the air gun can be fired again. The opening of the shuttle is very rapid, lasting only a few milliseconds, which allows the high-pressure air to be discharged very rapidly.

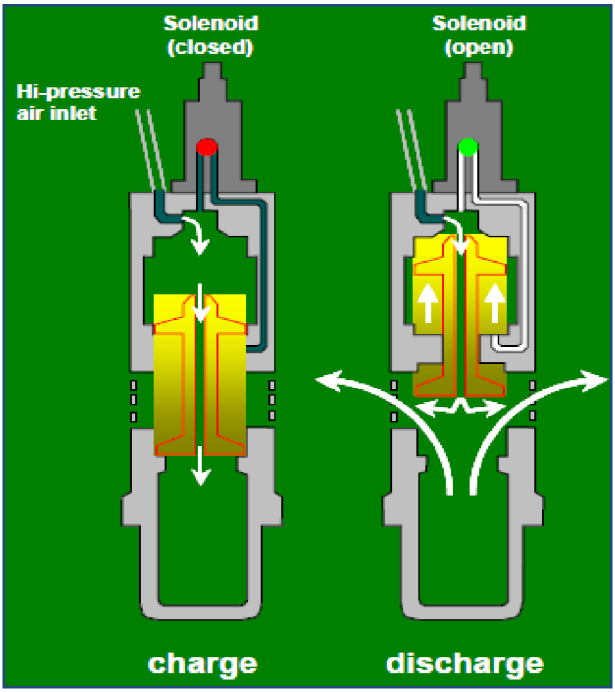

Figure 5 - Seismic air gun [10]

Air guns are fired approximately every 50 meters, which propagates shock waves through the water down to the sea floor and beyond, into the subsurface of the Earth. Shock waves change their velocity depending on the density of the medium encountered in the subsurface (different rock layers, liquids, gas or void spaces). In the zone where different subsurface layers meet, one part of the wave is reflected to the surface, while the other is refracted further into the Earth. The speed of sound waves generated by air guns is about 2.500 m/s through the water column, and between 3000 to 5000 m/s through the ground [6]. For example, in the case of subsea area exploration at 10 to 20 km depth recordings of wave reflections start approximately four seconds after firing a source shock wave. During marine seismic survey covering 100 square kilometers more than one million shock waves are fired and several terabytes of recorded data are acquired [12].

Figure 6 - Seismic tail buoy [17]

Upon deployment, each streamer is usually towed at 6 to 12 meters depth i.e. below the sea surface to minimize the interference (noise) of surface waves [5]. Each streamer is equipped with a positioning system to maintain the wanted position and a precise distance between each neighbor streamer. Usually, horizontal distance between each streamer is 50 to 120 meters. The length of a typical streamer is 6 to 12 kilometers, depending on the depth of the area being investigated. A streamer is made up of five main components: hydrophones, electronic modules, stress members, electrical transmission system and protective skin of the streamer. Streamers are equipped with hydrophones, which are evenly positioned in groups approximately every 25 meters [6]. A hydrophone is a sensor designed to detect pressure fluctuations in the water caused by the reflected shock waves. The hydrophones' recordings are transformed into visual images of the Earth's subsurface. The hydrophones are spaced 1 meter apart and electrically coupled in groups. Electronic modules are used to digitize and transmit seismic data while stress members made of steel or kevlar provide the required streamer's strength. All of the above-mentioned components are housed in the streamer skin. Streamers have additional external devices such as: birds, magnetic compasses, acoustic positioning units and tail buoys (Figure 6). Birds are used for depth and lateral control between the streamers, while magnetic compasses and acoustic positioning units are used for precise streamer position. Birds are normally spaced at 300 meters apart on each streamer. Modern seismic so-called e-bird is a bird for lateral, vertical and roll streamer control in marine seismic acquisition, e-bird is equipped with robust and advanced steering devices ensuring continuous operation for all types of streamers. Paravanes are used for spreading the streamers on the left and right side of the ship.

One of the most important factors during the seismic operation is prevailing weather, predominantly sea conditions [12]. Other important issues are survey area size, current direction, fishing and shipping activity, other seismic operations in vicinity, marine mammal activity, drilling and subsea equipment maintenance. The time spent on acquiring seismic data is approximately 35-40% of the time spent for the whole seismic exploration project. During navigation following a certain pattern the time needed to change the direction of the streamers (line change) may last up to three hours. Except for the non-favorable weather conditions, one of the main challenges during seismic operations is when the direction of the current is perpendicular to the course and streamer orientation, causing larger streamers movements and irregularities in the subsurface data being collected. The presence of other ships or drilling ships/platforms could cause problems due to noise from ships' propulsion or drilling processes. Seismic ships are restricted in their ability to maneuver, which is particularly important when operations are carried out in coastal zones, in areas of dense traffic or near the existing oil or gas exploiting platforms.

Few modern advanced survey techniques should be emphasized. One of them is MAZ (Multi Azimuth), which represents a 3D survey over the same subsea area with multiple azimuth (orientations) passages (Figure 7) [9, 12]. The specific area is surveyed a number of times but using different navigation directions. With the MAZ technique it is possible to obtain an improved seismic image of the specific rather small area.

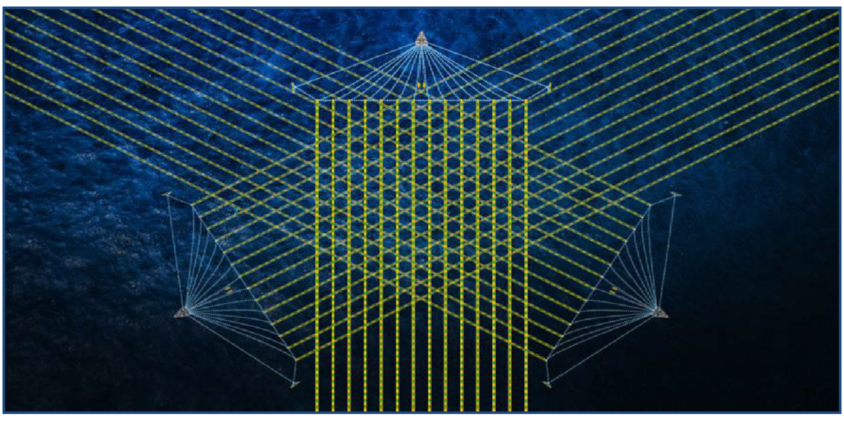

Figure 7 - Multi Azimuth seismic survey technique [16]

Another advanced 3D survey technique is WATS (Wide Azimuth Towed Streamer) and it is used to acquire an improved seismic image of a larger area (Figure 8). This surveying technique involves two or more vessels in one configuration, where one or more vessels are used to generate shock waves (source vessels) while other vessels are used to acquire data (streamer vessel). Usually the target area must be surveyed two or more times with different lateral separation between streamer vessels and source vessels [3,16].

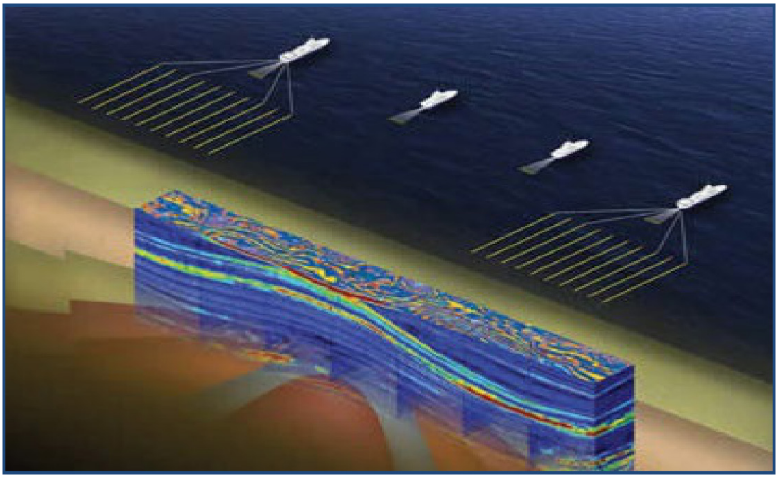

Figure 8 - Wide azimuth towed streamer seismic technique [3]

In some cases, advanced techniques MAZ and WATS may be used in combination, which is called FAZ or Full-Azimuth survey technique [16].

3. Other marine seismic survey methods

Other seismic survey methods used for hydrocarbon exploration include ocean bottom cable (OBC), permanent seismic installation, vertical seismic profiling (VSP) and the use of autonomous underwater vehicles (AUV) equipped with seismic instruments.

Ocean bottom cable (OBC) is a seismic survey method using a series of seismic cables which are fixed and laid down or buried in the seabed (Figure 9). Typically, there are two principal OBC setup approaches: two-component (2C) and four-component (4C). 2C type makes use of one geophone and one hydrophone, while a 4C type uses three geophones and one hydrophone. A geophone detects seismic waves on or below the Earth's solid surface and converts them into electric impulses proportional to the displacement, velocity and acceleration of the waves. A hydrophone then detects changes in water pressure. This method can be used for a 2D survey with one single seismic cable or 3D and 4D surveys with a multi cable setup. In that case a cable of 5 or 6 kilometers in length is laid down in rows every 25 to 30 meters [12, 15].

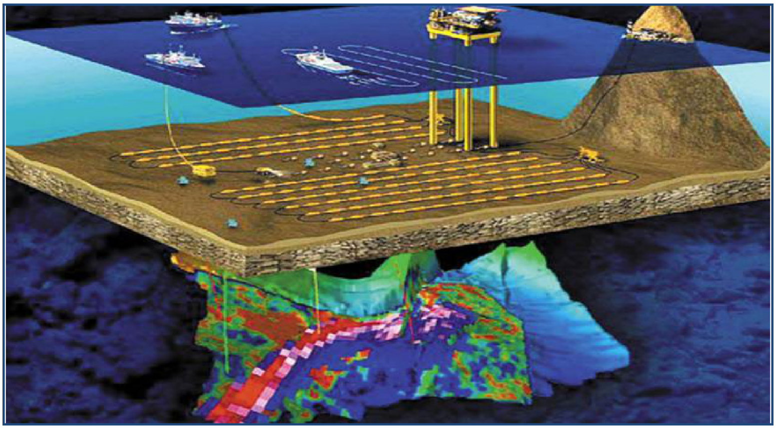

Figure 9 - Ocean Bottom Cable seismic method [15]

OBC operations include a seismic vessel used to deploy one or more cables, data recording and cable recovery. In seismic wave generation a separate "source vessel" periodically triggers seismic waves following a determined pattern over the cable setup. The use of multiple vessels increases the cost of OBC operations in comparison to the towed streamer method. On the other hand, the OBC method generates better-quality and higher-resolution imaging of potential sites compared to a widespread towed streamer method. OBC is typically used in areas with existing exploitation in the vicinity.

Permanent Seismic Installation. A permanent seismic installation is a method where a series of seismic sensors are trenched one meter in the seabed (Figure 10). This method is used next to a rather small number of existing and producing hydrocarbon fields, for the continuous 4D measurements (hydrocarbon fluid and gas behavior within the reservoir in time). This method needs only one vessel, a "source vessel" equipped with air-guns for seismic wave generation. A disadvantage of this system is a relatively high initial cost due to underwater works which include the sea bed preparation (excavation) and deployment of sensor cables [12, 14].

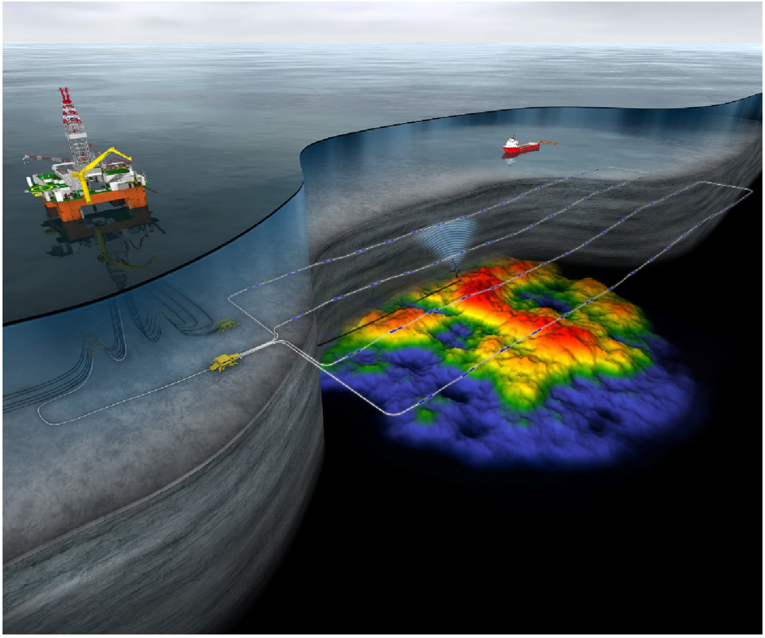

Figure 10 - Permanent seismic installation method [18]

Vertical Seismic Profiling (VSP) is a method where a number of geophones are lowered into the seabed through a borehole. The seismic wave source is still on the vessel or a platform on the sea surface, which can produce the seismic wave above the borehole or on other positions around the area (offset VSP). Surveys duration lasts typically one or two days and it is used for a rather small targeted area [12].

The advantage of this method is that the seismic wave travels in one direction through the seabed and the distance that the seismic wave travels is relatively short, compared to other methods. Due to this fact the wave energy is less absorbed in the Earth's structure, hence the image is of the higher resolution i.e. quality.

4. The future of marine seismic exploration

There are several new methods of marine seismic exploration currently being developed and tested, two of which should be emphasized.

One of the new seismic acquisition techniques is the FreeCable developed by French company "Kietta" [9]. This method is based on the usual reflection seismology. The system consists of one master vessel, one or more source vessels and an array of autonomous submerged cables equipped with seismic sensors to detect and measure the reflected waves (Figure 11). The array includes 20 cables of 8 km in length, which are independent and autonomous. The cables are controlled by a pair of small autonomous vessels (RAV - recording autonomous vessels), used to regulate the exact cable position as well as to collect, record and transmit the valuable data to the master vessel. All operations are supervised from a control room on board a master vessel.

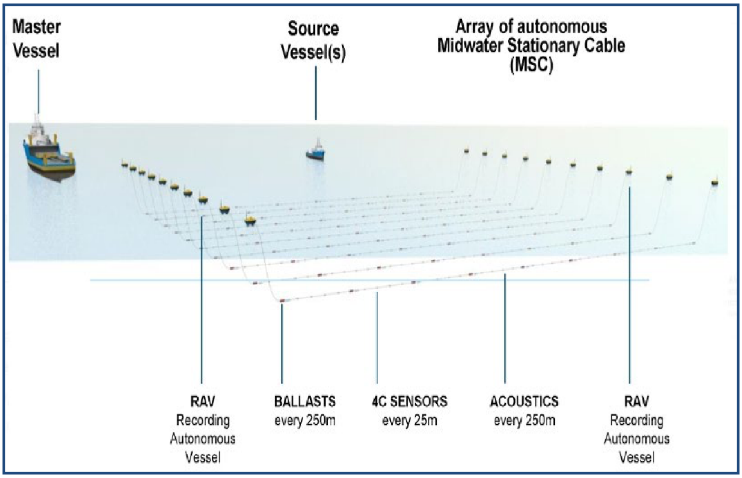

Figure 11 - FreeCable seismic method - vessels and equipment [9]

The cables are separated parallelly every 400 m and each cable is equipped with 4C sensors at every 25 m. Cables may be moved by autonomous vehicles at a very slow speed, approximately 0.1 knots to cover the desired areas (Figure 12).

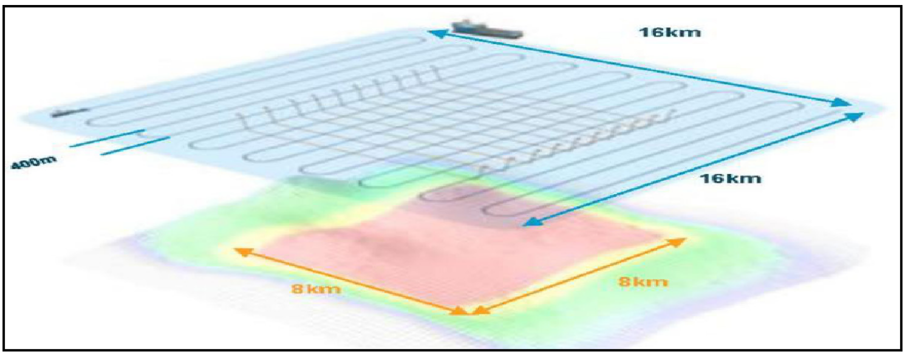

Figure 12 - FreeCable seismic method – survey concept [9]

Another novel method being developed is the WiMUST (Widely scalable Mobile Underwater Sonar Technology). The method is based on several autonomous underwater vehicles (AUV) working in a synchronized manner. They tow significantly shorter cables (streamers) making an underwater acoustic network (Figure 13). This method, like all others, still needs a surface vessel for deployment and recovery of the AUVs and cables but also for the seismic wave generation i.e. acting as a source vessel [13].

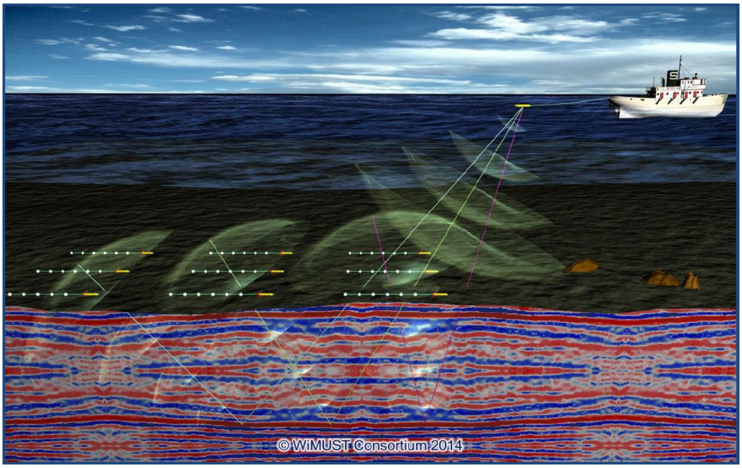

Figure 13 - WiMUST seismic survey method [13]

The main advantages of such a concept include a simplified use, once the equipment is deployed (submerged), and significantly decreased negative influences on the sea surface (e.g. lateral drift induced by wind currents, wave interference, propeller and engine noise and vibration, etc.) Two main challenges of this method are the precise synchronization of the AUVs acting as a swarm i.e. the development of the algorithm for their cooperative behavior and their autonomy.

5. Conclusion

Marine seismic measurements are the most efficient approach for quality assessment of the seabed geological structure. As a result of seismic survey and data collection it is possible to estimate the location and size of the hydrocarbon deposits in the seabed. The method which is most accepted and commercially used at this time is a towed streamer method. Other marine seismic operations commercially used are ocean bottom cable, permanent seismic installation, and vertical seismic profiling. Several new technologies are currently being developed, but two novel methods should be emphasized: FreeCable and WiMust, both based on the submerged seismic cable technology. Though very important for successful oil and gas exploitation, the seismic exploration is one of many activities in the sea that highly influences marine fauna, especially marine mammals. Seismic ships produce seismic waves from air guns approximately every 10 seconds during the seismic survey. Such waves propagate through the water column and negatively affect fish and mammals in the vicinity, especially those species which use sound for location and communication.

References

1. 4D Marine Seismic Acquisition (2015). online: https://www.iongeo.com/content/documents/Resource%20Center/Case%20Studies/CS_ION_Marine4D_110826.pdf (5.12.2018)
2. Babicz, J. (2015). Wartsila Encyclopedia of Ship Technology. Helsinki.
3. Brown, D. (2008). Resolution Undergoing Revolution, Wide azimuths combat salt ‘blur’, AAPG Explorer.
4. Building the 5th Generation Ramform Titan-class Seismic Vessel (2013). Mitsubishi Heavy Industries Technical Review Vol. 50.
5. Canadian Association of Petroleum Producers (2005). Seismic Surveys - The search for Oil and Gas In Offshore Atlantic Canada. http://www.oneocean.ca/pdf/seismic/surveys.pdf (Accessed 2.12.2018)
6. Deschizeaux, B., Blanc, J.Y.(2007). Imaging Earth’s Subsurface Using CUDA. GPU Gems 3, Nguyen, H., Addison-Wesley Professional, United States, New Jersey.
7. Dondurur, D. (2018). Acquisition and Processing of Marine Seismic Data. Elsevier.
8. Gordon, J., Gillespie, D., Potter, J., Frantzis, A., Simmonds, M., Swift, R., Thompson, D. (2003). A Review of The Effects of Seismic Surveys on Marine Mammals. Marine Technology Society Journal. 37. 16-34.
9. Haumonté, L. (2017). The Future of Marine Seismic Acquisition?. GeoExPro. Vol 14/1.
10. Lago Cameselle, A. (2010). Mapping of Sedimentary Bodies by 3D Seismic Reflection Data. Universitat de Barcelona & Universitat Ramón Llull, Spain.
11. Landro, M. (2015). 4D Seismic, Petroleum geoscience: From sedimentary environments to rock physics, Bjørlykke, K. (ed.), second edition.
12. Oil & Gas Producers (OGP), 2011, An overview of marine seismic operations, report No. 448
13. Pleskach, M. (2017). WiMUST–A Fleet of AUVs for Seismic Surveys, Hydro international, Vol 21/3.
14. Permanent Reservoir Monitoring (PRM), 2013, https://w3.siemens.com/markets/global/en/oilgas/PublishingImages/applications/subsea/products/surveillance/2013-09_Permanent-Reservoir-Monitoring_SiemensOctio.pdf (accessed, 4.12.2018)
15. Wang, Y., Grion, S., Bale, Richard. (2009). What Comes Up Must Have Gone Down the Principle and Application of Up-Down Deconvolution for Multiple Attenuation of Ocean Bottom Data. Recorder. Vol 34/10.
16. Why More Azimuths is a Good Thing, 2017. https://www.pgs.com/publications/feature-stories/why-more-azimuths-is-a-good-thing/ (accessed 5.12.2018)
17. http://www.romona.ru/en/resources/equipment/seismicity-of-high-and-ultrahigh-resolution (Ramona - Russian Marine Positioning & Survey Company
High resolution and ultra-high resolution seismic, accessed 10.11.2019)
18. http://www.octio.com (Octio AS, real time seismic monitoring, accessed 05.10.2019)