Reference document: Seismic surveys

- The oil and gas industry has used seismic surveys for more than 60 years.
- Seismic surveys determine geological features below the earth's surface by bouncing sound waves off various layers of rock and recording the time and strength of the returning sound waves.
- Efficient seismic surveying enables geologists to identify the depth, thickness and shape of subsurface rock formations.
- Seismic surveys use state-of-the-art technology and advanced recording and processing systems to focus the sound waves and provide the clearest images possible.

1. Enhancing exploration

In the early days of oil and gas exploration, geologists had to use visible geology and surface signs to make a best guess at likely locations for drilling. Very few wells were successful.

The development of seismic surveys that produced detailed images of rock formations thousands of meters beneath the earth's surface was a major technological breakthrough. It greatly improved the success rate of exploration wells – decreasing the number of wells that needed to be drilled, and the overall cost of exploration.

Seismic sources such as large vibrating metal plates on land, or compressed air in water, are used to generate sound waves which are bounced off the subsurface rock layers. The returning sound is measured by receivers and then recorded by a device called a seismograph. Analysing the time the waves take to return, and the details of the reflected sound wave spectrum provides valuable information about rock types and possible gases or fluids in the rock formations[1]. (See below, Figure 1 Interpreted composite seismic lines across the Exmouth Plateau, WA. (Geoscience Australia)

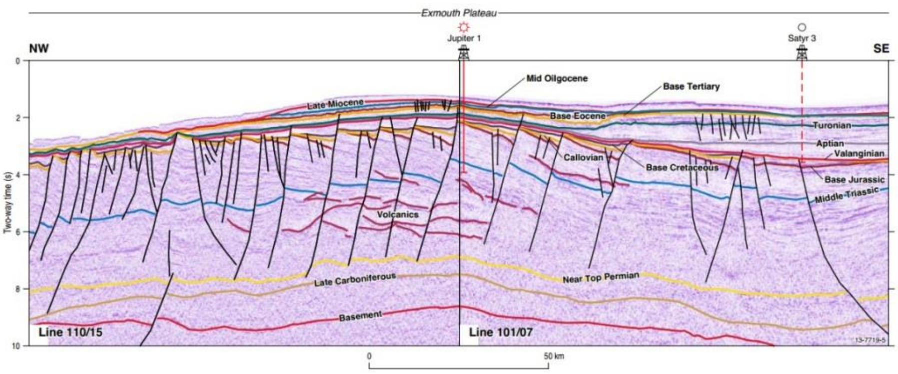

Figure 1 Interpreted composite seismic lines across the Exmouth Plateau, WA. (Geoscience Australia)

This is similar to the use of ultrasound in medicine. The information gathered is processed and interpreted by geoscientists who produce computer models of the rock layers. The ultimate product of a seismic survey is a cross section or vertical view of the earth.[2]

[1] http://www.ga.gov.au/scientific-topics/marine/survey-techniques/seismic
[2] http://www.epa.gov/esd/cmb/GeophysicsWebsite/pages/reference/methods/Surface_Geophysical_Methods/Seismic_Methods/Seismic_Reflection_Methods.htm

2. Onshore seismic surveys

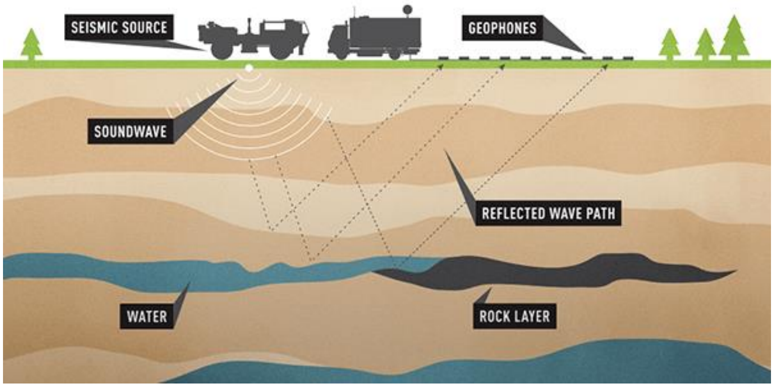

Figure 2. Onshore Seismic Surveys

On land, vehicles called vibroseis trucks (see Figure 2 and Figure 3. Onshore seismic vibroseis trucks (Source: Terrex Seismic) create sound waves that travel beneath the surface. Vibroseis trucks are highly specialised vehicles that use a vibrating steel plate or 'pad' which is placed on the ground and vibrated to generate a sound or seismic signal. The energy waves created by the vibrating pad are recorded by a high-speed digital data recording system and acoustic sensors (geophones).

Figure 3. Onshore seismic vibroseis trucks (Source: Terrex Seismic)

Modern onshore seismic activities are low impact. GPS locators have replaced the historical requirement for straight line-of-sight surveys. The truck-mounted seismic vibrators can be manoeuvred so that no trees need be removed. Environmental sensitivities such as dams, watercourses, pipelines, wells and bores, and third party infrastructure such as tanks and residences are considered when determining seismic survey locations and techniques.

3. Offshore seismic surveys

In marine seismic surveys, a specialised vessel tows a "seismic streamer", or a collection of cables with seismic sources and hydrophones attached. The seismic sources use compressed air to create air bubbles. The collapse of the bubbles creates sound waves that travel through the seabed and are reflected back by rock structures beneath the surface. The returning soundwaves are recorded by hydrophone sensors.

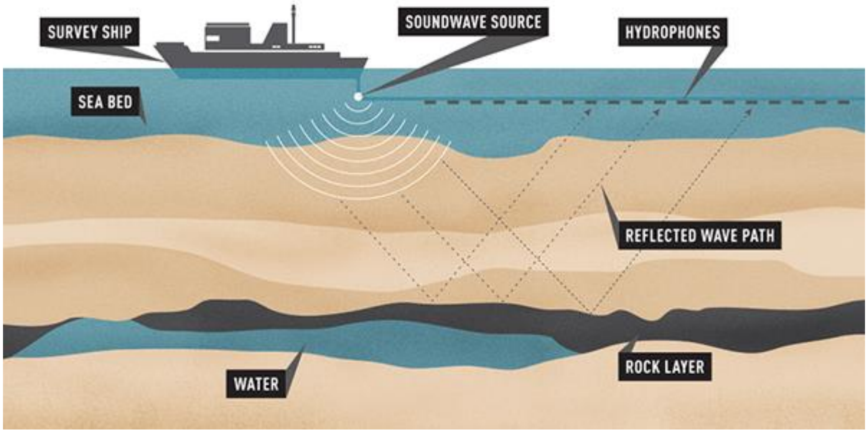

Figure 4. Marine Seismic Surveys

The hydrophones are either towed behind the boat in a streamer configuration or connected by a cable that sits on the ocean floor. The reflected sound is then processed to provide information about the structure and composition of geological formations below the seabed. This helps identify potential hydrocarbon reservoirs.

Figure 5. Western Legend Western Legend seismic exploration vessel (Source: Woodside Petroleum)

A seismic vessel traverses the survey area in a series of pre-determined lines at low speed – about 4-5 knots or 7-9 km/h. The sound generated by a marine seismic survey is comparable in intensity to many natural sounds (such as lightning strikes and sea ice). A survey usually uses periodic bursts of low frequency (10 - 300 Hz), high-intensity (<250 dB) sound. When these sound waves reach the different layers of rock under the sea bed, they are reflected back to the surface of the water and recorded by waterproof microphones (hydrophones) that are towed behind the seismic vessel.

3.1 Are marine animals affected?

Marine seismic surveys use tightly controlled sound to penetrate the sea floor. This can be heard by a variety of animals. How marine animals react to sound depends on the type of animal, the water depth, and many other factors. But all science indicates that disturbance (if any) is short-lived. In Australia, marine seismic surveying has been undertaken for decades. Numerous research projects have shown no evidence that offshore seismic surveys have caused noteworthy damage to marine animal populations or ecosystems.

Comprehensive regulatory controls and risk-based planning and mitigation measures applied by industry provide further levels of protection. For example, the Australian Government's *EPBC Act Policy Statement 2.1 Interactions between offshore seismic exploration and whales*, provides some of the world's most comprehensive mitigation measures. The strict regulations and responsible precautions taken by industry mean the effects of marine noise from seismic surveys on marine life are not significant.[3]

3.2 Mitigation measures

The risk of injury to marine animals as a result of sound from seismic surveys is very low. Nevertheless, mitigation measures are implemented, where a need is identified, to further reduce any risk. These include:

- Avoiding areas of known sensitivity (such as breeding or nesting sites), or environmentally sensitive periods (such as spawning or migrations).
- Soft-start, also sometimes called ramp-up or slow build-up. This involves visual observation before the start-up to determine that no mammals are in the safety zone, followed by gradually increasing the source sound pressure from some basal level to full operational levels. The soft-start procedure reduces the chance that an animal will be close to the source when turned on, and allows time for animals to move away, so they are less likely to be exposed to higher sound levels.
- Monitoring for certain species, such as turtles and whales. This is conducted before the soft-start of the seismic source and continues throughout seismic operations. In cases where behavioural reactions could be considered significant, such as operations near recognised whale breeding areas, additional mitigation measures may be designed. Such plans take into account both the particular sensitivities of the species (such as population status, auditory system sensitivities and activity), as well as the nature and scope of the planned operation.

The oil and gas industry incorporates basic mitigation measures as standard operating procedure and, where warranted by assessment of risk, enhances protection with additional measures. This demonstrates its ability to operate seismic exploration activities in a manner that protects marine mammals.

3.3 Are commercial fisheries affected by seismic surveys?

Studies have shown that seismic operations are unlikely to physically injure fish unless they are very near the sound source (Gausland 2000, McCauley et al. 2003; Popper and Hastings 2009). There are no documented cases of fish mortality from exposure to seismic sound under field operating conditions (Fisheries and Oceans Canada, 2004). Seismic surveys have frequently included follow-on vessels instructed to watch for fish kills, and none have been observed. The frequent observation of fish near operating seismic vessels indicates that some fish species are completely undisturbed by the sounds close to the seismic source. Sea birds often follow fishing vessels in search of food, but they generally do not follow seismic vessels. If there was any material impact on fish stock or impairment of their behaviour around a seismic vessel, sea birds would be quick to exploit the food opportunity – but this is not what has been observed.

Seismic sources may prompt behavioural changes in some fish species within audible distances of the source. But these changes are temporary and would have insignificant repercussions at a fishery level (McCauley 1994; McCauley et al. 2000; Wardle et al. 2001; Popper and Hastings 2009). The presence of the seismic survey vessel and support vessels may prompt fish to move to other areas but the potential displacement of fish stocks is short-lived and quickly returns to normal.

[3] Environmental implications of offshore oil and gas development in Australia. The finding of an independent scientific review. Swan, J.M.; Neff, J.M.; Young, P.C. (eds.); Australian Petroleum Exploration Association Ltd.,

Some studies have showed changes in behaviour reduced fish catch rates, or made the fish more difficult to catch as they moved in the water column (that is, changing depth and avoiding fishing gear). Conversely, other studies (Løkkeborg & Sodal 1993) found some catch rates increased following a survey. Surveys can be planned in detailed consultation with fishermen so that any catch variances are understood and minimised.

Figure 6: Barracouta Shoals - Inpex Australia

4. Types of Seismic Surveys (2D, 3D and 4D)

Reflection seismology is based on the principle that sound waves will bounce, or 'reflect', off the interfaces between rock layers below the earth's surface. Receivers collect the reflected sound waves, which are then recorded to produce an image (or profile) of subsurface structures and layers. Seismic data can be produced in two dimensional (2D), three dimensional (3D) and four dimensional (4D) images.

4.1 Two Dimensional (2D) Seismic Surveys

2D surveys are usually conducted as a precursor to exploration drilling. They involve the use of just one sound source and one cable. A 2D survey is less expensive than 3D or 4D options, and can be used to survey larger areas in less detail. A 2D survey gives an image across a single line segment of the earth's crust – much like cutting into a cake. These segments are called seismic profiles and are interpreted by geologists to evaluate the resource potential.

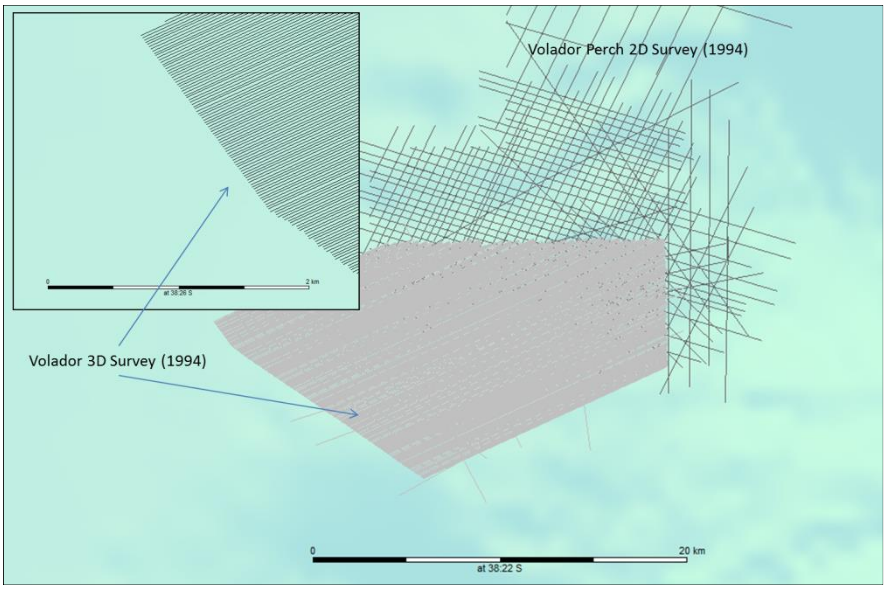

Figure 7. Number of lines in a 2D versus 3D survey

4.2 Three Dimensional (3D) Seismic Surveys

A 3D survey uses multiple lines to cover a specific area in great detail. Generally, this includes areas previously explored by the less detailed 2D seismic surveys.

In onshore operations, multiple receivers are placed on the ground to create a grid. In offshore surveys, the survey vessel runs multiple towed receivers and undertakes multiple sail lines, generally 200 to 400 meters apart. This gives a more detailed image of the surveyed area.

Because of advances in computer power and recording ability, 3D is commonplace today. While more expensive than traditional 2D seismic, the increased reliability of 3D seismic tends to make it cost-effective.

4.3 Four Dimensional (4D) Seismic Surveys

4D surveys are 3D surveys repeated over the same field at different times, usually years apart. A detailed comparison of one 3D survey with another provides insights into which parts of the reservoir have been depleted of oil or natural gas or which parts should be injected in an enhanced recovery process that introduces a gas such as carbon dioxide in order to help displace oil or natural gas.

5. Seismic profiling and interpretation

In seismology, the two important pieces of information are the time of arrival of a reflection from a geological surface, and the shape of the reflection (this includes signal strength, frequencies, etc).

The main signal that returns to a receiver looks like a squiggle. This is called the seismic trace (a group of traces is called a *gather).* Each trace is the record, in time, of when sound from each source reflected off each layer of rock. The amplitude is relative to the degree of change in rock properties between two layers. Putting multiple trace squiggles together in a line can develop a cross-section of the earth which can identify the structures in it.

5.1 Seismic Processing

Seismic processing removes noise from the raw seismic data and enhances the processed signal. Processing the sound from a seismic survey has been one of the key difficulties for geologists, but modern high-performance computing technologies have enabled the development of very effective programs.

The sound levels are measured and considered in many ways. The key and most difficult task is to differentiate the actual returning signal from noise. Raw seismic data has a very poor signal-to-noise ratio, and must be cleaned up before the image of the subsurface can be made visible – for example, volcanic activity can produce very distorted images.

This process of computer 'deconvolution' converts the raw output pulse from the reflected soundwave, and converts it into a cleaner, sharper, less confusing pulse for visualisation by the geologists.

6. Processing Power

One of the limitations on the seismic survey industry has been computer processing speeds. The sheer amount of data has been difficult to manage and the oil and gas industry has supported the development of faster computers with increased memories. Three dimensional imaging is now mainstream.

The oil and gas industry has pioneered processes such as seismic imaging on GPU (graphics processing unit) clusters. This process involved integrating hundreds of computers to create better performance and improve the speed, quality and physical fidelity of the images.

The technology has changed so much that some businesses focus solely on reprocessing old data using modern techniques. Doing this can often take months, but new insights into geology are often worth the effort. To better view data, many organisations now use state-of-the-art virtual reality rooms.

Figure 8 Geoscience Australia's large screen 3D visualisation centre. (Source: Geoscience Australia)

7. Summary

Seismic surveying is the most reliable form of initial exploration for oil and gas, and is essential in identifying geological features beneath the surface. Efficient seismic surveying reduces the need for excess exploration and maximises the efficiency and safety of further operations. Detailed seismic surveying allows geologists to identify the most efficient way of producing a resource, which reduces unnecessary well drilling.

The oil and industry has used seismic surveying as an exploration method for over 50 years. With risk-based planning and mitigation, seismic surveys have minimal impact on the environment.

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