Marine Seismic Operations

An Overview

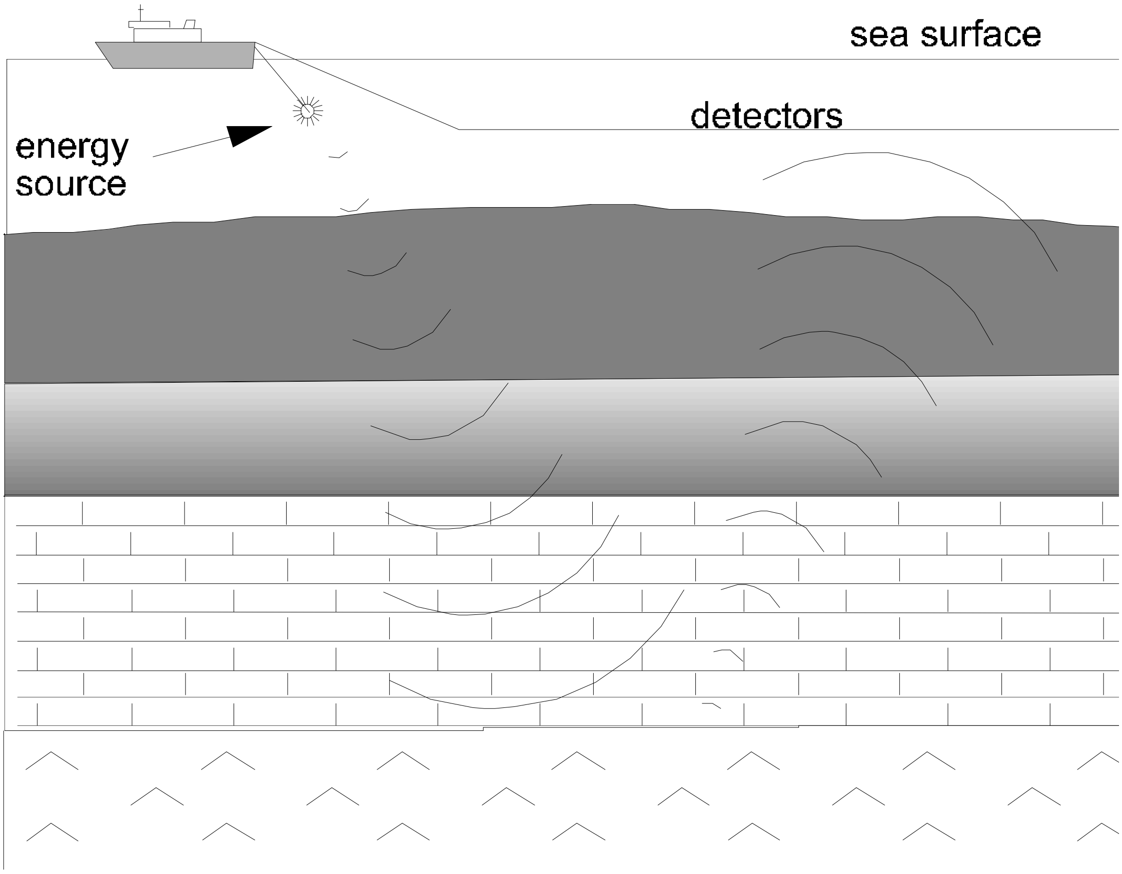
Produced by IAGC to provide a
reference to other marine operations
in general and the fishing industry
in particular.

Underlying Principles

The dictionary definition for the word seismic means "of or relating to an earthquake" and indeed it comes from the Greek word seismos meaning an earthquake. In its broad scholarly or teaching sense this is what seismic study is about. It involves earthquake measurement, monitoring and prediction. What is measured are the energy waves created by the earthquakes and the effect of these waves close to where the earth's crust actually moved.

Basic Seismic Reflection

In seismic surveying, geophysicists use the same basic physical properties as the earthquake seismologists. Relatively low energy waves are mechanically generated and directed into the earth. Some of the energy is reflected back to the surface from the different layers of rock below the surface. The returning waves are detected with sensitive measuring devices that accurately record the strength of the wave and the time it has taken to travel through the various layers in the earth's crust and back to the surface. These recordings are then taken and, after various adjustments, done mostly by computers, transformed into visual images that give a picture of what the subsurface of the earth is like beneath the seismic survey area. To summarise, although geophysicists cannot see directly beneath the ground, they can use seismic surveying to get a picture of the structure and nature of the rock layers indirectly.



There are many reasons for doing seismic surveys. They are used to check foundations for roads, buildings or large structures such as bridges. They can help to detect ground water. They can be used to assess where coal and minerals are. One of the most common uses is in the search for hydrocarbon resources, gas and oil, and most commercial seismic surveying is carried out in this energy sector.

Oil and gas exploration takes place all over the Earth's surface. It can be generally considered as falling into the two main categories:
- Onshore or Land Exploration
- Offshore or Marine Exploration.

There is a third zone, which is currently of lesser commercial significance. This is commonly called Shallow Water Exploration, but is also sometimes referred to as Transition Zone Exploration (TZ). This involves shallow water areas such as tidal zones, river estuaries or swamplands. Exploration activities in these areas can be very complex.

This document will focus on marine seismic exploration.

2D and 3D Seismic Methodology

The complexity of the seismic survey operation can vary enormously. There are, however, two main types of seismic surveying. These are Two Dimensional or 2D Exploration and Three Dimensional or 3D Exploration. 2D can be described as a fairly basic and inexpensive survey method, which although somewhat simplistic in its method, has been and still is used very effectively to find oil and gas. 3D surveying on the other hand is a much more complex and accurate method of seismic surveying, which involves greater investment and much more sophisticated equipment than 2D surveying. Until the beginning of the 1980's, 2D work predominated in oil and gas exploration but now 3D is the dominant exploration tool.

2D Acquisition

In the 2D method, a single seismic cable or streamer is towed behind the seismic vessel, together with a single source. The reflections from the subsurface are assumed to lie directly below the sail line that the seismic vessel traverses – hence the name 2D. The processing of the data is, by nature of the method, less sophisticated than that employed for 3D surveys. 2D lines are typically acquired several kilometres apart, on a broad grid of lines, over a large area. The method is generally used today in frontier exploration areas before drilling is undertaken, to produce a general understanding of the regional geological structure.

3D Acquisition

A 3D survey covers a specific area, generally with known geological targets generated by previous 2D exploration. Prior to the survey, careful planning will be undertaken to ensure that the survey area is precisely defined, usually carried out by the Oil Company or by specialist contractor personnel. Since much time, money and effort will be put into the acquisition, processing and interpretation of the survey, it is very important that it is designed to achieve the survey objectives. The result of the detailed planning will be a map defining the survey boundaries and the direction of the survey lines. Specific acquisition parameters such as energy source, firing and receiver station intervals, together with the seismic listening time, will also be defined. In 3D surveying, groups of sail lines (or swathes) are acquired with the same orientation, unlike 2D where there is a requirement for orthogonal or oblique lines to the prominent acquisition direction. Simplistically, 3D acquisition is the acquisition of many 2D lines spaced in parallel close together over the area.

The 3D sail line separation is normally of the order of 200 to 400 metres. By utilising more than one source and many parallel streamers towed by the seismic vessel, the acquisition of many closely spaced sub-surface 2D lines, typically between 25 and 50 metres apart, can be achieved by a single sail line. A 3D survey is therefore much more efficient in that many times more data is generated than for 2D. The size of a 3D survey is usually referred to in square kilometres or sometimes the number of line kilometres to be acquired. A small 3D survey size is of the order of 300 square kilometres or 1000 sail line kilometres or 12000 sub-surface 2D kilometres.

3D surveys are typically acquired with a racetrack pattern being employed, to allow adjacent sail lines to be recorded in the same direction (swathe), whilst reducing the time necessary to turn the vessel in the opposite direction. This increases the efficiency of acquiring the data and minimises processing discontinuities, which could adversely affect the interpretation of the data.

With the number of sail line kilometres involved, 3D surveys can take many months to complete. The way in which the data is acquired greatly affects the efficiency of the acquisition and considerable planning goes into this aspect. Whilst a racetrack approach is the favoured one, size and shape of the survey, obstructions, tides, wind, weather, fishing vessels and client specifications amongst others, will clearly affect the efficiency and design of the operations. Usually, a survey is broken into areas and swathes of lines are completed in phases or individual racetracks, but there is no rigid procedure which is followed.

Powerful computers are required to process the large volume of data acquired into a three-dimensional image of the subsurface – hence the term 3D seismic. 3D surveys have now become the preferred method for providing the geological interpreter with subsurface information and account for more than 95% of marine seismic data acquired worldwide. 3D surveys are used in all phases of hydrocarbon exploitation from identifying geological structures which are considered likely to contain hydrocarbons to, in areas of established production, establishing those portions of the reservoir which are not being drained by existing wells. Increasingly, 3D surveys are being repeated regularly on established production fields to monitor the reservoir characteristics and depletion rates, so-called Time Lapse surveys.

Seismic Survey Vessel

Now days, seismic vessels are purpose built with many special features, including accommodation for the seismic crew, the instruments, helideck and quiet engines and propellers. The Captain, is responsible for the safety of the seismic vessel and he has the final say in how the seismic vessel is operated and manouvered.

A recently built seismic vessel has the following specifications:
Length: 84 m
Beam: 18.5 m
Draft: 6.2 m
Displacement: 5600 metric tons
Cruising speed: 13.5 Knots
Berths: 50
Endurance at sea: 50 days

Courtesy of Veritas DGC

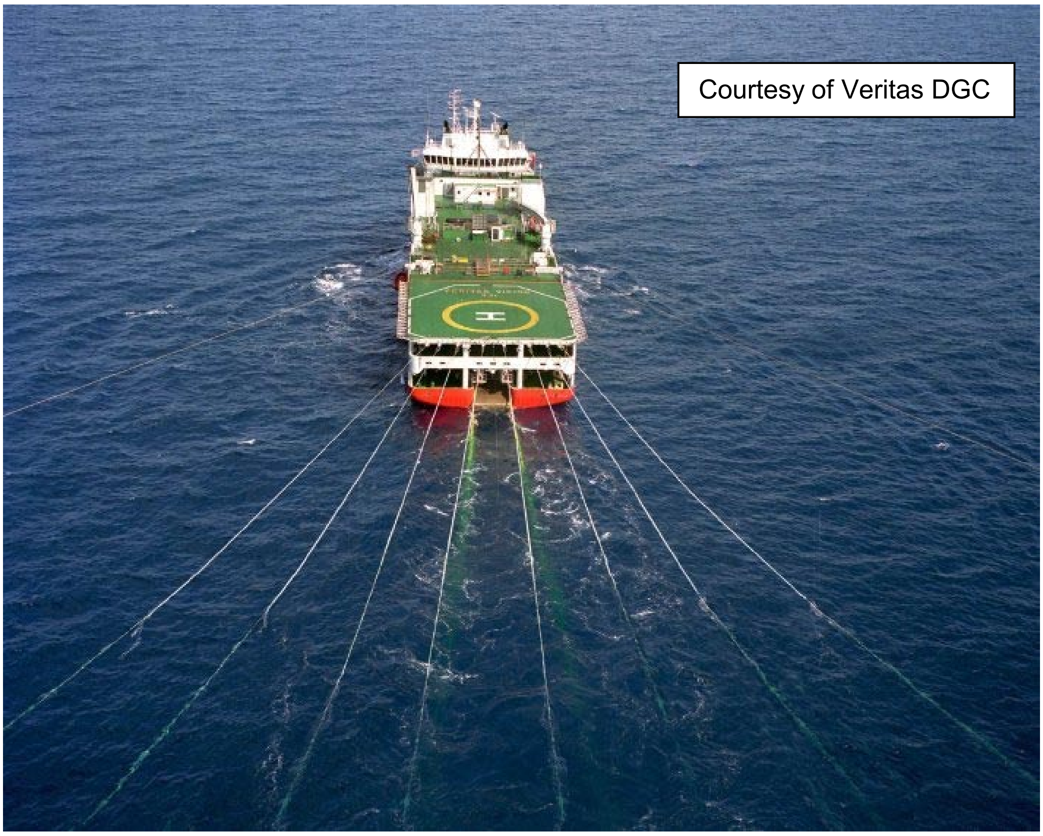
The instrument room

This is where the main seismic instrumentation is located and operated. The position of the instrument room varies from vessel to vessel but normally is located centrally, somewhere below the bridge and forward of the back deck. It contains the main seismic instruments for recording seismic data and controlling the seismic streamer(s) and energy source firing. The main navigation system is also here with its links to satellite, radio systems, compasses and all the various positioning control devices and monitors. There is usually a working area for instrument testing and repair.

The back deck

This is an area, which although in detail can vary from vessel to vessel, has the same basic purpose – storage, retrieval and deployment of the seismic equipment that is placed in the sea. The seismic streamers are stored here on large reels and when acquisition is ongoing, they are deployed over the back and/or sides of the vessel and towed directly behind the vessel, subject to feather. The number of streamers varies depending on the vessel but can be as many as sixteen for 3D surveys. All the wiring from the streamers is fed through special connectors to the instrument room. Most vessels have a small streamer repair area on the back deck. The seismic streamers are under control of the geophysical observer section of the crew.

The back deck is also the location of the energy source equipment. The energy source is usually made up of airguns, which are fed with high-pressure air. Each source is made up of an array of many different sizes of airguns, linked together with special harnesses and fed with airlines and electronic control cables. When not in use, these cables are stored on reels usually at the forward end of the back deck. During deployment, they are put to sea through a slipway at the rear of the deck. The air feed from the seismic vessel compressors to the arrays is monitored from a control panel, which is housed in a small work shack where airgun repairs can also be done.


Courtesy of Veritas DGC

In association with the streamers and source arrays is the towing equipment. This is a complex, carefully designed arrangement of specialised gear that enables the multiple streamers and source arrays to be positioned accurately behind the seismic vessel and allows different source and streamer separations depending on the survey design. The airgun system and the towing equipment are the main responsibilities of the mechanical section of the seismic crew.

Finally on the back deck is the navigation or positioning equipment. This usually involves buoy systems containing navigation instruments. Tail buoys are attached to the end of each of the streamers furthest from the vessel. Additional buoys can be attached to the source arrays and towing equipment for example. These are not the only buoys in the system however, and in complex multi streamer/ source/ boat arrangements, the navigators need a lot of other control and monitoring systems on sources, streamers and any other vessels so that the relative positions of all the equipment can be recorded.

Compressor room

This contains the compressor engines and compressors, which supply high pressure (nominally 2000 psi) air to the source arrays. The compressors are capable of recharging the airguns rapidly and continuously, enabling the airgun arrays to be fired, typically every ten seconds or so during acquisition of data and for periods of up to 12 hours continuous firing, depending on the length of the sail line. This room is under the mechanics' control and is usually situated in proximity to the back deck.

Seismic Streamer

It is worth noting that due to the action of wind, tides and currents, the seismic streamer does not normally tow directly behind the seismic vessel, but lies in an arc offset from the nominal sail line. This is referred to as feathering and whilst such lateral displacements are not typically crucial to the success of 2D data surveys, they are critically important in 3D, where accurate knowledge of the positions of all sources and receivers is fundamental to the successful application of the technique.

The seismic cable or streamer detects the very low level of reflection energy that travels from the seismic source, through the water layer down through the earth and back up to the surface, using pressure sensitive devices called hydrophones. The hydrophones convert the reflected pressure signals into electrical energy, that is digitised and transmitted along the seismic streamer to the recording system on board the seismic vessel, where the data is recorded on magnetic tape.

The sensitivity and robustness of the streamers is remarkable. Normal noise levels in calm weather conditions are of the order of 2-3 μbar and it is quite common for streamers to remain operating in the water for months at a time.

The streamer itself is made up of five principal components:

- hydrophones, usually spaced one metre apart, but electrically coupled in groups of 12.5 or 25 metres in length.
- electronic modules, which digitise and transmit the seismic data.
- stress members, steel or kevlar, that provide the physical strength required, allowing the streamer to be towed in the roughest of weather. Each streamer may be subjected to several tonnes of towing strain.
- an electrical transmission system, for power to the streamer electronic modules and peripheral devices, and for data telemetry.
- the skin of the streamer in which all the above are housed.

The streamer is divided into sections, each 50-100 metres in length, to allow modular replacement of damaged components. Each section is terminated with a connector unit, which houses the electronic modules. Each section is filled with electrical isolating fluid, which has a specific gravity of less than one, to make the overall streamer neutrally buoyant. Although historically, this fluid was an organic compound, more recently a purely synthetic material has been used.

Recent advances in cable technology have led to a new generation of seismic streamers, moving away from the traditional fluid filled cable to a solid cable, constructed of extruded foam, where the requirement for fluid is minimised or removed entirely. This generation of streamers has many advantages in that they are more robust and resistant to damage, do not leak when damaged either on the vessel or in the sea, and are less sensitive to weather and wave noise. This has been achieved without reducing the sensitivity of the cable to the reflection energy.

Streamer lengths have increased over time with improving technology. The streamer length utilised is dependent on the depth and type of the geological target for a given survey. Recent surveys have seen streamer lengths typically in the order of 5000 to 6000 metres, with some detailed surveys using streamers up to 12000 metres in length. This increase in length, coupled with the increasing number of deployed streamers, has resulted in a marked increase in the quantity of streamers in the water, with seismic vessels deploying 40 to 50 kilometres of streamer becoming more prevalent.

Streamer tow depths are a compromise between the requirement to operate these sensitive devices away from the surface weather and wave noise, which limits the usability of the recorded data, and other technical requirements. The deeper the tow depth, the quieter the streamer and the greater the immunity to weather noise, but also unfortunately, the narrower the bandwidth of the data.

Typically the range of operating depths varies from 4 to 5 metres for shallow, high resolution surveys in relatively good weather areas to 8 to 10 metres for deeper penetration, lower frequency targets in more open waters.

In addition to the internal components of the streamer, there are three types of external device, which are attached to the streamer:
- depth control units or birds.
- magnetic compasses.
- acoustic positioning units.

Power for these systems is provided both through the streamer itself, inductively coupled, and by batteries in each external device.

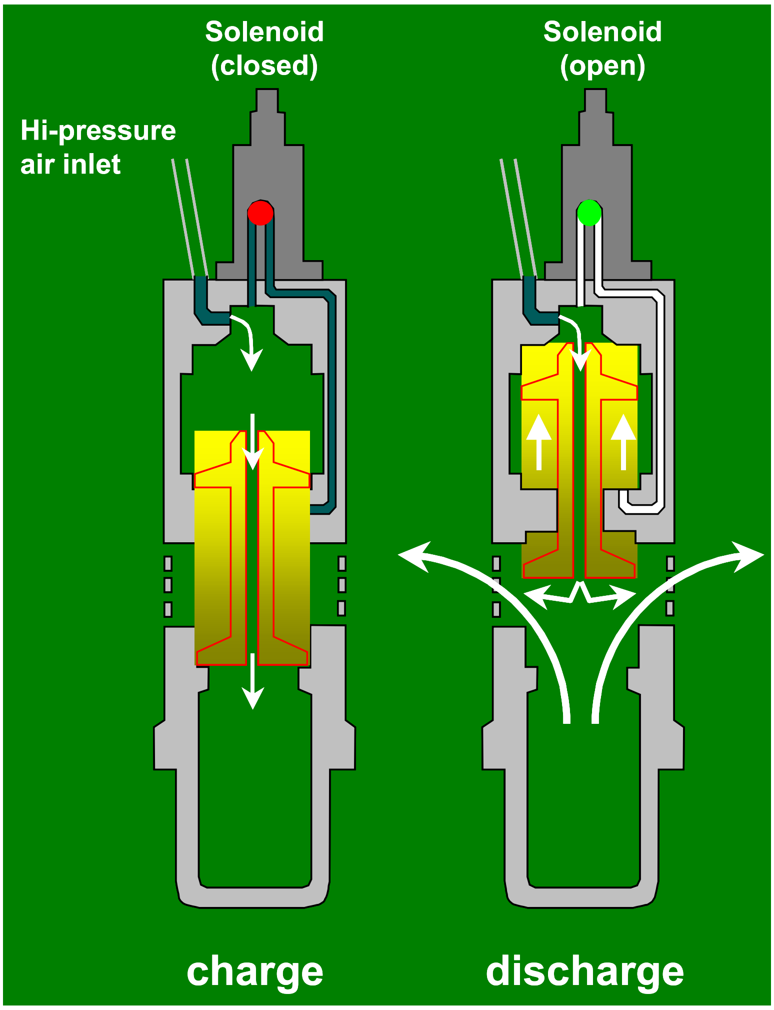
In addition, a tailbuoy is connected to the far end of each streamer to provide both hazard warning of the submerged towed streamer, especially important at night, and positional information.

The Seismic Source

Although there are now three types of seismic source, airguns, waterguns and vibrators, that can be utilised, almost all surveys conducted world-wide use airguns. Explosives are an historic source, and are not used in present day operations.

The airgun, comprises two high pressure air chambers; an upper control chamber and a discharge chamber. High pressure air, at typically 2000 to 2500 psi, is supplied to the upper control chamber from the compressor onboard the seismic vessel via an air hose and bleeds into the lower firing chamber through an orifice in the shank of the shuttle. The airgun is actuated by sending an electrical pulse to the solenoid valve which opens, allowing high pressure air to flow to the underside of the triggering piston. The high pressure air in the lower (firing) chamber is

discharged into the surrounding water through the airgun ports. The air from these ports forms a bubble, which oscillates according to the operating pressure, the depth of operation, the temperature and the volume of air vented 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 airgun can be fired again. The opening of the shuttle is very rapid, taking only a few milliseconds, which allows the high-pressure air to be discharged very rapidly.



Total energy source volumes vary from survey to survey and are designed to provide sufficient seismic energy to illuminate the geological objective of the survey, whilst minimising environmental disturbance.

An airgun array is made up of sub-arrays or strings, which are suspended from floatation devices to maintain the specified operating depth. Array dimensions are usually of the order of 25 metres wide by 15 to 20 metres long.

Typical source outputs in use today will output approximately 220 dB relative to 1µ Pascal/Hz at 1 metre. In pressure terms the zero-peak output of an array is of the order of 40 bar-metres.

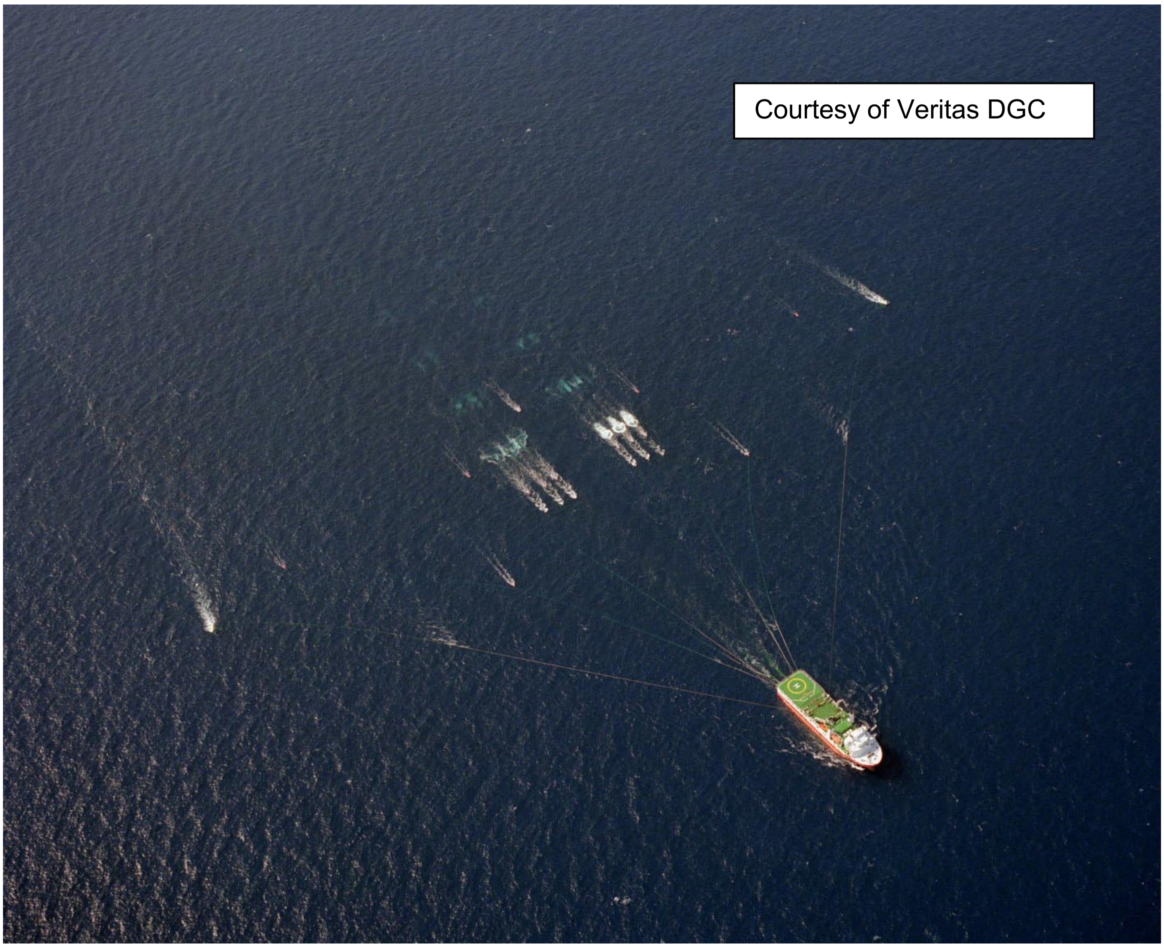
Source arrays are designed to focus energy downward into the subsurface.

Operations

The first stage of normal operations is that the seismic vessel should be fully supplied with all necessary fuel, water, food, seismic equipment and crew. It will then transit to the designated survey site. The seismic vessel will have been provided in advance with all necessary details regarding the survey layout and design and what and how much equipment will be deployed. The navigators will have information, which specifies where each seismic line must start and finish, and what the energy source firing, or shooting, interval must be. This information will have been fed into the onboard integrated navigation system.

On the bridge, the captain will ensure that while the seismic vessel is under normal manual control, he will be navigating as agreed to the first line start position. The seismic vessel will maintain a constant speed of around 5 Knots. He and the seismic crew (party) manager will be closely monitoring wind, weather and any incoming reports.

As the survey area is approached, the geophysical observers will deploy and check the streamers, attaching depth monitor and control devices (birds) as they go. The mechanics will start the compressors and prepare and check the required airgun arrays. These will be launched when necessary but after the streamers. The navigators will work with both mechanics and observers to attach the necessary buoys for positioning.



Courtesy of Veritas DGC

In the instrument room, all equipment will be powered up, tested and checked for trouble free operation. Test records (no airguns operating) for insea noise will be made. The streamer, airgun and buoy links will all be checked and tested and the whole system confirmed as OK and ready to go.

As the seismic vessel approaches the line start or first firing point, it is said to be on the run in. This is the stage where it is very close to the agreed start position and the seismic vessel has the correct heading and the streamers are as much in line behind the seismic vessel as conditions will allow. The seismic vessel by this point is steered according to the input from the navigation system. Around the seismic vessel all involved crew members will be monitoring the seismic vessel's position from information screens in their areas. The navigator will be at his desk keeping a close eye on his console, where he can monitor in detail the approach to line start in terms of distance to go, heading and speed and can ensure that no positioning problems arise at the last moment. The mechanics will be keeping a close eye on the compressor monitors and will make a last minute visual inspection of the airgun equipment that can be seen from the vessel. The observers will take final test records and record the system noise for future reference and will check out the airgun control system.

It is during the approach to the line start, that environmental protection procedures may be applicable. Depending on the country of operations and the area specific environmental controls in place, a visual watch for marine mammals from the seismic vessel may be ongoing for at least 30 minutes before the first firing of the airguns. On some surveys, acoustic methods may additionally be utilised to identify the presence of marine mammals within the vicinity of the airgun array. It is only when the crew has been informed that no marine mammals are present, that the survey line can proceed with the firing of the airguns. A 20 minute run-in is required in some regions where the airgun array energy output is slowly increased to full power.

All systems are now ready to go and at the first predetermined position, the first shot is fired from the airgun array and data recorded. At successive intervals, as determined by the navigation system programme, the recording process is repeated and so on, to the end of the line. Throughout the recording period, all personnel involved perform detailed prescribed tasks. The navigator monitors the system output, checking for any discrepancies and completes the line paperwork and prepares plans for moving to the next line to be recorded. The mechanic watches the compressor performance, checks the back deck towing systems and is ready to deal with any hose or airgun problems. The geophysical observer monitors each shot, keeps an eye on insea noise, changes recording media and fills in the line log as the line progresses.

When the line is complete, all systems stop recording. The ship is now in line change mode. The navigator has planned how the vessel should manoeuvre to get into the run in for the next line. The line change time varies according to the layout of the survey and the configuration of the equipment but is usually between one and three hours. During the changeover period, all the crew involved work quickly to resolve any problems and make modifications or repairs in readiness for the next line. The run in is then started, all equipment is readied, and the cycle repeats.

Infrequently, technical failures occur and line starts are delayed or lines are terminated early.

Other types of Seismic Source

Waterguns

Waterguns operate in a similar manner to airguns, but in place of air being vented into the water when the gun is triggered, a volume of water is used. The advantage of this is that as there is no air in the water, there is consequently no air bubble to oscillate, so the need to use differing volumes of guns is removed.

The disadvantage is that the low frequency bandwidth of the signal generated by forcing water under high pressure into the surrounding water, is much less than that provided by an equivalent airgun and thus the signal is unable to penetrate as deeply into the subsurface. Water guns were briefly popular in the 1980s but are not used commercially today.

Marine Vibrators

A marine vibrator operates by using either hydraulic or electrical power to drive an actuating plate, that is immersed in the sea, in a controlled manner.

The advantage of this is that a very precise signal can be injected into the subsurface. The signal usually employed is a sweep of frequencies, say 10-80 Hz for example, over a 10-second interval. The instantaneous sound pressure level is much lower than that from an airgun. The recorded data is then correlated against the input sweep to recover the reflection record.

The control of these devices is very complex. The output from a single vibrator is comparable to that from an airgun sub-array but suffers the disadvantage, like waterguns, that its low frequency response has historically been poor, so that deep penetration into the subsurface has not been possible. The vibrator has also suffered poorly in comparison with airguns with regards to mechanical failure, having a much higher failure rate.

Other insea equipment

Depth control birds are used to control the depth of the streamer to an accuracy of typically plus or minus 1 metre. The wings on the bird are electronically controlled to pivot in response to the hydrostatic pressure (depth) measured by a pressure transducer inside each bird. As the streamer is weighted to be neutrally buoyant, the birds are used to counteract depth variations in the streamers introduced by seismic vessel pitching movements in heavy weather or when different currents are experienced, with corresponding fluctuations in density and/or temperature of the sea water.

Birds are normally spaced approximately 300 metres apart on each streamer.

Positioning

One of the most critical elements in the 3D seismic method is the positioning of the in-sea equipment. The tailbuoy is used to house Differential Global Positioning System (DGPS) receivers that are used in the positioning solution for the hydrophone groups in the streamers. Compasses, and acoustic ranging units are fitted along each streamer which contribute to the location accuracy of 3 to 8 metres absolute, with which seismic surveys are normally conducted. Differential GPS is the standard system used for positioning the seismic vessel itself and Relative


Courtesy of Veritas DGC

DGPS is used to position both source floats and tailbuoys.

Vessel Configurations

The 2D method involves the use of a single source and a single streamer from which one subsurface data is generated. In 1984, the first twin streamer operation was undertaken, which effectively doubled the efficiency of the seismic vessel by generating two subsurface lines per vessel traverse. By moving to twin source/twin streamer configurations in 1985, the output was increased to four lines per pass. The next logical step of towing three streamers and two sources behind a single vessel, six lines per pass, was not achieved until 1990, but thereafter the rate of progress has been very rapid.

Multi-Vessel Operations

In addition to the single vessel geometries described above, the industry has been using a number of multi-vessel operations.

By using two three streamer seismic vessels side-by-side, with two sources deployed from one vessel, twelve subsurface lines per traverse can be achieved.

There are many variations in the numbers of vessels, streamers and configurations, and the techniques to acquire data.

The system used for a particular survey will best match the objectives of the survey and the conditions found at the survey site.

Other Marine Seismic Techniques

Seabed Recording Systems

There are three principal types of seabed recording systems used in marine seismic; Ocean Bottom Seismometers (OBS), Dragged Array (DA) and Ocean Bottom Cables (OBC). Of these, OBS and DA are used in multi-component (sensor) acquisition and OBC is used in both dual component and multi-component data acquisition. The term multi-component refers to the use of three component geophones in addition to a hydrophone for each seismic receiver location. The term dual component refers to the use of just a single geophone in addition to a hydrophone. A geophone measures particle displacement velocity in contrast to pressure which a hydrophone detects. The use of geophones, which must be in contact with the sea floor, sense particle motion along three orthogonal axes, allowing the geophysicist to infer more information concerning the subsurface geological layers from which the reflections occur. This has particular application in producing reservoirs, where multi-component techniques have the potential to enhance hydrocarbon recovery.

Of the three techniques, OBC is by far the most prevalent technique in use in world-wide marine acquisition.

Ocean Bottom Seismometers

Such systems have been historically used by university research groups to provide large-scale information for crustal studies and lithospheric investigations. They are battery powered individual units, which contain both the three-component geophones and hydrophone detectors, in addition to the associated recording system. The electronics are placed in a pressure housing, which also includes a flotation collar and navigation pinger. The unit, with an anchor system attached, is deployed onto the sea floor, typically in fairly deep water. The unit is then used to record data internally from a seismic energy source operating near the sea surface as in conventional marine seismic. Once this has been accomplished, the unit is released from its anchor to float up to the sea surface to be recovered. The data recorded on the internal tape drive is then removed from the buoy for subsequent processing and analysis, the batteries replaced or recharged and the whole operation repeated.

Buoys are typically deployed several kilometres apart for crustal investigations, but more recently have been used in areas like the Atlantic Margin for oil related projects in a closely spaced configuration. The interest here has been to see if the OBS method can assist in enabling geophysicists to “look through” the basalt rocks which cover much of the subsurface area and which are opaque to conventional towed streamer seismic techniques.

The fact that the buoys are physically separate and their positions are not, especially in deep water, sufficiently accurately known for 3D means that this technology is unlikely to see large volume commercial usage.

Dragged Array

In this system, a number of multi-component sensors are connected together by a short length of streamer that is electrically connected to a recording vessel. The equipment, which can comprise no more than 16-24 individual sensor stations, is lowered onto the seabed and a separate seismic source vessel used to conduct a 2D shot line over the seabed deployed sensors. The data is transmitted to the recording vessel, which is usually dynamically positioned off to one side of the survey line. Once this line has been acquired, the recording vessel repositions itself online and moves forward along this line, carrying the seabed deployed equipment with it, the so-called dragging operation. The system is moved forward to provide continuous coverage of the subsurface and the shot line re-acquired by the source vessel. The system used has operational capability down to 2000 metres of water depth.

Dual Component/Multi-Component Ocean Bottom Cable

The dual component or multi-component OBC technique utilises both geophones and hydrophones in a combined cable that is deployed from a cable/recording vessel down to the seabed. Existing equipment design has limited the depth to which these sensors can be used to less than 200 metres, although newer generations of cables are being used in deeper waters. Unlike the dragged array, the equipment is laid out or dropped on the seabed and data recorded using a separate source vessel.

The principal difference between OBC and dragged array operations is that as much as 72 kilometres of ocean bottom cables can be laid or deployed on the seabed, compared to less than one kilometre for the dragged array. This allows the OBC method to be used for 3D surveys.

The separations of source and recording vessel allow for different acquisition approaches to be used in ocean bottom cable 3D surveys. Two different methods are typically used: swath, where the source and seabed receiver lines are oriented along the same direction, and patch where they are oriented at right angles.

Vertical Cable

A rarely used technique, closely related to VSP. Only one survey has been conducted in the North Sea so far. This involves the use of hydrophone cables set out vertically in the water column across the survey area.

Each cable typically comprises single hydrophones spaced at intervals, together with a concrete anchor block, subsurface flotation buoys and a surface buoy, which houses the recording and radio telemetry systems.

The vertical cables are deployed at pre-determined locations by a dynamically positioned cable-laying vessel. The separation of the cables is determined by both the water depth and the geological objective. A separate source vessel fires its airguns into the 2D source lines producing a regular grid of shot point locations. The cable vessel replaces batteries and recovers the recorded data. The source technology is identical to that used for conventional towed streamer.

Survey duration will depend on the specific target objective for the survey but the method is more focussed towards reservoir imaging rather than general exploration.

Vertical Seismic Profiling (VSP)

In this technique, a number of geophones are lowered into a well and used to record data from a seismic source deployed from the well platform itself, called zero offset VSP, or from a source vessel which travels away from the well, known as offset VSP.

The main advantage of this method is that the seismic energy only has to travel one way through the earth. The reflected signal only has to travel a short way from the reflector to reach the downhole geophones. This results in higher bandwidth data being recorded, since there is less absorption of the higher frequency energy due to the shorter ray path lengths.

Source volumes are generally smaller than for conventional data but larger than for site surveys. The duration of these surveys is typically short, one or two days at most.

There have been a number of 3D VSPs recorded but these are relatively expensive to acquire. Much like the dragged array system, they require many passes of the source vessel to achieve complete 3D coverage and are hence relatively expensive, especially when the cost of the well time is included.

Site Surveys

Before a well is drilled, there is both a legal and operational need to have detailed information about the seabed in the area immediately surrounding the well location and the geological layers immediately below the subsurface.

The information about the nature of the seabed is needed to ensure that the rig legs and/or anchors will not encounter any problems when they are lowered to the seafloor and will provide the necessary stability for the structure. If the well is successful, this information will also be needed for any platform or subsea completion systems that would be installed.

The near subsurface data is needed to ensure that there are no unforeseen hazards, such as shallow gas pockets or buried river channels, that could have catastrophic effects when penetrated during the drilling process. The sudden release of gas below a drill rig could result in a catastrophic loss of life.

The resolution from conventional seismic is not sufficient for these purposes and a high resolution or site survey is undertaken. This technique is identical in principle to conventional 2D marine, except that the energy source is much smaller, and the streamer is much shorter at between 600 to 1200 metres. The source and streamer are towed at a depth of only two or three metres, corresponding to the much shallower depth of investigation. This limits operations to very good weather conditions only, to avoid wave noise.

Survey durations are short, depending on weather, but are usually of the order of four or five days. Other equipment may be deployed from the survey vessel during the course of the site survey. This may include side scan sonar fish for seabed profiling and the dropping of coring equipment to determine the seabed conditions.

Transition Zone Acquisition

This is by far the most complex and challenging area of seismic acquisition.

Shallow shelving waters are the most common problem, for they often require small, shallow draft, specialised vessels to move cables, sources, people and equipment around. With bad surf conditions it is very difficult to deploy, retrieve or operate equipment in a flat-bottomed boat.

Source types may have to be varied across an area. Where water is deep enough, it might be possible to deploy the source from the back of a barge for example, but where it is shallow, the use of explosives might be required, which are jetted or pushed into the mud or sand of the sea bottom.

Providing reliable recording sensors is also problematic. Marine hydrophones are suitable, provided they are located in deep enough water to enable them to operate properly, They are unreliable when the tide goes out for example. An additional problem involves placing the cable at a reasonable depth in the deeper water. In these environments, the streamer is not being pulled through the water with depth controlling devices. Personnel are often required to weight the cable to the sea bottom with chains and anchor blocks. With active surf or current conditions, it is likely that the cables will move and then subsequently have to be manhandled back into position.

One form of cable that can be used very successfully in transition areas is called a bay cable. It is effectively a very well sealed land cable with geophones on gimbals so that they remain upright. Some variants of these cables can contain hydrophones as well. This cable is lighter and easier to handle than a marine type of cable, but it is still not either straightforward or effortless in its use.

Another method of recording data in these zones is to integrate the sensors with electronics, creating rugged sensor stations that radio transmit the received earth signal back to an instrument position, either continuously or on command from the observer. In some areas this is often the only equipment that can be effectively used, but these units still need to be positioned and anchored appropriately and this is seldom easy.

Positioning of the equipment can be complicated. Close inshore areas are usually less problematic, but the highly variable mid zone complete with fast currents, drifting cables, wandering shots, big tides and lots of mud can make it a navigator's nightmare.

Transition zone surveys conducted in UK waters are limited in number and are unlikely to become more numerous in the future.

Operational Performance

The rate of progress for a seismic survey is constrained by many factors but the most dominant is usually the weather. Other issues that affect the duration of a specific survey are:

- Survey Location
- Time of Year
- Survey Size, particularly Sail Line Length
- Technical Acquisition Parameters
- Vessel Configuration
- Line Orientation and Prevailing Current Direction
- Fishing and Shipping Activity in the Survey Area – trawling especially
- Other Seismic Operations nearby
- Marine Mammal Activity
- Drilling and Subsea Equipment Maintenance, including diving
- Technical Equipment Downtime

The net effect of all of these factors is to limit the time actually spent acquiring seismic data to just 35-40% of the available time.

The reason the weather is so important is that the signal levels that are recorded by the seismic streamer are very small. Because there is a requirement to record data with as wide a bandwidth as possible, to improve the resolution with which geologic features in the subsurface can be identified and mapped, the streamers are towed at quite shallow depths to avoid technical problems. Thus any wave action, which is directly proportional to weather conditions, causes noise that degrades the quality of the recorded data.

The location of the survey dictates the weather environment for the survey, as does the time of year the survey is being conducted. Offshore West Africa, for example, the weather is much better than in the North Sea, and thus two identically sized surveys in these two regions would have significantly different durations.

Activity Levels – Historical - Europe

The first 2D seismic was acquired in the Dutch sector of the North Sea in 1959. Activity started in the UK sector some three years later, Norway two years after that. A steady increase in exploration saw a peak in the mid seventies, followed by a lull until the late eighties. 2D activities have been trailing off since then apart from the UK non North Sea area, namely the Atlantic Margin area, which has seen a major upturn in activity since 1993.

The decline in 2D acquisition has been matched by a rapid increase in the use of the 3D technique. This is a result of the reduction in unit costs for 3D, following the rapid increase in the capabilities of seismic vessels to tow more streamers. From just two streamers towed in 1989, 8 to 10 streamers in 1998, up to the current maximum of 16 in 2001. 3D seismic acquisition therefore, has changed from being just a tool to appraise discoveries and fine tune production, to being used for exploration purposes in frontier areas.

The sharp peaks and troughs in seismic acquisition operations can be traced to a number of factors. Exploration seismic is usually acquired in the period immediate before and after Licencing Rounds issued by the governments, originally annually in the UK but now every two years or so. Oil company budgets are subject to the vagaries of the oil price; downturns in the oil price have led historically to reductions in exploration.

Other Marine Operations

If the survey is in an area of high shipping activity or other marine operations, seismic operations can be difficult. A seismic vessel is limited in its manoeuvrability due to the streamers deployed from the stern, which may be several kilometres long. The seismic vessel itself is in little danger, but with lots of vessels in close proximity, the streamers may well be fouled or cut. Trawl fishing can be a particular hazard. With very high towing strain (may be several tonnes) on the insea equipment cables, there is a danger of both a safety and environmental accident. Aside from the large financial loss from the value of the streamers themselves this can mean a serious loss of earnings through disrupted operations. In difficult areas, chase or escort boats are employed. These are smaller vessels, usually ex-fishing boats, which contact potentially threatening shipping traffic and direct them away from possible contact with the streamers.

Legislative Environment - UK

Under the terms of the Petroleum (Production) Act of 1934 and the 1964 Continental Shelf Act, the Exploration Companies (oil companies) of all surveys conducted in the UKCS to search for petroleum in the strata in the islands and in the sea and subsoil require a license from the UK Department of Trade and Industry (DTI). These exploration licenses have a three year term, are renewable, and have no specific geographical reference.

Production licences for specific blocks or areas are usually applied for in response to invitations issued by the DTI or national equivalent, in respect of blocks or areas specified in the invitation or ‘Round of Licencing’. The licence grants the holder exclusive rights to explore for, and produce petroleum, in the block covered by the licence. The duration of the licence has varied with each Round. Blocks or areas may on occasion be offered for Licencing between Rounds (out-of-Round).

The conditions for each licensed area have evolved over time.

JNCC Requirements

All seismic surveys in designated areas in the UK are subject to the JNCC (Joint Nature Conservation Committee) Guidelines for Minimising Acoustic Disturbance to Marine Mammals. These guidelines have been in place, and formed part of licence conditions, since 1995. These guidelines cover:

1) Before starting a survey line, seismic company personnel should carefully make a visual check to see if there are any cetaceans within 500 metres

   If cetaceans are present, the start of the survey should be delayed until the cetaceans have moved away, allowing adequate time after the last sighting (30 minutes) for the animals to move well out of range. Hydrophones may also be useful in determining when cetaceans have moved out of range.

2) Airgun energy should be built up slowly from low energy to operating level over 30 minutes, to give adequate time for cetaceans to leave the vicinity.

3) Throughout the survey, the lowest practicable energy levels should be used.

4) Reporting of sightings and details of watches (using standard forms)

All seismic acquisition contractors have agreed to conduct survey operations in the UK in accordance with these guidelines and have employed marine mammal observers on their vessels. The JNCC have reported that the data that has been gathered from seismic vessels in the Atlantic margin in recent years has added significantly to their knowledge of cetacean population distributions in the area.

Future Trends

3D survey sizes have historically been increasing due to a variety of economic and technical factors. This trend is likely to be maintained for exploration 3D, but the areas covered in the mature UKCS in recent years are very large and there is a finite limit to the acreage to be surveyed. This does not, however, take into account the potential for reacquiring older 3D surveys in the light of new acquisition and processing technology when it becomes available.

Reservoir specific 3D surveys, which are designed to maximise hydrocarbon recovery from a given reservoir, are necessarily much smaller than exploration 3Ds, since almost all reservoirs in the North Sea are much less than 100 square kilometres in extent. With increased subsurface imaging potentially available from multi-component data, it is probable that there will be a number of geographically small, but geophysically intense, production 3D surveys in the coming years. The exact configurations and techniques employed will be very specific to each particular reservoir, but will involve combinations of most, if not all, the methods described in this booklet.

The complexity of the equipment deployed in the water has dramatically increased in the last decade and whilst there are geophysical limits to how many streamers can be used to image a specific geological target, it is certain that this trend will continue.

The use of seabed receivers, especially multi-component systems, will increase for both 3D surveys and the newly emerging 4D or time lapse 3D technique. In this method, successive 3D surveys acquired months or years apart depending on the characteristics of reservoir production, are compared to determine where fluid movement has occurred (or not) in the reservoir itself.

Research into how improvements to both the quality and productivity of the seismic method will continue as will investigations into how best to quantify and minimise any environmental impact that seismic surveys may have.

Marine seismic surveys have experienced strong growth in the last ten years and it is likely that this growth will continue well into the next millennium. However activity levels will always reflect the economic conditions in which the oil companies are working.

Worldwide there are presently a total of some 80 seismic vessels available. In the past a maximum of about 120 seismic vessels were operating.