SHIFTS IN SEISMIC TECHNOLOGY

O. Valishin, Sercel, France, discusses developments in borehole seismic technology.

Borehole seismic technology has developed over the years from the simple analogue single geophone measurement, primarily oriented on the checkshot velocity calibration, into very complex systems, capable of answering multiple technological objectives. This article provides an overview of where borehole seismic technology is today, and the promising technologies that are in the process of validation for the future.

Figure 1. *SlimWave.*

Figure 2. *GeoWave II.*

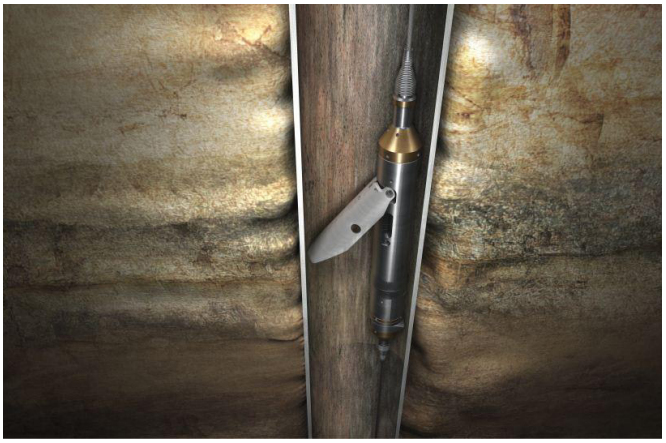

Figure 3. *MaxiWave.*

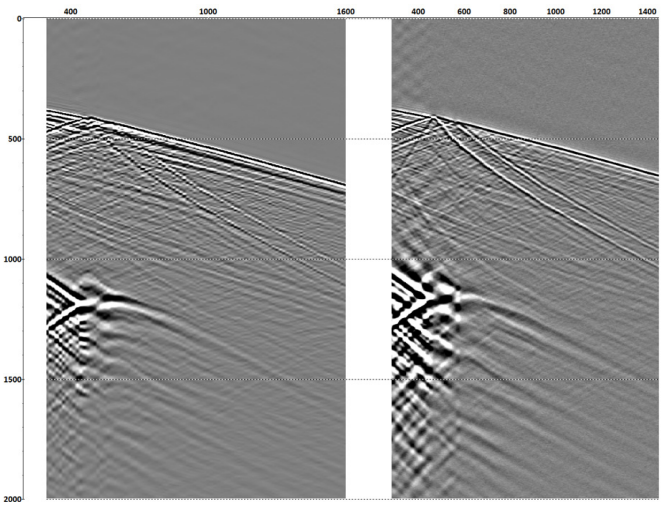

Figure 4. *Left: SlimWave (single geophone per axis). Right: Sercel & Fotech DAS solution (raw field gather).*

The current conditions of the industry and the overall technological shift in the oil and gas sector have been driving borehole seismic in the following directions: overall and sustained reduction of services and equipment cost, significant reduction of rig time requiring well shutdown, and reducing the cost of the source while increasing data quality.

The manufacturers of borehole seismic equipment have been working for years to lower the cost per seismic trace in order to maximise value to the final customer and enable the use of large seismic arrays. However, at the same time, increasing the amount of electronics in the well (up to 120 levels in the case of Sercel GeoWave II, or up to 100 levels for Sercel MaxiWave) has required manufacturers to put significant effort into the overall reliability of the systems. The same is true for the continuously increasing temperature and pressure requirements for the tools, which lead to more complex downhole tools using more expensive, ruggedised components and materials.

Reducing the overall cost of equipment, and the cost of ownership, while providing the step change in the performance of the systems has proved to be a challenge that is still very acute today. Another avenue for the overall cost reduction were the advances in wireline telemetry that enabled the use of sub-standard wireline units comprised of single or 3 - 4 conductor slick wireline cables, and consequently smaller and more cost-effective wireline units. Advances in telemetry also provided the capability to increase the number of tools deployed while maintaining high sample rates, allowing the industry to achieve the optimum number of shuttles run in the well versus rig cost and deployment time.

Nowadays, and particularly offshore, rig time allocation is critical and can be the determining factor on whether or not to perform a borehole seismic acquisition. Current 3D shooting programmes can be 5 - 10 days in duration, and include up to 60 000 source points. Vast operations such as these are simply not economical if the downhole seismic array cannot cover the entire area of interest, as the entire shooting programme would need to be repeated when the array is moved to a new position. Current downhole systems with >40 levels and very high-speed telemetry rates help to resolve this problem by covering up to 2000 or even 3000 m of the wellbore with 3C sensors.

Environmental specifications

Manufacturers of borehole seismic systems use the latest advances in electronics and manufacturing materials to achieve better resistance to harsh environments while maintaining the highest possible data quality.

The Sercel GeoWave II system allows reliable operations up to 205˚C/400˚F, enabling applications such as microseismic monitoring in deep shale plays in the USA and China, or deep exploration VSP (Vertical Seismic Profile) worldwide. The continued increase in well depth, and HPHT conditions (such as that frequently encountered in the Gulf of Mexico) have led to the development of 25 000 psi, 30 000 psi and 35 000 psi borehole seismic tools providing high reliably in the harshest conditions.

Most commercial arrays allow for deployment in wells as small as 3 in. and as large as 26 in. in diameter, in both open and cased hole conditions. The motorised arms of Sercel systems provide strong coupling, which results in recording high vector fidelity data, while maintaining high production rates of acquisition.

Reliability

Continuous increases in temperature and pressure requirements and improvement in overall system reliability continue to be the targets of most manufacturers. Sercel performs detailed testing of the equipment according to the quality control system (ISO 9001), both at the qualification and the production stage. The environmental conditions (temperature and pressure) are systematically applied beyond customer specifications in order to achieve full compliance of the product's published performance specifications. Sercel has been using advances from the electronics industry and knowledge shared by its customers to continuously improve the components used in the products. The company was the first in the borehole seismic industry to shift to inherently more reliable ceramic and fit-for-purpose encapsulation of the electronic components for high temperature applications. Consequently some of the critical items, such as high sensitivity/high temperature geophones, are designed and manufactured in-house. The manufacturing process starts with constant monitoring and auditing of suppliers, incoming inspection and testing of critical components, rigorous testing at various stages of production for temperature, pressure vibration and shock resistance. All Sercel downhole seismic products go through a comprehensive evaluation in a deep test well (3000 m deep), as well as temperature and pressure testing in one of the largest temperature and pressure chambers in Europe in order to ensure full system operation prior to delivery.

Due to the increasing number of shuttles (levels) being deployed in wells, precautions are taken to mitigate the possibility of failure. Modern Sercel arrays are equipped with a bypass feature that allows the operator to bypass a failed level and continue acquisition without having to pull the array out of the well. Sercel system architecture also allows electronic cutoff of the failed elements in the bottom part of the toolstring that allows the acquisition with the upper part of the array to continue.

The introduction of the large arrays has required manufacturers to design tools incorporating simplified maintenance procedures to reduce the manpower necessary to service large fleets of tools. Sercel GeoWave II system has been designed with this in mind to allow for the fastest turnaround of assets when maintenance is required. The system is also equipped with a temperature exposure tracker on every electronics board, which allows field engineers to mitigate risks during the job planning, and for maintenance personnel to track the ageing of the system and schedule component replacement.

Conveyance

Most borehole seismic surveys are performed using a wireline, usually limited to 45 - 50˚ of deviation (well deviations as high as 70˚ have been achieved). The increased use of microseismic in the unconventional wells in North America has made the use of tractors a common mode of operation. Most systems on the market can be tractored, and some are capable of reliable operation with any type of tractor (all of Sercel's tractorable tools are qualified for up to 7 Amps and 1000 V at maximum operating temperature). Pipe conveyance or pump down for horizontal wells are also options for deployment of downhole seismic tools in deviated wells, although used less regularly versus a tractor.

Telemetry

Ever-increasing demands on the number of shuttles in the well and high sampling rates have necessitated an overall increase in wireline telemetry rates. While some manufacturers have switched to fibre optic telemetry, its use is limited due to the limited availability of fibre optic wirelines on the market. Sercel has improved real time telemetry without data loss on standard wirelines, and currently has the industry's highest telemetry rate of 4.2 Mbits/sec., and guaranteed telemetry of 2.5 Mbits/sec. on a 7000 m wireline. In practical terms, this has enabled operators to conduct 100 level VSP field surveys with a 2 msec. sampling rate, or microseismic surveys with 40 levels at 0.5 msec. sampling, or 20 levels with 0.25 msec. sampling rates – all of these on standard wireline cables. While most downhole seismic tool manufacturers use 24 bit sigma-delta ADC converters in their shuttles, the high speed of Sercel's telemetry enables it to achieve high channel count and high bit rate without data loss over a standard wireline.

Array length

Current systems allow for very large apertures (up to 2000 m for Sercel MaxiWave, and 3000 m for Sercel GeoWave II), providing coverage of the zone of interest for most VSP and microseismic operations. The increasing use of horizontal wells in the unconventional plays of North America has led to the use of split array configurations for microseismic, where two groups of geophones are separated by 400 - 800 m (1400 - 2800 ft), pushing the need for systems capable of large aperture acquisition with high sample rates.

Sensitivity

System manufacturers have been working on improving overall system sensitivity. Sercel has been actively working on several aspects of this:

- Ultra-low noise shuttle digitisers introduced in 2007 creating the industry benchmark, the effort to bring the noise floor even lower continues.
- Ensuring consistent and true vector fidelity response of the shuttle to the seismic wave. This is achieved by optimising the shuttle geometry to ensure the best possible wellbore contact, improving signal reception of horizontal components and reducing tube waves effect by having the best anchoring mechanisms with active and strong locking arms anchoring.
- Increasing the sensitivity of the sensor. The Sercel SGHT-15 high temperature high sensitivity sensor provides enhanced performance and reliability. A further increase in sensitivity is achieved by combining multiple geophones per axis, for example four geophones per axis for SlimWave Quad and GeoWave II Quad configurations, which increases the signal to noise ratio by up to 10 dB.

Deployment and safety

The ever-increasing use of large arrays for 3D VSP and microseismic operations has led to some issues for the industry: time for rig up and rig down of the equipment became unacceptably long, and the increased manual handling of equipment has resulted in HSE hazards for the operating personnel. Sercel has addressed these concerns and integrated their solution into the architecture of the systems from the start. The quick deployment systems were introduced to the market in 2008, and have proven their efficiency in a variety of

conditions. The deployment systems not only allow the operator to perform the rig up and rig down safer and faster, but also prevent and detect failures during deployment as the systems are rigged up while connected (thus avoiding water entry during connection and disconnection process), and deployment is done 'live', with the system powered up. This approach allows the operator to detect any anomaly during the rig up process. Current deployment time onshore for 100 levels is around 6 hrs, with the world record being 80 levels in 1.5 hrs when shorter interconnects (7.5 m) were used.

Current Sercel range of downhole seismic arrays

GeoWave II

This modular probe is a downhole tool that performs any type of seismic logging, in configurations from 1 to 120 modules. Each module has three high-sensitivity geophone components, with two geophones per axis for higher sensitivity. Each shuttle is 70 mm in diameter and can work in wells with temperature of up to 205 °C (400 °F) and pressures up to 2070 bar (30 000 psi). GeoWave II was designed based on the input of customers and oil companies for technical characteristics, universal functionality, safety, and ease of maintenance. GeoWave II currently holds several world records for deployment in the highest temperature and deepest wells for a digital tool.

Recent examples of added value to the customers were: regional record set for deepest exploration VSP in Asia (over 8000 m deep); successful de-risking of HPHT wells by looking ahead of the bit VSP in hot wells offshore North Sea; microseismic monitoring in hot wells.

SlimWave

This small-diameter modular probe can be used in wells with temperatures up to 150 °C and pressures up to 1000 bar (14 500 psi) in configurations from 1 to 24 modules (each module with three components). The 43 mm diameter probe allows it to be deployed in many types of installations, including under the tubing shoe, in small diameter wells, and in the mining industry. SlimWave, like GeoWave II, can operate on three conductor cables, but SlimWave is the only downhole tool on the world market capable of operating on any type of geophysical cable (from single conductor to seven conductor).

Recent examples of added value to the customers were: successful hydraulic fracturing monitoring in Russia where competitive systems failed to detect microseismic events; split array configuration for microseismic; enabling academia to have cost effective VSP/microseismic solutions by using SlimWave with light monoconductor winches.

MaxiWave

This downhole modular probe was specifically designed for large VSPs, with a configuration of up to 100 modules. The probe's design characteristics allow it to be used in wells with temperatures of up to 150 °C (300 °F) and pressures up to 1200 bar (17 400 psi). MaxiWave is the industry benchmark for 3D VSP operations, with the highest number of 3D projects acquired.

Recent examples of added value to the customers were: a series of 3D VSP offshore using 100 levels (array coverage of 2000 m) to resolve complex geology offshore the Gulf of Mexico; 4D VSP for detection of bypassed zones in the steam injection EOR in a heavy oilfield in the Middle East.

DAS (distributed acoustic sensing)

The use of the DAS for borehole seismic is becoming increasingly common. This technology, while still in the early stages of its introduction for geophysics applications, is very promising for cases where the use of electronic arrays is either not feasible or uneconomical. These applications are primarily 4D (time lapse) VSP, microseismic in treatment wells, and cost efficient velocity surveys.

The fundamental challenges for the adoption of this technology in today's market are:

- The industry's lack of knowledge on the calibration and measurement using DAS.
- DAS is a single component measurement, which is sufficient in most cases, but not always, in particular for microseismic.
- DAS depth control remains an issue.
- The overall sensitivity of the DAS is lower than that of geophones.
- The fibre has a directional response, meaning that seismic waves arriving at a right angle (+/- 15°) to the fibres cannot be sensed by the fibre.
- Overselling of current DAS capabilities by some vendors has caused clients to have unrealistic expectations, resulting in what the client considers to be disappointing results.

The industry has yet to develop an overall understanding and characterisation of DAS system performance. Somewhat different to geophone systems, DAS overall sensitivity and characterisation is a combined effect of interrogator performance, acquisition conditions, fibre specifications, fibre condition, fibre packaging in the cable, and cable coupling to the formation – with some of these parameters changing over time, particularly in case of time lapse monitoring. Despite the mentioned limitations and challenges, DAS is a promising technology that has secured the place in the borehole seismic market.

Figure 4 shows a snapshot of an acquisition performed on the CO2CRC Otway Carbon Capture & Sequestration (CCS) project, where a 4D acquisition was executed by Curtin University using a Sercel 428 buried array, Sercel SlimWave downhole array, and a Sercel/Fotech DAS system using a cemented fibre in the well. While the acquired DAS data is inferior to the geophone data in terms of S/N and directional response, it offers a clear advantage of a non-intrusive, on-demand 4D measurement. A combination of different technologies (as in the case of the Otway CCS project) is a clear example of intelligent industry application of synergies, creating extra value to the final customer.

Sercel has addressed this application via partnership with Fotech Solutions, a worldwide leader in DAS technology. Sercel currently proposes the complete solution by industrialising DAS measurement. More specifically, Sercel solutions make DAS solutions available industry wide, and offer standard and must-have features of a seismic product, such as source control, real time advanced seismic traces display and quality control, and real time SEG-Y data generation. Moving forward, Sercel is promoting the use of hybrid systems, where the DAS technology is used in conjunction with the electronics systems in a single array in order to maximise the value to the customer. The examples of this are deep 3D arrays allowing complete well coverage, or microseismic surveys with extended arrays. The appropriate use of this combination of technologies is a promising direction for the industry.