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Land seismic: the 'quiet' revolution

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Introduction

The combination of several recently introduced technologies suggests that land seismic acquisition is undergoing a quiet, but profound, revolution. This revolution is driven by the need to better characterise existing reservoirs as well as quickly identify new, more challenging, unconventional, and even, non-hydrocarbon, exploration targets. In addition, data needs to be acquired more quickly and at a lower cost, both environmental and economic. In this paper I describe these new technologies in the same order in which they are applied in the field, namely survey planning, positioning, recording systems, seismic sources and techniques to improve productivity. Some of these technologies are now being used in Australia.

Survey planning

Assessment of the geophysical objectives of a survey ultimately leads to the determination of the survey geometry, i.e. the source and receiver station and line spacing. The survey is thus designed as a regular grid (e.g. Figure 1a), a requirement for the data processing algorithms that will later be applied. Unfortunately occupying these exact source and receiver positions is rarely possible, particularly in areas with significant obstacles. Thus, points need to be offset (e.g. Figure 1b), a time-consuming process that introduces offset and azimuthal discontinuities in the sub-surface coverage.

The development of data-processing algorithms that do not require surface positions to conform to a rectilinear grid, instead being actual-location driven, allows the survey to be designed so that it efficiently follows paths of least resistance around obstacles (identified from high-resolution satellite images) while retaining smooth variations in offset and azimuth (e.g. Figure 1c). These new non-grid-based algorithms also improve the processed data as the actual positions of the sensors can be used, rather than their planned position, which we know to be only an approximation.

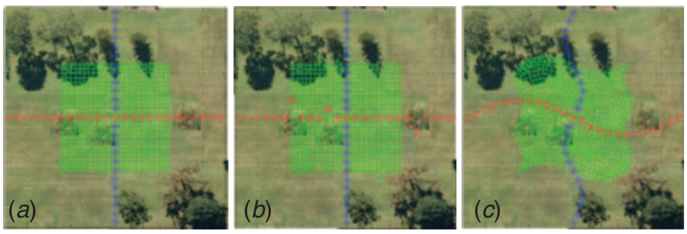

Fig. 1. *(a) An ideal regular grid layout. Source locations are in red, receiver locations in blue, and the resulting common midpoints in green. (b) The same layout after the source positions have been moved to avoid some trees. (c) A new layout made possible by recent developments in processing software. The locations do not need to conform to a grid or to any particular pattern. Provided the locations vary reasonably smoothly, the result is uniform coverage.*

Positioning

Previously, once planning was finished, surveyors using GPS would mark the receiver and source positions, either with wooden stakes, pin-flags or small photodegradable bags of sand. The layout crew would then place receivers as close as possible to the marked positions. This process is now almost entirely obsolete as the latest generation of recording systems allows *positioning-with-layout,* i.e. integrated positioning and placement of receivers.

Using GPS with satellite based augmentation systems (SBAS) allows accurate positioning (Figure 2a) without the need for the cumbersome radio infrastructure associated with other GPS-based surveying methods. In WesternGeco's UniQ system, the layout crew use GPS to navigate to the planned position before planting the sensor and programming its position into the sensor using an RFID system (Figure 2b). If the planned position cannot be achieved then the sensor can be offset and, as its actual position is recorded, time-consuming re-surveying is not required. Most cable-less systems (discussed later) incorporate

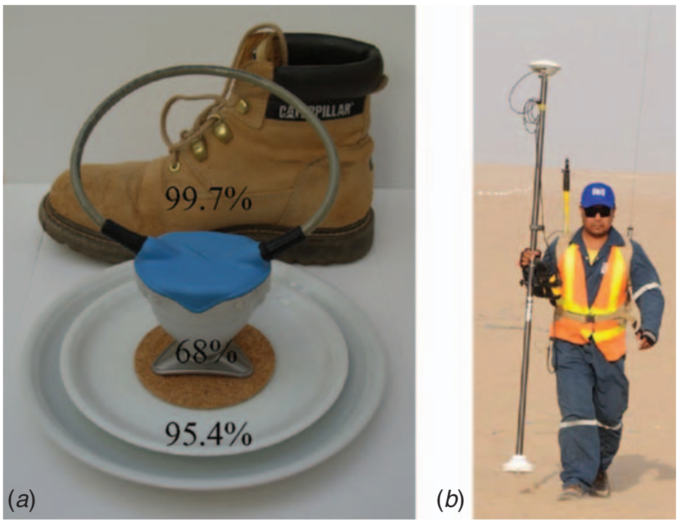

Fig. 2. *(a) Accuracy of SBAS positioning. The probability that the measured position of an object will be within its true position is shown for objects of varied size relative to the size of a sensor. For example: boot or plate 99.7%, coaster 68%, saucer 95.4%. (b) UniQ positioning-with-layout equipment in use. A GPS antenna is at the top of the pole and the RFID system at the bottom. (Image courtesy of WesternGeco.)*

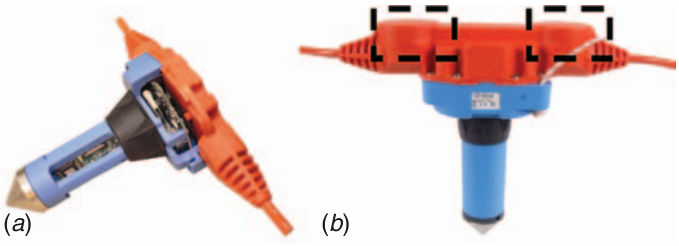

Fig. 3. *Sercel DSU3 3-component MEMS sensor (left) and DSU3GPS sensor (right). The latter includes a pair of GPS antennas, highlighted by the dashed black boxes, to record the position and orientation of the sensor. (Image courtesy of Sercel.)*

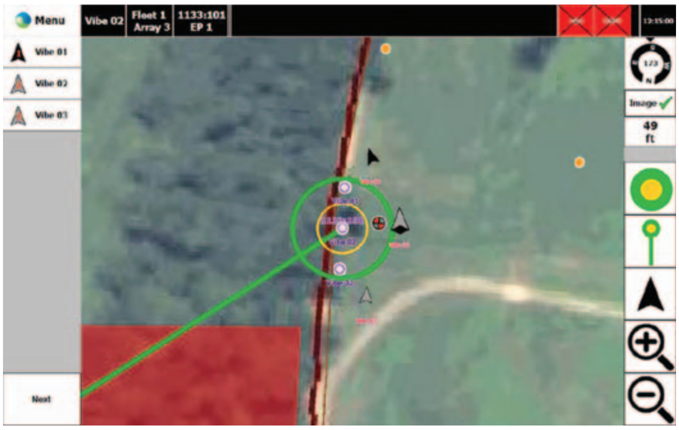

Fig. 4. *Screenshot of stake-less navigation, the planned source positions are shown by the circles at the centre of the screen with the current positions of three vibrators (shown as arrowheads) to the right. (Image courtesy of INOVA.)*

GPS positioning while Sercel's new DSUGPS sensors are unique among cabled systems as they incorporate a pair of GPS sensors (Figure 3). The GPS antennas add little weight and increase the cost by 15% but become redundant once the position of the sensors is recorded.

Source positioning has also been revolutionised. Inside the vibrator driver's cab, the source point and vibrator positions appear on a screen, allowing accurate placement without the need for a survey (Figure 4).

Recording systems

The basic building block of a land seismic acquisition system is the sensor, usually a geophone, which is a magnet surrounding a coil attached to a spring. Vibrations in the ground cause the magnet to move, generating a small electric signal in the coil. The design principle of the geophone has remained practically unchanged since the 1930s, although its size, at least for exploration purposes, has been reduced considerably.

The amplitude response of geophones varies with frequency, limiting their ability to record low frequencies. The response of the geophone peaks at the natural frequency, and although this can be reduced to record lower frequencies, this makes the sensor larger and more susceptible to errors if not placed exactly vertically. Recently two alternative acceleration sensors have been introduced: the geophone accelerometer (GAC) and micro-electro-mechanical-systems (MEMS). The GAC utilises geophone elements and advanced active circuitry. Its improved frequency response compared with a standard geophone is

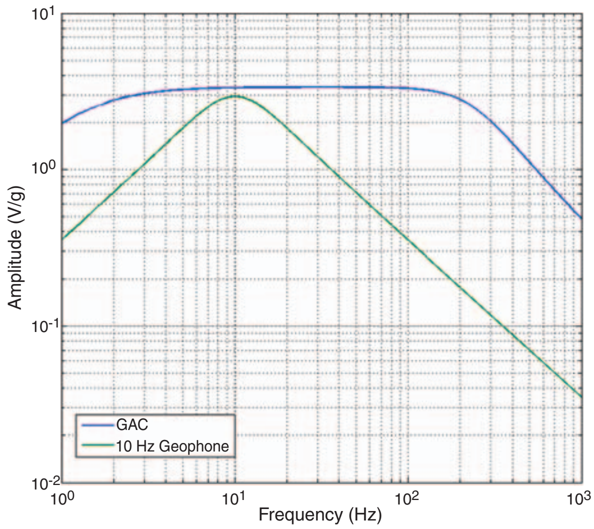

Fig. 5. *Amplitude response curve for a geophone (in green) and a GAC (in blue). (Image courtesy of WesternGeco.)*

shown in Figure 5. MEMS sensors are tiny chips (smaller than a coin), as used in electronics such as smart phones. Although MEMS sensors are much smaller than geophone elements their associated electronics and housing considerably increases their size.

Geophones have been traditionally wired together and placed in an areal pattern to reduce both coherent and random noise. These analogue arrays are good at attenuating noise at the wavenumbers for which they have been designed but have drawbacks in terms of flexibility (noise at other wavenumbers is not fully attenuated) and spatial aliasing. In practice the ideal response of an array is easily weakened by small errors in the positioning (x, y, and z) of individual geophones.

A dramatic increase in the recording capacity of acquisition systems, with 100 000+ channels now available from a number of suppliers, has allowed the output from large spreads of individual sensors to be recorded and noise digitally removed. As digital filtering is more effective at removing noise than the use of analogue arrays, superior noise-removal results can be achieved using a much smaller number of sensors (typically 10–20% as many). This improvement reduces the logistic overheads and allows the deployment of much larger spreads, albeit at the expense of deferring the noise attenuation from acquisition to processing.

Recently a growing number of cable-less (also known as nodal) recording systems have become available, although most (95%) recording systems being sold are still cable based (Mougenot, 2010). There are various different systems (Figure 6), but they typically consist of a sensor that is either attached to the recording unit by a small cable or, less commonly, integrated within the recording unit. The recording unit contains a GPS clock for timing synchronisation and flash memory to record the data. Some units are autonomous; others can send quality control information or even data via radio or wireless links, either in real-time or via intermittent 'harvesting'.

Cable-less systems offer increased flexibility and freedom from cables, which in turn makes recording free from interruptions due to cut cables, although modern systems guard against this by having multiple transmission paths between each sensor and the recording truck (Figure 7). On the other hand, if the spacing

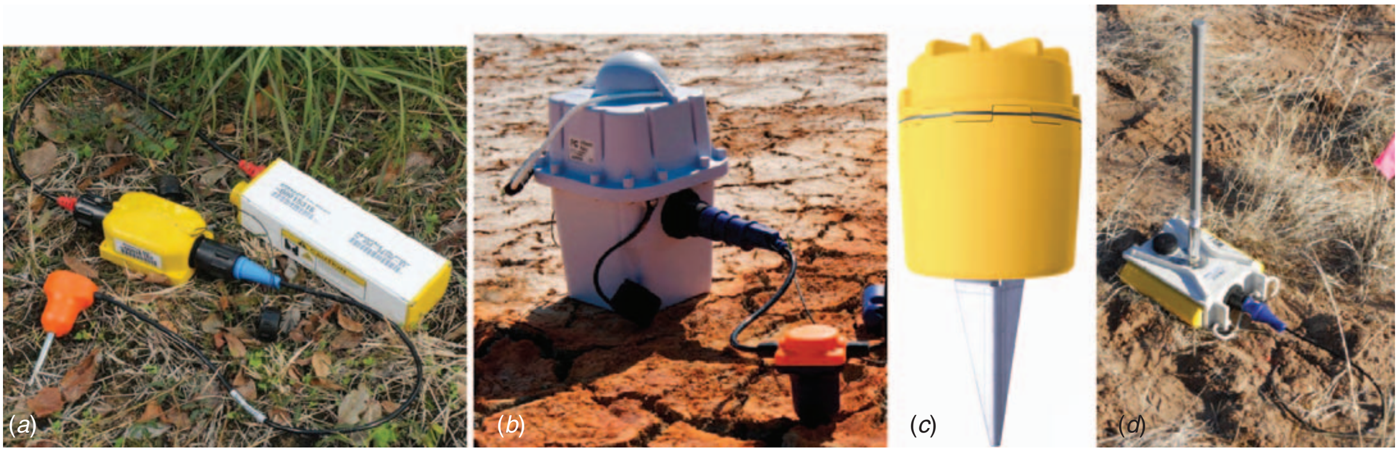

Fig. 6. *Examples of cable-less recording systems. (a) OYO Geospace GSR with separate geophone, recording unit, and battery (image courtesy of OYO Geospace), (b) Sercel UNITE node with an internal battery and separate geophone string (image courtesy of Sercel), (c) ZLand with all components integrated, the unit is 15.9 cm high without the spike (image courtesy of FairfieldNodal), (d) Wireless Seismic RT 1000 unit, capable of sending data in real-time via a radio network. (Image courtesy of Wireless Seismic.)*

of receivers is less than about 50 m apart (spacing of ~10 m is required to protect against spatial aliasing in most areas), the weight of batteries needed can be more than the weight of cables they have replaced (Lansley *et al.*, 2008).

Although the choice of either a cabled or cable-less system is usually clear, sometimes a combination of both offers advantages (Lansley, 2012). For example, the hundreds of thousands of channels required for a very large area (Figure 8) is unlikely to be balanced by improvements in batteries, wireless communication and data harvesting. Thus cabled systems are likely to be preferred, with cable-less systems reserved for survey areas with restricted access.

Sources

Vibroseis continues to be the predominant land seismic source and seems unlikely to be replaced (not that a replacement is needed). The development of vibrators continues to be incremental, primarily driven by increases in the hold-down weight with 80 000 lb units and even 90 000 lb units available. These increases have allowed fewer vibrators to be used in surveys, and sometimes a single vibrator is sufficient. The introduction of rubber tracked vibrators (Figure 9) has improved their mobility, allowing them to reach previously inaccessible areas and reduced the need for line clearance. The much reduced ground pressure of these vehicles also ensures that deep ruts are not created.

Data with enhanced low frequency content has various benefits such as overcoming attenuation, improving vertical resolution and enhancing inversion results. Although modern vibrators are capable of emitting low frequencies with reduced force, specialised sweeps, such as the Maximum Displacement Sweep (Bagaini, 2008), are required to ensure that the sweep does not attempt to exceed the performance limitations of the vibrator.

Productivity

Conventional sequential vibroseis acquisition requires that the time between consecutive sweeps be at least equal to the sum of the sweep length and listen time, typically around 14 to 20 seconds. Once crews became equipped with sufficient fleets this became the ceiling on productivity. Techniques to overcome this limit have existed since the mid-1990s but have been little used due to concerns about noise contamination. Recently the advantages of acquiring additional source points with less source energy ('Fold vs. Force') have become commonly accepted. Although improvements in vibrators have allowed fleet sizes to be reduced, and thus the number of fleets to be increased, such that these extra source points could be acquired, to achieve them

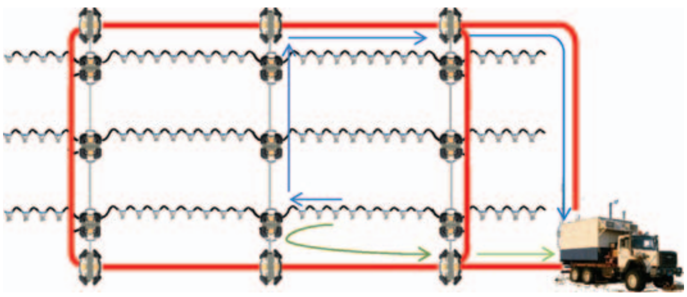

Fig. 7. *Diagrammatic representation of a WesternGeco UniQ system layout, strings of point receivers can be joined (only a single 10-receiver string is shown but 15 contiguous strings (~1800 m) are supported), removing the need for line cables. The red lines are fibre-optic cables. Multiple paths from each sensor to the recording system ensure that recording can continue even if some of the cables are cut. Two examples are shown by the coloured arrows but many others are possible. (Image courtesy of WesternGeco.)*

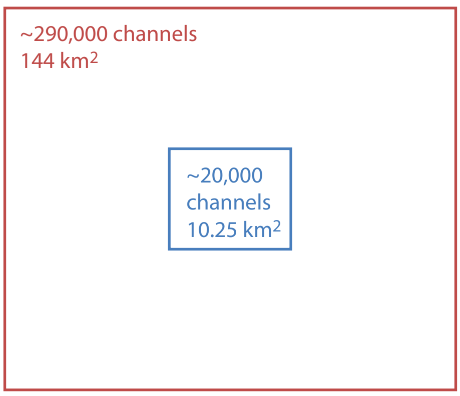

Fig. 8. *Areas and channels for surveys in Kuwait during 2004 (10.25 km^2, 20 000 channels) and one proposed in 2010 (144 km^2, 290 000 channels).*

Fig. 9. *Rubber tracked DX80 80 000 lb vibrators. (Image courtesy of WesternGeco.)*

in a timely manner requires overcoming conventional productivity limitations. To do this various high productivity techniques have been introduced including overlapping sweeps (slip–sweep; Rozemond, 1996); separating the fleets so they interfere below the horizon of interest (distance separated simultaneous source; Bouska, 2010); and even allowing vibrators to sweep autonomously (independent simultaneous sweeping; Howe *et al.*, 2008). The current acquisition record is over 45 000 source points in a single day (Pecholcs *et al.*, 2010), although a sustainable figure is ~20 000/day, an order of magnitude higher than that achieved just five years ago. Many of these high productivity methods are enabled by continuous recording with the recorder and sources synchronised using GPS timing.

Conclusion

Land seismic data acquisition is undergoing a quiet revolution. This revolution is driven by the need to map more demanding geological targets at lower economic and environmental cost. The data needs to be uncompromised by its own acquisition so that it can be used as an input for advanced seismic imaging and inversion processes. Survey planning is no longer based on rigid grids but follows paths of least resistance around obstacles identified from remote sensing images. Teams of surveyors operating in advance of the layout teams are no longer required because receivers are now being located and their actual positions recorded by the layout teams. Vibrators proceed directly to their source positions using their own navigation systems. High productivity acquisition techniques allow tens of thousands of source points to be acquired each day, into spreads covering tens of square kilometres containing over a hundred thousand individually recorded accelerometers, generating terabytes of data.

Tim Dean *has an Honours degree in Geophysics from Curtin University and a PhD in Physics from the University of New South Wales. He has spent the last eight years working for WesternGeco and Schlumberger in a variety of roles including field operations, software development and research located in Saudi Arabia, England and Norway. He is currently a Senior Research Geophysicist in WesternGeco's GeoSolutions Development Group in Perth researching various topics associated with land seismic acquisition.*

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