New Dimensions in Land Seismic Technology

Advanced seismic acquisition and processing technology has come onshore. A high-fidelity, high-resolution, integrated single-sensor system is now available for use on land. This technology marks a significant step forward for exploration, field development and production.

Seismic technology has achieved amazing feats in exploration and production activities in the past few decades. The advance to three-dimensional (3D) seismic acquisition and imaging of the subsurface, introduced in the 1980s, was perhaps the most important step. Another was development of four-dimensional (4D), or time-lapse, seismic data to monitor how reservoir properties such as fluids, temperature and pressure change during the productive life of a field. Introduction of multicomponent seismic data acquisition with the recording of shear wave signals, in addition to compressional wave data, provided a tool for rock characterization and identification of pore-fluid types.

With the world’s ever-growing demand for oil and gas, the emphasis in the oil and gas industry has shifted to exploring deeper, more complex reservoirs and to enhancing production from existing assets. Field life can be extended by delineating bypassed oil and gas and by placing production and injection wells optimally. The proactive monitoring of reservoir fluid behavior—saturation and pressure—over time, allows remedial actions to be implemented before production is affected.

Challenges in Conventional Land Acquisition

Single-sensor seismic recording has been available since the early days of seismic exploration. The principle is simple. An impulse source such as dynamite or a controlled-frequency source such as a vibrating plate on a truck sends acoustic energy into the Earth. This energy propagates in many different directions. Downward traveling energy reflects and refracts when it encounters boundaries between two materials with different acoustic properties. Sensors or geophones placed on the surface measure the reflected acoustic energy,
converting it into an electrical signal that is displayed as a seismic trace.⁴

A complication in land acquisition is that, unlike marine data, a seismic line is rarely shot in a straight line because of the presence of natural and man-made obstructions such as lakes, buildings and roads. More importantly, variation in ground elevation causes sound waves to reach the recording geophones with different traveltimes. The Earth’s near-surface layer may also vary greatly in composition, from soft alluvial sediments to hard rocks. This means that the velocity of sound waves transmitted through this surface layer may be highly variable. Static corrections—a bulk time shift applied to a seismic trace—are typically used in seismic processing to compensate for these differences in the elevations of sources and receivers and near-surface velocity variations.⁷

Another major problem in land acquisition is that land sources typically generate energy that travels horizontally near the surface, also known as airwaves and ground-roll noise. Conventional sensor arrays comprising strings of geophones

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4. Coherent noise is unwanted seismic energy that shows consistent phase from one seismic trace to another. This may consist of waves that travel through the air at very low velocities such as airwaves or air blast, and ground roll that travels through the top of the surface layer, also known as the weathering layer. The energy trapped within a layer, also known as multiples, is another form of coherent energy. Noncoherent energy is typically nonseismic-generated noise, such as noise from wind, moving vehicles, overhead power line or high-voltage pickup, gas flares and water injection plants.
5. A vibrator source sends a controlled-frequency sweep into the Earth. The recorded data are then convolved with the original sweep to produce a usable signal.
6. Each trace consists of one recording corresponding to a single source-receiver pair. In practice, traces from one source are simultaneously recorded at several receivers. Then, sources and receivers are moved along the survey line and another set of recordings is made. When a seismic wave travels from a source to a reflector and then back to the receiver, the elapsed time is the two-way traveltime. The common depth point (CDP) is the halfway point of the path; it is situated vertically below the common midpoint. Sorting of traces by collecting traces that have the same subsurface midpoint is called a common-midpoint (CMP) gather. The number of traces summed or stacked is called a fold. For instance, in 24-fold data, every stacked trace represents the average of 24 traces. In the case of dipping beds, there is no common depth point shared by multiple sources and receivers, so dip-moveout (DMO) processing becomes necessary to reduce smearing or inappropriate mixing of data. For more on seismic recording: Farmer P, Gray S, Whitmore D, Hodgkiss G, Pieprzak A, Ratcliff D and Whitcombe D: “Structural Imaging: Toward a Sharper Subsurface View,” Oilfield Review 5, no. 1 (January 1993): 28–41.
are based on the assumption that the upward traveling energy, or the reflected wave, arrives at the array essentially vertically and simultaneously, while the surface-wave noise arrives mainly horizontally and sequentially. To cancel this source-generated noise, spatially distributed receiver groups—arrays—are summed. Ideally, this process results in an attenuation of the noise and an improvement of the signal.

However, there are problems associated with conventional arrays. In reality, the sensor array is often not located on flat and homogeneous ground, so local changes in elevation and surface geology lead to fluctuations in the signal arrival time (left). These fluctuations are called intra-array perturbations. The hard-wired sensor array instantaneously sums all traces, and in the case of intra-array perturbations, this would lead to a partial cancellation of signal. The resulting output trace would then be at a lower frequency than each of the input signals, and the amplitude would be smaller than the sum of the individual amplitudes, a phenomenon known as the array effect.

Aliasing is a well-known problem that arises when the sampling rate of a signal is inadequate to capture the higher frequencies in the signal. Not only is the information contained in higher frequencies lost, it is incorrectly represented. Aliasing is a consideration for spatial sampling too, not just temporal sampling. Ground roll typically contains many different wavelengths—related to the distance between successive peaks in a waveform—that are shorter than the typical group interval or the distance between receiver array centers of gravity in a conventional survey. Due to undersampling of ground-roll energy, this energy is aliased and passed on to the signal bandwidth, causing ambiguity between signal and noise.


9. Aliasing is the ambiguity that arises because of insufficient sampling. It occurs when the signal is sampled less than twice the cycle. The highest frequency defined by a sampling interval is termed the Nyquist frequency and is equal to inverse of 2∆t, where ∆t is the sampling interval. Frequencies higher than the Nyquist frequency will be “folded back” or “wrapped back.” This condition can be observed in video or motion pictures: the spoke wheels on horse-drawn wagons sometimes appear to be turning backward instead of forward. Aliasing can be avoided by a finer spatial sampling that is at least twice the Nyquist frequency of the waveform.


Tests of varying array lengths have shown the degradation in signal quality caused by increasing the array size (right). For longer offset receiver arrays, the arrival time of the signal can vary significantly at either end of the array, smearing the higher frequencies when summed within the group. Therefore, just as adequate temporal sampling of the recorded trace is needed to successfully record a given frequency, a sufficiently small group interval is required to record a particular spatial frequency.

A problem common to all seismic acquisition is energy trapped between subsurface layers, known as interbed multiples, caused by a strong velocity contrast between layers. This occurs when the energy from the source reflects more than once in its travel path. Interbed multiples are analogous to a bouncing ball trapped between two layers, which continues to bounce until it loses its energy. Borehole seismic data, which are acquired when sources are placed on the surface and receivers are anchored in a borehole, help identify the interfaces that generate these interbed multiples. Recent developments in data-driven methods and the use of vertical seismic profile (VSP) data to guide surface-seismic multiple attenuation, such as Interbed Multiple Prediction (IMP), seem promising.

The quality of the raw seismic dataset is fundamental to achieving superior frequency resolution and high signal-to-noise ratio. Amplitude and phase preservation of the input signals is critical in all facets of stratigraphic interpretation, including prestack seismic inversion, amplitude variation with offset (AVO) and amplitude variation with angle (AVA) interpretation. An analysis of the variation in reflection amplitudes with source-geophone distance or offset gives some valuable insights into reservoir properties such as lithology, porosity and pore fluid.

Because land data often exhibit poor signal-to-noise ratios arising from irregular geometries and noise contamination, a fundamental change in acquisition and processing methods was required.

Signal degradation with an increase in array size. A point-source, point-receiver test was carried out with single sensors spaced 2 m [6.6 ft] apart and a single vibrator source. A 16-m [53-ft] array was formed by summing groups of nine consecutive geophones and assigning the summed signal to a channel placed in the center of gravity of the array (bottom). The group interval is the distance between consecutive channels. Similarly, a 32-m [105-ft] array was formed by summing groups of 17 consecutive geophones. By using 2-m sensor spacing, wave types were recorded without aliasing (top left). As the sensors were grouped into arrays of increasing length of 16 m (top middle) and 32 m (top right), first the airwave, then the ground roll and finally the first breaks became aliased, manifested as cross-banded signal areas in the shot domain. Aliasing also manifests as a wrap-around of the noise energy in the frequency-wavenumber domain, not shown here. (Data courtesy of Shell.)
A Change in Acquisition Philosophy

In the early 1990s, WesternGeco began extensive research on compressional wave (P-wave) sensitivity that led to a fundamental change in acquisition philosophy. Experiments conducted on synthetic signals revealed the effects of source and receiver statics, recording electronics specifications, source phase distortion and receiver sensitivity on P-waves (below).

Knowledge gained from these experiments was used to design and build the Q-Land single-sensor land seismic system to reduce the effects of these perturbations while addressing the issue of coherent noise removal such as ground roll. A receiver spacing that is half (or less) of the ground-roll wavelength would be adequate to sample ground-roll noise without aliasing. Just as temporal aliasing arises from insufficient sampling in time, a large receiver interval leads to spatial aliasing.

The new Q-Land system digitizes each sensor at the recording location (next page, top). To achieve this fine spatial sampling, the recording system requires a massive increase in the number of live channels. A live channel means that the receivers are connected to record simultaneously. Compared with a typical high channel-count conventional system, which may have 4,000 to 5,000 channels that record live, the new point-receiver acquisition system has 20,000 or more live channels. The Q-Land system is the first to implement an integrated point-receiver acquisition and processing methodology.

The same concept is applicable to the seismic sources. The source array can be replaced by point sources. In addition, to prevent aliasing in the common midpoint domain, the source interval should be small, ideally equal to the receiver interval. The new point-source, point-receiver recording technique replaces the conventional method of using sensor and source arrays to attenuate noise and to improve signal-to-noise ratio. Recording seismic data through point receivers rather than analog receiver arrays has several potential advantages, including better static solutions, velocity estimation, amplitude preservation, bandwidth retention and noise attenuation.

This point-source, point-receiver methodology increases data volume by more than an order of magnitude. Advances in data transmission and computing power have enabled the development and deployment of this cost-effective, high channel-count recording system.

A New Integrated Acquisition and Processing System

The new Q-Land system is a 20,000 live-channel seismic acquisition and processing technology. The typical sampling rate for the system is 2 ms. However, the Q-Land system can record with 30,000 live channels when the sample rate is changed to 4 ms. Digital recording of the incoming wavefield at densely spaced receiver positions ensures that the recorded signal and noise are properly sampled and are therefore unaliased.

In Q-Land acquisition geometry, one source line and one receiver line that are orthogonal to each other form a cross-spread. These are then repeated spatially within the acquisition area. Each source-receiver pair generates a trace that corresponds to a subsurface midpoint. If the midpoints corresponding to all source-receiver pairs are binned, with a bin size equal to half the receiver by half the source interval, every bin will be one midpoint corresponding to single-fold coverage. Thus, the cross-spreads provide single-fold subsets of the continuous wavefield, sampled finely enough to prevent aliasing of the coherent noise, through which a cross-spread volume is generated (next page, bottom).

^ P-wave sensitivity chart for land acquisition. Experiments were conducted on synthetic signals to understand the effect of perturbations such as source and receiver statics, recording electronics, source phase distortion, and receiver sensitivity. The chart shows that hardware changes in the receiver or the recording system have low signal error, as compared with other factors that cause a significantly higher signal error. The ability to correct for these higher order perturbations allows for the preservation of signal fidelity and bandwidth within the seismic data.

Sophisticated algorithms are then applied in a processing technique called digital group forming (DGF). DGF comprises three main steps. The first is correction to each geophone for intra-array perturbations such as amplitude, elevation differences and near-surface velocity variations. After the geophone outputs are grouped, the result is a signal with a frequency bandwidth similar to that of the individual traces and an amplitude almost equal to the sum of the individual amplitudes. This step is similar to the one applied in the Q-Marine single-sensor marine seismic system.

The Q-Land acquisition and processing system. A line of receivers is laid out perpendicular to a line of sources and every source point is recorded by every receiver point. The example shows 18 receiver lines that are 200 m [656 ft] apart, with 1,824 point receivers per receiver line that result in 18,240 live receivers (top). In digital group forming using the Omega2 software processing system, the seismic traces from individual geophones have perturbation corrections made to each geophone (bottom). Data-adaptive filters are then applied over a number of traces to suppress coherent noise. An output trace from a number of sensors can then be produced at the desired spatial sampling.

A three-dimensional (3D) display of the cross-spread volume. A cross-spread configuration is achieved by deploying receivers along a line in one direction and placing sources along an orthogonal line (right). Each source-receiver pair generates information from a subsurface point that, for a flat surface, is located at the midpoint between source and receiver (gray area). In this example of cross-spread configuration, with receiver sampling at 5 m [16 ft] and source sampling at 20 m [66 ft], the subsurface coverage is single fold. A 3D view of the cross-spread volume shows that the ground-roll noise is confined within a conical shape volume, making its removal or attenuation by 3D filters in the frequency-wavenumber domain more effective (left).
The second step applies data-adaptive filters for noise suppression. Noise attenuation can include, but is not limited to, coherent and ambient-noise attenuation, high-voltage power line pickup cancellation, and airwave and flare-noise attenuation. There are different ways to attenuate noise using digital filtering techniques. However, the design of optimal 3D digital filters is important to realize the potential of point-receiver recording.

An ideal filter would pass all the desired frequencies in the pass band with no distortion, and completely reject all frequencies outside the range of interest, called the stop band. The ideal spatial anti-alias filter response would also be azimuthally isotropic, that is the array response would be the same for energy arriving from all angles. There are two problems associated with anti-alias filter performance for conventional data acquisition: imperfect rejection of azimuthally varying levels of noise in the stop band and an imperfect flat response in the pass band (below). The Q-Land technique of forming an orthogonal acquisition geometry into cross-spreads is well suited to the application of three-dimensional anti-alias filters. A filtering technique based on the APOCS method—alternating projections onto convex sets—is an effective approach that works optimally on cross-spread geometry.14

14. A well-known mathematical technique, APOCS is an iterative technique that derives filter parameters to remove coherent noise. The algorithm, working in 3D space, switches constantly between sample domain—with time on one axis and x and y on the other two axes—and frequency transform domain—with frequency on one axis and wavenumber in x and y directions, k_x and k_y, on the other two. Wavenumber is the inverse of wavelength and represents the frequency of the wave in space. For more on APOCS: Özbek A, Hotel I and Dumitru G: “3-D Filter Design on a Hexagonal Grid for Point-Receiver Land Acquisition,” EAGE Research Workshop, Advances in Seismic Acquisition Technology, Rhodes, Greece, September 20–23, 2004.


16. The Q-Borehole system optimizes all aspects of borehole seismic services, from job planning through data acquisition, processing and interpretation. Well logs, VSP and surface-seismic data are combined to build a property model of vertical velocities, frequency attenuation factors, anisotropy related to vertical variations in interval velocities and the multiples wavefield. The model is then used for enhanced surface-seismic processing and calibration in the Well-Driven Seismic process.

The last step is spatial resampling of the output data according to the desired group interval. Analog arrays, once laid out in the field, have almost no flexibility to adjust the output-sampling interval, whereas with digital group forming, any output sampling is possible down to the granularity of the individual sensors.

While data from conventional arrays may provide reasonable results for structural interpretation, detailed reservoir analysis using seismic inversion or AVO techniques is limited to a narrow frequency band because of aliased noise wrapping back in the frequency range of interest (below right). With such reduced bandwidth, AVO and inversion are unlikely to produce meaningful results. The densely spaced point receivers employed by Q-Land methodology provide alias-free data, and hence, a more complete bandwidth for AVO interpretation.

In complex geological settings where conventional array data are unable to deliver the required results, single-sensor data provide significant improvement in signal fidelity and frequency bandwidth. This improvement enables interpretation of subtle stratigraphic features and increased vertical and lateral resolution of the seismic response as demonstrated in the following two examples from Kuwait and Algeria.

**Pioneering New Technologies in Kuwait**

The Minagish field in southwestern Kuwait was selected for a Q-Land pilot study in 2004, to address several development and exploration objectives. One goal was to provide a detailed image of multiple reservoir intervals within the Cretaceous for fluid-front monitoring.

Discovered in 1959, the Minagish field is one of the country’s main producers, with production primarily from carbonate rocks, including the Minagish oolites. A waterflood program resulted in water influx overriding oil in layers with high permeabilities.

A previous 3D seismic survey in 1996, with source and receiver arrays of 50-m [165-ft] spacing, provided poor imaging of deeper prospects and limited the vertical and lateral resolution at principal reservoir zones. Characterizing fracture density and orientation, necessary to optimally place horizontal wells and maximize production, was also a problem. Noise arising from gas flares and water injection plants, coupled with seismic-generated noise such as air blast, ground roll and multiples, caused extreme distortions in the seismic data.

In addition, the Minagish field posed an unusual operational hazard. The area was strewn with unexploded cluster bombs and mines from earlier military activity.

A detailed understanding of the internal reservoir structure was essential for a planned water injection scheme to work. Forward seismic modeling using rock properties from core samples and logs has shown that a 5 to 95% change in water saturation could result in a 5% difference in acoustic impedance—a product of velocity and density of the rock. However, a previous 4D study in 1998 shows the inability to detect these small changes due to the background noise level in conventional seismic data. Some of the limiting factors were frequency resolution, inferior noise attenuation and a low signal-to-noise ratio. To allow monitoring of minute changes in reservoir behavior, it was obvious that a step change in acquisition methodology was necessary to reduce noncoherent signal and coherent noise.

Four tightly grouped vibrators in a rectangle of 12.5 m [41 ft] by 5 m [16.4 ft] vibrated in synchrony at 60% of their peak force capability of 80,000 lbf [356 kN]. Driving at less than peak force provided a low distortion in the seismic source. The vibrators were set as close as possible to resemble a point source while maximizing energy input into the Earth. The Q-Land system recorded 14,904 channels at a 2-ms sampling rate. Perturbation corrections were made to each receiver and each source prior to summation in the DGF process.

In addition, a Q-Borehole integrated borehole seismic study was planned at the inception of the Q-Land pilot program. A zero-offset VSP and two walkaway VSPs recorded the data around the center of the survey area. The integration of surface seismic and borehole geophysical data was vital to ensure that all steps in the processing sequence, from digital group forming through to the final migrated stack, were optimally calibrated utilizing some of the latest

![Impact of aliasing on frequency bandwidth. A test conducted with a 16-m receiver array displays aliasing of ground roll and airwave because of the wrap-around effect seen in the frequency-wavenumber (fk) domain (left). The airwave (solid black line) is completely aliased. However, the ground-roll noise (dashed black line) is folded back into the signal frequency band above the frequency where the dashed lines intersect. The signal, which is expected to dominate the central area of the fk plot as k approaches zero, becomes contaminated. This means that data-adaptive spatial filtering can no longer remove the coherent noise without damage to the signal. The usable frequency bandwidth for AVO processing, for example, is substantially reduced for conventional array data because aliasing distorts the higher frequencies in both amplitude and phase. In contrast to this, point-receiver data clearly show an unaliased response that permits processing of the entire useful frequency range without coherent noise contamination (right). (Data courtesy of Shell.)](image-url)
developments in the Well-Driven Seismic process. Restoration of true amplitude and phase, effective multiple suppression and compensation for frequency absorption with depth provided superior imaging and resolution (above).

The zero-offset VSPs at two control wells, an injector and a producer, resolved seven intra-reservoir zones. Conventional seismic data, with a frequency bandwidth of 10 to 45 Hz, showed only three of these events, which led to a flawed interpretation that there were no obstructions between the two wells and injected fluids could flow freely between two wells. The Q-Land volume imaged the same seven intrareservoir zones seen on the VSPs. The enhanced resolution from Q-Land data, with a frequency bandwidth of 6 to 70 Hz, enabled the seismic interpreters to map stratigraphic features. Also identified were tar mats at the injector well that act as baffles and inhibit fluid movement. In addition, minor faults and deeper gas targets obscured by interbed multiples energy were now imaged.

Encouraged by the results of this Q-Land pilot study, the operator is in the process of planning a full-field survey using the Q-Land system. Plans to reevaluate pore pressure and fracture characterization incorporating the new Q-Land data are also under consideration.

The Seismic Challenge in Algeria
An oil field in Algeria, known to be one of the most seismically challenging fields in the world, was selected for a Q-land study. Since the discovery of this field in the 1950s, many wells have been drilled. Oil and gas production is mainly from Cambro-Ordovician fluvimarine, clastic reservoirs. Despite the large number of wells drilled, abrupt changes in lithology and fault compartmentalization have made full-field reservoir characterization from well data alone difficult. Few seismic surveys have been attempted in the past because of a poor seismic response and fault characterization from well data alone difficult. Few seismic surveys have been attempted in the past because of a poor seismic response and failure to image the reservoir zones. As a result, reservoir zones were identified from petrophysical and pressure data. In addition, a weak correlation between well log and core permeability indicated that the permeability could be strongly influenced by fractures.

There are several geophysical and geological challenges. The main producing reservoir, a braided-channel fluvial system, has a highly heterogeneous distribution of sand and shale. The oil field has also been affected by multiple episodes of fault deformation and reactivation, resulting in complex fault and fracture patterns that are difficult to image. Added to these problems, a small velocity and density contrast at the top of the reservoir and within the reservoir units makes detection of reservoir units difficult. In addition, the influence of strong interbed multiples obscures the signal, and the presence of a thick evaporite layer above the reservoir causes severe attenuation of higher frequencies, resulting in a poor signal-to-noise ratio. All these problems lead to a poor tie to wells, making it extremely difficult to map the interwell region.

Typically, the maximum usable frequency obtained from the target reservoir has been around 35 to 40 Hz. This translates into a maximum vertical resolution of 40 m [131 ft]. However, mapping the reservoir units with any degree of confidence requires a vertical resolution of less than 20 m and much lower noise levels.


A pilot survey with the Q-Land system was initiated to address these geophysical and geological challenges. Integration of borehole-seismic data and surface-seismic data was planned at the onset of the project, and the acquisition parameters were optimized through presurvey planning and testing.

Q-Land seismic data were acquired over an area covering 44 km² [17 mi²], with a dense grid of sensors, equating to a density of 20,000 sensors per km². Borehole geophysical data included measurements of zero-offset VSP, a two-dimensional (2D) walkaway VSP using the VSI Versatile Seismic Imager with 154 geophone positions in the borehole, and sonic measurements using the DSI Dipole Shear Sonic Imager. The Q-Borehole seismic system aided in Well-Driven Seismic processing.

The surface-seismic processing results were compared with well data at key stages in the processing sequence, so that the processing parameters were optimized to tie the final seismic data to the wells. The bandwidth obtained ranged from 6 Hz to 80 Hz, nearly double the previously recorded high-resolution 2D seismic results. For the first time, the frequency resolution obtained from surface seismic data matched that obtained from a VSP, providing an excellent well tie (below).

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*Figures:

- A Q-Land example from Algeria. Exceptional resolution (frequencies above 80 Hz) was obtained with the Q-Land survey (top right), in which the frequency bandwidth has nearly doubled in comparison to a high-resolution 2D survey (top left). In addition, the excellent match between the vertical seismic profile (VSP) data (shown within the red box, bottom) and Q-Land data will permit advanced reservoir characterization studies. (Data courtesy of Sonatrach.)*
Seismic amplitude was inverted to compute absolute acoustic impedance (AI) volume (above). Low AI correlates reasonably well with high-porosity sands. At 80-Hz frequency, for an interval velocity of about 4,500 m/s [14,765 ft/s], this low AI zone equates to a thickness resolution of about 14 m [46 ft]. This degree of resolution has never been achieved in this geological environment.

To assess the relationship between permeability and fault proximity, which is generally associated with higher fracture density, several seismic attributes were computed.

Extraction of fractures and faults from the seismic data involved several steps. Seismic attribute cubes that enhance discontinuities in the data, also known as edge-enhancing attributes, were computed. The edge-detection seismic volumes include variance, dip and deviation. The ant-tracking algorithm was then applied to the edge-detection cube to highlight the discontinuities in the seismic data, and to map faults and fractures.20 Distance to fault (DTF) attributes were then generated from filtered sets of faults from the ant-track cube and mapped into the 3D geocellular grid (next page).

The DTF attribute helps identify zones that are highly fractured. A crossplot between permeability and DTF confirms the trend: higher well log permeability when close to faults. A strong inverse relationship between core permeability and DTF was observed on about 70% of wells.

However, to answer questions about whether those fractures and small-scale faults enhance or degrade permeability, grid cells were extracted in the vicinity of seismic faults with greater length, that is, those that intercept both basement and the overlying Hercynian unconformity. Seismic acoustic impedance was then mapped into these cells to discriminate between sealing and draining faults. A high cell-average acoustic impedance in the vicinity of a fault suggests that the fractures act as flow barriers, because the fractures were cemented with pyrite or shale. Conversely, a low acoustic impedance in the vicinity of a fault suggests a higher proportion of open, fluid-filled fractures, which have lower density than rock. This may suggest that tectonically induced fractures enhance draining of hydrocarbon.

Wells are continually being drilled in this area, and additional drilling is planned in 2006 guided by the interpretation results of the Q-Land data.

**Toward Fit-For-Purpose Seismic Data**

The fundamentally improved measurements delivered by Q-Land technology radically expand the potential of seismic data. With the lower noise associated with single-sensor acquisition and processing, and the ability to correct for perturbations within a group, array design and fold are no longer the dominant factors in improving signal-to-noise ratio. Rather, sensor spacing and a requirement to adequately sample coherent noise become the main drivers in designing the acquisition geometry. Since it is now possible to record a signal more faithfully, the vibrator source can also be reevaluated, making it possible to record shorter, single sweeps of frequency with a better sampling of the wavefield.

These design considerations now offer the possibility of acquiring point-source and point-receiver exploration surveys with a lower field effort, compared with equivalent surveys using conventional source and receiver arrays. The Q-Land surveys acquired to date suggest that the use of smaller groups of vibrators can provide data that are equal to or better than larger arrays of vibrators and geophones. Smaller groups of vibrators allow for more efficient operation. The Q-Land VIVID imaging services enhance the value of seismic data recorded throughout the life of a field. In the exploration phase, the low-noise Q-Land data make it possible to acquire high-quality seismic surveys with wider line spacing and lower fold than a survey acquired with conventional technology and still meet or exceed the imaging expectations. In subsequent surveys for appraisal or development, it is possible to acquire the data by interleaving lines between the previous surveys to build up the fold. The data from the original surveys and the current survey are processed together using

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20. The ant-tracking algorithm delineates discontinuities in a seismic cube and maps faults and fractures. The algorithm tracks discontinuities built upon previous knowledge, mimicking the behavior of ants when they find the shortest path between their nest and their food source. The ants communicate using pheromones, a chemical substance that attracts other ants. Therefore, the shortest path to the food source will be marked with more pheromones than the longest path, so the next ant is more likely to choose the shortest route, and so on. The idea is to distribute a large number of these electronic “ants” in a seismic volume. Ants deployed along a fault should be able to trace the fault surface for some distance before being terminated. The algorithm then automatically extracts the result as a set of fault patches, a highly detailed mapping of discontinuities. Fault discrimination is based on the size of the fault, its orientation, and on the amplitude of vertical displacement. For more on ant tracking: Pedersen SI, Randen T, Sanneland L and Steen Ø: “Automatic Fault Extraction Using Artificial Ants,” Expanded Abstracts, 2002 SEG International Exposition and 72nd Annual Meeting, Salt Lake City, Utah, USA (October 6–11, 2002): 512–515.
the required group interval to image the target correctly. This is the concept of uncommitted seismic data for the life of a field.

Exploration leads can be pursued during the same survey. This results in a lower cumulative environmental footprint of the overall seismic program, in addition to reduced development time. As the data have a high signal-to-noise ratio and fidelity, they can be reused at each stage of a field’s development, ensuring that the exploration investment is not lost.

With unsurpassed seismic data quality and a versatile approach to acquisition geometry and innovations in processing, the Q-Land acquisition and processing system will have a major impact on the life of the field, in exploration, development and reservoir monitoring. —RG