The seismic method has been used in the exploration business since the early 1920s. Since then there has been a dramatic increase in the number of measurements acquired. Despite continuous growth in computer processing capacity and affordability, several assumptions and approximations often have been required for the practical application of processing algorithms in seismic imaging.

The integral summation method proposed by Kirchhoff in the 19th century is widely used in the process of “migration,” which focuses seismic reflection energy and positions it in the correct location in space and time or depth. Prestack time migration (PSTM) has become a standard stage processing; however, it assumes that the downgoing and upgoing ray paths from subsurface reflections are symmetrical. In complex geological environments such as thrust belt regions, there are likely to be steeply dipping reflectors and complex nonsymmetrical raypaths.

Advances in computer hardware and software in the last decade have allowed many processing shortcuts and approximations to be reduced. Processes that have now become viable for application to large 3-D datasets include prestack depth migration (PSDM), which overcomes the assumption of symmetry in PSTM.

A 3-D seismic survey was acquired using an ultra-high channel point-receiver recording system and broadband source in a difficult geological and logistical environment in a structural exploration play at the edge of the prolific oil-prone Arabian plate. This play extends from the United Arab Emirates (UAE) through to Oman, where the stable Arabian plate was deformed by the Late Cretaceous orogeny, resulting in structurally controlled traps. During this time the allochthonous Semail Ophiolite and Hawasina Complex were emplaced into the survey along thrust faults. As a result, imbricate layers of fast- and slow-velocity material with dips up to approximately 60° project up to just below a low-velocity surface layer of sand. Further compressional deformation occurred in the Miocene to Oligocene with the collision of Arabia and Eurasia. An advanced processing sequence was applied to the data, including PSDM.

**Point-source and point-receiver acquisition**

The advent of ultra-high count continuous recording systems and new coherent noise removal techniques allows great flexibility in designing full-azimuth survey geometries that deliver optimal noise attenuation and dense sampling of the seismic signal. The WesternGeco UniQ integrated point-receiver land seismic system is capable of supporting more than 200,000 live channels. High-channel capability enables the recording of long-offset, full-azimuth point-receiver data at high trace densities.

In addition to high-fidelity measurement of the upcoming seismic wavefield, dense sampling of various types of coherent noise enables it to be effectively removed or analyzed to provide additional subsurface information.
information. A survey design study considered how to meet the geophysical objectives of the UAE survey while maximizing acquisition productivity, and potential methods were modeled to determine the most cost-effective solution. As a result of this modeling, it was decided to deploy only 40,000 channels for efficient recording. The data were acquired with single 80,000-lb ft vibrators using a special Vibroseis sweep to generate useful energy below 6 Hz. Sweep time was 18 sec with listening time of 6 sec. The spacing between source and receiver lines was 200 m (656 ft). The sampling interval along source and receiver lines was 12.5 m (41 ft).

The use of source productivity enhancement techniques enabled the shooting of the required number of vibrator points (VPs) within the two-month period planned for the survey. These techniques are used to allow a vibrator to start its sweep before the end of the sweep and listening time of another vibrator while minimizing interference between the two in the recorded data. The managed spread and source technique is based around optimizing the sequence of acquisition of vibrators that are in position and ready to record with certain rules. These rules include that vibrators must be separated by a minimum distance, sweep times must be separated by a minimum time interval, and the appropriate receiver spread must be available. Implementation of the rules is managed automatically with no operator intervention.

Vibrators were distributed across the block both north and south of the spread. Each vibrator moved up at its own speed, so the sequence that the vibrators were shooting was a random pattern. This random sequence ensured that interference crosstalk and harmonic energy were random and of different energy levels in the common receiver direction and hence could be readily attenuated in processing. Figure 1 shows an example of data with interference from other vibrators before and after attenuation of this noise.

Data processing
Surface wave propagation across the near surface was complex, with multiple modes and large lateral velocity variations generating both direct and scattered noise with significantly higher amplitudes than the desired signal. Simultaneous shooting introduced source interference noise. The signal-to-noise ratio of the individual seismic traces was low, so a careful and targeted approach to noise attenuation was required to avoid damaging signal.

Noise attenuation was followed by a signal processing sequence that included surface-consistent processing and iterations of time-domain velocity picking and residual statics. A robust algorithm was applied that combines robust surface-consistent deconvolution, surface-consistent amplitude correction, and noise attenuation in one pass to provide relative amplitude preserved data.

Near-surface characterization
The near surface on top of which the sources and receivers are placed has a large influence since it introduces travel-time variations between receivers and VPs. Accurate definition of the shallow velocity structure is a key step for onshore PSDM and reliable extraction of rock properties from the imaged data. The surface of the survey area is characterized by sand dunes and outcropping formations. The near surface is complex, with steeply dipping layers, faults, extreme lateral and vertical velocity variations, and vertical velocity inversions. Because of this complexity, the refraction layer-based solutions normally used would be inaccurate.

A new methodology was used to unravel the near surface and produce a detailed velocity model from which time corrections (“statics”) could be derived. The method was based on analysis of the surface-waves analysis and inversion to a geologically consistent near-surface velocity model. This was integrated and validated using other near-surface data such as analysis of refractions and upholes. Figure 2 is an example of stacked data before and after application of the model-based statics.

**FIGURE 2.** In this example of a shallow-stack section the top panel has basic elevation statics applied. The bottom panel has model-based statics. The shallow velocity model is shown in the middle panel.
Imaging

To be able to position reflections accurately in 3-D space requires an accurate 3-D velocity model of the subsurface, development of which is performed in an iterative approach using several imaging techniques of increasing fidelity. For this survey, the imaging process started with Kirchhoff PSTM and then moved to Kirchhoff PSDM before finally incorporating a migration algorithm using the most exact solution to the 3-D wave equation modeling for both upgoing and downgoing wavefields called reverse time migration (RTM). Time migration positions data in space and time \((x, y, \text{ and } t)\), while depth migration and RTM place the events in 3-D space \((x, y, \text{ and } z)\).

The initial velocity model, used as a starting point, was a long scale-length representation of the geologic model (Figure 3). It was built using two wells within the survey area plus information from three wells located slightly outside the survey boundaries. The two wells inside the project area clearly delineated the high-velocity carbonates present in the allochthon and also indicated the slow-velocity Lower Aruma shale located between the allochthon and deeper Thamama carbonate. The well located outside the eastern edge of the survey contained the allochthonous Semail Ophiolite.

The two wells to the west and northwest of the survey indicated an absence of fast-velocity carbonates normally found in the allochthon and had slower velocities down to the Thamama, suggesting that the western edge of the allochthon was close to the western edge of the survey. Between well locations, the initial model was derived from velocity analysis on PSTM data. An interpretive approach was used and was closely guided by the well velocities, preliminary interpretations of the allochthon, and indicators from nonseismic data (gravity).

The velocity model was updated using multiple iterations of cell-based common image point tomography, starting by targeting shallow zones above the fast-velocity carbonates and then extending down to update the entire model. Each iteration output PSDM gathered data using the latest velocity model. Analysis of the gathers identified where and how the model should be updated. In such a complex geologic setting with interbedded shaley sediments and carbonates, anisotropy plays an important role in the imaging. Because of the significant dips across the survey area, tilted transverse isotropy was built into the velocity model.

As expected in an area of complex geology, the final RTM 3-D volume shows improvement in event continuity and focusing compared to the equivalent field brute stack and PSTM volumes (Figure 4). Imaging directly into the depth domain has enabled a revised and more accurate geological model of the survey area.

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