Integrated Seismic Solution Delivers Unparalleled Imaging of Complex Strata for Crescent Petroleum

UniQ high-density 3D acquisition system and advanced depth processing successfully image complex thrust-belt geology in UAE

CHALLENGE

To image deep carbonates in a complex thrust-belt geology where steep dips and strong velocity heterogeneity render conventional seismic imaging ineffective.

SOLUTION

Integrated survey design, acquisition, and processing solution using the UniQ* integrated point-receiver land seismic system, surface wave modeling and inversion, tilted transverse isotropy (TTI) reverse time migration (RTM), and depth imaging.

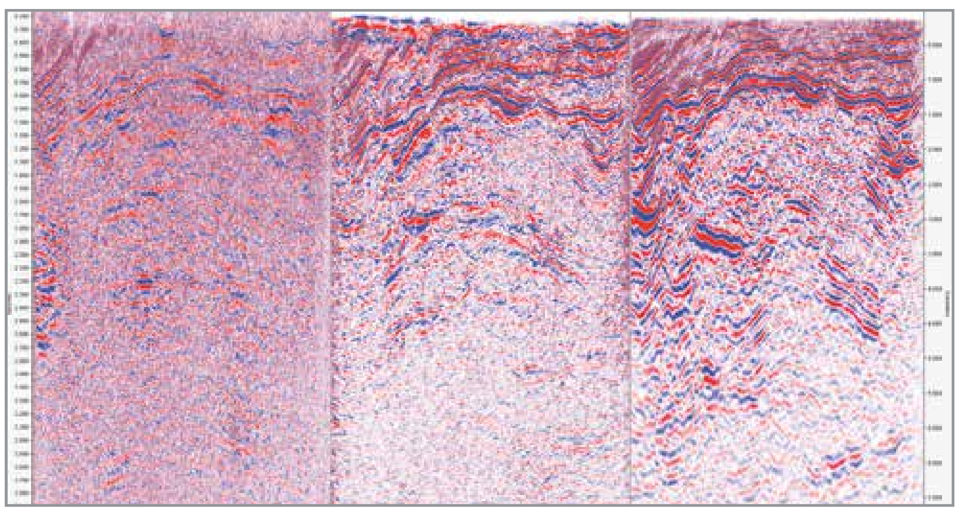
RESULTS

Subsurface detail, never previously imaged, was revealed within a complex over-thrust zone.

Complex carbonate geology requires an integrated approach

The objective of this 2011 3D seismic survey conducted in the United Arab Emirates was to image a carbonate formation in an exploration environment at a depth of 3,200 m to 3,600 m. The surface geology is characterized by varying thicknesses of sand dunes and rock outcrops underlain by an over-thrusted sequence of sediments with steep dips in all directions resulting in strong lateral velocity variations.

Complex near-surface and geological structure required an integrated design, acquisition, and processing approach. The decision was made to acquire a full-azimuth, symmetrically-sampled point-source, point-receiver 3D seismic survey to provide better noise suppression and improved illumination and imaging.



TTI anisotropic velocity model and depth migration reveal previously unseen structural detail. Brute stack (left). Prestack time migration (center). RTM prestack depth migration (right).

Recording duration and project cost minimized

A UniQ integrated point-receiver land seismic system with 40,000 broadband point-receiver channels was used in combination with the MSS* managed spread and source high-productivity simultaneous source technique. The MSS technique uses source timing and distance rules to optimize the acquisition sequence while managing interference noise to maintain signal quality in a time and offset-defined "data protection zone" surrounding the target horizons. This combination enabled efficient block-spanning, super-spread recording, which minimized recording duration and project cost. During acquisition, daily production peaked at over 10,000 vibrator points per day.

With complex, steeply dipping structures, careful consideration needs to be given to both spatial sampling and offsets coverage to ensure full capture of diffraction energy and to prevent aliasing of events and of the migration operator. Despite a nominal target depth of 4 km, extra-long offsets up to 6.5 km were required to ensure capture of all the reflected energy.

Point-source and point-receiver spacing of 12.5 m allowed recording of noise either unaliased or mildly aliased, which could then be removed in subsequent processing using an FX least-squares minimization routine that does not require regularly sampled data. This “non-uniform” noise suppression was important as the terrain and man-made obstacles led to considerable irregularities in the geometry.

Broadband data enables creation of complex anisotropic velocity models from surface

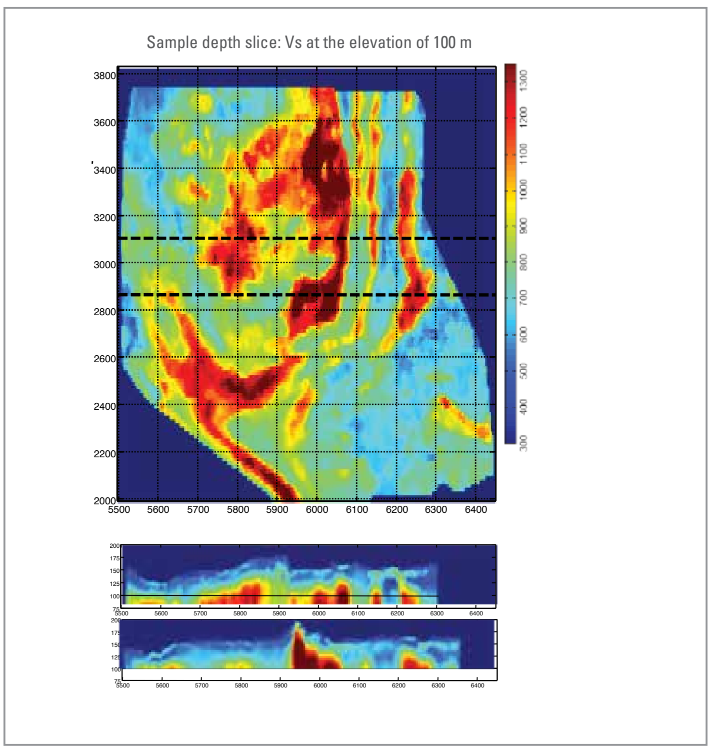
The near surface was very inhomogeneous with sand dunes resulting in short period lateral velocity and elevation changes. The dense point receiver spatial sampling employed by the UniQ system enables the recording of unaliased ground roll, while the broadband sensors capture deeply penetrating low frequency energy.

These data were used to produce a detailed near-surface velocity model via shear-wave inversion. The survey used a custom low-frequency enhanced vibroseis sweep (3.5 Hz at -3 dB) producing an investigation depth that consistently reached down to 100 m. The shear volume was converted to P-wave velocity via calibration with uphole data and used in subsequent statics and velocity modeling.

The steep dips and strong velocity heterogeneity resulted in complex wave propagation and required advanced prestack depth migration (PSDM) for successful imaging.

A velocity model was created that incorporated the near surface model plus anisotropic tilted TTI elements to accommodate the geologic complexity. Final imaging was performed using RTM. Input data were shot organized without regularization so that accurate source and receiver point coordinates were fully honored.

An integrated approach to seismic survey design, acquisition, and processing is required to successfully image areas of complex geology. This case study demonstrates that only through a combination of state-of-the-art technologies, including broad-bandwidth source and sensors, high-productivity acquisition, advanced noise attenuation, detailed near-surface characterization, and accurate prestack depth imaging, were structural details, previously considered impossible to image, revealed for the first time.



Broadband point-receivers recorded low-frequency surface wave energy which was used to build an accurate near-surface velocity model using the SWAMI surface wave analysis, modeling, and inversion technique.*

No of channels per line	1,056
No of active lines	33
Spread type	1 line roll symmetric split spread–66 line emulation
Nominal channels live	34,848[†]
Receiver interval	12.5 m
Receiver line interval	200 m
Source interval	12.5 m
Source line interval	200 m
Nominal fold 6.25 m x 6.25 m bins	1,089
Source repeat factor	2
Roll factor VP per receiver	2

[†] Up to 40,000 channels were live during acquisition to account for the super-spread required to shoot the survey effectively.

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*Mark of Schlumberger