

PEERING INTO THE PERMIAN

TREVOR COULMAN, RON KENNY, SUE REZAI, ALAIN VIAU, AND OLIVIER WINTER, CGG, REVIEW AN INTEGRATED PROJECT IN THE PERMIAN BASIN INVOLVING DATA ACQUISITION, IMAGING, RESERVOIR CHARACTERISATION, AND INTERPRETATION.

When faced with complex geology in today's challenging market, advanced seismic imaging offers a cost-effective method for thoroughly assessing and planning exploration before engaging the drill bit. However, due to the large surface acquisition spreads required to best image the subsurface, it is difficult to justify the cost of proprietary seismic surveys over some US onshore areas that can be a mosaic of small fragmented lease areas. Multi-client seismic surveys offer a solution to mutualise the cost of seismic where mineral acreage is leased or operated by several companies. In addition, a full reservoir optimisation package offers an integrated geoscience solution, including reservoir characterisation studies of elastic rock properties, fracture information and lithological volumes, which can provide a better understanding of the formations where the horizontal drilling targets are located.

Figure 1. Pumpjack amidst cotton flowers east of Andrews, TX, © User: Zorin09/Wikimedia Commons/CC-BY-SA-3.0.

Selected oil-producing formations in the Permian Basin

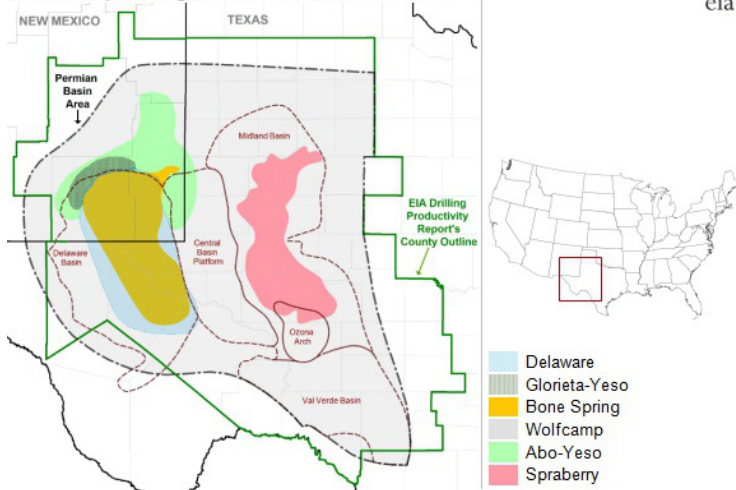


Figure 2. Map of the Permian Basin, source: U.S. Energy Information Administration.

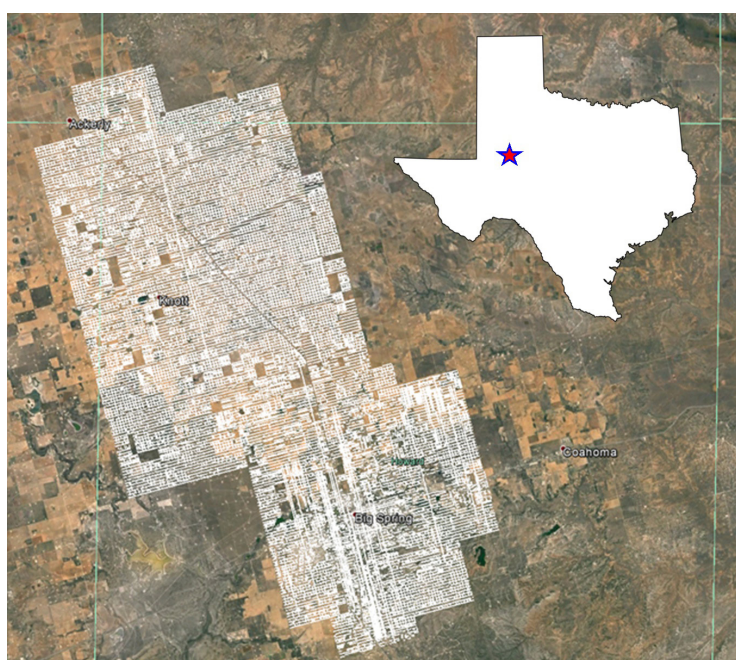


Figure 3. Hobo 3D survey position map.

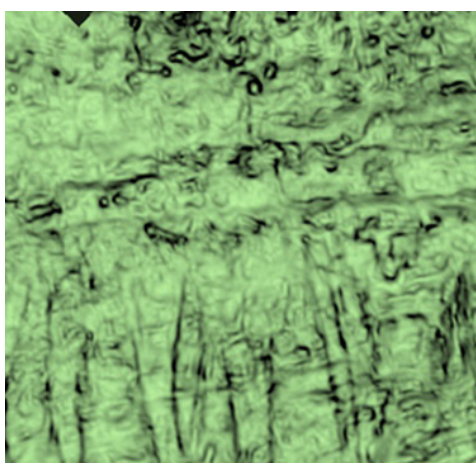


Figure 4. Linear canyons incised into the slope of the Eastern Shelf, forming a basinward conduit for sediment deposition. Note also the sinuous channels resulting from that transport.



This article presents a case history of a multi-client project in The Permian Basin, West Texas, which spanned seismic, acquisition, imaging, and reservoir interpretation.

Introduction

The Permian Basin stretches across more than 50 counties and 86 000 square miles in the states of Texas and New Mexico. From west to east it breaks down into the Delaware Basin, the Central Basin Platform and the Midland Basin (Figure 2). CGG’s Hobo 3D multi-client survey, a project covering 342 square miles, is located in the latter. 20 miles to the East, Westbrook, in Mitchell County, is the site of the first oil production well in West Texas, dating back to 1921. Since then, the Eastern Shelf Permian Carbonates have produced conventional oil. In the mid-2000s, the shale boom dramatically augmented conventional production. In the Midland Basin, fracking methods and horizontal drilling targeted the Spraberry formation and later the Wolfcamp.

A decade later, the market adjusted sharply to overinflated supply and stagnant demand. The oil price tanked, investments in exploration and production collapsed; the industry experienced the longest downturn since the 1980s. Oil companies refocused on plays providing the lowest break-even prices, which meant ruling out most shale plays in favour of resilient and economical onshore ‘super fields’ in the Middle East.

Unlike many other shale plays, the Permian Basin has the potential to produce at low cost and the area is still deemed to have high potential, given its vast reserves. A publicly available report published by the USGS in November 2016 estimates mean recoverable resources from the Permian at 20 billion bbls of oil and 16 trillion ft³ of gas. This represents ~US\$1 trillion using January 2017 oil and gas prices as a reference. The basin has seen a mini-investment boom since May 2016 and as of early 2017, it remains one of the few active shale plays in the United States.

Project presentation/reservoir-oriented survey design

Located in Howard, Borden and Martin counties (Figure 3), the Hobo survey expands CGG’s Permian Basin multi-client 3D data library as part of the company’s strategy to offer the industry ultramodern high-quality seismic data in high-potential locations. Tying the seismic to the geology of a full reservoir optimisation package will enable a better understanding of the target Spraberry and Wolfcamp formations. The scope of the survey includes survey planning, seismic acquisition, seismic imaging and quantitative interpretation. Full completion will take over 18 months. Seismic acquisition began in January 2016; a year later, seismic imaging is complete and the final processed time volumes (Orthorhombic Kirchhoff PreSTM) are available for license. The reservoir characterisation and interpretation is ongoing at the time of writing and should be available in July 2017. This article will focus mainly on the acquisition and imaging results.

The Spraberry and Wolfcamp formations are commonly referred to as the Wolfberry play (see stratigraphy in Table 1). The depth of the zone of interest ranges from 6000 to 8000 ft, which corresponds roughly to 1.1 to 1.5 seconds in seismic time. The geology is far from simple as the survey spans

the Eastern Shelf of the Basin in the east and the Horseshoe Atoll in the north. An example of canyons on the Eastern Shelf is presented in Figure 4. One significant challenge is the Middle Permian Clearfork Formation, a mixture of carbonates, evaporites and red bed above the target, which causes both reflection and absorption of seismic energy and therefore requires careful selection of the right acquisition and processing techniques. These effects were particularly prevalent in the northern part of the survey closer to the atoll.

Achieving optimal data at the reservoir level required careful geophysical, as well as operational, planning. The survey covers a variety of terrains including agricultural and urban areas, which create specific challenges to seismic acquisition. These have to be balanced against acquiring the right data for use in reservoir characterisation and accurate imaging of the target. By managing the whole project and involving reservoir and imaging experts, as well as operational acquisition experts, in the initial planning stages it was possible to tailor the acquisition to the reservoir requirements and make a real difference to the quality of the final results.

In order to ensure optimal illumination of the target, ray tracing through a velocity profile extracted from a well log was performed prior to acquisition. To image structural features

accurately and achieve the 40° pre-stack angle of incidence at a depth of 7500 ft required for azimuthal inversion, full azimuth offsets of 14 000 ft are necessary, which was why an offset aspect ratio of 0.9 was selected (see rose plot in Figure 5). The line spacings were selected by setting a minimum fold at the Yates Formation. Point spacings were selected according to the Fresnel Zone at the shallowest targets and the maximum frequency expected at these levels.

Sweep testing was conducted and as there was evidence of useful signal down to 3 Hz, a broadband 3 - 96 Hz sweep was retained, with a non-linear start to build up the low frequencies with reduced force. These low frequencies allow quantitative seismic reservoir characterisation with less reliance on an *a priori* model for more accurate and unbiased results. For optimal operations, the sources were vibrating simultaneously using dynamic slip-sweep, whereby the delay between consecutive vibrations was adjusted to suit the number of working groups.

Acquisition planning

Acquiring seismic data on privately owned land requires a permitting effort that is both time-consuming and expensive. In the United States, surface estate ownership is often severed from mineral estate ownership. Failure to obtain an approved permit from either estate owner - surface or mineral - will result in an acquisition exclusion zone. CGG has experience of acquiring such permits and negotiating with landowners to ensure minimal disruption of either agricultural activities or leaseholder's operations during acquisition without unduly compromising the seismic data. The Hobo 3D project area consisted of many farm fields planted with cotton (Figure 1), as well as the city of Big Spring, a heavily developed urban area that posed both operational and geophysical challenges.

Farmland acquisition

Operating on cotton-cultivated land imposes a narrow seasonal window for seismic operations. Ploughing began at the end of February into early March (Figure 7). This was followed by seeding later in the spring, with the landowner sometimes only granting access for all seismic operations to be completed (and equipment removed) between January and the end of March. Occasionally, access was negotiated on a case-by-case basis across ploughed fields. In several instances, a mutual agreement was reached by aligning the survey to traverse the field in the same direction as the listed furrows.

Infilling with source lines aligned with the receiver lines was considered as the only practical way to build up near-offset fold over the area, in spite of it being a known recipe for fold striping and irregularities in the migration operator summation. However, 5D interpolation was able to regularise the data. This technique uses interpolation dimensions selected for the particular situation (e.g. inline, crossline, offset, azimuth and frequency) to infill gaps, increase fold and improve offset-azimuth distribution. Therefore, the parallel shot lines were acquired to help provide supporting data for the regularisation, rather than leaving a large hole in the acquisition, which could not be interpolated.

Making this decision required coordinating the processing know-how with the acquisition constraints to

Table 1. Stratigraphy of the Midland Basin; the Wolfberry play is in the lower formations.

PERIOD	SERIES	FORMATION
GUADALUPIAN	White Horse	Tansill
		Yates
		7 Rivers
		Queen
		Grayburg
	Ward	San Andres
		Glorieta
LEONARD	Clear Fork	Upper Leonard
	Upper Spraberry	
	Lower Spraberry	
	Dean	
WOLFCAMP		
PENNSYLVANIAN		

Receiver Line Interval (ft)	750
Receiver Interval (ft)	150
Source Line Interval (ft)	750
Source Interval (ft)	150
Patch Size	34 x 190
Fold	323
Inline Offset (ft)	14175
Crossline Offset (ft)	12675
Maximum Offset (ft)	19015

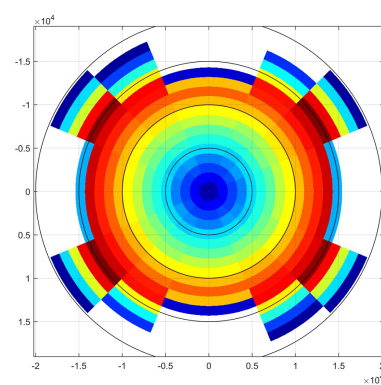


Figure 5. Wide-azimuth acquisition parameters and rose plot.

come up with a plan to meet the challenge of acquiring the survey with the optimal acquisition geometry. The 5D interpolation algorithms were proofed prior to acquiring the shots, and the imaging team was informed of the possibility of fold striping. Figure 7a shows the position of sources (red) and receivers (blue) as acquired. The unmigrated crossline shows the striping, which creates artifacts after migration. Figure 7b shows the result that would have been achieved by 5D interpolation had the parallel infill source lines not been acquired. The interpolation gives good results in the vicinity of the existing data but cannot fill the gap where no support data is available. Figure 7c shows the 5D interpolation using the full dataset, where the infill shot lines are used as support data to interpolate across the gap. Acquiring those shot lines in the farmer's ploughing direction proves harmful for non-regularised migration algorithms. However, as support data for 5D regularisation they allowed the recovery of shallow data and accurate images and amplitudes in the target zone below those ploughed fields, which would not otherwise have been possible.

Urban area acquisition

The seismic vibrators weigh over 65 000 lbs each and develop a force of approximately 270 kN. The International Association of Geophysical Contractors (IAGC) has published guidelines for safe operating distances and energy buffer zones around cultivated farmland and infrastructure. To ensure an additional layer of protection from potential damage in built-up areas, the use of third party contractors and equipment is required to monitor and record the three-dimensional peak particle velocity (PPV) on the nearest piece of infrastructure to each vibrator group. A predetermined velocity threshold was tested and then used as a reference. When PPV was reached, the drive levels of the vibrators were reduced.

Using real time feedback from the monitoring results, the force radiated was dynamically adapted from two vibrators driving at 70% of force down to two vibrators driving at 30%, using 10% incremental reductions. The lowest energy setting is more than 10 dB lower than the original setting.

Acquiring data in urban areas presents many challenges. Throughout most of the survey, recording sensors were buried beneath the surface as close as possible to the surveyed receiver location. However, this was not possible within the city limits where there is concrete everywhere. For these locations, sensors were buried in sandbags and positioned on the ground (Figure 8). Many source and receiver locations in urban areas have to be skipped because of infrastructure and the constant buzz of activity, which creates ambient noise. Figure 9 shows an example of the impact of the reduced source energy, poorer geophone coupling and higher noise levels on the raw shot data quality when acquired in the city.

To mitigate this issue, a higher spatial trace density was acquired in the area, with roughly twice as many shot records acquired at half the line interval. Figure 10 displays a line crossing an urban area, and although the middle area has a lower signal-to-noise ratio, the image and prestack gathers are still suitable for quantitative interpretation.



Figure 6. Vibrator group acquiring in a ploughed field.

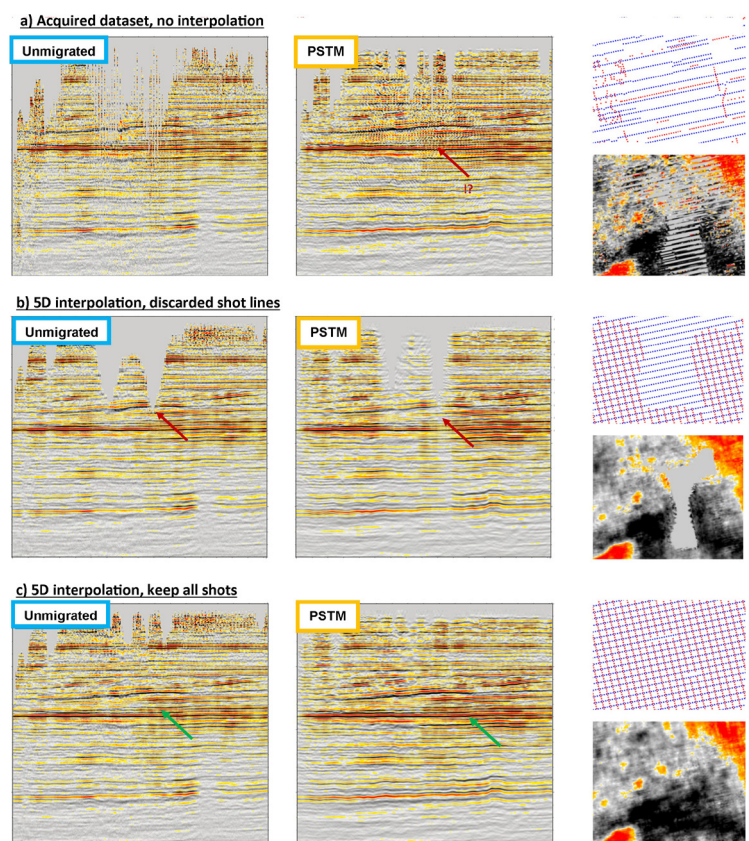


Figure 7. Leveraging 5D interpolation when making field decisions.



Figure 8. Urban receiver: node unit with geophone spike stuck into sandbag.

Processing

For the Wolfcamp and Spraberry targets, petrophysical work and isotropic inversion will provide attributes to qualify geological facies (e.g. porosity and clay volume), and azimuthal inversion will yield anisotropy (fracture) density and orientation, which is useful for effective well planning. The seismic processing

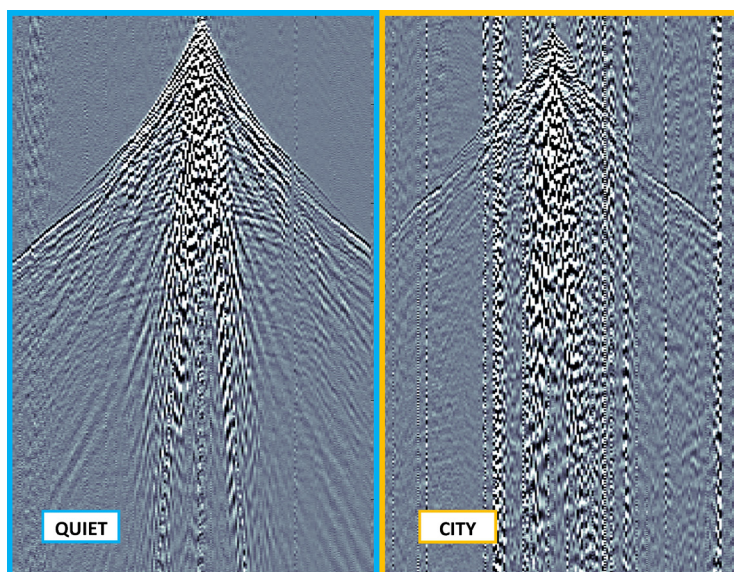


Figure 9. Near cable for shot point in a quiet area (left) and urban area (right).

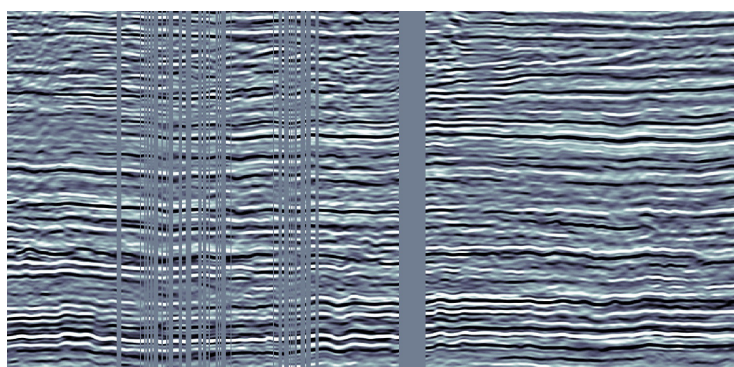


Figure 10. Arbitrary line going through an urban area (vertical gray stripes are no permits).

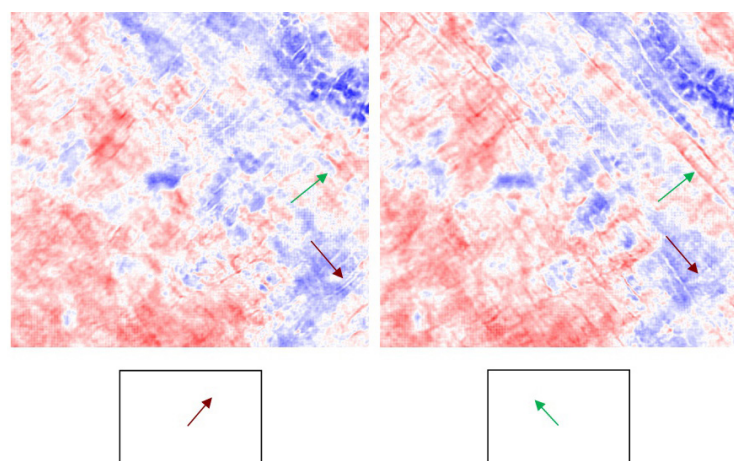


Figure 11. The case for wide-azimuth imaging: RMS time slice through Offset Vector Tile volumes shows the delineation of the geological features' dependency on azimuth.

sequence used has therefore been optimised to deliver seismic data that is ideally suited for this reservoir characterisation with state-of-the-art amplitude-preserved imaging that honours the orthorhombic anisotropy.

The first pass of statics is derived from a tomography model of the near-surface using first-arrival times. The surface wave noise, 'ground roll', is adaptively removed using local spatial transforms with true x,y coordinates. A surface consistency constraint is applied on scaling, deconvolution and residual statics computation. Prior to migration, the data is 5D-interpolated onto a denser grid to provide uniform-offset-vector tiles (OVT) for the migration. An example of a section before and after interpolation is shown in Figure 8. The imaging is an orthorhombic Kirchhoff prestack time migration (PSTM).

Offset-vector-tile sorting is the workhorse of azimuthally-preserved amplitude processing. After migration, each OVT contains a full single-fold volume that has a unique source-to-receiver 'vector', i.e. a unique offset and azimuth. Figure 11 demonstrates the sensitivity of each OVT to the orientation of geological features. By imaging in the OVT domain, using orthorhombic Kirchhoff pre-stack time migration, all amplitude variations with offset and azimuth (AVO and AVA) are preserved in the pre-stack gathers. This delivers ideal data for reservoir characterisation and quantitative interpretation.

The way forward

The Hobo 3D survey was acquired and processed using state-of-the-art seismic technology, suited to resolve the above and below ground complexities onshore United States. Advanced 5D interpolation and sophisticated noise attenuation techniques were successfully employed to address the challenges of acquiring data in urban areas and farmland. The processing sequence was specifically designed to provide optimal data for quantitative interpretation, by honouring the anisotropy and preserving all AVO and AVA information. Work on this aspect of the reservoir optimisation package, including petrophysics, quantitative interpretation, geomechanics, geochemistry and mineralogy is ongoing and is expected to be completed in July 2017.

Mineralogy studies on core samples, using CGG's RoqScan™ rock properties analyser, plug directly into petrophysical model building. The petrophysical work serves as a basis for the geomechanical and geochemistry analysis at the wells. The petrophysical model is being combined with the seismic for an isotropic AVA inversion, followed by an anisotropic AVAz inversion calibrated with geomechanics at the well locations. This will provide details of the brittleness, fracture orientation, and stresses in the reservoir.

By using the inverted volumes, elastic, mechanical, and mineralogical attributes can be inferred away from the well and propagated through the 3D seismic volume, to obtain useful indicators for the production engineer, geologist, geomodeller or petrophysicist. CGG's vision is to assess and predict well performance using rock properties derived from 3D seismic as part of a complete integrated reservoir optimisation package that enables companies to optimise their well planning and completions while minimising risk. ■