Subsurface Imaging and Reservoir Characterization Evolution in Onshore Seismic: Four Recent Case Studies

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The advent of new processing techniques and technology have enabled an imaging evolution in onshore seismic: high-density data with well sampled signal and noise, improved illumination and very high fold, free from source and receiver array effects - perfect for the highest standard subsurface imaging and reservoir characterization.

To illustrate this, we show in this presentation four published case studies available in a range of geographical areas and geological settings from Alaska (Winter et al., 2014), France (Baris et al., 2014), South Africa (Moinet et al., 2013) and Qatar (Setiyono et al., 2014).

1. Alaska Example (Tabasco 3D)

High-productivity vibroseis acquisition (HPVA) technology was employed to increase the efficiency of the slip-sweep vibroseis operations and, therefore, allow enough shot points to be acquired in the short season. In the Tabasco program, the application of HPVA, using three fleets of three vibrators, allowed the crew to complete the work with average productivity of more than 4,000 VPs per day. It was the first time that such techniques had been employed, or such high-density data had been acquired, on the North Slope. This was also the first western hemisphere survey to employ our proprietary broadband vibroseis technique. Typically, the technique is used to increase the low-frequency content of the sweep to provide better deep imaging and inversion results. On the Tabasco survey, a 4-80Hz sweep was used, providing considerably improved deep illumination than had previously been seen in the area. The benefit of the additional low frequencies that were recorded by this technique is demonstrated by the improved resolution of the migrated data, with sharper wavelets and reduced side lobes. This leads to stable and accurate acoustic inversion results.

Processing data from the Arctic presents some unique challenges, such as solving imaging challenges related to permafrost and dealing with noise from ice breaks. The dense sampling and high fold of the Tabasco survey meant that the ice break noise did not pose a severe challenge and was tackled by the standard noise burst attenuation procedures. Ground roll was attenuated using a 3D adaptive ground noise reduction technique applied in the cross-spread domain. Permafrost causes at least two distinct challenges related to seismic data imaging. The first is a short wavelength static problem caused by low-velocity anomalies associated with melting beneath perennial water bodies or ice lakes. In permafrost areas, turning-ray tomography has been used successfully to invert first-arrival travel times and derive a high-resolution, near-surface velocity model for static corrections. This is much more effective where high-density data provide sufficient fold and sampling at the near surface. The second challenge is long wavelength structural distortion in the time domain related to the variable thickness of the overall permafrost zone. This is most effectively dealt with by careful velocity model building and depth imaging.
2. France Example (Lussagnet-Izaute 3D)
Single source-single receiver wireless systems reduce acquisition to its most elementary components, allowing high flexibility to adapt to all environments. The advent of these new solutions enables a shift from equipment-driven and access driven to image-driven survey planning. In the Lussagnet-Izaute case study, we illustrate how such advanced systems lead to highly efficient operations to produce high resolution 3D seismic volumes. The objective of this land survey was to acquire 3D seismic data to improve the knowledge of underground natural gas storage capabilities (namely structural aspects, fault network characterization, and steep dip structural imaging). It constitutes the main gas storage facility enabling the operator to meet seasonal variations of gas consumption in Southwest France and Spain. The presence of fault networks on the northern side of both structures was known but not yet clearly imaged. Geological seal is ensured by a thick, continuous shale layer (>500m thick). This seal is commonly called the Molasse d’Aquitaine. Reservoirs are formed by porous Infra-Molassic sands (Lussagnet Sands) and Top Ypresian layers. These gas reservoirs sit in the regional massive Eocene/Paleocene aquiferous deposit. The high level of permitting success was related to the use of Unite wireless solution, significantly less intrusive than cable acquisition. In addition, the decision to exclude dynamite sources strongly contributed to this positive result (Berron et al., 2014). The ability to harvest data during production is a unique advantage of the acquisition system as it provides an opportunity to make near real-time, in-field adjustment to the equipment and program based on the ability to QC not only the trace attributes but the actual raw data as it is being acquired. TeraQc (a tool developed by CGG to build attribute maps derived from seismic data) has been instrumental in generating a clear picture of the real data acquired and predicting the impact on the final image. The end result after full processing is a pre-stack time migrated volume with tremendous improvement in subsurface resolution compared to the legacy 2D data and where GWC can be easily mapped for improved reservoir management.

3. South Africa Example (Moab 3D)
To assess the potential of high-end land seismic and further increase the value for the mining industry, AngloGold Ashanti (AGA) has acquired a prospect area of 35km². The geophysical objective of this survey is to image the formations above and below the Ventersdorp Control Reef (VCR) and down to the carbon leader reef, for depths ranging from 2.7 to 3.8km. This program was the opportunity to illustrate how dense and broadband seismic can significantly improve land seismic imaging. The benefit of a dense acquisition, with a broadband source is illustrated on the AGA prospect. We compare a conventional acquisition (420m shot line interval (SLI), 70m shot interval (SI), 300m receiver line interval (RLI), 50m receiver interval (RI); 10-90Hz sweep) with a dense acquisition (50m SLI, 50m SI, 100m RLI, 50m RI; 10-90Hz sweep) and a dense acquisition with a broadband source (50m SLI, 50m SI, 100m RLI, 50m RI; 3-160Hz sweep). The expectations from dense acquisition are confirmed by an outstanding imaging quality for all depth levels simultaneously for ultra-shallow and ultra-deep targets. This in turn leads to significantly improved depth velocity models for a simultaneous optimal focalization and positioning of the seismic reflections. The broadband sweep achieves remarkable seismic wavelet compression with a sharp main lobe and minimum side lobes. This leads to a textured image with unprecedented stratigraphic details available for the interpretation. Borehole seismic can also be used as a tool to study and quantify the surface seismic bandwidth high-end with the optimum one achieved in borehole seismic by 2D walkaways and/or 3D VSP.
4. Qatar Example (Dukhan 3D)

The Dukhan oilfield is located along the southwest coast of Qatar, extending 70km north-south. In 2007, Qatar Petroleum invested in a new full-field, land and shallow-water high-density, wide-azimuth 3D seismic program of the area. Seeni et al., 2014, describe in detail the context, parameters and results of the survey. Despite considerable and continuous innovation in seismic technology, getting a sharp and accurate seismic image in the reservoir interval is still challenging. On land seismic, poor understanding of the near-surface geology can be detrimental to imaging, and remains one of the main challenges to be addressed. As near-surface layers influence the travel time and amplitude of seismic waves, knowledge of the near-surface is critical for an accurate focalization of the seismic reflections at the right vertical and lateral position and accurate quantitative depth interpretation. To improve the near surface velocity model of the Dukhan oilfield, a dense non-seismic microgravimetry (gravity) survey in combination with vertical electrical sounding (resistivity) method was implemented. Measurements of high precision gravity and resistivity on top of the 3D seismic acquisition were performed. The resistivity is particularly important as it gives a geoelectrical layering of the subsurface which constrains and greatly enhances the gravimetric inversion. The objectives were for both static corrections and building a robust velocity model of the near surface to be integrated into the depth imaging velocity model. The near-surface model was to be extended down to the Top Simsima horizon, which is the first clearly defined seismic reflector, at depths ranging from 300 to 600m.

Using the sparse available information - seismic, upholes and well logs - we calibrated Gardner and Faust relations (Faust, 1954) to obtain 1) resistivity to density and 2) density to velocity conversion laws. From the resistivity model, we obtain an initial density model. This density model is updated via gravity inversion, and transformed into a velocity model through the density to velocity conversion. The final result is a velocity model, optimized to match the electrical and gravimetric information. We integrated the derived velocity model in a pre-stack depth migration workflow. Comparison of a depth migrated section with and without using the near surface velocity model shows that introducing the velocity model had a visible impact on the deeper structure obtained by the imaging, and resulted in a better fit between the seismic horizons in depth and well control.

References
Moinet, F., Denis, M., Brem, V., and Pradalie, F., 2013. *Is Broadband Land Seismic As Good As Marine Broadband?*, 83rd SEG annual meeting and exposition.