Improving Structural and Stratigraphic Interpretation using Borehole-Integrated Seismic Processing–Ledjmet Block, Algeria

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Summary

First Calgary Petroleums Ltd. (FCP) along with its partner Sonatrach (National oil company of Algeria) has drilled several successful exploration wells in the Ledjmet Block 405b of the Berkine basin, Algeria within the last two years (Fig.1). 2D data of different vintages could not provide an accurate interpretation; therefore two 3D seismic surveys (~850 sq km) using vibroseis 100-fold parallel-geometry were acquired. This acquisition geometry allowed a better sampled offset distribution (50-5000m) in the CDP domain. This also resulted in effective noise attenuation, a better velocity analysis, improved S/R (Signal-to-Noise Ratio) and a stable full Kirchhoff Pre-Stack Time Migration (KPSTM). Despite careful planning and utilizing all the knowledge available at the time, the 3D processing was faced with several challenges in terms of statics, noise (random, linear, multiples and acquisition footprint), and most of all velocity analysis. These all had an effect on the integrity of structural and stratigraphic interpretation

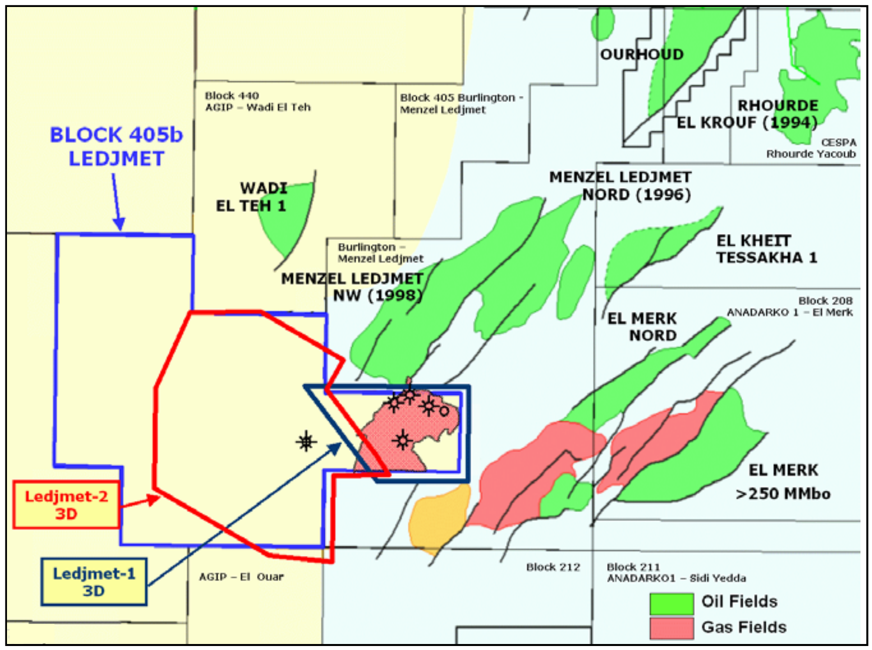

Fig.1 Berkine Basin Oil and Gas Trend – more than 5 Billion Barrels of oil discovered to date.

Several processing flows were rigorously tested using specialized programs to deal with the issues discussed above, particularly

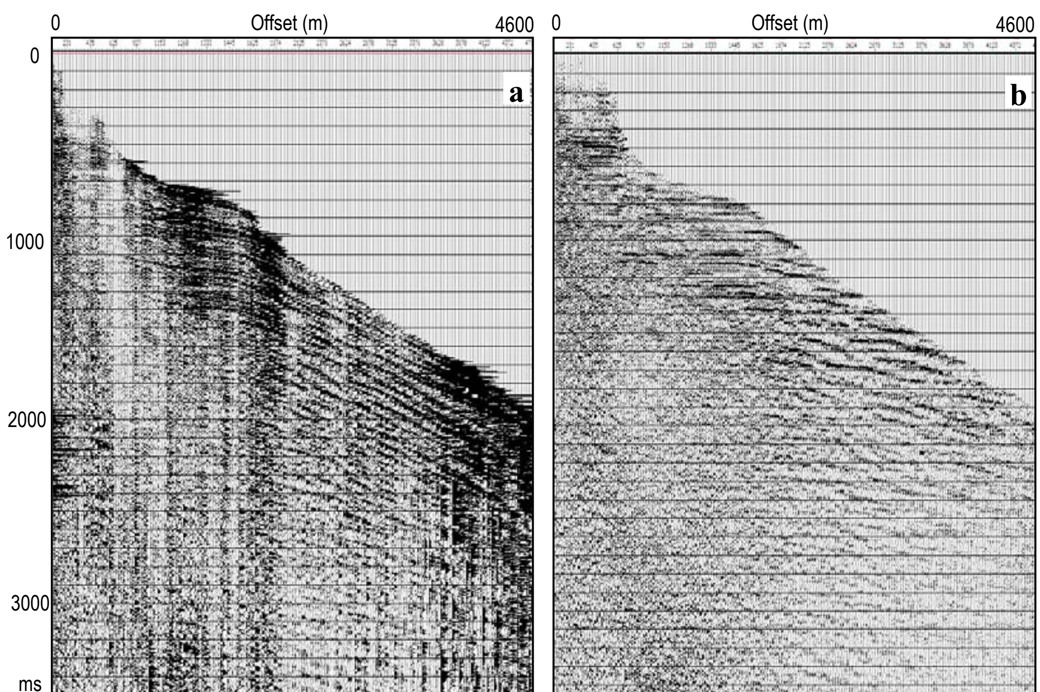

Fig.2. (a) A typical CDP gather from the Ledjmet 3D volume. Poor S/N due to random noise, ground roll, surface-generated noise, interbed multiples and refractions produced by several high velocity sand, limestone & anhydrite layers posed the main challenges in the surface-consistent amplitude preserving processing flow.

(b) CDP gather after application of random noise & linear noise attenuation in shot & offset domain and multichannel median filters in selected frequency bands.

near-surface model for statics, very sensitive velocity picking, noise attenuation and demultiple. One of the several recommendations from this effort was to collect near-surface data, such as dense uphole surveys, wireline logs and High Resolution VSP (HRVSP) to build a geological near-surface model that can be integrated into seismic derived model to help derive an accurate static solution (Drummond et. al., 2001, Marsden, 1993). These recommendations were followed through during 2003 acquisition programs: 50 additional upholes, VSPs on all exploration wells, and a HRVSP & wireline logs in a shallow well were recorded and integrated into the reprocessing of the merged 2002 and 2003 volumes.

This paper discusses the results achieved and challenges of integrating borehole data into seismic data processing.

Data Processing

The data processing started in early 2002 with the reprocessing of Ledjmet-1 3D volume covering the MLE structure situated on the eastern side of the block. Presently, the Ledgmet-2 3D volume acquired in mid-2003 is being merged and reprocessed. A typical raw CDP gather before and after, noise attenuation & surface-consistent amplitude correction is shown in Fig. 2. A precise near-surface model was prepared using uphole and well data to compute statics caused by shallow sand layers (as most upholes were less than 100m deep). First break analysis of the 2000m/s and 3000m/s layers resulted in the modelled depth of ~100 and ~320m below ground level (approximately 250m above sea level) respectively. Refraction statics were then computed based on this model. Another ~4000m/s deeper layer, which is known to be present could not be picked reliably for the full 3D, hence this was not used in refraction static analysis. However, a reflection based specialized algorithm, which uses a known shallow reflection as reference to compute residual medium-to-long wavelength statics was applied successfully. Fig.3 compares the stacks before and after calibrated near-surface model used for statics computation. To further enhance the coherency of the reflections, three passes of residual statics were applied, after every pass velocity picks were refined and the frequency bandwidth was broadened to achieve a high resolution seismic volume.

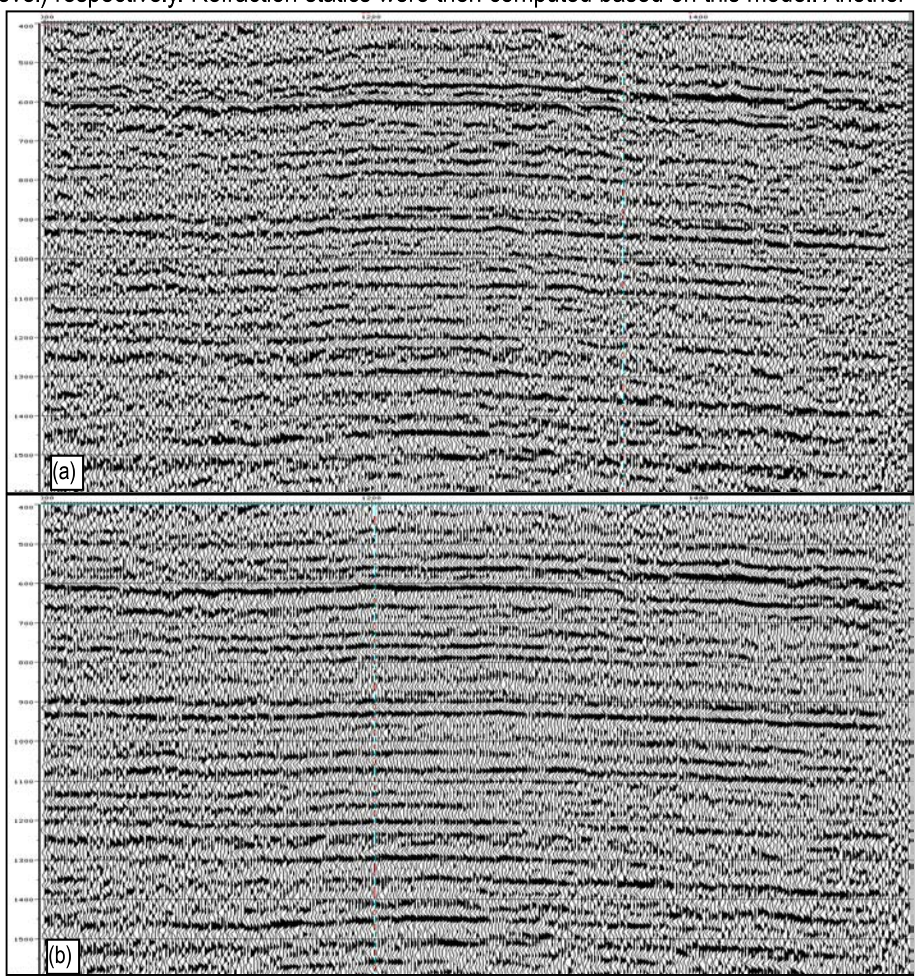

Fig.3 Stack section of a SE-NW profile (a) before and (b) after calibrated near-surface model used for statics computation.

As mentioned earlier the data exhibited poor S/N with significant random, linear, surface-related noise and long-period & interbedded multiple noise. Rigourous testing of several noise attenuation algorithms (FK, shot-FX, Offset-FX, High-res τ-p, median filters) were used to selectively remove noise without affecting the signal. Tests are underway for the multiple attenuation using high-resolution τ-p (Hermann et.al.,2000) and for the KPSTM, and results of these tests, along with a full processing flow will be presented later.

VSP and Log data integration

Early in the exploration it was recognized that VSPs and log data would be essential not only for interpretation, but as fully integrated components of the seismic data processing. Conventionally, VSPs have provided a correlation of time to depth between seismic and log derived geological sequences. In the Ledjmet 3-D, VSP data was also integral in the differentiation of primaries from multiples. All the four wells have been logged with a full suite of wireline logs including a zero-offset VSP. Fig.4 shows a time domain correlation plot combining seismic, logs and VSP data of a typical MLE well. The higher frequency content of the VSP (~80Hz) meant the corridor stack had to be bandpassed to tie the seismic data.

The seismic data was very sensitive to the velocity picking. At certain horizons even a 1% velocity change exhibits significantly different events on the stacked sections. For this reason, interval velocities obtained from VSPs were converted to an RMS velocity function and used as a guide in the velocity picking. Positive identification of primary multiples from the VSP also aided in accurate velocity picking.

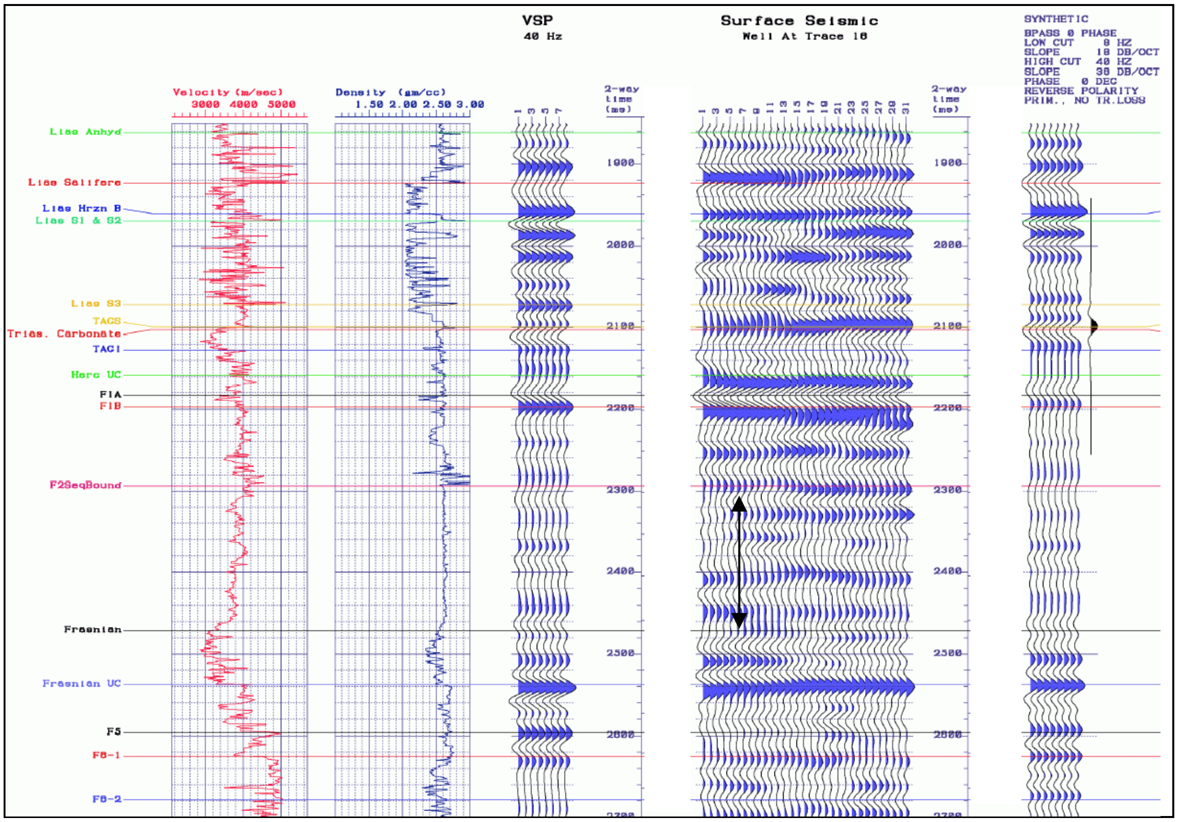

Fig.4 A composite showing tie between logs, VSP and seismic. Primaries in the seismic data match very well with the synthetic and VSP. However, the seismic exhibit several events between 2300-2500ms, which do not match VSP and/or synthetic, suggesting these events are multiples.

High Resolution VSP (HRVSP)

A tightly spaced high frequency, hence high resolution VSP was acquired within the top few hundred metres of the most recent well prior to setting surface casing. The purpose was to obtain a precise depth and velocity of the low and high velocity layers in order to construct an accurate near-surface model and calibrating seismic derived statics. The HRVSP was acquired in 2m intervals from TD to ~100m below the surface with a single vibrator placed 15m offset from the wellhead sweeping from 6 to 120 Hz. A HRVSP dataset (up to ~110Hz) was collected along with full suite of shallow wireline logs. The match between the shallow synthetic, HRVSP and the seismic data is excellent and the low and high velocity layers correlate very well. The results of this experiment were encouraging enough to plan for HRVSPs and near- surface logs at numerous deep uphole locations. These will be collected field-wide in the 2004 acquisition program and will be fully integrated in to the seismic data procesing.

Conclusions and Future work

The integration efforts have resulted in a high-quality 3D seismic data in terms of statics, velocities, frequency content and primary-multiple identification. HRVSP and log data in a shallow well provided much needed information for building a confident near-surface model that resolved ambiguities in the statics. These results have led us to acquire a consistent grid of deep upholes over the 2004-3D area. A full suite of wireline logs and HRVSPs will be recorded in all the deep upholes ahead of seismic data acquisition, so that these datasets can be fully integrated with the seismic data processing.

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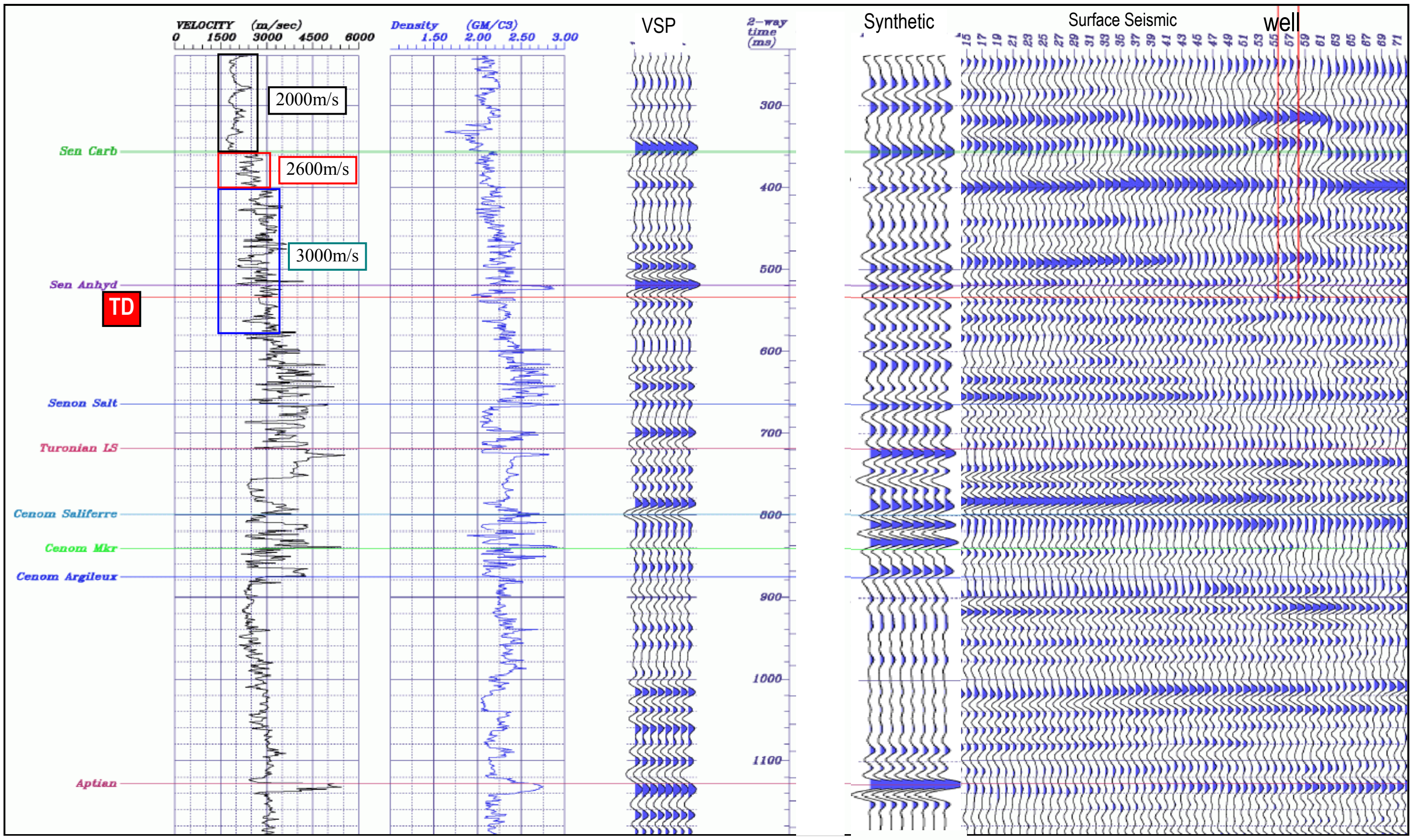

Fig.5. A composite showing the correlation between HRVSP, synthetic and surface seismic. The layers needed to build the near-surface model for statics - 2000m/s, 2600m/s and 3200m/s layers are clearly identifiable. There is an excellent match between seismic HRVSP and synthetic at most of the geological horizons above the TD. Below TD the seismic and HRVSP allow visualization of multiples, for example 900-1100ms. As the VSP deconvolution below the deepest VSP receiver is no longer deterministic and is susceptible to primary multiples, a correlation can be made to the multiples present in seismic. Once the deep VSP is acquired and appended to the HRVSP data, a continuous multiple-free corridor stack will provide further multiple delineation.

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