Single-sensor HD-3D in China: case studies from MEMS-based accelerometers

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Introduction

In the Chinese domestic market, the main seismic contractors have been early adopters of MEMS-based accelerometers. With the active support of the national oil companies they recorded single-sensor 3D as early as 2004. Today, the many surveys acquired with these 1C or 3C digital sensors cover a full fold area of about 2000 km², mainly in the northern and central parts of China. All these surveys were shot with explosives (up to 10kg). The receiver interval was from 10 to 50m, and spreads requiring up to 11,520 RP's were used. The resulting trace density ranged from 105,000 traces/km² for the early surveys up to 7.2 million traces/km² for the most recent ones.

Compared with previous conventional 3D surveys based on geophone strings and lower trace density, the main benefits were higher signal-to-noise ratio and improved vertical resolution. The enhanced amplitude preservation was a nice surprise particularly for prestack data at far offset (AVO). On the other hand, improvement in low frequencies was not as great as expected due to source limitations. With respect to PS waves, sections were better than before, but in general their added value for reservoir characterization did not meet expectations. One of the reasons for this was the lack of vertical resolution due to high-frequency attenuation occurring at some intermediate levels. The other was often an insufficient well calibration to perform a proper depth PS to PP depth registration.

Two case studies to which CGGVeritas contributed are selected to illustrate the range of benefits obtained from single-sensor high-density 3D acquisition in China.

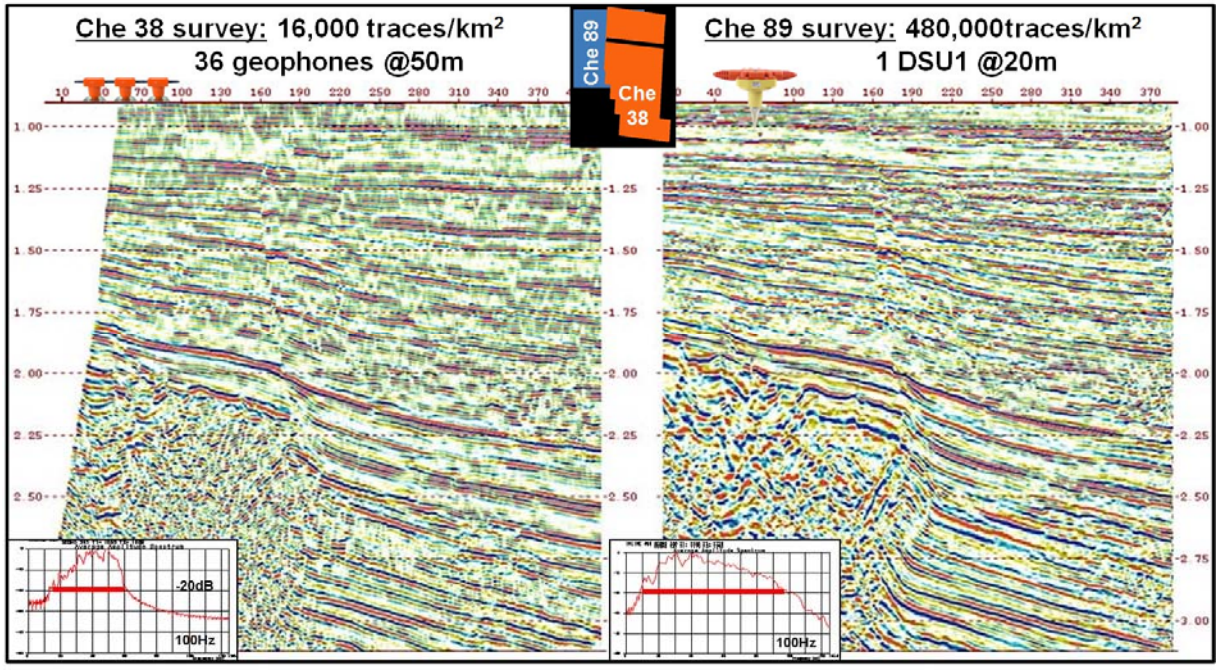

Figure 1: Benefits of single sensor high-density 3D acquisition to improve vertical resolution and seismic imaging.

1C 3D high-density survey in the Junggar basin (NW China)

Oil production in the Junggar basin (XinJiang province) comes from shallow Tertiary layers. The Paleogene formation holds the main reservoir that is 3-5 m thick. Oil distribution is controlled by faults some of them with small throws (<10 m). Imaging this reservoir would require the dominant frequency to be at least 60Hz, a target inaccessible to conventional seismic based on geophone strings. In the winter of 2007, BGP on behalf of PetroChina shot a single-sensor high-density 3D survey (180km² full fold) overlapping old 3D's (Figure 1).

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Che 89 spread was made up of a total of 4,608 live 1C Digital Sensor Units (DSU1) at 20m spacing. More than 10,000 shots were recorded every 40m along source lines perpendicular to the receiver lines. The resulting fold was 96, a bin size of 10m x 20m and a density of 480,000 traces /km², up to 30 times more than the previous 3D surveys. A comparison is made with Che 38, a conventional 3D survey shot in 1991 using 240 channels, 25m x 75m bins, a full fold of 30 and a density of 16,000 traces /km². Pre-stack time migration displays a big improvement in vertical resolution due to the different bandwidth of the two datasets. In addition, the small faults as well as the large reverse fault are better imaged which is due to the improved trace density and better signal-to-noise ratio even at deep levels (Li et al., 2009; Liu & Mougenot, 2009).
The improved vertical resolution made it possible to display more stratigraphic details. The negative bright spot that corresponds to the oil-water contact (OWC) is well imaged. Its flatness is more apparent and it has a larger extension than on previous seismic. On the amplitude map of the reservoir interval, the relationship between bright spots, fault distribution and the productive wells is now made obvious.

HD 3D-3C survey in the Shengli oil field (E China)

The Shengli oil field lies along the Bohaï bay and is the second oil field in China (194 million bbl in 2011). It produces from highly faulted and heterogeneous deltaic formations that have been explored for the last fifty years. More than 30,000km² of full fold 3D have been shot to date over this mature oil field. Single-sensor high-density 3D seismic is now required to identify thin reservoirs (<10m), subtle stratigraphic and structural traps as well as deep horizons (>3000m). 3C data are important for sand-shale discrimination and better reservoir characterization.
The LuoJia 3D-3C survey (30km² full fold) was acquired in 2009 by Sinopec Shengli in a flat but densely populated and industrialized area. The active spread was made up of 11,200 3C Digital Sensor Units (DSU3) at 12.5m intervals to avoid ground roll aliasing (Zhao et al., 2011). Shot points were every 25m. The resulting bin size was 6.25m x 12.5m, 280 full fold and the density up to 3.6 million traces /km². Each 3C shot point recorded at 1ms was 920MB and the total amount of data acquired was about 30TB which required an upgrade of processing capabilities.
The frequency content above the main unconformity (1.8-2 s twt) was extended from 60-70 to 80-100Hz. Compared to the previous 3D survey shot in 1990 (240 channels, 25m x 50 m bins and 30 fold), the improved horizontal and vertical resolution led to clearer evidence of the stratigraphic relationships between the different sedimentary sequences (pinch-outs) as well as the small faults (throw <10m) sealing the thin Paleogene limestone reservoirs (Cai et al., 2011).
The correlation with well data was significantly improved not only for lithology but also for fluid content. At the level of the gas reservoirs, better preservation of the AVO effects resulted in a straightforward relationship between the magnitude of the flat-spot anomalies and the fluid content (high amplitude for gas, low for water and intermediate for a mix). This was not the case with the previous 3D surveys based on low-density acquisition (24,000 traces /km²) and geophone arrays.

All these positive improvements made single-sensor high-density 3D surveys based on digital accelerometers a standard for domestic acquisition in China, at least for regular terrain.

References:

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