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Multi-component seismic gaining momentum in China thanks to digital accelerometers

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Introduction

As a leading provider of land recording systems, we had the opportunity to contribute to the spectacular growth of land multi-component (MC) projects in China fostered by the availability of the new three component (3C) digital accelerometers. We present in chronological or geographical order the fast development of MC acquisition that is illustrated by typical examples. Then, a summary showing the general characteristics of these surveys is proposed, as well as the difficulties in processing and interpreting these datasets.

Historical and geographical developments of MC surveys

Before 2000, the MC activity was stagnant in China due to the difficult operational implementation of 3C survey using string of triphones: three completely independent receiver lines were to be laid out, one for each of the 3 components (see analogue configuration, Figure 1); multiple take-out and connectors were to be assigned correctly; each triphone was to be levelled and oriented. In addition, converted wave (PS) sections were very poor due to the sparse spatial sampling and to the lack of channels. Processing software were not yet mature and combined interpretation of PP & PS data were not available.

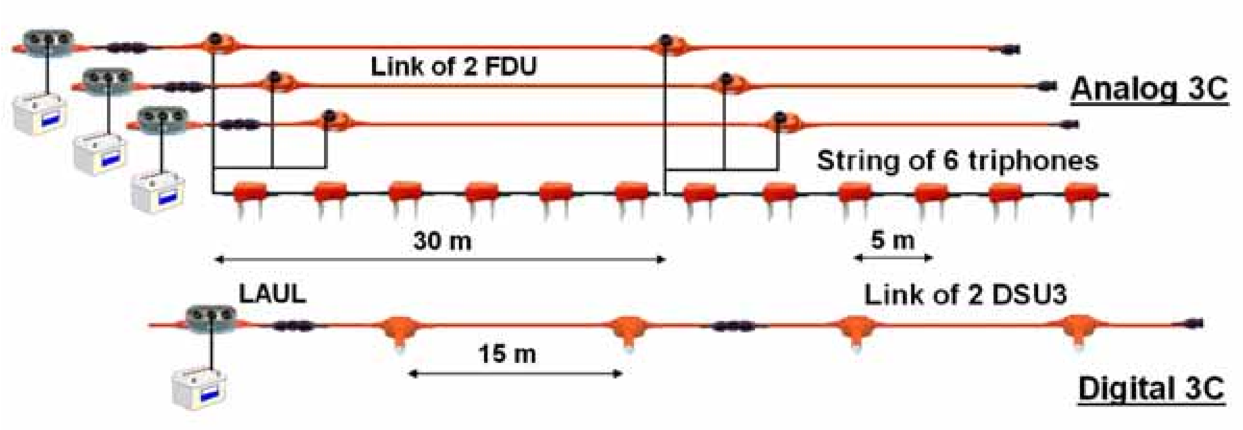

Figure1: Comparison of an analogue 3C with a digital 3C line.
(FDU: Field Digitizing Unit, DSU: Digital Sensor Unit, LAUL: Line Acquisition Unit Line)

During 2003, 2D-3C tests were performed with different Chinese contractors including Daqing, Jilin & Liaohe Geophysical, the Sichuan Petroleum Administration, and the Heilongjiang coal mine. These tests were aimed at demonstrating the operational efficiency of the Links of 3C Digital Sensor Units (DSU3), including in a single piece of field equipment the Micro-Electro-Mechanical-Systems (MEMS accelerometers), the field electronics, the cables and the connectors (see digital configuration, Figure 1). This equipment was compatible with all new recording systems (408UL/CMXL) sold in China since 2001. Assuming a spacing half the one of the conventional receivers, the price of such digital sensor line is less than the one of the equivalent analogue sensor equipment (FDU, connected to triphones) and the weight is divided by as much as four. In addition, tilt is automatically measured and compensated (no levelling), and connections to sensors are not necessary. These early tests, using less than 200 digital sensors, provided good quality PS waves with obvious anisotropic effects (see Liaohe shot point, Figure 2). However, short maximum offset, large spacing and off-end geometry prevented to get better sections than the conventional PP data. The only improvement observed was a better vertical resolution in the upper part of the section due to the fact that digital sensors, as point receivers, better preserve the high frequencies (no intra-array statics; see Liaohe stack, Figure 3).

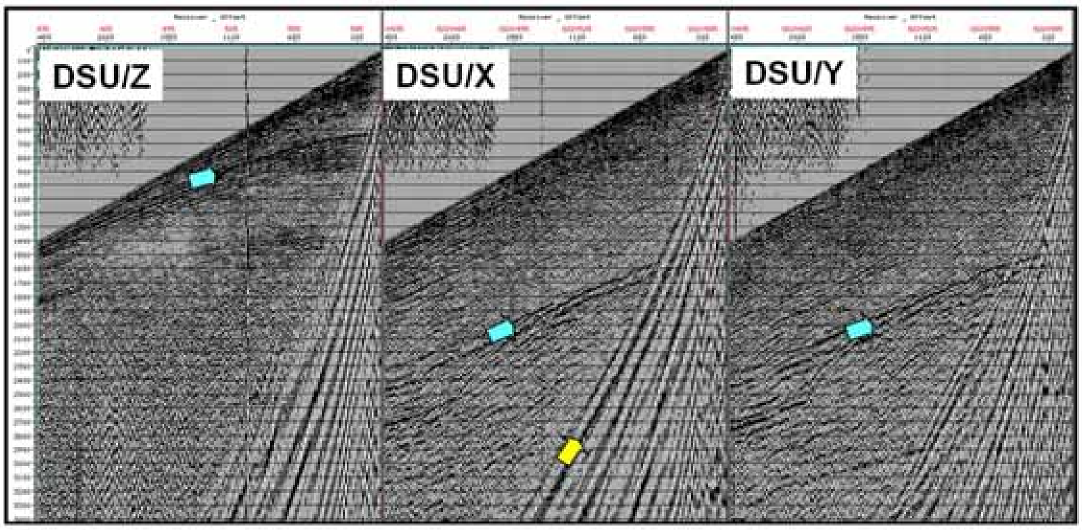

Figure 2: 3C SP from DSU3 (courtesy of Liaohe Geophysical).
Blue arrow outlines the corresponding reflected arrival from PP & PS
(energy on Y (crossline) is related to shear wave splitting).
The ground roll is far to be identical on Z (vertical) & X (inline).
Yellow arrow outlines the shear wave first break.

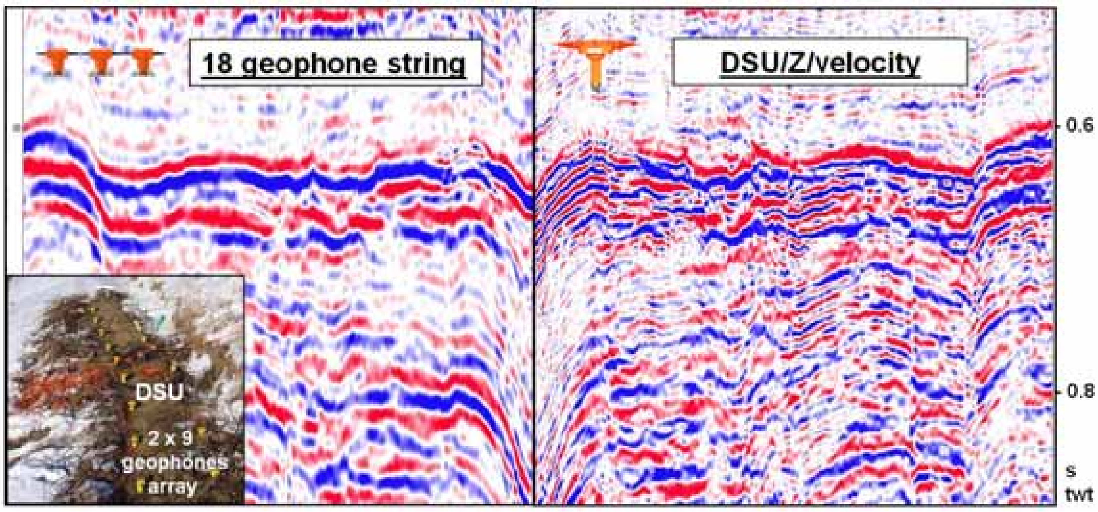

Figure 3: Comparison of the vertical resolution on the PP stacks recorded with the same spacing (15 m) between geophone strings (18) and DSU3 (courtesy of Liaohe Geophysical).

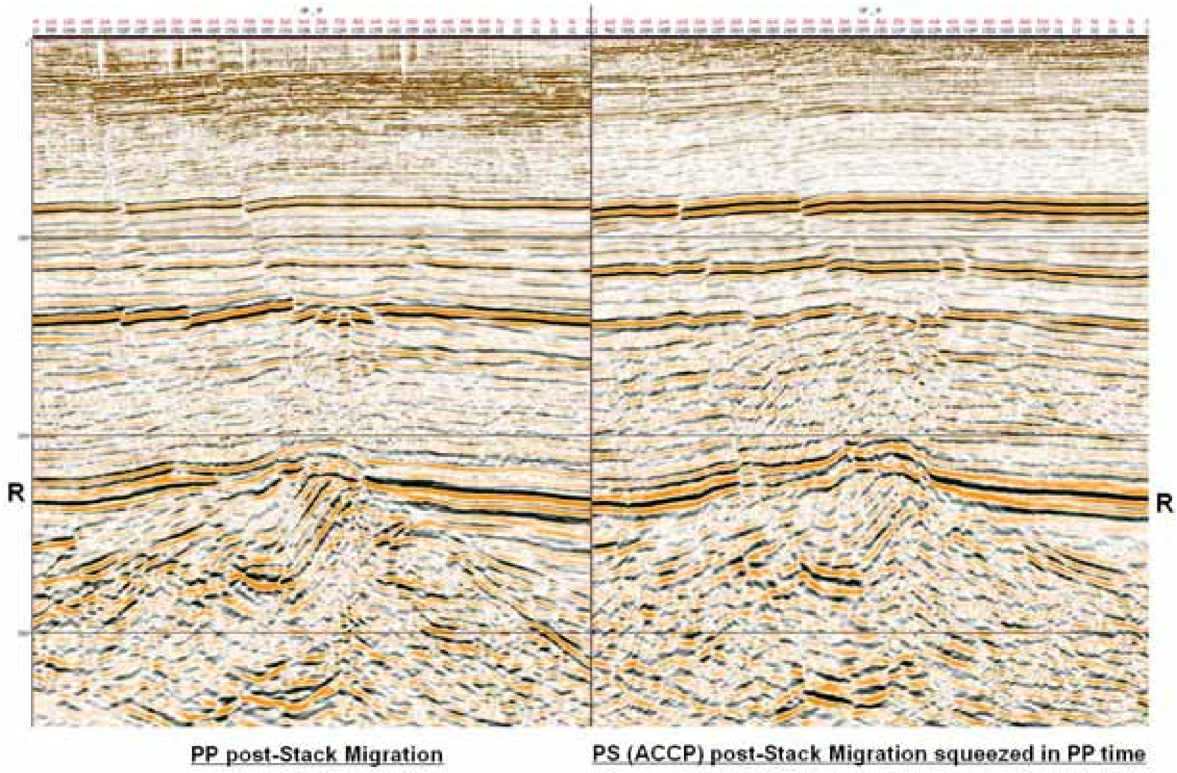

Figure 4: Comparison of the PP with the PS post-stack time migration performed from the ACCP stack. PS section was converted in PP time using a gamma zero section. R: reservoir (courtesy of Daqing Geophysical).

During 2004, after the purchase of a significant amount of DSU3, more suitable 2D-3C lines were acquired by Daqing (CNPC) and Shengli (Sinopec), organizations in charge of two of the main oil fields in China. The Shengli line, recorded off-end with 600+ DSU3 @ 5 m, displays interesting reflectivity contrasts in the sand-shale deltaic formations between the PP & the PS sections: better vertical resolution for PS in the shallow part, better continuity for PS in formation where PP reflectivity is weak, but lower frequency content on most part of the PS section, due to the strongest absorption of the upgoing share waves. About 90 km of full fold 2D-3C was shot by Daqing geophysical using 1000+ DSU3 @ 10 m. Like for all acquisitions reported, the source was explosive. As expected, the frequency content of the PS migrated section is significantly narrower the PP one (30 Hz vs. 50 Hz at the reservoir level). However, both sections, as processed by CGG, display the deep gas reservoir made of volcano-clastic formations (see Daqing migrated sections, Figure 4) with significant contrasts of reflectivity that helped in delineating this gas field (Xianyi Sun et al., SEG 2006; Shumin Chen et al., EAGE 2006 & First Break, April 2007). From that result, PetroChina decided to perform a large 3D-3C that started during winter 2007 and will probably be extended over several years.

During 2005, started real size production projects with the first 3D-3C (50 km², Ken-7) combining a conventional spread made of FDU's with another one, interleaved, made of DSU3's. The total amount of active channel @ 20 m were more than 13,000 recorded in real time on tape @ 1 ms sampling rate. Shengli was able to record more than 18,000 SP's in less than 50 days, using orthogonal geometry. PP data shows large improvement compared to the previous 3D survey (Fu Jinrong et al., SPG-SEG Kunming, October 2006). The vertical component of the single sensors, planted with the same spacing (20 m) as the geophone strings (18), provides better vertical resolution than the geophone arrays and helped interpreters to delineate subtle stratigraphic features. However, below the unconformity at 2 s twt, signal-to noise of the DSU3 data degrades because of the ambient noise that is not attenuated, contrary to what happens with the geophone strings (square root of 18 attenuation). PP & PS prestack time migrated data coming from DSU3 were also compared. The processing done by the Edinburg Anisotropy Project (EAP) of the British Geological Survey includes the compensation of the non hyperbolic move-out related to the vertical transverse isotropy (VTI) that is common in sand-shale formations (Yanguang Wang et al., SPG-SEG Kunming, October 2006). The resulting PS section is of remarkable quality down to 5,5 s PS time.

Another 3D-3C was acquired by BGP over Xinchang gas field (**Sichuan province**) using 3,000+ digital sensors @ 50 m. More than 10.000 SP's @ 50 m were performed using a brick geometry and resulting in a 134 km² area of full fold. Targets were fractured tight sandstone reservoirs within Triassic Jurassic formations that may be as deep as 6,000 m. In the same basin, the Sichuan geophysical company (SCGC) shot, during spring 2005, 5 lines of 2D-3C (90 km) crossing gas wells in different directions to detect the Horizontal Transverse Isotropy (HTI or azimuthal anisotropy) that is related to open fracture orientation and density. Obvious travel time and amplitude contrasts were observed on the different X sections depending on the azimuth (Li Zhong et al. SEG 2006). Shooting (10 kg at 15 m depth every 80 m) was split-spread of a line of 800 DSU3 @ 10 m. P & S impedances were computed in order to better characterize the reservoir of the Guangan structure: P impedance was used to differentiate tight sand from gas sand, and S impedance to differentiate sand from shale. In January 2007, SCGC started a 3D-3C over the same Guangan structure using 2,500+ DSU3 @ 20 m and shot with the same interval.

In the Ordos basin, over the Sulige & Changqing gas fields, 2D-3C & 3D-3C surveys were performed by BGP (Shifan Zhan et al. SPG-SEG Kunming, October 2006). Prediction of gas bearing sandstone reservoir using Vp/Vs ratio, PP & PS amplitude ratio, as well as elastic impedance were confirmed by well data (Zhiven Deng et al., The Leading Edge, March 2007). These surveys were the opportunity for BGP to develop a new methodology to compute S wave statics using the time difference between first breaks on Z & X components at some receiver locations. This difference is the one between P & S transits in the weathering zone (Yanpeng Li, SEG 2002). In 2006, a 2D-3C line was acquired by BGP for Total over the Sulige gas field to prepare a 3D survey.

The Tarim basin is more like a frontier area for MC seismic due to the complex topography and structures. First tests were done by BGP in 2004. In May05, Sinopec Hunan DSU3 did a 2D-3C test in the Tarim desert (dunes) using a fat receiver line made of 3 parallel lines at 10 m spacing, each of 500 DSU3 @ 20 m, and shot split-spread. Different group forming using inline & crossline digital sensors were performed. 15 DSU over 100 m provided a stronger noise attenuation and a better high frequency preservation than an array 36 geophones over 20 m. In December 2006, Sinopec started a 3D-3C survey, in another area of the Tarim basin (Tarhe), using 4,000+ DSU3 @ 30 m and explosive (5,000+ SP's @ 30 m). 5000+ FDU were also recorded at the same time using a second CMXL central unit in a master-slave configuration with respect to the shooter. Overall, more than 17,000 live channels were recorded (10 s @ 1 ms) that should correspond to about 520 MB records.

To complete this survey of MC projects, it is worth mentioning a very small (1.7 km²) 3D-3C survey over the Huainan **coal mine** (Anhui province) using 720 DSU3 and a 10 x 20 m bin size. Records were 3 s @ 0.5 ms. However, all frequencies above 80 Hz were already attenuated at the targets, that are coal seams less than 15 m thick from 700 to 1,300 m depth.

Conclusion

As we can see from the previous survey, MC projects were numerous in China since 2003. They were performed over the main oil fields in the plain of Eastern China where oil & gas reservoirs are located in sand-shale deltaic formations (Daqing, Shengli, Liaohe, Jilin…). They were also acquired in the Sichuan and Ordos basins, to better delineate gas fields in old sandstone formations. In the Tarim basin, the target corresponds to Palaeozoic carbonate reservoirs bearing oil. A very few application are related to coal mines. This fast growth was related to the availability of a sufficient amount of 3C digital sensors thanks to the interest of the oil companies and of the geophysical contractors. Overall, we estimate the amount of 3C digital sensors available in China to about 25,000. Concerning DSU3, this represent 45% of the total sales.

At least six 3D-3C surveys, with a total of 700 km² of surveyed area, were acquired as well as about 1000 km of 2D-3C lines. All shots were explosive with a spacing from one to five times the receiver interval. Depending on the methodology selected to attenuate ground roll (GR), digital sensors were from 5 to 20 m spacing (as you rely to FK filter) or from 30 to 50 m (as you prefer to use polarization filter). However, from the data we know in China, GR may be quite complex, and not only with a radial propagation and an elliptical polarization (Figure 2). All these surveys were not only aimed at recording

converted PS wave but also at testing point receiver recording and their advantages for PP waves. As single sensors and geophone strings were often compared with the same spacing, PP sections display better vertical resolution only in the upper 2 s twt of the images. This improvement can be extended deeper by reducing the spacing between digital sensors.
If acquiring land MC seems not to be not any more an issue in China, processing land 3D-3C still requires from the geophysicists to gain experience and to have access to the necessary algorithms. As a result, the delivery time of the PS volumes may be quite long, and projects are often subcontracted overseas to some service companies. Interpretation as well is an issue, and we are not sure the oil companies got the best added value from the money they spent to acquire 3C data. Most methodologies to combine PP & PS data were implemented, including Vp/Vs (gamma ratio), amplitude ratio and P & S impedances comparison. However, most of these approaches may fail if a precise correspondence is not established between the PP and the PS images. Since the reflectivity (including phase) may be very different between the two wave fields, such registration should be done in depth, using 3C-VSP (Bob A. Hardage, AAPG Explorer, February 2006).

Acknowledgements

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