Teal South: the first 4D - 4C

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These last years have seen a dramatic increase in the growth curve of conventional P-wave (acoustic mode) 3-D time-lapse surveys. The same pace has also characterized the number of multi-component surveys acquired on the seafloor. These are designed to record an image of the subsurface which results from a downgoing P-wave and an upgoing S-wave (converted mode). The converted waves (or PS-waves) and the conventional P-waves are recorded on the bottom of the sea with four-component (4C) sensors comprising a hydrophone, a vertical and two horizontal geophones. Combining time-lapse and multi-component technology seems natural, yet until today no sea floor 4-D survey involving shear waves has been documented.

Questions regarding seismic monitoring in the marine environment with multi-component technology remain therefore unanswered. Is the state-of-the-art in acquiring and processing the shear waves generated by the conversion of acoustic waves in the ground adequate? If multi-component data are necessary to monitor fluid movement, are their acquisition and processing cost effective? What are the best methods to acquire these data in the Gulf of Mexico? What methodology will be needed in ultra deep waters?

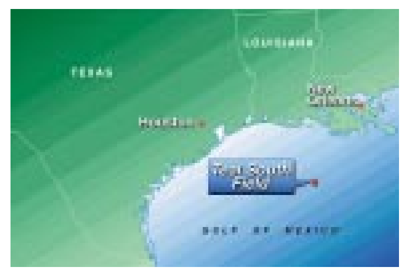

Fig. 1. Position map.

The Houston-based Energy Research Clearing House (ERCH) launched a multi-million dollar consortium aimed at answering such questions. Three categories of members belong to the consortium: Eight oil companies as full participants (Agip, Anadarko, BP, ExxonMobil, Marathon, Petrobras, Shell and Texaco), 11 service companies as in-kind participants (including CGG) and 10 academic partners. The site chosen was Teal South, located in the Eugene Island Block 354 (see figure 1), a field originally operated by Texaco and nowadays by Apache. The field produces oil with associated gas with a GOR exceeding 800. The producing sands are located between 4500 and 7300 feet and the average porosity is circa 28%.

Texaco PTD had acquired a 4-component baseline survey of 9.0 km^2 in July 1997. The cross-spread acquisition configuration involved a primary vessel shooting with a single-source array on a 25 by 25 m grid, and a recording spread of four cable lines lying at a depth of 337 feet on the sea floor. The receiver lines were separated by 400 m and each line supported six 4-C receivers, spaced 200 m apart. The original bottom cables were left in place for the second survey. Unfortunately three original cables were lost, due to fishing trawler activity in the area. The acquisition of the second survey was completed in April 1999. Four sea bottom cables were re-laid and trenched as close as possible to the old locations. Three additional cables that do not concern the 4-D study were added to the field layout for further studies of the coupling conditions. The processing of the multi-component data sets began at CGG's Houston processing center in the fall of 1999.

Repeatability, or rather the lack of it, was the first issue to be addressed. While the redeployment of the layout during the second acquisition led to an acceptable mis-positioning of the 4-C receivers of the order of 20 m, two of them were found to be located more than 100 m away from their planned positions. Errors in the orientation of the horizontal geophones between the two acquisitions were determined and corrected for. More importantly, the coupling conditions to the sea floor were found to be variable, not only between the two surveys, but also between geophones of the same survey.

In the acoustic mode, the repeatability issue had little impact on the quality and resolution of the final data volumes. The acoustic 4-D signal was extracted by matching the second survey data volume, of higher quality, to the baseline data volume. Clear differences could be observed, despite the relatively short time-lapse (18 months) between the two surveys. Specifically, the difference in the acoustic response at the 4500' sands level indicates the release of free gas.

Maximum attention was given to the processing of the data acquired by the horizontal geophones. Indeed, it is well known that the task of processing shear data generated by the P to S conversion mechanism is more difficult than processing acoustic data. These difficulties may arise among others from the presence of static time shifts in the converted mode due to shallow sediments, the asymmetry of the conversion ray path, or the presence of azimuthal anisotropy in some geological layers.

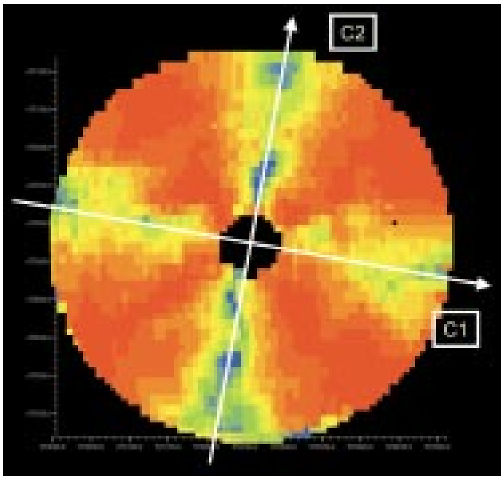

Fig. 2: Amplitude ratio between the radial and transverse components in a window between 2500 and 2700 ms of a common geophone gather. The two natural axes of anisotropy can be easily seen.

Teal South data was characterized by strong converted shear energy that produced high-quality images. Due to the relatively quiet marine environment, the study of the anisotropy showed shear waves polarized along two orthogonal natural axes (figure 2). The anisotropy defines two shear wave fronts, one travelling faster (along C_1) than the other (along C_2). The directions of the axes are constant for all the receivers, with the "slow" axis pointing towards the Mississippi delta. This splitting of the shear wave provides interesting information about the stress conditions at Teal South. The processing flow was resumed after rotation of the data volumes in the new coordinate system defined by the two natural axes.

The PS final data volumes show that the shallow events (down to 2000 ms PS time) are affected by the sparse acquisition geometry and by the presence of the anisotropy. Nevertheless, the final resolution achieved at the target level is unusually good, a result certainly due to careful processing (see Figure 3). The results also show that coupling issues had more impact on the horizontal geophones than on the vertical ones, with the trenched geophones leading to a better frequency content. As a consequence, the PS 4-D signal was estimated after matching the C_1 and C_2 volumes from the second survey to the baseline volumes. For instance, figure 4 shows time slices through the C_1 volumes at the level of the 4500' sands. The fact that the images show the same event recorded by the two surveys proves that the converted waves processing has actually preserved the relative amplitude, an obvious requisite for time-lapse studies.

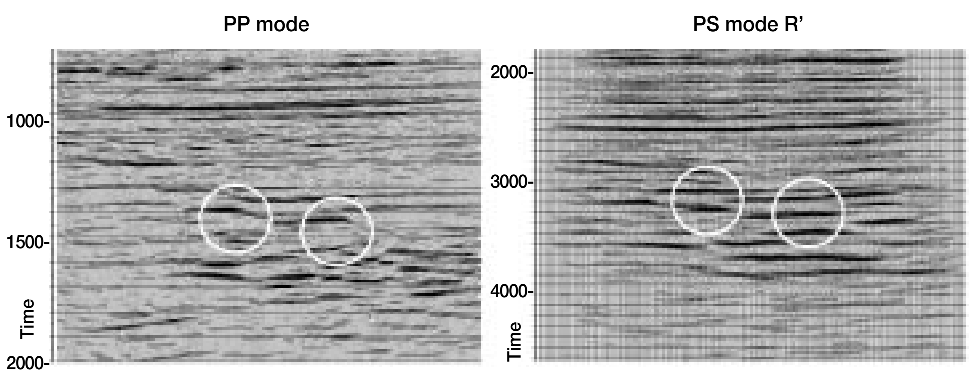

Fig. 3: PP and PS mode migrated sections on a specific inline of the second acquisition data set.
The PS mode section corresponds to the radial component, after compensation for the anisotropy.
The circled events correspond to the same reflectors. Note the vertical resolution of the PS data.

The lack of coherent signal on the time slice of the difference confirms that the strong difference observed on the acoustic data at that level is related to the release of gas.

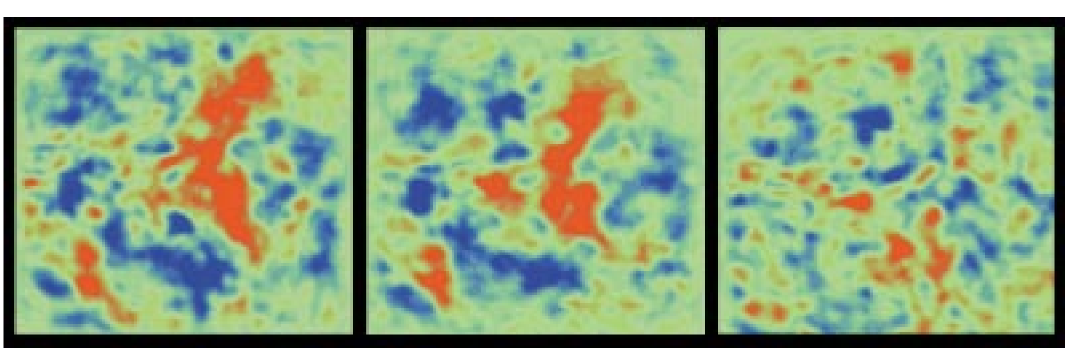

Fig. 4: Time slices at 3372 ms through the "fast" C_1 volumes, after matching.
On the left, first acquisition.
In the center, second acquisition.
On the right, the time slice of the difference.
The three images are on the same amplitude scale.
The corresponding time slices through the "slow" C_2 volumes show images of similar quality.

The processing of the Teal South pilot is a definite success. Despite the short time lapse of 18 months between the two acquisitions, clear differences can be observed at the reservoir levels. The processed data is being distributed among consortium members for further work relating to the dynamic description of the Teal South reservoirs.