Detecting reservoir fractures and their orientation using multi azimuth walkaway VSP.

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Abstract

Four walkaway VSP lines were acquired in the Kashagan East 1 well located in the Caspian Sea. Fracture orientations in the reservoir were obtained by acquiring data from multi azimuths and offsets recorded with several 3-component geophones lowered into the carbonate zone. Orientations were detected by interpreting the polarization of the fast and slow shear waves (figure 1) observed in the horizontal geophone component data.

Introduction

The oil column in the Kashagan East 1 well spans several hundred meters in depth and can be productive only if fractures exist in the reservoir. The well was drilled to a total depth of about 4500 m and the water depth in the area is only a few meters.

OKIOC acquired 4 walkaway VSP lines to illuminate the reservoir zone (figure 2) with high resolution (shallow geophone settings), to allow for calibration of their AVO model (middle geophone settings) as well as to detect fracture orientations (deep geophone settings), as described in this paper.

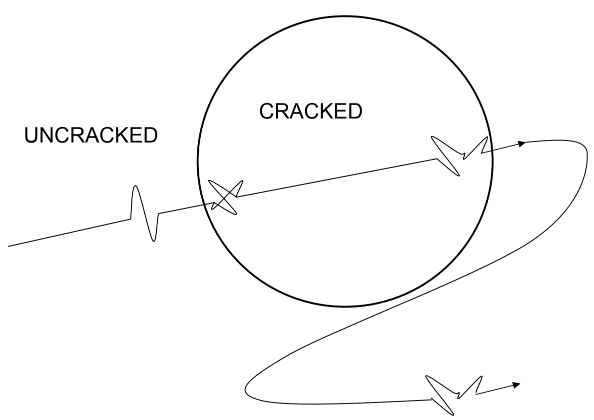

Figure 1 - Schematic illustration of shear wave splitting. Upon entering a region of effective anisotropy, such as a rock containing aligned cracks, the shear wave splits into phases with the fixed polarizations and velocities determined by the particular direction of the ray propagating through the anisotropic symmetry. Once the wave returns to an isotropic region, or when being recorded, a characteristic pattern is retained in the 3-D shear wave train (from Crampin, 1986).

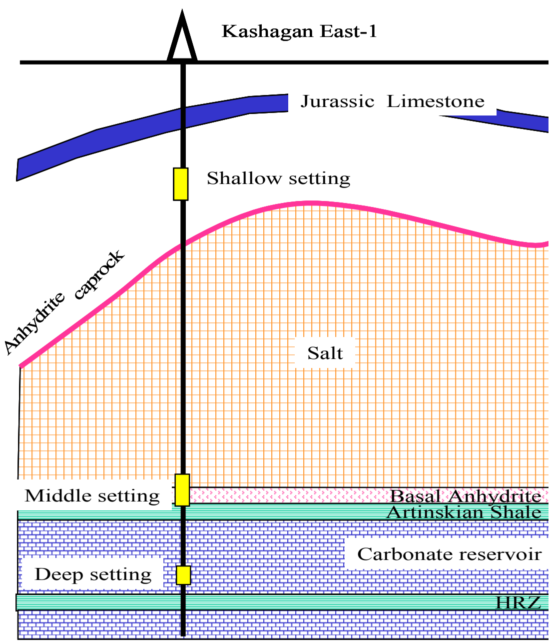

Figure 2 – Outline of the geology around and receiver configuration in the well.

Down going shear waves were recorded by multi component VSP acquisition. Using a standard air gun cluster the recorded down going shear waves are converted waves (P-waves transmitted to shear waves). In a vertically cracked medium and with vertical propagation, the polarization of the faster shear wave indicates the crack orientation in the horizontal plane. Hence, interpreting the polarization of the fast and slow shear waves allows us to detect the fracture orientation.

Acquisition parameters.

The 4 walkaway lines were shot with +/- 4 km long lines relative to the well head. The directions (20, 72, 114 and 157°N) were chosen based on the direction of the existing 2D surface seismic data. From each line, 10 shots were selected for shear wave splitting detection. The shots were selected evenly with +/- 500 to 2500 m source to receiver offsets. The 5 level array (at depth ~4300 m) in the well is the 'deep setting' shown in figure 2.

Processing sequence

After correction for system delays and data editing the source and receiver configurations were regularized to 2D geometry with 25 m source spacing. Each tool orientation was calculated by polarizing the X- and Y-component (horizontals) based upon both the down going P direct arrival and the locations of the source and receiver. Median filters were used to remove the down P, up P and up S (converted) waves. Down going shear waves were extracted from the remaining wavefield (figure 3).

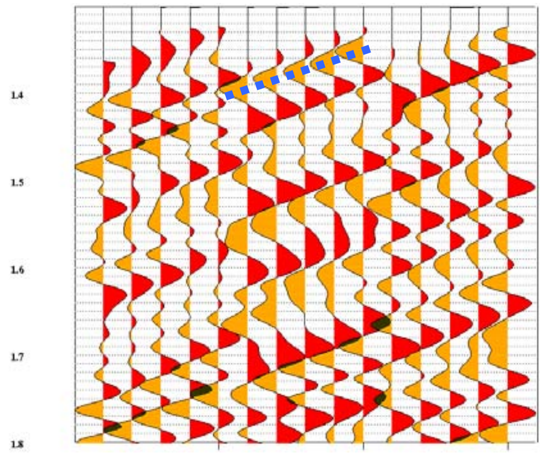

Figure 3 – Down going shear waves from Line 20° N, offset +2000 m. Trace 1 is bottom geophone, trace 5 is top geophone, trace 1 to 5 is Z component, trace 6 to 10 is horizontal inline component and trace 11 to 15 is horizontal crossline component.

The first arriving down going shear wave was picked from each of the 5 levels in the 40 shot gathers (blue line in figure 3). Because the geophones were located inside the reservoir, the first down going shear wave event was assumed to be a P-wave traveling from the surface and transmitted to a shear wave at top of the reservoir. The particle motion of the shear waves were identified by running hodogram analyses on the 200 gathers (40 shots times 5 levels).

In the absence of shear wave splitting (isotropic media) the hodograms would display the linear particle motion radiating from the source and registering only on the horizontal inline components (Crampin, 1985). Since strong down going shear waves are seen on the horizontal crossline components we assume this to be a result a result of fracture related splitting (5 last traces in figure 3).

Results

Figure 4 shows one example of the 200 hodogram analyses. Shear wave splitting is clearly identified when a particle motion is first seen in the direction of the fast shear (green line) and later in the direction of the slow shear (red line). The window of analysis was -20 to +60 ms relative to the time picked (blue line in figure 3). The direction of the fast shear is parallel to the strike of the fractures. Knowing the tool orientation allows us to plot all 200 fracture orientation detections in a rose diagram (figure 5).

Conclusions

We have identified two main fracture strike directions (figure 5): one dominant at ~125° N and another at ~15° N. These data fit well with the stress regime interpreted from the surface seismic in the area. Thus, this survey clearly demonstrates the potential of using VSP data for analyses of fractured reservoirs.

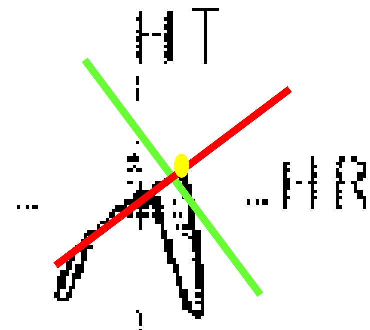

Figure 4 – Hodogram from one source-receiver combination illustrating the observed shear wave splitting. The particle motion starts at the yellow circle and moves along the black line with the direction of the green line (fast shear parallel to the fracture strike direction). Later the particle motion of the following slow shear wave was detected, ~90 degrees off from the fast shear wave. HR labels the direction of the horizontal inline component, parallel to the source line direction.

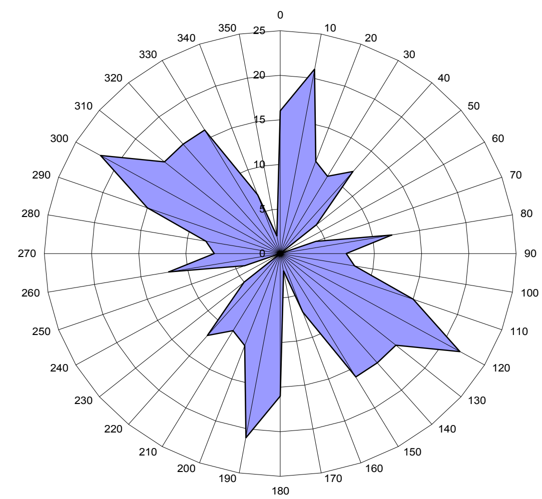

Figure 5 – Rose diagram showing interpreted strike directions for the detected fractures. The direction is shown as an angle relative to north around the circle. The extension of the blue area is a measurement of the number of detections (with 5 detections per circle, as numbered in the figure). The diagram is mirrored along the 0 to 180 ° axis for illustration purposes.

References

Crampin, Stuart, 1985: Evaluation of anisotropy by shear-wave splitting, Geophysics 50, 142-152.
Crampin, Stuart, 1986: Geophysical Development Series, Volume 1. SEG Publication. Tulsa, Oklahoma.