Previous observations have suggested that the effects of fractured-related seismic anisotropy is observable, particularly in vertical seismic profiles (VSPs) (Crampin et al. 1986; Johnston 1986, and among many others). Fractures can be a significant feature of hydrocarbon reservoirs where their presence (either natural or induced) may increase the productive capacity. Many reservoirs with a low matrix permeability would not be commercially attractive without a natural or induced fracture system. Fractures at the shallow depths are also important for the fluid flow in engineering and hydrological applications. The recognition and observation of shear-wave splitting offer the possibility of using seismic shear-waves to evaluate the fracture parameters (orientation, dip, fracture density, etc), and pore-fluid properties. Crampin (1990) has suggested that such techniques offer possible ways of monitoring reservoir development during enhanced oil recovery. However, reservoir description and recovery monitoring require high-frequency and broad-band seismic data. A potential technique, as suggested by Nur (1989), is to take advantage of the distribution of injection and recovery wells, to monitor the reservoir by mounting cross-hole surveys between wells.

As part of this attempt, a combined reverse vertical seismic profiles (RVSPs) and cross-hole surveys were performed at five shallow boreholes (down to 45 meters) at the Conoco Borehole Test Facility (CBTF), Oklahoma (Queen and Rizer 1990). The study area is highly fractured with two distinct fracture sets visible at the surface. Conoco downhole rotary sources were located downhole and have been decomposed into linear equivalents of radial and transverse components, i.e. in-line and cross-line. Three-component geophones were located on the surface (for RVSPs) and in wells (for cross-hole surveys). The surveys cover several different azimuths, which makes it possible to study fracture-induced azimuthal anisotropy.

Several characteristic features related to seismic anisotropy can be seen on the data. Shear-wave splitting can be identified with the maximum delay between two split shear waves of about 3 to 5 milliseconds for the source-geophone distance of less than 100 meters, which indicates a large fracture density. The amplitudes on the vertical components are large in comparison with horizontal components for both in-line and cross-line sources, even for the azimuth where the source and geophones are assumed to be in the dominant fracture direction. A possible interpretation is that the fractures are slightly dipping. Perhaps the most significant observation is that the observations display distinctive particle motion, which can be interpreted as guided waves (or interface modes).
between wells, result from interference between direct, reflected, refracted, and mode converted waves, at high incident angles in a multilayered structure.

The polarizations of leading shear-waves from the cross-hole surveys extracted with automated techniques are consistent with the fracture orientation if the fractures are deviated slightly from the vertical direction. Finally, we match the observations with the synthetic seismograms, which further confirm our analyses. In conclusion, CBTF site is highly fractured with a fracture density of at least 0.1, and (at least) the dominant fracture set is slightly deviated from vertical orientation. The combination of crosshole surveys and RVSPs are an efficient way to evaluate fracture parameters. The guided waves observed in cross-hole surveys can be used as new tool for help identifying fracture-induced anisotropy.

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REFERENCES