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S-wave birefringence and subcritical stress in north central Oklahoma, USA

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It has been long known that the preferred crack alignments and fractures in rock cause seismic anisotropy and corresponding S-wave birefringence. Here the S-wave birefringence caused by the preferred alignment of cracks due to subcritical stress in the granitic basement of north central Oklahoma is examined. The data used for this study was collected during the IRIS Community Wavefields Experiment (CWE) in June and July of 2016, where more than 300 3-component (3-C) short-period seismographs were deployed in dense arrays with station spacings of 100m or less. These arrays were also in an area where many small earthquakes were occurring on a monthly basis, so that many were recorded by these arrays.

The seismic data were cut from the original 30-day field records to produce short 3-C SEG-Y records of local earthquakes and explosions at a variety of back azimuths from the CWE array. Each 3-C record was rotated to the back azimuth of the source, such that the components become vertical, radial, and transverse with respect to the source. Vertical components are dominated by P arrivals, while radial components are dominated by SV arrivals and transverse components are dominated by SH arrivals. Seismic sections of the radial components of the array are then plotted in one color and overlain by the corresponding transverse components from the same array in another color. S-wave birefringence can then be directly observed as the time difference between arrivals, particularly first arrivals.

S-wave birefringence is proof of seismic anisotropy and some characteristics of that anisotropy can be observed in record sections. For instance, birefringence is high along some azimuths and absent along other azimuths. Where birefringence is absent arrivals coincide, this could be either due to arrivals crossing or arrivals meeting but do not crossing. The latter case is important because it is the direction of an axis of symmetry for the anisotropic medium where the arrivals are propagating. This is also the case is observed in the record sections. The axis of symmetry observed in the record sections has an azimuth of 335 +/- 5 degrees. The fact that an axis of symmetry with no birefringence exists in the horizontal plane indicates that the anisotropic medium exhibits hexagonal symmetry, also known as horizontal transverse isotropy (HTI). It indicates that cracks and fractures are open perpendicular to the axis of symmetry and closed in other directions.

Because of the large number of earthquakes occurring in this area a number of studies have been conducted on the in-situ stress orientations. In the sedimentary section overlaying the basement close to the CWE seismic array, borehole image logs indicate that the azimuth of drilling induced tensile fractures is 59 +/- 12 degrees. This is interpreted as the orientation of the maximum horizontal stress in the borehole. The axis of seismic anisotropy, which indicates the direction of minimum horizontal stress is 335 degrees or a difference of 84 degrees, nearly perpendicular.