Azimuthal anisotropy potpourri

D. F. Winterstein, G. S. De and *M. A. Meadows* - Chevron Petroleum Technology Co.

Until the 1980s, anisotropy to exploration geophysicists meant only transverse isotropy with a vertical symmetry axis (TIV), the kind of anisotropy one could get from combining thin, isotropic horizontal layers. Shear-wave data recorded on orthogonal horizontal receivers forced a paradigm change: Many such data could be explained only in terms of anisotropy with a higher degree of complexity than TIV. Initially little was known about this anisotropy other than that it caused shear-wave splitting along vertical raypaths. Because azimuthally isotropic rocks, including rocks of TIV symmetry, cannot cause such splitting, the newly detected anisotropy was often called simply azimuthal anisotropy.

Since then a great many measurements of shear-wave splitting have been done on in situ rocks. We now know a fair amount about what ranges of S-wave splitting are likely, but we still know little about the actual anisotropy. Many studies assume a model of transverse isotropy with a horizontal symmetry axis, where the anisotropy is assumed to be caused by a single set of aligned vertical cracks. A few attempts to measure in situ rocks in detail have found them to be orthorhombic or monoclinic.

VSP and crossed-dipole log measurements have established that anisotropy is blocky almost everywhere. It is rare to measure constant S-wave splitting from top to bottom in any well. Instead, the rocks will usually have at least two thick zones of relatively constant splitting, where the degree of splitting, or birefringence, often changes abruptly from one zone to the next. However, while birefringence in a given zone often appears more or less constant at the VSP scale of resolution, high variability seems to be the rule in crossed-dipole logs. Also, transitions that appear sharp to the VSP may be more gradual to the crossed dipole. Nevertheless, at the scale of tens to hundreds of meters, blockiness often is an accurate characterization of observed vertical birefringence.

A common pattern is for rocks to be moderately birefringent over several hundred meters near the surface but then to become isotropic at greater depths. In one case no birefringence was detected from surface to TD at about 1.0 km. In other cases large birefringence near the surface is followed by small birefringence at depth. Less common is the reverse situation, where small birefringence at small depths is followed by larger birefringence at greater depths; but that also happens.

The level of birefringence detectable by multicomponent VSP depends both on data quality and on the consistency of the birefringence over a thick depth interval. In some cases measurements smaller than 0.5 percent seem reliable. Birefringence magnitudes measured in Chevron wells have ranged from zero (i.e., none detectable) to 20 percent, but all values above 3.5 percent were observed in the southwest San Joaquin basin of California within 30 km of the San Andreas fault, and most of those were from depths less than one kilometer. Recent studies suggest the minimum level of birefringence detectable by crossed-dipole logs is not yet established. Another common feature of azimuthally anisotropic rock-originally discovered by VSP but subsequently supported by crossed-dipole measurements-is change of S-wave polarizations with depth. Not only are birefringence magnitudes blocky, but polarization directions are similarly blocky in that a single polarization direction often persists over a considerable depth interval and then changes abruptly and by a large amount to a different azimuth. The new polarization then persists over a second considerable interval. Almost every Chevron VSP in California has shown such changes in polarization direction. Such changes have been less common in VSPs recorded elsewhere. Layer stripping or other special analysis technique is usually necessary to observe such changes. What causes the anisotropy to be blocky is not well understood in most cases. The boundaries between zones of different birefringence usually have not corresponded to obvious lithologic boundaries.

(1998) Geo-triad '98: Abstracts: Plenary, Oral, Posters, Core Workshop

Of what practical use is this hard-won, high-cost knowledge of azimuthal anisotropy? There are many conceivable uses, among them the study of stress or fracture orientations for oil field development. A potentially important use is related to the recording of converted (P-S) shear waves. Converted shear waves have taken on new importance for reflection seismology as ocean-bottom multicomponent geophones have come into widespread use. When recording 3D data from azimuthally anisotropic media, there will be two S waves, not just one, at nearly every offset and azimuth. To process and analyze the data properly requires separating the fast and slow S waves, and separating the waves requires knowing the wave polarizations. In isotropic or TIV media, the polarizations are easily predicted from the shooting geometry. For azimuthally anisotropic media, modeling shows that polarizations can vary irregularly with azimuth and offset.