CC/NUMBER 40
OCTOBER 1, 1990

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Crampin S. A review of wave motion in anisotropic and cracked elastic-media.
Wave Motion 3:343-91. 1981.
[British Geological Survey, Edinburgh, Scotland]

The article reviews pioneering investigations into seismic wave propagation in anisotropic solids by modelling with computers. These indicate that the most diagnostic effect of anisotropy is shear-wave splitting, and such splitting, due to stress-aligned fluid-filled inclusions, is now observed almost everywhere in the crust. This has important applications to enhanced oil recovery, earthquake prediction, and much else besides. [The *SCI* ® indicates that this paper has been cited in over 80 publications, making it the most-cited paper from this journal.]

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Seismic Anisotropy in the Earth's Crust

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May 9, 1990

For many years the assumption of seismic isotropy (elastic properties independent of direction) in the crust has been extraordinarily successful in modelling the Earth's structure, particularly for finding oil. I first got interested in anisotropy (properties varying with direction) in attempting to interpret the particle motion of surface waves propagating across Asia. The equations of motion for isotropy are simple. The equations for anisotropy, with up to 21 elastic constants and necessitating complex arithmetic, are not. Similarly, laboratory experiments in anisotropy are difficult to set up. Almost the only way that one can begin to gain any physical insight into the behaviour of seismic waves in anisotropic solids is by making numerical experiments, using computer programs as "laboratory" tools. Such procedures are common enough now, but were much less common when I began, when computers were much smaller and slower.

Eventually, I could explain the surface-wave observations by a thin layer of anisotropy (probably crystalline) below the Moho discontinuity, 20 miles below the surface.[1] I then began to look at body waves in cracked solids.[2] There were no observations at the time, so it was largely an academic exercise, but I embarked on this long voyage through uncharted waters because I was enchanted.

It was fascinating. Although superficially similar to propagation in isotropy, the effects are subtly different, and the underlying behaviour, with three body waves instead of two, is fundamentally different. It was an entry into a completely new environment for wave propagation, where everything was not quite what it seemed. The principal parameter for interpreting waves in isotropic models is the travel time of the faster *P*-wave, with longitudinal particle motion. In anisotropy, the principal effect is shear-wave splitting (bi-refringence), where a shear wave, with transverse motion, splits into two or more components with different polarizations and different velocities.

The article reviewed over 30 papers, setting up the equations for computer modelling and reporting the first (numerical) experiments investigating body and surface waves in multilayered cracked and anisotropic structures. There were real discoveries. I was lucky to find such an intriguing subject that had not been investigated and was able to clean up many easy tidbits. I was also lucky to find a patron in the British Geological Survey (BGS), Bill Bullerwell, who encouraged me to pursue a line with no obvious applications. Such freedom would not be possible with the financial constraints in today's BGS!

The breakthrough came when developments in technology allowed digital three-component recording at high sampling rates for the first time. Shear-wave splitting was observed almost everywhere in the uppermost 10 to 20 km of the crust in all sorts of rock and in all kinds of tectonic regimes.[3]

Shear-wave splitting can be interpreted in terms of the internal crack- and stress-structure of the rock. This ability to estimate the internal structure of the *in situ* rockmass by monitoring shear waves recorded remotely has many applications.[3] These range from investigating the internal structure of hydrocarbon reservoirs[4] and enhanced oil recovery,[5] to possible techniques for monitoring stress changes before earthquakes.[6] This understanding of shear waves opens a new window for examining the interior of the Earth and has been recognized by the oil industry by the Conrad Schlumberger Award (1986) of the European Association of Exploration Geophysicists and the Virgil Kauffman Gold Medal (1988) of the (American) Society of Exploration Geophysicists. A small consortium of companies currently supports much of my present research, but none of this would have been possible without almost 50 coauthors, and the collaboration and enthusiasm of a small group of colleagues and students to whom I owe many thanks.

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1. **Crampin S & King D W.** Evidence for anisotropy in the upper mantle beneath Eurasia from generalized higher mode seismic surface waves. *Geophys. J. Roy. Astron. Soc.* 49:59-85, 1977.
2. **Crampin S.** Seismic wave propagation through a cracked solid: polarization as a possible dilatancy diagnostic. *Geophys. J. Roy. Astron. Soc.* 53:467-96, 1978. (Cited 75 times.)
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5. -------. The potential of shear-wave splitting for monitoring recovery: a letter to management. *Leading Edge* 9:50-2, 1990.
6. **Crampin S, Booth D C, Evans R, Peacock S & Fletcher J B.** Changes in shear-wave splitting at Anza near the time of the North Palm Springs earthquake. *J. Geophys. Res.* (In press, 1990.)

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