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Seismic Anisotropy in the Lower Oceanic Crust

HESS[1] suggested that upper mantle compressional wave velocities near the Mendocino and Molokai fracture zones of the Pacific vary with azimuth and this anisotropy is the result of preferred mineral orientation. Recent seismic refraction evidence indicates that in many regions the Earth's upper mantle is anisotropic[2–4] and the observed anisotropy in the upper mantle correlates well with laboratory studies of velocity anisotropy in dunites and peridotites[5,6]. Although anisotropy complicates seismic refraction investigations its importance cannot be overestimated; it places severe limitations on probable upper mantle compositions and provides a means of estimating the stress fields which existed during the formation of preferred mineral orientation in the upper mantle.

Laboratory studies of seismic velocities in rocks[7,8] show that many common crustal rocks are highly anisotropic to compressional wave propagation, so it is plausible that in many regions the Earth's crust is anisotropic, and Dorman[9] has recently presented seismic data which indicate anisotropy of the continental crust in the south-eastern United States. Here I report evidence for seismic anisotropy in the lower oceanic crust, which is interpreted as due to preferred orientation of amphibole.

The lower oceanic crust has been frequently referred to as being rather uniform in seismic velocity. This is certainly the case when its velocities are compared with those of the overlying layer 2 of the oceanic crust. But a plot of lower oceanic crustal velocities tabulated by Raitt[10] shows considerable variation (Fig. 1). Three recent seismic investigations of the oceanic crust suggest strongly that some of the variation may result from anisotropy.

Keen and Barrett[4], in their study of mantle seismic anisotropy of the Pacific Ocean basin off the coast of British Columbia, report oceanic crustal velocities for two reversed profiles, one in a north–south direction and the other in an east–west direction. The shot lines crossed one another at approximately 134° W and 51° 30′ N. The crustal structure determined by Keen and Barrett gives a layer 3 velocity of 6.99 km s^{-1} for the north–south profile and a velocity of 6.73 km s^{-1} in an east–west direction. A circular pattern of shots was established around these profiles to obtain upper mantle first arrivals. Keen and Barrett found 8% anisotropy in the upper mantle, but made no mention of the possible anisotropy of the lower crust in this region. Their data indicate that the low velocity in layer 3 is nearly parallel to the fast velocity in the upper mantle, which approximates the direction of seafloor spreading in this region.

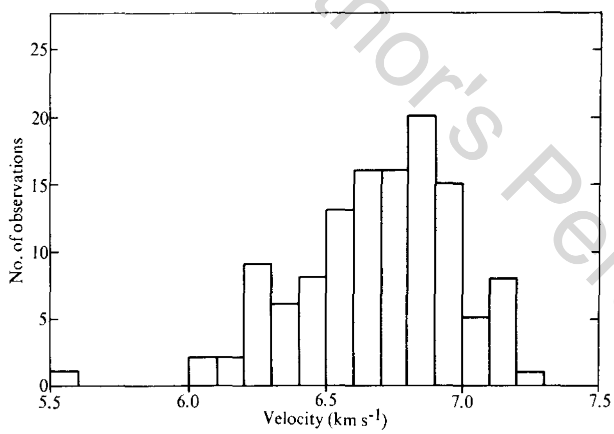

Fig. 1 Variations in layer 3 velocities (after Raitt[10]).

Seismic refraction studies along the Hawaiian Ridge[11] also suggest the presence of seismic anisotropy in the lower oceanic crust. In this study several refraction lines were run approximately normal to one another in order to investigate upper mantle anisotropy. The pertinent refraction traverses are those flanking the ridge crest approximately parallel (Y, Z) and normal (B, E, F, N, X) to the trend of the ridge. The lower crustal velocities parallel to the ridge are fast (6.9 to 7.1 km s^{-1}), whereas velocities normal to these traverses tend to be relatively slow (6.3 to 6.7 km s^{-1}).

Seismic refraction profiles of young oceanic crust in the Scotia Sea of the South Atlantic Ocean[12] suggest that layer 3 may be highly anisotropic in this region. Profiles 83 and 84, which are approximately normal to each other in the West Scotia basin, have layer 3 velocities of 6.29 and 6.75 km s^{-1}. Profiles 101 and 102, located on the South Georgia platform, are also perpendicular but unreversed, and have lower crustal velocities of 6.95 and 6.18 km s^{-1}. For both sets of stations the slow velocities are north–south. Ewing *et al.*[12] noted the discrepancy in velocities given in profiles 101 and 102 and suggested that they are apparent velocities produced by a dipping layer.

It is difficult to attribute the wide range in velocities of layer 3 in these regions to observational error. Rather, it seems likely that these observations are related to seismic anisotropy in the lower oceanic crust. Detailed seismic investigations of crustal anisotropy will be necessary to establish how common anisotropy is in the lower crust and the exact nature of this anisotropy.

Recent studies of elastic wave propagation in rocks suggest a probable cause of oceanic crustal seismic anisotropy. Common igneous rocks are nearly isotropic[7], so lower crustal regions which contain abundant gabbro would be expected to show little variation of compressional wave velocity with azimuth. Metamorphic rocks are highly anisotropic[7,8], and in particular, hornblende bearing metamorphic rocks such as amphibolites have velocities similar to those observed for layer 3, combined with a strong preferred mineral orientation which produces high seismic anisotropy. Christensen[8] found maximum compressional wave velocities at 1 kbar of 7.21 and 6.97 km s^{-1} for propagation parallel to maximum concentrations of hornblende *c* axes in two amphibolites. Further, the hornblende *c* and *b* axes show a strong tendency to lie in the foliation planes of the amphibolites. Propagation normal to the foliation planes gave minimum velocities at 1 kbar of 6.29 and 6.01 km s^{-1}. If the crustal anisotropy cited here does arise from preferred hornblende orientation, it seems that in the Hawaiian and Scotia Sea regions the amphibolite foliation planes are dipping steeply and the hornblende *c*-axes maxima are nearly horizontal and parallel to the fast velocities. If the two profiles off British Columbia give maximum anisotropy, the lower anisotropy in this region would be consistent with a nearly horizontal foliation plane.

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