High seismic P-wave-speeds, radial anisotropy and fossilised superplumes

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Superplumes, originating deep in the Earth's mantle, are thought to have triggered prolific melting, eruption of extensive basaltic lavas that form Large Igneous Provinces (LIP), and climate change that led to mass extinctions. Although direct seismic imaging of plumes has proved challenging, we show from new passive and active source seismic studies that parts of the now dispersed largest known LIP - the 120 million year old Ontong-Java-Manihiki-Hikurangi Plateau (OJMHP) - are associated with unusually high upper mantle P-wave speeds. P_n phases of ~8.8±0.1 km/s at depths of 25-60 km in a region at least 1000 km wide show negligible azimuthal seismic anisotropy, but strong radial anisotropy (~10%) is detected from split S-wave arrivals (V_{sh} ~ 5.1 km/s, V_{sv} ~ 4.6 km/s) generated by a local earthquake. These data were recorded on an 850 channel, 80 km-long, active source array spread out across the lower North Island of New Zealand. Here the Hikurangi Plateau is being subducted beneath the eastern North Island, and the P_n phase is from the mantle of the subducting plateau. Similarly high P_n speeds are also obtained from the Manihiki Plateau, on mutually perpendicular lines.

These seismic results are characteristic of forsterite-rich (Fo_{90}) olivine with a distinct crystallographic and seismic fabric, as a consequence of a strain regime involving isotropic horizontal dilation and vertical flattening. We interpret this as the AG fabric that has been identified from dredge samples from the ocean floor of the western Pacific, and also generated in the lab by high pressure experiments. Measured P-wave speeds on the AG fabric rocks are 8.8 and 8.7 km/s in the X and Y planes, and 7.8 km/s in the Z plane. The strain regime implied by the AG fabric is atypical of plate tectonics and large-scale mantle convection, and therefore these rocks should be relatively rare. The fact that AG fabric rocks make up ~ 10-15% of samples from the sea floor suggests there must be some significant earth-process to produce the fabric. Based on the link of these high wave speeds with the OJMHP we suggest that the AG fabric is generated by late stage gravitational collapse and compaction in the top 10-20 km of a highly depleted, mushroom-shaped, superplume head. This hypothesis is further supported by the second largest LIP – the Siberian traps- also being associated with sub Moho P_n speeds of 8.7-8.9 km/s. Finally, identification of the AG fabric on a spatial scale >1000 km lends support to the plume hypothesis, and provides a seismic tool to track plumes long after the thermal effects have ceased.