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Seismic anisotropy; a window on how the Earth works: multiple mechanisms and sites, from shallow mantle to inner core

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Since the seismic anisotropy (SA) in the uppermost oceanic mantle was discovered [1] and attributed to the shearing of olivine by an MOR-divergent flow velocity gradient, rheological mobility interpretations of this type have dominated studies of SA there and elsewhere in the Earth. Here I describe two other SA-generating mechanisms. I will reason that one of these, the anisotropic crystallization from melt, bids fair largely to replace the shearing one and be present in even larger volumes of the Earth, both within its outer 100km and in the Inner Core. The other, the layered deposition of disparate substances, offers to explain the ULVZs and SA in D".

We start with the Upper Mantle. New constraints on its rheological properties and dynamical behaviour have come from two directions. Firstly, contrary to the seismologists' rule-book, the oceanic LVZ is no longer to be thought of as mobile because the presence of interstitial melt strips out the water-weakening of the mineral structure [2, 3]. So we require a substitute for the divergent-flow model for MORs. In fact it also has three other, apparently unrecognized, dynamical inconsistencies. One of these [4] is that there are in the record many rapid changes of spreading rate and direction, and ridge jumps. This cannot happen with a process driven by slow-to-change body forces.
Secondly, during the past decade, my work on the global dynamics for the past 150Ma (I will show examples) has shown [4 - 7] that the tectospheres of cratons must extend to very close to the bottom of the upper mantle. And that East Antarctica's 'keel' must actually reach it, because its CW rotation [7] suggests it has been picking up an electromagnetic torque from the CMB via the lower mantle. Xenoliths suggest that the reason for this downwards extent of 'keels' is the same as [3].
To meet these two sets of constraints I will demonstrate my now not-so-new MOR model, which has a narrow, wall-accreting subaxial crack. Among its many features, including generating internally a very strong push-apart force, the straightness of MOR segments is the automatic result of accretion controlled by lateral cooling [8]. Olivine crystal has grossly anisotropic thermal conductivity, high on the a-axis [9] so, contrasting with the much lower conductivity of melt, suitably oriented ones on the crack walls grow the fastest and build in the seismic anisotropy from the start. For ophiolites, I will illustrate a close relative of this thick-plate model, but geared to their specific near-continent genesis and emplacement, which provides for their very real shearing and anisotropy at the crust-tectonite junction and for the 25 – 50 km metamorphic pressures in their soles [10]. A remarkably fertile model for the genesis of intraplate volcanism, without plumes, is also provided by this thick-plate perspective of plate dynamics [11].
We now move to deeper in the mantle. Attachment of the LVZ material to the ocean plate and the low conductivity of its interstial melt renders it still buoyant when the bigger ridge push makes it subduct [12]. Seismological transects of subduction zones show that this heat re-emerges at depth to partially melt the interface former oceanic crust, the result (on experimental evidence) being stishovitic residue plus (because of its compressibility) very dense ultramafic melt [12]. Both will shower into the lower mantle and eventually form layers on D", the melt being prevented from freezing because that would need the energy to increase its volume. Hence the seismic anisotropy of D".
Moving still deeper, to the outer-core flows from which the Inner Core has grown. I attribute its cigar shape to preferential addition to its polar regions, from a downwelling flow, not to deformation of the IC, except perhaps as weak isostatic adjustment to that polar addition. I speculate that polar-aligned columnar growth of iron crystals, although themselves not strongly anisotropic, would impound 'less pure' alloy between them, with lower seismic property, thus giving the anisotropy. A.m. conservation in the poleward outer-core flow just below the CMB, needed to provide that cooler polar downwelling flow to the IC, would accelerate it clockwise. This seems likely to be the ultimate agent of Antarctica's CW rotation.
Finally we come right back to the surface, to the nominally continental crust. Important thermal epeirogenic sensitivity resides in its deep constitution [13]. But much of the crust of continental shelves and beneath deep

sedimentary basins appears to lack this sensitivity. So I have reasoned [13] that this 'intermediate crust' (IC) is the product, not of stretching, but of a sedimentation-dominated pre-oceanic stage of continental splitting that has modified crustal genesis by the MOR process but retained the accreting-deep-narrow-crack aspect and resulting seismic anisotropy. If, as geometrical reconstructions lead me to believe, this is the origin of the widespread block-and-basin structures in continents, then it offers also a fascinating explanation of the seismic anisotropy, and its direction, increasingly reported beneath the epeirogenically identifiable IC areas of crust.
In that case, as noted at the beginning, crystallization from melt would indeed emerge as the principal agent of seismic anisotropy in the Earth.

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