

binomial variation. But reed buntings and other birds⁷ seem unable to do this, because some reed bunting males fed broods in which they had no paternity. Instead, they probably use a behavioural cue such as time spent with the female during her fertile period. The male then has no information about binomial variation in paternity, and can only respond to above-binomial variation.

Dixon *et al.* did not carry out the critical analysis of variation in paternity of individual males. But if broods contain four chicks each with a 55% chance of being illegitimate, the probability of a male with

two broods having one with complete and the other with zero paternity is less than 1%. This occurred in three of the 13 cases reported by Dixon *et al.*, so it seems that there is more than enough variation in paternity. It will be interesting to investigate whether those species lacking a relationship between paternal care and paternity also lack above-binomial variation in paternity between broods of individual males. □

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GEOCHEMISTRY

Fast cleaning in the deep

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THE Earth's transition zone is something of an enigma. It encompasses the region between two seismic 'discontinuities', the first one 400 km deep in the Earth's mantle, the second 670 km deep, and as the name suggests, it marks the transition between the upper and lower mantle. The transition zone is of interest in part because of the role it plays in the fate of slabs of oceanic crust and lithosphere that are subducted into the mantle at plate margins. Although the path of subducting slabs can be traced to the base of the transition zone by seismology, what actually happens to the slabs within the transition zone and beyond remains a mystery. A current model holds that slab material may pile up for some time in the transition zone until it either descends into the lower mantle in an avalanche¹ or is swept aside by large-scale flow². But do the slabs emerge as mere shadows of their former selves?

In part, the question is how long it takes to wipe out the distinctive chemical signature of slab material. Now Farber *et al.*, on page 693 of this issue³, have measured cation diffusion rates experimentally in the high-pressure phases of Mg₂SiO₄ thought to be present at transition-zone depths. They conclude that the remarkably high rates of chemical diffusion they find will reduce the time required to mix chemical heterogeneities (such as the subducted oceanic crust) into the transition zone to three-quarters of the time required for mixing heterogeneities in the shallower upper mantle.

Mixing consists of two processes; convective thinning of heterogeneities followed by homogenization by chemical diffusion. According to these new results, chemical diffusion acts on the scale of metres in the transition zone (as opposed to centimetres within the shallow upper mantle). Heterogeneities must be thinned substantially by convection first, but be-

cause the final action of diffusion is more effective in the transition zone, the total time required for mixing is reduced.

The rate of mixing throughout the mantle is undoubtedly controlled primarily by the rate at which convection stirs the material⁴, dispersing heterogeneities into the mantle. Convection stretches and folds heterogeneities, increasing the contact area between the different components being mixed together. The final stage is when diffusion eliminates the finest-scale heterogeneities by smoothing chemical variations.

In the Earth's mantle, convective mixing thins subducted oceanic crust from its initial thickness of 6 km until it is thin enough for diffusion to destroy its distinctive chemical signature. In the shallow upper mantle, diffusive homogenization takes place when the remnants of oceanic crust are only a few centimetres thick. Because diffusion acts only in the last stages of mixing and on such a small length scale, it is usually appropriate to disregard its role in the mixing process.

The new measurements of Farber and colleagues indicate otherwise. In the transition zone, the chemical diffusivity is three orders of magnitude higher and as a result the mixing rate is faster than in the upper mantle. True, the mixing time is only about 25 per cent shorter, even for this enormous change in diffusivity; but that is enough to produce some intriguing predictions.

The higher diffusivity means that the fine-scale structure of the transition zone could be quite different from the structure in the overlying mantle. Very fine-scale heterogeneity (on a scale of 1 cm – 1 m) can exist in the uppermost mantle but only relatively coarse heterogeneity (on scales of 1 m or more) in the transition zone. Heterogeneities less than about a metre thick in the transition zone will be rapidly destroyed by diffusive homogenization.

An interesting additional effect of these results is that, if diffusive equilibrium is more rapidly attained in the transition zone than in the overlying mantle, incompatible components from slabs moving through the transition zone could be deposited more readily into the transition zone than into the overlying mantle. Over the course of hundreds of millions of years, this would add up to a significant enrichment in incompatibles, such as water, in the transition zone. Observations of high concentrations of water in the transition zone have indeed been reported by Nolet and Zielhuis⁵, who observed that seismic shear waves travelled very slowly through a region about 400 km beneath the westernmost Russian Platform. They interpret this and similar anomalies elsewhere as revealing a high water content in the transition zone associated with subduction. The high chemical diffusivity of the spinel and β -phase measured by Farber and colleagues provides a mechanism for homogenization of volatiles from the slab into the transition zone. The increased rates of mixing by chemical diffusion within the transition zone would thus paradoxically lead to development of large-scale heterogeneities between the uppermost mantle and transition zone in the form of layers with different quantities of incompatible elements.

The higher chemical diffusivities could also affect the rheology of transition-zone material. Mantle rock flows by thermally activated creep; increasing the molecular diffusivity by an order of magnitude could decrease the viscosity substantially. If the high diffusivity results in enrichment of incompatibles in the transition zone, the presence of volatiles may also reduce the viscosity. On the other hand, if an excess of garnet were present in the transition zone, that would tend to increase the viscosity⁶. Some recent work⁷ does suggest that the transition zone has a lower viscosity than the shallow upper mantle.

The next step will be to reconcile the mineral physics with additional geodynamical, seismological and geochemical data. Further constraints on the volatile content and rheology of the transition zone will help determine the composition and behaviour of this enigmatic and important region of the Earth's mantle. □

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