less 'charismatic' species.

How does the re-introduction of the red wolf relate to these ecological reasons for protecting species? Information gathered by the captive breeding programmes about, for example, artificial insemination, may be valuable in saving other less controversial taxa. Likewise, the introductions of the red wolf to islands and other areas where the coyote is absent may provide information about how to re-establish similar species. From just which taxa we learn these lessons may be less important than the lessons themselves.

Wayne and Jenks's results on the red wolf suggest that here no species is being saved (and certainly nothing of great taxonomic distinctness); that in areas where the coyote is already present, no new ecological role in the community is being created by the introduction of red wolves; and that any lessons about re-introducing species are likely to be obscured by hybridization with the coyote. No new reserves are being created for the red wolf. In this case, then, the re-introduction comes down to asking whether the red wolf's undeniable cuddliness is enough to warrant according it special attention. ☐

John L. Gittleman and Stuart L. Pimm are in the Department of Zoology, University of Tennessee, Knoxville, Tennessee 37996, USA.

EXTENSIONAL MAGMATISM

The rift narrows

Rob Ellam

OVER the past few years, physical models of the melting processes that occur in the Earth's crust and mantle, producing the lavas erupted by modern volcanoes and the igneous rocks of the geological record, have reached new levels of sophistication. Igneous petrologists, who previously relied largely on chemical information to elucidate magmatic processes, have not been slow to embrace the physical approach, but some intriguing questions have emerged. One particular puzzle is the occurrence of magmatism where there is little tectonic extension and where there is no obvious relationship to anomalously hot plumes of mantle like those beneath oceanic hotspots such as Hawaii and Iceland. Previous models had difficulty in explaining even the modest amounts of basalt found in these areas, but on page 559 of this issue[1], Latin and Waters discuss refinements in the melting models that appear to explain these somewhat enigmatic magmatic events.

When tectonic processes stretch the rigid continental and oceanic plates (lithosphere), the underlying convecting mantle (asthenosphere) is forced to rise. If the pressure release is sufficient, the mantle will melt. To predict the amount of melting for a given degree of lithospheric extension requires knowledge of the mantle solidus curve, the line on a plot of pressure versus temperature that defines the initial occurrence of partial melt. In 1988, McKenzie and Bickle[2] used the results of experimental melting studies to define the solidus and thereby calculate the melt distribution beneath a mid-oceanic ridge. They concluded that for mantle of normal temperature, that is where there is no influence from a hot ascending mantle plume, melting is restricted to the upper 50 km or thereabouts of the asthenosphere.

In a continental rift, like the North Sea graben studied by Latin and Waters, the pre-rift lithospheric thickness probably approaches 120 km, so that the lithosphere would need to thin by a factor of about 2.5 (the β-factor) while stretching before the rising asthenosphere penetrates the maximum depth at which melting occurs (about 50 km). Not least because the amount of extension is critical in the assessment of the petroleum potential of a rifted basin, β-values tend to be well constrained in the North Sea. For the most stretched part β is only about 2, yet basalts from the Forties volcanic province indicate that quite substantial magmatism has occurred, apparently without the influence of elevated mantle temperature.

McKenzie and Bickle[2] themselves identified the uncertainties likely in laboratory experiments as an important restriction on their conclusions. Experimental charges are, by necessity, both very small and enclosed. Thus the experiments simulate batch melting, in which all the melt produced remains in equilibrium with the solid residue until it separates as a single batch. In the mantle, even very small melt fractions (less than 2 per cent by volume) are probably able to escape from a deforming matrix[3], and a 'dynamic' melting model is perhaps more appropriate (see, for example, the recent paper by Elliot *et al.*[4]). The melt distribution generated by dynamic melting might differ significantly from the experimental prediction.

Now McKenzie and O'Nions[5] have used an inversion technique to calculate melt distributions from rare-earth-element (REE) abundances in mid-ocean ridge basalts, assuming a Rayleigh melting process in which melt and matrix separate as soon as the melt is formed, and which therefore better approximates a dynamic melting process. Critically, melting commences at about 80 km depth, which corresponds to $\beta = 1.5$ for a normal initial lithospheric thickness. Using the new calculated melt distributions it is possible to have melt formation between 80 km and the base of the stretched lithosphere in low-β rifts such as the North Sea, without recourse to elevated mantle temperatures.

However, when Latin and Waters apply the results of the REE inversion to the North Sea case, there is significant discrepancy between the relatively low light-REE concentrations predicted by the Rayleigh melting model and the light-REE-rich basalts of the North Sea. An additional source of light REE is required. Nephelinite and ultrapotassic magmas found towards the flanks of the graben apparently provide the additional REEs, and have suitable Nd isotope compositions to explain the low (close to bulk Earth) $^{143}\text{Nd}/^{144}\text{Nd}$ ratios of the Forties basalts compared with typical depleted mantle. The nephelinites are taken to originate in lithospheric mantle, not the asthenosphere, that has been metasomatized (altered by fluids). This melts in response to rifting because the presence of volatile-rich phases substantially reduces its solidus temperature.

The role of lithospheric material in magma generation is of great interest to geochemists because the mechanical boundary layer (approximately the upper 100 km) of the lithosphere is isolated from the homogenizing effects of asthenospheric convection. In the mechanical boundary layer, isotopic heterogeneities can evolve for long periods of time (1–2 $\times 10^9$ years) in response to ancient changes in trace-element ratios. For example, domains in the boundary layer with low Sm/Nd ratios will gradually evolve lower $^{143}\text{Nd}/^{144}\text{Nd}$ ratios than the average (higher Sm/Nd) asthenosphere. On melting, the mantle portion of the boundary layer yields melts of broadly basaltic composition, but with unusual isotopic signatures. A recent breakthrough has been to define rather precisely the lithospheric contribution to extensional magmatism. Thus in the North Sea, Latin and Waters demonstrate the involvement of magmas similar to locally occurring nephelinites, whereas Thompson *et al.*[6] in northwest Colorado and our own work[7] in the Karoo flood basalt province of southern Africa have identified ultra-potassic, lamproitic end-members also attributed to fusion of volatile-rich lithospheric mantle.

Even these few studies serve to illustrate the assortment of magmas that might be produced by partial fusion of enriched lithospheric mantle. Clearly the geochemical effects of interaction between asthenospheric and lithospheric melts will be very variable. An obvious goal for the future must be to relate those variations to the diverse metasomatic processes that apparently control the formation of the low-melting-temperature fraction of the mantle lithosphere. ☐

Rob Ellam is in the Isotope Geology Unit of the Scottish Universities Research and Reactor Centre, East Kilbride, Glasgow G75 0QU.

1. Latin, D. & Waters, F. G. *Nature* **351**, 559–562 (1991).
2. McKenzie, D. & Bickle, M. J. *J. Petrol.* **29**, 625–679 (1988).
3. McKenzie, D. P. *Earth planet. Sci. Lett.* **74**, 81–91 (1985).
4. Elliot, T. R. *et al. Nature* **351**, 201–206 (1991).
5. McKenzie, D. P. & O'Nions, R. K. *J. Petrol.* (in the press).
6. Thompson, R. N. *et al. Earth planet. Sci. Lett.* **98**, 139–153 (1989).
7. Ellam, R. M. & Cox, K. G. *Earth planet. Sci. Lett.* (in the press).