

# matters arising

## Sm–Nd systematics of Lewisian gneisses and the origin of granulites

THE demonstration by Janardhan *et al.*<sup>1</sup> of the purging of H<sub>2</sub>O from previously hydrous hornblende–biotite gneisses by CO<sub>2</sub>-rich volatiles of possible mantle origin to form pyroxene gneisses is an important development in the study of deep crustal materials. A popular model to explain the chemical peculiarities of granulite facies gneisses (depletion in K, Rb, Th and U; high K/Rb ratios and low Rb/Sr ratios) has been degassing of their precursors during high grade metamorphism<sup>2–5</sup>. The probability of this having been initiated by increase in  $p_{\text{CO}_2}$  has been recognised by Tarney and Windley<sup>5</sup>. The degassing model received significant support from Nd isotope studies of the Lewisian gneisses from Scotland<sup>6</sup>. There, Sm–Nd dating revealed an age ( $2,920 \pm 50$  Myr) of primary separation from the mantle some 200 Myr older than that of chemical differentiation (loss of Rb and U in particular) recorded by whole rock Rb–Sr and Pb–Pb and zircon U–Pb methods. Hamilton *et al.*<sup>6</sup> imply that the repository for Rb expelled from the granulite facies Lewisian is, in part, the tectonically higher amphibolite facies component of that complex, which now has an Rb/Sr ratio that is far higher than is compatible with their <sup>87</sup>Sr/<sup>86</sup>Sr ratio at 2,670 Myr ago<sup>7</sup>.

There are important geochemical differences between the granulite and amphibolite facies components of the Lewisian complex that are not discussed by Hamilton *et al.*<sup>6</sup> and to which the discovery of Janardhan *et al.* is relevant. The pyroxene gneisses in the Lewisian of the isles of Tiree and Barra have positive Eu anomalies and abnormally high Sr (average, 837 p.p.m.) whereas tectonically higher hornblende–biotite gneisses have negative Eu anomalies and much less Sr (average, 381 p.p.m.) (refs 4, 9 and unpublished data). Both may be features of a primary igneous fractionation of the gneiss precursors, the pyroxene gneisses representing crystallisation under low  $p_{\text{H}_2\text{O}}$  of a precursor tonalitic magma, the hornblende–biotite gneisses the ex-

pelled, residual, hydrous magma<sup>8,9</sup>. The complementary patterns could not reflect simple loss of a hydrous vapour phase from the granulites, but could reflect the addition of Sr and Eu to more normal precursors of the pyroxene gneisses from a mantle-derived vapour phase<sup>4</sup>, such as that indicated by Janardhan *et al.*<sup>1</sup>.

The dilemma is first that a model involving primary igneous fractionation at low  $p_{\text{H}_2\text{O}}$  (implying high  $p_{\text{CO}_2}$ ) of the pyroxene gneisses can as equally account for the K, Rb, Th and U depleted nature of the Lewisian pyroxene gneisses as for their high Sr and positive Eu anomalies<sup>9</sup>, thereby making degassing unnecessary as a means of chemical fractionation. Second, that addition of Sr, Eu and presumably other rare earth elements (REEs) from mantle depths in a CO<sub>2</sub> rich vapour phase would have a significant effect on Sr and Nd isotope systems in pyroxene gneisses.

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HAMILTON *ET AL.* REPLY—There may be differences in Sr content between granulite and amphibolite facies gneisses in the Scottish Hebridean Islands, but in the much more extensive outcrop on the mainland, Tarney (ref. 1, Table 1), using a much larger sample population, found only a small difference (615 as against 580 p.p.m. Sr) in gneisses of equivalent major element composition. Moreover, studies of REE distributions in the granulites<sup>2,3</sup> show that it is the more frac-

tionated siliceous gneisses which have the more prominent positive Eu anomalies. The rare earth relationships are very similar to those described recently by Arth *et al.*<sup>4</sup> in a Proterozoic gabbro–diorite–tonalite–trondhjemite plutonic suite from South-West Finland, interpreted as resulting from 'wet' hornblende fractionation. Thus they indicate the opposite petrogenetic relationship from that suggested by Drury<sup>5</sup>, but are entirely consistent with the isotope systematics which indicate that the dry granulite facies metamorphism reached its peak some 100–200 Myr after the gneisses were formed. This is also consistent with the conclusions of Janardhan *et al.*<sup>6</sup>.

With regard to Drury's dilemma, we can only point out that both granulite facies and amphibolite facies samples define the  $2,920 \pm 50$  Myr Nd isochron. Had there been extensive addition of Sm, Nd and other REEs to the granulite facies gneisses, it seems to us most unlikely that the observed Sm/Nd–<sup>143</sup>Nd/<sup>144</sup>Nd correlation would have been maintained. Thus, until we see firm evidence to the contrary, we consider that the normally stable REEs have remained relatively immobile during granulite facies metamorphism, while the commonly mobile elements K, Rb, Th and U have indeed been partially removed.

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