# Constraints on the thermal evolution of the Indian Himalaya from manganese and erbium distributions in metapelitic garnets

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## Introduction

The duration and rates of heating and cooling during a metamorphic cycle are important potential constraints on the tectonic processes that determine the evolution of a metamorphic belt. At temperatures appropriate to crustal melting, however, the diffusion rates are so fast that the distributions of the elements used in both thermobarometry and chronology are modified both within and between minerals such that all but a short portion of the cooling history is eradicated from the rock's memory. The other approach available is to make use of this modification and use the time required to cause it to set some limits on the timescale of the metamorphic event. In order to do this we need to know the temperatures reached, the diffusion rates of the relevant elements and their initial distributions.

We present here the results of some modelling of trace element and Mn data for garnets from the Zanskar area of the Indian Himalaya with the aim of putting some limits on the timescale for the Tertiary high-grade metamorphism which resulted in temperatures of 700–750°C, crustal melting and the production of leucogranites (eg. Searle *et al.*, 1992). The particular rocks studied were collected close to a large normal fault – seen all along the Himalayan chain – which is thought to have brought the metamorphism to an abrupt end and resulted in very rapid cooling.

## Rationale and relationship to previous work

In practice, the only common metamorphic mineral that has diffusion rates sufficiently slow to preserve any information is garnet and Lasaga (1983) and Muncill and Chamberlain (1988) have previously used the distributions of Fe and Mg in garnet resultant upon diffusional modification to extract information on cooling rates. Our approach differs from these authors in that we choose instead to model Mn and the heavy rare-earth elements in garnet. Diffusion data for erbium (Coghlan, 1990) and manganese (Chakraborty and Ganguly, 1992) in garnet are available. We have chosen these elements for two main reasons:

(1) The mathematics of extracting time information are considerably simplified if the garnet can be assumed to have simply homogenised and not to have lost or gained material during diffusion

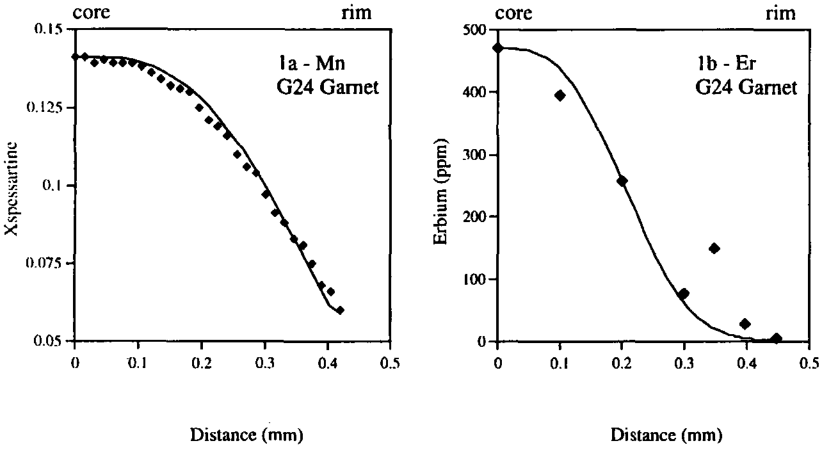

FIG. 1.

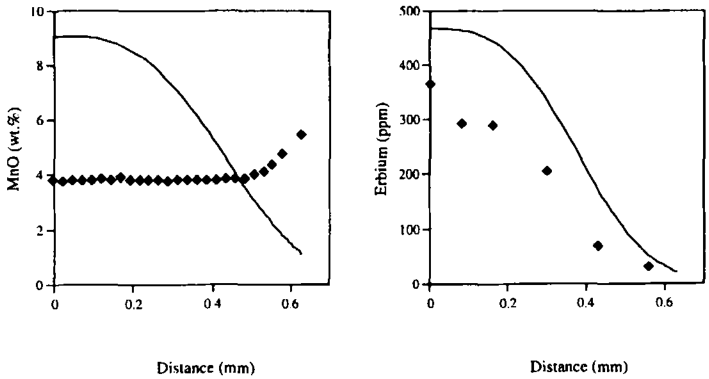

FIG. 2.

(*cf.* Muncill and Chamberlain, 1988). While this is obviously not appropriate for Fe and Mg whose exchange between garnet and biotite is well-known, Mn and the heavy rare-earth elements (*HREE*) are so compatible in garnet relative to other metamorphic minerals ($K_D^{\mathrm{gt-matrix}} > 50$) that the assumption of a closed-system may be much more closely approached.

(2) A major uncertainty in the calculation is the initial distribution of the element in the mineral. Again, because of the extreme compatibility of these elements in garnet, they almost always exhibit a Rayleigh fractionation profile that forms during growth of the garnet. Thus the initial profile is readily modelled. Mn and Er zonation profiles in low-grade garnets, unmodified by diffusion, from the Zanskar Himalaya are shown in Fig. 1. The diamonds show the analysed points while the lines are fitted assuming the distribution of Er and Mn in the garnet can be modelled by Rayleigh fractionation.

## Results

Crank (1975) gives the relationship between the initial profiles, C(r,0), the concentration profile after diffusion has effectively stopped (and the one that is measured today using an electron or ion microprobe), C(r,t′) and dimensionless time t′. This dimensionless time is related to real time by the diffusion parameters and the grain size. The Mn and Er profiles typical of high-grade rocks from Zanskar are shown in Figure. 2 (diamonds). Also shown (solid lines) are the predicted initial profiles assuming Rayleigh fractionation.

The first order observation is that while the Mn concentration has been homogenised to a single value (except for an increase in the outer 100μm due to retrograde exchange with biotite) Er still exhibits some zoning. This implies a slower diffusion rate for Er than Mn and is in agreement with the experimental diffusion data (Coghlan, 1990).

Isotopic data show that these rocks reached their peak temperature at 22Ma and then cooled very quickly to 300°C in 2–3Ma. Using these constraints on the cooling history and assuming a very simple scenario whereby heating to 700–750°C occurs instantaneously, the initial and final profiles can be used to give the time required at 700–750°C for the zonation profiles to be modified to the extent observed. In the case of Mn, since the profile has been completely homogenised the time obtained – 0.25–2Ma – is only a minimum estimate for the metamorphic event. The erbium profile and the diffusion data imply, in this very simple model, that the rock must have been at 700°C for 10Ma or at 750°C for 3Ma.

## References

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