Behaviour of Sm-Nd and U-Pb systematics during migmatization and its effect on crustal growth studies

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In Sm-Nd studies aimed at constraining crustal growth history, Sm-Nd systematics are normally considered to be undisturbed at the whole rock scale during intracrustal processes such as alteration, metamorphism or even partial melting. However, if Sm-Nd systematics are disturbed during intracrustal processes, this could put wide ranging conclusions from Sm-Nd crustal studies into question.

Migmatites are ideal rocks to study the chemical and isotopic fractionation which may occur during high grade metamorphic events. From this perspective, we carried out Sm-Nd, U-Pb work associated with major and trace element analyses on three outcrops of migmatites generated during the 2.0 Ga orogeny in the Central Zone of the Limpopo Belt (Botswana and South Africa). The Central Zone which is mainly composed of orthogneisses and paragneisses underwent granulite facies metamorphism followed by decompression metamorphic conditions (clockwise $P-T$ loop) at 2.0 Ga. Partial melting following the Bt breakdown reaction in high temperature, low pressure rocks did lead to different behaviour of Sm-Nd systematics for metagreywacke and metapelite. In the first case, chemical equilibrium and full Nd isotope exchange were not reached due to the effect of accessory minerals (monazite and apatite) on the compositions of the partial melt. Monazite entered the melt in preference to apatite, either by dissolution or by entrainment and its unradiogenic Nd isotope signature dominates the leucosome (Fig. 1). As a consequence, the Nd model ages on partial melt are up to 400 Ma older than those on paleosomes. The Nd model ages of these rocks cannot be used to constrain the evolution of the Southern African continental crust and in view of this, Nd model ages on any leucocratic crustally derived rocks in this region are suspect.

In constrast, partial melts obtained by the same metamorphic reaction on metapelite exhibit chemical equilibrium with palaeosomes as well as nearly full Nd isotope echange while Pb-Pb systematics are not fully reset and reflect an errorchron of *c.* 2300 Ma (Fig. 2). The same accessory minerals are present in both palaeosome and leucosome but they were either newly formed, or recrystallized during the metamorphic event. In other words, the accessory minerals were chemically and isotopically equilibrated with the partial melt and the palaeosomes. The Nd model ages on leucosomes and palaeosomes therefore coincide and they can be used to constrain the crustal growth in the region.

In migmatites formed by metamorphic differentiation at subsolidus conditions, chemical equilibrium and Nd isotope exchange were not reached during migmatization (Fig. 3).

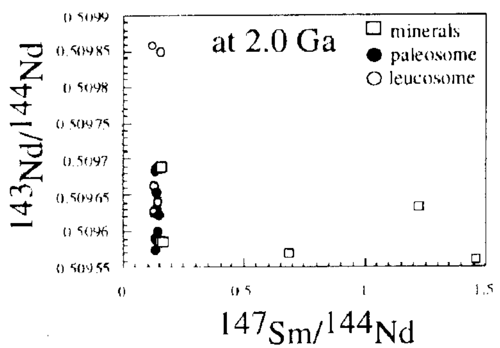

FIG. 1.

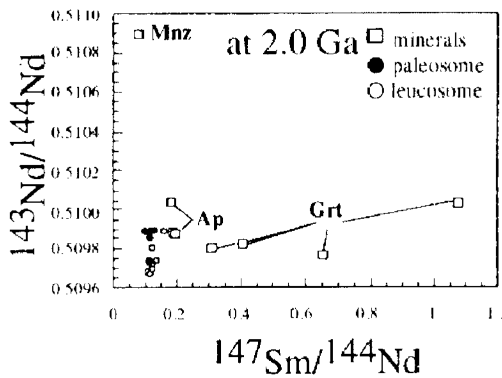

FIG. 2.

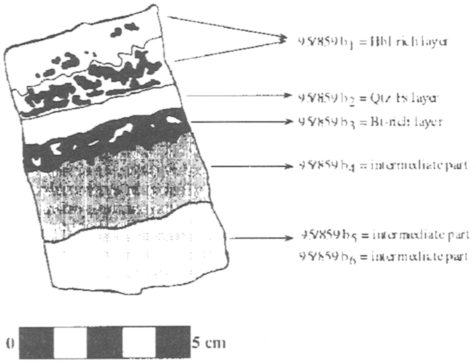

FIG. 3.

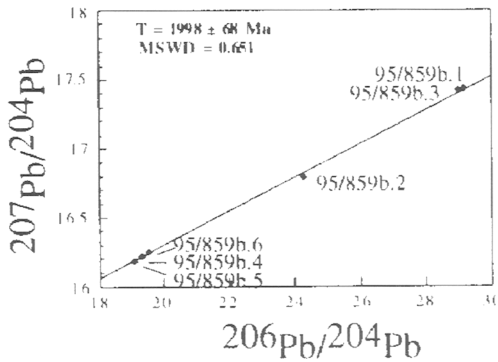

FIG. 4.

The distributions of the elements are related, in that case, to the proportional amounts of each mineral in the migmatitic components, which resulted from reorganization according to rheological competency under stress. However, full Pb isotope exchange is reached as highlighted by a Pb-Pb WR isochron yielding 2.0 Ga, the age of the metamorphic event (Fig. 4).

Lack of isotope exchange reflects in the main: (1) the presence of pre-metamorphic, magmatic hornblende; and (2) accessory minerals such as apatite or monazite, with very high concentrations of unradiogenic Nd and remained preferentially in the palaeosome, lowering the Nd isotopic composition of that migmatitic component. However, even if chemical equilibrium and full Nd isotope exchange were not reached, the geochemical characteristics combined with *REE* modelling provided arguments for closed system behaviour of the whole rock during migmatization. Therefore, the chemical and isotopic compositions of the protolith may be obtained via mass balance calculations and can be used as markers for the crustal evolution.

The discrepancy between the Sm-Nd and U-Pb systems during migmatization cannot be explained in a unique manner. It is clear that, in the absence of chemical equilibrium, full isotope exchange of Nd or Pb (full 'resetting' of the Sm-Nd and U-Pb isotope systems) cannot be assumed to have taken place. On the one hand, apatite, monazite, xenotime, titanite, allanite and zircon mainly control the *REE* as well as Th and U budget of a rock, and equilibration of nascent melt with these accessory minerals could be poor (Sawyer, 1991; Watt and Harley, 1993) whereby armouring within residual phases would be an important, but not necessary, contributing factor. This could have a particularly strong effect if combined with rapid melt extraction (Watt *et al.*, 1996). On the other hand, the protolith lithologies with regard to their grain size (metagreywacke and metapelite) and their quantity of fluid available during metamorphism, may be an important factor for the redistribution of trace elements and for isotope exchange. The presence of a mobile fluid will enable the resetting pf Pb-Pb systematics (subsolidus segregation) but not of Sm-Nd; once a melt is formed, fluid is dissolved in it and therefore less mobile. Whether a Nd model ages can be reconstructed for a migmatized rock further depends on whether the total sample is really representative of the protolith and not dominated by either the leucosome or melanosome. This should be taken into consideration in Nd WR studies in high and medium grade terrains.

References

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