Goldschmidt 2023 Abstract
https://doi.org/10.7185/gold2023.14899

Hafnium isotopic ratios in zircon reveal processes of anatexis and pluton construction

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Heterogenous isotopic ratios in magmatic rocks have been interpreted to be a result of magma mixing or inheritance from the source rock. Isotopic heterogeneities in zircons in the source may be homogenised in the melt by magma flow and chemical diffusion. This implies that the degree of homogenisation of the inherited Hf isotopic signal can be indicative of the degree of magma homogenisation, which depends on the nature and duration of magma flow before crystallisation. In order to understand the systematics of Hf isotope transfer from zircons in the source to those crystallised from the melt, we measured Hf isotopic ratios of magmatic and inherited detrital zircons in migmatites from turbidites of the Puncoviscana Formation in NW Argentina, as well as a granite domain within the sequence. Detrital zircons show ~30 Eps units of variation in Hf isotope values. Anatectic zircons also show a large range of isotopic values but it is narrower than, and lies within, the range of the detrital zircons. Using analysis of variance (ANOVA), we found that the Hf isotope ratios of zircon rims are partly controlled by their cores and partly by the mean value of the magma. This demonstrates the effect of a boundary layer around dissolving detrital zircon grains that contains a high concentration of the core's isotopic signature (the "core effect"; Fig. 1). Anatectic systems can be divided into four end-members (Table 1) on the basis of the extent of the core effect, the degree of magma homogenisation, and nature of the magma prior to zircon crystallisation. Recognising these end-members allows constraint of the nature of processes in anatectic rocks that homogenise and modify Hf isotopic ratios.

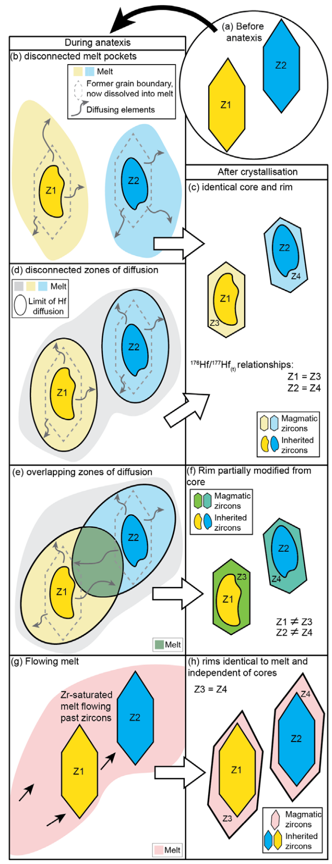

Figure 1. Hf signature transfer between inherited cores and newly formed magmatic rims. (a) Two zircons, Z1 and Z2 within close proximity before anatexis. The response of the zircons and their dissolution boundary layer vary depending on the nature of anatexis (figures on the left), resulting in anatectic rims with different isotopic signatures (figures on the right). (b) Z1 and Z2 have partially dissolved into isolated melt pockets, keeping their isotopic signatures isolated. (c) When anatectic zircon rims crystallise they have the same isotopic composition as the pre-existing grain, because of the closed-system behaviour. (d) Z1 and Z2 dissolve into a melt pool that encompasses both zircons but time availability for diffusion of the Hf signal through the melt is insufficient for mixing between the two isotopic signatures. When anatectic rims crystallise they will have the same isotopic composition as the pre-existing grain, as shown in (c). (e) Same as (d) but if there is time for Hf to diffuse through the melt, the isotopic signatures of Z1 and Z2 will mix to different extents. Anatectic rims will have a different isotopic composition to the pre-existing grain and all rims will tend towards the mean Hf isotopic value of the rock, depending on the extent of homogenisation of the melt, as shown in (f). (g) If Z1 and Z2 are entrained within a melt they may or may not be partly dissolved, depending on the Zr-saturation state of the melt. When anatectic zircon crystallises around the grains it will have an isotopic signature reflecting that of the melt, independent of the pre-existing grains, as shown in (h).

	Closed system		Open system	
Isotopic diversity in magma ▷	Heterogenous	Homogenous	Heterogenous	Homogenous
	End member one	*End member two*	*End member three*	*End member four*
Rims have large range of isotopic values	√	X	√	X
Same range of isotopic ratios for cores and rims	√	Narrower	Shifted by external melt inflow	
Isotopic ratios from same grains (cores and rims) are more similar than ratios from different grains	√	X	X	X

Table 1. The four end-members for the relationship between inherited and magmatic grains depending on the degree of mixing and homogeneity of the magma, and whether the migmatite or magma receives input from external sources with Hf isotope ratios different from the inherited zircons (open system) or if the only source of hafnium is the inherited zircons (closed system). In a closed system with a heterogenous magma it is assumed that the magma is not flowing and that magma patches are effectively disconnected from each other.