Heat transfer mechanisms in magmas: Constraints from Ar loss in thermal aureoles

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Thermal exchange between magmas and their country rocks governs important processes such as fractional crystallisation, crustal melting and assimilation. Theoretical models predict extreme differences in wall rock heating between dykes or sills through which magmas flow in either turbulent or laminar mode. Turbulent flow theoretically causes much higher temperatures in wall rocks, and thus assimilation during ascent of magmas. However, such behaviour has never been quantitatively measured in natural samples.

Radiogenic argon ($^{40}Ar^*$) loss from K-rich minerals has long been recognised adjacent to igneous intrusions though its ability to measure heat flow quantitatively depends upon the measurement techniques.

$^{40}Ar^*$ loss profiles within mica grains of the Moine schists (420 Ma) in the thermal aureoles of Tertiary sills (Isle of Mull, Scotland) have been measured at high spatial resolution (5-10 microns) using the ultraviolet laser ablation microprobe (UVLAMP) and modelled.

Data have been used together with intrusion temperatures estimated from temperatures calculated from the chemistry of the intrusion (Kille *et al*, 1986) and breakdown reactions of micas (Chatterjee and Johannes, 1974; Brearley, 1986, 1987), to produce quantitative models of the heat flow with time from intrusion walls.

UVLAMP $^{40}Ar/^{39}Ar$ studies of biotite and white mica grains, collected 2.4–3.0 metres away from a 6 metre thick sill suggest that 300 micron diameter grains have lost ~50–70% respectively of their total $^{40}Ar^*$ during sill emplacement at ~60 Ma (Fig. 1).

Various models can be put forward to account for the degree of $^{40}Ar^*$ loss observed and measured in the mica grains. Two models are presented here:

Model 1 assumes that the contact was held at a constant temperature (T_o), and the temperature at distance x from the sill will be:

$$T_x = T_o - (T_o - T_{Cr})\ erf\,(x/2kt)$$

where T_{Cr} the temperature of the country rock, *erf* is the error function, k is the thermal diffusivity of the country rock, and t is the duration of heating.

Approximately 9 months of continuous heating would be necessary to achieve temperatures of sufficient intensity to result in the breakdown of biotite and white mica 2.4–3.0 metres from the sill contact. This does not agree with estimated durations of up to 2 years required to achieve mica argon degassing of 50–70% at these temperatures.

It is very difficult to envisage the length of time required to accomplish the degree of argon degassing found in these mica grains. This 6 metre thick sill would be comparable to the 8 month Laki (Skaftár Fires, ~2.5 km long × 150–300 m wide) fissure eruption of 1783-4 in Iceland, one of the largest and most devastating basaltic fissure eruptions witnessed by humanity (Thordarson and Self, 1993). A pre-eruptive 4 metre wide dyke was monitored for 2 years accompanied by vigorous degassing, prior to the Mt Etna 1991 eruption (Rymer *et al*, 1993).

Model 2 assumes that there was a brief (1 day) high temperature pulse followed by a longer lower temperature heating event, yielding heating times of 2–3 months.

The $^{40}Ar/^{39}Ar$ mica data and thermal modelling suggest that both a large thermal input and long durations were required to achieve sufficient argon

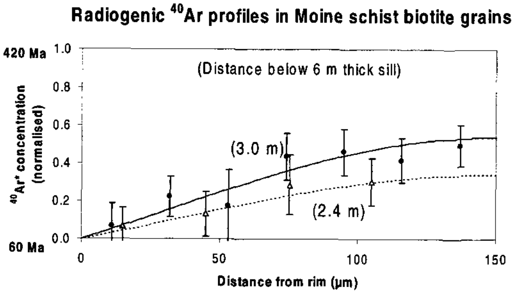

FIG. 1.

loss in the micas and the degree of country rock melting and mineral breakdown. We conclude that this 6 metre thick sill was an important feeder for magma distribution in this area.

References

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