# Tectonic implications of short metamorphic episodes

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Quartz inclusions in garnet undergo exchange of Ti with the host garnet resulting in diffusion of Ti into the quartz. Modeling of this diffusion in samples from the Barrovian terrane of eastern Vermont reveals that the entire metamorphic episode (heating from 450 C to metamorphic peak and cooling back to 450 C) has occurred in less than 1 m.y. and perhaps in as little as a few hundred thousand years, depending on the presumed peak metamorphic temperature. This terrane does not contain volumetrically significant plutons, so the only possible cause must be tectonic.

Two-dimensional thermal modeling has been used to constrain the rates of thrusting required to achieve such short-lived metamorphic episodes. Rocks heat rapidly when overthrust by hot rocks and cool rapidly when they are thrust onto cooler rocks, a process that has been modeled as a simple, mid-crustal duplex structure. A typical model involves the first thrust sheet moving up a 20 degree ramp at a rate of 10 cm/year (0.1 m/year) for 0.1-0.5 m.y. then the fault stepping out (in sequence) and a second thrust sheet moving up a similar ramp for a similar time interval. The rocks of interest are those in the horse between the two thrusts which are initially loaded quickly and subsequently heated by thermal conduction from the overlying hotter rock mass. The second thrust places these hot rocks onto cooler substrate which initiates cooling of the mass but not necessarily a change in pressure. Exhumation was likely to have been rapid following the metamorphic peak, consistent with the rapid post-peak cooling history inferred from the diffusion studies. The near isothermal loading exhibited by P-T paths of rocks from eastern Vermont also supports the hypothesis of crustal loading at rates of 5-10 cm/year.

The rate of heating and cooling depends on the thermal difference between the overthrust sheet and the rocks of interest, and the proximity of the rocks to the thrust. Models with different thrust sheet dimensions reveal that it is impossible to rapidly heat and cool the same rock if the sheet is thicker than ca 5 km. This fact raises the interesting possibility that metamorphic terranes that have experienced such rapid heating and cooling are comprised of thin thrust sheets bounded by ductile shear zones stacked together in duplex-like geometries with significant internal deformation. Such geometries might be very difficult to decipher with the limited outcrop exposure in Vermont. It is also interesting to speculate that the two major “deformations” that produce the two dominant fabrics in these rocks were caused by the initial loading and subsequent ramping of the thrust sheet, respectively. Thrust ramps also produce ramp anticlines that, in ductile terranes, will have the geometries of domes as are seen in eastern Vermont.

Such rapid tectonic juxtaposition is unresolvable by current geochronologic techniques, and is only revealed through diffusion modeling of systems with diffusivities appropriate for the metamorphic conditions.

# Timing and mechanism for intratest Mg/Ca variability in living planktic foraminifera

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## Problem and Results

Recent microscale data indicate that Mg/Ca in foraminifera tests is distributed heterogeneously, thereby challenging its use as a robust tool for paleotemperature reconstructions. We present Mg/Ca and Ba/Ca data collected by laser ablation (LA) ICPMS from living *Orbulina universa*, that were grown in controlled laboratory experiments. Test calcite was labeled with Ba-spiked seawater for 12h periods during either day or night calcification, to quantify the timing of intratest Mg-banding across diurnal cycles. Results demonstrate high Mg bands are precipitated during the night, whereas low Mg bands are precipitated during the day. Similarly, the amplitude of the Mg/Ca ratios in Mg-rich bands decreases in experiments with elevated pH (and $[CO_3^{2-}]$). These results suggest that symbiont photosynthesis influences but does not fully control Mg/Ca banding. We hypothesize that mitochondrial uptake of $Mg^{2+}$ may explain Mg-depleted calcite layers. Symbiont photosynthesis and foraminifera respiration may exert a secondary influence on shell Mg/Ca via their effect on $[H^+]$ in the microenvironment around the calcifying shell. Data obtained from specimens growing at 20º and 25ºC show that intrashell Mg/Ca ratios increase with temperature in both high and low Mg bands, such that average test Mg/Ca ratios are in excellent agreement with temperature calibrations based on bulk solution ICPMS analyses.

## Conclusion

Results presented here demonstrate that Mg banding is an inherent component of the biomineralization process. However, despite intratest Mg/Ca variability, the Mg/Ca paleothermometer as measured on whole tests remains a robust tool for reconstructing past ocean temperatures from the fossil foraminifera record.