Abrupt changes in subduction-zone geothermal gradient revealed by contact metamorphism during arc–arc collision in central Japan

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The geothermal gradient in subduction zones is a fundamental thermal parameter controlling fluid migration, metamorphic reactions, magma generation, crustal rheology, and seismic processes. Conventional thermal models treat geothermal gradients as quasi-steady fields governed by plate age and slab geometry, evolving gradually over tens of millions of years. However, recent numerical studies suggest that arc–arc collision–related crustal thickening, subsequent lithospheric delamination, and episodic magmatic heat input can reorganize crustal thermal structures in a transient manner. Direct quantitative constraints on such non-steady thermal changes from natural records remain limited.
Here we reconstruct regional geothermal gradients at the time of pluton emplacement using contact metamorphic aureoles, extracting time-resolved "snapshots" of crustal thermal structure. Because contact metamorphism represents a short-lived thermal event, intrusion ages combined with metamorphic temperature estimates allow geothermal gradients to be constrained with high temporal resolution. We apply this method to two Miocene plutons of different ages located in close proximity in central Japan, where collision between the Izu–Bonin arc and the Honshu arc began at ~15 Ma.
Along the Itoigawa–Shizuoka Tectonic Line (ISTL), the Kaikomagatake (~13 Ma) and Kifune (~11 Ma) plutons intrude pelitic accretionary-complex basement rocks under similar conditions (granodiorite composition, ~2 kbar emplacement pressure, ~10 km diameter). Because host-rock lithology and emplacement depth are nearly identical, the two areas provide a natural quasi-controlled experiment in which time is the primary variable.
Biotite and cordierite isograds preserved in both aureoles indicate retention of the intrusion-related thermal field. High-density sampling perpendicular to the contacts was conducted, and peak temperatures were estimated using Raman carbonaceous-material geothermometry. A one-dimensional conductive heat-transfer model was used to back-calculate initial host rock temperatures and regional geothermal gradients.
The Kaikomagatake aureole yields initial temperatures of ~160–180 °C and a geothermal gradient of ~15 °C/km, whereas the Kifune aureole records ~310 °C and ~35 °C/km. Despite nearly identical geological conditions, the geothermal gradient doubled within ~2 Myr. Such a rapid increase is inconsistent with quasi-steady thermal evolution and indicates that subduction-zone thermal structures can reorganize on million-year timescales. The higher gradient is consistent with rapid crustal heating associated with arc–arc collision–driven crustal thickening, subsequent lithospheric delamination, and asthenospheric upwelling (Arnold et al., 2001, Journal of Geodynamics, 31, 273–291). Geophysical observations also indicate crustal thickening beneath central Japan (Matsubara et al., 2017, 710–711, 97–107), supporting this interpretation.
These results demonstrate that geothermal gradients derived from contact aureoles provide time-resolved thermal snapshots that empirically constrain the temporal evolution of subduction-zone thermal structures.

Keywords: contact metamorphism, geothermal gradient, Raman CM geothermometry, thermal modeling, arc–arc collision, Miocene

