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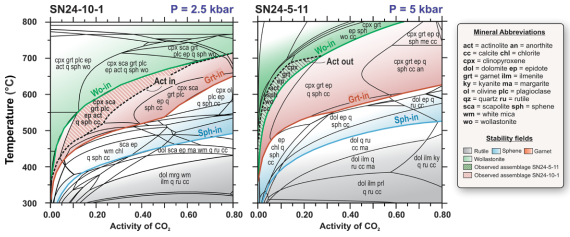

Depth-dependent metamorphic decarbonation and implications for CO_2 flux in the Sierra Nevada continental arc

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Arc magmatism intersecting carbonate country rocks may have partially contributed to long-term warm climate in Earth's history. This is supported by the temporal coincidence between fluctuations in continental arc length and major climate intervals. A modern analogue occurs at Mount Etna (Italy), where the carbon isotopic composition of volcanic CO_2 reveals a clear crustal signature, indicating interaction between magma and carbonate rocks prior to degassing. Most field-based studies of contact metamorphism focus on shallow crustal conditions (~ 2 kbar), because phase equilibria predict that decarbonation reactions are suppressed at higher pressures. However, field-based constraints on this depth dependence remain limited. Here we explore the pressure control on metamorphic decarbonation using carbonate wall rocks adjacent to the Sierra Nevada Batholith (SNB, California, USA). The SNB intruded carbonate wall rocks over a wide range of depths, generating contact metamorphism from 2 kbar to at least 8 kbar. Its tilted framework exposes shallow metacarbonate rocks in the northern Sierra and deeper equivalents in the south. We integrated detailed petrography, bulk-rock chemistry, mass balance analysis and thermodynamic modelling. Area-based petrographic analysis (Image-J) shows that deep arc samples are dominated by marble with negligible carbon loss, whereas shallower samples are dominated by calc-silicate assemblages with only minor carbonate restite, indicating substantial decarbonation.

Thermodynamic modeling further demonstrates that increasing pressure from 2 kbar to 5 kbar shifts stable assemblages toward higher temperature and lower X_{CO2} conditions, suggesting that decarbonation at greater depth requires both higher thermal input and enhanced fluid availability. Such a pressure-dependent relation is further being tested using mass balance analysis and thermodynamic modeling. When scaled to the areal extent of roof pendants in the SNB, the estimated carbon flux ranges from <<1 tera mole per year (Tmol/year) to 5 Tmol/year, depending on the depth distribution. This pressure-dependent variability implies that crustal carbon release from continental arcs cannot be treated as uniform through time, but instead depends on the depth of magma emplacement and wall-rock interaction. Accounting for this depth effect refines estimates of arc-related CO_2 flux and improves our understanding of how metamorphic decarbonation may contribute to the long-term global carbon cycle.