Constraining the temperature conditions of paleo-subduction plate interfaces

Kayleigh M. Harvey, Xin Zhou, Besim Dragovic, Sarah Penniston-Dorland, Ikuko Wada, and Peter van Keken

Pressure-temperature (P-T) estimates from exhumed metamorphic rocks are often used to constrain the thermal conditions of paleo-subduction zone plate interfaces. However, the exhumed rock record on average indicates temperatures 200-300°C warmer than those predicted by geodynamic models for modern subduction zones. To elucidate the difference in the paleo and modern subduction zone thermal structures, we compare newly acquired P-T estimates from petrologic data to newly constructed geodynamic models of the regional tectonics at selected paleo-subduction localities, including the Franciscan Complex in California, the Raspas Complex in Ecuador, the Rio San Juan Complex in the Dominican Republic, the Sanbagawa Belt in Japan, and the Pam Peninsula in New Caledonia. For this nugget we focus on the Rio San Juan Complex in the Dominican Republic. For the geodynamic models we develop 2-D coupled kinematic-dynamic models, using the paleo-subduction parameters, such as convergence velocity and plate age, that are constrained by global plate reconstruction models and regional geological and petrological studies. The effects of uncertainties in these parameter values on the temperature estimates are also evaluated. As there are no constraints on the geometry of the subducting slab, we construct a range of generic model geometries and quantify the effect of slab geometry on the subduction interface temperature. For the petrology we use quartz-in-garnet and zircon-in-garnet elastic thermobarometry combined with Zr-in-rutile thermometry to evaluate the P-T history of a block within mélange zone of the Rio San Juan Complex in order to test assumptions about chemical equilibrium commonly made to reconstruct P-T paths. Previous work suggests that this subduction complex is a warm end-member relative to other exhumed terranes. Mélange zones within the Rio San Juan Complex preserve a near-continuous record of its P-T history during subduction and exhumation. We compare the model-predicted subduction thermal structures with the P-T conditions that are estimated from exhumed rocks in the selected localities and assess the key factors that contributed to the petrologically constrained P-T conditions. ■

Results to date

- Sample 25-228 followed a counter-clockwise P-T path consistent with heating during nascent subduction
- Validated by petrologic observations, phase equilibria modeling and trace element and elastic thermobarometry
- P-T conditions agree with 2D coupled kinematic-dynamic models for early subduction
- Elastic thermobarometry methods are still being refined to consistently reproduce results from other methods
- Working to reduce uncertainty
- May help elucidate parts of the P-T path where phases did not reach chemical equilibrium
- Combining trace element thermometry, elastic thermobarometry and pseudosection modeling shows promising results for predicting P-T paths of paleo-subduction rocks
- This approach is broadly applicable to a variety of lithologies and metamorphic grades
- 2D coupled kinematic-dynamic models for Rio San Juan can reproduce the P-T estimates from the rocks without invoking frictional heating

References

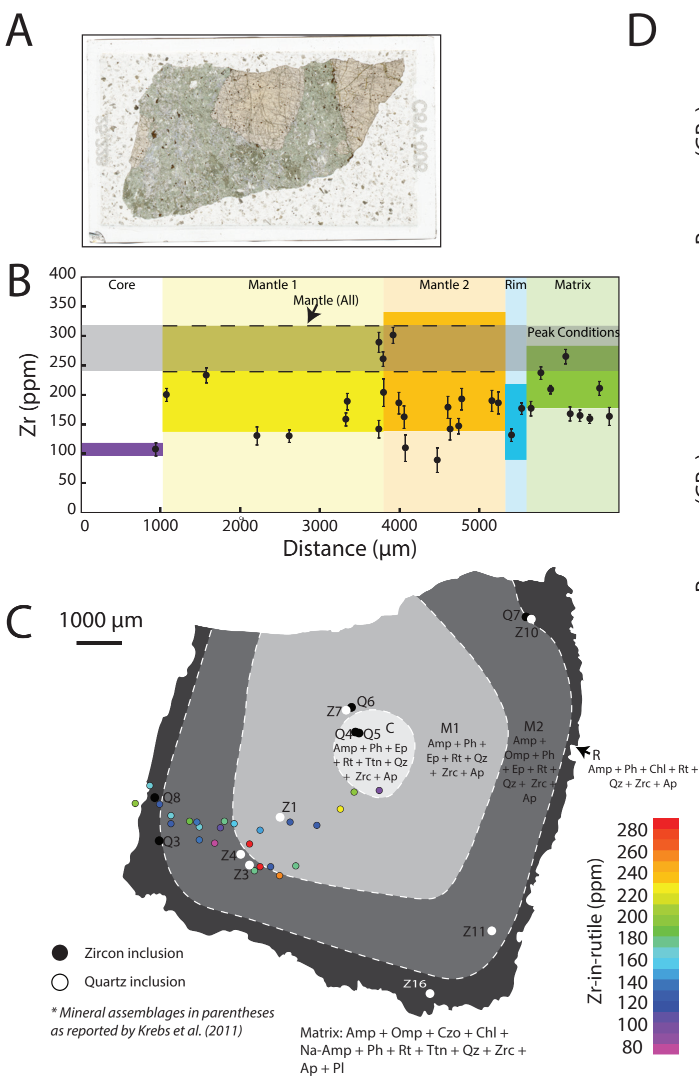
Angel, R.J., M. Alvaro, R. Miletich, F. Nestola (2017). A simple and generalised P–T–V EoS for continuous phase transitions, implemented in EosFit and applied to quartz. Contrib Mineral Petrol, 172, 29, doi.org/10.1007/s00410-017-1349-x

Kohn, M.J. (2020). A refined zirconium-in-rutile thermometer. Am Mineral, 105, 6, 963-971, doi.org/10.2138/am-2020-7091

Krebs, M., H.-P. Schertl, W.V. Maresch, G.Draper (2011). Mass flow in serpentinite-hosted subduction channels: P–T–t path patterns of metamorphic blocks in the Rio San Juan mélange (Dominican Republic). Jour Asian Sci, 42, 4, 569-595, doi.org/10.1016/j.jseaes.2011.01.011

Milani, S., F. Nestola, M.Alvaro, D. Pasqual, M.L. Mazzucchelli, M.C. Domeneghetti, C.A. Geiger (2015). Diamond–garnet geobarometry: The role of garnet compressibility and expansivity. Lithos, 227, 140-147, doi.org/10.1016/j.lithos.2015.03.017

Petrologic Data



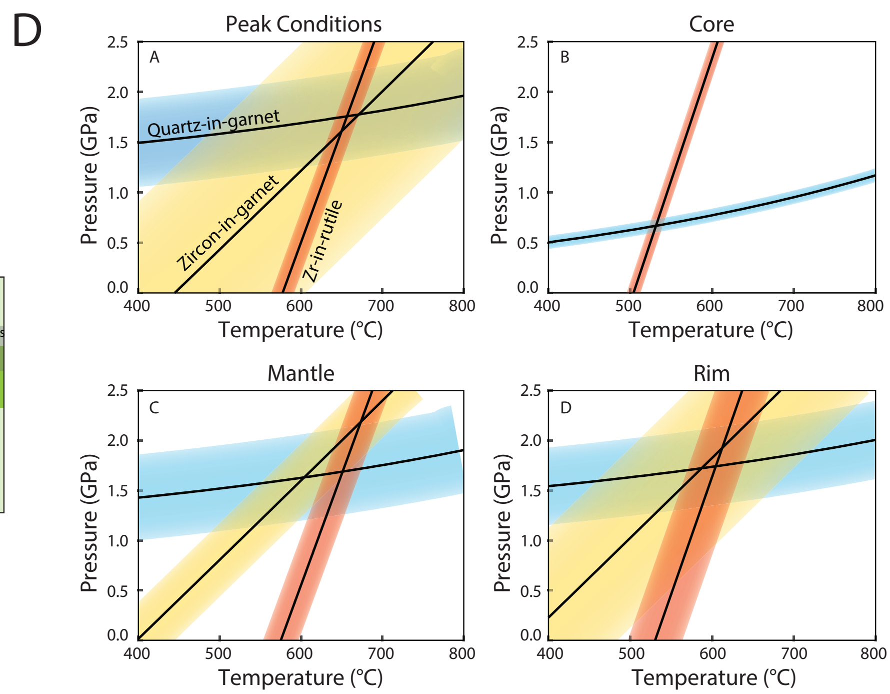
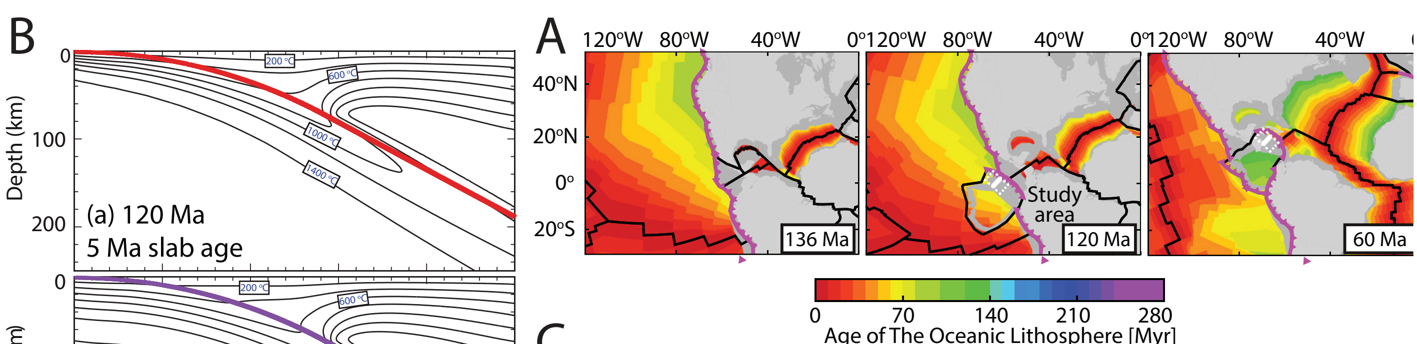


Figure 1. A. Ca-Amph-bearing eclogite mélange block (sample 25-228) with blueschist-facies overprint suggesting counter-clockwise P-T path (Krebs et al., 2011); B. Concentration of Zr in rutile for both rutile inclusions in garnet and matrix rutile; C. Sketch of garnet showing mineral assemblage and location of rutile, quartz and zircon inclusions. Rutile inclusions are colored by Zr concentration. Zones are drawn based on major element zoning in garnet; D. P-T estimates for each zone of the garnet using Zr-in-rutile (red) thermometry paired with quartz-in-garnet (blue) and zircon-in-garnet (yellow) elastic barometry. Isomekes calculated using the equations of state for quartz (Angel et al., 2017), zircon (Ehlers et al., in prep), and pyrope (Milani et al., 2015). Zr-in-rutile isopleths (red) calculated using the combined experimental-empirical thermometer by Kohn (2020).

Thermal Models



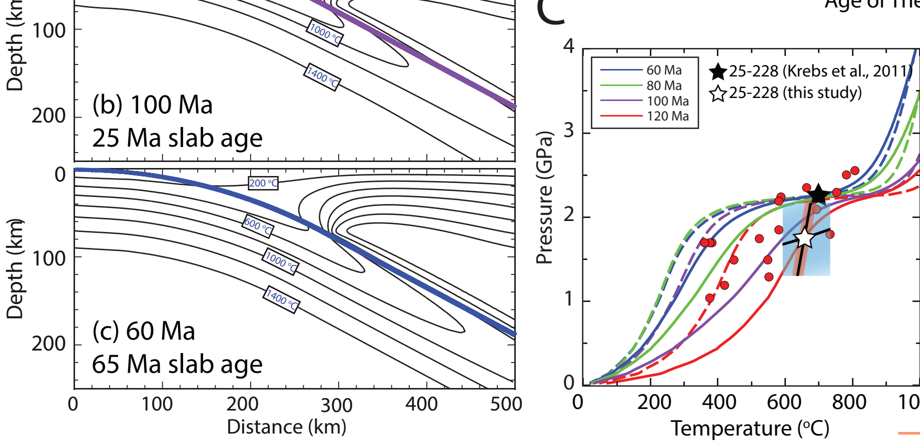


Figure 2. A. Subduction initiates around 136 Ma at Rio San Juan. Both the subducting and overriding plates are relatively young; B. Time-dependent models at time (a) 120 Ma, (b) 100 Ma, and (c) 60 Ma for Rio San Juan; v = 3 cm/yr, R = 600 km. The slab ages as subduction proceeds; C. Slab surface P-T conditions predicted by the model in Fig. 11 (solid lines) and another time-dependent model that assumes a 10 Ma slab at 120 Ma (dashed lines). Peak P-T estimate shown along with P-T estimates from Krebs et al. (2011) (red dots). The subduction interface is relatively hot given the relatively young age of the subducting plate, and the petrologic data can be explained if the slab age is ~5 Ma without invoking frictional heating (μ' = 0).