Implications of open system melting for zircon and monazite geochronology

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Introduction and methodology

Phase equilibria modeling of pelite and greywacke along three *P–T* paths is coupled with experimental data for zircon and monazite solubility to evaluate the consequences of closed (undrained) and open (drained) system melting on the dissolution and growth of zircon and monazite in residual source rocks (Fig. 1). For open system melting, at each point along the *P–T* path where the melt fraction reaches the melt connectivity transition (MCT) of 7 mol.% (~7 vol%; Rosenberg and Handy, 2005), six-sevenths of the melt produced is removed and a new bulk chemical composition is calculated. After a melt loss event, the residual bulk chemical composition is used to calculate a new *P–T* pseudosection that remains valid until the next melt loss event is reached. The chemistry and quantity of melt at *P–T* are combined with solubility equations for zircon (Boehnke et al. 2013) and monazite (Kelsey et al. 2008; Stepanov et al. 2013) to determine the amount of zircon and monazite dissolution needed to saturate the melt. The results are plotted as '% remaining' in Fig 4.

Closed system melting

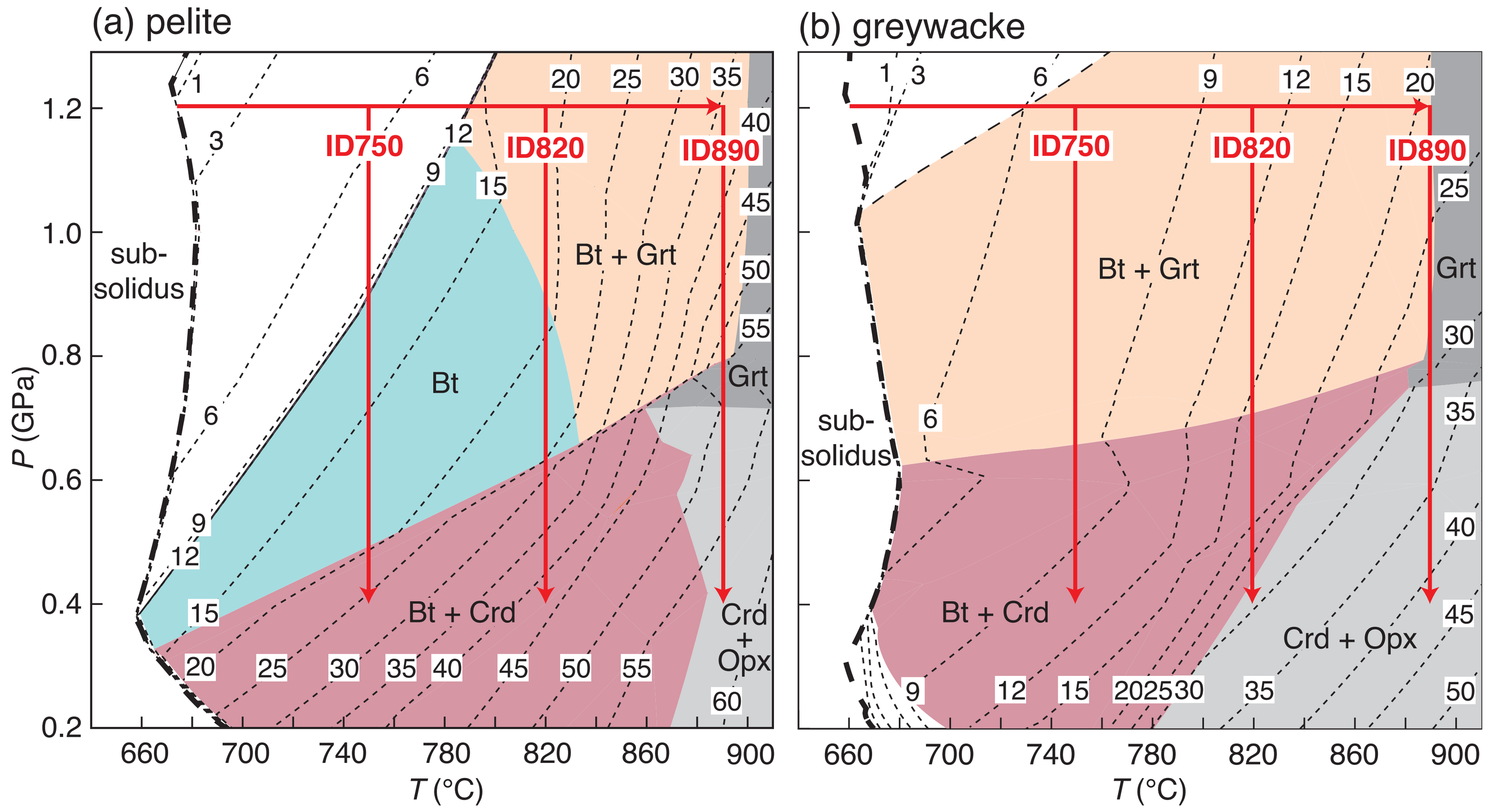

Fig. 1. Simplified *P–T* phase diagrams calculated for closed system melting for: (a) an average amphibolite-facies pelite (Ague 1991), and (b) an average passive margin greywacke (Yakymchuk and Brown 2014). The thick dashed line is the fluid-present solidus and the short dashed lines represent isopleths of mol.% melt. For the pelite, the total amount of melt produced along the *P–T* paths ID750, ID820, ID890 and HP is 26, 43, 58 and 52 mol.%, respectively. For the greywacke, the total amount of melt produced along these *P–T* paths is 11, 29, 42 and 35 mol.%, respectively.

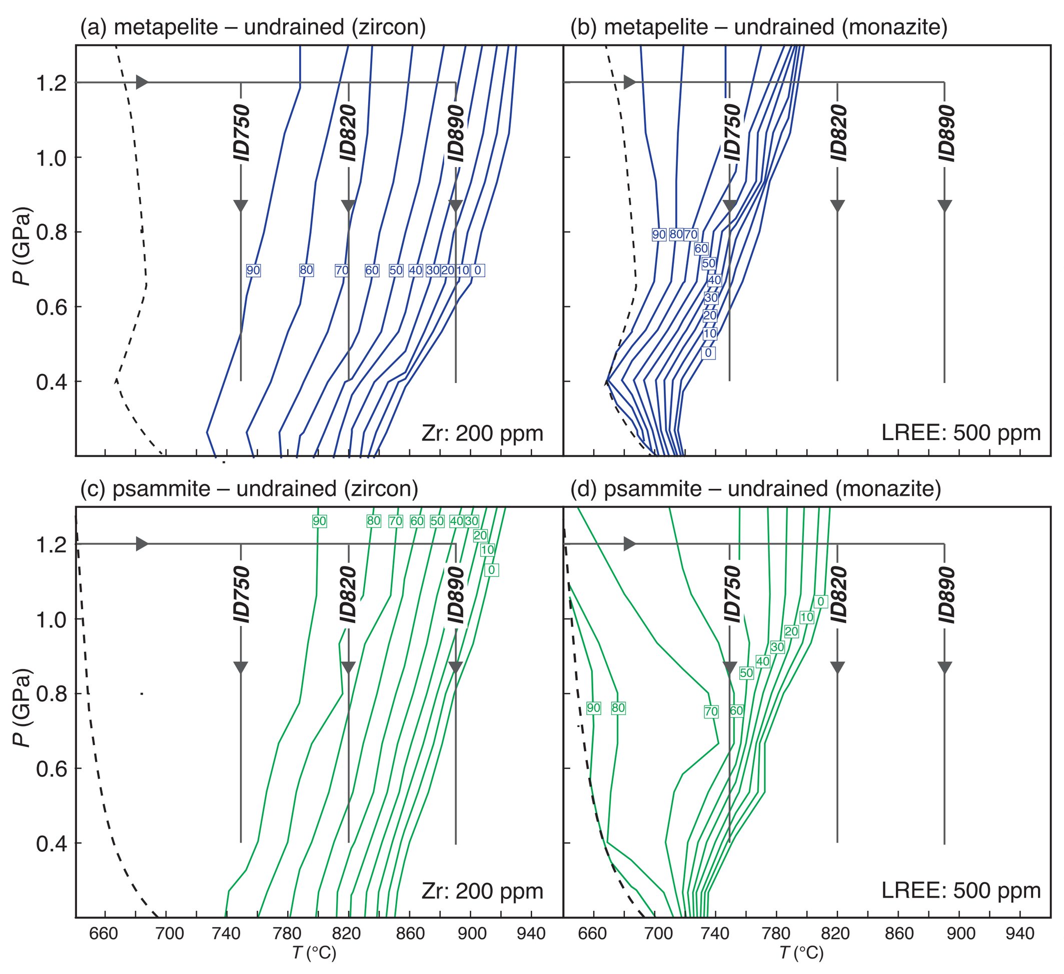

Fig. 2. *P–T* diagrams to show the stability of zircon and monazite during closed system partial melting (modified from Kelsey et al. 2008). Contours represent the proportion of zircon or monazite remaining. Zircon persists to ultrahigh temperatures and only during decompression along the ID890 path is zircon completely consumed. In contrast, during isobaric heating, complete dissolution of monazite is predicted to occur within 120°C of the fluid-present solidus for the metapelite and within 180°C for the psammite. During decompression, for the metapelite, all remaining monazite is consumed along path ID750. For the psammite, ~10% monazite survives after decompression along path ID750. The dissolution contours for both zircon and monazite are more closely spaced at high temperature, which suggests that dissolution of these minerals is non-linear and increases with temperature. Since the system is undrained, after decompression both zircon and monazite will crystallize during cooling to the fluid-present solidus.

Open system melting

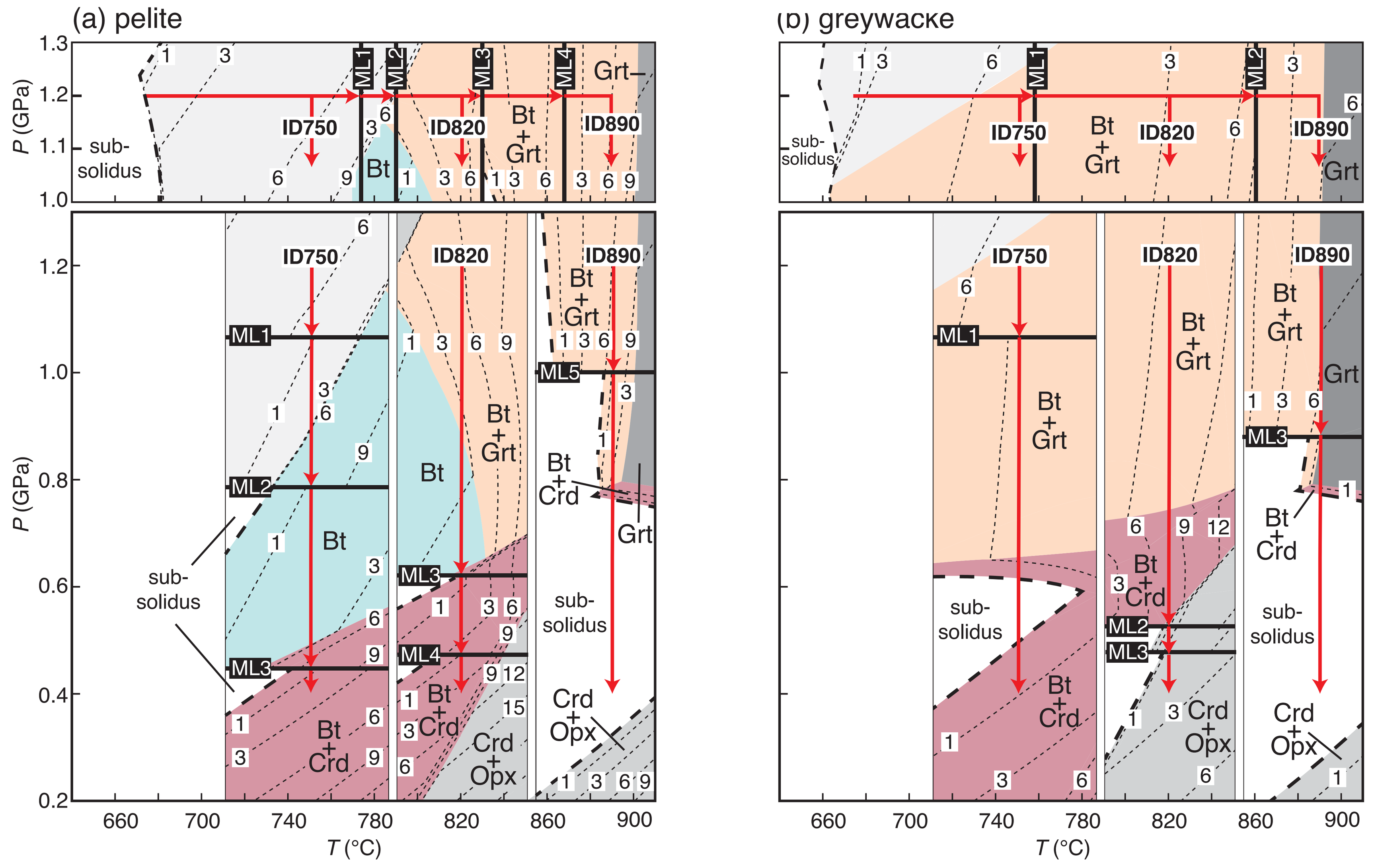

Fig. 3 (to the left). Composite *P–T* diagrams for conditionally open-system melting for each of the different *P–T* paths in Fig. 1. Each diagram comprises a series of panels that are arranged from low to high temperature and stacked from high to low pressure calculated for incrementally melt-depleted bulk compositions along each *P–T* path. The heavy dashed line is the fluid-absent solidus and the short dashed lines represent isopleths of mol.% melt. At each point where the *P–T* path intersects the 7 mol.% melt isopleth, 6/7ths of the melt is removed and the bulk composition recalculated. This residual composition is used to calculate the pseudosection appropriate for the next segment of the *P–T* path until the melt reaches the MCT once again, which is the threshold for next melt loss event, and so on. Each panel shows melt mol.% isopleths and the stability field of major ferromagnesian minerals. Melt loss (ML) events are located on the seams between the panels. The amount of melt produced is significantly less than for closed system conditions (Fig. 1).

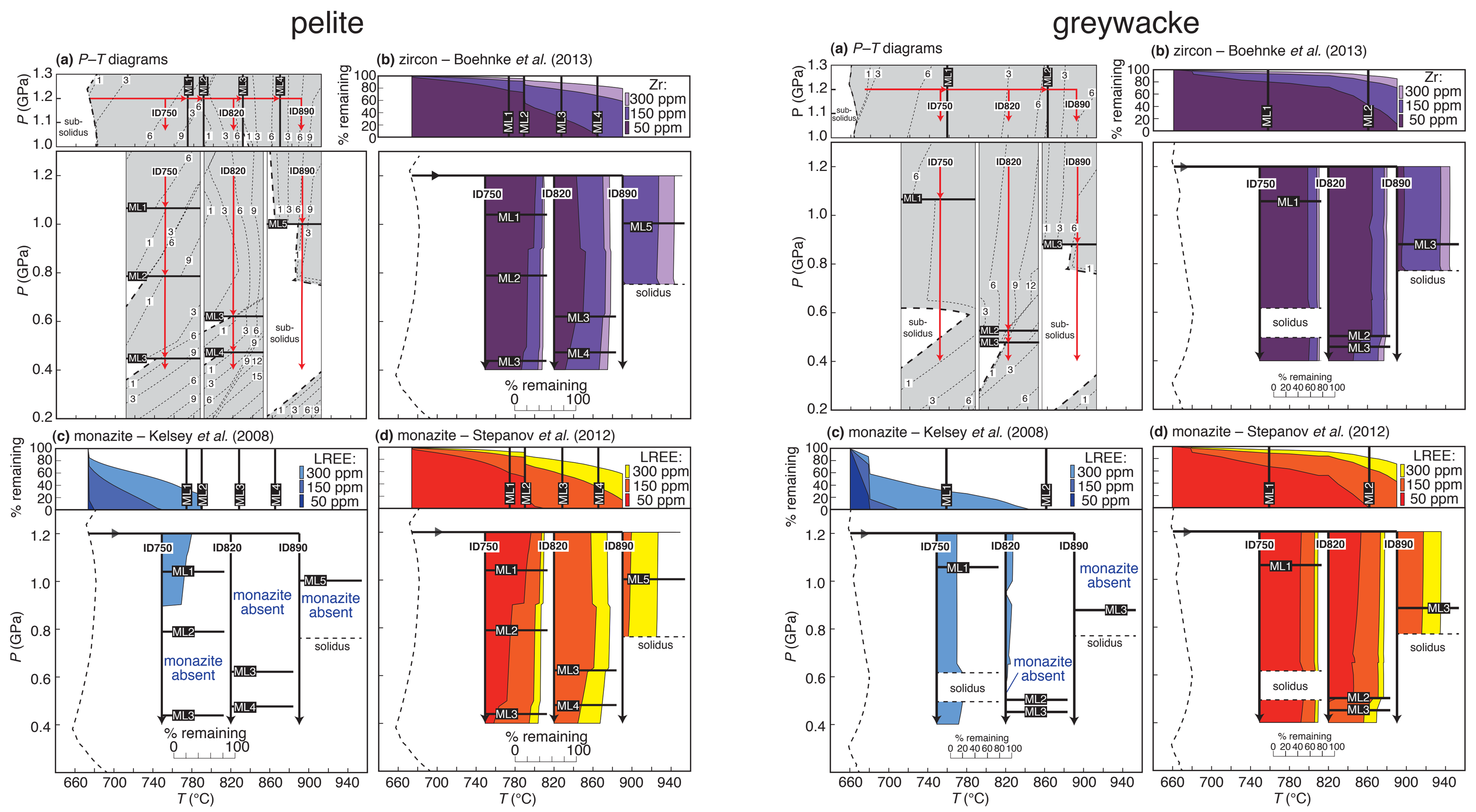

Fig. 4. (a) Composite *P–T* diagrams for conditionally open-system melting along the paths ID750, ID820, and ID890 from Fig. 3. (b–d) *P–T* diagrams of the calculated proportion of zircon and monazite remaining during open system melting of a pelite along the moderate pressure *P–T* paths. Results are presented from the monazite solubility equations of Kelsey et al. (2008) in (c) and Stepanov et al. (2012) in (d). Three initial concentrations (50, 150, and 300 ppm) were modeled. The dashed line is the fluid-present solidus. Except for very low (50 ppm) initial Zr concentrations, most zircon is likely to survive during prograde heating through the granulite facies. The amount of dissolution expected for monazite is very different according to which of the two solubility equations is used. Using the equation of Kelsey et al. (2008), monazite is completely consumed along the low temperature part of all *P–T* paths for the pelite and along most *P–T* paths for the greywacke. In contrast, using the equation proposed by Stepanov et al. (2012), for lower LREE concentrations monazite may be consumed in both the pelite and the greywacke along all *P–T* paths, but for higher LREE concentrations some monazite is expected to survive.

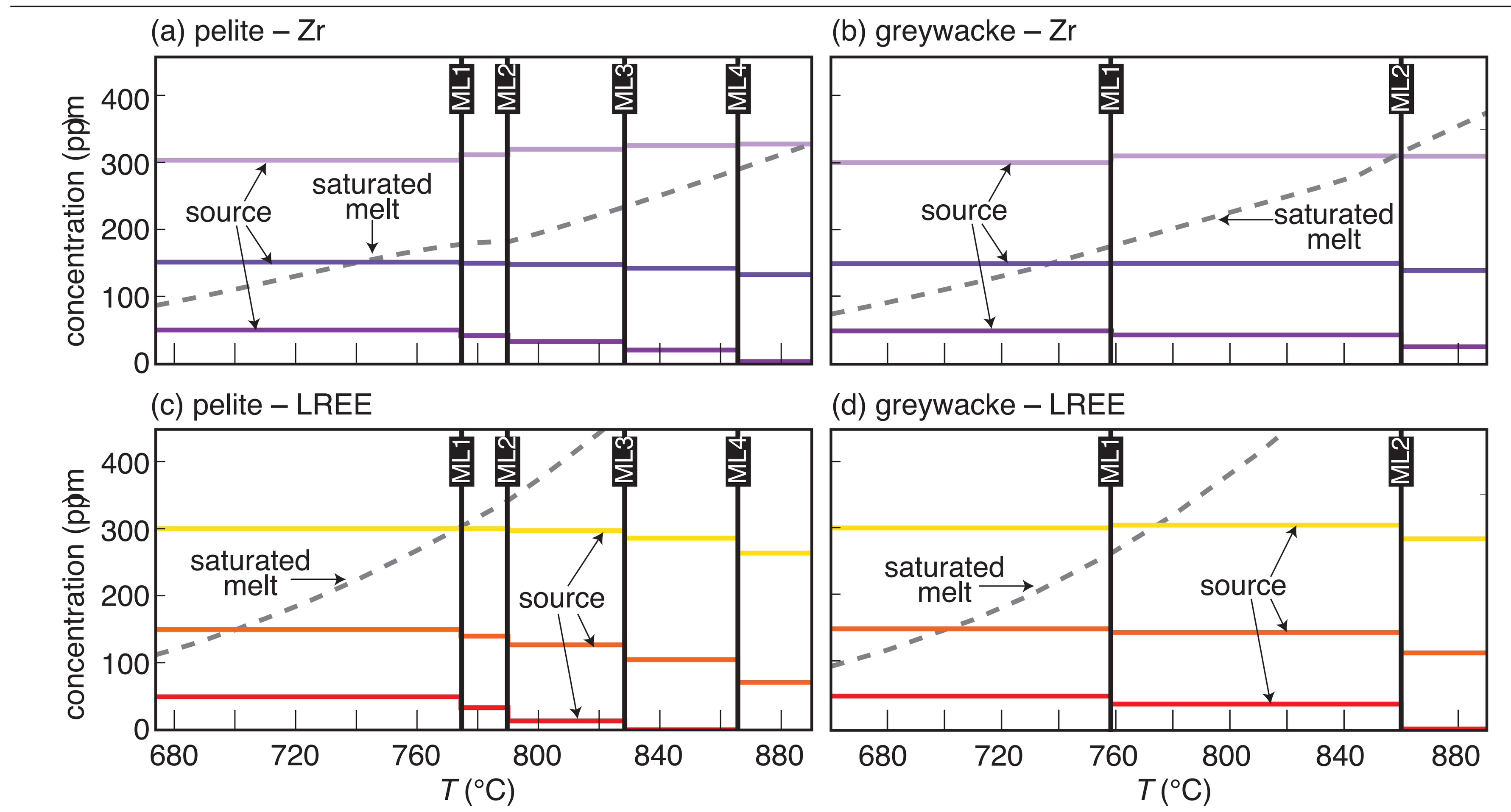

Fig. 5. Concentration of Zr and LREE in the source and melt for conditionally open system behavior along an isobaric heating path at 1.2 GPa. The concentration of the source changes in a stepwise fashion after each melt loss event. The saturation concentration of the melt is shown by the dashed curve. Extraction of melt with lower concentrations of Zr and LREE than the source will lead to relative enrichment of the source whereas loss of melt with higher concentrations will lead to relative depletion of the source. In most cases, the extracted melt will have higher LREE concentrations than the source. This will promote further monazite dissolution. Therefore, for open-system melting, more monazite dissolution is required to saturate the melt than for closed-system melting. ML: melt loss event.

Implications for accessory mineral geochronology

- Melt loss from the residue is expected to progressively deplete the source of Zr and LREE, which may enhance the dissolution of zircon and monazite during heating to high temperature
- Zircon is expected to survive heating to high-temperature followed by isothermal decompression, whereas monazite may be mostly consumed
- In residual rocks, some zircon is expected to survive heating to high-temperature and isothermal decompression, whereas monazite may be completely consumed and inherited cores are predicted to be less common than in zircon
- Leucosomes in migmatites and granites are predicted to contain newly formed zircon and monazite with minimal inherited components, but the common occurrence of cores in zircon in granites suggests that dissolution is inhibited by fast ascent

References

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