

## Unravelling P-T-t paths: Pseudo-sections versus classical phase petrology

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Crystalline rocks record critical information about the magnitude and rates of geodynamic processes. Important factors such as: how deep; how hot; how fast; and for how long are all in some way encoded in the mineral assemblages, mineral compositions and microstructures. Our ability to estimate metamorphic pressure-temperature (*P-T*) conditions has improved markedly with the increased availability of thermodynamic data for both simple and complex solid-solution phases, internally-consistent thermodynamic datasets and powerful computer programs to manipulate this data for a variety of equilibrium calculations. An increasingly popular tool is the single composition *P-T* section (commonly termed pseudosection) which allows rapid determination of mineral assemblages, compositions and their modal amounts for a given bulk composition within a specified *P-T* window. Unfortunately, with the increasing popularity has come an increasing disregard for the fact that a rock in equilibrium can only define a single point on such a diagram and that *P-T* paths, interpreted due to compositional zoning, inclusion suites and reaction textures, cannot be reliably indicated on the same, single pseudosection. Fortunately, the solution to this dilemma already exists. It is possible to model the consequences of bulk compositional fractionation along a *P-T*-path and even to define local bulk chemical sub-domains (e.g. for a single inclusion or between two specific grains). Conventional geothermobarometry, typically utilising standardised formulations of exchange, net transfer or solvus reactions, is only of limited, indicative use. However, if one is confident of having identified a preserved equilibrium assemblage, and assuming that the compositions of the phases have not been subsequently modified, the same conventional thermobarometric reactions can be determined with thorough consideration of the *P*- and *T*-dependence of thermodynamic parameters, including activities, with the internally consistent data. Rocks in perfect (metastable) equilibrium are ideal for studying by a single pseudosection but of zero use for determining *P-T*-time paths. It is only by the combination of petrography, careful microanalysis and thoughtful application of various equilibrium thermodynamic tools, including pseudosections, that we will advance to a better quantification of, and thus also ability to model and predict, geodynamic processes.

## Mercury distribution and speciation in a seasonal wetland impacted by mine waste

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Ephemeral pond waters and surface sediments were studied in a seasonal wetland adjacent to the former Sulphur Bank Mercury Mine and Clear Lake (CA, USA) in order to evaluate *in situ* stabilization treatments as a remedial option for Hg-contaminated sediments. Surface ponds fed during winter by acidic groundwater seepage from a pit lake on the adjacent mine site have high and variable total dissolved Hg concentrations ( $[Hg]_{tot} = 70\text{--}2300 \text{ ng l}^{-1}$ ), but low methylmercury (Me-Hg) (<0.1% of  $[Hg]_{tot}$ ). Higher dissolved Me-Hg concentrations, comprising 22–41% of total Hg, are correlated with pond waters influenced by groundwater flux from Clear Lake with circum-neutral pH (~6.6–8.6) and relatively high dissolved organic carbon (~30 mg l<sup>-1</sup>). Characterization by X-ray diffraction and X-ray absorption spectroscopy (XAS) showed sulfate-rich (gypsum, jarosite) and clay alteration phases in surface sediments influenced by acidic groundwater, and less altered primary minerals and the presence of calcite in neutral pH sediments. Results from bulk and micro-focused Hg XAS of sediments indicated the presence of metacinnabar (HgS (s)), most likely as residual mine waste particles, nearest the former mine with high sediment  $[Hg]_{tot}$  concentrations (100–500 mg kg<sup>-1</sup>). Sediments from weakly acidic and neutral pH ponds had lower  $[Hg]_{tot}$  (3–15 mg kg<sup>-1</sup>), but a higher fraction of Hg associated with extractable organic matter. There was no evidence in sediment Fe or S XANES spectra for the presence of reduced Fe-sulfide minerals, and all surface pond waters were oxidized, with measurable dissolved oxygen and low dissolved Fe. The lack of evidence for active sulfate or Fe reduction in neutral pH ponds with high dissolved Me-Hg suggests that Hg methylation is occurring in the subsurface, with possible transport of Me-Hg by organic matter complexation. Thus, remediation strategies must consider both (1) stabilization of residual HgS (s) particles, but limiting bacterial sulfate reduction and Hg methylation as pond water pH increases with remediation of the pit lake, and (2) transport of Me-Hg in groundwater to surface biological receptors where Hg bioaccumulation may occur.