Metamorphic rocks seek meaningful cooling rates: New views from muscovite $^{40}Ar/^{39}Ar$ dating

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Abstract

The cooling and exhumation rates of metamorphic terranes determined using muscovite $^{40}Ar/^{39}Ar$ chronology underpin many tectonic models. Infra-red laser single grain fusion and UV-laser spot-profiling $^{40}Ar/^{39}Ar$ muscovite data from variably overprinted high pressure terranes in Oman [1], the Alps [2] and Norway show that individual samples and even individual grains can yield age ranges which span >50 Ma. Samples analysed in this spatially detailed way commonly yield bulk average ages that are similar to ages determined by single- or multi-grain step heating techniques. This result suggests that the latter technique may commonly mask the absolute variation in $^{40}Ar/^{39}Ar$ age between and within grains. Core to rim $^{40}Ar/^{39}Ar$ age profiles within individual grains determined by UV laser ablation vary from no determinable difference across the grain to grains with older cores or even apparently older rims [1]. These data suggest heterogeneous grain boundary Ar reservoirs during metamorphic evolution. Many of the single grain fusion ages are older than the timing of peak metamorphism determined from e.g. U-Pb on zircon and are therefore attributable to "excess argon" (^{40}Ar decoupled from its parent ^{40}K). For ages which are younger than the timing of peak metamorphism, it is more difficult to assess whether any resulting ages constrain the "true" timing of cooling and exhumation due to a varying amount of excess argon contamination, inefficient Ar removal from the grain boundary or system resetting by deformation or recrystallisation. Careful evaluation of the metamorphic pressure-temperature-time history experienced since the time of mica crystalisation coupled with detailed UV-laser intra-grain age profiling and predictions from numerical diffusion modelling places constraints on data interpretation [3]. In many cases the age variability is best explained by spatial and temporal variations in grain boundary Ar concentration which act to hinder open system Ar removal. Muscovites affected in this way do not yield "true" cooling ages as suggested by the Dodson equation [4] and cooling rates based on these ages may not be tectonically reliable.

[1] Warren et al., (2011) *Contrib. Min. Pet.* **161**, 991-1009; [2] Warren et al., (2012) *J. Met. Geol.*, **30**, 63-80; [3] Warren et al., (2010) *Chem. Geol.* **291**, 79-86; [4] Dodson (1973) *Contrib. Min. Pet.* **40**, 259-274

Controls on summer deposition of atmospheric sulphate and nitrogen in alpine valleys of the Southern Canadian Rocky Mountains

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Introduction

Alpine ecosystems, which are generally nutrient poor and exist under extreme climatic conditions, are particularly sensitive to environmental and climatic stressors, including enhanced N and S deposition. The magnitude of regional N and S emissions in Western Canada oppose the Canadian norm and are increasing, a trend that is forecast to continue. However, evaluation of the magnitude of atmospheric deposition, and processes controlling deposition at potentially vulnerable alpine sites is lacking.

Methods

This study evaluates the controls on summer 2010 nitrogen (N) and sulphate (S) deposition to alpine valleys in the Southern Canadian Rocky Mountains. Deposition is evaluated using bulk precipitation collected from sites at three elevations, in adjacent valleys, on opposing sides of the Continental Divide. Major ion concentrations and stable isotope signals ($\delta^{18}O_{H2O}$ and $\delta^{2}H_{H2O}$, $\delta^{34}S_{SO4}$ and $\delta^{18}O_{SO4}$, $\delta^{15}N_{NO3}$ and $\delta^{18}O_{NO3}$) of the precipitation in combination with synoptic metrological conditions are evaluated.

Results

A dominant source of well mixed atmospheric sulphate is suggested by the relatively uniform precipitation $\delta^{34}S$ values (7.2 ± 3.8‰). These values are higher than commonly reported for well mixed continental sources in North America, and suggest the influence of an emission source with higher positive $\delta^{34}S$ values such as coal, oil, or sour gas. Strongly correlated $[NO_3^-]$ and $[SO_4^{2-}]_{nss}$ ($r=.88$ $p<0.1$) implies they have a common pollutant origin.

Generally, the north-west facing Robertson Valley (RB) receives lower precipitation volumes, but higher NO_3^- loads, and similar SO_4^{2-} and NH_4^+ loads, than the south-east facing Haig Valley (HG).

Precipitation accumulated over discrete intervals also shows variable trends in stable isotope signals as well as ion loads with elevation. Increasing elevation is usually associated with higher $\delta^{34}S_{SO4}$ and $\delta^{18}O_{NO3}$ and lower $\delta^{18}O_{H2O}$ and $\delta^{15}N_{NO3}$ although inverse relationships also occur. We anticipate evaluation of the synoptic metrological conditions, along with back trajectory analysis associated with each sampling interval will help elucidate the dominant controls on atmospheric N and S deposition at the field sites.