Spatial and temporal variations in exhumation across the NW-Himalaya

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Erosional exhumation and topography in Mountain belts are temporally and spatially variable over million year time scales due to changes in both the location of deformation and climate. However, many studies are limited in the extent to which spatial variations in exhumation can be quantified due to the limited geographic extent over which samples are collected. We investigate spatial and temporal variations in exhumation and deformation across a 150x200 km region of the NW Himalaya, India. 25 new and 168 previously published apatite and zircon fission track and muscovite $^{40}Ar/^{39}Ar$ ages are integrated with a 1D model to quantify rates and timing of deformation and exhumation along strike of several major structures in the Lesser and Greater Himalaya. The model solves the advection-diffusion equation and predicts thermochronometer ages for variations in exhumation rates, thermophysical properties, and basal temperature.

The new and previously published AFT ages range from 10 to 0.6 Ma. The sample area is characterized by 0.7-5 km-high-topography, high relief (~4 km), and large (~1 to 4 m/yr) precipitation gradients. All the thermochronometer data indicate large temporal and spatial variations in exhumation. AFT ages are inversely correlated with local relief, but not with modern precipitation gradients. Results from thermokinematic modeling of all thermochronometer systems indicate: (1) Greater Himalaya exhumation rates were .0.5-0.8 before ~12 Ma and increased to 2-3 mm/yr after ~10 Ma. (2) In the Lesser Himalaya exhumation rates are 1-2 mm/yr over the last 10 Ma. The previous temporal variations in erosion in the Greater Himalaya are spatially consistent along 200 km of strike, regardless of structural variations. This implies that erosion, rather than tectonics, has controlled the topographic evolution of this region over the last ~15 Ma.

Ca-Sr fractionation between margarite, anorthite, calcite, and fluid at 400-500 °C and 3.5-5 kbar

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We determined experimentally the Ca-Sr distribution between an 1 molar aqueous $(Ca,Sr)Cl_2$-solution and (Ca,Sr) solid solutions of margarite, anorthite, calcite ± slawsonite and clinozoisite at 400-500 °C and 3.5-5 kbar using conventional cold-seal hydrothermal experiments. Solid oxide-hydroxide starting mixtures were prepared from SiO_2, Al_2O_3, $Ca(OH)_2$, and $Sr(OH)_2 \cdot 8H_2O$ (containing small amounts of carbonate impurities) weighted in stoichiometric amounts of the desired margarite composition plus ~ 3 wt% SiO_2 excess to compensate for Si solubility in the fluid at run conditions. Strontium bulk compositions X_{Sr}^{bulk} [Sr/(Sr + Ca)] ranged from 0.07 to 0.40 with initial $X_{Sr}^{solid} = X_{Sr}^{fluid}$. The initial solid/fluid weight ratios were ~ 1:1. Solid run products were analyzed by REM, electron microprobe, and XRD; fluids were analyzed by inductively coupled plasma emission spectrometry.

Syntheses products are margarite, anorthite, and calcite in all runs ± clinozoisite and slawsonite in one run each at $X_{Sr}^{bulk} \geq 0.15$. Margarite forms idiomorphic hexagonal plates of generally less than 5 µm diameter. Anorthite and also clinozoisite are likewise idiomorphic but form significantly larger crystals with up to 100 and 150 µm lengths, respectively.

In all runs, X_{Sr} of margarite, anorthite, and calcite is less than the corresponding X_{Sr}^{bulk} and X_{Sr}^{fluid} and ranges up to $X_{Sr} = 0.166$ in margarite, 0.137 in anorthite, and 0.031 in calcite. Within these compositional ranges, electron microprobe analyses indicate continuous Ca-Sr solid solution series for all three minerals. X_{Sr} of clinozoisite is slightly higher than X_{Sr} of coexisting margarite, anorthite, and calcite but still less than the corresponding X_{Sr}^{fluid}. Contrary, slawsonite has notably higher X_{Sr} than X_{Sr}^{bulk} and X_{Sr} of coexisting fluid and other solid phases. We used our data to calculate exchange coefficients K_D for the generalized reaction $Ca^{Phase\ 1} + Sr^{Phase\ 2} = Sr^{Phase\ 1} + Ca^{Phase\ 2}$ [where $K_D^{Phase\ 1 - Phase\ 2} = (Sr/Ca)^{Phase\ 1} / (Sr/Ca)^{Phase\ 2}$]: $K_D^{margarite\text{-}fluid}$ ranges from 0.49 to 0.67, $K_D^{anorthite\text{-}fluid}$ from 0.47 to 0.59, and $K_D^{calcite\text{-}fluid}$ from 0.08 to 0.11; $K_D^{clinozoisite\text{-}fluid}$ is 0.72 and $K_D^{slawsonite\text{-}fluid}$ is 7.75. The data clearly show a preference of Sr over Ca for the fluid when compared to margarite, anorthite, calcite, and clinozoisite, but a preference of Ca over Sr for the fluid when compared to slawsonite. Calculated $K_D^{margarite\text{-}calcite}$ and $K_D^{anorthite\text{-}calcite}$ range from 5.14 to 8.60 and 4.91 to 7.55, respectively, and indicate notably Ca-Sr fractionation. On the other hand, $K_D^{margarite\text{-}anorthite}$ ranges from 1.01 to 1.26 and suggests only weak Ca-Sr fractionation between margarite and anorthite.