Changes in the north-Alpine climate as a function of the Alpine upliftment: constraints from isotopic compositions of fossils and sediments of the Molasse, and Alpine vein quartz.

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While much is known about the geological-geochronological framework of Alpine tectonism, including associated erosional rates and sediment volumes, estimates of changes in paleoelevation and its direct influence on paleoclimate have been less well constrained. Over the course of the past several years this relationship has been examined on the basis of combined geochemical-isotopic studies of the Tertiary northern Alpine Molasse sediments. These sediments were deposited in marginal basins that were partly to completely isolated from other major oceanic basins during major periods of Alpine tectonism but also at a time of large global climatic change. As will be outlined below, they are well suited to study the effects of tectonic forcing on regional climate. By comparing the past climatic and oceanographic evolution indicated by the Molasse sediments to those on a global scale, a qualitative evaluation of the relationship between tectonism and regional climate is made possible.

One approach to determine changes in paleoelevation is to investigate the hydrogen (and oxygen) isotopic composition of clay minerals within the Molasse sediments. It has been known for some time, that the H and O isotope composition of clay minerals formed in a weathering environment reflects that of the average ambient precipitation (e.g., Lawrence and Taylor, 1971). The H- and O-isotopic composition of precipitation, in turn, is largely controlled by mean ambient air temperature, which in mountainous regions is itself directly related to the mean elevation (e.g., Schürch et al., 2003). Hence, the H- and O-isotopic composition of clay minerals derived from the Alps as weathering material and deposited as detritus in the Molasse sediments may be used as a proxy for climatic and/or topographic changes in the source terrain (e.g., Chamberlain and Poage, 2000). The H-isotope composition of the less than 2 μm size fraction sampled from drill-cores in the German Molasse changes throughout the two transgressive-regressive cycles of Molasse deposition from average δD values (relative to VSMOW) of about −66‰ in the Lower Marine Molasse to −77‰ in the Lower Freshwater Molasse, −71‰ in the Upper Marine Molasse, and reaching values as low as −98‰ in the Upper Freshwater Molasse. Hence, clays in both freshwater cycles have lower values compared to those from the preceding marine units. This change in the H isotope composition would be compatible with decreasing temperatures throughout sedimentation from the Late Oligocene up to the Late Miocene and/or with several phases of upliftment of the source terrain. A cooling trend is in agreement with the overall global cooling during the Tertiary. Isotopic composition of precipitation estimated to be in equilibrium with the clay minerals is compatible with a source terrain changing in average elevation of weathering from about 500 to 1200 m, given a typical altitude effect for the precipitation as is observed for recent precipitation sampled in Switzerland (Schürch et al., 2003).

A completely independent approach to estimating past changes in elevation is given by isotopic analysis of vein and fissure quartz formed during retrograde metamorphism in Alpine rocks (e.g., Mullis et al., 2001). Several distinct groups of vein and fissure quartz can be differentiated on the basis of their occurrence, textural appearance, and composition of included fluids. Sometimes, these distinct generations of quartz even occur within the same fissure. While fluids calculated to be in equilibrium with early Tessin-habitus quartz, formed at 450 to 410 °C and 3.5 to 2.2 kbars, has O isotope compositions and H isotope compositions of its included fluids that are typical of metamorphic fluids (+6 to +23‰ and +7 to −70‰, respectively), late stage split-growth quartz, formed at about 250 to 180 °C and 1.2 to 0.5 kbar, approaches isotopic compositions that are clearly in
equilibrium with meteoric fluids: quartz $\delta^{18}O$ values as low as $-3.7\%_{\text{o}}$, with corresponding fluid $\delta^{18}O$ values between $-7$ and $-16\%_{\text{o}}$ and measured $\delta D$ values between $-78$ and $-140\%_{\text{o}}$). Again using recent altitude effects as an analogue, these isotopic compositions would imply paleotopographic highs during the Mid-Miocene in excess of 3500 m for the Gotthard massif area.

A third, recently discovered indicator of the paleotopography is based on the analysis of fish teeth, in this case “exotic” shark teeth from Swiss Upper Marine Molasse sediments. Two teeth out of six measured had $\delta^{18}O$ values (VSMOW) of about 11\%$_{\text{o}}$, values completely different from teeth of the same species sampled in the same locality (La Molière; 20.7 to 21.8\%$_{\text{o}}$). These exotic teeth also had Sr isotope ratios compatible with a freshwater, Jurassic carbonate-dominated composition, which is in contrast to that for the other teeth that have more typical Miocene marine compositions. All teeth, however, have the same types of REE patterns, supporting the same marine pore-fluid type diagenetic history. Thus, a freshwater formation for the exotic teeth is postulated and, assuming a similar habitat temperature for these sharks, suggests $\delta^{18}O$ values for water of about $-10\%_{\text{o}}$, hence minimum altitudes of about 1500 m.

These three independent lines of evidence, collectively indicate significant changes in altitude of the Alps during the Oligocene to Miocene, with average altitudes of about 1500 to 2000 m and peak elevations in excess of 3500 m during the Late Miocene, that is elevations similar to those of today.

Paleoclimatic reconstructions from North Alpine Molasse sediments are based on oxygen isotope compositions of fossil mammalian tooth enamel for freshwater molasse deposits, and shark teeth, marine ostracoda, foraminifera, and mammalian phosphatic fossils for the Upper Marine Molasse deposits. The $\delta^{18}O$ values (VPDB) of carbonate in phosphate from Oligocene and Miocene large mammal teeth (n=270), for example, vary over a large range from $-11.9\%_{\text{o}}$ to $-0.5\%_{\text{o}}$, but these variations parallel the composite $O$ isotope curve of Tertiary benthic foraminifera from the Atlantic ocean, thus similarly reflecting major global climatic changes such as the Late Oligocene warming, Mi-Miocene climate optimum, and Middle to Late Miocene cooling trends. The $\delta^{18}O$ values (VSMOW) of phosphate in shark teeth (19.5 to 23.5\%$_{\text{o}}$, n=155) from Miocene marine Molasse sediments as well as those of ostracods and foraminifera from these sediments all have variations that also parallel those of composite curves for global changes (e.g., Vennemann and Hegner, 1998; Janz and Vennemann, 2005). In addition, the Sr-isotope compositions of these marine fossils largely support open marine conditions, indicating that the marginal basins had good connections to the open oceans. Exceptions do exist for some localities, most notably those situated close to old siliceous massifs, where a local input of Sr was important during certain periods.

Collectively, the data support a paleogeography for the Tertiary Alps represented by a high mountain belt with altitudes similar to that of today adjacent to marginal marine or freshwater depositional basins but with a regional climate, at least for the northern Molasse realm, that was strongly coupled to the global climate. The Alps thus appear not have influenced the local climate and/or atmospheric circulation patterns significantly at this stage. Further investigations will focus on north-south comparisons of climatic change across the Tertiary Alps.

REFERENCES


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