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From source terrains of the Eastern Alps to the Molasse Basin: Detrital record of non-steady-state exhumation

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Abstract

Fission-track cooling ages of detrital apatite (AFT) in the East Alpine Molasse Basin display age groups corresponding to geodynamic events in the orogen since Jurassic times. These age groups are typical of certain thermotectonic units, which formed a patchwork in the Swiss and Eastern Alps. By a combination of petrographic and thermochronologic data, progressive erosion of source terrains is monitored in different catchments since the Oligocene. The AFT cooling ages show a decrease in lag time until when rapidly cooled debris derived from tectonically exhumed core complexes became exposed. After termination of tectonic exhumation, lag times of debris derived from the core complexes increased. Neither on the scale of the entire Eastern Alps, or on the scale of individual catchments, steady-state exhumation is observed, due to the highly dynamic changes of exhumation rates since Late Eocene collision.

Keywords: Detrital thermochronology; Apatite fission track; Eastern Alps; Foreland basin; Provenance

1. Introduction

Exhumation rates in collisional orogens such as the Alps are recorded in the cooling history of orogenic debris in adjacent basins (Einsele et al., 1996). The cooling history in the depositional record monitors timing and rates of exhumation processes more effectively and regionally than local cooling paths deduced from surface samples of an orogen (Brandon and Vance, 1992). Exhumation processes in active orogens may operate at different rates throughout their evolution, depending on, e.g., varying rates of convergence, varying thickness of subducted continental crust and varying lithospheric strength along strike of the orogen (Schmid et al., 1997; Pfiffner et al., 1997). Such temporal and spatial variability is typical in the Alps, and several studies have shown discontinuous exhumation in the Western Alps (Dunkl et al., 2001; Carrapa et al., 2003; Fügenschuh and Schmid, 2003) and the Swiss Alps (Von Eynatten et al., 1999; Spiegel et al., 2000, 2001). Nevertheless, the Swiss Alps have recently been quoted as an example of a steady-state exhuming orogen since Oligocene times (Bernet et al., 2001). Detailed knowledge of provenance, however, is crucial for the interpretation of thermochronologic data of distal detrital material. If rapidly cooled detritus is shed from varying fastly exhuming source terrains in migrating catchments, and also from volcanic sources, apparent steady-state exhumation may be misleading. Rapid cooling of exhuming rocks causes a very short lag time, which expresses the time span between the age of mineral cooling below its closure temperature at

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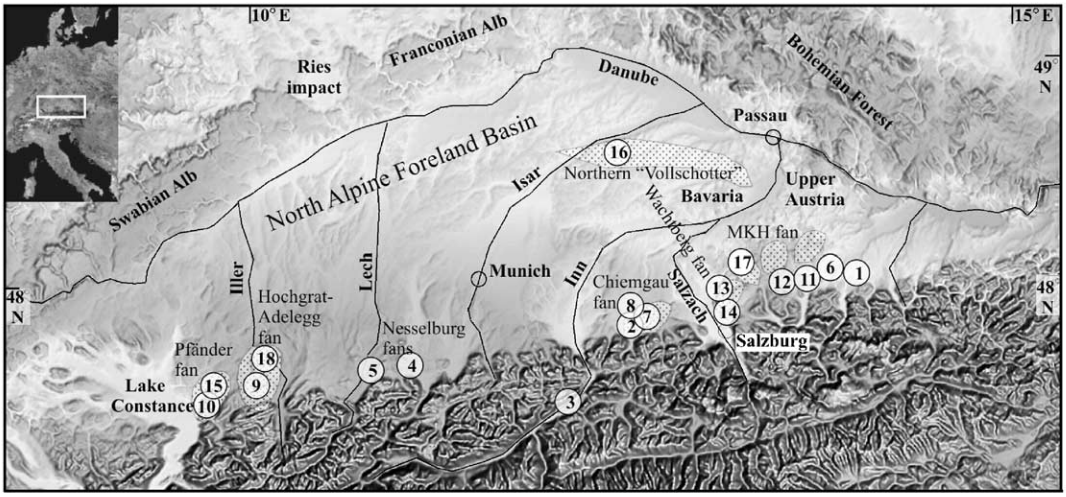

Fig. 1. Digital elevation model (shaded relief) of the eastern part of the Molasse Basin, showing major fan deposits and sample locations. The Chiemgau-, Wachtberg- and Munderfing-Kobernausser-Hausruck (MKH) fans represent fan delta deposits of the Paleo-Inn river. The sample numbers follow stratigraphic order (for localities see Table 1).

some kilometer depth (F-apatite: around 110 °C; Gleadow and Duddy, 1981) and its surface exposure, subsequent detrital tranport and deposition (Brandon and Vance, 1992). In the light of the recent discussion, data from the Eastern Alps provide evidence for a better understanding of the entire orogen.

In this study, we present thermochronologic data from the eastern part of the Molasse Basin (Fig. 1), which we partly relate to well-defined feeder systems and catchments with distinct source terrains. The Eastern Alps are characterised by erosion rates that are about half as high as those detected in the Swiss and Western Alps (Kuhlemann et al., 2002). The purpose of this study is to provide details on the exhumation of the Eastern Alps in space and time. The Oligocene to Early Miocene period is of special interest, since it monitors the erosion of upper plate Austroalpine units which had already been removed from the Swiss Alps during this period (Pfiffner et al., 1997).

2. Tectono-thermal setting of the Eastern and Swiss Alps

The Alps are composed of three mega-units representing the northern tip of African/Adriatic continental crust in upper plate position (Austroalpine mega-unit), the southern margin of Europe in lower plate position (Helvetic mega-unit), and the complex terrane of the Penninic mega-unit sandwiched in between (Fig. 1c; Frisch, 1979; Schmid et al., 1997). The Austroalpine mega-unit is exposed over large parts of the Eastern Alps whereas it is largely eroded in the Swiss Alps. It consists of crystalline basement characterised by Variscan amphibolite-facies metamorphism and Cretaceous (Eoalpine) metamorphic overprint, as well as of low-grade metamorphic Paleozoic terrains and post-Variscan (Permian to Eocene) cover sequences (Ratschbacher et al., 1989). The Penninic mega-unit is composed of Variscan basement fragments with Mesozoic cover sequences, and relics of Mesozoic oceanic crust and its sedimentary cover. Metamorphosed Penninic units are exposed in the tectonic windows of the Swiss and Eastern Alps, whereas an unmetamorphosed flysch belt crops out at the northern front of the Alps. Penninic units exposed in the windows experienced Early Tertiary metamorphism up to amphibolite facies grade. Temperature maximum was attained in Oligocene times around 30 Ma (Von Blanckenburg et al., 1989; Christensen et al., 1994; Inger and Cliff, 1994). The Helvetic mega-unit is subordinately exposed in the Eastern Alps but abundant in the Swiss Alps. It is composed of a granite-rich Variscan basement with Miocene low-grade metamorphic overprint, and post-Variscan (Permian to Eocene) cover sequences (Schmid et al., 1997).

Presently exposed litho-terrains of the Alps show highly contrasting cooling histories. Core complexes experienced Miocene tectonic exhumation during lateral extension (Fig. 1b; Hunziker et al., 1992; Frisch et al., 2000a). Differential erosional exhumation also caused contrasting cooling paths in the Austroalpine units of the Eastern Alps with AFT cooling ages spanning from Cretaceous to Miocene times (Hejl, 1997; Elias, 1998). Moreover, Early Oligocene magmatic ac-