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The potential of detrital garnet as a provenance proxy in the Central Swiss Alps

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ABSTRACT

Detrital garnet is a promising candidate to reliably fingerprint sediment sources in the Alps, which has so far been complicated by the wide range and similarity of some of the lithologies. Garnet is present in most Alpine sediments, is easy to identify, is fairly stable and, most importantly, reflects the type and the metamorphic grade of its source rock in its chemical composition. This study aims to establish fingerprints based on detrital garnet composition for the most important tectonic units of the Central Alps, including European, Penninic and Adriatic basement rocks and their respective metasedimentary covers. Sediments collected from modern rivers, which drain representative portions of the individual tectonic units, contain a natural mixture of the various garnet populations present in each unit. We selected six catchments in southwestern Switzerland draining the External massifs, Helvetic sediments and the Penninic nappe stack at the transition of Alpine greenschist- to amphibolite-facies metamorphism in order to test the variability of Alpine garnets and the role of inherited (pre-Alpine) garnets. Extraordinary grossular- and spessartine-rich garnets of the External massifs, which experienced greenschist facies metamorphism, are clearly distinguishable from generally almandine-rich garnets supplied by the higher-grade metamorphic Penninic nappe stack. The variable pyrope, grossular and spessartine components of these almandine-rich garnets can be used to further distinguish pre-Alpine, Alpine eclogite-facies and low-grade metasedimentary garnets. This provenance proxy has the potential to be used for reconstructing sediment sources, transport and dispersal patterns in a variety of settings throughout the Alpine sedimentary record.

1. Introduction

The European Alps were formed as a result of the convergence between the European and the Adriatic continent plates (Trümpy, 1960; Frisch, 1979; Schmid et al., 1996). Ongoing subduction and closure of two marine basins, the Piedmont-Liguria ocean and the Valais trough, resulted in continental collision that gradually incorporated the European continental margin into the orogen. Ever since the first collisional stage in late Cretaceous times (Lihou and Allen, 1996), the Alps have been one of the most important sediment sources in central and southern Europe (e.g., Kuhlemann et al., 2002). Alpine sediments have been either incorporated into the orogenesis from Cretaceous to Oligocene times (flysch), deposited in the foreland basins between the Oligocene and the Miocene (Molasse) or have been transported out of the orogen by fluvial and glacial processes since Miocene times (Allen et al., 1985; Graf, 1993; Schlunegger et al., 1993; Winkler, 1996; Hagedorn and Boenigk, 2008; Garzanti et al., 2011; Reiter et al., 2015).

In order to understand the sources, transport and dispersal patterns of Alpine-derived sediments throughout this geological record, it is important to have fingerprinting tools available which allow to reliably trace the material back to its source. However, the large variability of lithologies within the Alps, and their similarity to rocks outside of the Alps considerably complicates the fingerprinting. Detrital garnet is a promising candidate to address this problem, because its composition varies significantly depending on the chemistry and metamorphic grade of the source rock (Spear, 1994). Garnet geochemistry has been proven suitable to distinguish different source rocks in a variety of settings (Morton, 1985; Teraoka et al., 1998; Sabeen et al., 2002; Morton et al., 2004; Krippner et al., 2014; Andò et al., 2014, Alizai et al., 2016, Krippner et al., 2016). Furthermore, it is relatively common in most Alpine-derived sediments (Füchtbauer, 1964; Garzanti and Andò, 2007, Garzanti et al., 2012), easy to identify and fairly stable during sediment transport and particularly during diagenesis (Morton and Hallsworth, 2007; Andò et al., 2012; Garzanti et al., 2015).

The aim of this study is to understand the overall compositional variety of garnet grains supplied by the major source rocks exposed in the Central Swiss Alps. Several authors have investigated garnet

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compositions from individual litho-tectonic units and outcrops, which provide valuable petrological details for the bedrocks, but rarely information representative enough for provenance studies.

We therefore complement existing data with analyses on garnets extracted from modern fluvial sediment of selected river catchments.

2. Geological setting

The investigated part of the Central Alps comprises the following main units (Fig. 1): The External massifs, the Helvetic nappes, the Penninic nappes and the Dent Blanche/Sesia zone (Federal Office of Topography Swisstopo, 2011).

The External massifs (Fig. 1) are made up from European continental crust, which was exhumed from deeper crustal levels during the Miocene (e.g., Michalski and Soom, 1990). In the Central Alps, these are the Mont-Blanc, the Aiguilles-Rouges and the Aar massifs (e.g., von Raumer et al., 1999). The External massifs comprise mostly polycyclic basement gneisses with intercalations of amphibolites intruded by Variscan and post-Variscan granites (Berger et al., 2016). Locally, their Carboniferous to Mesozoic metasedimentary cover is preserved as well. The basement units underwent polycyclic metamorphism at different times during the Paleozoic (von Raumer et al., 1999). In addition, all units underwent lower to upper greenschist facies metamorphism during the Tertiary (Frey and Ferreiro Mählmann, 1999; Bousquet et al., 2012) (Fig. 2).

The Helvetic nappes represent the sedimentary cover of the European passive continental margin, which comprises basically a carbonate shelf sequence of Jurassic, Cretaceous and Eocene age (Pfiffner, 1993, 2015). During Alpine metamorphism, temperature and pressure conditions in these nappes never exceeded 300 °C and 2–3 kbar, respectively (Frey and Ferreiro Mählmann, 1999).

The Penninic nappes include three paleogeographic units: The Valais trough (lower Penninic), the Briançonnais swell (middle Penninic), and the Piedmont-Liguria ocean (upper Penninic). The lower Penninic consists mostly of calcschists and flysch sediments deposited in the Valais trough during the Cretaceous with an Alpine greenschist- and blueschist-facies overprint (Schmid et al., 2004; Bousquet et al., 2012).

The middle Penninic units were part of the Briançonnais swell, a non-continuous eastern spur of the Iberian plate separating the Valais trough in the North from the Piedmont-Liguria ocean in the South (Schmid et al., 2004). This unit comprises Paleozoic metagranitoids, gneisses and schists of the Briançonnais basement as well as their metasedimentary Permian and Mesozoic cover. The Alpine metamorphic overprint of the middle Penninic units increases towards the South, ranging from lower greenschist-facies conditions in the more external Zone Houillère, Pontis and Siviez-Mischabel nappes to blueschist-facies conditions in the more internal Mont Fort, Cimes Blanches and Frilihorn nappes (Desmons et al., 1999; Bousquet et al., 2012) (Fig. 2). Parts of the middle Penninic basement units, however, preserve amphibolite to eclogite-facies metamorphism of pre-Alpine age (Thélin

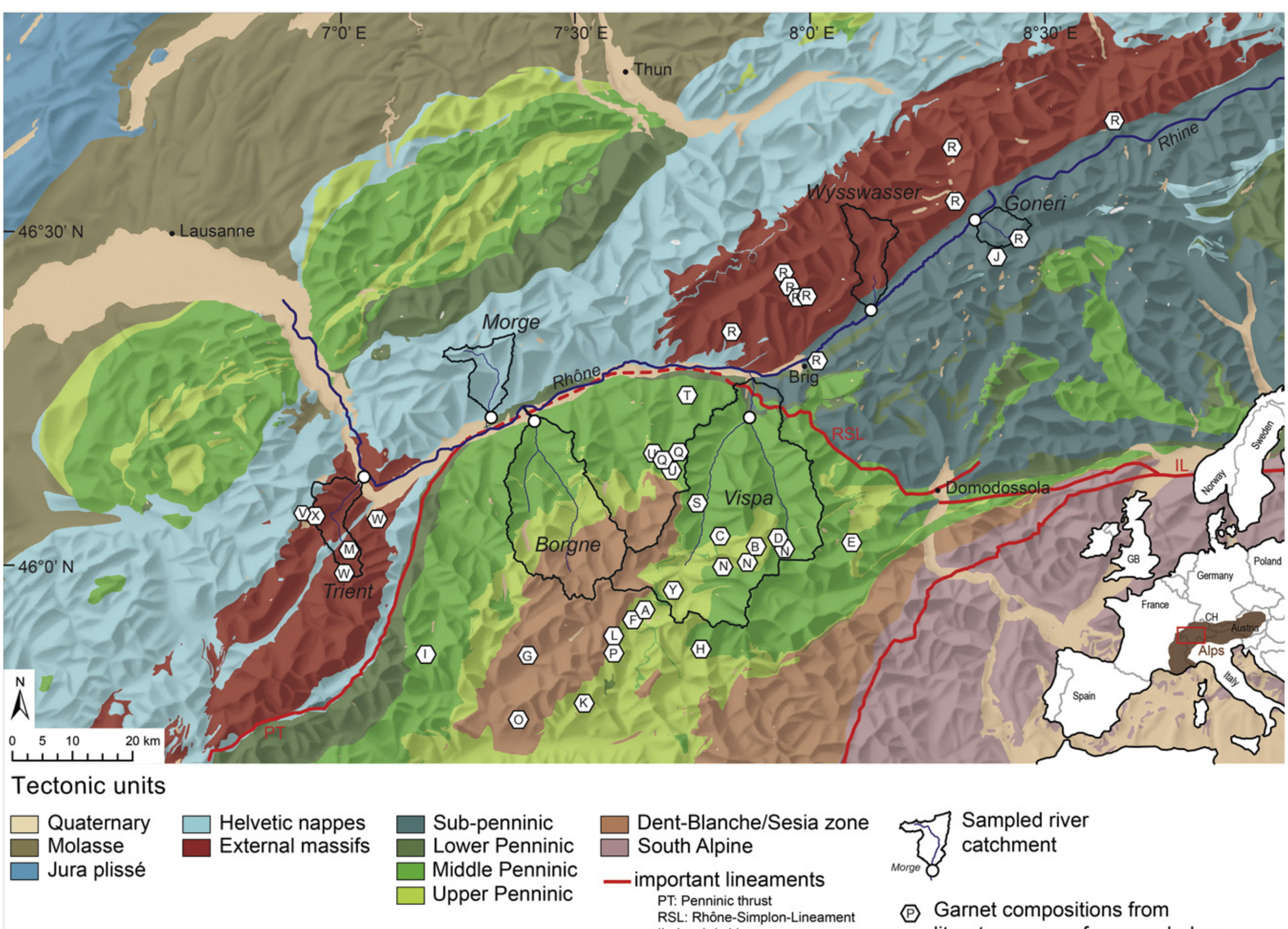

Fig. 1. Tectonic map of the Central Swiss Alps, indicating the major tectonic units. Modified after Federal Office of Topography Swisstopo (2011). The six sampled catchments are outlined in black. Garnet compositions from the literature are indicated as white polygons. The letters refer to the following references: A: Angiboust et al. (2009), B: Bucher and Grapes (2009), C: Cartwright and Barnicoat (2002), D: Chinner and Dixon (1973), E: Engi et al. (2001), F: Ernst and Dal Piaz (1978), G: Gardien et al. (1994), H: Gasco et al. (2011), I: Giorgis et al. (1999), J: Kamber (1993), K: Kirst (2014), L: Manzotti et al. (2012), M: Marshall et al. (1997), N: Oberhänsli (1980), O: Pennacchioni and Cesare (1997), P: Reinecke (1998), Q: Sartori (1990), R: Steck and Burri (1971), S: Thélin (1987), T: Thélin and Ayrton (1983), U: Thélin et al. (1990), V: von Raumer et al. (1990), W: von Raumer and Bussy (2004), X: von Raumer and Schwander (1985), Y: Weber and Bucher (2015). Not on map: Bucher and Bousquet (2007).