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Application of electron probe microanalysis Th–U–total Pb geochronology to provenance studies of sedimentary rocks: An example from the Carpathian flysch

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ABSTRACT

Two gneiss and one granulite cobble from the ca. 60 Ma Silesian Unit flysch rocks (Western Outer Carpathians, southern Poland) have been studied. These cobbles are considered to represent rocks derived from the Silesian Ridge, one of the internal source areas that supplied the Carpathian sedimentary basins with clastic material. This ridge developed at the boundary between Variscan and Cadomian crustal fragments of the European platform, and formed an elongated thrust belt rapidly uplifted and eroded during Late Cretaceous to Paleocene times. The pebble to cobble size clastic material present in the Carpathian flysch rocks provides the only opportunity to improve knowledge concerning the evolution of the Silesian Ridge. Electron probe microanalysis Th–U–total Pb monazite chronology has been used to constrain the timing of metamorphism and magmatic protolith of gneiss cobbles derived from the Silesian Ridge. Based on microtextural observations and chronological results four monazite populations were identified. The oldest age of ca. 592 Ma was obtained from the core and rim of grains with igneous concentric growth zonation in augen gneiss from Gródek. Monazite dates from gneiss from Izdebnik define two age populations of ca. 368 Ma and ca. 333 Ma. Similar results were obtained from a zoned monazite inclusion in garnet from granulite. Monazite cores, which pre-date garnet growth give an age of ca. 372 Ma, whereas the rims are ca. 336 Ma. The rims have lower Y content and reflect monazite growth after the onset of garnet growth. Results obtained in this study using improved electron microprobe analyses techniques are consistent with existing data, but much more tightly constrained. The increased precision is related to consideration of the complex compositional zonation and textural setting of monazite, and also to treating each compositional domain as a unique chrono-chemical system investigated in isolation by multi-point analyses. This study provides new geochronologic data for the Carpathian source terrain, and highlights the potential role for electron probe microanalysis of monazite to provenance studies.

1. Introduction

Provenance studies, via the study of clastic sediments, their individual minerals, and major mineral groups can provide a window into the composition and tectonic history of the source area (as reviewed by Weltje and von Eynatten, 2004). The geochemical link between source rocks and the geochemistry of the resulting sedimentary rocks is also long established (McLennan et al., 2003). For example, studying the major mineral components of sediment budgets, such as quartz, is an established technique in provenance studies (e.g. Pettijohn et al., 1987; Seyedolali et al., 1997). Heavy mineral placer deposits have long held significant economic importance and their distribution is linked to the sediment source rocks. On the other hand, the study of heavy mineral compositions and ages to reconstruct sediment budgets and their sources has only become more common in response to developments in analytical techniques that enable statistically significant datasets to be accumulated in relatively short periods of time (Andersen, 2005). Minerals such as zircon, due to their physical, compositional, and isotopic stability are particularly useful and are routinely used to determine the nature of source rocks (Hoskin and Ireland, 2000; Belousova et al., 2002; Fedo et al., 2003), although it is important to bear in mind that parent rocks cannot be positively identified on the basis of zircon studies alone (Fedo et al., 2003). Monazite, with its compositional and textural complexity and common occurrence in a diversity of lithologies (Williams et al., 2007) also represents a potential target mineral for elucidating information concerning the provenance of

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sediments (Suzuki and Adachi, 1991; Suzuki et al., 1991; González-Álvarez et al., 2006; Kusiak et al., 2006).

The Outer Carpathian flysch rocks of southern Poland represent a suite of clastic sediments for which the most probable source rocks are no longer preserved in-situ. The petrography of exotic clasts within the Carpathian flysch has been described (Wieser, 1949; Książkiewicz, 1965; Oszczypko, 1975; Malik, 1978; Wieser, 1985), and the dominant source of the material was attributed to the Silesian Ridge (e.g., Książkiewicz, 1965; Sikora, 1976; Oszczypko, 2006). The Silesian Ridge is interpreted to have formed an elongate thick-skinned thrust belt that was rapidly uplifted and eroded during the Late Cretaceous to Paleocene (Golonka et al., 2005; Poprawa and Malata, 2006). Because the ridge is no longer exposed, the clastic material in the Carpathian flysch rocks offers the only opportunity to investigate its evolution, and indeed, prove its existence.

A number of recent studies have also used a range of geochronological methods including K–Ar dating of micas, Th–U–total Pb dating of monazite and U–Pb zircon geochronology in an effort to constrain the timing of magmatic and metamorphic events recorded in the clasts, and by extrapolation, the history of the Silesian Ridge. These studies have resulted in a spectrum of dates between ca. 140 Ma and ca. 2740 Ma (Table 1) and significant uncertainty about the history of the Silesian source rocks. In this paper high-resolution electron probe Th–U–total Pb geochronologic data from clasts collected from Carpathian flysch are presented. The ages of monazite grains and sub-domains from several gneiss cobbles have been linked to microtextural features to define ages of crystallization and metamorphism for the crystalline source rocks, i.e. the proposed Silesian Ridge. The new results will shed light on the previous results and help constrain the history of the Carpathian flysch.

2. Background

2.1. Geology

The Carpathian mountain belt is approximately 1300 km long and stretches from the Vienna Forest in Austria to the Iron Gate on the Danube in Romania (Fig. 1a). To the southwest, the Carpathians merge into the Eastern Alps. In the southeast they are connected to the Balkan chain. The Carpathian orogen was formed by the collision of the European platform with an assemblage of microplates (Alcapa, Tisza, and Dacia), and an associated accretionary wedge, in the Tertiary (Csontos and Vörös, 2004).

The Western Carpathian Mountains in Poland consist of the Inner Carpathians, considered to be the oldest part of the range, and to their north, the younger Outer Carpathians (Fig. 1b; Oszczypko, 2006 and refs. therein). The Inner Carpathians consist of pre-Alpine crystalline basement covered primarily by calcareous sediments deposited from the Early Triassic to mid-Cretaceous (e.g. Oszczypko, 2004; Poprawa and Malata, 2006). The Outer Carpathians consist mainly of Late Jurassic to Miocene flysch rocks that were folded and upthrusted onto the European platform in the upper Oligocene to middle Miocene (e.g. Książkiewicz, 1972; Oszczypko, 2004; Poprawa and Malata, 2006). Several Outer Carpathian subbasins, distinguished on the basis of lithostratigraphy, are interpreted to have developed on the margin of the European platform, including (from south to north) the Magura, Silesian, Sub-Silesian and Skole basins (Bieda et al., 1963; Książkiewicz, 1972; Cieszkowski et al., 1985; Oszczypko, 2006). Based on studies of paleotransport directions in Carpathian flysch rocks, it was concluded that terranes to the north, including the Małopolska and Brunovistulian Terranes (e.g., Pharaoh, 1999; Winchester, 2002), and the proposed Silesian Ridge were the most important source areas for terrigenous material supplied to the basin (e.g., Wieser, 1949; Książkiewicz, 1965; Sikora, 1976; Wieser, 1985). Both Małopolska and the Brunovistulian Terranes are interpreted to have docked near the SW margin of the European platform along the Trans-European Suture Zone (TESZ) in the Cambrian (Pharaoh, 1999; Kalvoda et al., 2002; Winchester, 2002; Nawrocki et al., 2004).

2.2. Monazite geochronology

Monazite, the light rare earth element (LREE) phosphate mineral, is a common accessory phase in igneous, metamorphic and sedimentary rocks. The incorporation of Th, and to a lesser extent U provides an isotopic system for radiometric Th–U–Pb dating (Parrish, 1990). Monazite dating is performed using various analytical techniques, including mass ablation isotopic techniques and ionizing radiation, non-isotopic techniques (Williams et al., 2007; their Table 1). In-situ geochronological methods are particularly powerful because they allow monazite to be studied in direct microstructural context, allowing ages to be linked to specific metamorphic or deformational processes. Because electron probe microanalysis (EPMA) has very high spatial resolution, it is useful for analysis of monazite with fine compositional zonation (e.g., Williams et al., 1999; Williams and Jercinovic, 2002; Williams et al., 2007). A steadily increasing knowledge of monazite geochemistry, and particularly its response to changes in temperature, pressure, fluids and mineral assemblage is allowing for better geologic interpretation of monazite composition and chronology (e.g., Suzuki and Adachi, 1991, 1994; Bingen et al., 1996; Broska and Siman, 1998; Finger et al., 1998; Michalik and Skublicki, 1999; Simpson et al., 2000; Wing et al., 2003; Dahl et al., 2005; Broska et al., 2005; Janots et al., 2006; Mahan et al., 2006; Majka and Budzyń, 2006; Dawood and El-Naby, 2007; Finger and Krenn, 2007; Janots et al., 2007; Budzyń and Harlov, 2008; Hetherington and Harlov, 2008; Janots et al., 2008; Dumond et al., 2008-this issue). Isotopic analysis of monazite has also been used to constrain source lithologies, the timing of deposition and diagenesis,

Table 1
Previous chronological constraints on the igneous and metamorphic events recorded in the crystalline rocks clasts considered to be derived from the Silesian Ridge

Technique	Mineral	Age	Interpretation	Reference
Th–U–total Pb, EPMA	Mnz	140–300 Ma	Metamorphism	Michalik et al. (2004)
Th–U–total Pb, EPMA	Mnz	156–189 Ma 289–346 Ma	Metamorphism	Poprawa et al. (2005)
Th–U–total Pb, EPMA	Mnz	196 ± 26 Ma 322 ± 11 Ma 332 ± 6 Ma 367 ± 11 Ma	Metamorphism	Budzyn et al. (2006)
K–Ar	Micas	300–390 Ma	Metamorphism	Poprawa et al. (2004, 2005, 2006)
Th–U–total Pb, EPMA	Mnz	390–491 Ma 536–596 Ma	Igneous	Poprawa et al. (2005)
Th–U–total Pb, EPMA	Mnz	413 ± 20 Ma 628 ± 6 Ma	Igneous	Budzyn et al. (2006)
U–Pb, LA-ICP-MS	Zrn	530–570 Ma 1250–2740 Ma	Igneous	Michalik et al. (2006)
U–Pb, SHRIMP II	Zrn	ca. 605 Ma	Igneous	Budzyń et al. (2008)
Nd model ages	Whole rock	1780–2520 Ma	Sedimentary protolith rocks	Jacher-Śliwczyńska (2004)

Mineral name abbreviations are given after Kretz (1983).