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Morphology and mineral chemistry of monazite–zircon-bearing stream sediments of continental placer deposits (SE Germany): Ore guide and provenance marker

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ABSTRACT

Monazite and zircon, two heavy minerals which are rather stable against meteoric and intrastratal solutions, were investigated in drainage systems very much different as to the level of fluvial hierarchy (colluvial, alluvial, fluvial) and size (creek through trunk river) at the western edge of the Bohemian Massif, SE Germany, and in its immediate foreland. The variegated source rock lithologies and the good preservation potential of these minerals are the basis for this study of applied economic geology, aimed at finding out if these placer minerals may play a role as an ore guide to localize mineral deposits, constrain fertile source rock lithologies in the hinterland or simply be used as a provenance marker during the unroofing of a crystalline basement. In the current study mineralogical and chemical approaches were taken, involving the investigation of the crystal morphology of monazite and zircon combined with the analyses of the most diagnostic elements in monazite (Ce, Th, La, Na, U).

Using the discrimination triplots and x–y plots for statistical treatments, may conduce to pinpoint a wide range of source rocks of monazite: (1) pegmatite and aplites, (2) carbonatites and alkaline igneous rocks, (3) granites, (4) volcanic and volcaniclastic rocks, (5) phosphorites, (6) paragneisses (plus clay), (7) evaporites and calcareous sediments, (8) coal- and biolites, (9) ferricretes, (10) phoscretes, (11) orecretes, and (12) fluorine concentrations. To draw a more precise picture of the source area the crystal morphologies of zircon and monazite were considered. Zircon provides the best insight, offering a tool to characterize not only the source rocks of zircon but also additional information to constrain the temperature of formation. The morphology of monazite is less variable and as such may only be diagnostic to distinguish pegmatite/aplite-related REE phosphates from monazite derived from gneisses and granites. On the other hand, recycling and redeposition play a much greater part among the zircon populations than among those of monazite. Ultrabasic source rocks cannot be tracked down to the placer deposits by means of monazite and zircon. The strong points of both minerals as marker minerals and ore guide lie in drainage systems with catchment areas located in acidic and intermediate magmatic rocks, including their pegmatitic and aplitic derivates, to a lesser extent in volcanic and gneissic areas. Some basaltic rocks containing gemmy zircon may be identified by the morphology, color and fluorescence of zircon grains in the stream sediments. Fluorescence in zircon disappears with the age of formation. The mineralogical and chemical composition of placer deposits abundant in monazite and zircon are to be reviewed in view of the level on which the placer deposits developed in the hierarchy of the drainage system. Joint mineralogical and chemical studies of placer mineral assemblages containing monazite and zircon offer a tool to delineate fertile source areas in basement blocks from tributary rivers (class II) to perennial and ephemeral drainage systems of small creeks (class III). Class-I trunk rivers can provide a rough overview of the heavy mineral community in the hinterland.

1. Introduction

Monazite and xenotime are the most important REE-bearing phosphates (rare-earth elements) that occur in a wide range of magmatic and metamorphic rocks as an accessory or even rock-forming mineral and, hence, be upgraded to form mineral deposits such as in some carbonatites (Chang et al., 1998; Dill, 2010; Nash, 1984; Orris and Grauch, 2002; Overstreet, 1967). Both REE phosphates form part of the accessory minerals of Sn-bearing granites and pegmatites and may be traced in metapelites up to the granulite facies conditions (Finger and Krenn, 2007). As it is with zircon often associated with these phosphates, the main focus, when studying monazite, has been placed upon the U–Pb systematics and the resultant age data that can be obtained from U/Pb and Th/Pb dating of these REE

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phosphates (Kingsbury et al., 1993; Kusiak, et al., 2006). Zircon, monazite, and xenotime are rather stable against meteoric and intrastratal solutions and, hence, may survive even diagenesis upon to the deepest burial as well as long distance transport in stream sediments so that they often may end up in coastal placer deposits (Duk-Rodkin et al., 2001; Hou et al., 2008; Lalomov and Bochneva, 2008; Morton, 1991; Siegfried, 2008). The variegated source rock lithologies and the excellent preservation potential of these minerals offer a clue to the provenance analysis and may contribute to the unroofing story of uplifted basement complexes (Dill, 1995). In terms of applied economic geology, these minerals may be used as pathfinder minerals or as an ore guide to localize mineral deposits of a wider range of commodities and constrain fertile source rock lithologies in the hinterland. It is especially the REE, which western nations are currently in short supply and consequently play an important part when it comes to an in-depth study of monazite and xenotime. A great deal of REE are concentrated in a few primary deposits, e.g., Tomtor, Russia, Mountain Pass, USA, Kangankunde, Malawi, Bayan Obo (Baotou), China, Sarfartôq and Qaqarssuk, Greenland,, Mount Weld, Nolans Bore, Australia and Hoidas Lake, Canada (Dill, 2010; Kanazawa and Kamitani, 2006; Orris and Grauch, 2002). In addition to those primary deposits, large placer deposits spread across the coastal areas of Australia and India (Acharya et al., 2009; Dhana Raju, 2008; Mohanty et al., 2003). Especially in search of the last-mentioned type of sediment-hosted deposits, heavy mineral analyses can help delineate ore deposits. In the current study mineralogical and chemical approaches were taken, involving the investigation of the crystal morphology of monazite and zircon combined with the analyses of the most diagnostic elements in monazite (Ce, Th, La, Na, U). These data were applied to constrain the source rock areas and unravel the way from the primary host rock to the depocenter in drainage systems very much different as to the level of fluvial hierarchy and size within the western edge of the Bohemian Massif, SE Germany, and in its immediate foreland (Fig. 1) (Dill et al., 2008). While chemical analysis is not anything out of the ordinary during the study of common heavy minerals such as garnet, amphibole, apatite or ilmenite, REE-bearing minerals particularly monazite, have seldom been addressed (Basu and Molinaroli, 1991; Dill, 1994; Morton and Hallsworth, 1999; Schäfer, 1996). Morphological studies of heavy mineral grains are very rare (Kostov and Kostov, 1999; Pupin, 1980; Pupin and Turco, 1981). In the succeeding sections the joint application of crystal morphology and chemical exploration methods is described and the applicability of monazite and its associated mineral zircon discussed for different drainage systems as to their use as an ore guide or as a marker mineral for peculiar source rocks in SE Germany, a region characterized by a variegated source lithology and wide spectrum of mineral deposit alike (see succeeding chapters).

2. Geological and geographic setting

2.1. Geological outline

The oldest rocks exposed in the SE part of the study area are of Upper Proterozoic age (Franke, 1989) (Fig. 1). These pre-Variscan basement rocks form part of the Moldanubian zone at the north-Gondwana margin and were subdivided into the Monotonous and Varied Groups (Von Raumer et al., 2003). The Monotonous Group consists of paragneisses derived from greywackes and arenites, whereas the Varied Group is made up of amphibolites, metabiolites, marbles and calcsilicates which may be interpreted as a volcano-sedimentary series (Dill, 1989). Locally some basic and ultrabasic rocks are intercalated with these metamorphic rocks. During the Late Paleozoic granites and pegmatitic rocks were intruded into the Proterozoic rocks.

Low to medium grade metamorphic Paleozoic and Upper Proterozoic rocks of the Saxothuringian zone occupy much of the central part of the study area in the NE Bavarian Basement. Toward the NW unmetamorphosed sedimentary and volcanic rocks of Middle Cambrian through Early Carboniferous age developed. The Münchberg Gneiss Complex is interpreted as a tectonic klippen. Late stages of Variscan convergence in mid-Carboniferous times resulted in the deformation and folding of these aforementioned rocks and the emplacement of synorogenic granites (Seltmann and Faragher, 1994). During the Upper Carboniferous and Permian a basin-and range topography evolved in the uplifted Variscan orogen, with narrow basins acting as sedimentary traps collecting the debris of the Proterozoic and early Paleozoic basement rocks which underwent erosion. Continental and marine sequences made up of clastic rocks alternating with calcareous and evaporitic beds were deposited during the Triassic, followed by a marine transgression during the Jurassic leaving behind a vast carbonate platform. After an emersion during early Cretaceous the sediments were drowned again and invaded from the southern Thetis Ocean (Fig. 1). The continental-marine terrigenous sediments of the lower Triassic Bunter Series (Buntsandstein), the Middle Triassic Muschelkalk and the Upper Triassic Keuper were also targeted in this study for their heavy mineral accumulations enriched in monazite, zircon and, locally, xenotime, as well.

2.2. Geographic outline

A low-relief landscape in the basement evolved during the Neogene under subtropical climates (Borger et al., 1993). By the end of the glacial period, channels of the present-day fluvial drainage systems incised into the rocks and shaped the northeastern part of the NE Bavarian basement which is characterized by a rather rugged terrain at an altitude of between 500 and 1000 m a.s.l. with rivers draining it mainly toward the S (Villinger, 1998). Rivulets and gorges drain the Variscan basement area and flow into the Naab River which is tributary to the Donau trunk river system. All of them are host to stream sediments, locally forming placer-type deposit of colluvial, alluvial and fluvial origin.

The terms colluvial, alluvial and fluvial were used according to Gary et al. (1977) either in the strict sense or supplemented as to address the peculiar geomorphological situation in the study area. For that reason the three terms are briefly explained below.

Colluvial deposits are loose, heterogeneous and incoherent mass of soil material or rock fragments chiefly deposited by mass-wasting from fall to creep deposits. They are usually encountered at the base of slopes an at the valley flanks.

Alluvial deposits are unconsolidated detrital material deposited by stream or other bodies of running water as a semi sorted sediment in the bed of a stream or as cone or fan at the base of mountain slope. They may consist of clay, silt, sand and gravel.

Fluvial deposits consist of material that was transported by, suspended in or laid by river drainage systems.

Within the lines of placer development discussed in this paper, these terms were used as hierarchy consecution.

2.3. Metallogenetic outline

The Saxothuringian–Moldanubian border zone along the western edge of the Bohemian Massif has seen during 600 million years a variegated spectrum of mineral deposits that may be categorized into four different types: type I stratabound (Fe, Cu, Zn, Pb, Au, PGE, Mo, U, Sb, Ni); type II: thrustbound (Sb, As, Hg, Au); type III: granite-bound (Sn, W, F, Li, U); and type IV: unconformity-related (Ba, F, Cu, Pb, Zn) (Dill, 1989). This sequence is more or less in line with the chronology of the lithological and geodynamic evolution of the study area. Type-I deposits formed from the Late Proterozoic through the Devonian, type-II deposits from the Devonian to the Lower