The origin of Ti-oxide minerals below and within the eastern Athabasca Basin, Canada

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ABSTRACT

Titanium oxide minerals along the P2 fault in the eastern Athabasca Basin are characterized to constrain their origin and the geological history of the area. Two types of rutile are recognized in the basement rocks. Early rutile is disseminated in graphitic metapelite and quartzite, and it formed during regional metamorphism and post-metamorphic hydrothermal activity. Late rutile occurs as a needle-like alteration product of mica and likely formed during retrogression of the basement. In graphitic metapelite, early rutile commonly occurs with an assemblage of oxy-dravite, quartz, graphite, zircon, pyrite, biotite, and muscovite. In quartzite, rutile occurs with quartz, sillimanite, muscovite, and zircon. Metamorphic rutile is characterized by high Nb/Ta ratios (up to 47) with high concentrations of U (up to 126 ppm) and V4+ (up to 1.44 wt%; V valance calculated from EPMA data). Hydrothermal rutile contains distinctly low Nb/Ta (as low as 4.80) with high Ta (≤3050 ppm), and relatively low V (as V3+; as low as 0.02 wt%) and U (as low as 9.06 ppm), reflecting fluids in reduced oxidation conditions. Anatase forms small anhedral (rarely coarse and euhedral) grains in the basal sandstones and altered basement rocks. In sandstones, anatase occurs with the late diagenetic mineral assemblage, whereas in basement rocks it commonly occurs with the clay-sized minerals related to uranium mineralization. In both rocks, anatase likely formed through the dissolution of rutile and/or other Ti-bearing minerals. Anatase is characterized by variably high Fe (up to 0.99 wt%; possibly contributed by hematite micro- or nano-inclusions) and U (up to 180 ppm). The mineral assemblages and composition of anatase suggest its protracted crystallization from relatively low temperature, oxidizing, acidic, uraniferous fluids of the sandstones during late diagenesis and hydrothermal activity. Therefore, the occurrence of anatase records the incursion of basin fluids into the basement, and the interaction of basement rocks with fluids responsible for the formation of the McArthur River uranium deposit. The results of this study confirm that Ti-oxides are useful in unraveling the geological history of an area that underwent prolonged hydrothermal activity.

Keywords: Rutile, anatase, P2 fault, McArthur River, unconformity-type uranium deposits, alteration

INTRODUCTION

The Paleoproterozoic Athabasca Basin and crystalline basement rocks experienced multiple alteration events, including hydrothermal activity related to the formation of world-class unconformity-type uranium deposits. Many petrological studies over the past 40 years aim to unravel the paragenesis of the area (e.g., Hoeve and Sibbald 1978; Kotzer and Kyser 1995; Fayek and Kyser 1997; Alexandre et al. 2005, 2009, 2012; Cloutier et al. 2011; Reid et al. 2014; Adlakha and Hattori 2015, 2016) to evaluate the nature of uranium mineralization and its timing with respect to the geological evolution of the basin. This information is critical to assess the conditions and geological environments for the formation of these giant uranium deposits. Although Ti-oxide minerals are noted in these rocks (e.g., Kotzer and Kyser 1995; Fayek and Kyser 1997; Alexandre et al. 2005, 2009; Cloutier et al. 2009, 2010, 2011), there have been no detailed studies of the minerals.

Titanium-oxide minerals form different polymorphs (rutile, anatase, brookite) and accommodate a wide variety of minor elements, reflecting their crystallizing environments (e.g., Meinhold 2010). Although the P-T conditions for the stability of the polymorphs are not well constrained considering contradicting interpretations (Osborn 1953; Dachille et al. 1968, 1969; Jamieson and Olinger 1969; Gribb and Banfield 1997; Zhang and Banfield 1999, 2000; Ranade et al. 2002; Navrotsky 2003; Levchenko et al. 2006; Smith et al. 2009; Mei et al. 2014; Curnan and Kitchin 2015; Plavska et al. 2018), it is generally accepted that rutile is more stable than anatase and the polymorphic transition of anatase to rutile is favorable over rutile to anatase under most conditions (Dachille et al. 1968). This argument is supported by observations of rutile in both high- and low-temperature environments and anatase in only low-temperature environments. Regardless of the polymorph stability, it is apparent that rutile is the most common Ti-oxide polymorph in Earth’s crust (Meinhold 2010). It occurs in metamorphic rocks of various facies ranging from greenschist to granulite and eclogite; as detrital and authigenic grains in sedimentary rocks; in igneous rocks, particularly evolved granite rocks and pegmatite (Cerny 1989); and in hydrothermally altered rocks and metalic mineral deposits, including Cu-Mo porphyry deposits, volcanogenic massive sulfide deposits, and orogenic Au deposits (e.g., Schandl et al. 1990; Urban et al. 1992; Scott 2005; Scott and...