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DOI 10.1007/s00126-017-0756-2

ARTICLE

Multielement statistical evidence for uraniferous hydrothermal activity in sandstones overlying the Phoenix uranium deposit, Athabasca Basin, Canada

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Received: 26 October 2015 / Accepted: 27 June 2017

Abstract The Phoenix U deposit, with indicated resources of 70.2 M lb U_3O_8, occurs along the unconformity between the Proterozoic Athabasca Group sandstones and the crystalline basement rocks. Principal component analysis (PCA) is applied to the compositions of sandstones overlying the deposit. Among PCs, PC1 accounts for the largest variability of U and shows a positive association of U with rare earth elements (REEs) + Y + Cu + B + Na + Mg + Ni + Be. The evidence suggests that U was dispersed into sandstones together with these elements during the uraniferous hydrothermal activity. Uranium shows an inverse association with Zr, Hf, Th, Fe, and Ti. Since they are common in detrital heavy minerals, such heavy minerals are not the major host of U. The elements positively associated with U are high in concentrations above the deposit, forming a "chimney-like" or "hump-like" distribution in a vertical section. Their enrichment patterns are explained by the ascent of basement fluids through faults to sandstones and the circulation of basinal fluids around the deposit. The Pb isotope compositions of whole rocks are similar to expected values calculated from the concentrations of U, Th, and Pb except for sandstones close to the deposit. The data suggest that in situ decay of U and Th is responsible for the Pb isotope compositions of most sandstones and that highly radiogenic Pb dispersed from the deposit to the proximal sandstones long after the mineralization. This secondary dispersion is captured in PC8, which has low eigenvalue. The data suggests that the secondary dispersion has minor effect on the overall lithogeochemistry of sandstones.

Keywords Lithogeochemistry · Principal component analysis · Unconformity-type uranium deposits · Hydrothermal alteration · Multivariate statistical analysis

Editorial handling: M. Fayek

Electronic supplementary material The online version of this article (doi:10.1007/s00126-017-0756-2) contains supplementary material, which is available to authorized users.

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Introduction

The Athabasca Basin is a large Proterozoic sandstone basin located in northern Saskatchewan and Alberta, Canada (Fig. 1). This basin hosts the world's largest high-grade U resources along the unconformity between the sandstones and underlying crystalline basement rocks (Hoeve and Sibbald 1978; Jefferson et al. 2007). These U deposits are accompanied by alteration halos, which overprint the diagenetic minerals of sandstones and the metamorphic minerals of the basement rocks (Hoeve and Quirt 1984; Kotzer and Kyser 1995). The alteration halos commonly extend several hundred meters around major deposits (Hoeve and Quirt 1984; Kotzer and Kyser 1995; Kister et al. 2006), and alteration minerals include illite, kaolinite, dravitic tourmaline, aluminum phosphate sulfate (APS) minerals, and Mg-chlorite (Hoeve and Quirt 1984; Quirt et al. 1991; Quirt and Wasyliuk 1997; Jefferson et al. 2007). The alteration resulted in significant changes in lithogeochemistry of sandstones. For example, increased K/Al ratios due to illitization of sandstones above the Midwest U deposit are reported (Sopuck et al. 1983), and anomalously high contents of Na, Sr, Y, Pb, Th, As, and P occur above the Cigar Lake deposit and the Dawn Lake mineralized zones (Clark 1987). Enrichment of elements associated

Published online: 08 July 2017