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# Nanoscale relationships between uranium and carbonaceous material in alteration halos around unconformity-related uranium deposits of the Kiggavik camp, Paleoproterozoic Thelon Basin, Nunavut, Canada

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ABSTRACT

Concentrations of 7% U and 1% Cu were identified in massive, brecciated, and amorphous carbonaceous materials (CM) characterized by strongly negative values of carbon stable isotopes ($\delta^{13}C = -39.1‰$ relative to PDB). The anomalies are restricted to clay alteration halos developed in Neoarchean Woodburn Lake group metagreywacke that is the predominant host of unconformity-related uranium (U) deposits in the Kiggavik exploration camp. Petrographic and microstructural analyses by SEM, X-ray Diffraction, HRTEM and RAMAN spectroscopy identified carbon veils, best described as graphene-like carbon, upon which nano-scale uraninite crystals are distributed. CMs are common in U systems such as the classic Cretaceous roll-front deposits and the world-class Paleoproterozoic unconformity-related deposits. However, the unusual spatial and textural association of U minerals and CM described herein raises questions on mechanisms that may have been responsible for the precipitation of the CM followed by crystallization of U oxides on its surfaces. Based on the characteristics presented herein, the CMs at Kiggavik are interpreted as hydrothermal in origin. Furthermore, the nanoscale organization and properties of these graphene-like layers that host U oxide crystallites clearly localized U oxide nucleation and growth.



## 1. Introduction

Carbonaceous material (CM) of Mesoproterozoic and older ages is controversial, with two main hypothesized origins; one invokes life where solid bitumens were derived from thermal alteration of kerogen thermal evolution (e.g. Wilson et al., 2002) and the other calls upon abiotic synthesis of organic compounds, e.g. via Fischer-Tropsch type synthesis (FTT) in hydrothermal or magmatic systems (Shock, 1990; Gize, 1999; Foustoukos and Seyfried, 2004; McCollom and Seewald, 2006; Horita, 2005; Ueno et al., 2004; Curiale, 1986; McCollom, 2013). Variously referred to as bitumen, pyrobitumen or uranoan carbon (thucholite) (Kucha, 1993), CM has been identified within various ores. They are frequent in Mississippi Valley Type Pb-Zn (Spirakis and Heyl, 1993; Powell and Macqueen, 1984), Au lode deposits (Springer, 1985), and carbonaceous materials has been described in various geological settings from the Archean (e.g. Witwatersrand), to the Proterozoic in Scandinavia and Karelia (e.g. Boliden, Narestø, Shunga) (Inostranzeff, 1880). Numerous occurrences are also reported in the Phanerozoic in Great Britain (Eakin and Gize, 1992) and references therein, or Czech Republic in hydrothermally altered host rocks in the Příbram uranium ore field of the Bohemian Massif (Kribek et al., 1999; Petroš et al., 1986). CM are also nearly ubiquitous in alteration halos of many Proterozoic unconformity-type uranium (U) deposits of the Athabasca Basin (Hoeve and Sibbald, 1978; Hoeve et al., 1980; Hoeve and Quirt, 1984; Pagel et al., 1980; Sangély et al., 2007; Leventhal et al., 1987) and vein/unconformity type (controversial) U deposits of the Martin Basin (Beaverlodge District of northern Saskatchewan) (Tremblay, 1972; Ruzicka, 1996; Alexandre and Kyser, 2006). The reduction potential, source and distribution of CM in brecciated and altered Neoarchean to Paleoproterozoic metamorphic basement and in the Paleo- to Mesoproterozoic sedimentary basins that cover and host the U deposits have been discussed for U metallogenesis (Leventhal et al., 1987; Kyser et al., 1989; Landais and Dereppe, 1985; Yeo and Potter, 2010; Sangély et al., 2007) with inconclusive evidence for ore control. Similar CM has been proposed as an ore controlling parameter in gold bearing veins (Mastalerz et al.,

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1995). In the Athabasca Basin, bitumen is considered to either post-date the main U mineralization stage (Wilson et al., 2002; Leventhal et al., 1987) or to be contemporaneous (Alexandre and Kyser, 2006). By comparison, in the 1.74 Ga Oklo deposit of the Paleoproterozoic Franceville Basin the paragenesis clearly links bitumen, oil occurrences and U mineralization in a Phanerozoic-style diagenetic system. Faults at Oklo played key roles by creating traps and/or paths for oil migration as well as by favourably positioning marine black shale in contact with deltaic sandstone hosts of the bitumen (Gauthier-Lafaye and Weber, 1989; Nagy et al., 1991; Mossman et al., 1993).

Finally, the case of roll front deposits were reducing agent are not restricted to carbonaceous materials are represented by detrital plant debris, amorphous humate, or marine algae (Dahlkamp, 2009). Proterozoic or Phaneroic hydrothermal systems cannot fully be compared to these low temperature systems were oil, detrital organic matter either derived from bacteria or plants and can directly fix uranyl ions via sorption process or precipitate uranium minerals.

The first goal of the present study is to characterize the CM associated with U minerals in the Kiggavik exploration camp located at the southeastern margin of the Paleo- to Mesoproterozoic Thelon Basin, building on the paragenetic context developed by Riegler (2013), Riegler et al. (2014), Sharpe (2013), Sharpe et al. (2015), and Riegler et al.(2015). The second focus is on the solid properties of both the CM and uraninite at a nanoscopic scale to better understand their very unusual spatial and textural associations with U as oxide minerals, and not as organo-metallic complexes. These new results will be discussed in the light of other occurrences of CM described in Paleozoic and Proterozoic uranium deposits.

## 2. Geological setting

AREVA Resources of Canada's Kiggavik Project (Fig. 1) comprises several deposits at the advanced exploration stage, as follows from northeast to southwest: Kiggavik (formerly Lone Gull), Bong, End Grid, and Andrew Lake. The partially sub outcropping, basement hosted uranium mineralization, was first discovered in 1974 at 2 km south of the erosional contact with the Paleoproterozoic conglomerates and sandstones of the Thelon Formation. All of the high grade (>0.2% U) zones, in which the main U minerals are uraninite and coffinite, are surrounded by decametre-scale clay alteration envelopes mainly developed in lower amphibolite to upper greenschist facies Neoarchean metagreywacke of the Woodburn Lake group (Riegler et al., 2014; Lewry and Sibbald, 1980; Fuchs et al., 1986; Farkas, 1984). Unlike the basement-hosted deposits of the Athabasca Basin (Lewry and Sibbald, 1980), deposits in the Kiggavik Project area are not located along graphitic conductors although reactivated intersecting faults are important in both camps (Lewry and Sibbald, 1980; Miller and LeCheminant 1985; Fuchs and Hilger 1989; Jefferson et al., 2007; Tschirhart, 2014). During the alteration at Kiggavik, quartz was dissolved and all primary metamorphic silicate minerals (feldspars, muscovite, biotite, chlorite) were replaced by mainly illite and sudoite (Al-Mg di-trioctahedral chlorite) in various proportions. This alteration paragenesis is similar to that of many other Proterozoic unconformity-associated U deposits in Canada and Australia (Beaufort et al., 2005; Laverret et al., 2006; Hoeve and Quirt, 1984; Polito et al., 2004; Riegler et al., 2014, 2015). In addition the recent SIMS U-Pb isotope ages contributed to constrain the uranium mineralization events at Bong with 3 stages of uraninite crystallization, respectively at:

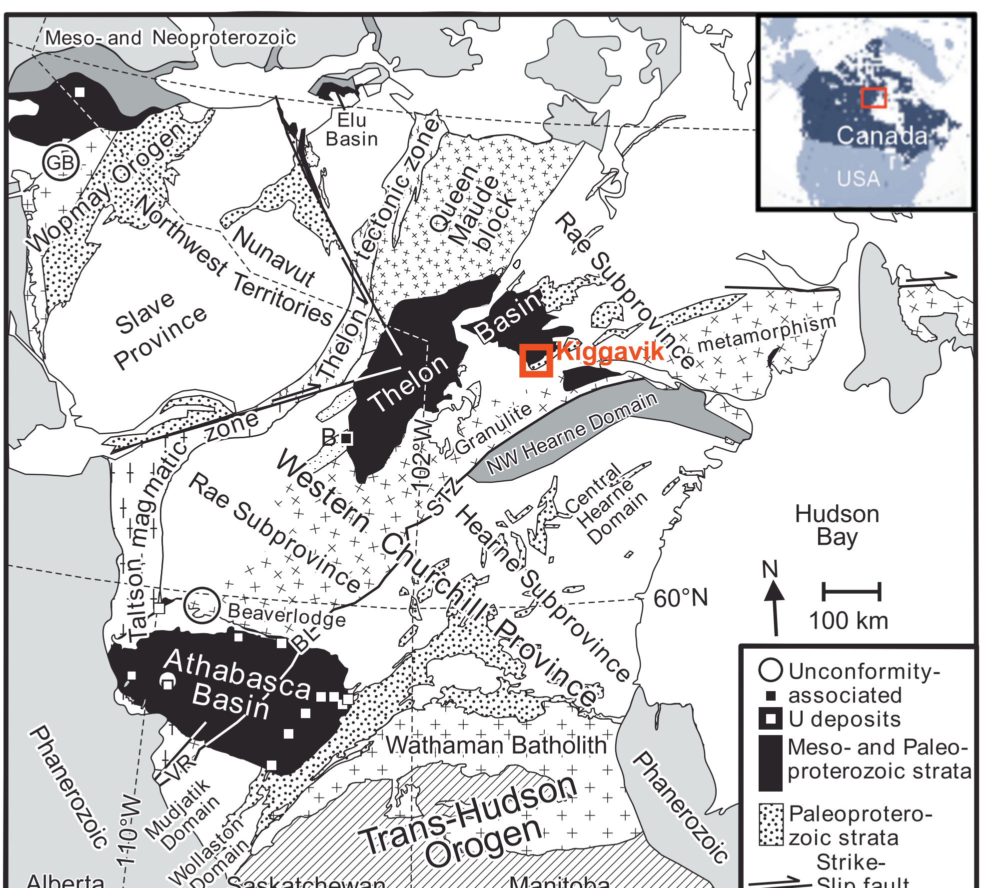


**Fig. 1.** Geological context of the Kiggavik project, modified from Jefferson et al. (2007).