

**THE GEOCHEMISTRY AND GEOCHRONOLOGY OF THE
END DEPOSIT, NE THELON REGION, NUNAVUT, CANADA:
INSIGHT INTO THE ATHABASCA BASIN'S CLOSEST
RELATIVE**

by

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Abstract

The Paleoproterozoic, intracratonic Thelon Basin, located ~100-500 km west of Baker Lake, Nunavut, has been studied over the past few decades by various researchers, but it is still relatively poorly understood. It displays many stratigraphic, sedimentological, and metallogenetic similarities to the uranium-producing Athabasca Basin located in Northern Saskatchewan and may share similar economic potential.

The Kiggavik uranium project area is located 80 km west of Baker Lake, Nunavut, adjacent to the northeastern extent of the Thelon Basin; the Aberdeen sub-basin. The project area contains a series of uranium deposits and showings generally located along a broad NNE-oriented structural corridor known as the Andrew Lake-Kiggavik structural trend. The End deposit, hosted by the Judge Sissions Fault (JSF) within this structural trend, and contained within the Woodburn Lake group (WLg) Pipedream metagreywacke (Ppd)

Three paragenetic stages of uranium mineralization are preserved, with the third stage comprising 3 sub-stages. The oldest dated stage is disseminated uraninite (U1; ~1500 Ma). This is transected by vein-type uraninite (U2; ~1300Ma). These in turn were remobilized as foliation-parallel (U3a), infill-type (U3b; ~970 Ma), and micro-roll-front style (U3c; ~750Ma). All uranium oxide minerals are now highly altered and the U-Pb ages obtained are highly discordant, suggesting that Pb-loss has occurred. Therefore, these ages are interpreted to represent thermal or tectonic resetting events. The U-Pb ages of uranium minerals from the End deposit are similar to the ages of uranium mineralization at the Bong deposit, which coincide with regional and tectonic thermal events.

Three alteration events were also dated at ~1600, ~1475 and ~1300 Ma using $^{40}\text{Ar}/^{39}\text{Ar}$ geochronology of muscovite and illite. The ~1475 and 1300 Ma events coincide with ages from uranium minerals in the End deposit. The fluid that deposited U1 and illite (Il1) had a temperature of 210 ± 16 °C with $\delta^{18}\text{O}$ and $\delta^2\text{H}$ values of 4.1 ± 0.8 ‰ and -131 ± 5 ‰ respectively. The stable isotope systematics of the uranium deposits of the Athabasca and McArthur River Basin (Australia) suggest that these deposits formed from interaction of basinal brines with basement fluids, the End deposit is likely to have formed from fluids similar to the Athabasca and McArthur basins, and illite may have been affected by present day meteoric water.

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Chapter 1.0: Introduction

As the global population increases and society moves away from carbon-based energy resources, the need for clean energy becomes apparent. Nuclear power has a negligible carbon footprint and contributes little to the greenhouse gas effect (World Nuclear Association, 2011). As of 2018, there are four-hundred fifty-four commercial reactors producing 400 GWe and supplying 10% of the world's electricity (Nuclear Energy Agency, 2019). With one hundred reactors planned to be built and fifty-five currently being constructed in the coming decades, the foreseeable future will bring continued demand for uranium (U) and the subsequent need for the discovery of new uranium deposits.

Several economically significant sedimentary basins formed during the Proterozoic. These basins include the Athabasca, Thelon, Hornby Bay, and Borden in Canada, the McArthur in Australia, and the Espinhaço in Brazil (Kyser, 2007; Richard *et al.*, 2011; Martins-Neto, 2000). Canada's uranium production has been primarily from unconformity-related deposits within the Athabasca Basin, Saskatchewan. The basin is host to numerous uranium deposits that are estimated to contain 430 million kg U, averaging 3% U. The basin does host two of the largest and highest-grade deposits in the world, Cigar Lake and McArthur River, with 5.38 million kg U at 12.28% U and 25.73 million kg U at 5.86% U respectively (Cameco, 2019). The Thelon Basin, including the Kiggavik area, has been attractive to uranium exploration companies because it shares many temporal, spatial, sedimentological and stratigraphic similarities to the Athabasca Basin.

The geology, metallogenesis, and fluid history of the Athabasca Basin has been extensively studied over the last four decades by many researchers (Hoeve and Sibbald, 1978; Hoeve and Quirt, 1984, 1987; Sibbald, 1985; Quirt, 1989, 2003; Kotzer and Kyser, 1993, 1995;

Fayek and Kyser, 1997; Hecht and Cuney, 2000; Kyser *et al.*, 2000; Alexandre *et al.*, 2005; Jefferson *et al.*, 2007a,b,c; Ramaekers *et al.*, 2007; Cloutier *et al.*, 2009; Mercadier *et al.*, 2012; Richard *et al.*, 2011; Sheanan *et al.*, 2016; among others). In comparison, the Thelon Basin and associated uranium deposits, have been much less studied and are therefore less understood (Farkas, 1984; Miller *et al.*, 1989; Renac *et al.*, 2002; Hiatt *et al.*, 2003, 2010; Rainbird *et al.*, 2002, 2003; Beyer *et al.*, 2011; Riegler, 2013; Riegler *et al.*, 2014, 2016; Sharpe *et al.*, 2015; Chi *et al.*, 2017; Shabaga *et al.*, 2017; Grare *et al.*, 2018a, b, 2020; among others).

The Paleoproterozoic intracratonic Thelon Basin and the surrounding region, located ~100-500 km west of Baker Lake, Nunavut, has been studied intermittently over the past 60+ years by the Geological Survey of Canada (GSC), but has been more extensively studied during the past 20 years (Rainbird *et al.*, 2003; Pehrsson *et al.*, 2013; Tschirhart *et al.*, 2013; 2017; Davis *et al.*, 2011; Jefferson *et al.*, 2011; Peterson *et al.*, 2015a,b; Anand and Jefferson, 2017a,b; Robinson *et al.*, 2016), AREVA Resources Canada (ARC; now Orano Canada Inc.: “Orano”), and several university groups (Renac *et al.*, 2002; Hiatt *et al.*, 2003, 2010; Uvarova, *et al.*, 2012; Riegler, 2013; Sharpe *et al.*, 2015; Scott *et al.*, 2015, Chi *et al.*, 2016; Johnstone *et al.*, 2016, 2017; Shabaga *et al.*, 2017; Grare *et al.*, 2018a, b, 2020). However, the area is still relatively poorly understood when compared to the uranium producing Athabasca Basin.

The End deposit is located 80 km west of Baker Lake, Nunavut, Canada and within the Kiggavik uranium camp. The camp consists of a series of uranium showings, prospects, and deposits that occur within an informally-termed “Andrew Lake-Kiggavik structural trend” (Fig. 1.1) (Quirt, 2011; Riegler *et al.*, 2014, Fayek *et al.*, 2017). The END-Grid deposit (referred in this paper as the End deposit) is hosted within the basement rocks to the Thelon Basin and contains an indicated resource of 11.7 million kg U at a grade of 0.467% U (Osorio, 2010).

Mineral resources for the entire Kiggavik project area are estimated at 51 million kg U at an average grade of 0.46% U (AREVA, 2011).

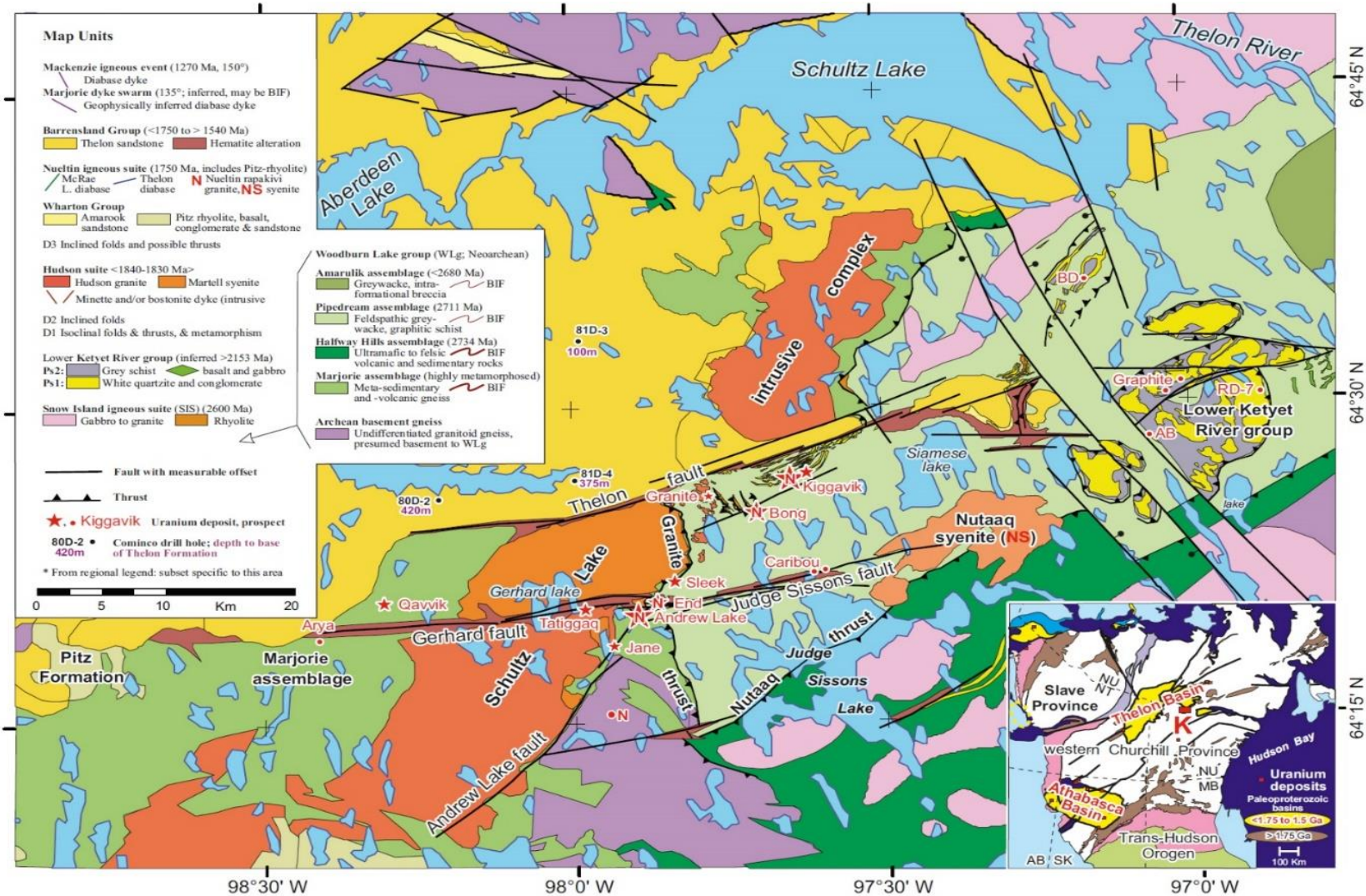


Fig. 1.1. Regional Geology and Location map of the Kiggavik uranium camp, Thelon Basin, Nunavut with respect to the Athabasca Basin, Saskatchewan. The Kiggavik uranium prospects and deposits are situated along the informally-termed “Andrew-Lake Kiggavik Structural Trend” (modified from Jefferson et al., 2015).

1.1 Kiggavik Project History

Uranengesellschaft Canada Limited (UG) discovered the first uranium showing in the Baker Lake area in 1974. Although initially named the Lone Gull property, it was later renamed the Kiggavik project. At the time, the company was exploring for unconformity-type uranium deposits similar to uranium deposits associated with the Athabasca Basin (Farkas, 1984). A strong radiometric anomaly was detected using a helicopter-borne radiometric system, 2 km south of the unconformity between the Archean basement and the Thelon Formation. This discovery was followed up by ground surveys, which resulted in the discovery of radioactive frost boils that yielded more than 1% U_3O_8 (Fuchs *et al.*, 1986). Diamond drilling, that began in the anomaly area in 1977, led to the discovery of the Main Zone of the Kiggavik deposit. Further drilling in 1978 led to the discovery of the Center and Eastern Zones of the Kiggavik deposit. Airborne resistivity and gravity surveys, and follow-up drilling, subsequently led to the discovery of the Bong, End, Andrew Lake, and Jane prospects in 1987.

The Kiggavik project was owned and operated by UG until 1992 before UG was acquired by the COGEMA Group (now Orano). In 1998, a prefeasibility study was completed, and the project was put into care and maintenance as the area was considered sub-economic at the time. It was not until 2006 that feasibility studies began on the Kiggavik, End, and Andrew Lake deposits with the intent of further exploration work to be completed in 2008. A detailed study on the structure and geochronology of deformation within the End deposit was also completed (Flotté, 2009). The Kiggavik project was recently shut down indefinitely by Orano due to the Nunavut Impact Review Board recommending against allowing Orano to build a uranium mine.

1.2 Previous Work

Over the last 50 years, research has largely been focused on the Thelon Basin itself and includes: stratigraphy, sedimentology, diagenesis, fluid history, and the basin's uranium potential (Donaldson *et al.*, 1965; Gall *et al.*, 1992; Renac *et al.*, 2002; Hiatt *et al.*, 2003, 2010; Rainbird *et al.*, 2003, 2010; Peterson, 2006 and Uvarova *et al.*, 2012). A few studies that focused specifically on the Kiggavik deposit were carried out in the late 1980's (Farkas 1984; Weyer 1992) to understand the timing of uranium deposition and metallogeny. More recently, an evaluation of the lithostratigraphic and structural controls on the Kiggavik Main, Center, and East zones was completed by Johnstone *et al.* (2016, 2017) and similar work was completed on the Contact prospect by Grare *et al.* (2016, 2018a). Extensive structural and geologic mapping has been conducted on the surrounding host basement rocks and intrusives in relation to the Kiggavik area (Rainbird *et al.*, 2010; Davis *et al.*, 2011; Jefferson *et al.*, 2011; Tschirhart *et al.*, 2013; 2017; Pehrsson *et al.*, 2013; Anand and Jefferson, 2017a, b; Weyer, 1992; Peterson *et al.*, 2015a, b; Scott *et al.*, 2015). Work conducted on the deposits within the Kiggavik area include; the alteration assemblage and distribution and chemical composition of APS minerals within the Kiggavik-Andrew Lake Structural Trend (Riegler, 2014, Riegler *et al.*, 2016), the geochemistry and geochronology of the Bong deposit and Andrew Lake deposit (respectively, Sharpe *et al.*, 2015, Shabaga *et al.*, 2017). Until recently, little work was completed on the End deposit which included geochemistry and geochronology on the uranium oxides (Lach *et al.*, 2012; Riegler *et al.*, 2014; Chi *et al.*, 2017) and fluid composition of fluid inclusions within quartz veins associated with uranium mineralization (Chi *et al.*, 2017).

1.3 *Scope of work*

The main goal of this MSc. thesis, in collaboration with Orano Canada Inc., is to develop a metallogenetic model for the formation of the End U deposit. The research done to achieve this goal included drill core logging, petrographic, paragenetic, geochemical, and geochronological studies. As part of the paragenetic work, geochronological analysis of both alteration and ore minerals was conducted. The objectives of this thesis include:

- I. Develop a mineral paragenesis of the End deposit;
- II. Characterize the mineralogy and chemistry of the pre-, syn-, post-alteration and uraninite phases;
- III. Determine the age(s) of uranium mineralization;
- IV. Evaluate and determine the mechanism(s) of uranium precipitation;
- V. Define the fluid history of the End deposit and determine the temperature of the mineralizing fluids;
- VI. Develop a metallogenetic model for the formation of the End deposit;
- VII. Determine the age of the retrograde metamorphic event within the Pipedream metagreywacke

Chapter 2.0: Geologic Setting

The geologic and tectonic history of the basement rocks host to the Kiggavik camp are fairly complex and only a limited amount of reconnaissance based studies have recently been conducted to properly constrain and understand their importance in Uranium metallogenesis throughout the Kiggavik area (Pehrsson *et al.*, 2013, Jefferson *et al.*, 2015). The underlying basement rocks have been separated into five groups: the Mesoarchean basement, Woodburn Lake group, Marjorie Hills assemblage, Snow Island Suite, and the Ketyet/Amer Group (Pehrsson, *et al.*, 2010; Jefferson *et al.*, 2015).

2.1 MesoArchean Basement

The Paleoproterozoic Thelon Basin unconformably overlies the Archean Western Churchill Province (WCP) (Fig. 2.1). The WCP is comprised of Meso- to Neoarchean, amphibolite to granulite grade gneisses and greenstone belts that underwent episodic reworking between 2.55-1.75 Ga (Hoffman, 1988, Peterson, 2002). The province is comprised of two Archean crustal blocks known as the Rae and Hearne (Hoffman, 1988). These crustal subdomains are separated by a major northeast trending Paleoproterozoic suture that is also observed as a large southwest-north east gravity and magnetic anomaly referred to as the Snowbird Tectonic Zone (STZ) (Gibb *et al.*, 1993; Thomas and Gibb, 1995; Hamner, 1997, Bernman *et al.*, 2007). The origin of this zone has been subject to debate by several workers, as to whether it was formed from the collision of the Rae and Hearne domains (Hoffmann 1988; Berman *et al.*, 2007) or due to intracontinental shear (Hamner *et al.*, 1995, 1997).

The WCP is bound by the Talston-Thelon (2.0-1.9 Ga) and Trans-Hudson (1.9-1.8 Ga) orogenies, to the west, and east, respectively (Fig. 2.1; Hoffman, 1988). The Talston-Thelon

orogeny has been described as a major plutonometamorphic belt that was initiated by eastern subduction beneath the Churchill Province that led to the collision of the Slave craton (1.83 and 1.81 Ga; Orrell *et al.*, 1999) and the Buffalo Head terrane with the Rae domain (Henderson *et al.*, 1990; Hoffman, 1988; McDonough *et al.*, 2000; McNicoll *et al.*, 2000; Pehrsson *et al.*, 2010, 2013). The Trans-Hudson orogeny was initially formed by intra-oceanic arc magmatism-accretion and subduction beneath the Churchill Province which led to the collision between the Churchill, Sask and Superior Cratons (1.84 – 1.79 Ga; Bickford *et al.*, 1990; Corrigan *et al.*, 2009; Lewry and Collerson, 1990, Peterson *et al.*, 2002, 2010, 2015a, 2015b).

The Archean and Paleoproterozoic rocks of the WCP were intruded by two igneous suites; the Hudson suite (ca. 1.85 – 1.80 Ga; Scott *et al.*, 2015) and the Nueltin granite of the Kivalliq Igneous Suite (KIS; ca 1.73- 1.76 Ga; Hoffmann, 1988; Berman *et al.*, 2007; Peterson *et al.*, 2015a). These suites are coeval with the Baker Lake and Wharton Groups, respectively, within the Dubawnt Supergroup (Rainbird *et al.*, 2003; Rainbird and Davis, 2007).

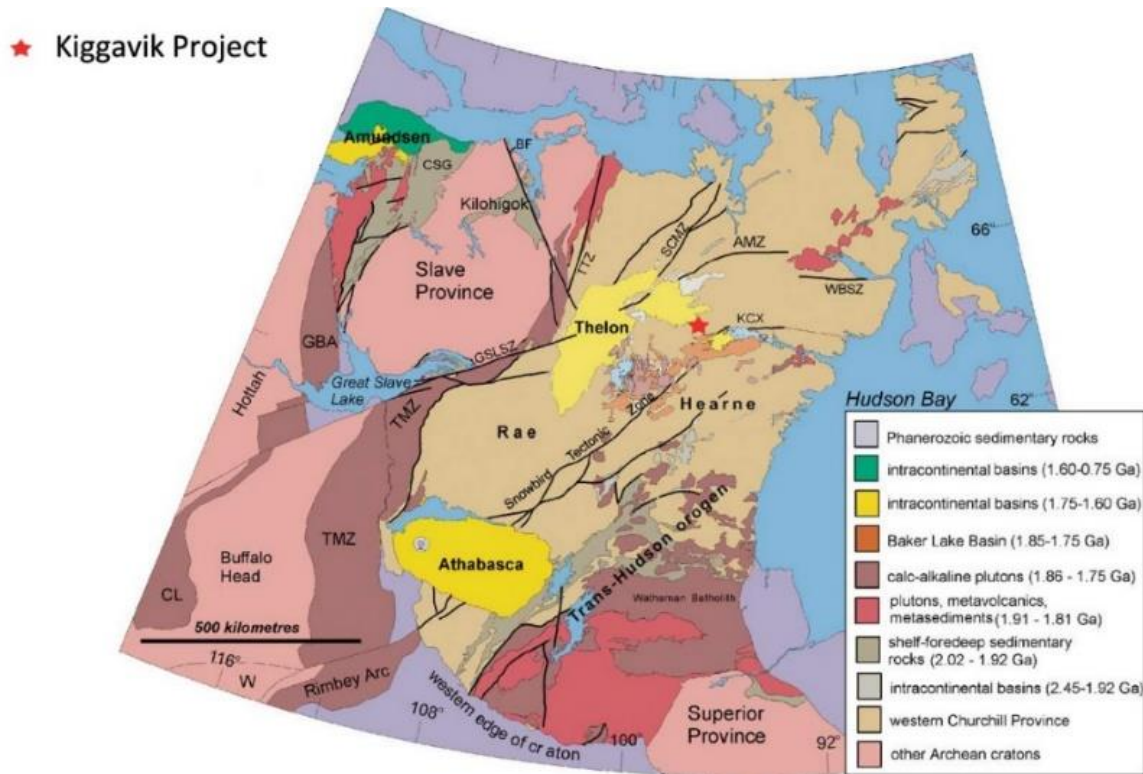


Fig. 2.1. Regional geology of the Western Churchill Province, including the overlying Athabasca and Thelon sedimentary basins (modified from Rainbird *et al.*, 2003).

2.2 Woodburn Lake group (WLg)

The Woodburn Lake Group (WLg) (~2.76 – ~2.68 Ga) consists of a southwest-northeast trending 1000 km network of greenstone belts that disconformably overlies the north-central part of the Rae domain (Pehrsson *et al.*, 2013). Initial mapping, petrography and geochemical work on the WLg was completed by Ashton (1988) and Annesley (1989). Their work was further expanded and led to more detail mapping and refinement of the WLg by Zaleski *et al.* 1997; Davis and Zaleski (1998), (2000). Zaleski *et al.* (2000) subdivided the WLg as two separate volcanic sequences, a lower group being comprised of komatiitic flows with interlayered quartz-porphyritic felsic volcanic rocks and iron formations and an upper group of mafic, felsic, and intermediate volcanic flows to volcanoclastics with iron-formation and cherty tuffs; including metagreywackes. Lithostratigraphic and geochronology studies by Pehrsson *et al.*, (2010, 2013)

and Jefferson *et al.*, (2011; 2015) further modified this nomenclature by subdividing the lower package into five depositional sequences; and the upper package was assigned to the Ketyet River Group. The WLg now includes the Halfway Hills greenstone belt, the Turqavik and north Meadowbank assemblage, the Pipedream assemblage, the Wading Lake assemblage, and the Amarulik assemblages (Fig. 2.2).

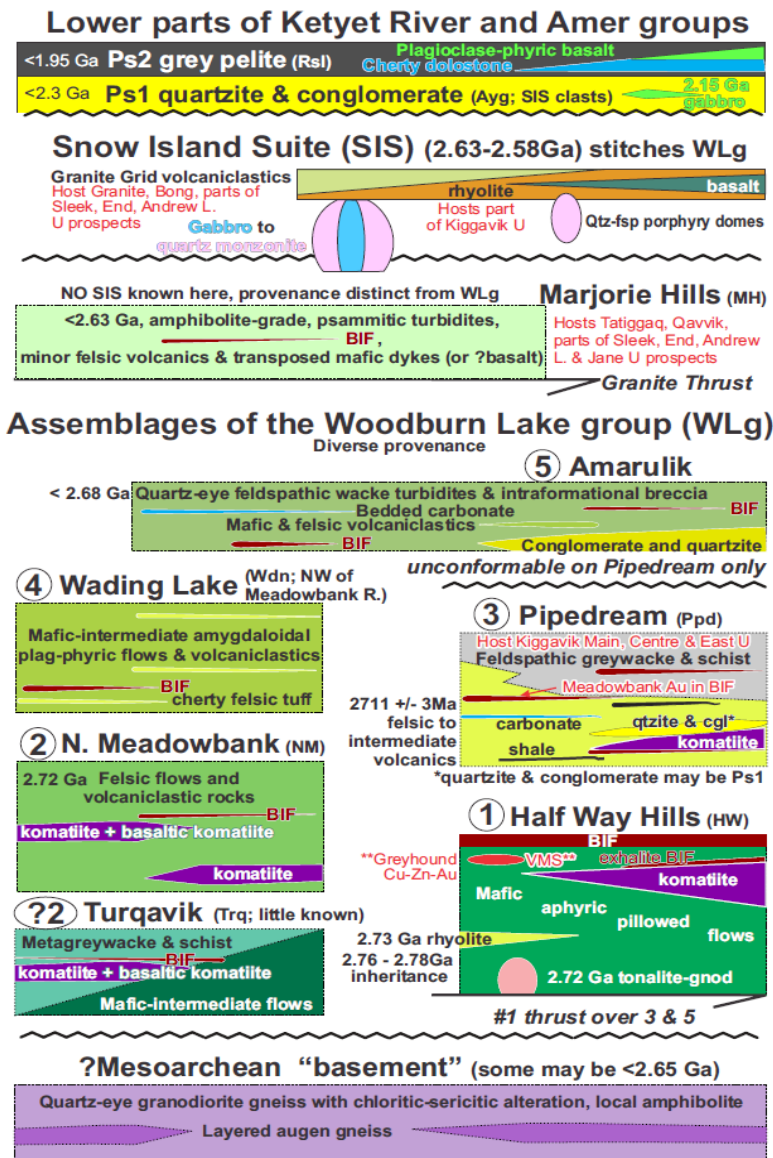


Fig. 2.2. The Woodburn Lake group (WLg) is comprised of six assemblages that overlie unconformably over Mesoarchean basement gneisses (from Jefferson *et al.*, 2015).

2.2.1 Halfway Hills, Turqavik and North Meadowbank Assemblages

The Halfway Hills (min deposition age 2.76 Ga), Turqavik and North Meadowbank Assemblages (~2.72 Ga) unconformably overlie the Archean basement (Zaleski *et al.*, 2000; Pehrsson *et al.*, 2013). The Halfway hills greenstone belt is comprised of mafic aphyric to pillowed flows intercalated with rhyolite and komatiite flows and is capped by banded iron formations. Little is known about the Turqavik assemblage and its temporal and stratigraphic relationship within the WLg is poorly understood (Jefferson *et al.*, 2015). This assemblage has been described as a package of mafic to intermediate flows overlain by a metagreywacke and schist package intercalated with banded iron formation and komatiite to basaltic komatiite flows. Unconformably overlying the Halfway Hills is the North Meadowbank assemblage, a sequence of dominantly felsic volcanic flows to volcanoclastics with intermingled basaltic to komatiitic flows (Pehrsson *et al.*, 2010, 2013).

2.2.2 Pipedream Assemblage (Ppd)

The Pipedream assemblage (Ppd) has been long thought to have served as the host to several of the Kiggavik deposits in particular the Bong, Andrew Lake and End given their large areal extent south of the Kiggavik uranium camp (Fig. 1.1; Fig. 2.2). The regional extent of the Ppd has only recently been subject to debate (Aand and Jefferson, 2017; Johnstone, 2017). This package of turbiditic feldspathic greywackes and schists with interbedded banded iron formation and deposited within an intra-continental back arc to marginal basin setting (Zaleski *et al.*, 2000) These have been suggested to be associated with felsic lapilli tuffs that were age dated 2710 ± 3.5 Ma (Davis *et al.*, 1998; Zaleski *et al.*, 2000). Not only is the Pipedream a focus for exploration due to it's potential for hosting economic uranium deposits but also gold bearing

Algoma-type Banded Iron Formations (BIF) (e.g. Meadowbank Gold Mine) (Sherlock *et al.*, 2004; Gourcerol *et al.*, 2015).

2.2.3 Wading Lake and Amarulik Assemblages

Overlying the Pipedream assemblage is the Wading Lake assemblage; a package of mafic-intermediate amygdaloidal plagioclase-phyric and volcanoclastic flows interbedded with banded iron formation and cherty felsic tuffs (Fig. 2.2) (Zaleski *et al.*, 2000, Jefferson *et al.*, 2015). The younger Amarulik assemblage caps the WLg sequence and unconformably overlies only the Pipedream assemblage. Limited geochronological work on the Amarulik assemblage suggests that maximum age of deposition was ~2.68 Ga (Zaleski *et al.*, 2001). The assemblage has been described as a package of feldspathic wacke turbidites interbedded with banded iron formation, carbonate beds, and mafic to felsic volcanoclastics (Jefferson *et al.*, 2011,2015).

2.3 Rumble assemblage

The Rumble assemblage (informal) is a newly proposed unit which is thought to underlie the Amer belt northeast of the Thelon basin and may possibly be a part of the WLg (Fig. 2.3) (Jefferson *et al.*, 2015; Tschirhart *et al.*, 2017). This assemblage contains volcanic, sedimentary, and iron formation units that are similar to the Pipedream assemblage within the WLg, however, it is yet to be dated. There is a possibility the Rumble assemblage is host to prospective uranium given its lithological similarities to the uranium bearing WLg and the presence of reactivated faults (Tschirhart *et al.*, 2017).

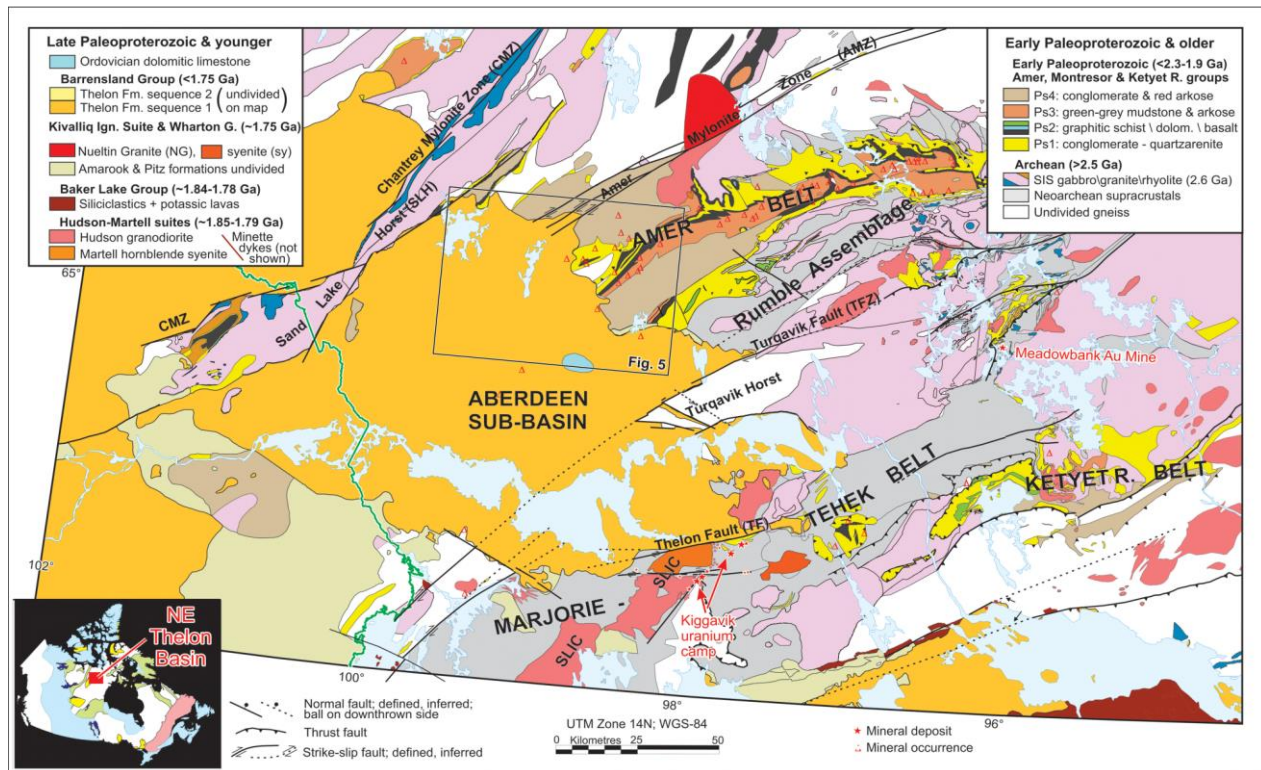


Fig. 2.3. A revised regional geologic map of the Amer Belt and proposed Rumble assemblage situated north-east of the Aberdeen sub-basin and north of the Kiggavik uranium camp (from Tschirhart *et al.*, 2017)

2.4 Marjorie Hills assemblage

The Marjorie Hills assemblage (~2.63 Ga) is described as a northwest dipping panel of intercalated amphibolite grade paragneisses that structurally overlie the WLg, separated by the Granite Thrust (Fig. 2.2) (Tschirhart, *et al.*, 2013; Jefferson *et al.*, 2015). It was only recently this package of rocks were separated from the WLg because this unit is much younger than the WLg, demonstrates a higher metamorphic grade, and is structurally isolated (Jefferson *et al.*, 2015). It has been suggested that this package may also be a co-host to potentially economic uranium deposits (Fig. 2.1, Fuchs *et al.*, 1985, Jefferson *et al.*, 2011; 2015).

2.5 Snow Island Suite (SIS)

The WLg is unconformably overlain by the Snow Island Suite (SIS) and include the Pukik Lake formation (PLF) (Fig. 2.2; Fig. 2.3; Tschirhart *et al.*, 2013, 2017; Peterson *et al.*, 2015b). The SIS comprises gabbro, diorite, granodiorite, granite, quartz-feldspar porphyritic (QFP) rhyolite schist, epiclastic, tuff, and ignimbrite that formed between 2.58 to 2.63 Ga and has been identified throughout the Rae Province (Davis *et al.*, 2015; Peterson, 2006; Pehrsson *et al.*, 2013; Peterson *et al.*, 2015b). The Pipedream assemblage was originally thought to host the Kiggavik and Bong deposits, however, recent work by Benedicto *et al.*, (2014), Anand and Jefferson, 2017a,b, and Johnstone *et al.*, (2017) have suggested that the epiclastic rocks of the Pukik Lake Formation extend further to the southwest and include the Kiggavik Main, Center, East and Bong deposits (Fig. 2.4).

2.5.1 Pukik Lake Formation

The Pukik Lake Formation (Fig. 2.4) is dominantly a texturally-distinct 2.604 Ga, quartz-feldspar porphyritic schist (QFP) and has been also referred to as the SIS 'metarhyolite' (Johnstone *et al.*, 2017). The QFP is likely the upper unit in the SIS and structurally underlies the Ketyet River group (McEwan, 2012). Mapping of this formation has revealed that the QFP is intercalated with epiclastic rocks (Peterson *et al.*, 2015b; Johnstone *et al.*, 2017, Anand and Jefferson, 2017a). The Pukik Lake Formation epiclastic rocks (PLF) are described as interbedded felsic volcanic-sourced metasedimentary material comprised of meta-arenite, metagreywacke to metapelite, and metatuffs (Johnstone *et al.*, 2017, Peterson *et al.*, 2015b, Jefferson *et al.*, 2015).

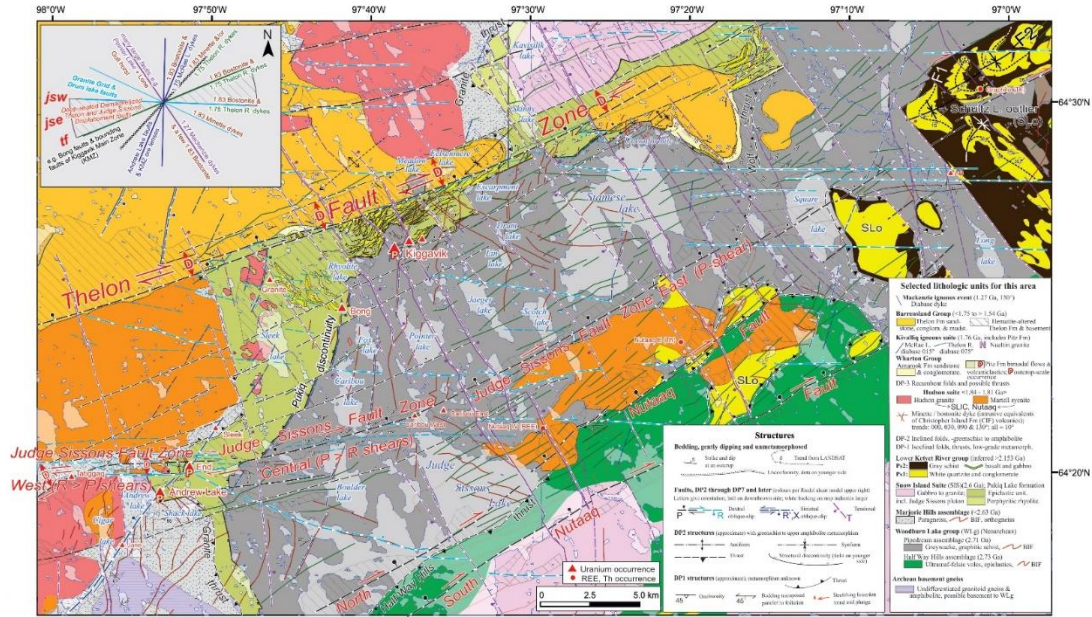


Fig. 2.4. Recent geologic mapping, and Remote Predictive Mapping (RPM) has suggested the epiclastics of the Pukiaq formation extend further to the south host the Kiggavik Center and East deposits and possibly Granite, Bong, End and Andrew Lake deposits. (modified from Anand and Jefferson 2017).

2.6 Ketyet River Group (KRg)

North of the Kiggavik uranium camp the Ketyet River and Amer Groups form a sequence of supracrustal rocks that overlie the Archean basement, WLg and underlie unconformably, the Paleoproterozoic Dubawnt Supergroup (Patterson, 1986; Rainbird *et al.*, 2010; Pehrsson *et al.*, 2010, 2013; Jefferson *et al.*, 2015). The Ketyet River Group (KRg) is correlative to the Amer Group and is located North of Baker Lake and due east of the Kiggavik uranium camp (Fig. 2.3; Fig. 2.5) (Zaleski *et al.*, 2000; Davis and Zaleski, 1998; Sherlock, 2004, Rainbird *et al.*, 2010).

This 200km southwest-northeast trending group was initially subdivided into two packages of volcanoclastics with siliceous carbonates and siliciclastics with carbonaceous mudstones by Schau *et al.*, (1982). Building upon Schau's findings, Rainbird *et al.*, (2010) and Jefferson *et al.*, (2011) have shown that the KRg is comprised of four stratigraphic sequences, Ps1, Ps2, Ps3, Ps4 (Fig. 2.5). The basal (Ps1 - max deposition 2.62 Ga) sequence is comprised of

a thick shallow marine-fluvial package of sandstones that were deposited within an intracontinental thermal sag basin (Rainbird *et al.*, 2010). This sequence is conformably to disconformably overlain by the Ps2 (2.1-1.95Ga) sequence, a package of feldspathic quartz arenites to quartz cobble conglomerates with thick continental flood basalts interpreted to have formed during active crustal extension (Rainbird *et al.*, 2010; McEwan, 2012). The third sequence (Ps3 - ~1.93 Ga) conformably overlies Ps2 and is comprised of carbonate-cemented sandstones, sulphidic shales and conglomerates that likely deposited in a shallow marine epicontinental environment (Rainbird *et al.*, 2010). Unconformably overlying all of these marine sedimentary sequences and the Archean basement in some areas is a polymictic conglomerate (Ps4 - ~1.93-1.83 Ga) that deposited as mass flows along submarine fans from reactivated faults during tectonic activity.

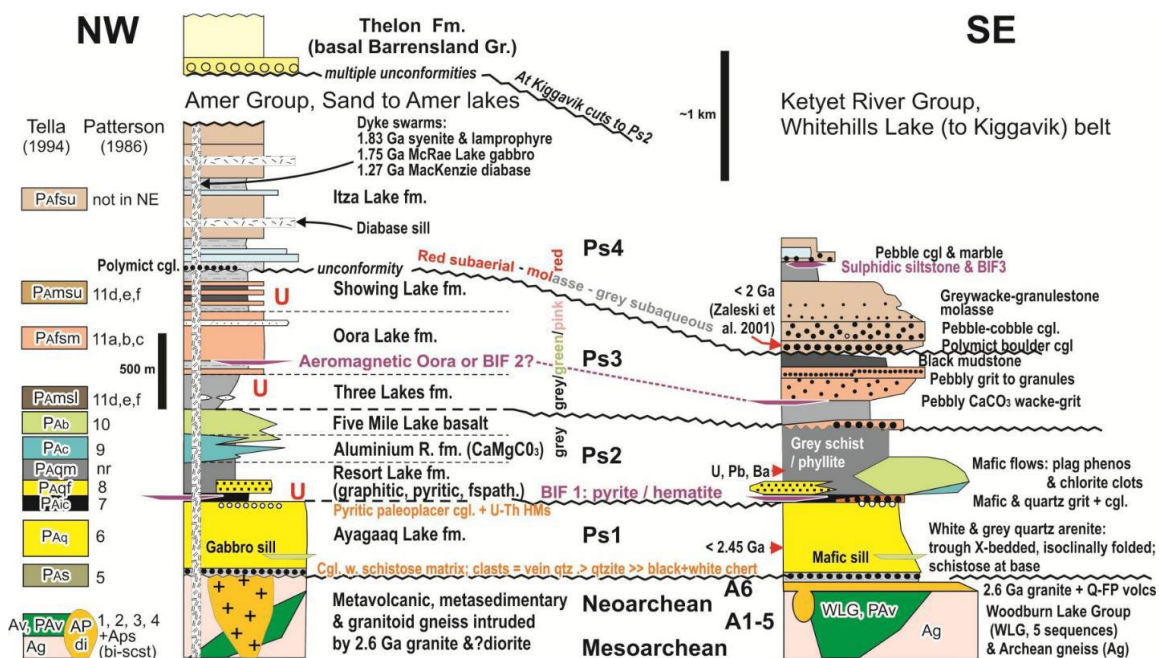


Fig. 2.5. Recent reinterpretation of the stratigraphy and geochronology have revealed four sequences that are correlative between the Amer and Ketyet River Group (from Rainbird *et al.*, 2010, Jefferson *et al.*, 2011).

2.7 Dubawnt Supergroup

The areally extensive (over 200,000 km²) Dubawnt Supergroup unconformably overlies the Archean crystalline basement of the Western Churchill Province (Fig. 2.1; Fig. 2.6) (Rainbird *et al.*,2003). This supergroup comprises three sedimentary sequences: the Baker Lake, Wharton, and Barrensland Groups that were deposited during intracratonic development and erosion of the Trans Hudson Orogeny and its tectonic evolution has been interpreted as a rift basin, a modified rift basin, and a thermal sag basin (Rainbird *et al.* 2003). This succession is discontinuous throughout the Thelon Basin area and several workers have described the stratigraphic sequence (Donaldson 1965; Rainbird *et al.*,2003; Peterson, 2006). Given the spatial and temporal relationship to the rocks within Athabasca basin, multiple studies have been conducted to evaluate the economic potential of the Dubawnt Supergroup (Miller, 1980; Miller and LeCheminant, 1985).

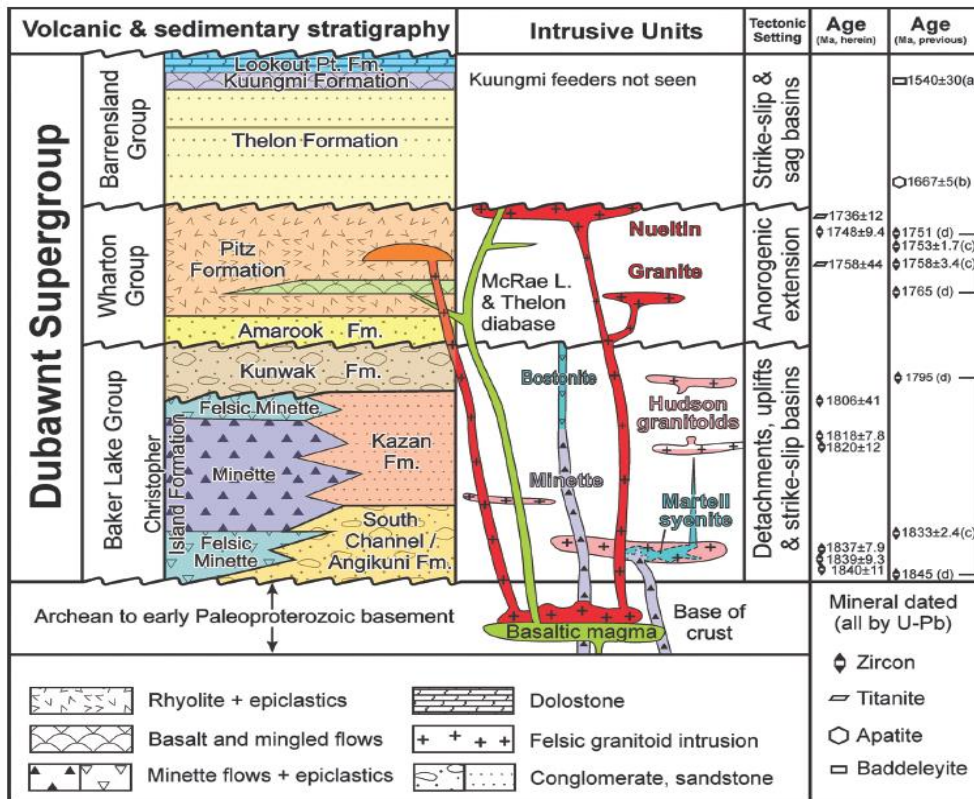
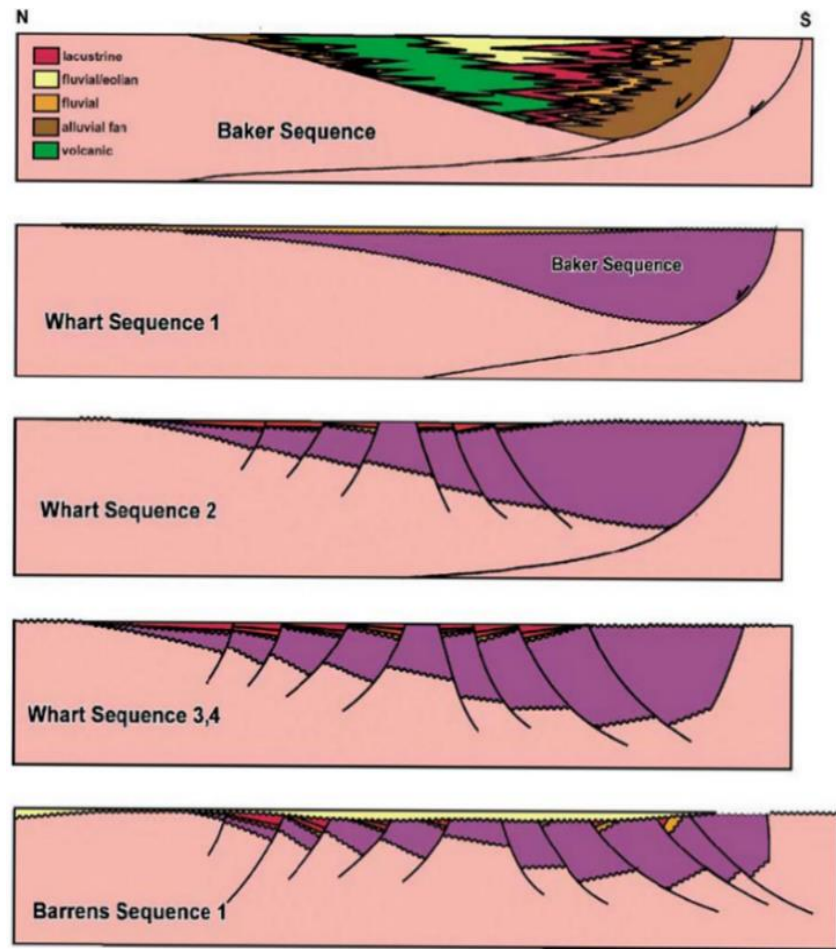


Fig. 2.6. Stratigraphy of the Dubawnt Super group including the temporal relationship between the Intrusive rocks in the Kiggavik area (Scott *et al.*,2015).

Fig. 2.7. Tectonic evolution of the Dubawnt Super Group, deposition of the Baker Sequence followed by the formation of horst and grabens. This sequence was then overlain by the Wharton group as the basin underwent thermal sagging and then finally towards the end of the Basin's formation, deposition of the Barren's sequence (modified from Rainbird *et al.*, 2003).



2.7.1 Baker Lake Group

The Baker Lake group (1.845 Ga – 1.785 Ga) (Fig. 2.6) unconformably overlies the Archean basement and, in places, is several kilometers thick. The group is composed of several series of unconformably, superimposed sedimentary and volcanic rocks that recorded the infilling of several structurally controlled basins and sub-basins (e.g. Thelon, Wharton, Baker Lake, Kamilukuak, Aberdeen, and Angikuni sub-basins) (Rainbird *et al.*, 2003).

The Baker Lake group is composed of five formations, the South Channel, Angikuni, Kazan, Christopher Island and capped by the Kunwak. The South Channel Formation, Angikuni, and Kunwak formations are typically 1-2 km thick and represent three stratigraphically separate

alluvial-fluvial fan environments that fed into braided river systems (Donaldson, 1965; Rainbird *et al.*, 2003) The Angikuni Formation is similar to the Kazan Formation but may be a distant equivalent to the South Channel Formation that unconformably underlies the Christopher Island Formation (CIF) (Blake 1980, Rainbird *et al.*, 2003). The origin of the Angikuni Formation is still poorly understood as recent geochemical and Nd isotopic studies of the mudstones within the Angikuni formation suggest they may have formed from rocks co-eval to the CIF volcanics or CIF-like rocks (Aspeler *et al.*, 2004).

The Christopher Island Formation unconformably overlies the Kazan formation and the Archean basement rocks (Donaldson, 1965; Blake, 1980). This formation is 2500 m thick and is comprised of subaqueous to subaerial volcanic flows and epiclastic rocks that may be derived from the Martell syenite (1.853 Ga) and a series of lamprophyre dykes that occur throughout the central Churchill province (Donaldson, 1965). These flows are potassic to ultrapotassic and have been classified as minette to lamproitic rocks due to their high K/Na and K/Al (Donaldson, 1965). Recently, Aspeler *et al.*, (2004) suggested volcanism within the CIF was deposited after tilting of the Angikuni formation.

The age of formation of the Baker Lake group is difficult to determine due to the lack of zircons-bearing flows and volcanic ash layers (Rainbird *et al.*, 2003). However, $^{40}\text{Ar}/^{39}\text{Ar}$ dating of phlogopite within an ultrapotassic flow that cross-cuts the lower Baker Lake group resulted in a minimum age of formation at $1845 \text{ Ma} \pm 12 \text{ Ma}$ (Rainbird *et al.*, 2002). A minimum age of deposition for the Kunwak formation is $1785 \text{ Ma} \pm 3 \text{ Ma}$ based on a Pb-Pb isochron age from laminated calcite cements (Rainbird *et al.*, 2002, 2003).

2.7.2 Wharton Group

The Wharton Group (1.785-1.753 Ga) (Fig. 2.6) overlies the Baker Lake Group via an angular unconformity. This group is comprised of well-indurated fluvial and aeolian sandstone of the Amarook Formation overlain by intercalated bimodal rhyolite-basalt flows, tuff, and epiclastic rocks of the Pitz Formation (Peterson 2006; Peterson *et al.* 2014, 2015a). The Wharton group has been interpreted as a package of alluvial fan and braided river sediments that fed into sub-basins consisting of ephemeral lakes and ergs, which were later intruded and covered by rhyolite flows and superimposed by coeval sedimentation during extension and block faulting (Rainbird *et al.* 2003). Zircons within these rhyolite flows that are part of the Pitz formation yielded U-Pb ages of 1757.6 ± 3.3 Ma and 1753.7 ± 1.6 Ma and thus represent a maximum deposition age of the Wharton Group (Rainbird *et al.*, 2001).

2.7.3 Barrenland Group

The uppermost sequence of the Dubawnt Supergroup is the Barrenland group (1.74 Ga-~1.54 Ga) (Fig. 2.6). The Barrenland group consists of the Thelon, Kuungmi, and Lookout Point Formations. The basal Thelon Formation unconformably overlies the Wharton Group and is the dominant basin-filling unit of the Thelon Basin. It comprises three dominantly alluvial siliciclastic upward-fining sequences and has a maximum preserved stratigraphic thickness of 1.8 km (Hiatt *et al.* 2003; Davis *et al.* 2011). Diagenetic apatite cements within the Thelon Formation have a Pb-Pb age of 1720 ± 6 Ma (Miller *et al.*, 1989). Overlying the Thelon formation in the western portion of the Thelon Basin, is a <10 m thick unit of altered shoshonitic basalt known as the Kuungmi Formation (1540 ± 40 Ma) (Peterson 1995; Chamberlain *et al.* 2010). The Kuungmi formation is in turn overlain by stromatolitic dolostone of the Lookout

Point Formation, which formed in a marine, intertidal environment and developed while the area was undergoing regional subsidence (Gall *et al.* 1992; Rainbird *et al.* 2003).

From ~1.72 Ga to ~1.74 Ga, the sub-Thelon Formation paleosol a paleosol developed as an erosional surface during a period of tectonic quiescence. This unconformity (Mantonabee unconformity) is identified throughout the Hornby Bay, Elu, Thelon and Athabasca basins (Gall and Donaldson, 1990; 2006; Gall, 1994;). The regolith ranges from 1 to 100m in thickness and developed within throughout the Pitz Formation, and Archean WLg (e.g. Pipedream metagreywacke) and SIS (Chiarenzelli, 1983; Miller and LeCheminant, 1985; Gall, 1994). The sub-Thelon formation has a characteristic alteration profile of quartz, hematite-kaolinite near surface that transitions to chlorite-muscovite-dolomite at depth (Chiarenzelli, 1983; Gall and Donaldson, 1990; Gall, 1994).

2.7.4 Hudsonian Igneous Suites

Past studies identified two igneous suites that cross-cut the Rae and Hearne Provinces between 1.84 to 1.81 Ga (Hudsonian Granitoids and Martell Syenite) and 1.75 to 1.76 Ga (Nueltin Granite part of the Kivalliq Suite) (Fig. 2.8; van Breeman *et al.*, 2005; Peterson *et al.*, 2002, 2010; Scott *et al.*, 2015). The emplacement of the Hudsonian Granitoids are considered coeval with active volcanism and deposition of the Christopher Island (Baker Lake) (Fig. 2.6; Rainbird *et al.*, 2003; 2006; Rainbird and Davis 2007). Within the Kiggavik area there are a series of minette and micro syenite dykes that intrude and surround the Baker Lake group basins (Jefferson *et al.*, 2015). Along with basin development granodiorite and monzogranite sills and laccoliths formed at mid crustal levels throughout the WCP (The Hudson suite) and pink weathered potassic syenites (Martell Syenite; Jefferson *et al.*, 2015).

The Nueltin granite are the youngest plutonic rocks and are part of the Kivalliq Igneous Suite that formed within the interior of the Nuna supercontinent led to the emplacement of the Pitz Formation rhyolites (Wharton Group) (Peterson, 2006; Peterson *et al.*, 2014, 2015a). These plutonic rocks cover a 700 km by 300km corridor (Nuelting Corridor) and are rich in quartz and alkali-feldspar phenocrysts and are texturally similar to the rhyolites of the Pitz Formation, which led to the initial interpretations linking these igneous events (Peterson, 2006; Peterson *et al.*, 2015a).

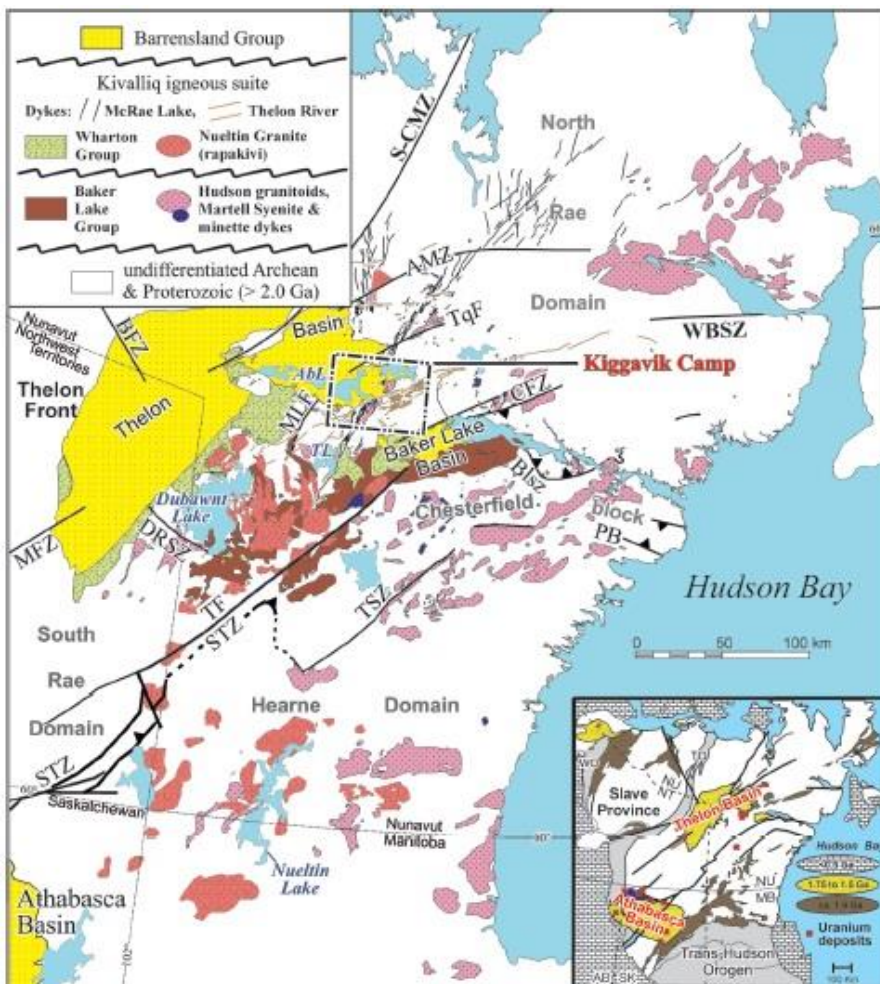


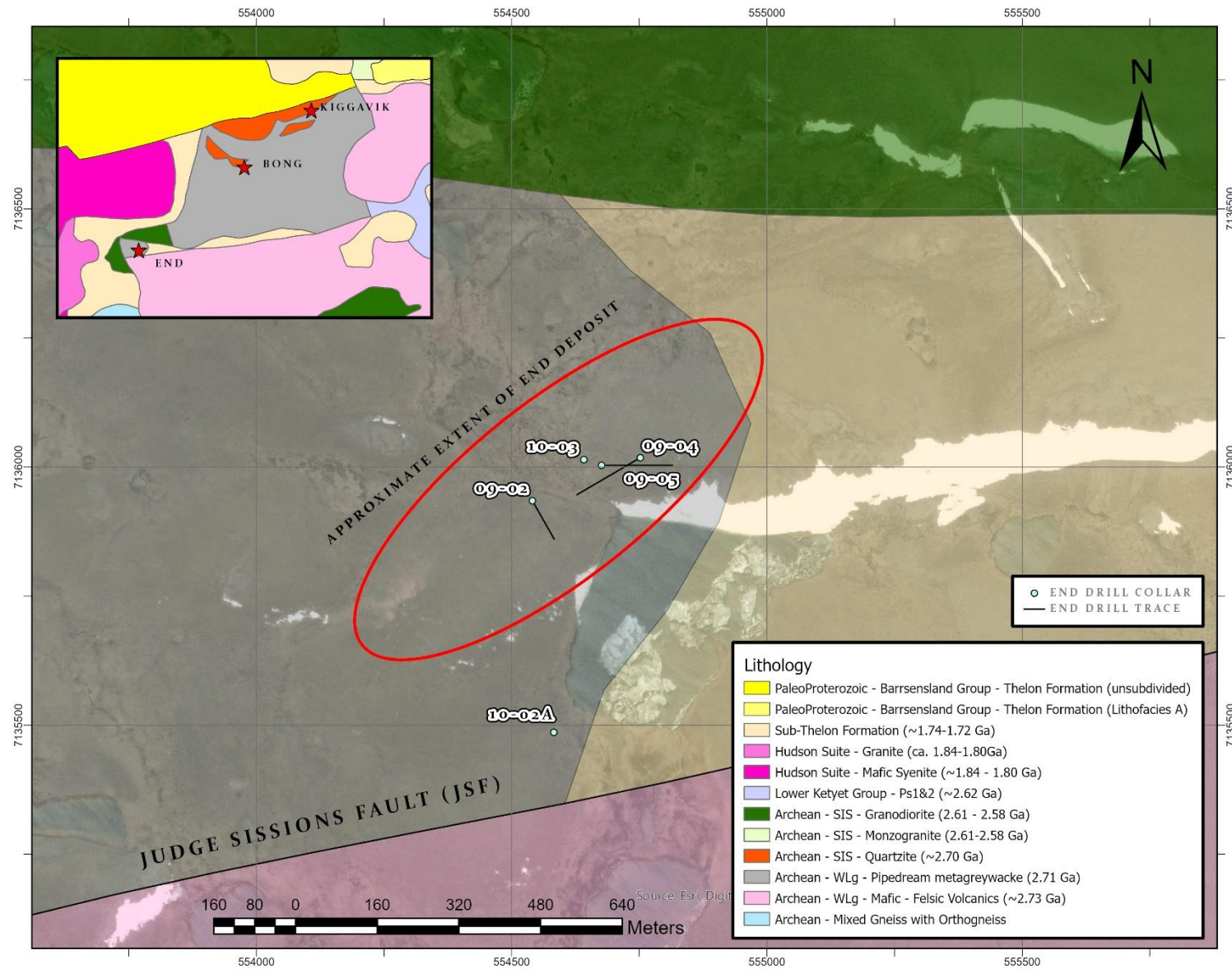
Fig. 2.8. The Rae and Hearne domains are cross-cut by two igneous suites; the Kivalliq Igneous Suite (which include the Nueltin granite (1765-1750 Ma)) and the Hudson granites (1820-1806 Ma) and Martell Syenite Dykes (~1840 Ma). (from Scott *et al.*, 2015).

2.8 Local Geology of the End U deposit

Several U deposits, including the End deposit, lie along the Kiggavik-Andrew Lake structural trend (informal term) and are hosted within the Pipedream metagreywacke assemblage of the WLg (Section 2.2.2, Fig. 1.1, Fig. 2.9) and the SIS epiclastic rocks (Section 2.5.1; Fig. 2.4). Historically, the consensus was the Pipedream assemblage served as the host to the majority of the Kiggavik deposits (Fuchs *et al.*, 1986; Jefferson *et al.*, 2011, 2015). However recent mapping by several workers have suggested that the epiclastic rocks of the Pukiq Lake Formation are more areally extensive and voluminous throughout the Kiggavik Camp and primarily host to the Kiggavik Main and Center Zones (Benedicto *et al.*, 2014, Johnstone *et al.*, 2016; 2017 and Anand and Jefferson, 2017). It is still subject to debate whether the Pukiq epiclastics extend further to the south and include the Andrew Lake, Bong and End deposits based on remote predictive mapping by Aand and Jefferson, (2017). The End deposit is hosted within the Ppd metagreywacke which is bounded to the North and West by equigranular gabbro and diorite of the SIS, the sub-Thelon paleosol to the East and undifferentiated mafic flows to felsic volcanoclastic rocks of the WLg (Fig. 2.9) (Donaldson, 1966; Hadlari *et al.*, 2004; Zaleski and Pehrsson, 2005)

The host rocks of the End deposit are cross-cut by numerous granitic veins composed of quartz and k-feldspar that are parallel and cross-cut the primary foliation (Flotté, 2009). These granitic veins are proximal to mineralization and was hypothesized that these veins were the primary source of uranium (Flotté, 2009). Granitic veins identified in this study did not contain any uranium mineralization.

Fig. 2.9. Local Geologic map of the End deposit including drill collars and traces of holes from this study (modified from Skulski et al., 2018; Hadlari et al., 2004; Donaldson, 1966).



These rocks are also cross-cut by a series of quartz breccia's (QB) hosted within the Judge Sissions Fault (JSF), and are described as narrow to widely fractured corridors containing a “jigsaw” like pattern of host rock fragments infilled with quartz in the Kiggavik Area (in particular Andrew Lake and the End deposit) (Flotté, 2009; Grare *et al.*, 2018b, 2020). The origin of the quartz breccia was not fully understood and had been recognized as a regionally extensive silicification event to sub-volcanic or peri-magmatic origins (Turner *et al.*, 2001; Hadlari and Rainbird, 2011; Flotté, 2009). A recent study on the significance of the quartz breccias have revealed they likely formed during orogenic rifting (1850-1750 Ma) and served as a hydrologic barrier to uprising uranium-bearing fluids (Grare *et al.*, 2018b).

At the End deposit observations by Flotté, (2009) suggested there is evidence of late reactivation of the quartz breccia based on fault gouge, rock dislocation, clay alteration and reduced-oxidation flows that appear parallel to the quartz breccia. The quartz breccia has also been displaced by late sub-vertical faults that are oriented near parallel (NS and EW, dipping to the S and the NW respectively) within the End Deposit (Fig. 2.9) (Grare *et al.*, 2018b). Several post-QB fractures, and uranium mineralization are contained within the hanging wall and footwall to the QB, while the main QB unit contains far fewer fractures. QB within the End deposit varies in thickness laterally and mineralization is constrained above and below the QB's (Fig. 2.9) (Grare *et al.*, 2018b). Clasts of QB veins have been identified within the Thelon formation constraining a maximum age of deposition (~1.72 Ga) and crosscutting the Hudsonian Intrusions (~1.83 Ga) (Chi *et al.*, 2017; Grare *et al.*, 2018b). It's suggested the QB was formed during the emplacement of the Kivalliq Igneous Suite (~1.75 Ga) which led to pervasive infill of silica throughout fault zones, these silicified fault zones served as hydrologic barriers to uranium mineralization (Grare *et al.*, 2018b).

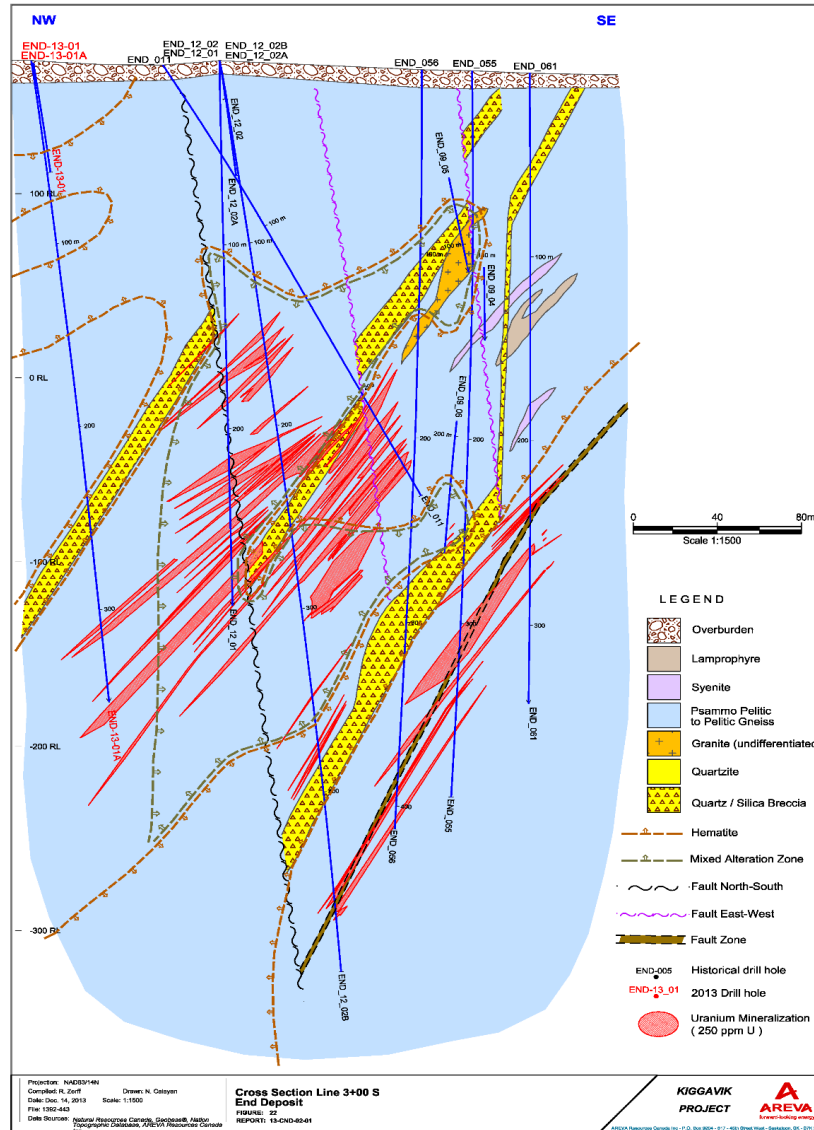


Fig. 2.10. A NW-SE cross section of the End deposit, the deposit consists of two ore zones that are oriented parallel to the Quartz breccia and constrained within the footwall and hanging walls (pers. communication, Quirt, May 26, 2015).

A recent fluid inclusion study was completed on several quartz phases and calcite within the End deposit (Chi *et al.*, 2016). These phases include quartz within the quartz breccia, quartz veins that developed prior to mineralization but are spatially associated with uraninite and calcite veins that formed after mineralization. The study suggested that the quartz within the breccia were formed by fluids with low salinities (0.4 to 6.6 wt. %) with moderate temperatures of 148 to 261°C, whereas the fluids that formed the calcite veins consisted of higher salinities (26.8 to 29.3

wt. %) and lower temperatures (146 to 205°C; Chi *et al.*, 2017). The authors proposed that the End deposit may have formed at less than 2 km depth based on fluid immiscibility and low fluid pressures within these fluid inclusions (Chi *et al.*, 2017).

2.8.1 Host-rock Alteration within the End Deposit

First observations on the regional alteration was first described, as primarily hematization, clay alteration (illite and sericite) and chloritization (Fuchs *et al.*, 1986). This alteration mineral assemblage is spatially associated with fault zones and thought to represent paleo weathering or hydrothermal alteration (Fuchs *et al.*, 1986). Riegler *et al.*, (2014) carried out a detailed paragenesis of the alteration associated with the uranium deposits within the Kiggavik project area. Prior to uranium mineralization and hydrothermal alteration, the region was subjected to retrograde greenschist metamorphism. This is evident from pervasive chloritization of biotite, sericitization of feldspars and the presence of veinlets of epidote, alkali feldspars and carbonates within the unaltered non-mineralized basement metasediments (Riegler *et al.*, 2014; Sharpe *et al.*, 2015; Shabaga *et al.*, 2017). The retrograde metamorphism is later overprinted by a later hydrothermal events during and post mineralization. Hydrothermal host-rock alteration throughout the Andrew Lake-Kiggavik structural trend is dominated by clay minerals such as illite and sudoite (Al-Mg chlorite), which are often accompanied by hematite and aluminum phosphate sulfate minerals (APS; Riegler *et al.*, 2014, 2016). Clay mineral alteration is generally restricted to faults and was later overprinted by several hematization events (Flotté, 2009; Riegler, *et al.*, 2013).

The Kiggavik deposits display similar macroscopic hydrothermal alteration features within the basement host rocks. These features more notably proximal to uranium mineralization

include pervasive bleaching and desilicification, followed by pervasive ochre to brick red iron oxide staining and a later silicification event (Riegler *et al.*, 2014; Shabaga *et al.*, 2017; Sharpe *et al.*, 2015; Grare *et al.*, 2018). The alteration mineral assemblage and paragenesis shows some similarities to the Thelon Basin's spatially distant relative the Athabasca Basin as evident by the geometric shape of alteration halos, crystal chemistry of illite, sudoite and chlorite associated with APS, and a similar alteration zone profile of structurally controlled mineralization with proximal illite $\pm$ sudoite $\pm$ apatite, an outer zone of APS $\pm$ veinlets of clinochore (Riegler *et al.*, 2014).

2.8.2 U Mineralization within the End Deposit

Uranium-bearing minerals at the End deposit are predominately finely disseminated along foliation planes and these have been suggested to be part of the primary mineralization (Flotté, 2009; Riegler *et al.*, 2014). A secondary stage of uranium mineralization was identified within late fractures and faults that are parallel to the quartz breccia (Fig. 2.11.; Flotté, 2009). Chi *et al.*, (2016) identified a third type of uraninite and coffinite mineralization spatially associated with the quartz breccia that formed prior. This style of mineralization has a U-Pb age of 1292 ± 12 Ma and it is suggested that the obtained age represents an isotopic resetting age (Chi *et al.*, 2017). Rare occurrences of pitchblende and sulphides within quartz/k-feldspar granitic veins have been observed within the End deposit and it has been suggested they may be the primary source of uranium Flotté (2009).

The Rare Earth Element (REE) composition of two phases of uranium mineralization at End were completed using LA-ICP-MS (Fig. 2.10) by Grare *et al.*, (2020). The chondrite-normalized REE profile on samples within the End displays a modified bell-shaped curve

centered around Terbium (Tb) which is consistent with unconformity-related deposits (Grare *et al.*, 2020) and also at Kiggavik Main (Fayek *et al.*, 2017). The profiles are also similar to what has been observed in Athabasca basin deposits and suggest that uranium mineralization occurred in similar physicochemical conditions (Grare *et al.*, 2020). The modification of the bell-shaped curve is suggested to have been caused by the interaction between primary UO_2 and low temperature ($<50^\circ\text{C}$) waters, suggesting an influence by meteoric waters (Grare *et al.*, 2020).

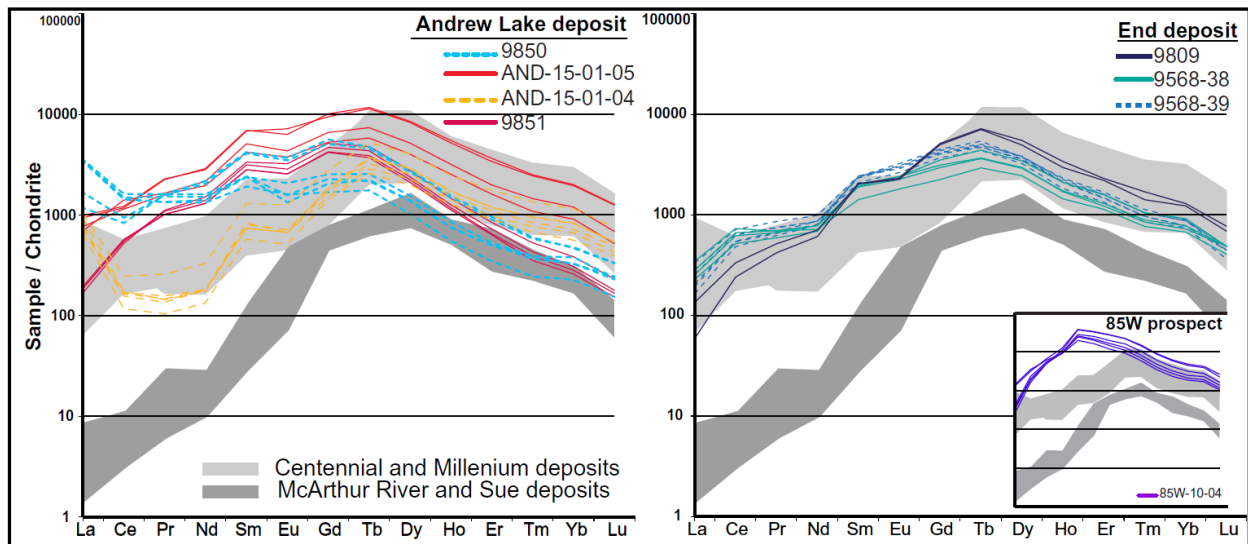


Fig. 1.11 Chondrite-normalized REE profiles from uranium mineralization at Andrew Lake, End and 85W (Thelon Basin) compared to the Centennial, Millennium, McArthur River and Sue deposits (Athabasca Basin) within the Athabasca Basin(modified from Grare *et al.*, 2020).

2.8.3 Structures associated with the End Deposit

Four major brittle faults within the Kiggavik area include the Thelon fault (TF), Main Zone fault (MZF), Judge Sissions fault (JSF), and the Andrew Lake fault (ALF) (Fig. 2.11.). These faults are closely associated with several Kiggavik deposits/prospects: (1) MZF - Kiggavik Main and Kiggavik Center, Granite Grid; JSF- End deposit; and ALF - Andrew Lake and Contact deposits (Grare *et al.*, 2018). Recent work by Johnstone *et al.*, (2017) suggested the deformation throughout the Kiggavik camp and surrounding area to be dominantly brittle and by

riedel shearing due in part to the crustal scale, strike-slip dextral motion of the Thelon Fault. The ENE trending JSF is dipping steeply to the north and formed along with the ALF during rifting and deposition of the Baker Lake and Wharton Groups (1.85-1.75 Ga) in response to the Trans-Hudson Orogeny (Grare *et al.*, 2018). The Andrew Lake and Bathurst faults don't appear to follow the riedel shearing model and, based on cross-cutting relationships, have been interpreted to occur pre-Thelon Fault (ALF) and post-Thelon fault (BF) (Johnstone *et al.*, 2017) (Fig. 2.12).

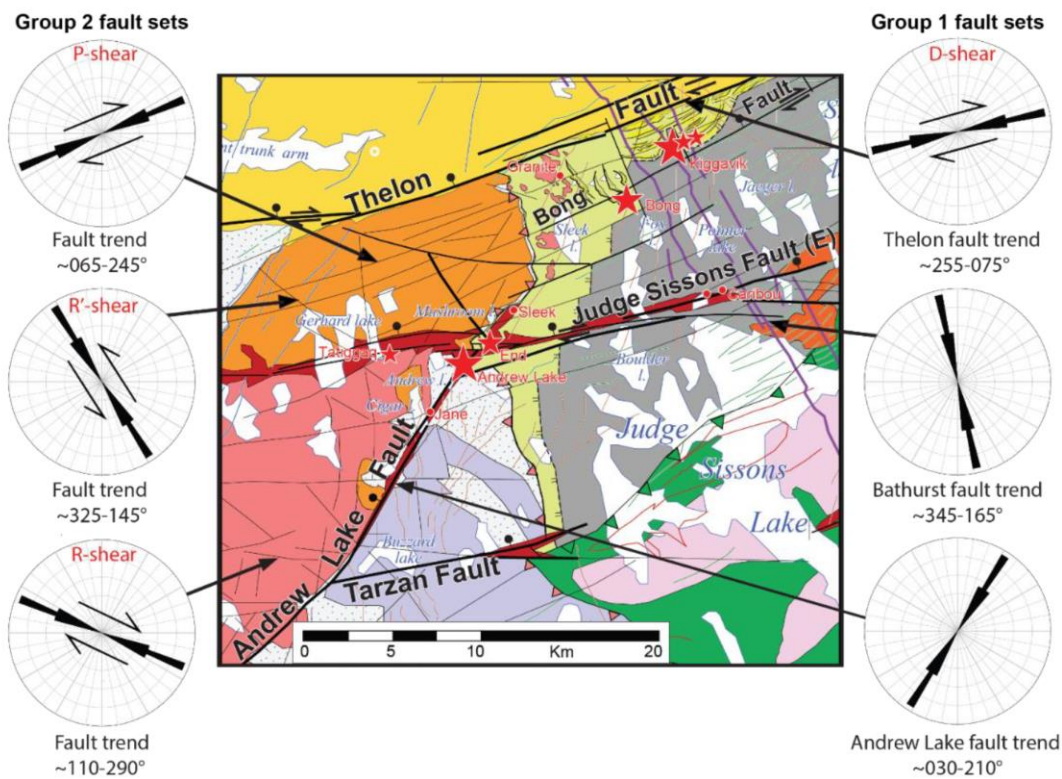


Fig. 2.12. Geological map of the Kiggavik area showing the main structures with respect to the End, Bong and Andrew Lake deposits. The End is situated along the JSF and near parallel to the Thelon fault trend (~255-075°) (from Johnstone *et al.*, 2017).

Very little work has been undertaken on the local structure within the End deposit, except for Flotté (2009), who evaluated the structure within the deposit and produced a 3D structural model. This model defined four structural features, a well-defined foliation and three fault sets (Fig. 2.13). The foliation throughout the End project area is oriented N170 and dips 10 to 30° to

the east. The three dominant structures are (1) N160 which represents late faults observed in outcrop, (2) N040 to N070 representing the ENE/WSW structural trend throughout the area and is also consistent with late brittle faulting, and finally (3) N110 to N120 that are structures identified in the 3D model. However the latter structures are not observed in outcrop and Flotté concluded that their relationship to the local geology is unknown.

Johnstone *et al.*, (2016, 2017) work on the Kiggavik deposit defined two group sets of faults; Group 1 comprises the regional scale structures including, TF, JSF and BF's; Group 2 are typically local R'-shears and trend N065-245, ~N110-290 and N325-145. The structures identified by Flotté (2009), (1) structures are likely associated with the Bathurst Fault, (2) structures appear associated with the Group 1 faults and finally (3) structures may be associated with the Group 2, R'-Shear trends.

The structural controls on how uranium-bearing fluids are concentrated and transported are crucial in understanding the metallogenesis of the Kiggavik and in particular the End deposit. Grare *et al.*, (2018a, 2020) recently completed a comprehensive, detailed, structural study on the Contact prospect along with the Kiggavik deposits and outlined eight fracture stages (Table 2.1) and took place in a brittle deformation regime. Three mineralization events took place; from 1.8-1.750 Ga within dense network breccia zones oriented NE-SW, from 1.5-1.3 Ga along NE-SW fractures and finally from 0.5 to 0.3 Ga along remobilized redox fronts (Grare *et al.*, 2020).

<u>Fracture Stage</u>	<u>Age(Ma)</u>	<u>Uranium Mineralization Stage – Macroscopic Characteristics</u>	<u>Structrual characteristics</u>
f0	~1830-1750	U0 – weakly disseminated within host rock and within microfractures	U-mineralized microbreccias contained in a dense network breccia zone up to 10m thick and at End are oriented NE-SW and steeply dipping to the NW
f1	-	-	Proto to ultra-cataclastic faults along the Andrew Lake Fault that are cross cut QB
f2	-	-	Mosaic white quartz-sealed veins and breccias that generated the QB throughout the Kiggavik area
F3	-	-	Centimetre thick dolomite veins and microbreccias
F4	-	-	Calcite-cemented veins and microbreccias and are spatially associated with U-mineralized fault zones
F5	~1500-1300	U1-Fracture controlled	Associated with ENE-WSW to ESE-WNW faults at Contact and NS and EW faults at Andrew Lake
F6a,b,c	~1500-1300	U2 -	Controlled by NW-SE and NNW-SSE faults dip to the east
F7	-	-	Dominated by green colored fault zones and are typically unmineralized but can contain reworked clasts containing U oxides
F8	~550-330	U3-Redox Fronts-Unmineralized oxidized zone with grey reduced mineralized zones	A weak reactivation network that contain remobilized redox fronts

Table 2.1 Fracture development and history throughout the Kiggavik area (modified from Grare et al., 2020).

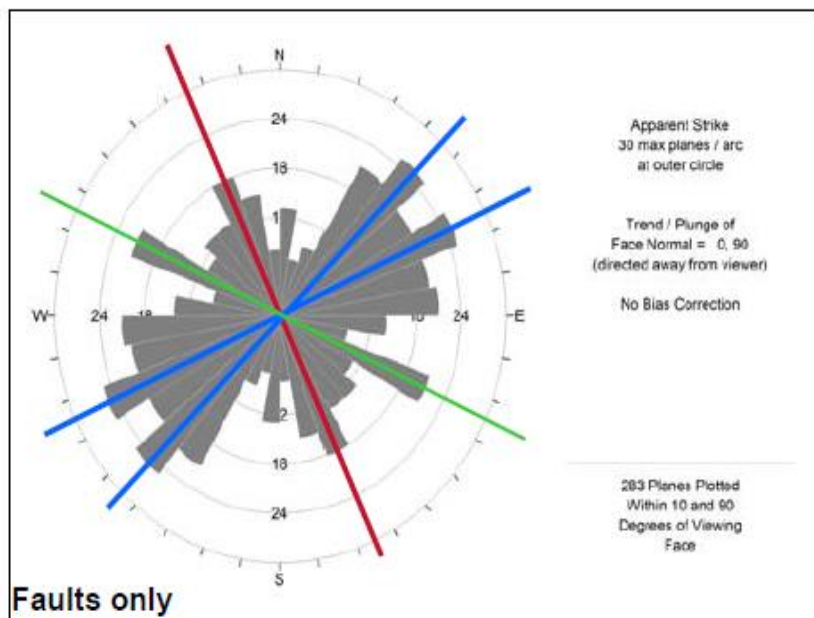
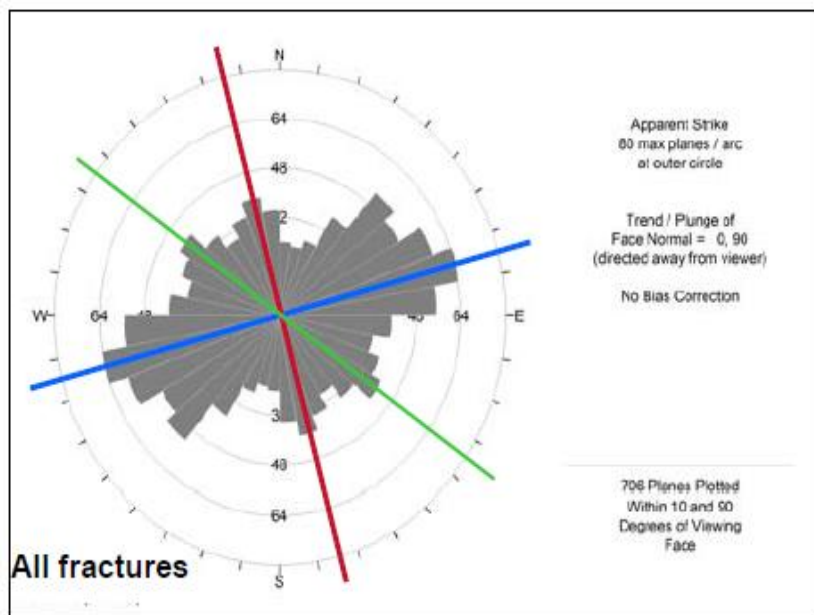


Fig. 2.13. A structural model of the three main structures identified in the End deposit Red representing the late faults (N160), the blue lines representing the ENE/WSW Structural Trend (N040 to N070) and the green lines representing a third structure of unknown origin (N110 to N120; from Flotée 2009).

Chapter 3.0: Sampling and Analytical Methodology

A one-week field program began on June 22nd and was completed June 29th, 2015. This program involved sampling drill core from the End deposit. In total, 382 samples were collected from six drill holes (END-09-02, END-09-04, END-09-05, END-09-10, END-10-03, and END-10-02A). Four of these drill holes (END-09-02, END-09-04, END-09-05, and END-09-10) were logged and sampled for petrographic, geochemical, and isotopic analysis in the field and 231 samples were shipped to the University of Manitoba. Prior to the 2015 field program, drill holes END-10-03 and END-10-02 were previously logged and sampled by Mostafa Fayek (University of Manitoba) and David Quirt (AREVA Resources Canada Inc.; now Orano Canada) in 2012. The sampling methodology for that program involved sampling of a barren hole (END-10-02A) and a well mineralized hole (END-10-03) at approximately every 10 m. A total of 152 samples were collected from these holes and subsequently polished thin sections were prepared from the samples.

3.1 General Analytical Methodology

Petrography of polished thin sections was completed using both reflected light and transmitted light optical microscopy, and Scanning Electron Microscopy (SEM). Detailed petrographic descriptions of the thin sections referenced in figures are included in Appendix A. An electron microprobe (EMP) was used to quantify the mineral chemistry of oxide and silicate minerals. Altered samples observed distal and proximal to the uranium mineralization were prepared for x-ray diffraction (XRD) analysis to characterize the alteration clay mineralogy. Oxygen isotopic ratios in illite, uraninite, quartz, and calcite, and hydrogen isotopic ratios in illite were measured using Secondary Ion Mass Spectrometry (SIMS). The U-Pb and Pb-Pb isotopic composition of uraninite was also measured using (SIMS). Radiogenic $^{40}\text{Ar}/^{39}\text{Ar}$ mass

spectrometric isotopic analyses were completed on muscovite and illite in samples located within, and outside of, the host-rock alteration halo of the End deposit.

3.2 Optical Microscopy and Scanning Electron Microscopy (SEM)

Optical microscopy and SEM using back scattered electron imaging (BSE) were completed on unmineralized and mineralized polished thin sections to characterize the ore, gangue, and alteration mineral assemblages. Thin sections were examined using a Nikon Eclipse 50i POL polarizing microscope at 2-5x magnification under both reflected light and transmitted light. Selected samples were carbon-coated and further examined using an Inspect S50 SEM. The SEM is equipped with a back-scattered electron (BSE) detector and an energy dispersive X-ray spectrometer (EDS) with digital-imaging capabilities. BSE imaging was used to select areas for subsequent EMP analysis and SIMS analysis.

3.3 Electron Microprobe Analysis (EMPA)

The chemical compositions of oxide and silicate minerals were analyzed with a Cameca SX100 Universal EMP. The EMP is equipped with five wavelength-dispersive spectrometers (WDS) and a Princeton Gamma-Tech energy-dispersive spectrometer (EDS). The EDS was used to qualitatively determine the mineral chemistry of minerals in the thin sections. Specific spots were located and then analyzed using WDS with a 1 to 20 μm beam with an acceleration voltage of 15keV and a 20nA current. Elemental detection limits were 1000 ppm for all elements except for Pb, Th, U, and F, which had detection limits of 1500 ppm, 1300 ppm, 6000 ppm, and 2200 ppm, respectively. The elements analyzed and the respective standard used are listed in Appendix B. The mineral chemical analyses of the silicates and oxide minerals are also provided in Appendix B.

3.4 X-Ray Diffraction (XRD)

Three samples of muscovite were separated from samples taken from mineralized drill holes (END-10-03-340 and END-10-03-40) and a barren drill hole (END-10-02A-263.3) for characterizing the alteration mineralogy and for $^{40}\text{Ar}/^{39}\text{Ar}$ geochronology. Sample preparation involved crushing the sample with a mortar and pestle and separating the clay minerals and mounting the crushed material on a glass slide. A Siemens D5000 powder diffractometer, scanning from 5° – 35° 2θ using Cu K α radiation, a step size of 0.02° , and a 1 second scan speed, was used to analyze the prepared material. The spectra were interpreted offline using the MDI Jade mineral identification software (V.7.5). XRD diffraction patterns and interpretations are provided in Appendix C.

3.5 Geochronology

3.5.1 *In Situ* Secondary Ion Mass Spectrometry (SIMS)

Due to the fine grained and chemically complex nature of uraninite, illite, and muscovite, SIMS was selected to measure the radiogenic and stable isotopic ratios in each mineral. This method provides *in situ* quasi non-destructive analytical capabilities to date uraninite and provide isotopic data to determine the type of fluids that deposited these various minerals (Fayek *et al.*, 2002; Sharpe and Fayek, 2016). Prior to SIMS analysis, the carbon coating from the previous EMP analysis was removed using a one-micron diamond-polishing compound. Samples were then immersed in an ultrasonic bath, first using tap water and soap for 10 minutes, then tap water only for 10 minutes, followed by distilled water for 10 minutes, and then a final bath with ethanol for 10 minutes. After cleaning was completed, the samples were coated with a 400Å thick layer of gold to improve conductivity.

3.5.1.1 U-Pb and Pb-Pb Analysis

The parameters for the analysis of U-Pb and Pb-Pb isotopes using a CAMECA 7f SIMS are as follows: a 15 μm spot diameter was obtained using a $\sim 12\text{nA}$ primary beam of O^- ions that was accelerated at 12.5 keV and focused using a 400 μm aperture in the primary column. The secondary column was set to accept 8 keV and a 50V voltage offset was applied to the sample to suppress hydride interferences. The contrast and field aperture were set to 400 μm and 1800 μm respectively. The energy bandpass was set to 50V. A mass resolving power (MRP) of 1300 with an entrance slit width of 35.9 μm was used, this produced flat-topped peaks. Individual ions were measured including $^{204}\text{Pb}^+$, $^{206}\text{Pb}^+$, $^{207}\text{Pb}^+$, $^{208}\text{Pb}^+$, $^{235}\text{U}^+$ and $^{238}\text{U}^+$. One cycle is composed of one second of measurement of each ion. Thirty cycles were completed for each spot analysis. Ions were detected with an ETP 133H electron multiplier with an overall dead time of 21 ns.

During SIMS analysis, a mass-dependent bias is introduced, and this is known as instrumental mass fractionation (IMF). This bias is generally in favor of the light isotope and is known to occur during the sputtering, secondary ion extraction (Williams 1979; Yu & Lang 1986), secondary transmission (Shimizu & Hart 1982) and detection stages of analysis (Valley & Graham 1991; Lyon *et al.* 1994). Sputtering and ionization are the greatest contributors to IMF and are dependent on the samples chemical composition; this is also referred to as ‘matrix effects’. Therefore, standards that are similar in chemical composition to the unknowns are required to correct for IMF.

In addition, the relative ion-yields of two elements and their isotopes (i.e. U and Pb) can vary due to chemical composition and sensitivity to ionization. Therefore, an ion-yield

normalizing coefficient (α_{SIMS}) or fractionation factor can be calculated (Eq.1) to correct for the variation in relative ion-yields with chemical composition (Holliger, 1991; Fayek *et al.*, 2002).

$$\alpha_{\text{SIMS}} = R_{\text{sims}}/R_{\text{true}} \quad [1]$$

Where R_{sims} is the SIMS measured ratio of the standard and R_{true} is the accepted isotopic ratio.

This equation can be rewritten to determine the “True” measured value as Eq 2.

$$R_{\text{true}} = \alpha_{\text{SIMS}} * R_{\text{sims}} \quad [2]$$

However, uraninite can be chemically zoned at the micrometer scale and samples can have varying amounts of Pb present in their structure. Mineral standards with varying PbO content are thus used for calibration, as the amount of Pb has an effect on the mass-bias (Fayek *et al.*, 2002). Therefore, for U-Pb measurements, three mineral standards with varying amounts of PbO were used to produce a working calibration curve to correct for IMF when determining $^{206}\text{Pb}/^{238}\text{U}$ and $^{207}\text{Pb}/^{235}\text{U}$ ratios. A summary of the U-Pb isotopic composition of the three mineral standards is provided in Table 3.1. Sharpe and Fayek (2016) developed a mass bias model that accounts for this effect by applying a second order polynomial line of best fit curve Eq. 3.

$$R_{\text{true}} = a * R_{\text{sims}}^2 + b * R_{\text{sims}} \quad [3]$$

Where R_{sims} is the measured U-Pb ratio and a and b are coefficients used from the calibration curve, and the y-intercept is 0. Samples that were least altered were considered and their U-Pb isotopic ratios were corrected using Eq.3 and plotted on concordia diagrams using the program ISOPLOT 4.15 (Ludwig, 1993).

Table 3.1. U-Pb isotopic and Pb composition of Uraninite standards (from Sharpe and Fayek, 2016).

	LAMNH ^a	Error(%)	TKK ^b	Error(%)	PC-06 ^c	Error(%)
PbO (wt. %)	4.700	≤0.1	12.7	≤0.10	20.7	≤0.10
²⁰⁷ Pb/ ²³⁵ U	0.411	1.00	1.721	0.86	8.359	0.25
²⁰⁶ Pb/ ²³⁸ U	0.055	1.00	0.170	0.72	0.361	0.25

aPb content and U-Pb ratios (Evins et al. 2001)

bPb content and U-Pb ratios from EMP and TIMS, respectively (Sharpe and Fayek, 2016)

cPb content from Sharpe and Fayek (2011) U-Pb ratios (Camacho *et al*, 2014)

Lead isotope ratios (²⁰⁷Pb/²⁰⁶Pb) were measured in uraninite and galena to calculate Pb-Pb ages using the equation:

$$^{207}\text{Pb}/^{206}\text{Pb} = ^{235}\text{U}/^{238}\text{U} * e^{\lambda_2 t} - 1 / e^{\lambda_1 t} - 1 \quad [4]$$

Where ²⁰⁷Pb/²⁰⁶Pb is the corrected ratio measured by SIMS, ²³⁵U/²³⁸U is 1/137.88, λ₂ and λ₁ are the decay constants for ²³⁵U (9.8485E-10y⁻¹) and ²³⁸U (1.55125E-10y⁻¹) respectively and t is the time in years (Nier, 1941).

All ²⁰⁷Pb/²⁰⁶Pb ratios and ages for uraninite are provided in Appendix D.

3.5.2 ⁴⁰Ar/³⁹Ar Analysis

Three samples within the alteration halo proximal (END-10-03-40 and END-10-340) and distal (END-10-02A-263.2) to the uranium mineralization within the End deposit contained muscovite that was dated using ⁴⁰Ar/³⁹Ar geochronology. Data for each sample is provided in Appendix E.

Samples were analyzed using a multi-collector Thermo Fisher Scientific ARGUS VI mass spectrometer at the University of Manitoba. Prior to analysis, all of the samples were irradiated in the Cadmium-lined, in-core CLICIT facility of the Oregon State University TRIGA reactor for 70 hours using the Hb3gr amphibole standard (1073 Ma; Jourdan *et al.*, 2006). The mass spectrometer is linked to a stainless steel Thermo Fisher Scientific extraction/purification line and a Photon Machines (55 W) Fusions 10.6 CO₂ laser. Argon isotopes (from mass 40 to 37)

were measured using Faraday detectors with low noise $1 \times 10^{12} \Omega$ resistors and mass 36 was measured using a compact discrete dynode (CDD) detector. The sensitivity for argon measurements is $\sim 6.312 \times 10^{17}$ moles/fA as determined from measured aliquots of Fish Canyon Sanidine (Dazé *et al.*, 2003; Kuiper *et al.*, 2008).

Standards and unknowns were placed in 2 mm deep wells in 18 mm diameter aluminium disks, with the standards placed so that the lateral neutron flux gradients across the disk could be evaluated. Planar regressions were fit to the standard data, and the $^{40}\text{Ar}/^{39}\text{Ar}$ neutron influence parameter (J) was interpolated for the unknowns. Uncertainties in J are estimated at 0.1 - 0.2% (1σ), based on Monte Carlo error analysis of the planar regressions (Best *et al.*, 1995).

Mass discrimination was monitored by online analysis of air pipettes based on a power law relationship (Renne *et al.*, 2009) which gave a $D = 1.0080 \pm 0.0004$ per amu, based on 10 aliquots interspersed with the unknowns. A value of 295.5 was used for the atmospheric $^{40}\text{Ar}/^{36}\text{Ar}$ ratio (Steiger and Jaeger, 1977) for the purposes of routine measurement of mass spectrometer discrimination using air aliquots, and correction for atmospheric argon in the $^{40}\text{Ar}/^{39}\text{Ar}$ age calculation. Corrections are made for neutron-induced ^{40}Ar from potassium, ^{39}Ar and ^{36}Ar from calcium, and ^{36}Ar from chlorine (Roddick, 1983; Renne *et al.*, 1998; Renne and Norman, 2001). $^{40}\text{Ar}/^{39}\text{Ar}$ ages were calculated using ISOPLLOT 3.7 (Ludwig, 1993) on an Ar-Ar plateau diagram from samples with greater than 50%.

3.6 *Stable Isotope Methodology*

3.6.1 *Oxygen Isotope Analysis*

The oxygen isotopic ratios of uraninite, illite, quartz, and calcite were also measured using the CAMECA 7f Secondary Ion Mass Spectrometer (SIMS). A ~2nA primary beam of Cs⁺ ions was accelerated at 10kV and focused to a 15 µm spot using a 100 µm aperture in the primary column. The secondary column was set to accept -9keV and a sample offset of 300 Volts was used to reduce molecular interferences (Riciputi *et al.*,1998; Fayek *et al.*,2002). Two oxygen isotopes were measured sequentially. The most abundant isotope (¹⁶O⁻) was measured for 1 second and the lesser abundant isotope (¹⁸O⁻) was measured for 5 seconds, this constitutes 1 cycle. A total of 70 cycles was completed on each spot that lasted for ~10 minutes. Ions were detected with an ETP 133H electron multiplier with an overall dead time of 21 ns.

3.6.2 *Hydrogen Isotope Analysis*

The hydrogen isotopic ratios of hydrothermal illite were measured using the CAMECA 7f series Secondary Ion Mass Spectrometer (SIMS) using the protocol by Liu *et al.*, 2010. A ~25nA beam of O⁻ was accelerated at 12 kV and focused to a ~30 µm spot. The aperture within the primary column was set to 750 µm. The secondary column was set to accept 10Kev and a -50V sample offset was used to suppress molecular ion interferences (Liu *et al.*, 2010). The mass resolving power was set to 800. Ions were detected using an ETP 133H electron multiplier coupled with an ion-counting system with an overall dead time of 21 ns. During analysis hydrogen was measured for 1 second and deuterium was measured for 5 seconds during a cycle. Analyses lasted ~9 minutes, with each analysis comprising 60 cycles.

Oxygen and Hydrogen isotopic ratios are presented in δ -notation. The isotopic ratios within the sample are reported relative to Vienna Standard Mean Ocean Water (V-SMOW) and calculated using equation 5. The units are in per-mil(‰) and the error represents 2σ .

$$\delta^2\text{H or } \delta^{18}\text{O} = (R_{\text{sample}}/R_{\text{VSMOW}} - 1) * 1000 \quad [5]$$

Where R_{sample} is the ratio of the heavy isotope to the light isotope of the unknown and R_{VSMOW} is ratio of the heavy isotope to the light isotope of the known standard.

The true $\delta^{18}\text{O}$ value of the internal uraninite standard (synthetic UO_2) is 8.1 ‰ with a range in spot to spot reproducibility of 0.7 – 0.8 ‰. The true $\delta^{18}\text{O}$ value of the internal illite standard (MP Mica) is 10.4 ‰ with a range in spot to spot reproducibility of 0.6 – 0.7 ‰. The true $\delta^{18}\text{O}$ value of the internal quartz standard (UMQ-1) is 12.3 ‰ with a spot to spot reproducibility of 0.9 ‰ (Kelly *et al.*, 2007). The true $\delta^{18}\text{O}$ value of the internal calcite standard (Joplin Calcite) is 5.7 ‰ with a spot to spot reproducibility of 0.7 ‰ (Mahon *et al.*, 1998).

Chapter 4.0: Results

4.1 Petrography

Petrographic descriptions, using an optical microscope and SEM, were completed on 66 polished thin sections to characterize the mineralogy of the host rock, alteration, and mineralization, with the goal of developing a mineral paragenesis for the deposit (Table 4.1). A summary of the petrographic work for all of the samples are provided in Appendix A. The mineralization is hosted within the WLg Pipedream (Ppd) metagreywacke, which has experienced episodes of silicification, desilicification, mineralization and post-mineralization hematization.

4.1.1 Pipedream (Ppd) Metagreywacke

Previous workers have recently suggested the Pukiq Formation epiclastics extend to the south east (Fig. 2.4) and include the End deposit (Aand and Jefferson, 2017). Based on drill core observations and petrography the End deposit is hosted within the Ppd metagreywacke and does not contain the distinctive package of Pukiq epiclastics described by Johnstone *et al.*, (2016). The relatively unaltered Ppd metagreywacke hosting the End deposit (Fig. 4.1A) is medium-dark grey-green (Fig. 4.1.B) to light grey, fine grained and moderately to strongly foliated throughout (Fig. 4.1.D). This unit is cross-cut by granitic veinlets, intrusives and a quartz breccia (Fig. 4.1.C). The metagreywacke is primarily composed of quartz (0.1-2mm, subrounded, 40-50%), K-feldspar (0.1-2mm, subrounded, 40-60%), biotite (<0.1-0.5mm, 1-15%) and muscovite (0.1-0.5mm, 1-15%; Fig. 4.2A). Biotite and muscovite occur as tabular laths and define the primary foliation. Biotite is replaced by chlorite and feldspar is moderately to strongly altered to sericite (Fig. 4.2D). Accessory minerals include pyrite, apatite (<0.1-0.2mm, euhedral) and rutile (<0.1-

0.2mm, euhedral laths) (Fig. 4.2.B).

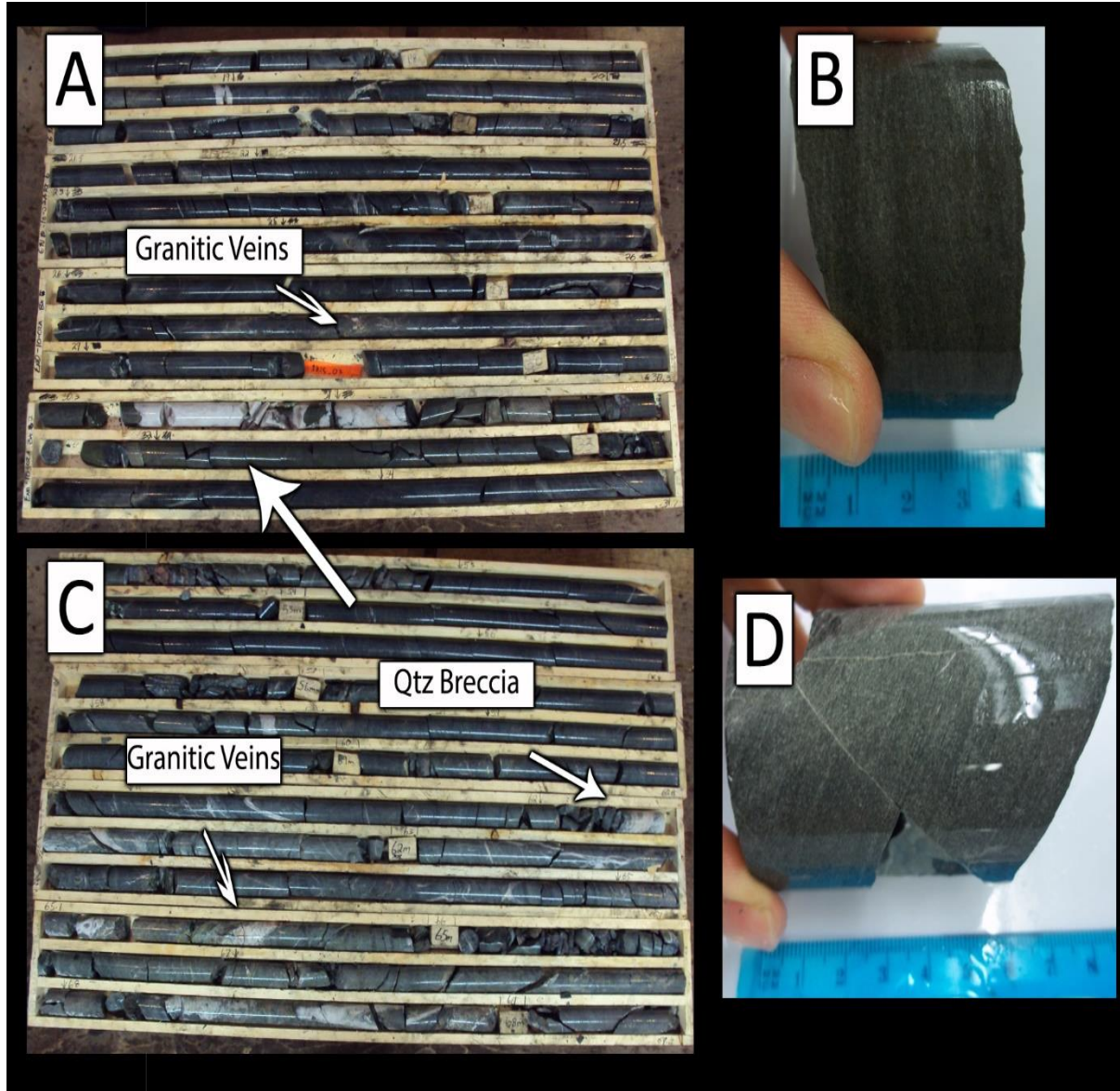


Fig. 4.1. Pipedream metagreywacke within the barren zone (END-10-02A). A. Dark grey weak to strongly foliated metagreywacke that has been cross-cut by several thin granitic veinlets to thick quartz breccia. B. Hand sample of typical fine-grained metagreywacke. C. The barren hole (END-10-02A) is also weakly to moderately altered as the rock appears off-white to light grey green in colour. D. Hand sample of weakly altered metagreywacke, the strong foliation fabric oriented $\sim 50^\circ$ to the core axis, which is typical throughout the host rock within the End deposit.

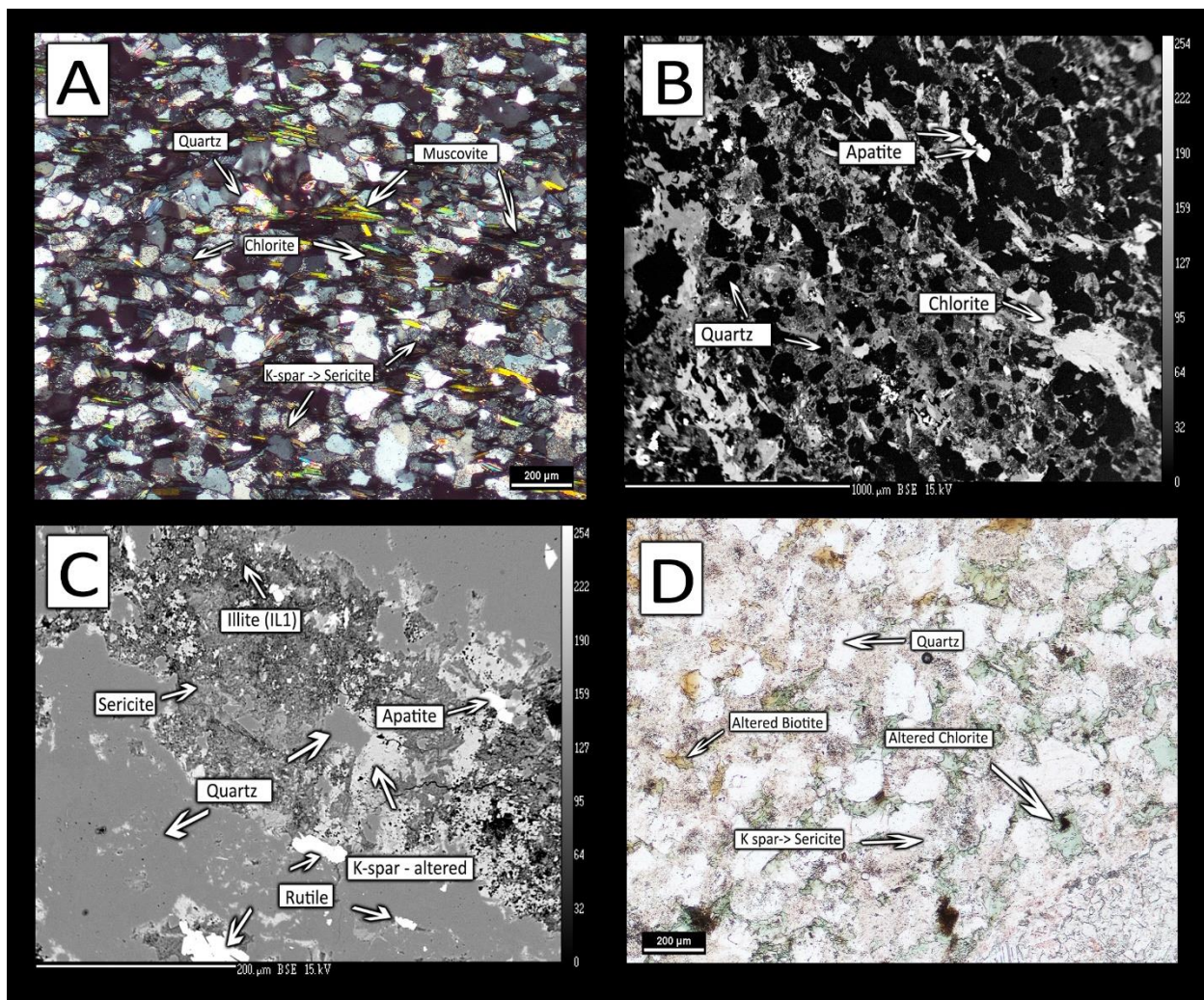


Fig. 4.2.A Moderately foliated metagreywacke, foliation is defined by muscovite and biotite (retrograded to chlorite) laths (XPL). B. BSE image of fine-grained apatite set in weak to moderately foliated unaltered metagreywacke. C. BSE image of strongly altered metagreywacke that has been cross-cut by quartz veins. Sericite has completely replaced feldspars and then proceeded by the first stage of illitization (IL1). Fine grained laths of rutile are also observed and likely a remnant accessory mineral prior to alteration. D. PPL image of strongly altered metagreywacke, in which biotite has not completely retrograded to chlorite, however grains appear semi-translucent and altered. Alkali feldspars are also moderately to strongly broken down into sericite.

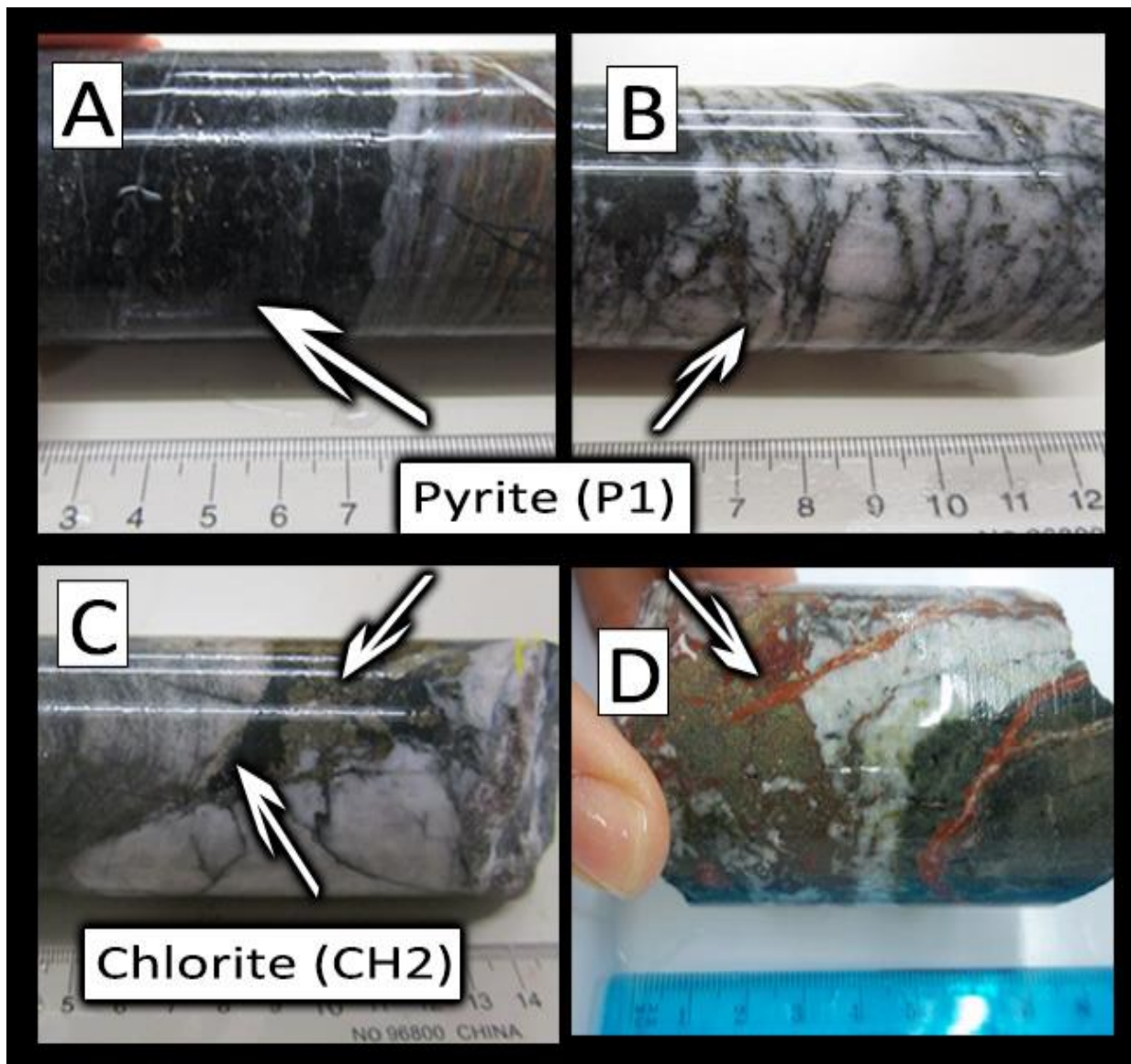


Fig. 4.3. A. Fine grained disseminated pyrite within chloritized metagreywacke B. Fine grained pyrite restricted to chlorite veins within silicified metagreywacke. C. Fine to medium grained blebby pyrite within chlorite veins associated with the quartz breccia D. Coarse (1-3cm) pyrite masses within the quartz breccia and appear to be crosscut by, or closely related in space to a late stage hematization event.

Table 4.1. Mineral paragenesis of the End deposit, Thelon Basin, Nunavut, Canada.

Host Rock	Pipedream– Metagreywacke	Regional Metamorphism	Retrograde Metamorphism	Pre-Mineralization	Syn – Mineralization Stage 1 (Disseminated)	Syn - Mineralization Stage 2 (Vein-type)	Syn – Mineralization: Remobilization Stage 3a (Foliation-parallel)	Syn - Mineralization: Remobilization Stage 3b (Infill-type)	Syn - Mineralization: Remobilization Stage 3c (Roll Front)	Post Mineralization – Stage 4
Quartz	_____ (Q1)	_____ (Q2)		_____ (Q3ab - Silicification)						_____ (Q4 - Euhedral)
Feldspar	_____									
K-Feldspar	_____									
Muscovite		_____								
Biotite		_____								
Chlorite			_____	_____ (CH2)						
Epidote		_____ (EP1) _____ (EP2)	_____							
Garnet		_____	_____							
Sericite			_____	_____						
Illite					_____ (IL1)	_____ (IL2)	_____ (IL3)			
Apatite	_____						_____		_____	
Rutile	_____						_____		_____	
Calcite						_____ (Cal1)?				_____ (Cal2)
Pyrite	_____			_____ (P1)						
Galena					_____	_____				
Uraninite					_____ (U1)	_____ (U2)	_____ (U3a)	_____ (U3b)	_____ (U3c)	
Ca - U									_____	
Ca - Si - U									_____	
Ca – Si – U -Ti									_____	
Coffinite							_____?			
Uranophane							_____			
Hematite						_____ (HEM1)?				_____ (HEM2)?
Specular Hematite						_____???				_____??

4.1.2 Lamprophyre/minette Dykes

Lamprophyre/minette dykes cross-cut the Pipedream Metagreywacke in some places and could be associated with the Martell Syenites (~1.83 Ga) (Peterson, 2006; Scott *et al.*, 2015). The dykes are narrow (~2-3 m thick), weak to moderately hematized (Fig. 4.4A) and composed of euhedral biotite phenocrysts (10%, 1-2 mm) (Fig. 4.4A). These phenocrysts are set in a strongly sericitized ground mass and are cross-cut by two generations of quartz veinlets (Fig. 4.4B). The dykes also contain fine grained (~<0.1-0.2 mm) laths of rutile and are locally cross-cut by chlorite veins (1-3mm; Fig. 4.5). The dykes to occurred outside of the mineralized zone and were subject to retrograde metamorphism (ie. biotite retrograded to chlorite and feldspars replaced by sericite) (Fig. 4.4B).

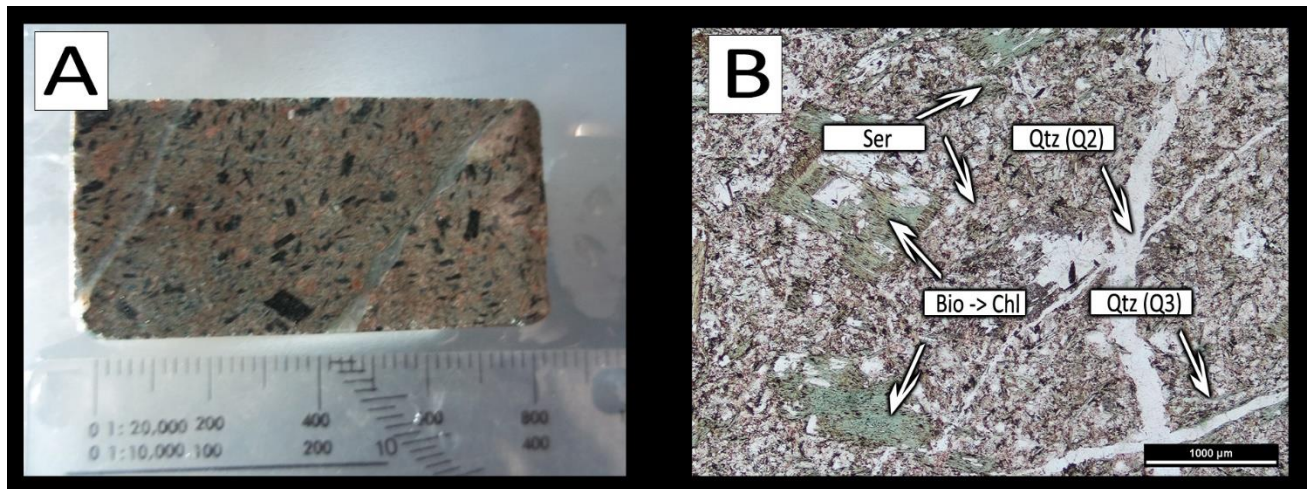


Fig. 4.4. A) Hand specimen of a weakly hematized lamprophyre. B. PP image of lamprophyre, biotite is altered to chlorite and the groundmass is completely replaced by sericite.

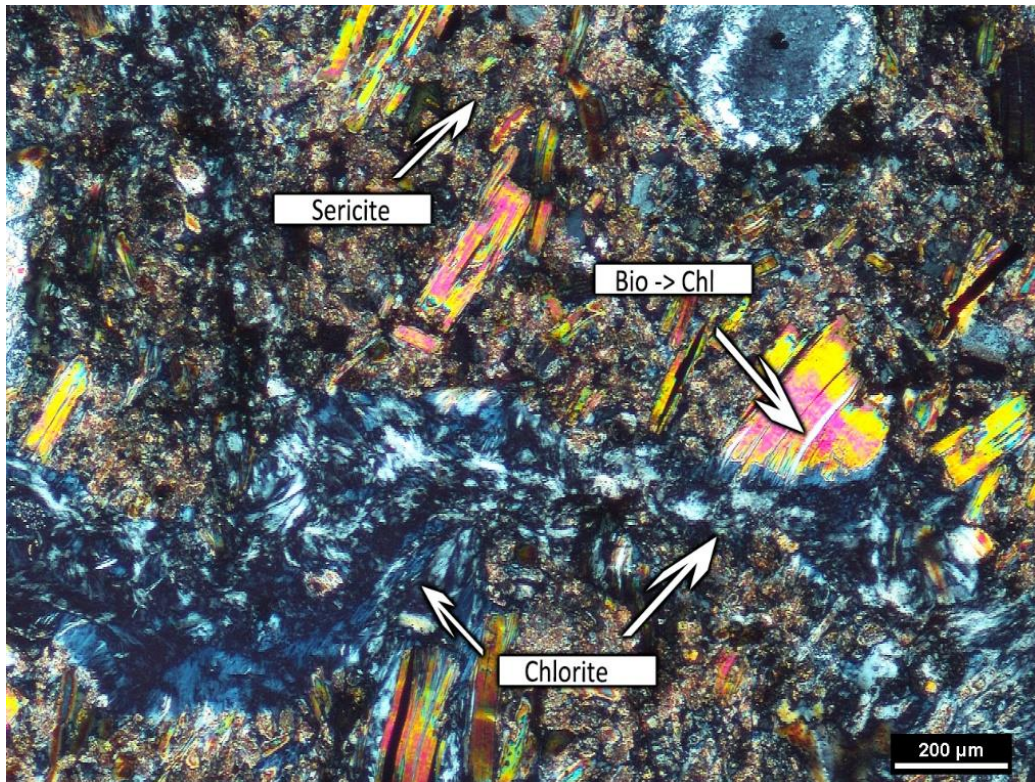


Fig. 4.5. Cross polarized (XPL) image of lamprophyre, here biotite has been completely replaced by chlorite and the groundmass has been replaced by sericite. The unit is cross-cut by a thin <0.5mm chlorite veinlet.

4.1.3 Quartz-feldspar porphyritic granite (QFP) Dykes (Nueltn granite)

Locally, the Ppd metagreywacke is cross-cut by (~2-15 m thick) quartz-feldspar porphyritic (QFP) dykes known as part of the Nueltn granites (Donaldson, 1965; Peterson, 2006) (Fig. 4.6A). These dykes are hematized and are composed of abundant euhedral feldspar phenocrysts (7%, 1-2 mm), euhedral chlorite (pseudomorph of biotite) (10%, 0.2-1 mm), pyrite (5%, <0.1 mm) set within a feldspar, quartz rich ground mass (60%, <0.1mm) that has been moderately to strongly sericitized (Fig. 4.6B, 4.6C).

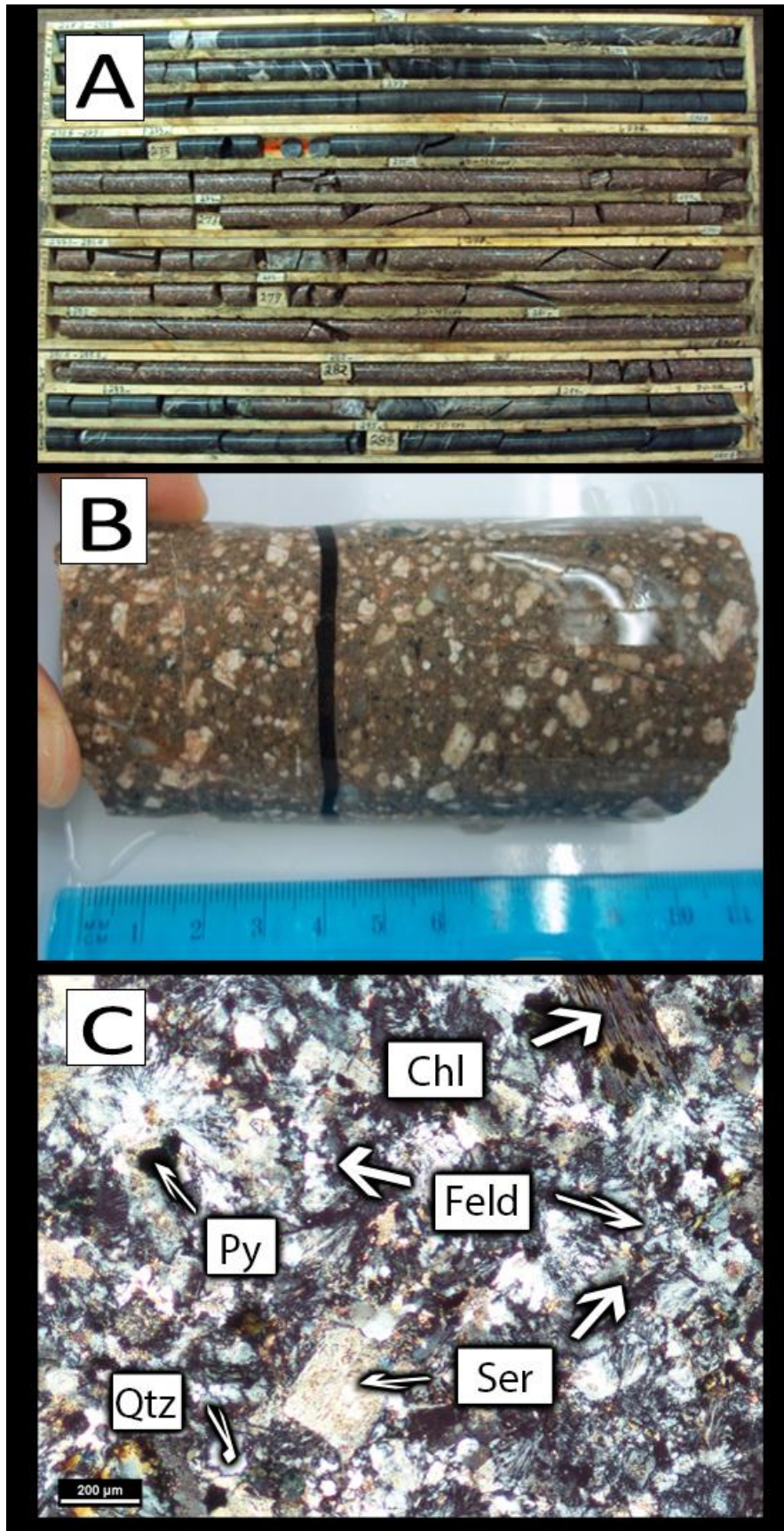


Fig. 4.6 A. Thick (~8m) dyke of Nueltin granite cross-cutting chloritized metagreywacke B. The Nueltin granite is identified in the field and in core by its abundant coarse-grained feldspar phenocrysts C. An XPL photomicrograph of the Nueltin granite, feldspar has been completely replaced by sericite and biotite grains have been altered to chlorite.

4.1.4 Granitic veins

The metagreywacke within the End deposit are cross-cut by thin (~1-2cm) granitic veinlets (Fig. 4.1A & 4.1B; Fig. 4.7A). These veinlets are composed of fine grained (0.5mm) k-feldspar, muscovite, quartz and minor chlorite (Fig. 4.7B). Some veins can contain disseminated euhedral pyrite cubes (0.1-0.5mm) that are commonly associated with late cross-cutting chlorite veins. Based on petrography these granitic veinlets could be related to the quartz feldspar porphyritic granites (QFP). The granitic veinlets were only observed within barren or non-mineralized Ppd.

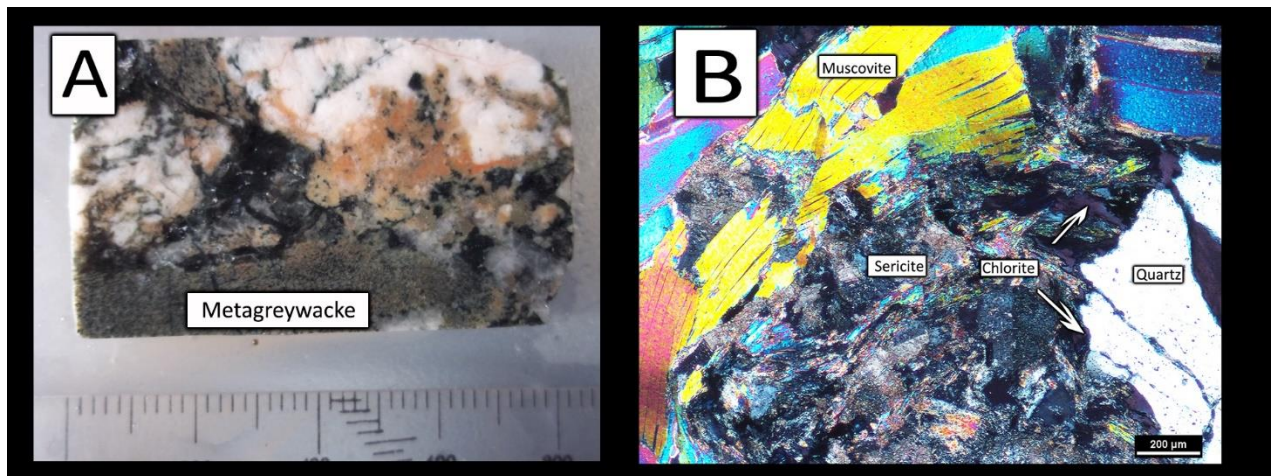


Fig. 4.7 A. photomicrograph of a 2cm granitic veinlet cross-cutting the metagreywacke. B. XPL image of a granitic veinlet containing coarse grained muscovite, quartz and k-feldspar, set in a strongly sericitized metagreywacke.

4.1.5 Pre-mineralization: Metamorphism

Prior to deposition of the Quartz breccias the Ppd at the End deposit was subject to greenschist to lower amphibolite facies metamorphism. This is evident by the presence of metamorphic garnet (Fig. 4.6), biotite (Fig. 4.2 A,B,C), muscovite (Fig. 4.2A), and epidote (Fig. 4.8 A,B). Biotite and muscovite are most prominent in distal areas to the alteration halo and

occurs as euhedral laths parallel to the foliation (Fig. 4.2A). These minerals likely formed during peak metamorphism. Locally there are garnet (0.1-3 mm, 1%) and epidote porphyroblasts (0.1-0.5mm, ~1-2%) and veinlets (~1mm in thickness, 1-2%; Fig. 4.8A & Fig. 4.8B, respectively). There appears to be two generations of epidote veining (EP1 and Ep2; Fig. 4.8B). Ep2 veining appears to have been later infilled by calcite (Cal2). The basement rocks are interpreted to have been subject to retrograde metamorphism (common throughout the Kiggavik area) as evident by the replacement of biotite by chlorite (Fig. 4.2D; Fig. 4.5), feldspars partially to completely replaced, by sericite (Fig. 4.2C,DA).

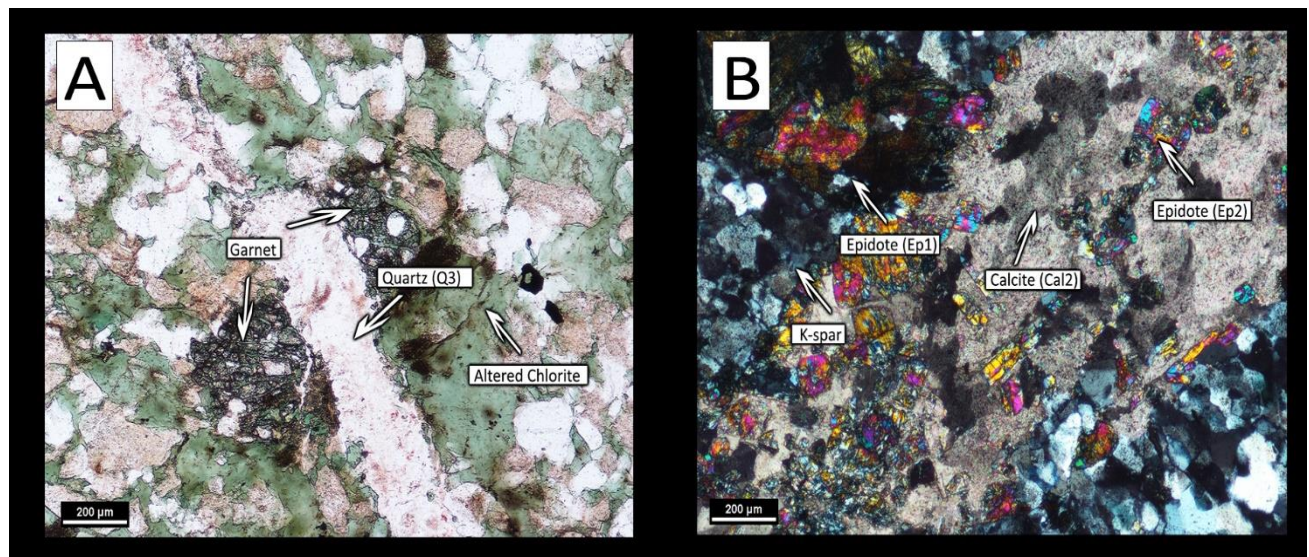


Fig. 4.8 A. PPL photomicrograph of garnet porphyroblasts within the Ppd metagreywacke, here chlorite has been completely altered. Garnet has been cross-cut by quartz veinlets (Q3). B. A XPL photomicrograph of the two stages of epidote veining, here the second generation of epidote (EP2) is also associated with a second generation of calcite (Cal2).

4.1.6 Pre-Mineralization: Alteration

Proximal to uranium mineralization the Ppd metagreywacke at the End deposit displays varying degrees of silicification and pyritization that took place prior to uranium mineralization. The Ppd Metagreywacke was subject to a significant silicification event which led to the

widespread precipitation of the Quartz breccia's (Q3ab). The thickness of these breccia intervals range from 10 cm to over several meters (Fig. 4.9A) and cross-cut non-hematized Ppd metagreywacke (Fig. 4.9B) or hematized metagreywacke (Fig. 4.9C). These zones consist of subangular to angular fragments of the WLg from 0.5 cm-5 cm in diameter and fragments of the Ppd can be cemented by a clay-rich matrix (Fig. 4.9D). The breccias are also observed within the alteration halo and mineralized zone of the End deposit. Fragments can be weakly to moderately altered to clay (Fig. 4.9C). The quartz breccias within the End deposit can contain centimetre scale vugs that are infilled with 2-5mm, drusy euhedral quartz crystals (Q4) (Fig. 4.9C). Quartz crystals (Q3) observed within the non-hematized Ppd (Q3a) and hematized Ppd(Q3b) (Fig. 4.3C, 4.3D, respectively) are subhedral to euhedral and are 1000 and 2000 μ m, respectively. These coarse microcrystalline grains appear similar to the microcrystalline grains (referred to as brown-blue luminescent in cathodoluminescence) observed by Grare *et al.*, (2018b). This final silica precipitation phase was also observed in the Bong deposit (Sharpe *et al.*, 2015). Fe-Mg chlorite $\pm$ titanium oxides $\pm$ hematite spherules $\pm$ minute crystals of barite have also been identified within the secondary porosity in the End Deposit (Riegler *et al.*, 2014).

Pyrite occurs as 0.1-0.5 mm subhedral to euhedral disseminated grains (<1% and 2%) throughout barren and weakly to unaltered Ppd (Fig. 4.3A). Locally there are large patches that are several centimetres in size within silicified metagreywacke, (Fig. 4.3B) chlorite-rich veins (Fig. 4.3C) and quartz veins (>10%; Fig. 4.3D).

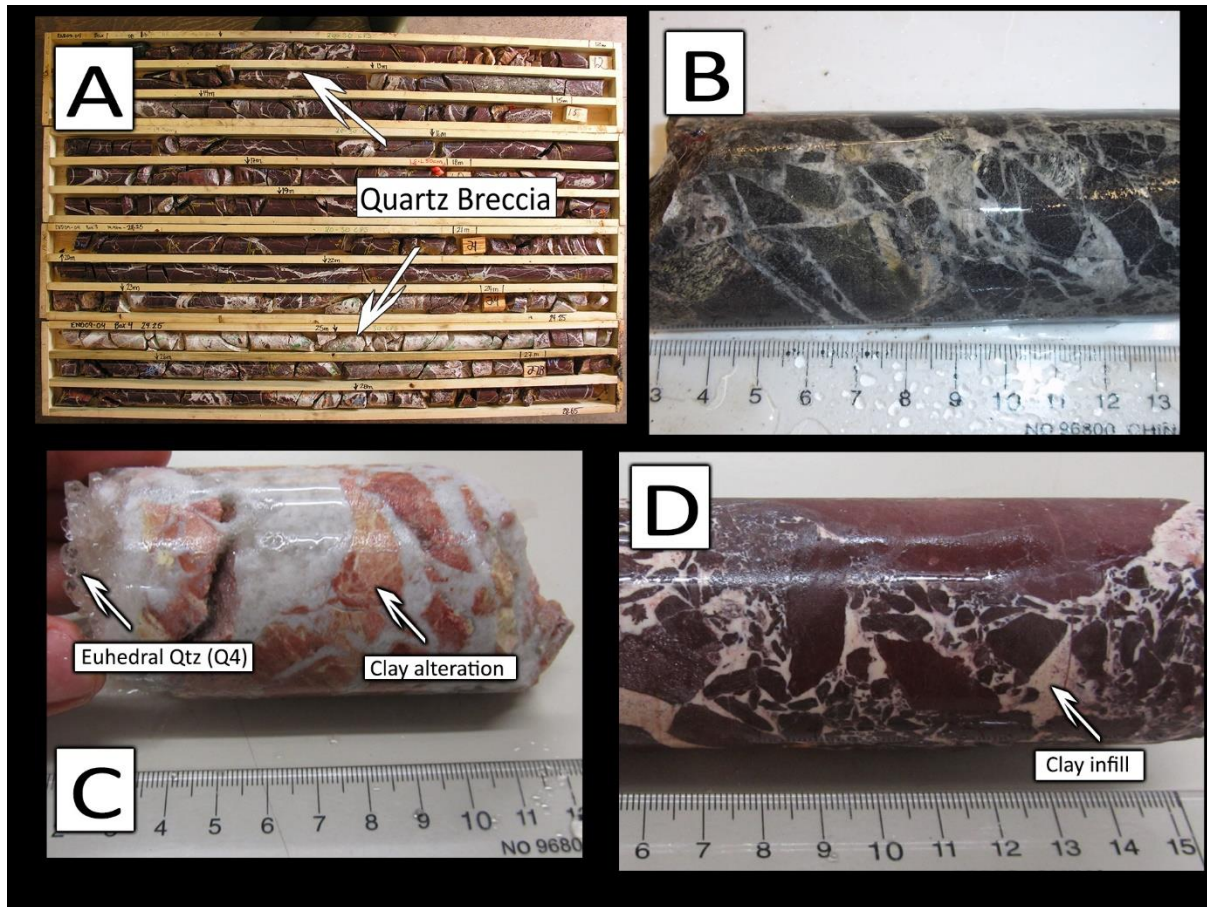


Fig. 4.9 A. Quartz brecciation throughout strongly hematized metagreywacke, quartz veining can range from <10cm in thickness to up to several meters. B. “Fresh” chloritized quartz brecciated metagreywacke taken from a barren zone. C. Some fragments within the quartz breccia have been weakly clay altered. Vugs in some places have been infilled with euohedral quartz (Q4). D. Breccia with clay-dominated matrix.

4.1.7 *Syn-Mineralization: Uranium Mineralization*

Based on petrography, major element chemistry and geochronology, there are three styles of uranium mineralization. The first style (U1) disseminated uraninite (Fig. 4.10). is then cross-cut by of fracturing and faulting that was infilled by uraninite (U2) (Fig. 4.11). The third generation are more characteristic of remobilization textures; the first style occurs as sub styles; foliation-parallel (U3a) (Fig. 4.12), infill-type (U3b) (Fig. 4.13) and roll-front style (U3c) (Fig. 4.14). Based on petrography and low PbO (Section 4.2.3 – Uraninite Chemistry) content of these stages, the third stage likely represents a later remobilization event.

4.1.7.1 *Syn- Mineralization: Disseminated Uraninite (U1)*

The disseminated style of uraninite occurs as very fine grained (<0.1-0.2 mm) anhedral grains and as blebs (~1-2 mm) confined to the primary foliation and hosted within a strongly bleached (Fig. 4.10A), illitized Ppd (Fig. 4.10B) that is occasionally stained by hematite (Fig. 4.10B.). Uraninite grains also tend to occur along quartz grain margins (Fig. 4.10C). This style of mineralization is typically associated with very fine grained (~0.1 mm) euhedral-anhedral, galena grains (Fig. 4.10C). Very fine grained illite (Il1) is throughout the groundmass, suggesting intense alteration and the complete replacement of feldspars (Fig. 4.10C,D).

Bleaching and illite-dominate alteration are proximal to mineralization (Fig. 4.10A) and are a common diagnostic of argillization observed in Athabasca and Kiggavik deposits (Hoeve and Quirt, 1984, 1987; Riegler *et al.*, 2014; Sharpe *et al.*, 2015; Shabaga *et al.*, 2017). Bleaching occurs during the breakdown of ferro-magnesian minerals (e.g. biotite, Fe-Mg chlorite, feldspars) within the host rock and produce as white-beige to cream discolouration (Fig. 4.10A).

Argillization is the process where muscovite, chlorite, amphiboles and feldspars are partially to completely replaced by illite and sericite (Fig. 4.2D).

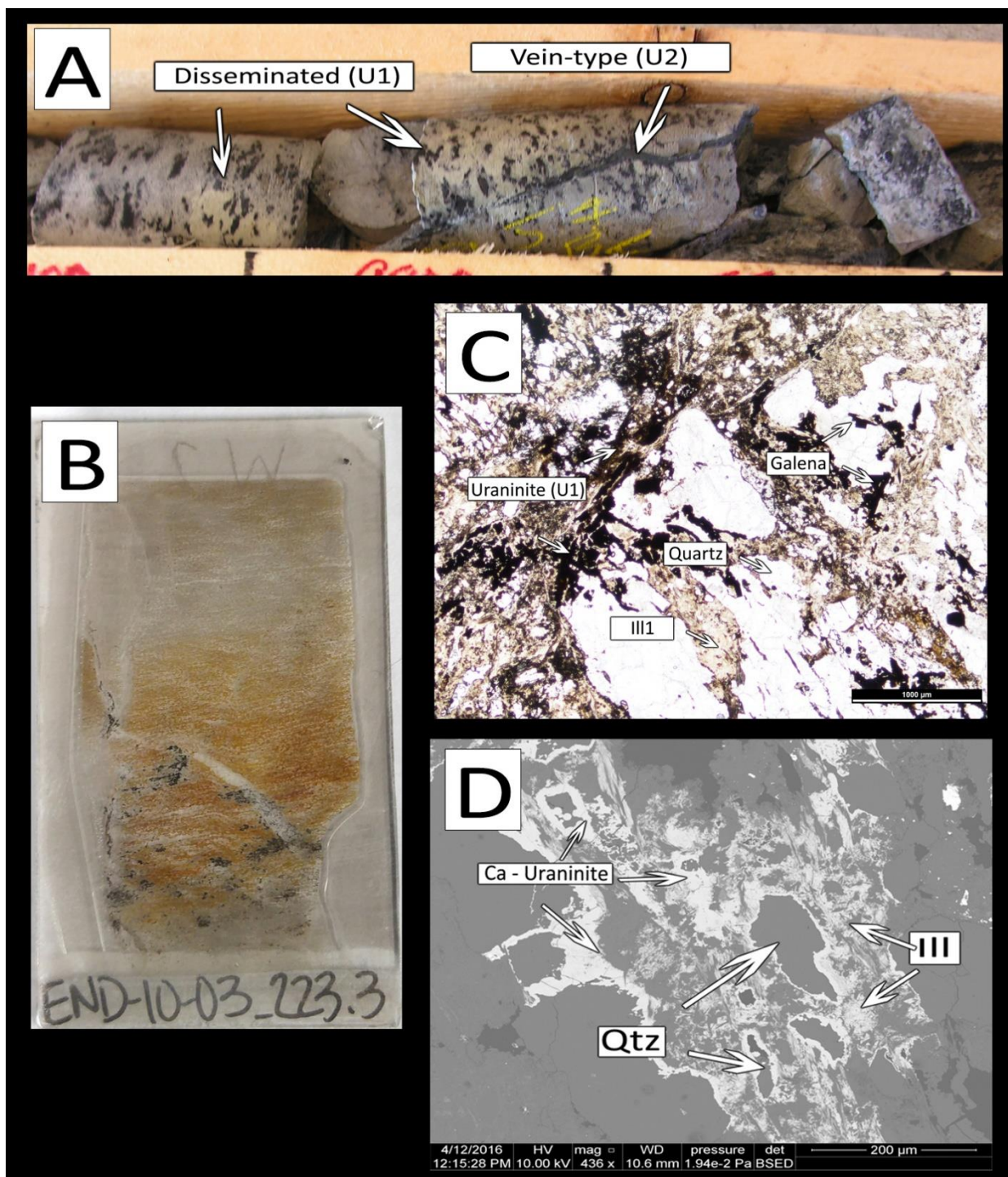


Fig. 4.10. A Disseminated uraninite (U1) set within strongly bleached metagreywacke and cross-cut by vein-type uraninite (U2). B. Thin section of hematite stained disseminated uraninite C. Plane polarized image of disseminated uraninite along quartz grains with trace fine grained galena. D. BSE image of a "bleb" of uraninite, here uraninite is altered and contains fine grained illite.

4.1.7.2 *Syn-Mineralization: Vein-type Uraninite (U2)*

The second style of mineralization is characterized by 1-2 mm thick veinlets of uraninite that consist of a moderately to strongly, illitized alteration halos extending several centimeters to tens of centimeters (Figs. 4.10 A and 4.11 A). These narrow veinlets cross-cut but also can be sub-parallel to the primary foliation (Fig. 4.11A). U2 uraninite is typically fine grained (0.2-0.5mm), subhedral to euhedral, and can be associated with fine-grained (0.1-0.2mm) anhedral galena, fine-grained anhedral illite (IL2) and subhedral calcite (Cal2) (Fig. 4.11 C&D). Bleached, argillized halos surround these veins and can also be rimmed by a weak ochre hematization (HEM1) (Fig. 4.11B; Fig. 4.15A). These halos can be intensely argillized and desilicified as relict feldspar and quartz grains have been completely removed. U2 is also cross-cut by younger quartz veinlets (<1mm) (Fig. 4.11D).

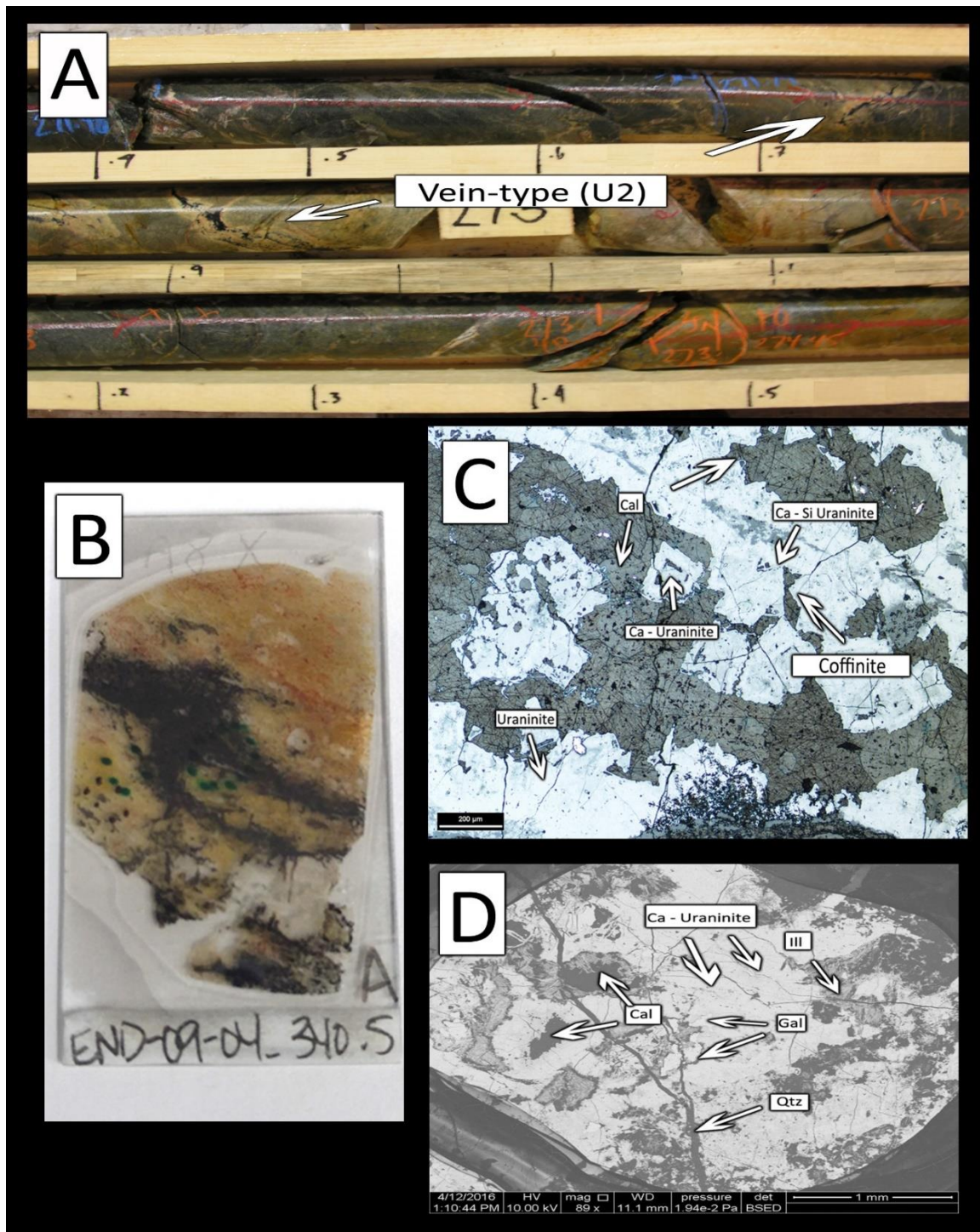


Fig. 4.11.A. Vein-type uraninite cross-cutting weakly clay-altered metagreywacke, and in some places veinlets have a halo of intense clay alteration. B. Thin section of vein-type uraninite in a strongly bleached clay altered halo with a weak hematite overprint. C. Reflected light image of vein type uraninite, consisting of euhedral to subhedral grains and later infilled with calcite. D. Back scattered electron image of altered uraninite, similar to the disseminated type, this style of uraninite contains fine grained illite.

4.1.8 *Syn-Mineralization: Uranium Remobilization*

4.1.8.1 *Foliation-parallel Uraninite (U3a)*

Foliation-parallel uraninite occurs as very fine grained (0.1-0.25mm) anhedral grains along the primary foliation (Fig. 4.12 A,B). Light orange and brick red hematization (HEM1) overprints the bleached clay halo rimming the mineralization (Fig. 4.12 A&B). Although macroscopically the alteration appears intense (strongly bleached) primary muscovite is still present in some places and can be replaced by illite (Il3) (Fig. 4.12C). Fine subhedral-euhedral grains of apatite (0.05-0.1mm) and rutile (0.05-0.1mm) are rare throughout this style of mineralization and are typically associated with weakly illite replaced muscovite along the primary foliation (Fig. 4.12 C). Uraninite grains are also altered to uranophane (0.1mm) and coffinite (<0.05mm), these secondary uraninite minerals occur as rims around quartz and feldspar grains but also serves as an outer rim to earlier stages of U3a (Fig. 4.12 D).

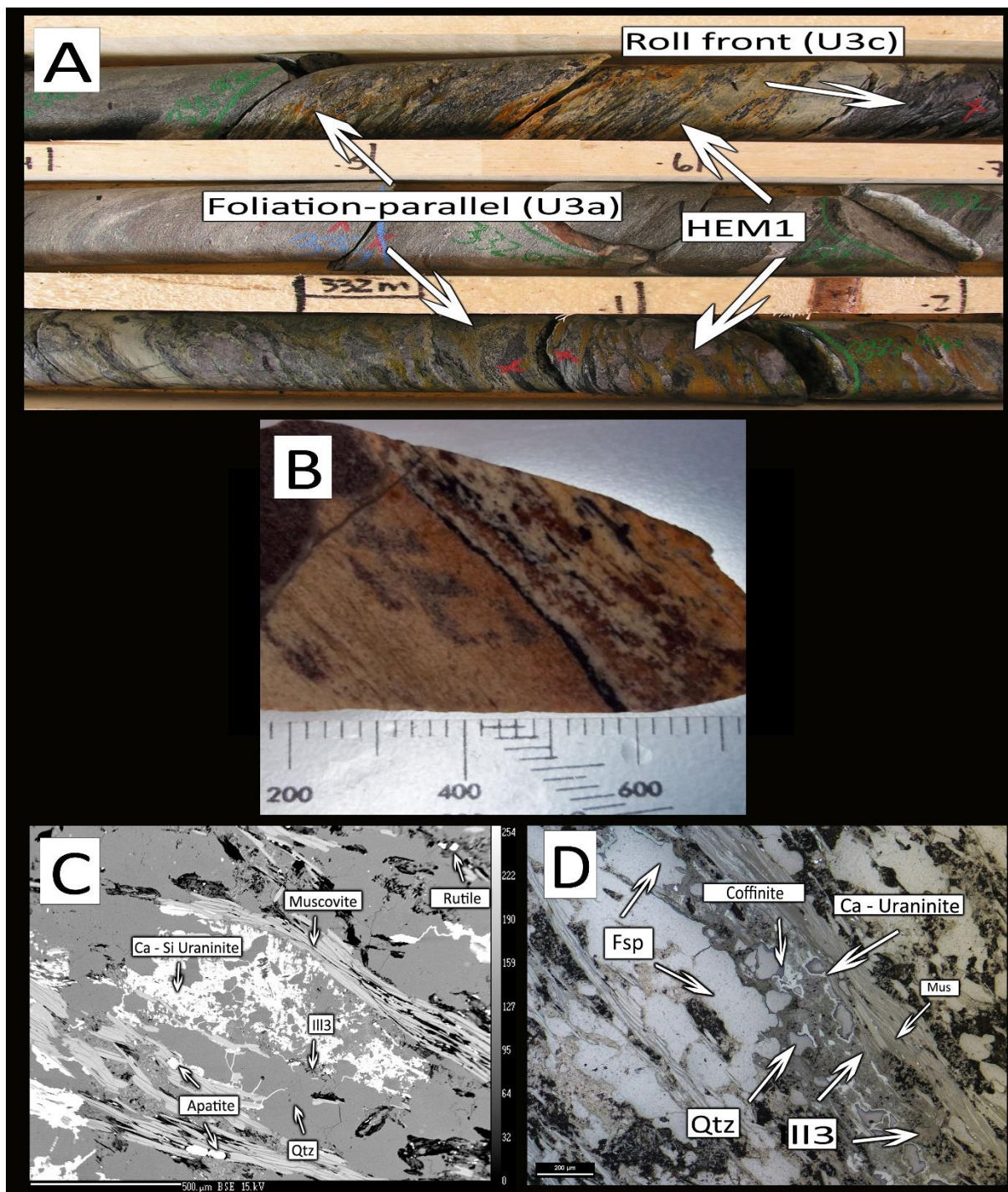


Fig. 4.12 A. Foliation-parallel mineralization can occur over 10s of cm within the strongly foliated Ppd metagreywacke as thin 1mm thick "veins" (B). Back scattered electron image of foliation parallel uraninite, typically associated with muscovite and fine grained illite and in some places trace rutile and apatite. D. Coffinite is present and typically forms along quartz grains parallel to the foliation.

4.1.8.2 Infill –type Uraninite (U3b)

Stage U3b uraninite is defined as “infill-type” mineralization that formed along the margins, to infilling pre-existing microfractures of quartz veinlets and are hosted by strongly bleached and argillized metagreywacke (Fig. 4.13 A). The “infill-type” uraninite is similar to the “leaky” uraninite described by Chi *et al.*, (2014). This style of mineralization can be overprinted by dark brick red hematite (HEM2) (Fig. 4.13 B&D). Quartz veins that contain U3b also developed along pre-existing fractures that appear to have been replaced by very fine grained illite (Il3) that may be coeval with U3 mineralization (Fig. 4.13E). Uraninite grains along the margins of fractures formed within the quartz veinlets are anhedral and very fine grained (<0.1mm) (Fig. 4.13 D&E).

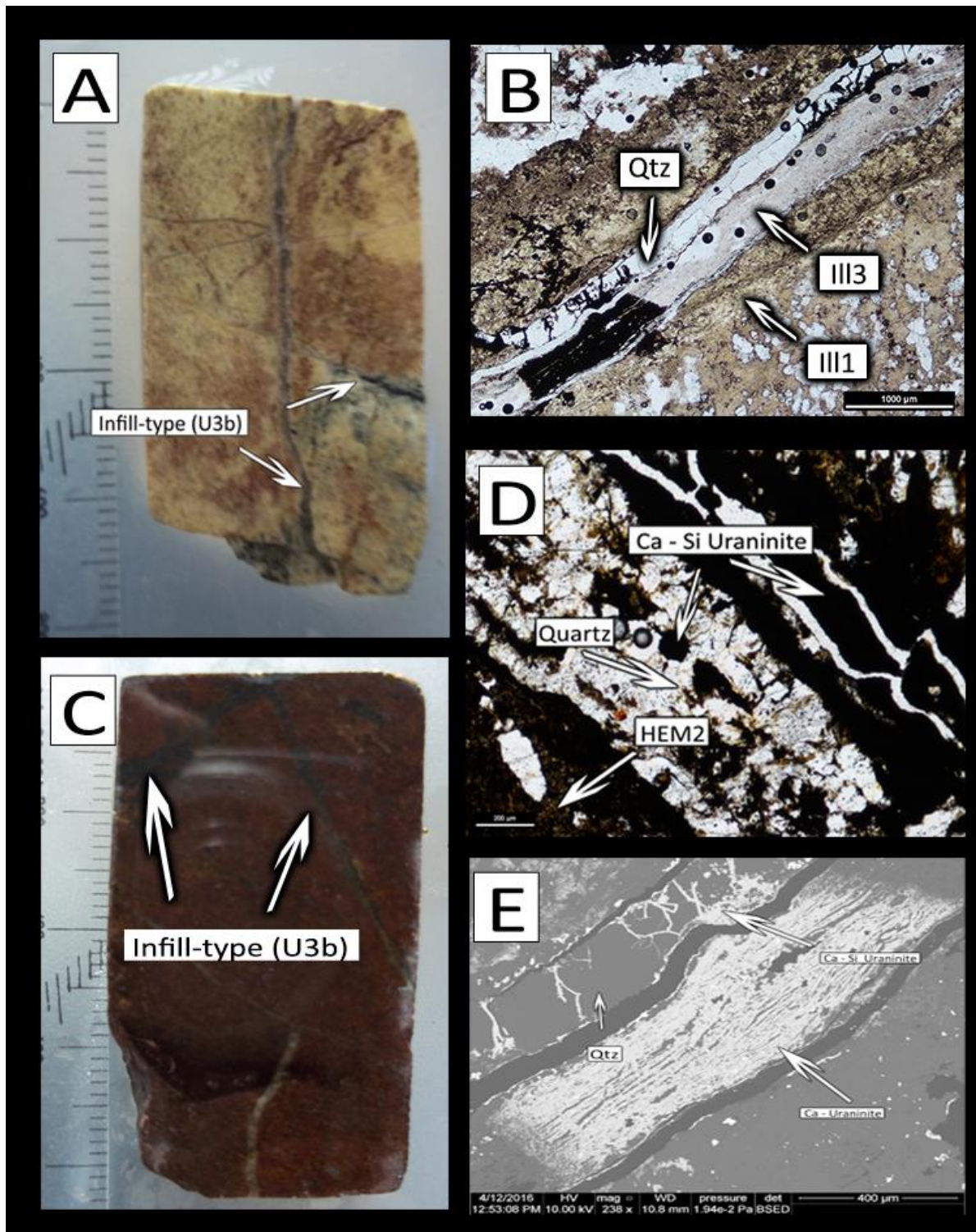


Fig. 4.13. A. Infill-type uraninite is associated with thin 1-2mm thick quartz veinlets in either bleached (A) or dark brick red hematized (B) metagreywacke. C. A single generation of quartz veining containing altered uraninite along with third generation fine grained illite. D. Plane polarized image of quartz veinlet infilled with altered uraninite and overprinted by dark brick red hematite (HEM2). E. Back scattered electron image of a grain of Ca-Si uraninite infilling fractures in a quartz vein.

4.1.8.3 Roll front-type uraninite (U3c)

Roll front-type uraninite (U3c) grains are very fine grained, (<0.05mm), anhedral, and hosted within strongly bleached, clay-altered metagreywacke and are situated at between a reduced (bleached) and oxidized (hematized) zone (Fig. 4.14 A&B). Typical U roll-front mineralization consists of uraninite that forms a crescent shaped pattern in which U-bearing fluids precipitated along a redox interface. The convex, oxidized altered zone is commonly comprised of ferric oxides (e.g. hematite, goethite) while the reduced zone is comprised of ferrous minerals (e.g. pyrite, marcasite, organic matter) set in an unaltered zone (McLemore 2007; Dahlkamp 2009). The uraninite “contact” separating the oxidized and reduced zones can be described as sharp along the oxidized zone, but diffuse along the reduced side (Fig. 4.14B). Roll front-type mineralization at End displays the classic roll-front classic mineralization style, however in some places aggregates of uraninite precipitated along a irregular-shaped redox interface and consist of a reduced zone on both sides (Fig. 4.14C).

The roll front-type uraninite can also appear as coarser grained “clots” or 1-2mm in diameter aggregates of uraninite minerals (Fig. 4.14C). Accessory minerals associated with this type of mineralization include trace amounts of subhedral (<0.1mm) zircon and euhedral, (<0.1mm) apatite set within a strongly illitized (Ill3) grained ground mass (Fig. 4.14D). The roll front-type uraninite can also consists of a strongly argillized ± hematized halo (Fig. 4.15B,C).

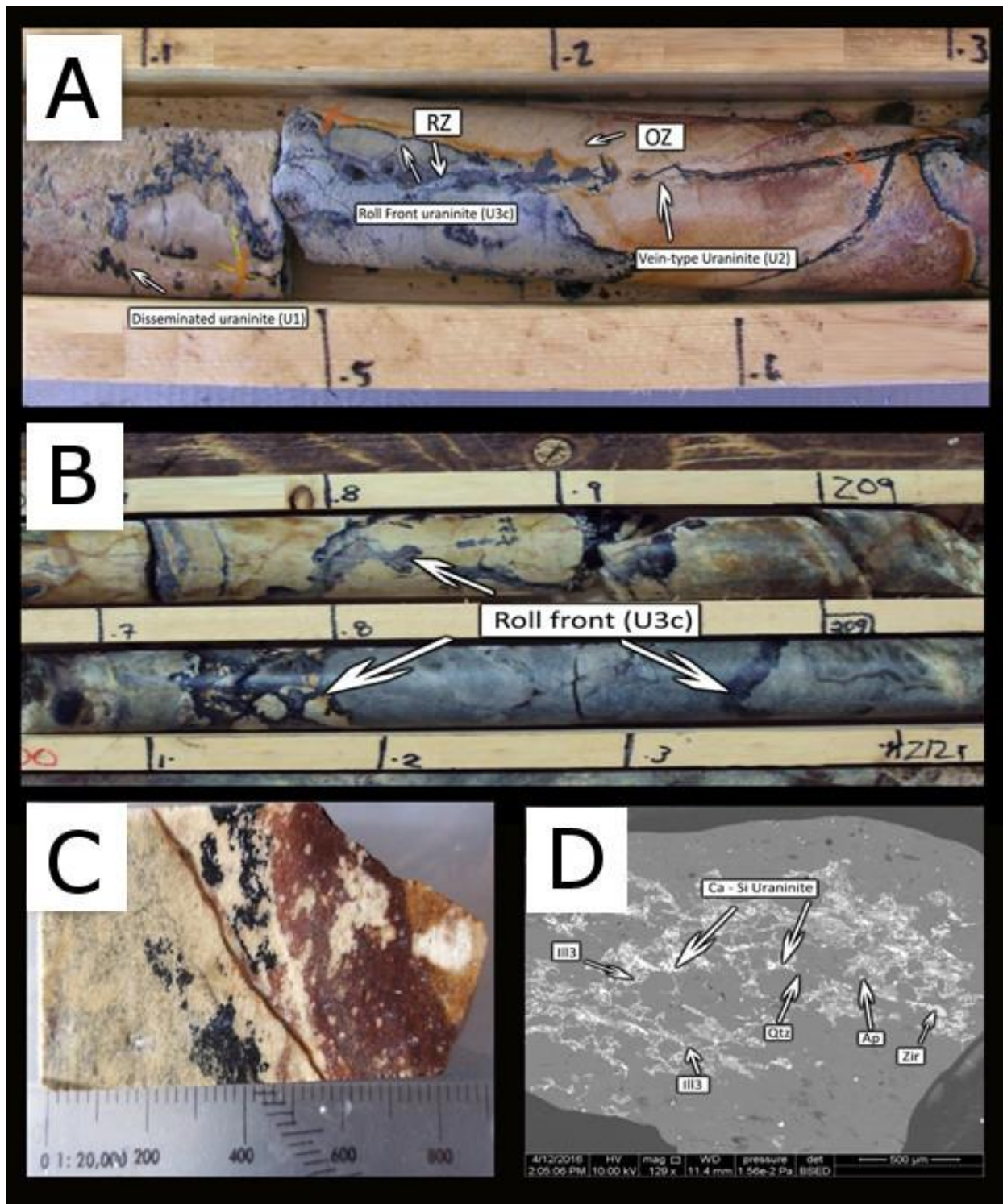


Fig. 4.14. A&B. Roll front type-uraninite is hosted within bleached clay altered metagreywacke (Reduced) and terminates at the interface with light orange to dark brick red (C) hematite (oxidized) zones. D. Back scattered electron image of altered roll front uraninite with associated fine grained illite (IL3) and trace fine grained apatite (Ap) and zircon (Zir).

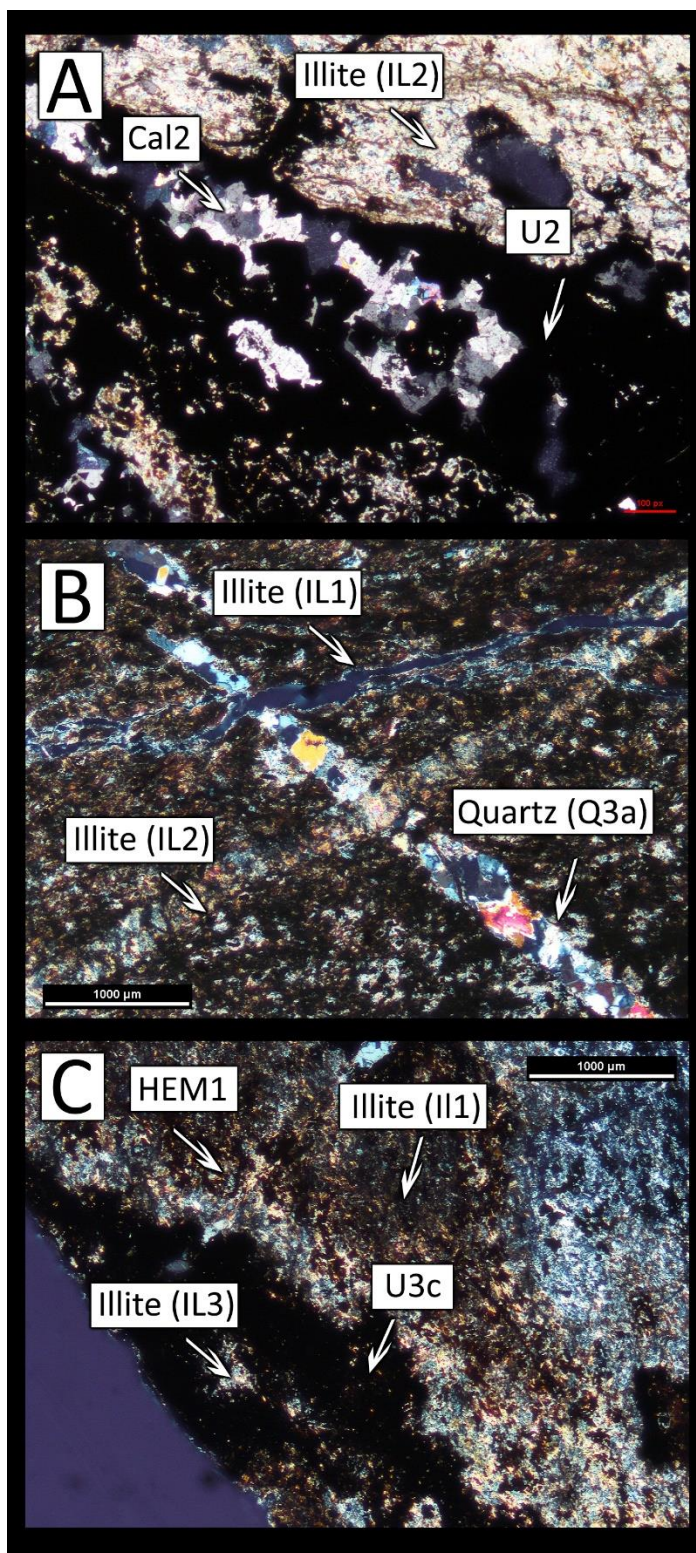


Fig. 4.15. A. Cross polarized image of strongly argillized and desilicified illitic halo (IL2) surrounding U2 ± Cal2 vein-type uraninite (END-09-04-240.5). B. Cross polarized image of argillization that overprints by later Illite veinlets (IL2) (END-10-03-209A). C. Cross polarized image of roll front-style uraninite (U3c) along an oxidized (HEM1) ± IL1 boundary. Relict quartz and feldspars have been completely replaced. (END-10-03-209B).

4.1.9 *Post-Mineralization Alteration*

The final stage in the genesis of the End deposit is the “Post-mineralization stage” alteration. This stage consists of widespread dark red to light pink hematization (Fig. 4.9A) that overprints the metagreywacke and can be spatially associated with U mineralization within the End deposit (Fig. 4.13 B; Fig. 4.14 C). The hematization extent is highly variable and ranges from 1 m to 100s of meters, is typically pervasive but it can also occur as small centimetre-scale pods to lenses. Hematite is also observed cross-cutting the quartz breccias (Fig. 4.3D). Given the complexity of fluid events and styles of hematization, it is hard to determine the relationship between the different stages of hematization.

Specular hematite is also observed within the End deposit and appears as very fine (0.1mm) grains parallel to the primary foliation (Fig. 4.16A), thick 1-2 cm veins hosted within dark hematized (HEM2) Ppd (Fig. 4.15B), and fine grains (0.1mm) along the margins of quartz veins (Fig. 4.16C). These textural styles are similar to foliation-parallel, vein-type, and infill-type uranium mineralization. The spatial and temporal relationship of specular hematite to the widespread hematization and mineralization is unknown. Flotté (2009) suggested that the origin of specular hematite may be volcanic. Dating of specular hematite by U/Th-He could help determine the relationship between specular hematite and the paragenesis of the End deposit.

A second generation of calcite (Cal2) also appears within the post-ore alteration stage of the End deposit. Calcite is quite rare throughout the End deposit and is typically located outside the mineralization. However, it does infill vein-type uraninite (U2) veins (Fig. 4.11C) and also cross-cuts the quartz breccia (Fig. 4.17).

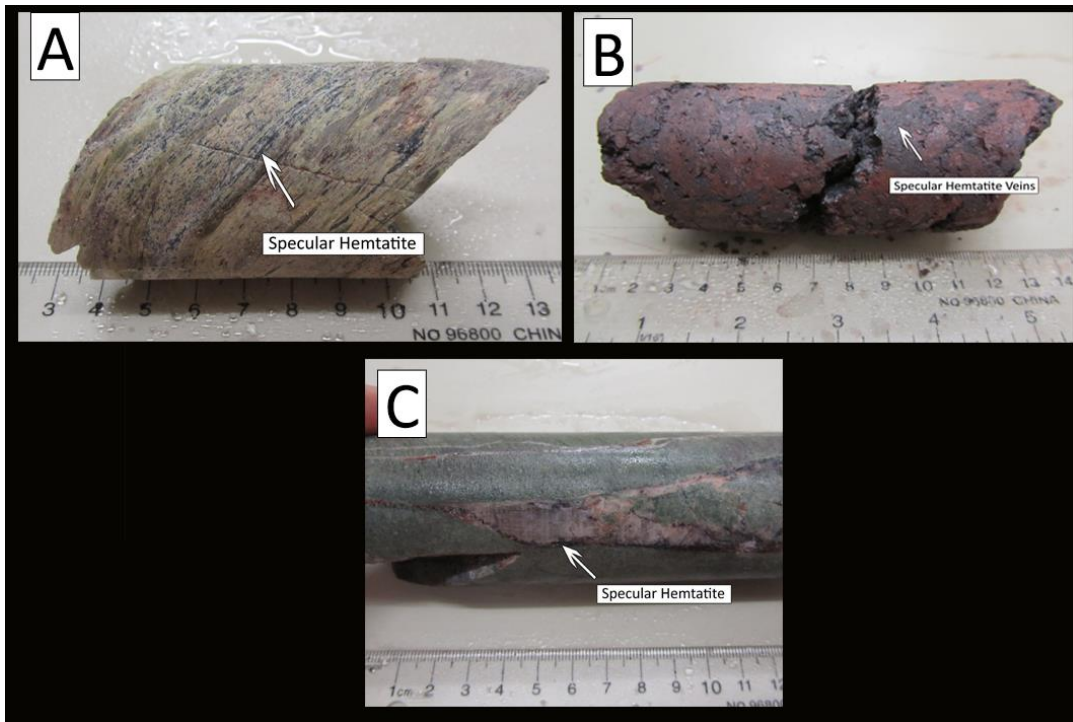


Fig. 4.16 A. Photograph of drill core from strongly foliated, clay altered metagreywacke with fine grained specular hematite formed along the dominant foliation. B. Specular hematite veins hosted within dark brick red hematite C. Fine grained specular hematite forming along the boundary between weakly altered metagreywacke and quartz veins.

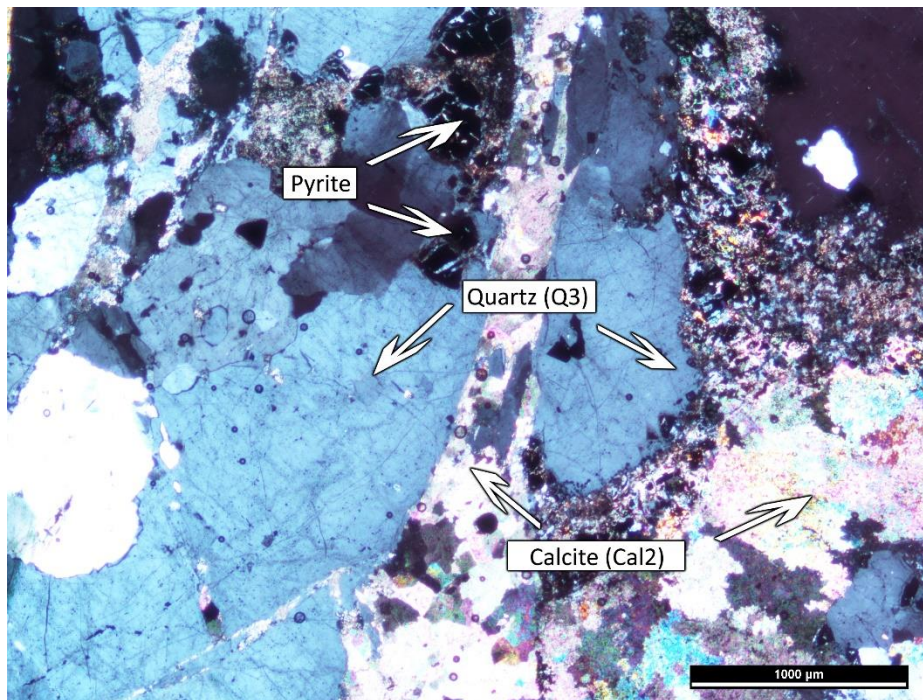


Fig. 4.17. Cross polarized image of the quartz breccia (Q3) cross-cut and infilled by calcite (Cal2).

4.1.10 Barren Ppd Metagreywacke and mineralized Ppd metagreywacke

Detailed petrographical and geochemical study was completed on a barren (END-10-02A) and mineralized drill hole (END-10-03) (Fig. 4.18) to characterize the alteration and clay mineralogy. The barren hole intersected predominately weak to strongly foliated Ppd metagreywacke (Section 4.1.1 – Pipedream Metagreywacke (Ppd)) that was cross-cut by the Nuelin Granite (Section 4.1.3 – Quartz Feldspar Porphyry (QFP) (Nuelin Granite)) and lamprophyre (Section 4.1.2 – Lamprophyre/minette). The Ppd in the barren hole appears to contain relict sericitization and retrograded chlorite from the top of the hole to the bottom (Fig. 4.2D). From the top of the hole to 90m, a dark brick red hematization (HEM2) overprints intense clay alteration within the mineralized hole. Uranium mineralization occurs from 196m to 273m and is predominately roll-front (U3c) with foliation-type (U3c), infill-type (U3b) and vein-type (U2) uraninite. Disseminated uraninite (U1) is rare but occurs at 222.3m (Section 4.1.7 – Disseminated Uraninite). Uraninite mineralization is haloed by intense illite alteration that typically is overprinted by weak ochre (HEM1) hematization. This alteration halo is ~ 100m thick on either side of the mineralized zone. The hole terminates in weakly to unaltered strongly foliated Ppd metagreywacke.

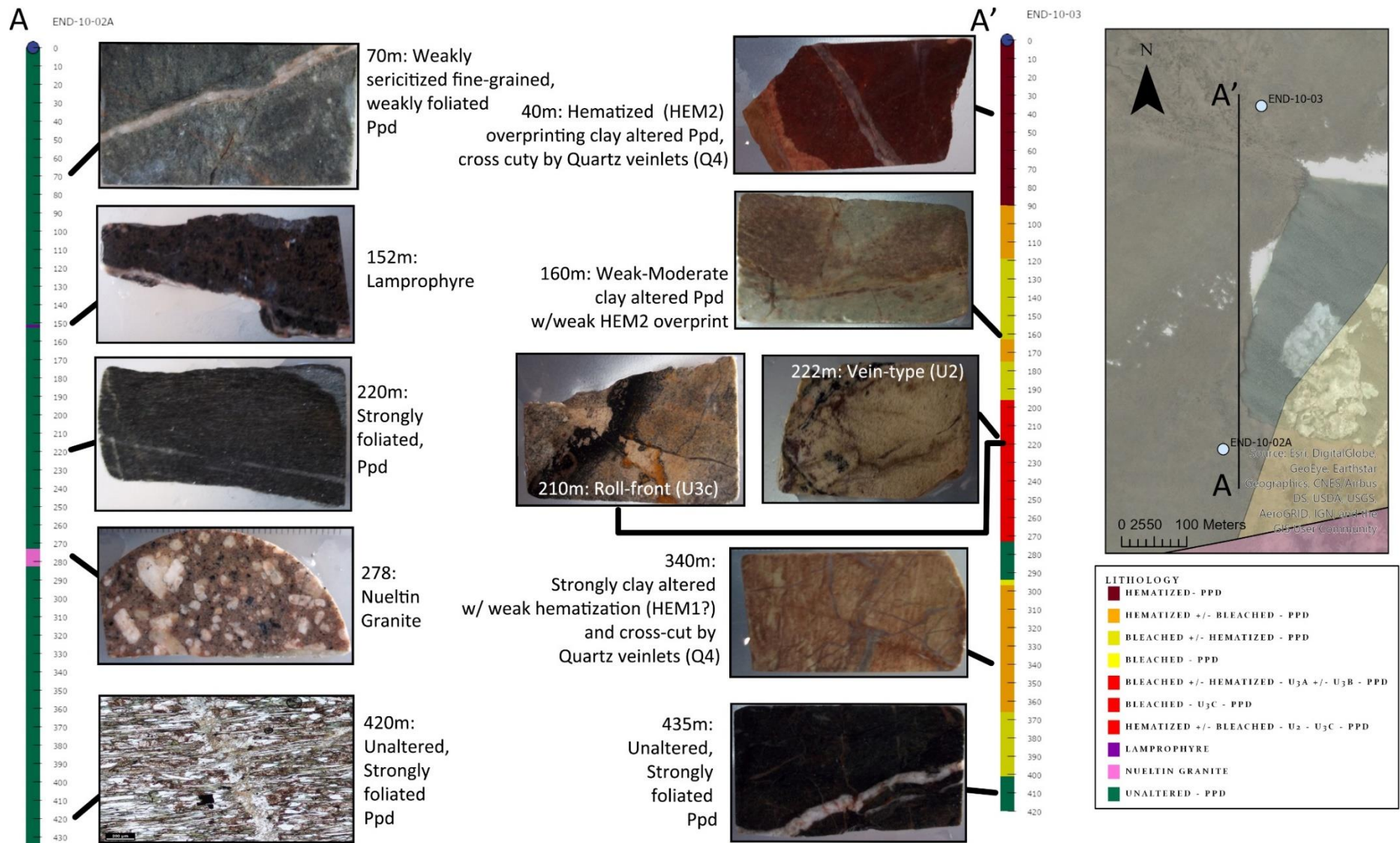


Fig. 4.18. A S-N, Graphical drill sections comparing the barren Ppd metagreywacke (END-10-02A) to mineralized Ppd metagreywacke (END-10-03).

4.2 Mineral Chemistry

4.2.1 Clay Mineralogy and Chemistry

The composition of illite, chlorite and muscovite from the barren hole (END-10-02A) and the mineralized hole (END-10-03) were plotted on a $MR^3-2R^3-3R^2$ diagram to chemically characterize the phyllosilicates present within the distal (END-10-02A) and proximal alteration halo to mineralization (END-10-03) (Fig. 4.19; Velde, 1975, 1977;). Major fields for illite-muscovite, prograde biotite, diagenetic or hydrothermal illite, and retrograde chloritization are indicated in grey from the Athabasca Basin (Quirt, pers comm). Phyllosilicates within the End deposit cluster in three groups, muscovite/hydrothermal assemblage (Yellow), illite (Red) and Fe-Mg chlorite (Green). Compared to the Athabasca Basin, there is some overlap between the phyllosilicate chemistry. Chlorite within the End deposit is dominantly Mg-bearing is consistent with the chemistry of retrograde chlorite in the Athabasca, as well there overlaps between the muscovite-illite composition in the Athabasca and the diagenetic hydrothermal assemblage (Fig. 4.19). Data used to calculate the $MR^3-2R^3-3R^2$ and Si, Fe + Mg vs. K diagrams are provided in Appendix B.

There are a wide range of compositions of illite throughout the End deposit and are dominantly phenetic-illite (Fig. 4.20A,B). The composition of illite proximal to mineralization can be quite variable between Si and Fe + Mg (Fig. 4.20A,B). Muscovite within the distal alteration halo clusters in relatively low Si, high K and low Fe + Mg content (Fig. 4.20A,B).

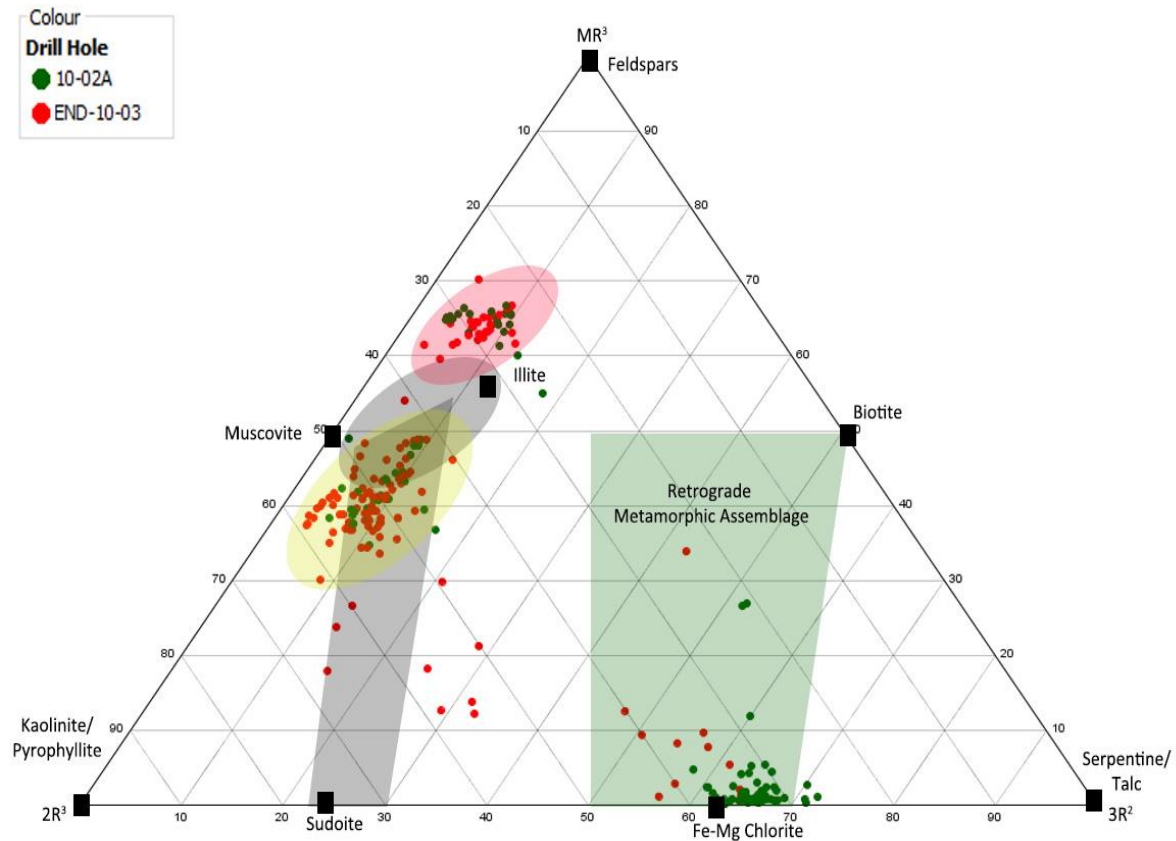


Fig. 4.19. A chemiographic $MR^3-2R^3-3R^2$ diagram comparing the hydrothermal and metamorphic phyllosilicate minerals found within the barren Ppd (END-10-02A) and the mineralized Ppd (END-10-03; Velde, 1975, 1977, Quirt, pers communication). Data is plotted where $MR^3 = Na^+ + K^+ + 2Ca^{2+}$, $2R^3 = ((Fe^{3+} + Al^{3+} + Ti^{4+}) - MR^3)/2$ and $3R^2 = ((Fe^{2+} + Mg^{2+} + Mn^{2+} + Ni^{2+})/3)$

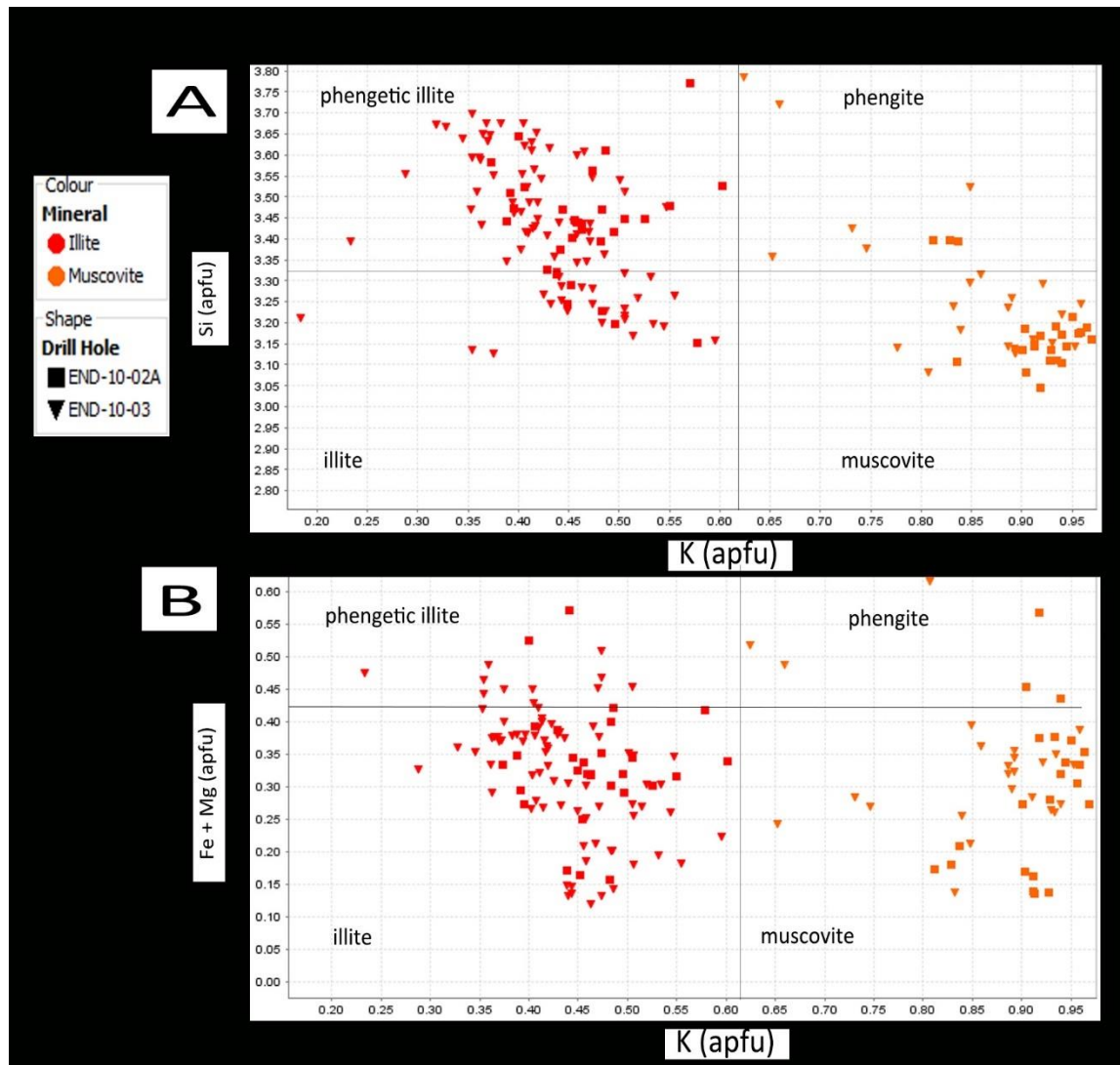


Fig. 4.20. A. Plot of Si (Apfu) versus K (apfu) to discriminate between muscovite, illite, and phengite. Throughout the End deposit the clay mineralogy is dominantly phenetic illite and contain high amounts of Si. B. Plot of Fe + Mg (apfu) versus K (apfu) comparing iron and magnesium rich varieties of phenetic illite and phengitic muscovite.

4.2.2 Temperature of Illite Formation

The chemical composition of illite can be used a geothermometer to estimate an approximate temperature of the rock altering fluids associated with deposition of illite at the End deposit (Eq. 6; Battaglia, 2004). This method is only useful for low temperature (<300°C) minerals. Chemical composition of illite that plotted within the hydrothermal field (Fig. 4.19)

were used to estimate the temperature of formation for the barren hole (END-10-02A; Table 4.2) and the mineralized hole (END-10-03; Table 4.3).

$$T(C) = 267.95x + 31.5 \quad [6]$$

Where $x = K + |Fe - Mg|$; K , Fe and Mg are represented as cations per 11 oxygen atoms and temperature is represented in Celsius. The error was calculated as 7% of the calculated value based on Battaglia (2004).

Illite within the barren hole gives a range of calculated temperatures from 151 to 205 °C and an average of $175 \pm 15^\circ \text{C}$. Illite from the mineralized hole gives a range of calculated temperatures from 116 °C to 246° C and with an average of $184 \pm 31^\circ \text{C}$. The barren hole had a normal distribution of values where the mineralized hole was skewed to higher temperatures (e.g. ~230-240°C) proximal to mineralization. Overall hydrothermal illite throughout the barren and mineralized zones are statistically similar (Fig. 4.21).

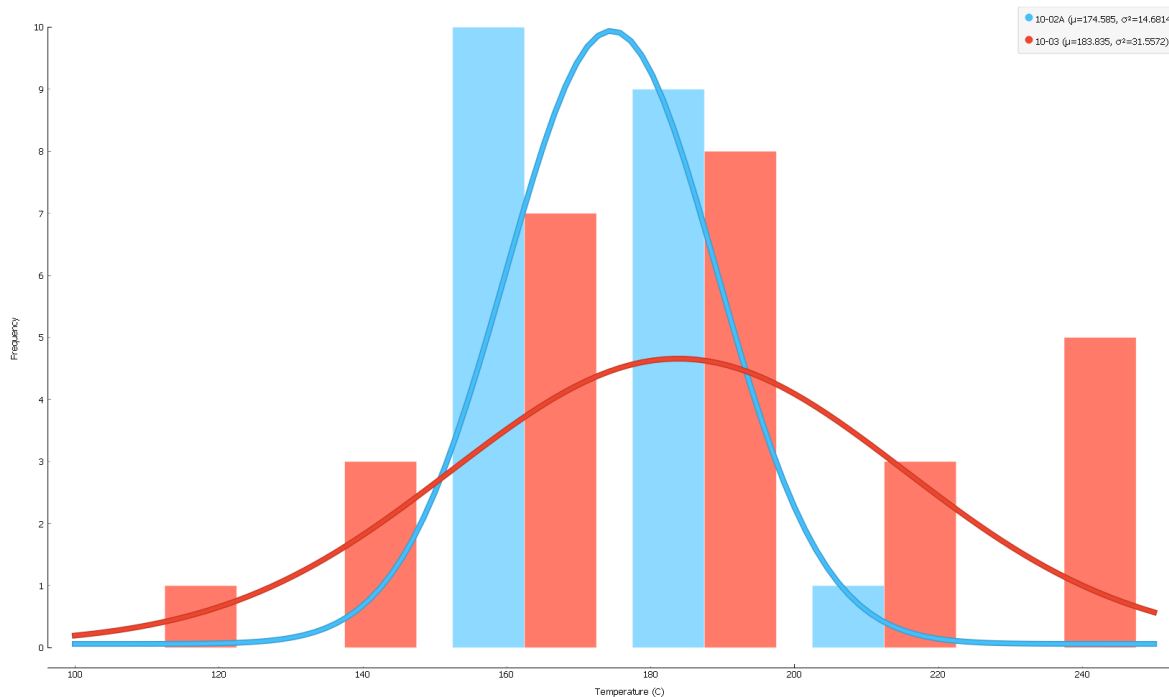


Fig. 2.21. Histogram of hydrothermal illite temperatures calculated from the barren (END-10-02A) and mineralized (END-10-03) drill holes (Battaglia, 2004).

Table 4.2. Temperature of Formation of hydrothermal illite from barren hole (END-10-02A).

Drill Hole ID	Depth (m)	Mineral	Fe*	Mg*	K*	Temperature (°C)
END-10-02A	190	Illite	0.075	0.198	0.395	170
END-10-02A	190	Illite	0.073	0.221	0.392	176
END-10-02A	190	Illite	0.058	0.274	0.372	189
END-10-02A	202.4	Illite	0.183	0.204	0.429	152
END-10-02A	202.4	Illite	0.202	0.143	0.449	168
END-10-02A	202.4	Illite	0.177	0.125	0.483	175
END-10-02A	217	Illite	0.137	0.186	0.498	178
END-10-02A	217	Illite	0.15	0.188	0.557	191
END-10-02A	250	Illite	0.203	0.145	0.388	151
END-10-02A	330	Illite	0.083	0.167	0.454	176
END-10-02A	330	Illite	0.183	0.388	0.441	205
END-10-02A	334.7	Illite	0.157	0.187	0.444	159
END-10-02A	334.7	Illite	0.148	0.171	0.459	161
END-10-02A	334.7	Illite	0.147	0.172	0.463	162
END-10-02A	334.7	Illite	0.152	0.186	0.456	163
END-10-02A	334.7	Illite	0.139	0.179	0.463	166
END-10-02A	334.7	Illite	0.126	0.18	0.496	179
END-10-02A	334.7	Illite	0.153	0.156	0.55	180
END-10-02A	334.7	Illite	0.147	0.207	0.557	197
END-10-02A	360	Illite	0.135	0.264	0.483	195
* Cations per 11 oxygen atoms used to calculate temperature					Average	175

Table 4.3. Temperature of formation of hydrothermal illite from mineralized hole (END-10-03).

Drill Hole ID	Depth (m)	Mineral	Fe*	Mg*	K*	Temperature (°C)
END-10-03	30	Illite	0.054	0.155	0.406	167
END-10-03	42.4	Illite	0.165	0.176	0.422	148
END-10-03	42.4	Illite	0.05	0.099	0.438	162
END-10-03	42.4	Illite	0.101	0.216	0.403	170
END-10-03	42.4	Illite	0.076	0.176	0.458	181
END-10-03	42.4	Illite	0.063	0.138	0.485	182
END-10-03	42.4	Illite	0.062	0.16	0.472	184
END-10-03	131	Illite	0.073	0.232	0.44	192
END-10-03	140	Illite	0.056	0.303	0.328	186
END-10-03	140	Illite	0.053	0.324	0.368	203
END-10-03	140	Illite	0.057	0.327	0.431	219
END-10-03	140	Illite	0.059	0.289	0.506	229
END-10-03	140	Illite	0.051	0.341	0.465	234
END-10-03	244.5	Illite	0.171	0.316	0.359	167
END-10-03	244.5	Illite	0.472	1.096	0.11	228
END-10-03	244.5	Illite	0.496	1.079	0.158	230
END-10-03	244.5	Illite	0.311	0.908	0.202	246
END-10-03	250	Illite	0.133	0.309	0.354	174
END-10-03	250	Illite	0.117	0.283	0.375	176
END-10-03	250	Illite	0.068	0.2	0.414	178
END-10-03	250	Illite	0.067	0.255	0.411	192
END-10-03	253.7	Illite	0.195	0.279	0.233	116
END-10-03	253.7	Illite	0.137	0.142	0.407	142
END-10-03	253.7	Illite	0.206	0.185	0.41	147
END-10-03	253.7	Illite	0.192	0.182	0.436	151
END-10-03	253.7	Illite	0.172	0.208	0.429	156
END-10-03	253.7	Illite	0.088	0.551	0.184	205
END-10-03	290	Illite	0.255	0.196	0.47	173
END-10-03	290	Illite	0.106	0.075	0.506	175
END-10-03	290	Illite	0.123	0.274	0.423	185
END-10-03	290	Illite	0.101	0.25	0.501	206
END-10-03	296	Illite	0.075	0.257	0.419	193
END-10-03	296	Illite	0.083	0.298	0.396	195
END-10-03	296	Illite	0.076	0.294	0.394	195
END-10-03	296	Illite	0.071	0.288	0.419	202
END-10-03	347.7	Illite	0.121	0.081	0.465	167
END-10-03	347.7	Illite	0.092	0.358	0.404	211
* Cations per 11 oxygen atoms used to calculate temperature					Average	186

4.2.3 Uraninite Chemistry

Uraninite throughout the End deposit shows characteristics of a protracted fluid history based on their mineral chemistry. All three styles of uraninite have been subsequently altered and they contain variable amounts of CaO, SiO₂ and PbO (Fig. 4.22A,B,C). It has been well documented within the Athabasca, uraninite from unconformity-related deposits can contain elevated amounts of CaO and SiO₂ and are indicative of alteration by later fluid-circulation (Fayek and Kyser, 1997; Alexandre and Kyser, 2005). Alteration of uraninite minerals can also be identified through BSE imaging and reflectance imaging (Fayek and Kyser, 2000). Pristine to less altered uraninite can have a high reflectance (Fig. 4.12D) whereas minerals such as uranophane and Coffinite (altered by-products of uraninite alteration) have lower reflectivity's (Fig. 4.12D). Mineral chemistry for uranium minerals from the End deposit is provided in Appendix B.

Based on the uraninite chemistry and BSE imaging, disseminated uraninite (U1) is weakly to moderately altered (Fig. 4.11) and UO₂ ranges from 76-85 wt.%, PbO ranges from 0.05 to 14.33 wt. %, CaO 1.2 to 8.18 wt.%, SiO₂ from 0.92 to 10 wt.%, ThO₂ from 0 to 0.14 wt.%. Uranophane was also identified within the U1 mineralization and has a composition of UO₂ (46-60 wt.%), PbO (0.85-3.51 wt.%), CaO (1.72-2.03 wt.%), SiO₂ (15.62-19.74 wt.%) and ThO₂ of (0.03-0.07 wt.%).

Vein-type uraninite (U2) consists of 71-81% UO₂, 0.72-8.49% PbO, 1-7% SiO₂ and 4-8% CaO and appears to be weakly to moderately altered (Fig. 4.22 A,B,C). Compared to U1, there is little TiO₂ in either altered or unaltered uraninite (0.2-0.3%). The PbO content of unaltered U2 uraninite (12-14% PbO) is higher than the third stages of uraninite (PbO 0-2.99%).

Foliation-parallel uraninite (U3a) is weakly to moderately altered based on BSE imaging and mineral chemistry. Altered uraninite in this phase ranges from 66-85% UO_2 , PbO 0.1-1.69%, SiO_2 (1-8.5%), CaO (2.5-4%), ThO_2 (0-0.03%). Titanium is also varied in U3a much like U1 with TiO_2 ranges from 0.1 to ~6%. Coffinite consists of 64-70% UO_2 with <2% PbO and ~3% CaO, ~12-15% SiO_2 . Infill-type uraninite (U3b) are characterized by 80-85 wt% UO_2 , 0-8% PbO, 2-7% CaO and 1-13% SiO_2 . Thorium is present in trace amounts 0-0.23 % ThO_2 . Uranophane and coffinite are also present in this style of mineralization with ~18% and 15% SiO_2 , respectively. Rollfront-type uraninite (U3c) is weakly to moderately altered with ~60-80% UO_2 with <1% PbO and ~5% CaO and 4-15% SiO_2 (Fig. 4.22A,B,C). Titanium is more abundant in this style of uraninite (0 to 22% TiO_2) compared to the other styles of uraninite within the End deposit.

Uraninite within the End deposit also has varied TiO_2 (ranges from 0-2.85%) which is likely due to very fine grained titanite. Much like U1 and U3a, titanium is also present in the vein-type uraninite and ranges from 0-0.84%. A single grain of altered uraninite contained up to 18% TiO_2 . TiO_2 is also present in uranophane from 1.71% up to 9.43%. The presence of titanite associated with uraninite has also been observed in the Contact prospect (Grare *et al.*, 2018a).

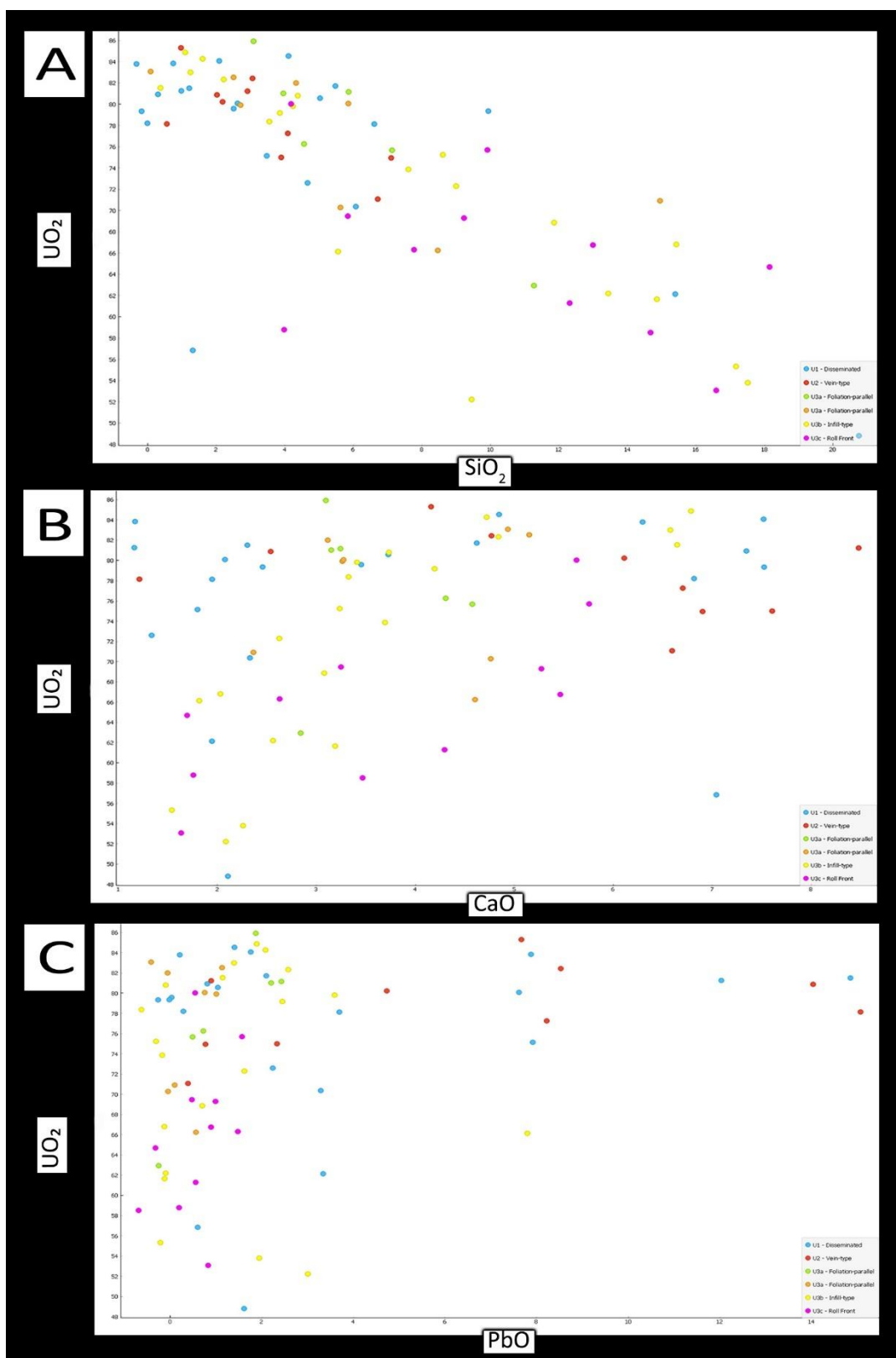


Fig. 4.22. Bivariate plots of EMPA data from uraninite phases within the End Deposit A. SiO₂ and UO₂ contents B. CaO and UO₂ contents; C. PbO and UO₂ content.

4.3 *Stable Isotopes*

4.3.1 *Oxygen isotopic composition of uraninite*

Oxygen isotope analysis was completed on samples containing the three styles of uraninite; disseminated uraninite (U1); vein-type uraninite (U2), and infill-type uraninite (U3b). The isotopic values are reported in Table 4.4. Disseminated uraninite (U1) gives a range of $\delta^{18}\text{O}$ values from -6.3 to -11 ‰, with an average value of -7.8 ± 1.8 ‰. Vein-type uraninite (U2) has a range of $\delta^{18}\text{O}$ values from -21.9 to -36.6 ‰, with an average value of $-27.8 \text{ ‰} \pm 5.3$ ‰. Infill-type uraninite (U3b) has a range from -19.9 ‰ to -24.0 ‰ and an average value of $-21.3 \text{ ‰} \pm 1.9$ ‰.

The differences in $\delta^{18}\text{O}$ values cannot be completely attributed to mineral chemistry because different styles (early (U1) vs. late (U2 and U3)) have different $\delta^{18}\text{O}$ values regardless of their chemical composition (Fig. 4.23). Disseminated uraninite has much higher $\delta^{18}\text{O}$ values compared to vein-type uraninite and infill-type uraninite.

Table 4.4. $\delta^{18}\text{O}$ (VSMOW) (‰) isotopic composition of uraninites from the End deposit.

Sample-ID	Mineral	Style	$^{18}\text{O}/^{16}\text{O}$	$\delta^{18}\text{O}$ (VSMOW) (‰)	1 σ
10-03-223.3-01	Uraninite	Disseminated (U1)	1.938924	-6.9	1.2
10-03-223.3-02	Uraninite	Disseminated (U1)	1.939709	-6.5	1.2
10-03-223.3-03	Uraninite	Disseminated (U1)	1.936379	-8.2	1.2
10-03-223.3-04	Uraninite	Disseminated (U1)	1.940100	-6.3	1.2
10-03-223.3-06	Uraninite	Disseminated (U1)	1.936040	-8.3	1.2
Average				-7.2	
09-04-340.5-01	Uraninite	Vein-type (U2)	1.924698	-23.4	1.2
09-04-340.5-02	Uraninite	Vein-type (U2)	1.898797	-36.6	1.2
09-04-340.5-03	Uraninite	Vein-type (U2)	1.910583	-30.6	1.2
09-04-340.5-04	Uraninite	Vein-type (U2)	1.927596	-21.9	1.2
09-04-340.5-05	Uraninite	Vein-type (U2)	1.922545	-24.5	1.2
09-04-340.5-06	Uraninite	Vein-type (U2)	1.919484	-26.1	1.2
09-04-340.5-07	Uraninite	Vein-type (U2)	1.908601	-31.6	1.2
Average				-27.8	
10-03-244.5-01	Ca - Si Uraninite	Infill-type (U3b)	1.928764	-21.3	1.2
10-03-244.5-02	Ca - Si Uraninite	Infill-type (U3b)	1.923567	-24.0	1.2
10-03-244.5-03	Ca - Si Uraninite	Infill-type (U3b)	1.931692	-19.9	1.2
10-03-244.5-04	Ca - Si Uraninite	Infill-type (U3b)	1.931376	-20.0	1.2
Average				-21.3	

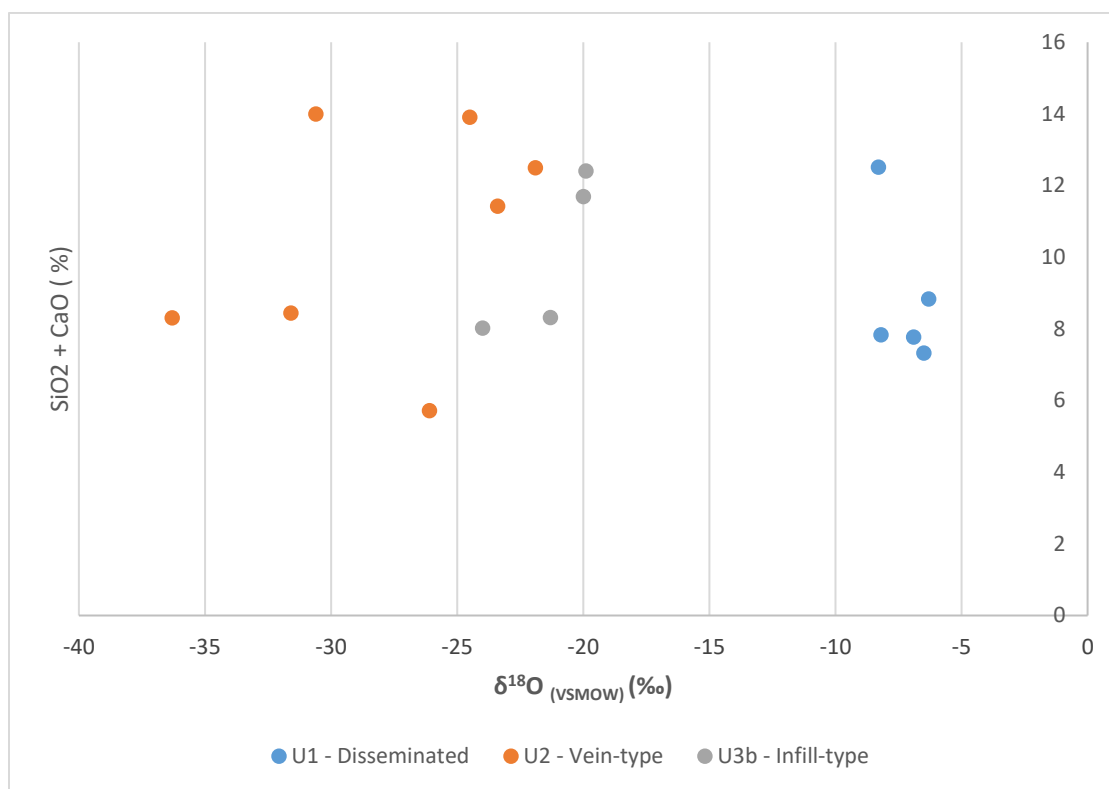


Fig. 4.23. Relationship of SiO₂ and CaO content of uraninite versus $\delta^{18}\text{O}_{(\text{VSMOW})}$.

4.3.2 Oxygen isotopic composition of illite

The oxygen isotopic composition of illite associated with each style of uraninite was also measured using SIMS (Table 4.5). Illite (II1) associated with disseminated uraninite (U1) has a range of $\delta^{18}\text{O}$ values from 5.3 to 12.1 ‰ with an average of 8.8 ± 0.6 ‰. Illite (II2) associated with uraninite veins (U2) has a range of $\delta^{18}\text{O}$ values from 9.6 to 20.0 ‰ with an average of 13.3 ± 0.7 ‰. Lastly, illite that is coeval with infill uraninite (U3b) has a range of $\delta^{18}\text{O}$ values from 10.0 to 12.6 ‰ and an average of 10.7 ± 0.7 ‰.

Table 4.5: Oxygen isotope data from Illite in the End deposit, Thelon Basin.

Sample-ID	Mineral	$^{18}\text{O}/^{16}\text{O}$	$\delta^{18}\text{O}$ (VSMOW) (‰)	1 σ
10-03-223.3-01	Illite (II1)	1.890998	12.1	1.2
10-03-223.3-02	Illite (II1)	1.87821	5.3	1.2
10-03-223.3-03	Illite (II1)	1.878915	5.6	1.2
10-03-223.3-04	Illite (II1)	1.883026	7.8	1.2
10-03-223.3-05	Illite (II1)	1.884044	8.4	1.2
10-03-223.3-06	Illite (II1)	1.879992	6.2	1.2
10-03-223.3-07	Illite (II1)	1.89452	14.0	1.2
10-03-223.3-08	Illite (II1)	1.888868	11.0	1.2
Average			8.8	
09-04-340.5-03	Illite (II2)	1.88784	11.1	1.2
09-04-340.5-04	Illite (II2)	1.894102	14.5	1.2
09-04-340.5-06	Illite (II2)	1.889973	12.3	1.2
09-04-340.5-07	Illite (II2)	1.904376	20.0	1.2
09-04-340.5-08	Illite (II2)	1.889242	11.9	1.2
09-04-340.5-09	Illite (II2)	1.885086	9.6	1.2
09-04-340.5-10	Illite (II2)	1.893403	14.1	1.2
09-04-340.5-11	Illite (II2)	1.891398	13.0	1.2
Average			13.3	
10-03-217.6-01	Illite (II3)	1.886218	10.3	1.2
10-03-217.6-02	Illite (II3)	1.886242	10.3	1.2
10-03-217.6-03	Illite (II3)	1.885784	10.0	1.2
10-03-217.6-04	Illite (II3)	1.890592	12.6	1.2
10-03-217.6-06	Illite (II3)	1.886371	10.3	1.2
10-03-217.6-07	Illite (II3)	1.886915	10.6	1.2
10-03-217.6-08	Illite (II3)	1.887309	10.8	1.2
Average			10.7	

4.3.3 Oxygen isotopic composition of calcite

The oxygen isotopic compositions of calcite associated with U2 uraninite veins (Cal1) (Fig. 4.11C) and calcite associated with the quartz veins carrying hematite/pyrite (Cal2) (Fig. 4.16) were analyzed using SIMS (Table 4.6). Calcite (Cal1) that is coeval with U2 veins has a range of $\delta^{18}\text{O}$ values from 11.5 to 17.9 ‰ with an average of $14.3 \pm 0.7\text{‰}$. Calcite within the hematite/pyrite-bearing veins (Cal2) has a range of $\delta^{18}\text{O}$ values from 5.3 to 8 ‰ with an average value of $6.8 \pm 0.7 \text{‰}$.

Table 4.6. Oxygen isotopic composition of calcite in the End deposit, Thelon Basin.

Sample-ID	Mineral	$^{18}\text{O}/^{16}\text{O}$	$\delta^{18}\text{O}$ (VSMOW) (‰)	1 σ
09-04-340.5-04	Calcite	1.868008	12.2	1.2
09-04-340.5-05	Calcite	1.871482	14.1	1.2
09-04-340.5-07	Calcite	1.870716	13.6	1.2
09-04-340.5-08	Calcite	1.866845	11.5	1.2
09-04-340.5-10	Calcite	1.875982	16.5	1.2
09-04-340.5-11	Calcite	1.878582	17.9	1.2
		Average	14.3	
10-02A-202.4-02	Calcite	1.856728	6.1	1.2
10-02A-202.4-03	Calcite	1.858962	7.3	1.2
10-02A-202.4-04	Calcite	1.857456	6.5	1.2
10-02A-202.4-05	Calcite	1.855378	5.3	1.2
10-02A-202.4-06	Calcite	1.860295	8.0	1.2
10-02A-202.4-07	Calcite	1.860130	7.9	1.2
10-02A-202.4-08	Calcite	1.858160	6.8	1.2
		Average	6.8	

4.3.4 Oxygen isotopic composition of quartz

The oxygen isotopic composition of quartz associated with the non-hematite-bearing quartz breccias (Q3a) has $\delta^{18}\text{O}$ values that range from 4.0 to 7.5 ‰ and an average value of $6.3 \text{‰} \pm 0.9 \text{‰}$. Quartz (Q3b) associated with hematite and pyrite has a range of $\delta^{18}\text{O}$ values from 15.5 to 16.6 ‰ and an average value of $15.8 \pm 0.9\text{‰}$ (Table 4.7).

Table 4.7. Oxygen isotope data from quartz veins in the End deposit, Thelon Basin.

Sample-ID	Mineral	$^{18}\text{O}/^{16}\text{O}$	$\delta^{18}\text{O}$ (VSMOW) (‰)	1 σ
10-02A.3347-01	Quartz(Q3b)	1.868877	4.3	1.2
10-02A.3347-02	Quartz(Q3b)	1.872799	6.4	1.2
10-02A.3347-03	Quartz(Q3b)	1.873699	6.9	1.2
10-02A.3347-04	Quartz(Q3b)	1.868344	4.0	1.2
10-02A.3347-06	Quartz(Q3b)	1.874501	7.3	1.2
10-02A.3347-07	Quartz(Q3b)	1.874523	7.3	1.2
10-02A.3347-08	Quartz(Q3b)	1.874919	7.5	1.2
Average			6.3	
10-02A-2024-01	Quartz (Q3a)	1.888717	15.0	1.2
10-02A-2024-03	Quartz (Q3a)	1.889141	15.2	1.2
10-02A-2024-05	Quartz (Q3a)	1.891726	16.6	1.2
10-02A-2024-06	Quartz (Q3a)	1.891687	16.5	1.2
10-02A-2024-07	Quartz (Q3a)	1.889831	15.6	1.2
Average			15.8	

4.3.5 Hydrogen isotopic composition of illite

The $\delta^2\text{H}$ composition of illite (Il1, Il2, and Il3) was analyzed using SIMS (Table 4.8). Illite (Il1) associated with disseminated uraninite (U1) has a $\delta^2\text{H}$ range from -139 to -124‰ and an average of $-132\text{‰} \pm 6 \text{‰}$. Illite (Il2) associated with the uraninite veins (U2) has a $\delta^2\text{H}$ range from -183 to 165‰ to with an average of $-176\text{‰} \pm 6 \text{‰}$. Illite (Il3) associated with roll front style uranium mineralization (U3) has a $\delta^2\text{H}$ range from -146 to -129 ‰ and an average of $-136\text{‰} \pm 4\text{‰}$.

Table 4.8. Hydrogen isotope data from Illite in the End deposit, Thelon Basin.

Sample-ID	Mineral	$^2\text{H}/\text{H}$	$\delta^2\text{H}$ (VSMOW) (‰)	1 σ
10-10-10-03-223.3-01	Illite (Il1)	4.92E-05	-137	1.2
10-10-10-03-223.3-02	Illite (Il1)	4.90E-05	-139	1.2
10-10-10-03-223.3-06	Illite (Il1)	4.97E-05	-127	1.2
10-10-10-03-223.3-08	Illite (Il1)	4.99E-05	-124	1.2
10-10-10-03-223.3-09	Illite (Il1)	4.92E-05	-135	1.2
10-10-10-03-223.3-10	Illite (Il1)	4.96E-05	-129	1.1
Average			-132	
10-10-09-04-340.5-01	Illite (Il2)	4.76E-05	-165	1.2
10-10-09-04-340.5-04	Illite (Il2)	4.69E-05	-177	1.2
10-10-09-04-340.5-05	Illite (Il2)	4.71E-05	-172	1.2
10-10-09-04-340.5-06	Illite (Il2)	4.67E-05	-180	1.2
10-10-09-04-340.5-07	Illite (Il2)	4.71E-05	-173	1.2
10-10-09-04-340.5-08	Illite (Il2)	4.65E-05	-183	1.2
10-10-09-04-340.5-09	Illite (Il2)	4.68E-05	-178	1.2
Average			-175.7	
10-10-10-03-217.6H- 02	Illite (Il3)	4.94E-05	-132	1.0
10-10-10-03-217.6H- 03	Illite (Il3)	4.96E-05	-129	1.3
10-10-10-03-217.6H- 04	Illite (Il3)	4.90E-05	-139	1.2
10-10-10-03-217.6H- 05	Illite (Il3)	4.93E-05	-134	1.3
10-10-10-03-217.6H- 06	Illite (Il3)	4.93E-05	-135	1.2
10-10-10-03-217.6H- 08	Illite (Il3)	4.86E-05	-146	1.2
Average			-136	

4.4 Temperature and composition of fluid

Disseminated uraninite (U1) is paragenetically coeval with illite (Il1) and therefore the temperature and composition of the fluid that was associated with U1 formation can be calculated using equilibrium isotope fractionation factors for illite-H₂O (Eq. 7; Sheppard and Gilg, 1996) and uraninite-H₂O (Eq. 8; Fayek and Kyser, 2000). The average $\delta^{18}\text{O}$ values of illite and uraninite were used in the calculations and a temperature of formation of 210 ± 16 °C was obtained. Using the calculated temperature, the average $\delta^{18}\text{O}$ and $\delta^2\text{H}$ values for illite, and the oxygen isotope fractionation factor for illite-water of Sheppard and Gilg (1996) and hydrogen isotope fractionation factor for illite-water of Capuano (1992), the $\delta^{18}\text{O}$ and $\delta^2\text{H}$ values for the fluid that precipitated Il1 are respectively 4.1 ± 0.8 ‰ and -131 ± 5 ‰.

$$1000 \ln \alpha = A (10^6)/T^2 + B (10^3) /T + C \quad [7]$$

Where $A = 4.140$; $B = -7.360$; $C = 2.210$

$$1000 \ln \alpha = A (10^6)/T^2 + B (10^3) /T + C \quad [8]$$

Where $A = 16.580$; $B = -77.520$; $C = 77.480$

4.5 Radiogenic Isotopes

4.5.1 Pb-Pb Isotope Geochronology

Uraninite Pb-Pb isotope ages range from 500 to 1435 Ma and appear to cluster at ~800 Ma, 900 to 1100 Ma and 1200 to 1300 Ma (Fig. 4.19). Disseminated uraninite (U1) provides a range of Pb-Pb ages from 1013 Ma to 1435 Ma and a median age of 1336 ± 47 Ma. Vein-type uraninite (U2) gives a range of Pb-Pb ages from 1099 Ma to 1288 Ma with a median age of 1232 ± 21 Ma. The Pb-Pb ages for galena associated with vein-type uraninite (U2) (Fig. 4.11D) have a range of 1202 to 1371 Ma and a median age of $1296 \text{ Ma} \pm 29 \text{ Ma}$. Galena contains little common-lead (ie. High relative abundance of $^{206}\text{Pb}/^{204}\text{Pb}$, $^{207}\text{Pb}/^{204}\text{Pb}$ and $^{208}\text{Pb}/^{204}\text{Pb}$) and is therefore radiogenic in origin (Table 4.2). Foliation-parallel uraninite (U3a) has a range of Pb-Pb ages from 948 to 1111 Ma with a median of 1043 ± 34 Ma. Infill-type uraninite (U3b) provides Pb-Pb ages from 564 Ma to 1132 Ma and a median age of 905 ± 48 Ma. Roll front uraninite (U3c) produces a large range of Pb-Pb ages from 711 Ma to 1435 Ma and an average of 884 ± 21 Ma.

Table 4.9. Pb isotope composition of galena coeval with vein-type uraninite from the End deposit, Thelon Basin, Nunavut, Canada.

Sample-ID	DDH ID	Depth (m)	$^{206}\text{Pb}/^{204}\text{Pb}$	$^{207}\text{Pb}/^{206}\text{Pb}$
904-340.5-01	END-09-04	340.5	745	0.080753
904-340.5-02	END-09-04	340.5	784	0.081445
904-340.5-03	END-09-04	340.5	1145	0.079970
904-340.5-04	END-09-04	340.5	1241	0.082260
904-340.5-05	END-09-04	340.5	905	0.083929
904-340.5-06	END-09-04	340.5	879	0.084377

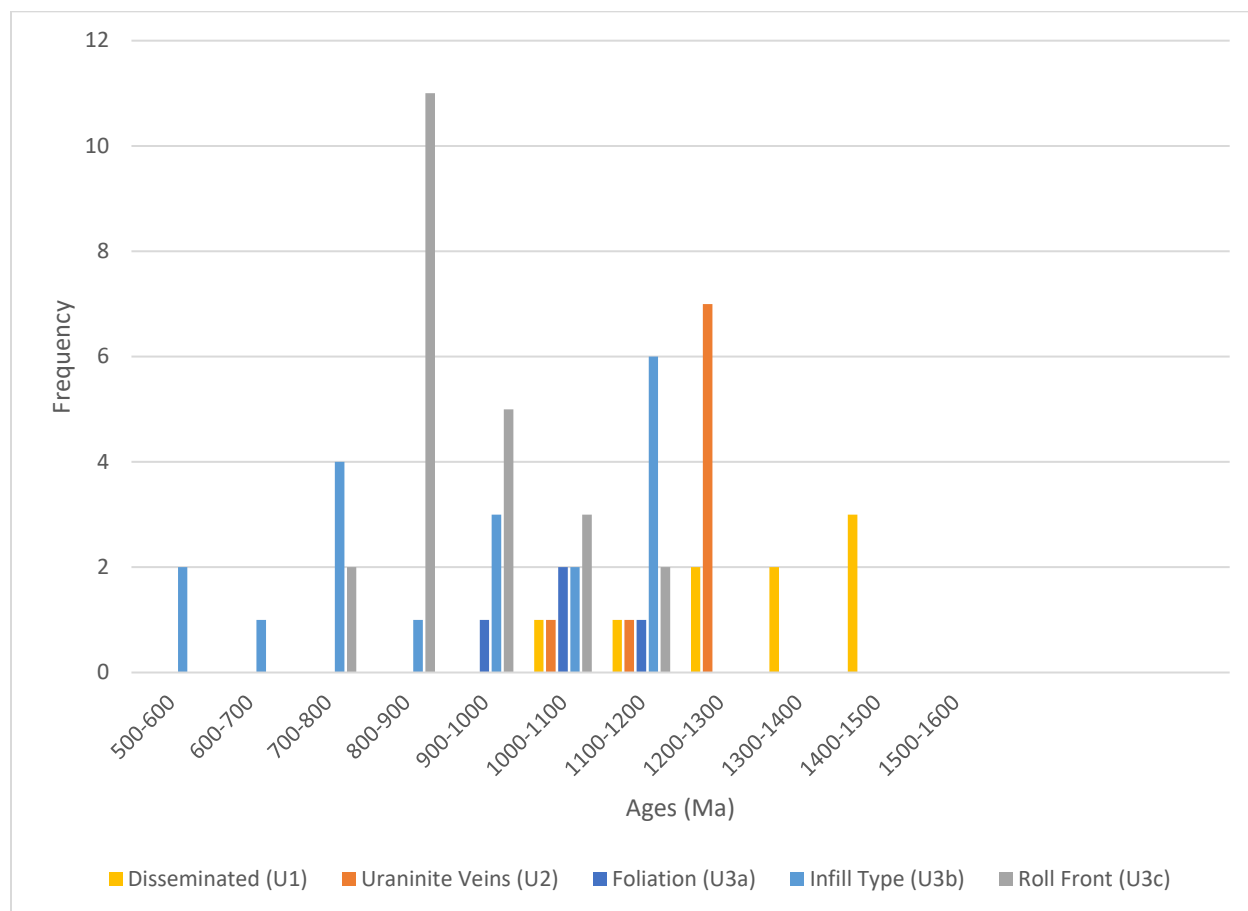


Fig. 4.24. Distribution of Pb-Pb ages from the disseminated (U1); Uraninite veins (U2); Foliation-parallel (U3a); Infill-type (U3b) and Roll front (U3c). Pb-Pb ages from all phases cluster at 800-1000 Ma and 1100-1300 Ma.

4.5.2 U-Pb Isotope Geochronology

Uraninite U-Pb isotopic ratios were corrected using Eq.3 and then plotted on Concordia diagrams (Fig. 4.20) using the program ISOPLOT 4.15(Ludwig, 1993). Uraninite that appeared least-altered based on petrography and mineral chemistry were considered.

U-Pb isotopic ratios from disseminated uraninite (U1) give an upper intercept of 1459 ± 55 Ma and a lower intercept of 8.3 ± 2.1 Ma with an MSWD of 1.8 (Fig. 4.20A). Data from vein-type uraninite (U2) give an upper intercept of 1280 ± 32 Ma and a lower intercept of 126 ± 45 Ma with an MSWD of 4.8 (Fig. 4.20B), whereas infill-type uraninite (U3b) gives an upper intercept of 971 ± 35 Ma and a lower intercept of -23 ± 35 Ma with an MSWD of 1.5 (Fig. 4.20C). The U-Pb ratios from roll-front type uraninite (U3c) are highly discordant and give an upper intercept of $750 \text{ Ma} \pm 74 \text{ Ma}$ and a lower intercept of 2.2 ± 8.3 Ma with an MSWD of 17 (Fig. 4.20D).

Since all the analyzed uraninite phases within the End deposit plot on the line of discordia (Fig. 4.20) the U-Pb system was subject to Pb-loss. Uraninite is sensitive to changes in physiochemical conditions and can experience Pb-loss due to diffusion and episodic precipitation of secondary minerals (Kotzer and Kyser, 1993; Janeczek and Ewing, 1995). Uraninite is altered within the End deposit (Section 4.2.3) and may have occurred during several thermal events. The lower intercepts are very young in comparison (~ 2.2 to 8.3 Ma (U1, U3b,c) and as high as 126 Ma (U2) and may represent U gain, however the significance of these lower intercepts is not really well understood (Faure, G, 1991).

The MSWD (mean square weighted deviation) is a statistical error that represents how good the data fits to the regression line (in this case the isochron). If the MSWD is greater than 1 then the isotopic system may not be fully understood, and the system was subject to outside geological factors (also known as “geological scatter”). MSWD of all analyzed uraninite phases

within the End deposit were above 1 which suggest the U-Pb isotopic system was not in equilibrium.

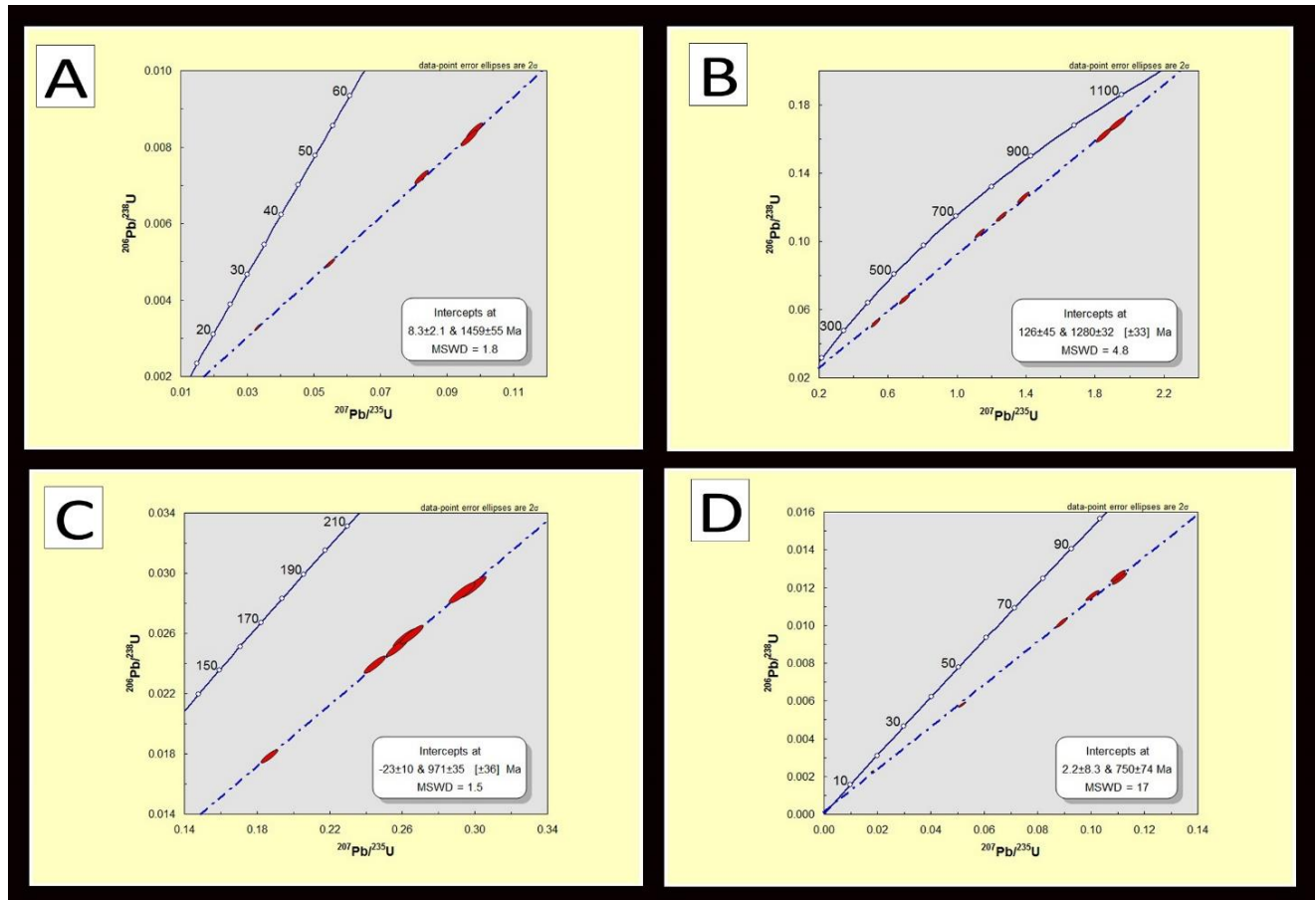


Fig. 4.25. U-Pb isochron geology plot of uranium mineralization within the End deposit A. Disseminated uraninite (U1) (END-10-03-223.3) B. Vein-type uraninite (U2) (END-04-340.5)- C. Infill-type uraninite (U3b) (END-10-03-222.4) D. Roll Front type uraninite (U3c) (END-10-03-217.6).

4.5.3 $^{40}\text{Ar}/^{39}\text{Ar}$ Geochronology

$^{40}\text{Ar}/^{39}\text{Ar}$ geochronological analyses on muscovite were completed on three samples from within the alteration halo of the End deposit and all data are provided in Appendix E. Two ages were calculated from muscovite and illite within the alteration halo proximal to mineralization (END-10-03-40; END-10-03-340), and a third age was calculated from a sample from a barren alteration zone devoid of uraninite (END-10-02A-263.2). Muscovite and illite from the base of the alteration zone (END-10-03-340) produced a plateau age of 1476 ± 26 Ma (Fig. 4.22). The plateau age was determined using 52.5% of the ^{39}Ar gas released from steps 4-6 which has step ages of 1478.5 Ma, 1483.1 Ma and 1461.6 Ma respectively.

$^{40}\text{Ar}/^{39}\text{Ar}$ analysis of two samples within the barren hole and mineralized hole did not release sufficient ^{39}Ar gas to calculate a plateau age however two ages were calculated using $>30\%$ Ar (Fig. 4.23 A&B). Muscovite and illite near the mineralization (END-10-03-40) has an age of 1308 ± 13 Ma. This age was calculated from steps 13 and 14 had stepwise ages of 1318.3 Ma and 1298.3 Ma respectively and released 31% ^{39}Ar gas. Muscovite within the barren zone had an age of 1603 ± 4 Ma. The age from the barren zone was determined using steps 6 and 7 had stepwise ages of 1606.4 Ma and 1600.3 Ma respectively and released 32% ^{39}Ar gas. The error of both these ages represents the standard deviation of the stepwise ages.

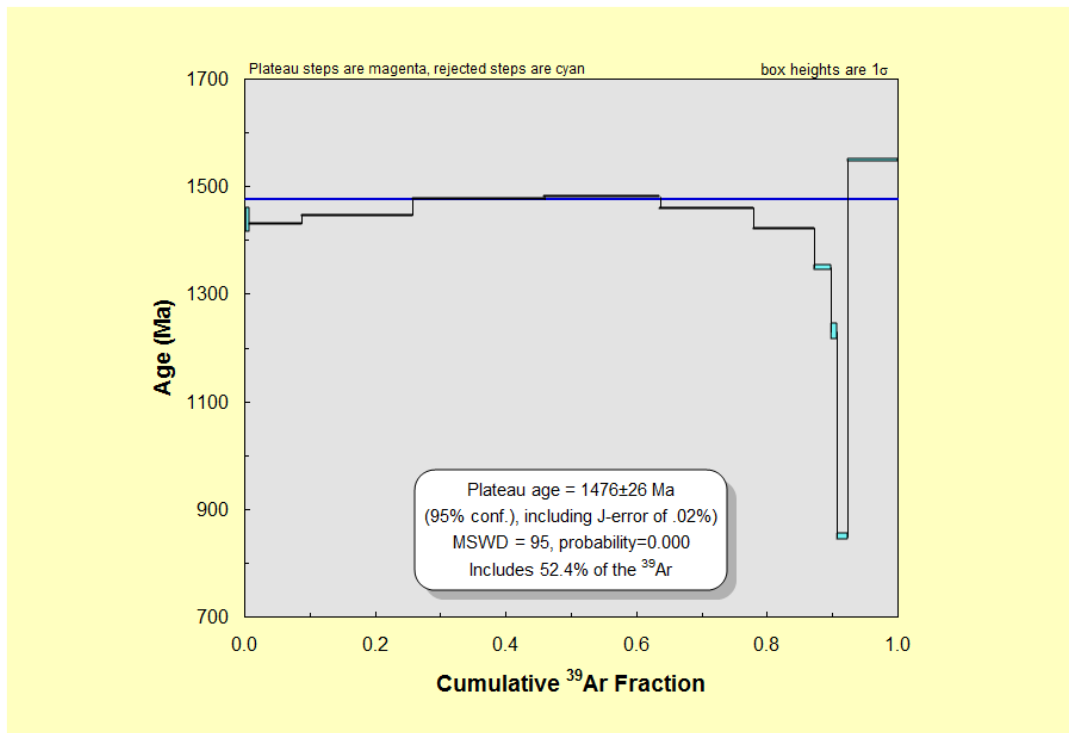


Fig. 4.26. ^{39}Ar Age spectra from muscovite associated with alteration below the End mineralization (END-10-03-340).

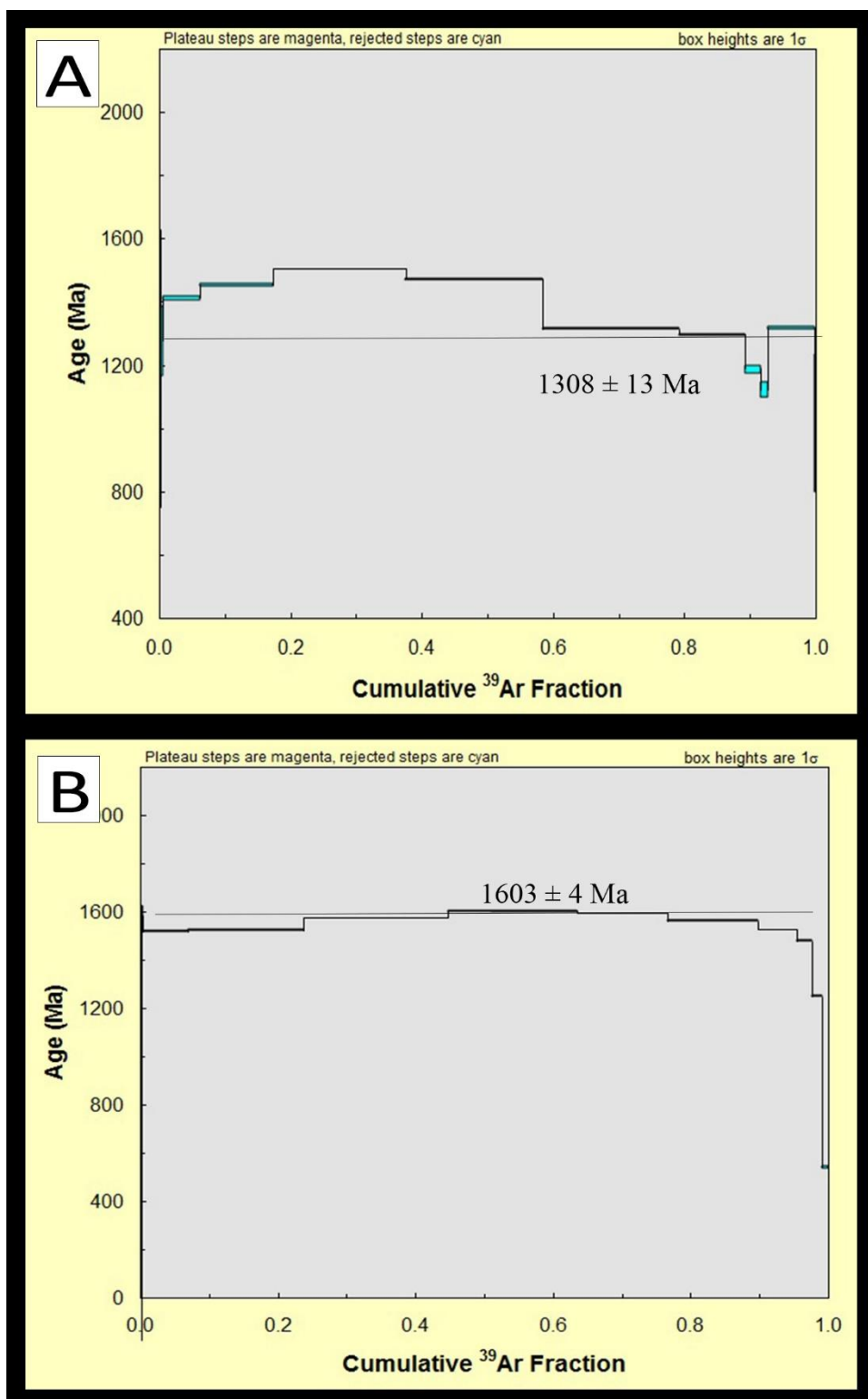


Fig. 4.27. A. ^{39}Ar age spectra from sericitization above the End deposit. B (END-10-03-40). ^{39}Ar age spectra from a barren distal alteration zone with respect to the End deposit (END-10-02A-263.2).

Chapter 5.0: Discussion

The Thelon Basin (Nunavut) and the Athabasca Basin (Saskatchewan) share many sedimentological and geological similarities (Renac *et al.*, 2002; Jefferson *et al.*, 2007a,b,c). Although the Thelon Basin is spatially and temporally related to the Athabasca Basin, it is still relatively poorly understood. Uranium deposits associated with the Thelon Basin are hosted within the metamorphic basement to the Thelon Formation; the Pukio Lake Formation Epiclastics (Kiggavik, Bong), Marjorie Hills Formation (Andrew Lake) and the Pipedream Metagreywacke (End, Bong). Friedrich *et al.* (1989) and Weyer *et al.* (1987) initially interpreted the Kiggavik deposit as an unconformity-related vein type deposit in which they suggested that oxidized fluids from the overlying sandstones mixed with reduced fluids from the basement host rocks that resulted in uranium precipitation similar to models proposed for the Athabasca Basin unconformity deposits. (eg. Hoeve and Sibbald, 1978; Hoeve and Quirt, 1984; Wallis *et al.*, 1985; among others). This model of uranium deposition is the classic diagenetic-hydrothermal model initially proposed by (Hoeve and Quirt, 1984) on the uranium deposits within the Athabasca Basin. However recent studies, including this one, suggest uraninite precipitation in the Kiggavik area is far more complicated (Sharpe *et al.*, 2015; Shabaga *et al.*, 2017; Grare *et al.*, 2016, 2018a, 2020),

5.1 Unconformity-type uranium deposits

Quirt (2003) and Jefferson *et al.* (2007a,b,c) summarized two styles of diagenetic-hydrothermal unconformity-related mineralization based on the geometric shape and alteration mineralogy; egress and ingress-style (Fig. 5.1). This diagenetic-hydrothermal unconformity-type, or unconformity-related, uranium deposit model was developed from extensive work

completed on uranium deposits located within the Athabasca Basin (Hoeve and Sibbald, 1978; Hoeve and Quirt, 1984, Fayek and Kyser 1997, and Quirt 1989; among others).

The diagenetic-hydrothermal model is best described as two types of convection (1) large-scale free convection within an overlying oxidized sandstone and (2) small-scale forced convection within the basement (e.g. along active and reactivated fault systems). This model requires (1) a thick oxidized sandstone cover acting as an aquifer (e.g. Athabasca Group); (2) a structural interface between the overlying cover and basement rocks (e.g. an unconformity) (3) deeply buried and reduced basement rocks (e.g. Metamorphosed graphitic basement) (4) a temporal variation in tectonic and magmatic activity to drive heat and fluid flow throughout each convective system (Hoeve and Quirt, 1984, 1987).

Egress-style alteration consists of two end-member varieties: 1) involving quartz dissolution and illite-chlorite-dravite, and 2) involving silicification with later illite-kaolinite-chlorite $\pm$ dravite (common in the McArthur River deposits) (Quirt, pers. Communication (Feb 1, 2020). Egress-style alteration haloes have been described as plume-shaped or flattened elongate bell-shaped halos that narrow gradually upward from the base of the sandstone and are narrow within the basement (Quirt, 2003; Jefferson *et al.*, 2007b). The alteration haloes within egress-style deposits consist of illite, sudoite (chlorite), dravite, local kaolinite, euhedral quartz, and local Ni-Co-As-Cu sulphide minerals (Hoeve and Quirt, 1984, 1987; Wallis *et al.*, 1985; Kotzer and Kyser, 1995). Two types of chlorite that appear within this style of alteration are the less common Mg-chlorite and the dominant Al-Mg-chlorite (sudoite; Hoeve and Quirt 1984, Percival and Kodama, 1989). These deposits are hosted either straddling the unconformity or immediately above the unconformity within the overlying sandstone. Egress-style deposits are polymetallic and contain not only U, but Ni, Co, Cu, Pb, S, and As and elevated amounts of Rare

Earth Elements (REE's).

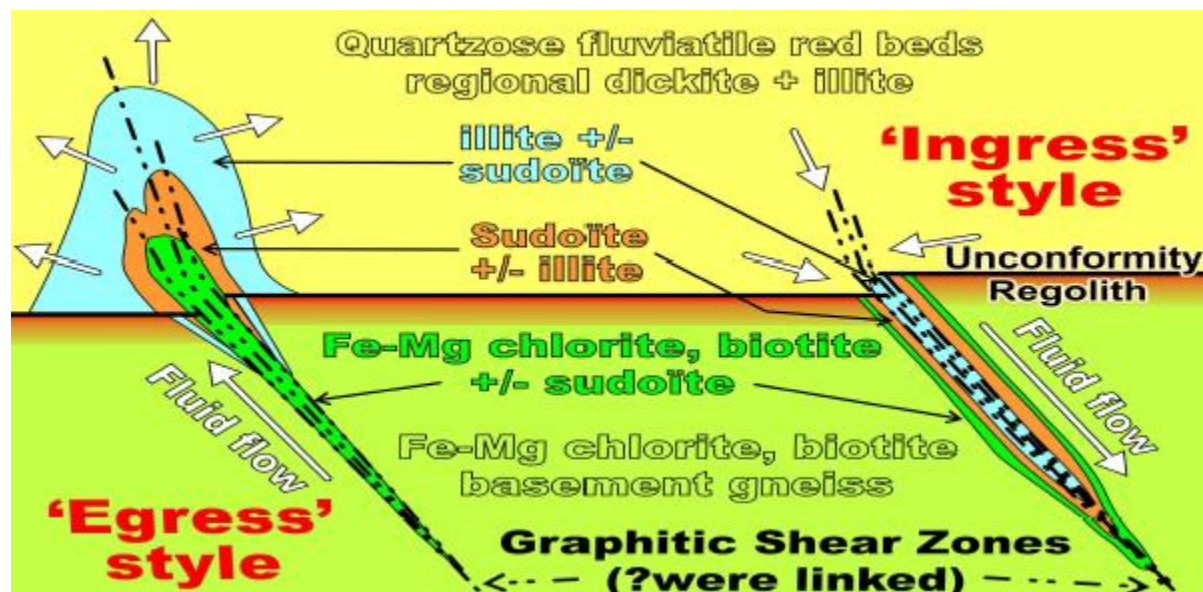


Fig. 5.1. Comparison of Egress and Ingress Style unconformity associated uranium deposits (from Jefferson *et al.*, 2007a,b,c; after Quirt, 1989, 2003).

The mineralogy of the ingress-style alteration haloes is similar to egress-style, however, the ingress-style mineralization and alteration are developed within the basement rocks. Alteration mineralogy is composed of an illite core that transitions outwards to sudoite, to Fe-Mg chlorite $\pm$ sudoite, then to Fe-Mg chlorite and biotite (Fig. 5.1.). These types of deposits have also been described as monometallic uranium, but they also contain lower amounts of REEs compared to egress-style deposits. Their small alteration footprint and the depth at which they typically occur result in them being described as “blind” targets for drilling compared to egress-style targets (Hoeve and Quirt, 1984; Jefferson *et al.*, 2007b).

Based on the geology and alteration features, the End deposit characteristics are consistent with an ingress-style unconformity-related classification. Much like ingress-style deposits, the End deposit is hosted within Archean basement metagreywacke and the U mineralization has an illite alteration halo. The uranium mineralization in the End deposit

consists of uraninite within veins (Section 4.1.7.2; Fig. 4.11.) and microfractures (Section 4.1.8.3.2; Fig. 4.13.). Away from mineralization, the host-rock alteration is primarily Fe-Mg chlorite and significantly decreases closer to mineralization (Section 4.2; Fig. 4.17). However, the ingress-style model was developed based on the unconformity-related deposits of the Athabasca Basin which are typically related to a graphitic reduced basement shear zones. The unconformity-related ingress-egress model could loosely be applied to the End deposit, based on the alteration assemblage; however, the deposit does lack a graphite and organic matter components which have long held to a reductant for uranium precipitation in the Athabasca Basin and some deposits within the Kiggavik area (e.g. Bong) (Hoeve and Quirt, 1984; Sharpe *et al.*, 2015). Given that the diagenetic-hydrothermal unconformity-related ingress-egress styles were developed based on deposits within the Athabasca Basin, it is suggested a new model can be developed for the End deposit.

5.2 *Geology and Geochronology of Paleoproterozoic Unconformity-related deposits*

5.2.1 *Athabasca Basin Unconformity-related deposits, Canada*

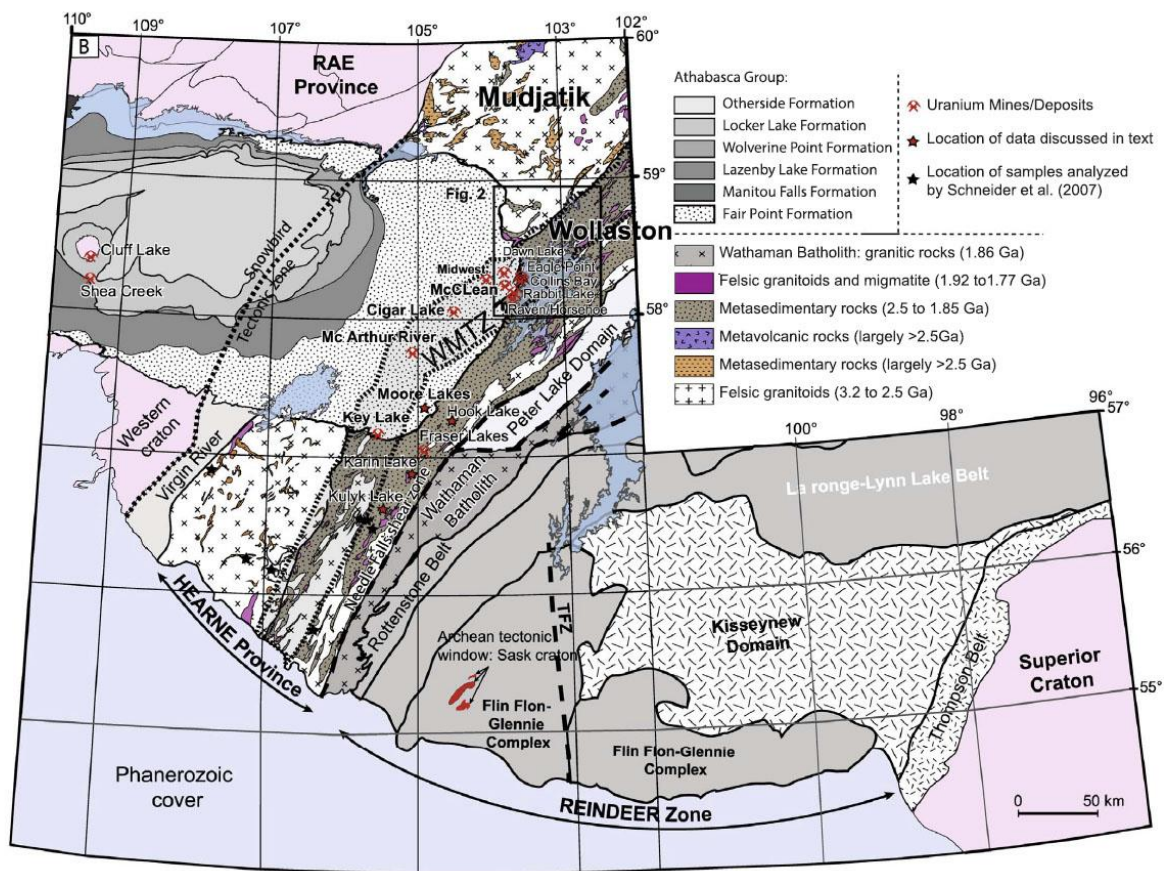
The Athabasca Basin contains a thick package of unmetamorphosed sedimentary fluvial sandstones, capped by marine dolomites, known as the Athabasca Supergroup (Hoeve and Quirt 1984). Ramaekers (2004) and Ramaekers *et al.* (2007) revised the stratigraphy of the Athabasca group and subdivided it into four unconformable sequences. Beginning with sequence (IV) is the Fair Point Formation, the basal unit in the West Athabasca, a package of arkose to subarkosic sandstones; then sequence (III) the Manitou Falls Formation, the basal unit in the East and Central Athabasca, a package of quartz arenites; then sequence (II) the Lazenby Lake and Wolverine Point Formation (1644±13 Ma; fluorapatite cement; U-Pb) , a package of quartz

arenites, and quartz arenites to siltstone, respectively, and finally sequence (I) the Locker Lake Formation and Otherside Formation quartz arenites, Douglas Formation shales (1541 ± 13 Ma; Pyrite; Re-Os; Creaser and Stasiuk, 2007), and Carswell Formation carbonate (dolostone). The age of deposition for the Athabasca Basin has been estimated at $\sim 1730 \pm 18$ Ma as an age of minimum has been suggested to represent a thermal cooling event within the basement rocks (Orrell *et al.*, 1999; Ramaekers, 2004; Rainbird *et al.*, 2007; Ramaekers *et al.*, 2007; Schneider *et al.*, 2007; Alexandre *et al.*, 2009; Jeanneret *et al.*, 2017).

The Athabasca Group unconformably overlies Archean and Paleoproterozoic metamorphic basement rocks of the Rae and Hearne cratons, separated by the Snowbird Tectonic (Fig. 2.1) (Alexander *et al.*, 2009, Jeanneret *et al.*, 2017). The majority of discovered world class uranium unconformity deposits (e.g. McArthur River, Rabbit Lake) reside along the southeastern margin of the Athabasca Basin (Fig. 5.2) and their basement rocks have been well documented (Jeanneret *et al.*, 2017) (Alexandre *et al.*, 2009). East of the STZ the underlying Hearne province is subdivided into several tectono-metamorphic lithological domains including the Virgin River, Mudjatik and Wollaston domains (Alexandre *et al.*, 2009). The underlying Archean Mudjatik domain is separated by the northeast trending Wollaston-Mudjatik Tectonic Zone (WMTZ). The Wollaston domain is predominately comprised of highly deformed Paleoproterozoic graphitic and non-graphitic pelites, psammopelitic and psammitic gneisses (Lewry and Sibbald, 1980). These graphitic lithologies have been considered key in the formation of the Athabasca Basin deposits as serving as reductants in the precipitation of uraninite (Hoeve and Quirt, 1984; 1987). However not only did these lithologies serve as chemical reductants but also as structural controls during regional deformation given their weak rheological nature (Hoeve and Quirt, 1984; 1987).

To the lesser explored western region of the Athabasca, significant unconformity to unconformity-related deposits (e.g. Shea Creek, Patterson Lake South) have been discovered and the current understanding of the basement geology is quite limited. Several workers described the western region is comprised of graphitic metasedimentary units, granulite-facies pelites and psammopelites, silicate iron-formations, granulite-facies mafic to ultramafic rocks that were later subject to retrograde metamorphism (Pagel and Svab, 1985; Card, 2002; Card *et al.*, 2007).

Uranium deposition has been well studied throughout the Athabasca basin and numerous studies have produced a wide range of ages (~1600 - ~300 Ma) (including Hoeve and Sibbald, 1978; Baagsgard *et al.*, 1984; Carl *et al.*, 1992; Phillipe *et al.*, 1993; Fayek and Kyser 1997; Fayek *et al.*, 2002; Alexandre *et al.*, 2009; Cloutier *et al.*, 2009; 2010; Sheahan *et al.*, 2016). The age of primary mineralization within the Athabasca is still is a subject of debate, however, recent studies have suggested primary mineralization formed between ~1600 Ma to ~1460Ma (Alexandre *et al.*, 2009; Sheahan *et al.*, 2016). There are multiple secondary remobilization events that occurred at ~1350, ~1100, ~900, ~535 and ~300 Ma (eg. Hoeve and Quirt, 1984; Cumming and Krstic, 1992; McGill *et al.*, 1993, Fayek and Kyser, 1997; Kyser *et al.*, 2000; Fayek *et al.*, 2002; Alexandre *et al.*, 2009; Cloutier *et al.*, 2010; 2011; Sheanan *et al.*, 2016).



The source of uranium within the Athabasca basin is still subject to debate and two potential sources have been hypothesized. One source of uranium could be from the breakdown of U-bearing detrital accessory minerals (eg. apatite, monazite, and zircon) from the Athabasca Group rocks as basinal brines percolated below (Fayek and Kyser, 1997; Hoeve and Sibbald, 1978; Kotzer and Kyser, 1995). A second source suggests uranium-bearing fluids were derived through the breakdown of uraninite and U-bearing accessory minerals from the underlying basement rocks (including the Hudsonian granites and granitic pegmatites) (Mercadier et al., 2013; Hecht and Cuney, 2000).

A generalized summary of the mineral paragenesis for the unconformity-related basement-hosted uranium deposits in the eastern Athabasca Basin was completed by Alexandre *et al.*, (2009) (Fig. 5.3). Pre- to syn-mineralization alteration consists of illitization and chloritization of the host-rock. Tourmaline (dravite) has also been identified within alteration halos at the Midwest (unconformity-hosted) and Rabbit Lake (basement-hosted) deposits (Hoeve and Sibbald, 1978; Hoeve and Quirt, 1984). This is followed by the uranium ore stage, which consists of the deposition of uraninite and illite. Post-mineralization stage consists of veins of chlorite, euhedral quartz, spherulitic dravite, dolomite and minor kaolinite. Euhedral quartz also formed during the syn-mineralization stage (Hoeve and Quirt, 1984). The uraninite is partially altered to coffinite. A second generation of uraninite occurs with fine grained galena (Alexandre *et al.*, 2009). Trace sulphides are also a part of the post-ore assemblage including pyrite, bornite, pentlandite and cobaltite along with rutile and magnetite.

The mineral paragenesis observed within the End deposit displays some similarities to the general paragenetic sequence observed within the Athabasca basin. Illite developed during syn-mineralization of the End deposit and was coeval with uranium mineralization within deposits of

the Athabasca basin. Post-mineralization events in both the End and Athabasca basin deposits contain hematite. There are however some stark differences which include the lack (to devoid) presence of chlorite within the End deposit associated with mineralization as well the lack of sulphides associated with post-mineralization.

	Host-rocks	Pre-ore alteration	Ore stage	Post-ore stage
Quartz Biotite Muscovite Plagioclase Tourmaline Sphene Graphite				
Illite Chlorite				
Uraninite				
Spherulitic dravite Kaolinite Euhedral quartz Carbonates Pyrite Chalcopyrite Rutile Galena Hematite Fe hydroxides				

Fig. 5.3. Paragenesis of the unconformity-related basement-hosted deposits within the Athabasca Basin (from Alexandre et al.,2009).

5.2.2 McArthur Basin Unconformity-related deposits, Australia

The McArthur basin is comprised of a thick (5 to 10 km) package of sedimentary and volcanic rocks that unconformably overlies the metamorphosed Nimbuwah Domain basement lithologies and that includes the quartz arenitic Komboglie supergroup (Polito *et al.*,2011). The Nimbuwah Domain which has been described as a package of folded amphibolite to granulite grade metamorphosed rocks comprised of the Nanambu Complex, Kakadu Group, the Cahill Formation and the Nourlangie Schist (Polito *et al.*,2011). The Kombolgie subgroup has been divided into six stratigraphic sequences comprised of alluvial fan to braided fluvial facies, proximal to distal braided fluvial facies, upper shoreface and eolian facies and distal braided fluvial to upper shoreface facies (Hiatt & Kyser 2002; Kyser 2007). These facies are quite similar to what is observed in the Thelon Basin. There is, however, one notable difference between the Kombolgie subgroup of the intracratonic McArthur Basin and the otherwise similar Thelon and Athabasca Basins: the age of deposition. The McArthur Basin has a maximum and minimum depositional age of 1822 ± 5 Ma and 1720 ± 7 Ma, whereas the Thelon and Athabasca Basins have slightly younger depositional ages of ~1730-1710 Ma.

The McArthur Basin is host to several unconformity-related deposits, including the Koongarra, Nabarlek, Ranger, and Jabiluka deposits, in the Alligator Rivers Uranium Field (ARUF; Fig. 5.4; Polito *et al.*,2011). The Jabiluka, Ranger, and Koongarra deposits are predominately hosted within the basement in the lower member of the Cahill Formation (graphitic bearing chlorite-biotite-muscovite-feldspar schists) and the Nabarlek is hosted within the basement Nourlangie Schist (muscovite-quartz biotite schist interlayered with thin layers of amphibolite, but without contain graphite or carbonate) (Polito *et al.*,2004; 2011). Uranium mineralization is hosted within major steeply dipping faults that cross-cut the overlying

sandstone and the basement rocks (Polito *et al.*, 2011). It has been suggested that the overlying sandstones within the Komboglie supergroup acted as a diagenetic aquifer that was capped by diagenetic aquitards (Hiatt and Kyser, 2002; Kyser 2007). These diagenetic aquitards acted as a barrier to uranium-bearing fluids and restricted flow towards the more favorable reduced, graphite-bearing rocks which served as a reductant for uranium precipitation (Polito *et al.*, 2004, 2005). Similar to the Athabasca situation, fluids within the McArthur Basin are interpreted to be basinal brines that were initially highly oxidized, acidic, and Ca-rich (Mernagh *et al.*, 1998).

Host-rock alteration within the basement-hosted uranium deposits of the McArthur Basin are spatially extensive and can extend as up to 1 km away from mineralization. The alteration halo within the ARUF deposits are divided into an outer and inner halo. The outer halo is characterized by metamorphic biotite, garnet, amphibole, feldspar, and sillimanite being replaced by chlorite and sericite (illite). Closer to mineralization, the replacement changes from dominant sericitization of feldspars to chloritization (Polito *et al.*, 2011). The inner halo is comprised of strongly chloritized, sericitized rock cemented by uraninite, hematite, sericite/illite, chlorite $\pm$ tourmaline $\pm$ quartz, and is cross-cut by generations of uraninite, chlorite, sericite/illite, and hematite (Polito *et al.*, 2011).

The McArthur Basin basement-hosted deposits are quite different compared to the End Deposit. Although uranium mineralization within the McArthur basin deposits are unconformity-related and “basement” hosted, their alteration halos and basement rocks are quite different compared to End and fit within an egress model. The graphitic basement rocks are served as the primary reductant in the precipitation of uraninite in the McArthur basin whereas the redox mechanism for the End deposit is not carbon-based. The End deposit consists of a distal alteration halo of biotite being replaced by chlorite and sericitization of feldspars (Fig.

4.2A, C, D). Closer to mineralization, the host rock has undergone intense clay alteration and is comprised of illite ($\pm$ phengite; Fig. 4.19;4.20) and is overprinted by hematite. Whereas alteration minerals proximal to mineralization within deposits in the McArthur Basin can be dominantly chlorite $\pm$ illite (e.g. Ranger deposit) (Skirrow *et al.*, 2016) or dominantly illite (e.g. Nabarlek) (Polito *et al.*, 2004). This further suggests that the formation of the End deposit is more closely related to the formation of Athabasca unconformity-related uranium deposits.

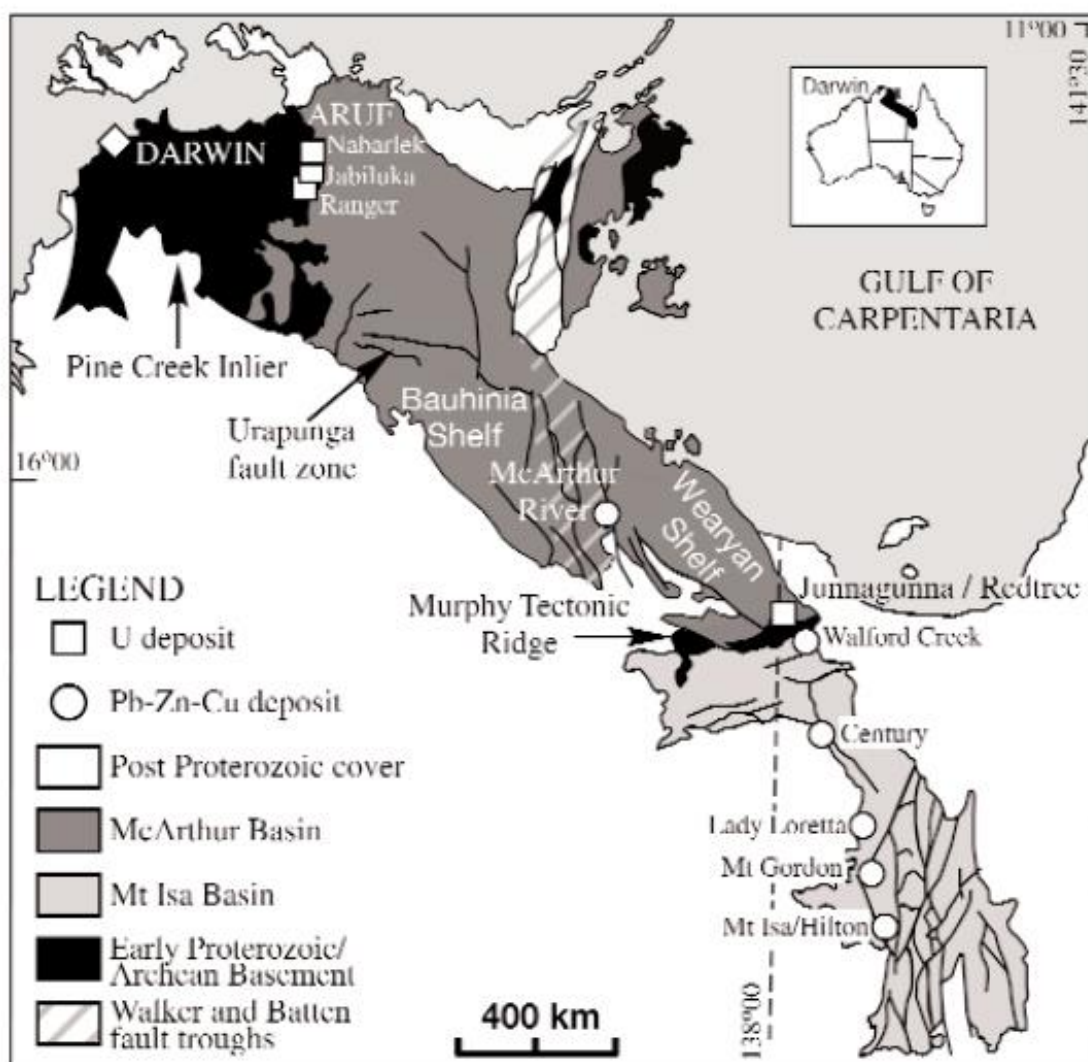


Fig. 5.4. The Alligator River Uranium Field (ARUF) is comprised of several unconformity-related deposits, including the Nabarelk, Jabiluka and Ranger deposits. These are hosted near the unconformity between the McArthur basin sediments and the Early Proterozoic/Archean basement rocks (from Polito *et al.*, 2011).

5.3 Comparison of Fluid Composition and Temperature

As the Thelon, Athabasca, and McArthur basins share a spatial and temporal relationship, the fluids associated with uranium deposition within the End deposit may also be similar. Fluids associated with the Athabasca and McArthur basins have a range of $\delta^{18}\text{O}$ values of 0 to 10‰ and $\delta^2\text{H}$ of -60 to -10‰ and are interpreted to have formed from basinal brines (Kotzer and Kyser, 1993, 1995; Kyser *et al.*, 2000; Alexandre *et al.*, 2005; Polito *et al.*, 2004, 2004; Kyser, 2007; Cloutier *et al.*, 2010). Several researchers have interpreted the fluids within the Athabasca Basin to have formed from basinal brines that may have originated from seawater (Richard *et al.*, 2011, 2012, 2013; Mercadier *et al.*, 2012).

It is likely that the $\delta^2\text{H}$ composition of illite for End deposit was modified by present day meteoric water. The composition of the fluid that deposited U1 and Il1 at the End deposit has a $\delta^2\text{H}$ and $\delta^{18}\text{O}$ of -131 ± 6 ‰ and 4.1 ± 0.8 ‰, respectively. Plotted on a $\delta^2\text{H} - \delta^{18}\text{O}$ discrimination diagram (Fig. 5.5.), the composition of the fluid that precipitated U1 and Il1 plots away from the meteoric hydrothermal fluid, which characterized the much younger (~1100 Ma) U2 event at the Bong deposit (Sharpe *et al.*, 2015). Based on paleo-reconstructions at 1.50 Ga the End deposit would have been located at ~15 ° N and ~15 ° E (Fig. 5.6.) whereas the Athabasca basin was located at ~20 ° N (Pesonen *et al.*, 2003). The $\delta^{18}\text{O}$ and $\delta^2\text{H}$ values of the meteoric fluid at 15 ° N at 1.50 Ga would have been -3.7 and -21 ‰ respectively (Bowen, 2010). Comparing the approximated composition of sea water at the time of U1 mineralization (~1500 Ma), the End deposit plots significantly further away. This type of isotopic modification has also been observed within the Athabasca Basin (Kotzer and Kyser, 1991, 1995). Illite near ore zones in the Athabasca basin have stable isotopic compositions consistent with equilibration with recent meteoric water permeating through existing fractures which resulted in lower $\delta^2\text{H}$ values (Kotzer

and Kyser 1991, 1995). The illite from the End deposit likely exchanged hydrogen isotopes with present day high-latitude meteoric waters resulting in a low $\delta^2\text{H}$ of -132 ‰.

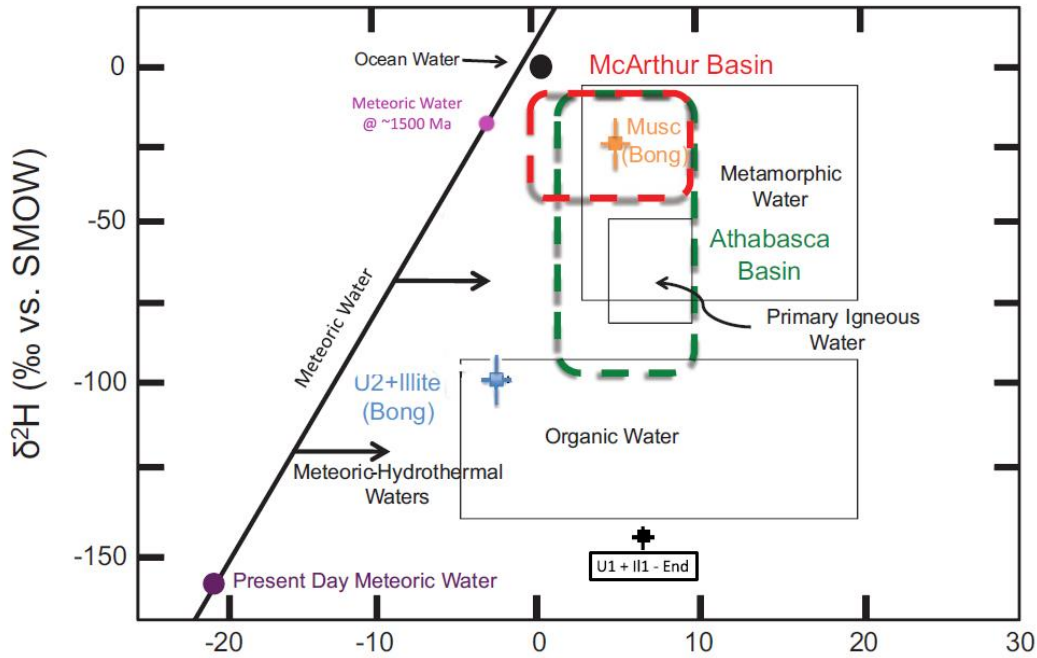


Fig. 5.5. $\delta^2\text{H}$ versus $\delta^{18}\text{O}$ discrimination diagram comparing fluid compositions of fluids associated with the Athabasca Basin (green) and McArthur Basin (red). These values are represented as published values for basement-hosted unconformity related deposits (data from Kotzer and Kyser, 1993; Kyser et al., 2000; Polito et al., 2004, 2005; Alexandre et al., 2005; Cloutier et al., 2010). The End deposit plots much further away compared to the Bong deposit and illite was likely influenced by present day meteoric fluid at the latitude of Kiggavik. The present and paleometeoric water (~1500 Ma) are also plotted for comparison (modified from Sharpe et al, 2015).

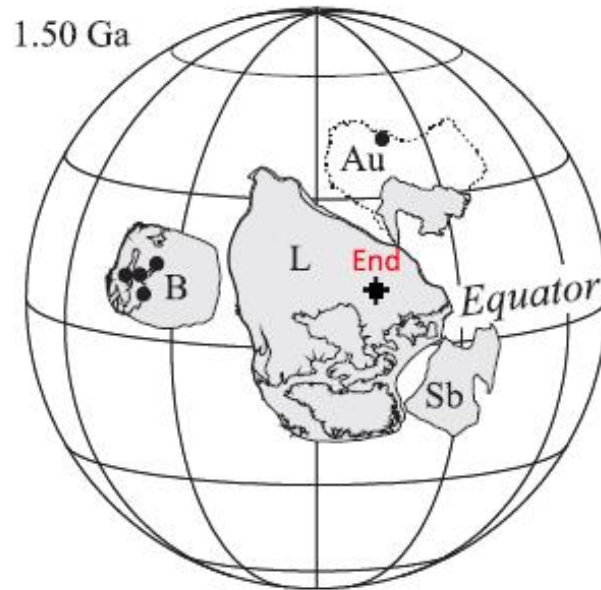


Fig. 5.6. The End deposit was approximately 15 ° N of the equator based on the paleo-reconstruction of the continents Laurentia, Baltica, Siberia and Australia at 1.50 Ga (Pesonen *et al.*, 2003).

The temperature of the fluid that resulted in uranium deposition was calculated using illite chemical composition and isotopic equilibrium thermometry. There are several illite thermometers using illite crystallinity (Frey, 1987), illite composition (Cathelineau and Nieva, 1985; Cathelineau, 1988; Battaglia, 2004) and the reaction of smectite to illite (Hower *et al.*, 1976; Hoffman & Hower, 1979). Work by Cathelineau (1988) observed a strong correlation between K interlayer occupancy and temperature, however these observations only applied to a single geothermal field and could not be carried over to other fields. Battaglia (2004) further expanded the Cathelineau's (1988) work and developed an updated illite thermometer that could be applied to various geothermal fields.

The use of clay minerals as geothermometers has been considered controversial due to diagenetic clay minerals occurring as heterogeneous assemblages with a high variability in composition for each structure type (Essene and Peacor, 1995). Therefore, the illite thermometer developed by Battaglia is only useful as an approximation and the equilibrium isotopic

temperature is far more reliable for calculating the fluid responsible for depositing uraninite and illite. The calculated temperature based on the average illite chemistry the End deposit is $184 \pm 31^\circ\text{C}$. Compared to the temperature calculated from Bong deposit (163°C) using illite chemistry, the temperature of illite formation within the End is $\sim 20^\circ\text{C}$ higher, but within error. Using illite chemistry as an approximate thermometer, illite within both deposits may have formed within temperatures between 163 to 184°C .

The End deposit isotopic equilibrium temperature is comparable to temperatures calculated for other deposits in the Thelon area, as well as those from the Athabasca and Kombolgie basins. The calculated equilibrium isotopic temperature for U1 and Il1 from the End deposit is $210 \pm 16^\circ\text{C}$ and is comparable (within error) to 191°C that was calculated by Sharpe *et al.*, (2015) from the Bong deposit. The difference between the calculated equilibrium isotopic temperature and the illite thermometer is $\sim 20^\circ\text{C}$. Although there is a difference between their isotopic temperatures it is difficult to compare these events directly as not only are they different mineralization styles (U1 at End is disseminated uraninite, whereas U2 at Bong is vein-style uraninite) they were also subject to separate hydrothermal resetting events (U1 at End ~ 1500 Ma, U2 at Bong ~ 1100 Ma). This temperature is also consistent with most deposits within the Athabasca Basin for which a range of temperatures from 200 - 220°C have been estimated (Hoeve and Quirt 1984; Kotzer and Kyser, 1995; Alexandre *et al.*, 2005). The formation temperature estimate of the syn-ore chlorite within the outer and inner alteration zone of ARUF deposits is $209 \pm 41^\circ\text{C}$, (Polito *et al.*, 2004; 2005).

The average oxygen isotope compositions of two styles of quartz breccia (Q3a and Q3b) within the End deposit are 6.3 ‰ and 15.8 ‰ , respectively, which suggests there was more than one quartz deposition event during the extensive silicification phase (QB) as they are isotopically

different. Grare *et al.*, (2018b) identified four main quartz generations using petrography and cathodoluminescence (CL) throughout the Kiggavik area. Quartz brecciation associated with pyrite and hematite (Q3b) have values that are much higher compared to quartz brecciation that occurred within the non-hematized Pipedream assemblage metagreywacke (Q3a). The oxygen isotopic value of Q3a coincides with the alternating blue and brown luminescence euhedral quartz (+7.5-9.3 ‰ $\delta^{18}\text{O}$) observed by Grare *et al.*, (2018b). Quartz associated with hematite and pyrite (Q3b) has a similar oxygen isotopic value of “Late” microcrystalline quartz (Deep blue luminescent) (+14.4-15.5‰ $\delta^{18}\text{O}$) observed by Grare *et al.*, 2018b.

The average oxygen isotope values of calcite associated with the vein-type uraninite (Section 4.1.8.2; Fig. 4.11B) and calcite veins that cross-cut the hematized silica breccia (Section 4.1.9; CAL2; Fig. 4.16) are quite different. The $\delta^{18}\text{O}$ of calcite associated with U2 mineralization is 14.3‰ and the $\delta^{18}\text{O}$ of calcite within CAL2. The oxygen isotopic composition of uraninite throughout the End deposit is very low (<-25‰) whereas $\delta^{18}\text{O}$ within calcite is very high. It is likely then that these represent two generations of calcite veining and that the calcite veinlets that cross-cut the WLg and are not associated with mineralization.

5.4 *The importance of fluid flow for unconformity-related deposits*

Although the egress- and ingress- styles of unconformity-related mineralization are characterized mainly by the host rock, host-rock alteration, and mineralization components, the hydrodynamic and tectonic regime should be included to further characterize unconformity-related uranium deposits. The hydrodynamic models on fluid flow for unconformity-related deposits have been studied by several workers that largely focused on deposits within the Athabasca Basin (Cui *et al.*, 2012; Chi *et al.*, 2012; 2013; 2014; Li *et al.*, 2016). Prior to

developing a fluid flow model to the End deposit, Cui *et al.*, (2012) outlined several constraints/assumptions when developing a conceptual fluid flow model for the unconformity-related U deposits. These include; i) Deposit must be located within or near an unconformity set between highly permeable (sediments, eg. sandstone) and low-permeable (igneous or metamorphic, eg. metamorphosed metagreywacke), ii) spatially associated with basement faulted structures and rocks of reduced lithology, iii) overlying high-permeability sandstone sequences that are covered by relatively low permeable shallow marine sedimentary facies (eg. carbonates), iv) temperature of fluid involving primary mineralization is $\sim 200^{\circ}\text{C}$, 50 to 250 m.y. after basin formation, v) the ore-hosting sedimentary basins experienced protracted fluid histories, and vi) a series of remobilization events occurred after the primary mineralizing event. The conceptual model developed by Cui *et al.* (2012) also assumes that the sedimentary fill must have been 6 to 7 km thick so that the temperatures needed for mineralization could be sustained (with a geothermal gradient of $30^{\circ}\text{C}/\text{km}$).

The End deposit fits several of these constraints and therefore a fluid flow model could be applied to the End deposit. These constraints include the spatial proximity to basement faulted structures (ie. Judge Sissions Fault, Fig. 2.12), temperature of fluid for primary mineralization ($\sim 216^{\circ}\text{C}$) that formed ~ 1540 Ma, 200 m.y after the deposition of the Thelon Formation (~ 1.72 Ga); several deposits within the Kiggavik area (End included) have undergone several remobilization events (Sharp *et al.*, 2015; Shabaga *et al.*, 2017; Grare *et al.*, 2018a; 2020; this study).

The two major forms of tectonic deformation; extensional and compressional deformation can lead to downward and upward flow, respectively. This has implications for the style of unconformity-related deposit that may form. In a compressional regime, reduced fluids

would be forced upwards along reactivated or newly formed basement faults and interact with the oxidized basinal brines within the overlying sandstone (Cui *et al.*, 2012). Whereas in an extensional regime, oxidized basinal brines within the overlying sandstone are forced or pumped downwards along pre-existing faults and interact with the reduced basement rocks. During periods of tectonic quiescence free convection is the dominant form of fluid flow within the overlying highly permeable rocks (Fig. 5.7A) (Hoeve and Quirt, 1984; Cui *et al.*, 2012; Li *et al.*, 2016). When there are periods of tectonic activity this free convection is interrupted and the reduced fluids are then either forced upwards (compression) into the overlying highly permeable rocks or oxidized fluids flow downwards (extension) into the low permeable basement (Fig. 5.7B; Hoeve and Quirt, 1984; Cui *et al.*, 2012; Chi and Xue, 2014).

The hydrodynamic regime also plays a role in the location of uranium mineralization with respect to sedimentary basins. Uranium deposits typically can be located near surface, at moderate depths or at the base of the basin and immediately below the unconformity (Jefferson *et al.*, 2007a,b; Chi and Xue, 2014). Deposits associated near surface are typically associated with the interaction between fresh water and basinal brines (Northrop and Goldhaber, 1990; Sanford, 1992). The conditions needed to form near surface deposits include strong compaction-driven upward basinal fluid flow (Northrop and Goldhaber, 1990) or through the interaction between deep, regional fluids and shallow, local groundwater systems (Sanford, 1992). At moderate depths within the sedimentary basin, uranium mineralization is typically controlled by the interaction between downward flowing, oxidized, uranium bearing fluids and the upward flow of reduced, possibly hydrocarbon bearing, fluids (Hoeve and Quirt, 1989). At the base of the basin, U mineralization can be either at the unconformity or within the vicinity of the unconformity and formed by the interaction between oxidizing basinal fluids and reduced fluids

from the local basement (Kyser *et al.*, 2000, Jefferson *et al.*, 2011). The depth of uranium mineralization could be affected by the fluid over-pressuring which in turn affects the interface between the compaction-driven upward-flowing fluids and the gravity-driven downward-flowing fluids (Chi and Xue, 2014).

Fluid over-pressuring can be affected by the ratio of mud to sandstone within the basin and the overall rate of sedimentation. Sedimentary basins with a low ratio of mud to sandstone and slow sedimentation rates tend to have low fluid overpressures and therefore oxidizing fluids will be driven to the lower parts or the entire basin (Chi *et al.*, 2014). Basins with moderate or equal portions of mud to sandstone and moderate sedimentation rates can display moderate fluid overpressures and therefore uranium mineralization is typically located at moderate depths. Basins with a high ratio of mud to sandstone and rapid sedimentation rates often display high fluid overpressures and therefore uranium mineralization is typically located near the surface (Chi *et al.*, 2014). However, given that the Thelon and Baker Lake basins, and their sub-basins have undergone significant erosion, there is no complete stratigraphic record of the Dubwant Supergroup making a direct comparison difficult (Donaldson, 1965; Rainbird *et al.*, 2003). There is a temporal relationship with between the Athabasca and Thelon basins so it can be assumed that they are spatially related (Rainbird *et al.*, 2007).

The End deposit was likely to have formed in an extensional tectonic setting, given that the deposit is structurally-hosted within faults and reactivated faults within the basement rocks. The overlying Dubwant Super Group is predominately comprised of fluvial sandstones (Rainbird *et al.*, 2003) and rarely contains mud or shale components which would suggest the fluid overpressure within the Thelon was quite low (Cui *et al.*, 2012). Here oxidized fluids would be driven to the lower part of the basin where they would interact with the faulted and reduced

lithologies of the Archean basement. However, in the case of the End deposit, recent fluid inclusion work by (Chi *et al.*, 2017) suggested that the End deposit may have formed near the surface <2 km. Whereas most unconformity-related deposits typically form at depths >5 km (Hoeve and Quirt, 1984; Kotzer and Kyser, 1995). Given that the $\delta^2\text{H}$ illite associated with U1 is very low (-132‰) at the End deposit. If the End deposit formed closer to the surface, then the hydrogen isotopic composition of illite would be greatly influenced by present meteoric waters from the surface (Section 4. – 5.3; Fig. 5.5).

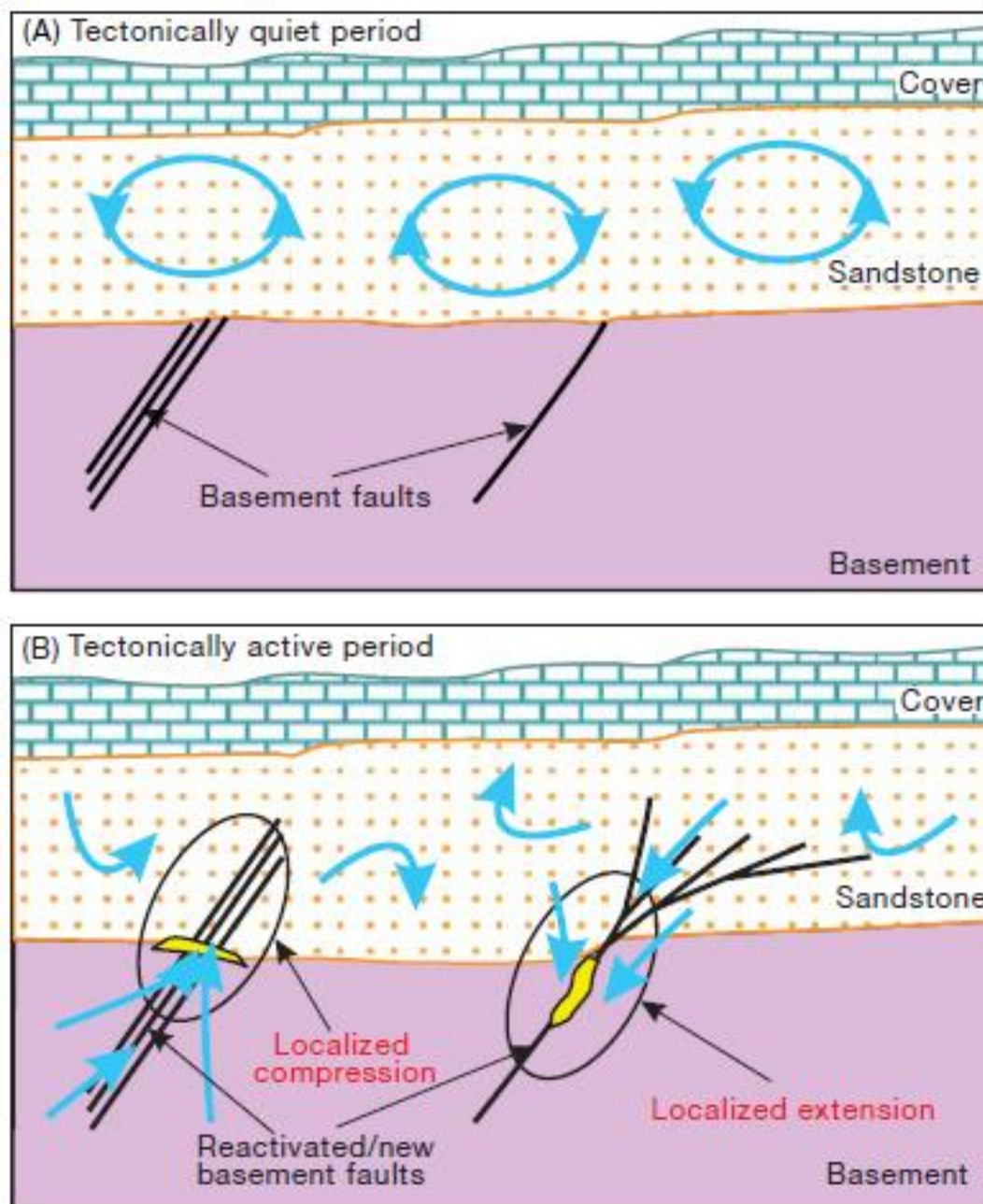


Fig. 5.7. A. During periods of tectonic quiescence, free convection is the dominant form of fluid flow within the overlying high permeable rocks (i.e. Sandstones). B. Periods of tectonic activity can lead to mineralization along the interface between the overlying and underlying host rocks (compression) or along pre-existing or newly reactivated basement faults (extension; from Cui et al.,2012).

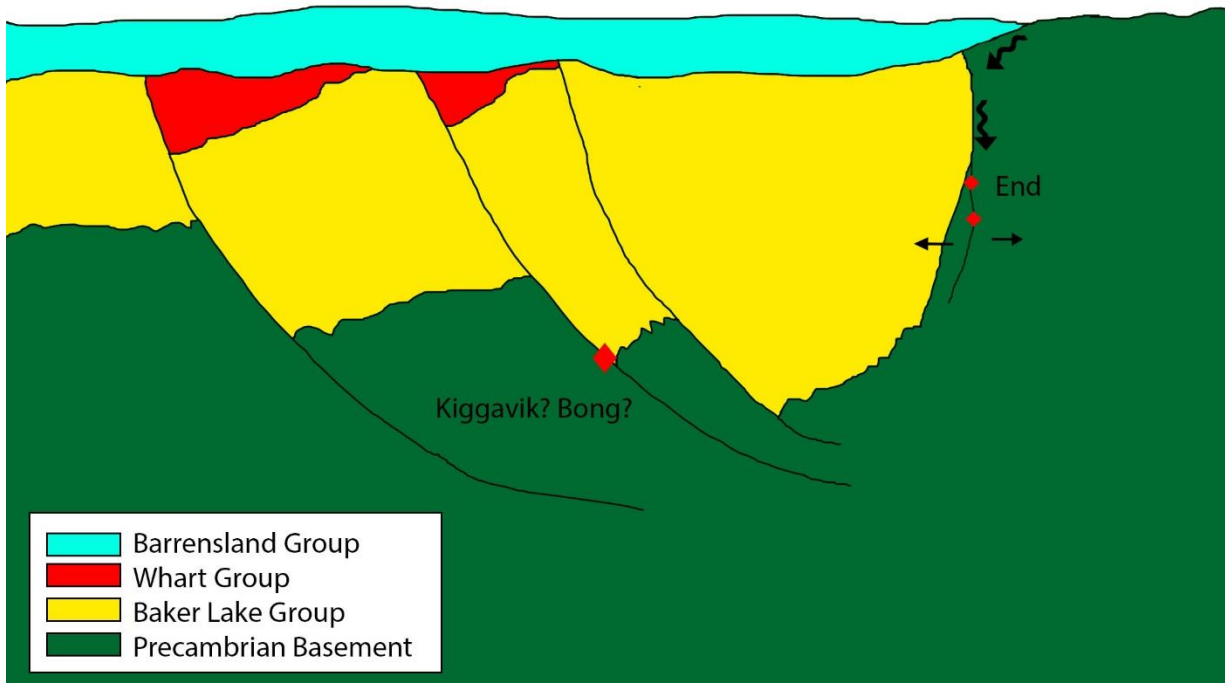


Fig. 5.8. Based on fluid inclusions the End deposit has been suggested to have occurred near the surface (<2 km) whereas most unconformity deposits occur at greater depths (>5 km). Uranium mineralization may have occurred along the basinal margins which also explains the fluid precipitating U1+II1 to be meteoric in origin.

5.5 The mechanisms of Uranium precipitation

The main mechanisms for the precipitation of uranium from aqueous uranium-bearing fluids include boiling, cooling, evaporation, microbial activity, adsorption, reduction-oxidation reactions, a change in pH, and decrease in ligand concentration (Fayek *et al*, 2011).

Uraninite (UO₂) is the geochemically stable in reducing conditions and forms by the reduction of U⁶⁺ to U⁴⁺ (Hostetler and Garrels, 1964; Burns *et al.*, 2006). The drivers of reduction can be 1) carbon-based (e.g. organic material, radiolysis of graphite (Hostetler and Garrels, 1964; Hoeve and Quirt, 1984; Kyser *et al.*, 1989; Alexandre *et al.*, 2005), fluid hydrocarbons (Hoeve

and Quirt, 1984, 1987; Alexandre and Kyser, 2006), or 2) non-carbon-based (e.g. ferrous mineral surfaces, Fe^{2+} or H_2S from oxidation of sulfides (Cheney, 1985; Ruzicka, 1993), or Fe^{2+} from the chloritization of biotite or illitization of hornblende (Wallis *et al.*, 1985; Alexandre *et al.*, 2005). Based on macroscopic and petrographical observations of the Ppd metagreywacke there appears to be no evidence of relict graphite or organic carbon or within faults associated with mineralization. However, this cannot be completely ruled out as the presence of graphite within the basement rocks and faults of the Athabasca Basin have played an important role on uraninite deposition (Hoeve and Quirt, 1984, 1987; Jefferson *et al.*, 2007b). This leaves several non-carbon-based mechanisms that may have led to uraninite precipitation.

The breakdown of pyrite can produce H_2S which can serve as a reductant of U^{6+} (Cheney, 1985; Beyer, 2010) [9]. Pyrite is present outside of the alteration halo and is finely disseminated throughout the Ppd metagreywacke barren zones (Section 4.1.1; Fig. 4.3.). However, this reaction would produce pyrrhotite as a by-product and no pyrrhotite (or any Fe-sulphides for that matter) are associated with the uraninite phases at the End deposit (Section 4.1.1X – Alteration, Desilicification)



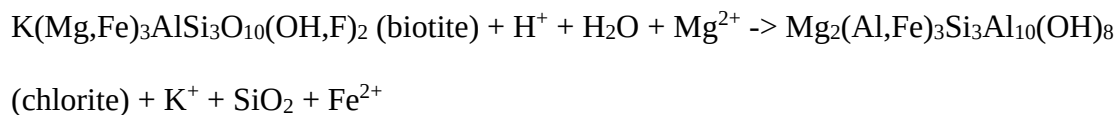
The oxidation of pyrite can also liberate Fe^{2+} [10]. Several phases of uraninite throughout the End deposit is haloed by hematite (Fig. 4.11; 4.12; 4.13; 4.14). Hematite rimming uraninite minerals may have formed from the oxidation and precipitated later [11]. The issue with this mechanism is there are no sulphate bearing minerals present throughout the End deposit. Sulphate bearing minerals including APS (Aluminum-phosphate-sulphate) minerals, gypsum ($\text{CaSO}_4 \cdot \text{H}_2\text{O}$) or barite ($\text{BaSO}_4 \cdot \text{H}_2\text{O}$) could serve as a potential sink for SO_4^{2-} and have been

observed in several deposits within the Athabasca Basin (Hoeve and Quirt, 1984; Gaboreau *et al.*, 2005, 2007) and the Thelon Basin (Riegler *et al.*, 2013). This study did not identify any APS minerals associated with uraninite mineralization, however minute crystals of barite within the secondary porosity has been identified at the End deposit (Riegler *et al.*, 2013). The lack of APS minerals at the End deposit could be due to several factors including their minute grain size (<0.10-10µm) , low concentration (<0.05 wt%) and are highly soluble at low temperatures making them sensitive to dynamic physiochemical conditions (Gaboreau *et al.*, 2005;2007; Dill 2001; Kolitsch and Pring, 2001).



A more likely driving mechanism for the precipitation of uranium in the End deposit is the introduction of Fe^{2+} from the chloritization of biotite (Hoeve and Quirt, 1984; Alexandre *et al.*,2005) [12]. Petrographically, weakly to unaltered metagreywacke contains abundant Fe-Mg biotite (Section 4.1.1; Fig. 4.2a). During retrograde metamorphism and subsequent alteration during uranium mineralization events, a significant amount of Fe^{2+} would have been liberated along with SiO_2 [12]. The chloritization of biotite and illitization of feldspar, biotite, and amphibole can also lead to mineral volume reduction which can create available pore volume for hydrothermal fluids to exploit (Kogure and Banfield, 2000; Alexandre *et al.*,2005; Kyser and Cuney 2008). This volume reduction can increase permeability for fluid flow as the chloritization of biotite results in the conversion of two biotite layers into one chlorite layer; two K interlayer sheets and two tetrahedral sheets are lost and less commonly a potassium interlayer sheet is replaced by a brucite-like sheet (Kogure and Banfield, 2000). However, the timing of

chloritization is important as chlorite can infill these voids, thus preventing uraninite to precipitate. (Alexandre *et al.*,2005). Therefore, dating the retrograde metamorphic event could aid in understanding why zones are strongly altered but are void of uranium mineralization. If the retrograde event occurred during syn-mineralization, then the available pore space would have been exploited during uraninite deposition. However, if the retrograde event occurred much earlier the pore space may have been exploited by the infill of Mg-bearing chlorites and thus preventing the precipitation of uraninite. This volume reduction mechanism could explain how uranium-bearing fluids would have precipitated uraninite along small scale mineral structures (grain boundaries) and lead to the precipitation of disseminated (U1) mineralization at End. Chlorite distal to mineralization is primarily Mg-bearing (Fig. 4.19) which would be expected from the conversion of biotite to chlorite [12]. This initial event would have introduced excess Fe^{2+} and SiO_2 into subsequent fluid events.



[12]* Stoichiometrically unbalanced

The temperature of the fluid that precipitated disseminated uraninite (U1) and illite (Il1) was approximately 210 °C. The presence of illite at this temperature suggests the pH of the fluid at the time of deposition was between ~5 and 6 (Fig. 5.9) (Romberger, 1984; Kotzer and Kyser, 1995). If the initial fluid was oxidizing (interaction of overlying sandstones) and acidic (pH ~5-6), then Fe^{2+} and U^{6+} would be the dominant species in solution (Fig. 5.9). During periods of extension this oxidized fluid would have flowed downwards towards the basement rock and penetrated within the foliated Ppd metagreywacke. This fluid would interact with mineral grain boundaries and lead to the breakdown of biotite and oxidation of pyrite which would produce

ferrous iron [10][12], and a fluid that is more reduced which would increase the fluid pH to ~6. This process could induce precipitation of uraninite and illite due to a decrease fO_2 by the addition of ferrous iron. The host rock would have been competent during the initial stage and the fluids may have traveled along planes of weakness (e.g., mineral grain boundaries). During retrograde metamorphism the decrease in volume from biotite altering to chlorite would have created a more permeable and porous matrix that would allow higher volumes of fluids to permeate the host rock, which could have resulted in forming disseminated uraninite (U1).

The final stage of mineralization (U3) represents localized uranium re-mobilization. Here an oxidized, acidic fluid would have stripped Ca from Ca-bearing silicates (e.g. Garnet) and Si from quartz. This introduction of Ca and Si to the fluid was then incorporated with remobilized uranium from the breakdown of U1 to produce altered by-products of uraninite (ie. Coffinite and uranophane). As the fluid exploited planes of weakness (e.g. foliation (U3a) and quartz vein margins (U3b) Fe^{2+} would be stripped from residual Fe-bearing silicates within altered and unaltered basement. Much like the precipitation of U1, U^{6+} would have reduced to U^{4+} as the fO_2 would have decreased by the incorporation of Fe^{2+} into the fluid. This oxidation of iron and reduction of uranium would have resulted in the precipitation of hematite and uraninite (U3) [11].

The roll-front style uraninite mineralization (U3c) observed within End deposit also displays textural similarities to other roll-front style mineralization observed throughout the Kiggavik region (Bong, Sharpe *et al.*, 2015; Andrew Lake, Shabaga *et al.*, 2017). Roll-front style mineralization is typically described as having a reduced, strongly bleached (reduced) concave side, with a hematite (oxidized) convex side with Uraninite occurring along a redox reaction front between these zones (McLemore 2007; Dahlkamp 2009). Similar to the Andrew Lake and

Bong deposits, the roll-front mineralization (U3c) at the End deposit occurs along these redox reaction fronts. These reaction fronts are not only irregular but can also display “inverse” roll-front mineralization, where the usual oxidized hematite and the bleached (reduced) illitized side appear on either the convex and concave sides (Fig. 4.14B,C) or in some cases the host rock can be strongly reduced on both sides (Fig. 4.14B).

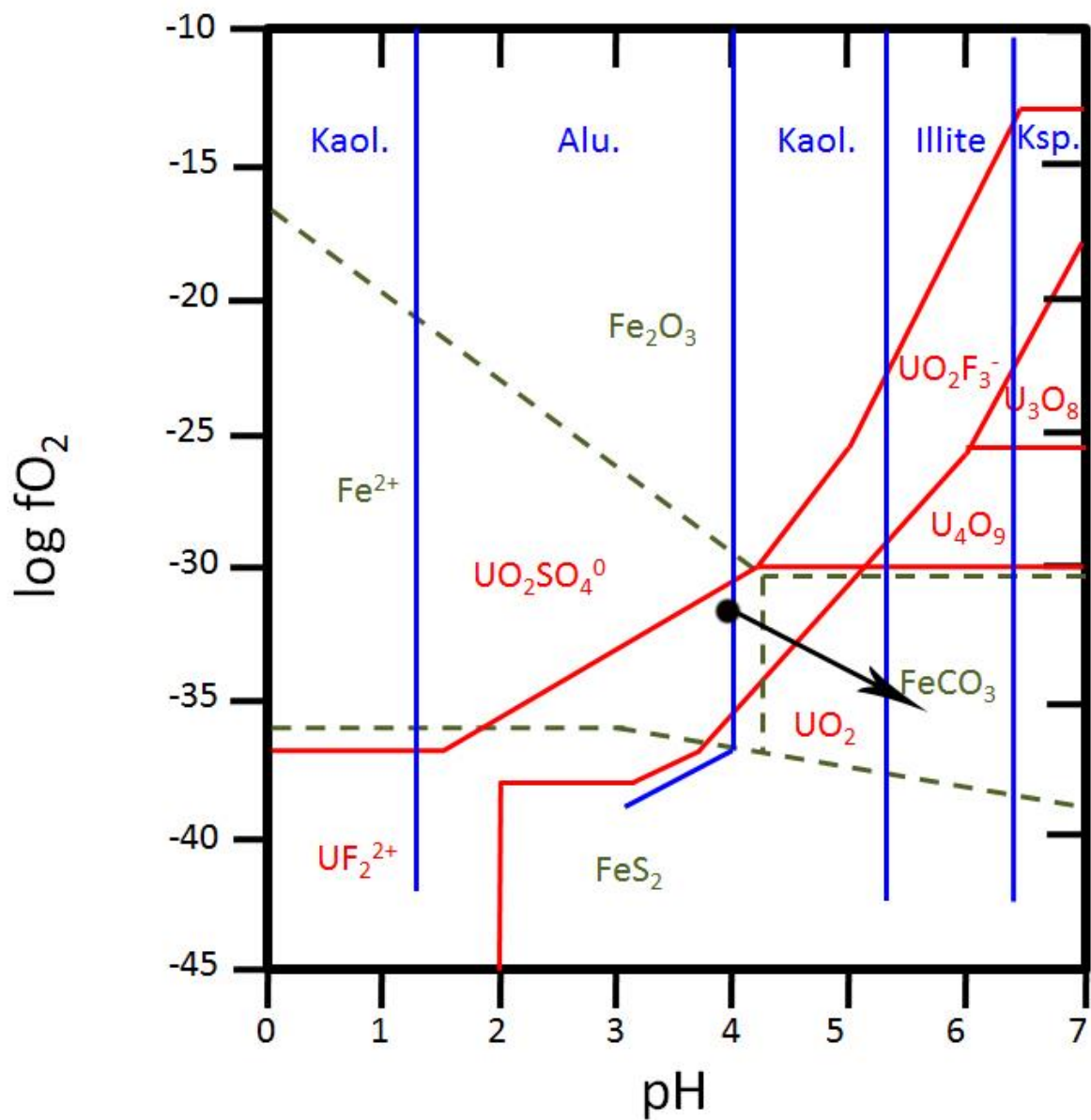


Fig. 5.9. Pourbaix diagram of the U-F-S-O system with a Fe-O and clay mineral system overlay @ 200°C 10 ppm Fe, 100 ppm F, S, 1000 ppm K, 1.0 m NaCl, $P_{\text{CO}_2} = 10$ atm. A change in pH and change from oxidizing to reducing conditions likely led to the precipitation of U1 (modified from Romberger, 1984).

5.6 Geochronology of the End deposit

Currently there are few published ages for uranium minerals from the Kiggavik region (Table 5.1). Farkas (1984) obtained bulk U-Pb isotopic ages of 1403 ± 10 Ma and 1000 ± 10 Ma from the Kiggavik deposit. More recent *in situ* dating was completed at the Bong, End, and Andrew Lake deposits (Reigler *et al.*, 2014; Sharpe *et al.*, 2015, Chi *et al.*, 2016; Shabaga *et al.*, 2017, this study,). Three mineralization events within the Bong deposit were dated by Sharpe *et al.* (2015): “disseminated” uraninite (1520 ± 79 Ma); vein type uraninite and uraninite associated with organic matter (1114 ± 8 Ma), and finally roll front uraninite (982 ± 18 Ma). Recent U-Pb geochronology on the Andrew Lake deposit by Shabaga *et al.* (2017) produced an age of 1031 ± 23 Ma on the first stage of uraninite known as “vein-type” uraninite. The second stage of uraninite altered to coffinite had an average age of 528 ± 34 Ma. A third event which lead to the alteration of all uraninite phases at the Andrew Lake deposit had an age of <1 Ma (Shabaga *et al.*, 2017). The uraninite “vein-type” mineralization at the End deposit has been dated by several workers and produced ages 1293 ± 3 Ma and 1296 ± 6 Ma (Chi *et al.*, 2016; Riegler *et al.*, 2014, respectively).

Including the U-Pb ages from the End deposit, there appear to be four distinct uranium mineralizing events in the Kiggavik area: at ~ 1500 Ma, ~ 1300 Ma, ~ 1000 Ma and 750 Ma. Disseminated uraninite from the Bong deposit dated at 1520 ± 79 Ma by Sharpe *et al.* (2015) is within error of End deposit U1 disseminated uraninite (1459 ± 59 Ma), which suggests the occurrence of a regional mineralization, or resetting event at ~ 1500 Ma. A second event occurred at ~ 1300 Ma, based on dating of the End deposit vein-type (U2) uraninite (this study; Chi *et al.*, 2016; Riegler *et al.*, 2014). Galena (1296 ± 29 Ma; Pb-Pb) associated with U2 uraninite likely formed coeval to uraninite given its similar age. Finally, there are several U-Pb uraninite ages

obtained that suggest a mineralizing event at ~1000 Ma (End Deposit 970 ± 35 Ma (this study); Bong 982 ± 18 Ma (Sharpe *et al.*, 2015); Andrew Lake 1031 ± 23 Ma (Shabaga *et al.*, 2017)). The ~750 Ma age from the roll-front style (U3c) has not been identified at other deposits within the Kiggavik area. Roll-front mineralization has been identified within the Bong and Andrew Lake deposits however those events yielded older and younger ages, 982 ± 18 Ma, and ~530 Ma, respectively. It is possible the roll-front style remobilization of uranium occurred at the same, but was subject to different hydrothermal isotopic resetting events.

Argon-argon geochronology of alteration minerals (illite and muscovite) from the End deposit is also in agreement with the uraninite U-Pb ages within the Kiggavik camp. Three ages were determined at 1308 Ma (step-wise age), 1474 Ma (plateau age), and 1603 Ma (step-wise age). The 1308 Ma age is likely associated with the resetting of the vein-type (U2) mineralization potentially by the emplacement of the Mackenzie Swarm diabase dykes (1267 ± 2 Ma; Le Cheminant and Heaman, 1989). The plateau age of 1474 Ma coincides with the age of the disseminated mineralization (U1: 1459 ± 55 Ma). These alteration ages are also in agreement with K-Ar ages of illite (1291 ± 23 Ma; 1287 ± 18 Ma) dating an alteration event of the Lone Gull intrusive (Weyer, 1992). Although the age of 1603 has not been observed elsewhere at the End deposit, this age is within experimental error of the age of disseminated uraninite (1520 ± 79 Ma) at the Bong deposit, and muscovite ($\sim 1599 \pm 20$ Ma) from the Andrew Lake deposit (Shabaga *et al.*, 2017).

Based on chemical composition, uraninite mineralization from the End deposit is weakly to highly-altered and, in turn, the U-Pb ages likely represent isotopic resetting events that resulted in Pb-loss and are also recorded throughout the Kiggavik area. The oldest age obtained from the disseminated (U1) mineralization (1459 ± 55 Ma) is within error of the deposition of

the Kuungmi basalts, one of the capping lithologies of the Barrenland Group (~1500 Ma). Vein-type uraninite (U2; 1280 ± 32 Ma (this study), 1293 ± 3 Ma, Chi *et al.*, 2016; 1296 ± 6 Ma, Reigler *et al.*, 2014) coincide with two thermal events the 1) MacKenzie Dyke Swarm (1267 ± 2 Ma; Le Cheminant and Heamen, 1989) or 2) an alteration event at 1292 ± 23 Ma defined by the K-Ar age of illite within the Lone Gull Granite (Weyer, 1992). Infill-type uraninite (U3b) has an age of 970 ± 35 Ma and may coincide with a late alteration event observed by Weyer (1992) within the Lone gull stock (~912-930 Ma). The roll front uraninite (U3c) within the End deposit (754 ± 79 Ma) may be attributed to initial rifting of the Rodinia supercontinent (850-750 Ma; Powell *et al.*, 1993).

The timing of various alteration and uranium mineralization events at the End deposit also appear to coincide with alteration and mineralization events that have affected the Athabasca Basin and the McArthur River Basin (Komboglie Formation), and they generally correlate with significant orogenic and regional plutonic events (Kotzer and Kyser, 1995; Fayek *et al.*, 2002; Alexandre and Kyser, 2005) (Fig. 5.10). Far-field tectonic stresses related to these orogenic events may have resulted in creation and/or reactivation of basement faults where uranium-bearing hydrothermal fluids would exploit (Alexandre and Kyser, 2005).

At ~1600 Ma, the accretion of Nena coincides with the initial alteration of the basement rocks associated with the End deposit (1603 ± 4 Ma), but also within syn-ore illite ($1583 \text{ Ma} \pm 17$ Ma) and pre-ore chlorite (1597 ± 11 Ma) from basement-hosted deposits within the Athabasca Basin (Alexandre *et al.*, 2009). Cloutier *et al.* (2010) reported an early alteration age (1607 Ma) for muscovite from the Athabasca Basin Eagle Point deposit. Syn-ore illite from the unconformity-related banded hosted Dawn Lake prospect in the Athabasca basin had a plateau age of 1583 ± 17 Ma (Alexandre *et al.*, 2009). There are few reported U-Pb ages of uraninite

within the ARUF as authors predominately relied on Pb-Pb and chemical ages of uraninite (Polito *et al.*, 2004; 2005).

There appears to be a thermal resetting event from ~1500-1400 Ma based on these ages and it is poorly understood what tectonic event it may correspond to (Alexandre *et al.*, 2009). Disseminated uraninite U1 (1459 ± 55 Ma) coincides with several U-Pb and Ar-Ar ages within the Athabasca basin. Illite within the pre-ore alteration in both sandstone-hosted and basement-hosted deposits had Ar-Ar ages of 1405 ± 24 Ma and 1399 ± 11 Ma, respectively and are within experimental error to U1 (Alexandre *et al.*, 2009). Dating of uraninite within the Virgin river prospect also produced a U-Pb age of 1471 ± 37 Ma (Alexandre *et al.*, 2009). The Ranger deposit within the ARUF has a single reported age of 1437 ± 40 Ma (Ludwig *et al.*, 1987). Alexandre *et al.*, (2009), suggested the (~1400 Ma) age could correspond to the Berthoud Orogeny located presently in South Western Colorado, USA during a period of contractional orogeny along the southern Laurentia (Nyman *et al.*, 1994).

At ~1300 Ma, there are several U-Pb ages within the Athabasca basin that coincide with the timing of remobilization of uranium at the End deposit. Sheanan *et al.* (2016) obtained an age of basement mineralization of ~1280 Ma from the Shea Creek deposit, which is similar in age to the age of U2 vein-type uraninite within the End deposit. Uraninite from one of the basement-hosted ore-bodies within the McArthur River deposit (Athabasca basin) was dated and yielded a U-Pb age of 1247 ± 17 Ma which coincides with U2 uraninite at the End deposit (Alexandre *et al.*, 2009). Cloutier *et al.*, (2011) completed U-Pb and Pb-Pb age dating of uraninite from the Eagle point (basement-hosted) deposit yielded several ages of 1294 ± 11 Ma (Pb-Pb) 1300 ± 14 Ma (U-Pb) and 1338 ± 44 Ma (Pb-Pb).

At ~1100 Ma, the Grenville orogeny (1085-985Ma) has been suggested be the cause of fault movement and resetting of uraninite ages from the Athabasca Basin (Hoeve and Quirt, 1984; Kotzer and Kyser, 1990; Sheahan *et al.*, 2016). This event is also recorded within U deposits of the Kiggavik area as evident from U-Pb and Pb-Pb ages (within error) from End (U3b: 971 ± 35 Ma (U-Pb); U3a: 1043 ± 43 Ma (Pb-Pb) , Bong (982 ± 18 Ma (U-Pb), 1030 Ma (Pb-Pb) and the Andrew Lake deposits (1031 ± 23 Ma (U-Pb).

At ~750 Ma marks the initial rifting of the Rodinia supercontinent (1000-750 Ma) (Powell *et al.*, 1993). At the time of this study there are few ages recorded during this event within the Athabasca and Thelon basin unconformity-related deposits (982 ± 19 Ma; U-Pb: Bong (Sharpe *et al.*, 2015). As for the McArthur Basin, Work by Polito *et al.*, (2005) reported a cluster of Pb-Pb age populations at 802 ± 57 Ma within the Jabiluka deposit.

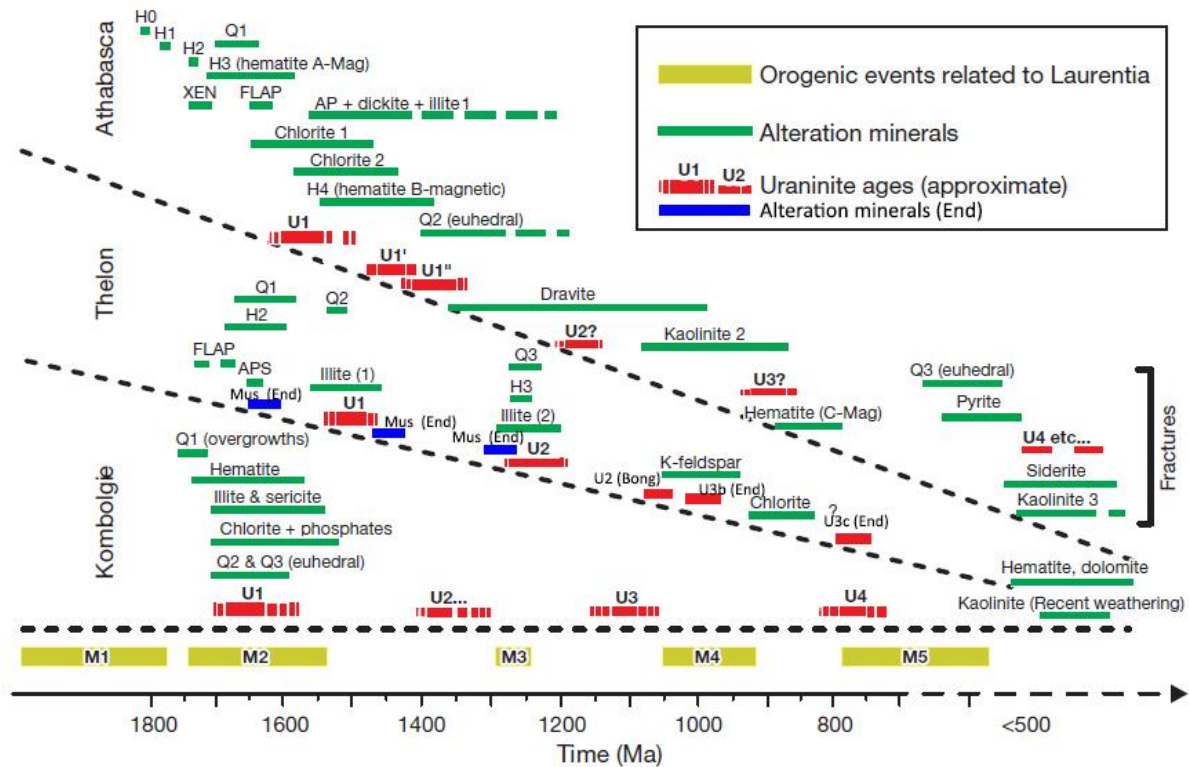


Fig. 5.10. Paragenetic relationship between the Athabasca, Thelon and McArthur basins with respect to significant orogenic and regional plutonic events. M1 = Trans Hudson Orogeny, M2 = Accretion of Nena, M3 = Mackenzie Dyke swarm, M4 = Grenville Orogeny, M5 = Breakup of Rodinia (modified from Cui et al., 2012; Jefferson et al., 2007; Betts et al., 2008; Hiatt et al., 2009).

Table 5.1. Summary of new and previous geochronological data from the Kiggavik area, including alteration, mineralization, and regional thermal events.

Reference	Type	Deposit/Alteration/Intrusion	Technique	Mineral	Age
Ashcroft (this study)	Alteration	End	Ar-Ar	Muscovite	1603 ± 4 Ma; 1474 ± 11 Ma; 1308 ± 8 Ma
Ashcroft (this study)	Mineralization	End	U-Pb	Uraninite	1459 ± 55 Ma; 1280 ± 32 Ma; 970 ± 35 Ma; 750 ± 74 Ma
Chi <i>et al.</i> ,2016	Mineralization	End	U-Pb	Uraninite	1293 ±3 Ma
Shabaga <i>et al.</i> (2017)	Mineralization	Andrew Lake	U-Pb	Uraninite; Coffinite	1031 ± 23 Ma; 524 ±38 Ma
Shabaga <i>et al.</i> (2017)	Alteration	Andrew Lake	Ar-Ar	Muscovite	1599 ± 20 Ma; 1782 ± 18 Ma
Shabaga <i>et al.</i> (2017)	Alteration	Andrew Lake	Ar-Ar	Illite	1794 ± 31 Ma; 1330 ± 36
Sharpe <i>et al.</i> (2015)	Mineralization	Bong	U-Pb	Uraninite	1520 ± 79 Ma; 1114 ± 8 Ma; 982 ± 19 Ma
Riegler (2013)	Mineralization	End	U-Pb	Uraninite	1293 ± 6 Ma; 1187 ± 19 Ma
Riegler (2013)	Alteration	Bong	Ar-Ar	Illite	1124 ± 9 Ma*
Weyer (1992)	Alteration	Lone Gull granite (Kiggavik Main/Centre)	K-Ar	Illite	912.8 ± 16.7 Ma; 930.4 ± 18.4 Ma; 930.0 ± 19.9 Ma
Weyer (1992)	Alteration	Lone Gull granite (Kiggavik Main/Centre)	K-Ar	Illite	1229 ± 18 Ma; 1166 ± 18 Ma
Weyer (1992)	Alteration	Lone Gull granite (Kiggavik Main/Centre)	K-Ar	Illite	1291 ± 23 Ma; 1287 ± 18 Ma
Farkas (1984)	Mineralization	Various Lone Gull	U-Pb	Uraninite	1403 ± 10 Ma; 1000 ± 10 Ma
Farkas (1984)	Alteration	Various Lone Gull	Pb-Pb	Galena	1418 Ma (no error reported)
Fuchs <i>et al.</i> (1986)	Alteration	Various Lone Gull	K-Ar (whole rock)	N/A	1648 Ma; 1563 Ma; 1358 Ma; 1073 Ma (no errors reported)
Scott <i>et al.</i> (2015)	Intrusion	Granite Grid monzogranite (Hudson)	U-Pb	Zircon	1840 ± 11 Ma
Scott <i>et al.</i> (2015)	Intrusion	Syenite dyke, Kiggavik (Hudson-Martell)	U-Pb	Zircon	1817.5 ± 7.8 Ma
Scott <i>et al.</i> (2015)	Intrusion	Monzogranite sill, Kiggavik (Hudson)	U-Pb	Zircon	1830 ± 16 Ma
Scott <i>et al.</i> (2015)	Intrusion	Lone Gull granite, Hudson portion	U-Pb	Zircon	1820 ± 12 Ma; 1836 ± 22 Ma
Scott <i>et al.</i> (2015)	Intrusion	Lone Gull granite, Nueltin portion	U-Pb	Zircon	1759 ± 20 Ma
Scott <i>et al.</i> (2015)	Intrusion	Lone Gull granite, Nueltin portion	U-Pb	Titanite	1759 ± 44 Ma
Scott <i>et al.</i> (2015)	Intrusion	Bong syenite, Martell (Hudson) portion	U-Pb	Zircon	1837.8 ± 7.7 Ma
Scott <i>et al.</i> (2015)	Intrusion	Bong syenite, Nueltin portion	U-Pb	Titanite	1758.5 ± 44 Ma
Scott <i>et al.</i> (2015)	Intrusion	Schultz Lake Intrusive Complex (Hudson-Martell)	U-Pb	Zircon	1839.7 ± 9.3 Ma
Davis <i>et al.</i> (2011)	Cement	Thelon Fluorapatite cement	U-Pb	Apatite	1667 ± 7 Ma
Chamberlain <i>et al.</i> (2010)	Intrusion	Kuungmi ultrapotassic Lavas	U-Pb	Baddeleyite	1540 ± 30 Ma
Weyer (1992)	Intrusion	Lone Gull granite (Kiggavik Main/Centre)	K-Ar	Muscovite	1804 ± 32 Ma
Weyer (1992)	Intrusion	Lone Gull granite (Kiggavik Main/Centre)	K-Ar	Biotite	1848 ± 33 Ma
Weyer (1992)	Intrusion	Lone Gull granite (Kiggavik Main/Centre)	K-Ar	Hornblende	1155 ± 19 Ma
LeCheminant and Heaman (1989)	Intrusion	Mackenzie diabase dykes	U-Pb	Baddeleyite and Zircon	1267 ± 2 Ma

*only plateau age from Riegler (2014) where >50% ³⁹Ar released

Table modified from Sharpe *et al.*, (2015)

5.7 Metallogenetic Model for the formation of the End deposit

The End deposit has a protracted fluid history. The metallogenetic model for the End deposit, described below, is based on petrography, mineral paragenesis, isotopic fluid compositions, proposed redox reactions, and U-Pb and Ar-Ar geochronology (Fig. 5.11A-G).

Stage 1: The Ppd metagreywacke was intruded by the Nuelin granite (~1760 Ma), lamprophyre and pegmatitic dykes (~1760 Ma). The basement was later subjected to retrograde metamorphism characterised by the replacement of biotite to chlorite and feldspars to sericite (Section 4.1.6)

Stage 2: Pre-mineralization consists of several sub-stages including silicification of the Ppd, by quartz brecciation (QB) during the Hudsonian intrusive event (Scott *et al.*, 2015; Sharpe *et al.*, 2015; Grare *et al.*, 2018b), and precipitation of pyrite (Fig. 5.11B), which is then succeeded by desilicification, and sericitization of the host rocks (Fig. 5.11C). Alteration from this stage is dated at 1600 Ma.

Stage 3: Primary mineralization stage begins with the precipitation or resetting of disseminated U1 uraninite at ~1500 Ma with coeval illite (Ill1) (Fig. 5.11D) from fluids at ~210° C.

Stage 4: Secondary subsequent fluid events at ~1300 Ma remobilized uraninite along pre-existing fractures and faults forming vein-style uraninite ((U2; Fig. 5.11E).

Stage 5: Late oxidized, acidic uranium-bearing fluids, precipitated uraninite along the primary foliation (U3a), infilled along quartz vein margins and fractures (U3b) and formed as inverse roll-front style uranium mineralization (U3c) (Fig. 5.11F; with a range of ages).

Stage 6: The post-mineralization stage consists of a late hematization event which is in turn cross-cut by quartz ± calcite veinlets (Fig. 5.11G).

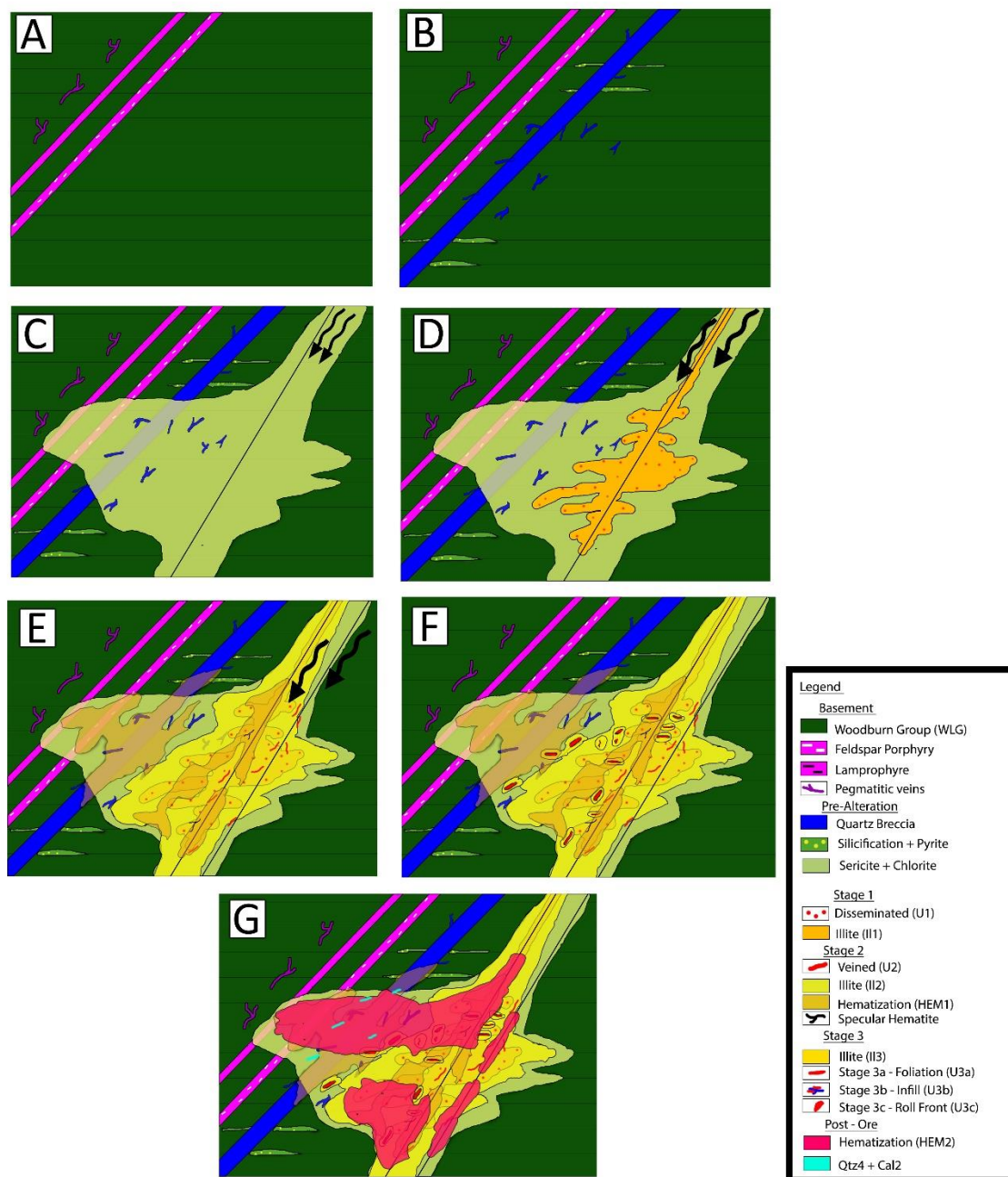


Fig. 5.11. Genetic model of the End deposit A. Geology of the basement rock. B. Pre-mineralization; Quartz brecciation, silicification and pyrite precipitation C. Pre-mineralization This is succeeded by faulting and sericitization of the basement rock. D. Primary mineralization; Hot acidic, oxidizing fluids move along faults leading to extensive argillization of the basement rock. This leads to precipitation of disseminated uraninite (U1) (~1500 Ma). E. Secondary mineralization; A second faulting and reactivation event leads to formation of vein-type uraninite (U2) (~1300 Ma). Residual Fe^{2+} leads to the oxidation of iron forming hematite (Hem1). F. U remobilization mineralization; A remobilization event forming foliation-parallel (U3a), infill-type (U3b) (~970Ma) and rollfront-type uraninite (U3c) (~750Ma). G. Post-mineralization; Dark brick red –pink hematite is precipitated and overprinted much of the End deposit and quartz breccia (HEM2). Calcite infills vugs and uraninite veinlets (Cal 2) and euhedral quartz (Q4) infills vugs within the quartz breccia (Q3).

Chapter 6.0: Conclusions

Petrographic, geochemical, and isotopic methods were completed to characterize and develop a genetic model for the formation of the End deposit. The main conclusions from this study are:

1. The End deposit consists of three styles of uranium mineralization, disseminated uraninite (U1); vein-type (U2), and a late style (U3) comprised of three sub-styles; foliation-parallel (U3a); infill-type (U3b), and inverse roll front type (U3c).
2. Primary disseminated uraninite (U1) has an age of 1455 ± 55 Ma; an age which may be a geochronological reset by the Kuungmi basalt igneous event (~ 1500 Ma); Secondary vein-type (U2) has an age of 1280 ± 32 Ma and may be related to the intrusion of the MacKenzie Dyke Swarm (~ 1270 Ma); Remobilization infill-type and roll front-type uraninite (U3b) and (U3c) give ages of 970 ± 35 Ma and 754 ± 79 Ma, respectively. This remobilization event may be associated with the Grenville Orogeny (~ 1100 - 980 Ma) and the breakup of Rodinia (~ 750 - 580 Ma).
3. $^{40}\text{Ar}/^{39}\text{Ar}$ geochronology of muscovite within the alteration zone of the End deposit gives three ages; 1603 ± 8 Ma, 1474 ± 26 Ma, and 1308 ± 13 Ma. The age of 1603 Ma doesn't correspond to any regional events, however, it is consistent the accretion of Nena and the primary mineralization of the ARFU and deposits.
4. The initial fluid had a temperature of 210 ± 16 °C based on the stable isotopic equilibrium temperature using uraninite-water and illite-water fractionation factors. The fluid had an isotopic composition of $\delta^{18}\text{O}$ 4.1 ± 0.8 ‰ and $\delta^2\text{H}$ of -131 ± 5 ‰. It appears that the hydrogen isotopic composition of illite had been strongly overprinted by present day meteoric water.

5. The End deposit formed in four stages. After the emplacement of the Nuelin granite (~1760 Ma) and lamprophyre dykes within the Pipedream metagreywacke (Stage 1), the basement rocks were subjected to retrograde metamorphism (Stage 2) and later quartz brecciation (silicification) and pyritization. This was succeeded by a syn-mineralization stage (Stage 3); comprised of 3 mineralization events; disseminated uraninite (U1 ~1500 Ma), vein-type uraninite (U2~1280 Ma) and a third fluid stage with three sub-stages (U3), where a oxidized fluid remobilized uraninite along the foliation (U3a), infilled fractures within quartz veins (infill-type; U3b; ~970 Ma) and along reduced-oxidation fronts as inverse roll front-type (U3c; ~750 Ma). A post-mineralization alteration event (Stage 4), consisted of a oxidized fluid event led to widespread hematization, altering uraninite and precipitating calcite and euhedral quartz.

6.1 *Recommendations for Future Work*

Although this work presented in this report advances our understanding of the uranium deposits of the Kiggavik region, the following work is still required to develop a more comprehensive exploration model:

- a) Characterization of all hematite phases (including specular hematite) within the End deposit area and determine the relative timing of each phase to uranium deposition. This also includes determining the potential of absolute age dating of all phases of specular hematite using U/Th/He geochronology, and carrying out this work if possible.
- b) Performance of additional Ar-Ar dating of the various alteration minerals amenable to this method of geochronology and non-mineralized structures to better link tectonic events to mineralization.

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**Appendix A –
Drill Log and Thin Section Descriptions**

Table A.1 – Drill Log description of END-09-04 from End Deposit, Thelon Basin, Nunavut, Canada.

Depth(m)	Lithology	Alteration	Description
0-10.80	Overburden		
10.80-53.95	Metagreywacke	Hematite	-Fine grained, moderately foliated, hematite stained throughout, 10-15% brecciated by quartz (QTZ) - 13-14m, contains quartz +/- clay veins and micro veinlets of fine-grained specular hematite that are cross-cut by quartz -44.22-53.95- quartz veining parallel to core axis (TCA)
53.95-58.80	Metagreywacke	Clay	-Strongly bleached, clay altered Metagreywacke, trace fine grained specular hematite along foliation (57.55-58.8)
58.80-63.50	Metagreywacke	Hematite	-Fine grained Metagreywacke with 1-3% quartz veins with clay infilled along fractures
63.50-69.0	Fault	Clay	-Fault gouge, comprised of strongly bleached host rock (likely Metagreywacke)
69.0-90.0	Metagreywacke	Hematite	-Light pink hematized Metagreywacke , 1-2% quartz veins, some veins associated with bleached white/green halos, possible graphite or specular hematite associated with halos @73.15m -Changes to red hematite from 75-81.8 with pink/orange hematite patches, 1-5% 1-2mm quartz veinlets -Pink/orange hematization from 81.8-90m
90.0-93.76	Metagreywacke	Hematite	-Brick red hematization with patches of bleached (clay altered), half of the patches are associated with quartz brecciation while the other with faulting, appears mostly in brittle zones (from 93.2-93.76)
93.76-98.90	Metagreywacke	Clay	-Strongly bleached and foliated, some quartz veining (~1%) parallel TCA with pink hematite?

Depth(m)	Lithology	Alteration	Description
98.90-117.69	Metagreywacke	Hematite	-Brick red hematized Metagreywacke with 5% patches of bleached/clay altered patches similar to (90-93.76) -Moderately to strongly foliated throughout -Possible chloritization @115m
117.69-132.30	Metagreywacke	Clay	-Bleached to patchy pink/orange, interval is strongly clay altered, some areas are hematized to dark purple, quartz veining is sub-parallel TCA
132.30-215.20	Metagreywacke	Hematite	-Brick red to purple hematite, foliation is weak to moderately defined, several brittle zones ranging from 0.5-0.75cm in length, 1% quartz veining throughout -weak to moderate hematization from 142.98-167.56 -brecciation of host rock and infilled with clay
215.20-238.50	Metagreywacke	Clay	-Strongly bleached, some patches of hematite alteration (5% of interval), disseminated specular hematite within clay altered zones
238.50-248.0	Metagreywacke	Hematite	-Pink/Orange hematized Metagreywacke, moderately foliated throughout, 80% of hematization is pink/bleached, 20% is dark purple, 1-3% quartz veinlets
248.0-252.60	Metagreywacke	Hematite/Clay	-Transition between hematized to clay altered Metagreywacke, contains green/bleached patches (Chloritization?)
252.60-267.0	Metagreywacke	Chloritized	-Foliation changes to very shallow (20°), some intervals of strongly clay altered zones (40% of interval), 1-5% quartz micro veinlets with specular hematite vein selvages

Depth(m)	Lithology	Alteration	Description
267.0-269.90	Metagreywacke	Hematite	-Brick Red hematite with patches of bleached/green altered (Chloritization), cross-cut by quartz+/- carbonate veinlets
269.90-273.70	Metagreywacke (Mineralized)	Clay	-3-5% Fracture controlled uraninite with bleached clay altered halos, limonite staining along fracture surfaces, interval appears as Metagreywacke based on textural preservation, chloritization from 271.1 to 271.6 (possible primary or secondary alteration?)
273.70-278.20	Metagreywacke	Hematite	-Brick Red hematization, moderately foliated, along top contact interval appears limonite stained along foliation
278.20-304.60	Metagreywacke (Mineralized)	Clay	-Strongly bleached/clay altered, uraninite is fracture controlled, some places mineralization occurs as roll fronts, hematization is local @286m and appears fracture controlled
304.60-309.0	Metagreywacke (Mineralized)	Hematite/Clay	-Increase in brick red hematization, fracture controlled uraninite is associated with limonite, uraninite also appears to be haloed by uranophane (yellow)
309.0-334.4	Metagreywacke	Clay/Hematite	-White/Light grey moderately foliated with alternating patches of limonite and bleaching/clay alteration
334.4-419.0 (EOH)	Metagreywacke	Chloritization	-Moderately foliated, strongly chloritized, cross-cut by quartz veinlets, these can contain fracture controlled pyrite (syn?), quartz veinlets cross-cut foliation and are parallel TCA, Chlorite veining also concentrates along foliation -@398.4m granitic veining -Towards bottom of hole quartz veining contains hematite selvages

Table A.2 – Drill Log description of END-09-02 from End Deposit, Thelon Basin, Nunavut, Canada.

Depth(m)	Lithology	Alteration	Description
0-6.0	Overburden		
6.0-79.4	Metagreywacke	Hematite	-Fine grained, brick red pervasive hematization, moderately to strongly foliated, cross-cut by quartz micro veinlets (2-5%, 1-2mm) and veins (10-15cm) +/- specular hematite selveges, clay +/- chlorite? Infill veinlets parallel TCA, specular hematite occurs within veinlets (1-3mm) appears at 24m and increases with depth (1-2%) -from 46.8-79.4, hematization changes from brick red to orange/pink, increase in quartz veining (quartz breccia)
79.40-108.43	Metagreywacke	Clay	-Bleached to pink/orange hematization (85% bleached, 15% hematite), texturally obliterated, clay altered zones contain disseminated to fracture controlled specular hematite, 1-3% 2-5mm quartz veins
108.43-123.5	Metagreywacke	Hematite	-90% brick red hematized with 10% bleached/clay altered zones, 1-2% quartz veins/veinlets cross-cutting foliation
123.5-201.0	Metagreywacke	Clay	-Transitions to grey weakly hematized, 5% bleached/clay altered patches, hematization is largely fracture controlled, 1-3% quartz veins with chlorite to specular hematite selveges
201.0-211.0	Metagreywacke	Hematite	-purple hematite with 10% chlorite/bleached patches 1-2% quartz veinlets +/- specular hematite selvege

Depth(m)	Lithology	Alteration	Description
211.0-241.65	Metagreywacke	Clay	-Texturally preserved, bleached/clay to pale green (chlorite?), moderately foliated, cross-cut by 1-3% quartz veinlets
241.65-264.0	Metagreywacke	Hematite	-dark purple hematization to limonite stained, some white/pale green (Chlorite?) (~25% of interval) -strongly bleached fault gouge zone from 246-249m contains uraninite, fracture controlled to roll front mineralization from 252.7-252.8m
264.0-271.0	Metagreywacke	Chloritized/Clay	-Dark grey/green moderately chloritized to weakly clay altered, cross-cut by 1-2% quartz veinlets, 1% of the veinlets contain chlorite
271.0-305.8	Metagreywacke (Mineralized)	Chloritized/Clay	-Weakly bleached/weak-moderately chloritized with fracture controlled hematite and limonite staining -uraninite is fracture controlled (1-3%) and restricted to clay altered/chloritized patches
305.8-322.0	Metagreywacke	Clay	-Strongly bleached/clay altered, texture is weakly preserved, cross-cut by 1-3% quartz +/- hematite veinlets, 5% patches of pink/red hematization,
322.0-324.0	Metagreywacke	Hematite/Clay	-dark purple hematization alternating to white/green (Chloritization), boudinaged quartz veins parallel TCA, strongly foliated throughout and cross-cut by 1% quartz veinlets
324.0-351.0	Metagreywacke (Mineralized)	Chloritized/Clay	-Moderately to strongly foliated, weak to moderately chloritized, uraninite is fracture controlled but also occurs within the foliation (336-350m)

Depth(m)	Lithology	Alteration	Description
351.0-390.0	Metagreywacke (Mineralized)	Chloritized/Clay	-weak bleached/clay altered (chloritized), uraninite is fracture controlled to foliation dominant
390.0-445.0	Metagreywacke	Chloritized	-Strongly chloritized, fine grained, cross-cut by quartz +/- carbonate veinlets and chlorite veinlets -413.0-413.4m, bands of chlorite with garnet porphyroblasts (10%) bands are < 0.5cm thick-444.5-444.7, chlorite bands with quartz and disseminated euhedral pyrite cross-cut by quartz and carbonate
445.0-474.49	Metagreywacke (Mineralized)	Chlorite/Hematite	-interval transitions from chloritized/hematized to bleached/clay altered with uraninite within fractures, interval is brecciated in places and infilled with chlorite, hematite and possibly epidote/k-spar, quartz +/- carbonate veining (1-3%) -from 470.4-470.6m possible BIF?, interlayering of quartz with hematite
474.49-495.0 EOH	Metagreywacke	Un Altered	-Dark grey, moderately foliated, cross-cut by quartz +/- carbonate veinlets, +/- epidote? (2% near parallel TCA) -faulted towards end of hole, interval consists of faults with clay haloes (texture is obliterated) and consists of hematite veinlets

A3. Thin Section Descriptions from END deposit, Thelon Basin, Nunavut, Canada

Drill Hole	Depth (m)	Lithology	Major Minerals					Alteration			Minor Minerals	General Comments
			Quartz	Uraninite	Muscovite	Biotite	Illite	Chlorite	Sericite	Hematite		
END-10-02A	20	PPD - Metagreywacke	45% <0.1 - 0.2mm		5% <0.1 - 0.2mm Sub. - Euh.			15% <0.1mm	35% <0.1-0.1mm		2% Pyrite	Strongly foliated metagreywacke, coarser grained muscovite is parallel to foliation, Overall strongly sericitized throughout. Veinlets of carbonate parallel to foliation.
END-10-02A	250	PPD - Metagreywacke	40 % <0.1- 0.3mm					40% <0.1-0.2mm	15% <0.1mm		3% Almandine, 1% Pyrite, 0.5% Calcite veinlets	Interval is strongly altered to chlorite Garnet Porphoblasts with quartz inclusions, grains infilled by chlorite?
END-10-03	244.5 A	PPD - Metagreywacke	40 % <0.1 - 0.4mm	30% <0.1mm Foliation	5% <0.1 - 0.2mm Sub. - Euh.		30% <0.1mm					Hematized and illitized, muscovite is secondary. Strongly foliated, crosscut by quartz veinlets infilled with clay minerals and opaques.
END-10-02A	80	PPD - Metagreywacke	55 % <0.1- 0.1mm		10% <0.1 - 0.2mm Euh.	15% <0.1- 0.3mm		15%	10% <0.1-0.1mm		0.5% Pyrite, 3% Calcite Veinlets	Grain size dramatically decreases, and foliation is strongly defined by micas. Chloritization of biotite throughout, with some "unaltered" biotite patches.
END-10-02A	70	PPD - Metagreywacke	40 <0.1 - 1mm					10%<0.1- 0.5mm	50%		0.5% Pyrite, 3% Calcite Veinlets	Weakly foliated metagreywacke, moderately sericitized throughout along with fine grained disseminated pyrite.
END-10-03	296	PPD - Metagreywacke							100% <0.1mm		3% Calcite infilling matrix	Clay altered throughout, bleached, hematite stained along a fracture that has been infilled in some places with quartz (based on hand specimen). Well foliated.
END-10-03	280	PPD - Metagreywacke	45 <0.1 - 0.2mm		2% 0.1-0.5mm Euh.		45% <0.1mm			10%		Quartz vein contains muscovite along the margins.
END-10-03	222B	PPD - Metagreywacke	60 <0.1 - 0.1mm	10% <0.1 - 0.1mm	2% 0.1 - 0.3mm Sub. - Euh.		30% <0.1mm					Uraninite replacing illite and trend along main foliation. Strongly illitized throughout and crosscut by illite veinlets, muscovite is secondary in host rock. Weakly foliated.

END-10-03	222A	PPD - Metagreywacke	60 <0.1 - 0.2mm	2% <0.1mm Roll Front	0.1 - 0.3mm Sub. - Euh.		40% <0.1mm				Muscovite in shear zone. Massive, multiple deformation events, quartz vein sinistrially sheared, sample is crosscut by veinlet of microcrystalline quartz, vein infilled with uraninite with an illitic halo.
END-10-03	217.6	PPD - Metagreywacke	55 <0.1 - 0.2mm	1% <0.1mm	1% <0.1-0.2mm Sub. - Euh.		35% <0.1mm		10%		Uraninite replacing illite. Void fracture has an illitic halo (sec. gen), fine grained secondary muscovite forming from the illite, hematite is situated along with illite and tends to rim around quartz grains.
END-09-02	329.8	PPD - Metagreywacke	40 0.1-0.5mm	5%0.1mmFo liation			55%<0.1mm				Intensely foliated metagreywacke that has been strongly illitized, uraninite is concentrated along quartz layers within fractures. Cross cut by quartz veins. Intensely foliated metagreywacke, quartz and feldspars within layers with alternating illitized layers.
END-10-03	203A	PPD - Metagreywacke	45 <0.1 - 0.2mm	5% <0.1 - 0.1mm Veinlet	15% <0.1 - 0.5mm Euh.		30% <0.1mm		5%		Uraninite replaces illite and form along quartz as rims, uraninite also forms parallel along the main foliation. Moderately clay altered, S quadrant of slide is hematized associated with illite, separated by bleached weakly hematized, Muscovite is secondary? Well foliated characterized by muscovite, crosscut by a recrystallized quartz vein, however quartz vein appears to be crosscut by muscovite (syn?)
END-10-03	80	PPD - Metagreywacke	60 <0.1 - 0.3mm					10% <0.1-0.1mm	30% <0.1mm		Crosscut by quartz veins with void space (may have been weathered carbonate). Bleached halos along quartz +/- sericite veinlets, Weakly foliated defined by chlorite.
END-10-03	140	PPD - Bleached	45 <0.1 - 0.1mm		1% <0.1 - 0.1mm Sub. - Euh.		55% <0.1mm				Strongly clay altered (illite?), Strongly bleached throughout, muscovite associated with a veinlet infilled with clay, muscovite might be an alteration halo? Weakly foliated.
END-10-02A	50	PPD - Metagreywacke	60 <0.1 - 0.1mm		0.1-0.5mmSubhedral			10%<0.1-0.2mm	30% <0.1mm	0.5% Pyrite, 3% Calcite Veinlets	Weakly foliated metagreywacke, disappearance of epidote. Weak - Moderately replaced by chlorite, strong replacement by sericite. Rock appears weakly foliated.

END-10-02A	110	PPD - Metagreywacke	55% <0.1 - 1mm		15% <0.1-0.5mm Euh.		15% <0.1mm	15% <0.1 - 0.1mm	0.5% Pyrite, 3% Calcite Veinlets	Strongly foliated metagreywacke, with trace pyrite, crosscut by three generations of brittle fractures infilled with carbonate, chlorite & quartz. Calcite vein, 5mm thick infilled with fragment of metagreywacke host rock, tapers off and is infilled with chlorite and pyrite. Foliation defined by muscovite/chlorite, crosscut by three generations of fractures infilled with chlorite and quartz.
END-10-02A	190	PPD - Metagreywacke	60% <0.1 - 0.5mm			10% 0.1-0.5mm		30% <0.1mm	0.5% Pyrite, 3% Calcite Veinlets	Moderately Foliated, quartz grain size is fairly irregular throughout, strong presence of "biotite" looking minerals. Calcite veinlets crosscut main foliation.
END-10-02A	217	PPD - Metagreywacke	30% <0.1mm				35% <0.1 mm	35% <0.1mm	0.5% Pyrite, 3% Calcite Veinlets	Accumulations of Pyrite associated with patches of chlorite (almost vein like). Increase in chlorite.
END-10-02A	310	PPD - Metagreywacke	60% <0.1 - 0.5mm			10% <0.1 - 0.5mm	5% <0.1 -0.2mm	25% <0.1mm	0.5% Pyrite, 3% Calcite Veinlets	Feldspars completely altered to sericite, biotite appears preserved, but some are altered to chlorite, some chlorite has altered to clay, there are quartz +/- carbonate? /epidote? Veinlets cross cutting the main foliation. Weak-moderately foliated characterized by micas.
END-10-03	330	PPD - Metagreywacke	50%<0.1-0.2mm					50%<0.1mm		Hematization restricted within quartz veining, reducing fluids localized as some portions are strongly bleached. Two generations of quartz veining, appears recrystallized pre-foliation.
END-10-03	30	PPD - Metagreywacke	50% <0.1 - 0.1mm		<0.1mm Euh.		50% <0.1-0.2mm			Strongly illitized? hematite stained throughout. Moderately bedded.
END-10-03	222A	PPD - Metagreywacke	45% <0.1 - 0.1mm		<0.1-0.5mm Sub.		55% <0.1mm		0.1% Vein Selvege Calcite	Strongly foliated. Moderately illitized with second generation of illite, some of these veinlets are associated with calcite, orange/light brown iron staining, muscovite is secondary. Quartz is recrystallized forming medium (~1mm) patches
END-10-03	223.3	PPD - Mineralized	50% <0.1 - 0.2mm	5% <0.1mm Infill			45% <0.1mm			Uraninite restricted to fractures within quartz veinlet and pelitic layers. Strongly illitized and foliated, there is a second generation of illite infilling fractures that crosscut the 1st gen quartz vein. 1st gen quartz veins are recrystallized and restructured.

END-10-02A	110	PPD - Brecciated	5%			5% <0.2-0.5mm	20% <0.1mm		Chlorite +/- pyrite appears to be infilling fractures, surrounding rock is highly sericitized.
END-10-02A	145	PPD - Metagreywacke	55% <0.1 - 0.5mm			20% <0.1-4mm	25% <0.1mm		Same as interval above, increase in abundance of chlorite. Large patches of chlorite (occurs as large patches - ~4mm in diameter).
END-10-02A	263.2	PPD - Metagreywacke	10% 1-2mm			20% <0.1-0.2mm	70% <0.1mm	0.1% Garnet and Epidote	Strongly sericitized metagreywacke, Chlorite is interstitial to sericite(clay) altered grains, calcite veinlets crosscut patches of recrystallized quartz, two grains of "garnet" appear shattered, and infilled with chlorite. Weak - moderately foliated
END-10-03	60	PPD - Hematized	30% <0.1 - 0.2mm	<0.1 - 0.1mm Sub. - Euh.		40% <0.1mm		30%	Opaques include hematite (entire slide is hematized), 10% large (1.-5mm) patches of recrystallized quartz these patches are crosscut by a void fracture and in some places infilled with quartz and sericite. Matrix strongly clay altered (sericite/illite?)
END-10-03	70	PPD - Hematized	55% <0.1 - 0.2mm			5% <0.1 -0.1mm	40% <0.1mm		Metagreywacke is massive and strongly clay altered. Strongly sericitized, iron stained throughout, fine grained chlorite associated with clay minerals.
END-10-03	90	PPD - Hematized	50% <0.1 - 0.2mm			50% <0.1mm			Strongly hematized, local differences in reducing fluid? Strongly foliated, characterized by quartz grains and sericite.
END-10-03	100	PPD - Bleached	60% <0.1 - 0.1mm			40%<0.1mm			Thin section is bleached, strongly clay altered (illite?) throughout. Strongly foliated characterized by recrystallized quartz.
END-10-03	150.2	PPD - Bleached	20% 5mm	20% <0.1 - 0.1mm Sub. - Euh.			60% <0.1mm		Strongly clay altered, clay layers contain muscovite likely secondary as it isn't oriented parallel to foliation. Moderately to strongly foliated characterized by quartz layers.

END-10-03	170	PPD - Hematized	60% <0.1 - 0.2mm				20% <0.1mm	20%		Hematized, strongly clay altered. Multiple generations of micro brecciation infilled with fine host rock fragments and clay minerals, some veinlets contain microcrystalline quartz hard to say if it's associated with brecciated veinlets or occurred post.
END-10-03	250	PPD - Metagreywacke	60% <0.1mm		10% 0.1 - 0.2mm Sub. - Euh.		30% <0.1mm			Strongly sericitized. Strongly foliated characterized by muscovite.
END-10-03	290	PPD - Brecciated	60% <0.1 - 0.1mm				35% <0.1mm	5% <0.1-0.1mm		Strongly clay altered throughout, bleached. Two generations of fracturing, there is a quartz veinlet crosscut by small veinlets infilled with clay material, quartz veinlet is broken up.
END-10-03	310	PPD - Hematized					60% <0.1mm	40%		Similar to 296m where interval is texturally preserved but intensely clay altered and hematized.
END-10-02A	62.4	PPD- Metagreywacke	50% <0.1- 0.2 mm				45% <0.1 - 0.1mm		2% Pyrite	Pyrite increases in this section compared to samples above. Strongly sericitized, chlorite appears, there is a quartz veinlet that contains pyrite and sericite. Strongly foliated, quartz veins appear to follow foliation (post deformation).
END-10-03	131	PPD- Metagreywacke	1% <0.1mm		<0.1 - 0.1mm Subhedral		99% <0.1mm			Quartz is trace as the entire interval has altered to clay. Slide consists of bleached reducing front, Intensely illitized throughout. Appears massive.
END-10-03	267	PPD - Mineralized	60% <0.1 - 0.3mm	1% <0.1mm Veinlet			40% <0.1mm			Quartz veining, thin (<0.1mm) micro veinlets of uraninite? cross cuts main foliation. Strongly illitized throughout, crosscut by thin calcite with drusy quartz veinlets, there is a quartz veinlet that separates intensely illitized (texturally obliterated).
END-10-03	180	PPD - Bleached	65% <0.1 - 0.1mm		10% Subhedral-Euh. 0.1mm		20% <0.1mm			Bleached, Qtz vein crosscut by veinlets infilled with clay (clay veinlets are parallel to foliation). Weakly foliated.
END-10-02A	180	PPD- Metagreywacke	60% <0.1- 0.2mm		0.1mm Euh.		10% <0.1-0.2mm	20% <0.1mm	0.5% Pyrite, 1% Calcite Veinlets	Rock is similar to intervals observed above 80-100m, biotite appears.

END-10-02A	435	PPD- Metagreywacke	60% <0.1 - 0.5mm				30% <0.1mm		0.5% Pyrite	Moderately sericitized, chlorite altered. Massive.
END-10-02A	330	PPD- Metagreywacke	50%<0.1 - 0.5mm				5%<0.1- 0.1mm	30%<0.1mm	0.1% Pyrite, 0.5% Calcite Veinlets	Increase in pyrite, coupled with moderate sericite. quartz +/- carbonate veinlets, chlorite appears illitized? Weakly foliated.
END-10-03	48	PPD - Brecciated	15% <0.1 - 0.3mm				65% <0.1mm			Decrease in quartz in host rock, dominated by clay minerals.
END-12-03	263B	PPD- Metagreywacke	15% <0.1 - 0.1mm				80% <0.1mm			Three stages of illitization, 1st - total replacement, 2nd stage veining, 3d stage cross cuts 2nd stage (almost appears micaceous). Weakly-Moderately foliated.
END-10-03	40	PPD - Hematized	55% <0.1 - 0.1mm	<0.1 - 0.1mm Subhedral			45% <0.1mm			Strongly illitized, foliation is crosscut by a quartz veinlet along with a "syn?" veinlet of quartz+/- illite, these veinlets are overprinted by sericite, there is one generation of quartz veining that appears to cede the dominant foliation. Strongly foliated
END-10-02A	152	Lamprophyre	10% <0.1- 0.2mm			25% 0.1-1mm		65% <0.1mm		Biotite is set in a clay altered matrix; unit is crosscut by calcite veining.
END-10-02A	147.2	PPD		7% <0.1 - 0.5mm Sub. - Euh.			70% <0.1mm	15%	1% Calcite Veinlets	Pyrite occurs as blebby aggregates. Muscovite altered to clay in some places, calcite veins parallel and acute to dominant foliation, intersection of calcite veins and pyrite.
END-10-02A	129.4	PPD - Quartz Veins		45% Euh.			10%	25% <0.1mm		Strongly sericitized throughout.
END-10-02A	360	PPD	10% <0.1- 0.2mm				7% <0.1mm		1% Calcite Veinlets	Same as moderately foliated and sericitized metagreywacke observed above.

END-09-04	340	PPD	1%		90% <0.1mm	5%	1% Calcite Veinlets	Uraninite nucleate on quartz and calcite grains within veinlet. Intensely illitized/sericitized throughout host rock.
END-10-03	42.4	PPD - Brecciated			100% <0.1mm		0.1% Pyrite	Quartz vein infilled with illitized metagreywacke, microcrystalline quartz formed within interstitial spaces, pyrite within quartz vein? Host rock strongly illitized/clay altered overprinted by hematite.
END-10-03	20	PPD - Hematized						Quartz grains are recrystallized. Multiple generations of veinlets that have been replaced by sericite, strongly iron stained throughout.
END-09-02	298.2	PPD - Mineralized	15% <0.1mm Disseminated		85% <0.1mm			Strongly clay altered metagreywacke, non-foliated, uraninite mineralization is disseminated? Doesn't form along foliation.
END-09-02	340.5	PPD - Mineralized	10% <0.1-0.2mm Disseminated-Vein		90% <0.1mm			
END-10-02A	127.4	PPD- Quartz Vein						Quartz vein, Chlorite with ~0.5mm pyrite along margin of highly sericitized rock
END-10-02A	160	PPD - Brecciated			10% <0.1-0.2mm			A quartz vein (associated with muscovite and contains interstitial chlorite) cross cuts the unit, however this vein is crosscut by calcite veinlets. Chlorite can appear isotropic to blue/grey in XPL
END-10-02A	202.4	PPD - Brecciated				100%		Metagreywacke crosscut by quartz +/- carbonate +/- microcline? Host rock is strongly sericitized.
END-10-03	253.7	PPD - Brecciated						Quartz vein infilled with clay minerals and opaques, opaques usually restricted to boundaries between clay veinlet and quartz.
END-10-03	340	PPD - Bleached			95%			Bleached, strongly clay altered. Similar to intervals above, several generations of quartz veining that has been recrystallized, quartz crystals in some places formed patches or re-crystallized quartz.

**Appendix B –
Electron Probe Microanalysis (EMPA) and Standards**

Table B.1: Elements and their respective standards for EMPA.

Element	Standard	Wt %
Na	Albite	8.59
Si	Diopside	25.7
U	UO ₂	88.1495
Ca	Diopside	18.34
P	Apatite	17.86
F	Riebeckite	2.56
Ti	Sphene	22.66
Fe	Pyrite	46.552
Al	Albite	10.4
K	Orthopyroxene	12.77
Mg	Olivine	30.62
Mn	Spessartine	31.4

Table B.2. Oxide Weight percentage of uranium minerals from the End Deposit, Thelon Basin, Nunavut, Canada.

Drill Hole	Depth (m)	Mineral	Style	SiO ₂	CaO	UO ₂	PbO	ThO ₂	TiO ₂
END-09-02	340.5	Uranophane	U1 - Disseminated	15.62	2.03	60.11	3.51	0.07	1.71
END-09-04	370.7	Uranophane	U1 - Disseminated	19.74	1.72	46.95	0.85	0.03	9.43
END-09-02	340.5	Uraninite	U1 - Disseminated	1.32	1.29	79.08	12.29	0.1	0.35
END-09-02	340.5	Uraninite	U1 - Disseminated	1.84	1.78	78.69	7.03	0.08	1.57
END-09-02	340.5	Uraninite	U1 - Disseminated	1.09	1.3	82.39	8.14	0.04	1.98
END-12-03	263.5	Ca - Uraninite	U1 - Disseminated	1.08	7.23	76.96	1.11	0.02	0.17
END-12-03	263.5	Ca - Uraninite	U1 - Disseminated	1.3	7.22	83.43	19.17	0.16	0.17
END-12-03	263.5	Ca - Uraninite	U1 - Disseminated	0.92	7.58	84.08	1.28	0	0.07
END-12-03	263.5	Ca - Uraninite	U1 - Disseminated	1.55	8.18	80.82	1.04	0.14	0.2
END-12-03	263.5	Ca - Uraninite	U1 - Disseminated	1.39	7.07	55.4	0.66	0	0.02
END-12-03	263.5	Ca - Uraninite	U1 - Disseminated	1.21	6.88	84.23	1.37	0.07	0
END-10-03	223.3	Ca - Si Uraninite	U1 - Disseminated	3.25	4.52	83.43	0.76	0	0.01
END-10-03	223.3	Ca - Si Uraninite	U1 - Disseminated	3.5	3.83	80.57	0.78	0.01	0.42
END-10-03	223.3	Ca - Si Uraninite	U1 - Disseminated	3.84	4	83.22	0.87	0	0
END-10-03	223.3	Ca - Si Uraninite	U1 - Disseminated	5.09	3.75	80.33	1.09	0	0.06
END-10-03	223.3	Ca - Si Uraninite	U1 - Disseminated	10.03	2.49	79.64	0.05	0.09	0.07
END-09-02	340.5	Ca - Si Uraninite	U1 - Disseminated	3.45	1.79	75.09	7.9	0.05	0.39
END-09-02	340.5	Ca - Si Uraninite	U1 - Disseminated	6.42	2.46	73.44	3.55	0.14	0.22
END-09-02	340.5	Ca - Si Uraninite	U1 - Disseminated	6.99	2.09	75.29	3.98	0.05	0.27
END-09-04	370.7	Ca - Si Uraninite	U1 - Disseminated	0.52	2.04	78.51	14.33	0	0.12
END-09-04	370.7	Ca - Si - Ti Uraninite	U1 - Disseminated	6.31	1.96	74.51	3.48	0	2.85
END-09-04	340.5	Uraninite	U2 - Vein-type	0.47	1.95	80.5	12.87	0.03	0.12
END-09-04	340.5	Uraninite	U2 - Vein-type	0.13	1.05	79.68	14.75	0.04	0.17
END-09-04	340.5	Ca - Uraninite	U2 - Vein-type	1.53	4.19	82.35	7.38	0.02	0.32
END-09-04	340.5	Ca - Uraninite	U2 - Vein-type	2.29	6.15	80.63	4.81	0.03	0.11
END-09-04	340.5	Ca - Uraninite	U2 - Vein-type	1.13	4.22	82.91	7.79	0	0.22
END-09-04	340.5	Ca - Si Uraninite	U2 - Vein-type	2.94	8.49	81.77	0.92	0	0.32
END-09-04	340.5	Ca - Si Uraninite	U2 - Vein-type	2.29	6.02	78.1	6.87	0	0.29

END-09-04	340.5	Ca - Si Uraninite	U2 - Vein-type	7.1	6.9	72.98	0.77	0.01	0.29
END-09-04	340.5	Ca - Si Uraninite	U2 - Vein-type	4.62	7.88	75.72	2.88	0	0.24
END-09-04	340.5	Ca - Si Uraninite	U2 - Vein-type	7.15	6.76	71.62	0.72	0	0.2
END-09-02	329.8	Coffinite	U3a - Foliation-parallel	12.64	3.36	64.22	0.78	0	0
END-09-02	329.8	Ca - Uraninite	U3a - Foliation-parallel	2.94	3.04	84.23	1.76	0.02	0.79
END-09-02	329.8	Ca - Si Uraninite	U3a - Foliation-parallel	4.8	2.84	81.79	1.63	0	1.21
END-09-02	329.8	Ca - Si Uraninite	U3a - Foliation-parallel	7.17	4.59	75.65	0.52	0	0.14
END-09-02	329.8	Ca - Si Uraninite	U3a - Foliation-parallel	3.27	2.89	82.94	1.69	0.03	1.63
END-09-02	329.8	Ca - Si Uraninite	U3a - Foliation-parallel	4.94	4.45	78.46	1.01	0	0.09
END-10-03	203	Coffinite	U3a - Foliation-parallel	15.31	2.5	68.69	0.37	0	0.1
END-10-03	203	Ca - Uraninite	U3a - Foliation-parallel	1.99	2.99	83.2	0.47	0	1.91
END-10-03	203	Ca - Uraninite	U3a - Foliation-parallel	1.15	5.34	81.52	0.39	0.01	0.04
END-10-03	203	Ca - Si Uraninite	U3a - Foliation-parallel	5.34	3.08	80.99	0.37	0	0.07
END-10-03	203	Ca - Si Uraninite	U3a - Foliation-parallel	5.08	3.4	82.81	0.51	0.04	0.03
END-10-03	203	Ca - Si Uraninite	U3a - Foliation-parallel	1.5	4.77	84.31	0.38	0.02	0.04
END-10-03	203	Ca - Si - Ti Uraninite	U3a - Foliation-parallel	8.51	4.62	66.46	0.6	0	6.08
END-10-03	203	Ca - Si - Ti Uraninite	U3a - Foliation-parallel	5.83	4.84	72.77	0.11	0	2.24
END-10-03	267	Uranophane	U3b - Infill-type	18.49	2.04	55.35	0.78	0.14	0.5
END-10-03	267	Uranophane	U3b - Infill-type	17.12	2.11	54.01	1.65	2.61	0.06
END-10-03	244.5	Coffinite	U3b - Infill-type	15.02	3.25	62.04	0	0	0
END-10-03	267	Coffinite	U3b - Infill-type	15.98	2.24	66.26	0.29	0.23	0.13
END-10-03	222.4	Ca - Uraninite	U3b - Infill-type	1.81	6.79	83.85	1.82	0	0.02
END-10-03	222.4	Ca - Uraninite	U3b - Infill-type	3.13	2.99	79.56	2.76	0	0.05
END-10-03	222.4	Ca - Uraninite	U3b - Infill-type	1.37	6.89	83.31	2.1	0	0
END-10-03	222.4	Ca - Uraninite	U3b - Infill-type	1.41	7.04	84.69	1.93	0	0.07
END-10-03	222.4	Ca - Uraninite	U3b - Infill-type	2.27	4.86	81.96	2.62	0	0.02
END-10-03	222.4	Ca - Uraninite	U3b - Infill-type	4.16	4.31	79.71	2.68	0.04	0.03
END-10-03	222.4	Ca - Uraninite	U3b - Infill-type	1.89	4.83	84.01	2.3	0.04	0.03
END-10-03	244.5	Ca - Si Uraninite	U3b - Infill-type	11.02	2.76	67.01	0.07	0.01	0.09
END-10-03	244.5	Ca - Si Uraninite	U3b - Infill-type	4.53	3.79	79.89	0.02	0	0

Drill Hole	Depth (m)	Mineral	Style	SiO₂	CaO	UO₂	PbO	ThO₂	TiO₂
END-10-03	244.5	Ca - Si Uraninite	U3b - Infill-type	4.38	3.64	79.12	0	0.07	0.05
END-10-03	244.5	Ca - Si Uraninite	U3b - Infill-type	9.02	3.39	75.74	0	0.07	0.07
END-10-03	244.5	Ca - Si Uraninite	U3b - Infill-type	7.89	3.8	74.14	0.04	0	0.4
END-10-03	244.5	Ca - Si Uraninite	U3b - Infill-type	13.57	2.61	62.54	0	0	0.04
END-10-03	267	Ca - Si Uraninite	U3b - Infill-type	6.3	2.1	68.16	8.36	0.26	0.28
END-10-03	267	Ca - Si Uraninite	U3b - Infill-type	9.25	2.72	72.08	1.81	0.09	0.84
END-10-03	267	Ca - Si - Ti Uraninite	U3b - Infill-type	9.15	1.97	52.67	2.78	0.18	18.72
END-09-02	298.2	Uranophane	U3c - Roll Front	18.64	1.88	63.66	0.05	0	3.57
END-10-03	217.6	Coffinite	U3c - Roll Front	16.16	4.03	57.3	0.43	0	0
END-10-03	217.6	Ca - Si Uraninite	U3c - Roll Front	12.17	4.24	61.52	0.45	0.02	0
END-10-03	217.6	Ca - Si Uraninite	U3c - Roll Front	12.43	5.25	69.72	0.47	0	0.04
END-10-03	217.6	Ca - Si Uraninite	U3c - Roll Front	4.24	5.65	80.38	0.59	0.03	0.06
END-09-02	298.2	Ca - Si Uraninite	U3c - Roll Front	8.37	5.17	73.53	0.41	0	0
END-09-02	298.2	Ca - Si Uraninite	U3c - Roll Front	8.43	4.97	70.15	0.39	0.02	0
END-09-02	298.2	Ca - Si - Ti Uraninite	U3c - Roll Front	4.41	1.92	62.38	0.52	0.12	22.09
END-09-02	298.2	Ca - Si - Ti Uraninite	U3c - Roll Front	6.59	2.18	66.33	0.59	0.12	11.55
END-09-02	298.2	Ca - Si - Ti Uraninite	U3c - Roll Front	15.74	1.31	50.82	0.19	0	12.12
END-09-02	298.2	Ca - Si - Ti Uraninite	U3c - Roll Front	5.79	3.23	69.58	0.44	0.02	9.28

Table B.3 Atomic weight percent data for uranium minerals from the End Deposit, Thelon basin, Nunavut, Canada.

Drill Hole	Depth (m)	Mineral	Style	U	Pb	Th
END-09-02	340.5	Uranophane	U1 - Disseminated	10.28	0.73	0.01
END-09-04	370.7	Uranophane	U1 - Disseminated	7.14	0.16	0
END-09-02	340.5	Uraninite	U1 - Disseminated	25.5	4.79	0.03
END-09-02	340.5	Uraninite	U1 - Disseminated	24.33	2.63	0.03
END-09-02	340.5	Uraninite	U1 - Disseminated	25.54	3.05	0.01
END-12-03	263.5	Ca - Uraninite	U1 - Disseminated	22.74	0.4	0.01
END-12-03	263.5	Ca - Uraninite	U1 - Disseminated	22.97	0.39	0.05
END-12-03	263.5	Ca - Uraninite	U1 - Disseminated	23.26	0.43	0
END-12-03	263.5	Ca - Uraninite	U1 - Disseminated	22.06	0.34	0.04
END-12-03	263.5	Ca - Uraninite	U1 - Disseminated	20.75	0.3	0
END-12-03	263.5	Ca - Uraninite	U1 - Disseminated	23.36	0.46	0.02
END-10-03	223.3	Ca - Si Uraninite	U1 - Disseminated	22.73	0.25	0
END-10-03	223.3	Ca - Si Uraninite	U1 - Disseminated	23.26	0.27	0
END-10-03	223.3	Ca - Si Uraninite	U1 - Disseminated	22.43	0.29	0
END-10-03	223.3	Ca - Si Uraninite	U1 - Disseminated	20.5	0.34	0
END-10-03	223.3	Ca - Si Uraninite	U1 - Disseminated	19.17	0.01	0.02
END-09-02	340.5	Ca - Si Uraninite	U1 - Disseminated	21.86	2.78	0.01
END-09-02	340.5	Ca - Si Uraninite	U1 - Disseminated	19.64	1.15	0.04
END-09-02	340.5	Ca - Si Uraninite	U1 - Disseminated	19.13	1.22	0.01
END-09-04	370.7	Ca - Si Uraninite	U1 - Disseminated	25.69	5.67	0
END-09-04	370.7	Ca - Si - Ti Uraninite	U1 - Disseminated	19.25	1.09	0
END-09-04	340.5	Uraninite	U2 - Vein-type	26.32	5.09	0.01
END-09-04	340.5	Uraninite	U2 - Vein-type	27.1	6.07	0.01
END-09-04	340.5	Ca - Uraninite	U2 - Vein-type	24.04	2.61	0.01
END-09-04	340.5	Ca - Uraninite	U2 - Vein-type	22.39	1.62	0.01
END-09-04	340.5	Ca - Uraninite	U2 - Vein-type	24.42	2.78	0
END-09-04	340.5	Ca - Si Uraninite	U2 - Vein-type	20.71	0.28	0
END-09-04	340.5	Ca - Si Uraninite	U2 - Vein-type	21.47	2.29	0
END-09-04	340.5	Ca - Si Uraninite	U2 - Vein-type	17.98	0.23	0
END-09-04	340.5	Ca - Si Uraninite	U2 - Vein-type	16.09	0.74	0
END-09-04	340.5	Ca - Si Uraninite	U2 - Vein-type	18.06	0.22	0
END-09-02	329.8	Uranophane	U3a - Foliation-parallel	12.47	0.18	0
END-09-02	329.8	Ca - Uraninite	U3a - Foliation-parallel	24.26	0.61	0.01
END-09-02	329.8	Ca - Si Uraninite	U3a - Foliation-parallel	20.6	0.5	0
END-09-02	329.8	Ca - Si Uraninite	U3a - Foliation-parallel	19.5	0.16	0
END-09-02	329.8	Ca - Si Uraninite	U3a - Foliation-parallel	22.78	0.56	0.01
END-09-02	329.8	Ca - Si Uraninite	U3a - Foliation-parallel	21.42	0.33	0
END-10-03	203	Coffinite	U3a - Foliation-parallel	11.44	0.08	0
END-10-03	203	Ca - Uraninite	U3a - Foliation-parallel	24.64	0.17	0
END-10-03	203	Ca - Uraninite	U3a - Foliation-parallel	24.87	0.14	0

Drill Hole	Depth (m)	Mineral	Style	U	Pb	Th
END-10-03	203	Ca - Si Uraninite	U3a - Foliation-parallel	21.48	0.12	0
END-10-03	203	Ca - Si Uraninite	U3a - Foliation-parallel	20.64	0.15	0.01
END-10-03	203	Ca - Si Uraninite	U3a - Foliation-parallel	25.35	0.14	0.01
END-10-03	203	Ca - Si - Ti Uraninite	U3a - Foliation-parallel	14.16	0.15	0
END-10-03	203	Ca - Si - Ti Uraninite	U3a - Foliation-parallel	19.43	0.04	0
END-10-03	267	Uranophane	U3b - Infill-type	11.06	0.19	0.03
END-10-03	267	Uranophane	U3b - Infill-type	11.23	0.41	0.56
END-10-03	244.5	Coffinite	U3b - Infill-type	10.93	0	0
END-10-03	267	Coffinite	U3b - Infill-type	14.42	0.08	0.05
END-10-03	222.4	Ca - Uraninite	U3b - Infill-type	23.14	0.61	0
END-10-03	222.4	Ca - Uraninite	U3b - Infill-type	24.39	1.02	0
END-10-03	222.4	Ca - Uraninite	U3b - Infill-type	23.32	0.71	0
END-10-03	222.4	Ca - Uraninite	U3b - Infill-type	23.35	0.65	0
END-10-03	222.4	Ca - Uraninite	U3b - Infill-type	23.97	0.93	0
END-10-03	222.4	Ca - Uraninite	U3b - Infill-type	22.21	0.9	0.01
END-10-03	222.4	Ca - Uraninite	U3b - Infill-type	24.42	0.81	0.01
END-10-03	244.5	Ca - Si Uraninite	U3b - Infill-type	13.97	0.02	0
END-10-03	244.5	Ca - Si Uraninite	U3b - Infill-type	22.18	0.01	0
END-10-03	244.5	Ca - Si Uraninite	U3b - Infill-type	22.3	0	0.02
END-10-03	244.5	Ca - Si Uraninite	U3b - Infill-type	18.84	0	0.02
END-10-03	244.5	Ca - Si Uraninite	U3b - Infill-type	17.11	0.01	0
END-10-03	244.5	Ca - Si Uraninite	U3b - Infill-type	11.81	0	0
END-10-03	267	Ca - Si Uraninite	U3b - Infill-type	19.57	2.9	0.08
END-10-03	267	Ca - Si Uraninite	U3b - Infill-type	18.45	0.56	0.02
END-10-03	267	Ca - Si - Ti Uraninite	U3b - Infill-type	9.77	0.62	0.03
END-09-02	298.2	Uranophane	U3c - Roll Front	11.62	0.01	0
END-10-03	217.6	Coffinite	U3c - Roll Front	9.58	0.09	0
END-10-03	217.6	Ca - Si Uraninite	U3c - Roll Front	11.08	0.1	0
END-10-03	217.6	Ca - Si Uraninite	U3c - Roll Front	12.39	0.1	0
END-10-03	217.6	Ca - Si Uraninite	U3c - Roll Front	20.4	0.18	0.01
END-09-02	298.2	Ca - Si Uraninite	U3c - Roll Front	16.29	0.11	0
END-09-02	298.2	Ca - Si Uraninite	U3c - Roll Front	14.77	0.1	0
END-09-02	298.2	Ca - Si - Ti Uraninite	U3c - Roll Front	12.19	0.12	0.02
END-09-02	298.2	Ca - Si - Ti Uraninite	U3c - Roll Front	14.16	0.15	0.03
END-09-02	298.2	Ca - Si - Ti Uraninite	U3c - Roll Front	7.6	0.04	0
END-09-02	298.2	Ca - Si - Ti Uraninite	U3c - Roll Front	15.56	0.12	0

Table B.4 Oxide weight percent data for phyllosilicate minerals from the End deposit, Thelon basin, Nunavut, Canada.

Drill Hole	Depth (m)	Mineral	Na ₂ O	SiO ₂	CaO	Fe ₂ O ₃	TiO ₂	K ₂ O	MnO	MgO	Al ₂ O ₃	Total
END-10-02A	20	Biotite	0.37	46.1	0	2.09	0.54	10.78	0.02	1	33.23	94.12
END-10-02A	20	Biotite	0.35	46.06	0.01	2.1	0.57	10.52	0	1.12	33	93.85
END-10-02A	20	Biotite	0.34	46.15	0.01	2.16	0.57	10.5	0.03	0.99	33.5	94.38
END-10-02A	20	Chlorite	0.07	25.45	0.02	32.33	0.04	0.04	0.35	12.77	18.61	89.79
END-10-02A	20	Chlorite	0.09	26.2	0.17	31.9	0.17	0.08	0.34	13.07	18.59	90.81
END-10-02A	20	Chlorite	0.08	26.08	0.02	32.81	0.04	0.04	0.38	12.72	18.42	90.65
END-10-02A	20	Chlorite	0.13	26.26	0.01	31.47	0.01	0.05	0.31	13.06	18.62	89.98
END-10-02A	20	Chlorite	0.08	25.69	0.01	32.06	0.11	0.03	0.38	12.81	18.57	89.9
END-10-02A	20	Chlorite	0.11	28.99	1.34	27.26	1.5	1.31	0.31	11.27	19.14	91.35
END-10-02A	50	Chlorite	0.08	26.23	0.03	32.08	0.01	0.06	0.54	12.42	17.73	89.23
END-10-02A	50	Chlorite	0.13	26.21	0.03	34.42	0.1	0.04	0.53	11.88	18.2	91.55
END-10-02A	50	Chlorite	0.02	28.35	0.07	21.78	0.09	0.05	0.31	15.6	19.58	86.2
END-10-02A	50	Muscovite	0.6	55.44	0.17	2.32	0.16	5.14	0.05	2.39	27.41	93.87
END-10-02A	50	Muscovite	0.07	50.08	0.03	3.5	0.1	5.7	0.15	0.92	32.77	93.39
END-10-02A	50	Muscovite	0.08	48.98	0.02	4.41	0.04	6.09	0.05	0.67	33.32	93.78
END-10-02A	62	Chlorite	0.06	27.85	0.01	23.15	0.05	0.08	0.22	19.12	19.68	100
END-10-02A	62	Chlorite	0.05	28.1	0.04	23.95	0.02	0.07	0.27	18.68	19.19	100
END-10-02A	62	Chlorite	0.05	34.97	0.06	8.3	0.04	0.54	0.22	15.83	27.17	87.42
END-10-02A	62	Chlorite	0.04	27.47	0.01	23.01	0	0.04	0.13	19	19.87	89.93
END-10-02A	62	Chlorite	0.07	28.79	0.02	21.41	0.1	0.05	0.23	18.99	19.77	89.73
END-10-02A	62	Illite	0.04	54.49	0.01	2.58	0	4.92	0.04	2.76	29.34	94.32
END-10-02A	62	Illite	0.08	55.32	0.06	2.18	0.03	5.76	0.02	2.55	28.79	95.09
END-10-02A	62	Illite	0.14	48.86	0.17	0.45	0.05	6.54	0	2.94	25.67	85.19
END-10-02A	62	Illite	0.16	54.77	0.13	0.54	0.02	5.78	0.02	4.01	26.53	92.19
END-10-02A	62	Illite	0.07	56.3	0.08	0.56	0.04	4.84	0	5.16	25.95	93.32
END-10-02A	70	Biotite - Altered	0.02	55.19	0.11	1.96	0.05	4.53	0.01	4.19	26.4	92.78
END-10-02A	70	Chlorite	0.05	26.34	0.03	29.17	0.06	0.08	0.45	14.19	18.97	89.62
END-10-02A	80	Biotite	0.34	49.26	0.01	3.38	0.55	5.33	0.06	1.63	34.29	94.85
END-10-02A	80	Biotite	0.31	50.44	0.02	2.98	0.47	5.38	0.06	1.62	32.99	94.28

Drill Hole	Depth (m)	Mineral	Na ₂ O	SiO ₂	CaO	Fe ₂ O ₃	TiO ₂	K ₂ O	MnO	MgO	Al ₂ O ₃	Total
END-10-02A	80	Chlorite	0.1	27.24	1.28	30.77	1.6	0.18	0.42	11.9	18.06	100
END-10-02A	80	Chlorite	0.07	26.53	0.09	32.8	0.08	0.04	0.37	12.19	18.27	90.46
END-10-02A	80	Muscovite	0.42	46.24	0.03	3.04	0.49	10.74	0.04	1.24	32.55	100
END-10-02A	80	Muscovite	0.07	47.78	0.03	10.78	0.19	5.62	0.12	4.85	25.44	95.05
END-10-02A	80	Muscovite	0.36	46.45	0	3.34	0.53	10.55	0.04	1.99	31.08	100
END-10-02A	110	Chlorite	0	27.33	0.03	30.46	0.07	0.92	0.37	12.45	19.56	91.49
END-10-02A	110	Chlorite	0.02	29.68	0.06	25.69	0.27	3.08	0.25	11.63	21.92	92.74
END-10-02A	110	Chlorite	0.01	26.18	0.02	37.97	0	0.01	0.53	10.34	16.79	91.91
END-10-02A	110	Chlorite	0	29.35	0.04	28.55	0.18	2.13	0.33	12.22	19.56	92.43
END-10-02A	110	Chlorite	0	31.63	0.01	25.58	1.06	5	0.28	10.47	19.46	93.5
END-10-02A	110	Chlorite	0	25.19	0.01	33.56	0.07	0	0.41	11.93	21.48	100
END-10-02A	110	Chlorite	0.03	25.34	0.01	33.66	0.09	0.01	0.49	11.75	20.34	100
END-10-02A	110	Chlorite	0.06	25.36	0.02	32.32	0.08	0.04	0.44	11.9	20.53	90.82
END-10-02A	110	Chlorite	0.04	34.76	0	22.73	0.29	8.29	0.28	10.21	19.49	96.59
END-10-02A	110	Chlorite	0	24.97	0	32.65	0.07	0.05	0.31	11.78	21.08	91.13
END-10-02A	110	Chlorite	0.03	33.02	0.14	15.73	0	0.13	0.09	20.17	18.66	88.19
END-10-02A	110	Illite	0.24	55.63	0.17	6.7	0	6.61	0.11	3.31	20.57	93.5
END-10-02A	110	Illite	0.22	46.14	0	4.47	0.43	6.63	0.02	1.84	32.58	92.4
END-10-02A	110	Muscovite	0.45	46.01	0.01	2.87	0.34	10.37	0.09	1.25	32.7	94.27
END-10-02A	110	Muscovite	0.28	43.89	0	6.06	0.27	10.37	0.04	2.42	31.23	100
END-10-02A	110	Muscovite	0.44	44.41	0	4.82	0.18	10.21	0.04	1.94	31.61	100
END-10-02A	110	Muscovite	0.34	44.89	0	4.57	0.22	10.66	0.01	1.92	31.43	100
END-10-02A	110	Muscovite	0.21	53.75	0.01	1.46	0	7.74	0	0.87	32.1	96.37
END-10-02A	110	Muscovite	0.33	49.91	0	2.86	0.42	5.58	0.01	1.33	34.27	94.76
END-10-02A	110	Muscovite - Altered	0.3	51.35	0.01	2.57	0.33	5.25	0.02	1.72	32.95	94.54
END-10-02A	127.4	Chlorite	0	24.95	0	34.03	0.1	0.02	0.35	5.99	19.98	85.48
END-10-02A	127.4	Chlorite	0	27.33	0.04	32.92	0.46	0.65	0.37	6.33	17.85	85.96
END-10-02A	127.4	Chlorite	0.03	27.61	0.12	32.88	0.52	0.27	0.33	6.33	16.91	85.03
END-10-02A	127.4	Chlorite	0.02	25.19	0.02	35.29	0.03	0.06	0.31	10.43	20.55	92.06
END-10-02A	127.4	Illite	0.09	51.48	0.13	2.15	0.01	5.33	0.03	0.71	34.76	94.72

Drill Hole	Depth (m)	Mineral	Na ₂ O	SiO ₂	CaO	Fe ₂ O ₃	TiO ₂	K ₂ O	MnO	MgO	Al ₂ O ₃	Total
END-10-02A	129.4	Chlorite	0.02	27.15	0.02	28.39	0.08	0.12	0.23	7.3	18.55	82.02
END-10-02A	129.4	Illite	0.17	52.15	0.03	1.52	0.02	5.81	0.01	0.87	32.99	93.8
END-10-02A	129.4	Illite	0.19	48.92	0.16	0.8	0.06	7.48	0	0.37	37.25	95.24
END-10-02A	129.4	Muscovite	0.32	45.7	0.01	4.57	0.57	10.59	0.02	1.23	29.33	92.54
END-10-02A	129.4	Muscovite	0.25	45.25	0	4.23	0.48	10.98	0.03	1.01	30.09	92.43
END-10-02A	129.4	Muscovite	0.3	45.25	0	4.31	0.39	10.68	0.05	0.74	30.67	92.49
END-10-02A	145	Altered Chlorite	0.11	41.18	0.15	4.78	0.02	0.85	0	13.44	29.9	90.78
END-10-02A	145	Chlorite	0.06	27.22	0.01	28.17	0.02	0.03	0.64	14.66	20	90.85
END-10-02A	145	Chlorite	0.11	39.44	0.11	5.11	0.07	1.03	0.02	13.79	26.29	86.12
END-10-02A	147.2	Biotite	0.24	47.6	0.02	5.3	0.56	6.16	0.03	1.7	32.45	94.09
END-10-02A	147.2	Biotite	0.34	45.31	0	4.93	0.51	10.66	0.05	0.82	31.4	100
END-10-02A	147.2	Chlorite	0.01	28.23	0.03	27.21	0.24	0.37	0.34	13.77	19.44	89.68
END-10-02A	147.2	Muscovite	0.41	45.91	0	4.96	0.53	10.8	0.02	0.8	31.55	100
END-10-02A	147.2	Muscovite	0.37	45.86	0.02	4.61	0.43	10.85	0.03	0.91	30.69	100
END-10-02A	147.2	Muscovite	0.37	46.27	0.01	4.71	0.43	10.75	0	0.74	31.33	100
END-10-02A	147.2	Muscovite	0.34	45.92	0	3.93	0.23	11.03	0.06	0.68	31.79	100
END-10-02A	152	Biotite	0.04	36.07	0.15	19.65	3.51	8.33	0.32	7.56	12.72	100
END-10-02A	152	Biotite	0.08	39.66	0.06	5.55	1.26	9.97	0	12.46	13.26	100
END-10-02A	152	Biotite	0.01	38.5	0.04	9.61	1.2	7.54	0.08	12.14	12.55	100
END-10-02A	152	Chlorite	0.01	34.43	0.04	12.44	0.03	0.02	0.15	26.86	12.76	87.45
END-10-02A	152	Chlorite	0.02	33.42	0.06	13.37	0	0.02	0.16	25.91	14.15	87.55
END-10-02A	152	Chlorite	0.04	34.65	0.05	12.14	0	0.02	0.19	27.73	12.14	87.63
END-10-02A	160	Chlorite	0.19	25.46	0.02	31.86	0.12	0.08	0.41	6.92	20.61	100
END-10-02A	160	Chlorite	0.07	24.96	0.02	33.96	0.14	0.06	0.35	11.36	20.66	91.68
END-10-02A	160	Muscovite	0.2	43.24	0.01	9.28	0.74	9.12	0.05	1.78	28.15	100
END-10-02A	160	Muscovite	0.29	46.01	0	5.08	0.25	10.9	0	0.85	30.55	100
END-10-02A	160	Muscovite	0.36	45.68	0	5.2	0.42	10.48	0.02	0.99	30	100
END-10-02A	160	Muscovite - Altered	0.13	52.23	0	1.35	0.06	5.62	0.02	1.08	35.99	96.5
END-10-02A	180	Chlorite	0.09	27.83	0.05	29.4	0.01	0.05	0.4	14.68	18.39	91.05
END-10-02A	180	Chlorite	0	36.41	21	14.82	0.13	0.03	0.12	0.09	20.78	93.58

Drill Hole	Depth (m)	Mineral	Na ₂ O	SiO ₂	CaO	Fe ₂ O ₃	TiO ₂	K ₂ O	MnO	MgO	Al ₂ O ₃	Total
END-10-02A	180	Chlorite	0.07	28.3	0.04	27.18	0.04	0.1	0.35	15.76	18.17	90.12
END-10-02A	180	Chlorite	0.09	27.53	0.3	29.3	0.23	0.07	0.46	8.15	17.73	100
END-10-02A	180	Chlorite	0.09	27.92	0.03	28.99	0.02	0.04	0.47	15.05	19.05	91.92
END-10-02A	190	Chlorite	0.05	29.88	0.05	29.64	0.49	0.82	0.35	12.8	17.64	91.81
END-10-02A	190	Chlorite	0.06	25.65	0.04	28.06	0.12	0.18	0.47	14.18	19.36	88.2
END-10-02A	190	Chlorite	0.03	27.12	0.03	27.33	0.11	0.09	0.46	15.66	18.97	90
END-10-02A	190	Illite	0.07	55.6	0.1	1.21	0	4.54	0	2.86	29.04	93.68
END-10-02A	190	Illite	0.11	53.68	0.26	1.53	0	4.79	0.03	2.05	31.09	93.75
END-10-02A	190	Illite	0.12	55.24	0.2	1.53	0.04	4.84	0.02	2.33	30.9	95.5
END-10-02A	202.4	Chlorite	0.13	27.06	0.07	28.81	0.07	0.1	0.41	14.13	19.43	90.27
END-10-02A	202.4	Chlorite	0.13	28.1	0.04	26.98	0.07	0.23	0.35	13.6	21.59	91.26
END-10-02A	202.4	Illite	0.28	47.72	0	3.54	0.43	5.8	0.06	1.12	33.8	92.97
END-10-02A	202.4	Illite	0.39	47.9	0.08	3.49	0.45	5.62	0.04	1.24	32.94	92.32
END-10-02A	202.4	Illite	0.39	48	0.03	3.58	0.45	5.21	0.03	1.42	32.5	91.77
END-10-02A	202.4	Illite	0.18	42.67	0.06	10.28	0.11	3.41	0.27	8.72	26.32	92.18
END-10-02A	202.4	Illite	0.32	50.92	0.05	3.73	0.38	5.15	0	2.09	31.91	94.8
END-10-02A	202.4	Muscovite	0.24	53.95	0.08	0.36	0	9.83	0	1.06	19.61	85.13
END-10-02A	250	Chlorite	0.05	25.23	0.03	37.48	0.34	0.25	0.15	4.92	18.06	86.58
END-10-02A	250	Chlorite	0	24.82	0.04	38.28	0	0.04	0.24	9.26	19.14	91.92
END-10-02A	250	Chlorite	0.06	26.02	0.04	37.06	0.39	0.33	0.18	9.51	18.5	92.22
END-10-02A	250	Chlorite	0.04	26.07	0.04	37.96	0.13	0.12	0.23	5	18.13	87.96
END-10-02A	250	Chlorite	0.03	25.59	0.06	37.54	0	0.04	0.19	4.89	18.43	86.89
END-10-02A	250	Illite	0.07	53.18	0.04	4.17	0	4.7	0.02	1.5	31.2	95.02
END-10-02A	310	Chlorite	0.02	26.23	0.03	31.34	0.05	0.04	0.29	13.5	19.42	91.15
END-10-02A	330	Chlorite	0.11	27.31	0.07	33.27	0.63	0.14	0.24	12.27	17.46	100
END-10-02A	330	Illite	0.16	51	0.17	1.66	0.05	5.34	0.02	1.68	31.31	100
END-10-02A	330	Illite	0.08	48.06	0.17	3.47	0.03	4.92	0.06	3.71	27.64	100
END-10-02A	330	Muscovite	0.46	46.68	0.01	1.8	0.38	10.37	0.02	0.77	32.59	93.13
END-10-02A	330	Muscovite	0.19	50.85	0.14	2.2	0	9.83	0	0.98	30.17	94.51
END-10-02A	330	Muscovite	0.31	51.09	0.18	1.78	0.01	9.77	0.01	0.92	30.41	94.6

Drill Hole	Depth (m)	Mineral	Na ₂ O	SiO ₂	CaO	Fe ₂ O ₃	TiO ₂	K ₂ O	MnO	MgO	Al ₂ O ₃	Total
END-10-02A	330	Muscovite	0.24	50.29	0.22	1.6	0	9.42	0.01	0.92	30.1	93.09
END-10-02A	334.7	Illite	0.07	52.38	0.1	3.08	0.05	6.02	0.01	1.96	30	100
END-10-02A	334.7	Illite	0.07	52.96	0.1	2.84	0	5.59	0	1.85	31.13	100
END-10-02A	334.7	Illite	0.06	52.72	0.12	3.1	0	5.47	0	1.91	30.58	100
END-10-02A	334.7	Illite	0.07	52.72	0.07	3.02	0.02	5.59	0	1.78	31.34	100
END-10-02A	334.7	Illite	0.06	52.31	0.11	3	0	5.47	0	1.74	30.64	100
END-10-02A	334.7	Illite	0.05	48.02	0.12	2.74	0	6.12	0	1.95	27.85	100
END-10-02A	334.7	Illite	0.08	54.87	0.16	3.3	0	5.5	0.02	1.98	31.08	100
END-10-02A	334.7	Illite	0.03	46.24	0.08	2.71	0	5.73	0	1.39	25.91	100
END-10-02A	334.7	Illite	0.07	51.98	0.1	2.55	0.05	5.91	0.01	1.84	30.84	100
END-10-02A	360	Chlorite	0.11	26.29	0.16	29.2	0.09	0.08	0.37	14.5	19.34	100
END-10-02A	360	Chlorite	0.15	26.13	0.2	34.91	0.6	0.24	0.4	11.12	17.02	100
END-10-02A	360	Chlorite	0.04	30.77	0.08	26.07	0.05	1.22	0.33	12.12	21.7	100
END-10-02A	360	Chlorite	0.06	27.17	2.58	26.83	2.94	0.08	0.25	13.51	18.58	100
END-10-02A	360	Chlorite	0.04	33.97	11.51	12.46	0.19	0.05	0.08	8.82	20.76	100
END-10-02A	360	Chlorite	0.04	31.14	0.12	24.19	0.44	0.91	0.27	13.07	20.83	100
END-10-02A	360	Illite	0.09	53.29	0.05	2.76	0.05	5.81	0.06	2.72	29.55	100
END-10-02A	435	Chlorite	0.05	28.74	0.09	24.24	0.42	0.52	0.4	8.3	18.7	81.62
END-10-02A	435	Chlorite	0.05	27.26	0.06	25.41	0.21	0.23	0.37	8.18	18.12	79.95
END-10-02A	435	Muscovite	0.52	46.2	0.01	1.61	0.47	10.51	0.04	0.57	33.53	93.58
END-10-02A	435	Muscovite	0.56	45.32	0.01	1.59	0.5	10.6	0.02	0.55	33.65	92.84
END-10-02A	435	Muscovite	0.53	45.36	0	1.78	0.52	10.3	0.05	0.67	32.51	91.82
END-10-03	20	Chlorite	0.23	32.34	0.04	25.37	0.26	5.51	0.04	0.61	21.36	100
END-10-03	20	Illite	0.4	47.87	0.19	1.05	0.03	5.11	0	0.92	34.02	100
END-10-03	20	Illite	0.12	48.81	0.03	1.28	0.02	5.76	0	0.8	35.47	100
END-10-03	30	Illite	0.09	48.6	0.19	0.79	0	5.22	0	1.4	31.9	100
END-10-03	30	Illite	0.04	50.32	0.11	1.07	0.03	5.37	0.02	1.56	32.88	100
END-10-03	30	Illite	0.05	50.83	0.14	1.18	0	6.39	0.03	1.41	33.96	100
END-10-03	30	Illite	0.03	44.05	0.02	1.34	0.03	7.44	0.02	0.88	35	100
END-10-03	30	Illite	0.15	49.47	0.17	1.12	0.02	6.59	0.05	1.28	34.18	100

Drill Hole	Depth (m)	Mineral	Na ₂ O	SiO ₂	CaO	Fe ₂ O ₃	TiO ₂	K ₂ O	MnO	MgO	Al ₂ O ₃	Total
END-10-03	30	Illite	0.07	51.94	0.1	1.03	0.01	5.7	0.01	1.69	33.8	100
END-10-03	30	Muscovite	0.09	49.55	0.13	1.01	0.01	10	0.01	1.62	31.98	94.52
END-10-03	42.4	Illite	0.11	51.51	0.08	1.03	0	5.32	0.04	1.03	34.87	100
END-10-03	42.4	Illite	0.04	53.16	0.02	3.52	0.06	5.07	0.05	1.9	31.23	100
END-10-03	42.4	Illite	0.09	52.32	0.03	2.24	0	5.69	0.03	1.65	32.27	100
END-10-03	42.4	Illite	0.18	50.26	0.2	1.26	0.03	5.68	0.03	1.38	32.16	100
END-10-03	42.4	Illite	0.06	54.53	0.02	2.11	0.01	4.97	0.01	2.28	31.58	100
END-10-03	42.4	Illite	0.13	52.32	0.09	1.54	0.08	5.51	0	1.81	31.91	100
END-10-03	42.4	Muscovite	0.08	47.35	0.01	3.42	0	10.83	0	0.98	31.69	94.53
END-10-03	42.4	Muscovite	0.06	48.6	0.01	3.63	0.23	10.66	0.01	1.51	29.95	94.81
END-10-03	42.4	Muscovite	0.15	48.03	0.01	3.2	0.49	10.31	0.04	1.57	31.12	94.97
END-10-03	42.4	Muscovite	0.2	47.69	0.02	2.51	0.11	10.21	0.05	1.65	30.68	93.29
END-10-03	50	Illite	0.03	50.41	0.06	1.16	0	5.71	0.02	0.78	35.31	100
END-10-03	50	Illite	0.01	52.29	0.06	1.25	0	5.45	0	0.77	35.96	100
END-10-03	50	Illite	0.02	50.79	0.04	1.18	0.16	5.36	0	0.82	35.38	100
END-10-03	50	Illite	0.02	50.9	0.02	1.06	0.07	5.62	0.01	0.71	35.67	100
END-10-03	50	Muscovite	0.33	46.5	0	2.57	0.38	10.76	0.01	1.32	32.63	94.51
END-10-03	50	Muscovite	0.06	48.95	0.07	1.09	0.01	9.86	0	0.85	33.87	94.77
END-10-03	60	Illite	0.07	50.11	0.02	4.21	0	6.25	0	1.01	34	100
END-10-03	60	Illite	0.12	49.17	0.03	2.73	0	5.82	0.06	0.7	35.99	100
END-10-03	60	Illite	0.13	48.47	0.02	5.9	0.3	5.94	0.01	1.58	32.13	100
END-10-03	60	Muscovite	0.12	46.37	0.01	4.34	0.05	11.22	0.08	1.06	30.99	94.37
END-10-03	60	Muscovite	0.16	47.08	0	3.77	0.26	10.91	0	1.86	29.6	93.77
END-10-03	60	Muscovite	0.28	45.9	0.02	3.41	0.24	10.91	0	1.54	31.88	94.42
END-10-03	70	Chlorite	0.06	34.06	0.09	27.67	0.01	1.28	0.34	8.23	23.34	100
END-10-03	70	Chlorite	0.09	30.87	0.07	25.04	0.03	1.16	0.34	12.89	21.21	91.85
END-10-03	70	Chlorite	0.03	27.89	0.07	29.94	0	0.24	0.43	13.32	20.31	100
END-10-03	70	Chlorite	0.09	35.37	0.26	19.38	0.01	1.5	0.28	8.58	23.38	100
END-10-03	70	Chlorite	0.09	27.38	0.13	24.03	0.03	0.61	0.42	13.87	18.91	100
END-10-03	70	Chlorite	0	24.05	0.02	33.76	0.11	0.09	0.37	11.4	20.78	100

Drill Hole	Depth (m)	Mineral	Na ₂ O	SiO ₂	CaO	Fe ₂ O ₃	TiO ₂	K ₂ O	MnO	MgO	Al ₂ O ₃	Total
END-10-03	70	Chlorite	0.02	29.89	0.05	22.94	0.05	0.4	0.28	13.55	22.29	100
END-10-03	80	Chlorite	0.04	38.26	0.08	17.3	0.12	1.33	0.19	13.34	22.5	100
END-10-03	80	Illite	0.13	57.9	0.29	1.14	0.05	5	0.04	3.96	26.61	100
END-10-03	80	Illite	0.11	56.85	0.3	1.4	0.02	4.5	0.02	3.29	29.04	100
END-10-03	80	Illite	0.11	55.51	0.2	1.07	0.09	5.54	0.01	2.59	28.27	100
END-10-03	90	Illite	0.04	55.65	0.41	1.23	0	4.14	0	3	27.37	100
END-10-03	90	Illite	0.02	53.92	0.11	3.64	0.14	4.91	0	2.48	28.6	100
END-10-03	90	Illite	0.05	55.5	0.12	1.63	0.17	3.52	0.01	2.59	29.96	100
END-10-03	90	Illite	0.03	51.1	0.14	1.95	0	6.3	0.02	2.44	28.4	100
END-10-03	90	Illite	0.03	51.99	0.18	2.7	0.21	4.15	0.01	2.84	29.08	100
END-10-03	100	Illite	0.1	56.03	0.33	1.7	0.01	5.02	0	3.3	27.57	100
END-10-03	100	Illite	0.09	57.15	0.33	1.81	0	5.1	0	3.36	27.59	100
END-10-03	100	Illite	0.12	57.64	0.25	1.52	0	4.71	0.01	3.21	27.08	100
END-10-03	100	Illite	0.1	55.77	0.32	1.72	0.05	4.9	0	3.05	27.36	100
END-10-03	100	Illite	0.13	56.83	0.26	1.57	0.02	4.48	0	2.75	29.28	100
END-10-03	100	Illite	0.16	49.16	0.21	1.1	0	8.22	0.04	2.17	28.16	100
END-10-03	100	Illite	0.07	42.71	0.1	0.74	0.09	6.5	0.01	1.69	26.56	100
END-10-03	100	Illite	0.04	47.96	0.08	1.13	0	8.31	0	1.99	28.89	100
END-10-03	131	Illite	0.09	52.55	0.14	1.48	0	5.27	0.02	2.38	30.97	100
END-10-03	131	Illite	0.12	54.79	0.18	3.2	0.01	5.89	0	2.42	31.49	100
END-10-03	131	Illite	0.03	46.84	0.06	1.49	0.03	5.37	0.02	3.78	31.01	100
END-10-03	131	Illite	0.04	51.21	0.02	3.3	0.03	6.11	0.06	1.16	33.44	100
END-10-03	131	Illite	0.34	48.35	0.09	2.49	0	5.96	0	1.31	34.29	100
END-10-03	131	Muscovite	0.49	46.55	0.07	2.59	0	9.62	0	1.2	32.44	93
END-10-03	131	Muscovite	0.47	45.26	0.02	3.77	0.28	10.11	0	1.55	31.6	93.04
END-10-03	131	Muscovite	0.49	45.88	0.05	3.55	0.29	10.14	0.04	1.46	31.93	94.07
END-10-03	131	Muscovite	0.37	46.23	0	2.95	0.24	10.44	0.02	1.3	32.18	93.74
END-10-03	140	Illite	0.12	57.11	0.39	1.09	0.02	4.48	0.01	3.38	26.81	100
END-10-03	140	Illite	0.04	55.91	0.4	1.05	0	5.65	0	3.54	27.4	100
END-10-03	140	Illite	0.07	56.47	0.39	1.18	0	5.28	0	3.42	27.68	100

Drill Hole	Depth (m)	Mineral	Na ₂ O	SiO ₂	CaO	Fe ₂ O ₃	TiO ₂	K ₂ O	MnO	MgO	Al ₂ O ₃	Total
END-10-03	140	Illite	0.08	54.94	0.27	1.23	0.1	6.2	0.05	3.03	29.51	100
END-10-03	140	Illite	0.18	49.97	0.23	1.1	0	4.48	0	2.77	23.89	100
END-10-03	140	Illite	0.09	58.12	0.4	1.19	0.01	4.08	0	3.22	27.88	100
END-10-03	150.2	Illite	0.32	48.59	0.01	2.99	0.6	6.17	0.02	1.25	34.19	100
END-10-03	150.2	Illite	0.36	49.88	0.01	2.93	0.56	5.21	0.04	1.31	34.26	100
END-10-03	150.2	Illite	0.36	49.9	0.01	3.08	0.47	5.44	0.02	1.17	34.88	100
END-10-03	150.2	Illite	0.37	47.92	0.06	3.26	0.5	6.27	0.01	1.4	33.51	100
END-10-03	150.2	Illite	0.25	33.6	0.03	2.14	0.44	7.09	0.03	0.81	22.2	100
END-10-03	150.2	Illite	0.06	52.82	0.15	1.21	0.03	4.38	0.08	2.39	31.7	100
END-10-03	150.2	Illite	0.17	53.14	0.04	1.78	0.24	4.96	0.02	1.91	33.35	100
END-10-03	170	Illite	0.06	56.63	0.4	1.71	0	4.52	0	2.99	27.8	100
END-10-03	170	Illite	0.04	56.48	0.42	1.64	0.06	5.69	0	3.37	27.24	100
END-10-03	170	Illite	0.05	53.87	0.4	2.21	0.03	4.93	0.01	2.65	27.83	100
END-10-03	170	Illite	0.04	57.34	0.37	1.54	0.04	4.49	0.04	3.18	27.64	100
END-10-03	170	Illite	0.06	58.26	0.43	1.51	0.01	3.95	0	3.62	27.41	100
END-10-03	180	Illite	0.17	55.28	0.39	2.33	0.04	4.15	0.02	3.48	24.69	100
END-10-03	180	Muscovite	0.32	48.99	0.02	2.84	0.6	9.95	0	2.15	29.19	94.2
END-10-03	180	Muscovite	0.28	50.18	0.05	2.66	0.45	9.48	0.01	2.42	28.44	94.2
END-10-03	180	Muscovite - Altered	0.11	56.38	0.15	1.27	0.07	7.83	0.04	4.32	23.31	93.74
END-10-03	180	Muscovite - Altered	0.08	57.78	0.08	1.3	0.04	7.46	0	4.64	22.32	94.15
END-10-03	244.5	Illite	0.1	44.7	0.18	6.03	0.11	3.95	0	5.42	29.29	100
END-10-03	244.5	Illite	0.06	54.14	0.2	3.51	0	4.34	0.02	3.27	28.65	100
END-10-03	244.5	Illite	0.34	48.25	0.02	2.91	0	6.45	0.03	1.17	34.72	100
END-10-03	244.5	Illite	0.03	36.32	0.24	8.8	0.11	1.65	0	9.66	29.2	100
END-10-03	244.5	Illite	0.04	38.53	0.29	8.19	0.22	2.63	0.05	8.02	28.19	100
END-10-03	244.5	Illite	0.04	38.24	0.36	8.85	0.09	1.17	0	10.02	28.7	100
END-10-03	244.5	Illite	0.04	40.16	0.25	5.72	0.15	2.19	0.06	8.42	29.95	100
END-10-03	244.5	Muscovite - Altered	0.33	48.82	0	3.15	0.07	5.84	0	1.09	35.28	100
END-10-03	250	Biotite - Altered	0.07	37.26	0.08	15.78	0.19	3.76	0.17	11.14	22.87	91.35
END-10-03	250	Chlorite	0.04	31.2	0.07	22.71	0.14	1.51	0.21	13.43	20.66	90.1

Drill Hole	Depth (m)	Mineral	Na ₂ O	SiO ₂	CaO	Fe ₂ O ₃	TiO ₂	K ₂ O	MnO	MgO	Al ₂ O ₃	Total
END-10-03	250	Illite	0.21	52.21	0.26	1.33	0.04	4.82	0.01	2.56	29.3	100
END-10-03	250	Illite	0.13	54.05	0.12	2.36	0.01	4.47	0.03	2.89	28.32	100
END-10-03	250	Illite	0.26	52.05	0	3.54	0.4	4.73	0.01	2.18	32.36	100
END-10-03	250	Illite	0.45	48.03	0.01	3.35	0.39	7.26	0	1.11	34.06	100
END-10-03	250	Illite	0.23	53.27	0.22	3.67	0	5.57	0.01	3.27	26.58	100
END-10-03	250	Illite	0.37	50.64	0.02	3.27	0.46	5.17	0	1.56	33.99	100
END-10-03	250	Illite	0.16	53.34	0.11	1.4	0.03	5.05	0.03	2.09	32.22	100
END-10-03	250	Illite	0.19	52.68	0.25	2.6	0	4.07	0.01	3.04	26.24	100
END-10-03	250	Muscovite	0.35	44.39	0.02	5.54	0.25	9.12	0.04	3.14	30.7	93.71
END-10-03	250	Muscovite	0.42	45.51	0.01	3.38	0.24	10.7	0	0.85	33.1	94.23
END-10-03	253.7	Illite	0.06	52.71	0.03	4.23	0.64	4.96	0	1.92	30.62	100
END-10-03	253.7	Illite	0.09	53.2	0.07	2.83	0	4.97	0	1.48	32.39	100
END-10-03	253.7	Illite	0.07	45.39	0.31	1.46	0.02	1.8	0	6.78	31.48	100
END-10-03	253.7	Illite	0.08	52.85	0.04	3.54	0.09	5.21	0.05	2.16	31.33	100
END-10-03	253.7	Illite	0.13	45.58	0.54	1.66	0.04	2.05	0	5.24	30.42	100
END-10-03	253.7	Illite	0.09	51.97	0.02	3.94	0.19	5.29	0.02	1.89	32.1	100
END-10-03	253.7	Illite	0.1	37.56	0.35	4.82	0.03	1.15	0.03	12.01	29.53	100
END-10-03	253.7	Illite	0.18	49.94	0.36	3.82	0	2.69	0.02	2.75	29.8	100
END-10-03	280	Muscovite - Altered	0.36	49.59	0	3.88	0.26	5.57	0.01	1.26	34.63	100
END-10-03	280	Muscovite - Altered	0.33	45.13	0.01	4.05	0.33	10.64	0.02	1.35	32.08	94.04
END-10-03	280	Muscovite - Altered	0.39	45.78	0	3.8	0.15	10.2	0.02	1.24	32.25	93.99
END-10-03	280	Muscovite - Altered	0.42	45.52	0	3.89	0.32	10.5	0.02	1.4	32.09	94.3
END-10-03	290	Chlorite	0.08	32.03	0.11	21.17	0.13	0.77	0.24	14.42	20.1	89.18
END-10-03	290	Chlorite	0.02	29.19	0.07	23.98	0.09	0.12	0.21	15.63	19.46	88.78
END-10-03	290	Illite	0.25	48.3	0.01	2.12	0.38	5.97	0.01	0.76	34.86	92.67
END-10-03	290	Illite	0.08	50.92	0.02	5.05	0.04	5.49	0	1.96	29.27	93.03
END-10-03	290	Illite	0.07	55.02	0.18	2.54	0.04	5.15	0	2.85	28.84	94.9
END-10-03	290	Illite	0.15	54.29	0.17	2.05	0.04	6.03	0.01	2.57	28.59	94.15
END-10-03	290	Muscovite	0.1	44.98	0.02	8.3	0.48	8.71	0.04	5.51	26.42	100
END-10-03	296	Illite	0.07	53.9	0.15	1.48	0	5.13	0.03	3.02	31.14	95.12

Drill Hole	Depth (m)	Mineral	Na ₂ O	SiO ₂	CaO	Fe ₂ O ₃	TiO ₂	K ₂ O	MnO	MgO	Al ₂ O ₃	Total
END-10-03	296	Illite	0.05	53.33	0.17	1.7	0	4.78	0	3.08	30.37	93.52
END-10-03	296	Illite	0.07	55.17	0.15	1.59	0	4.89	0.01	3.12	30.88	95.95
END-10-03	296	Illite	0.06	54.84	0.14	1.57	0	5.17	0.03	2.71	30.87	95.57
END-10-03	347.7	Illite	0.09	50.83	0.45	1.75	0	4.53	0.04	3.43	25.85	87.43
END-10-03	347.7	Illite	0.42	48.22	0	2.44	0.37	5.51	0	0.82	35.22	93.24
END-10-03	347.7	Illite	0.46	48.02	0.01	2.69	0.27	7.1	0.01	0.92	35.34	95.1

Table B.4 Oxide weight percent data for phyllosilicate minerals from the End deposit, Thelon basin, Nunavut, Canada.

Drill Hole	Depth (m)	Mineral	Fe	Mg	K	x	Temp (°C)
10-02A	190	Illite	0.075	0.198	0.395	0.518	170
10-02A	190	Illite	0.073	0.221	0.392	0.54	176
10-02A	190	Illite	0.058	0.274	0.372	0.588	189
10-02A	202.4	Illite	0.183	0.204	0.429	0.45	152
10-02A	202.4	Illite	0.202	0.143	0.449	0.508	168
10-02A	202.4	Illite	0.177	0.125	0.483	0.535	175
10-02A	217	Illite	0.137	0.186	0.498	0.547	178
10-02A	217	Illite	0.15	0.188	0.557	0.595	191
10-02A	250	Illite	0.203	0.145	0.388	0.446	151
10-02A	330	Illite	0.083	0.167	0.454	0.538	176
10-02A	330	Illite	0.183	0.388	0.441	0.646	205
10-02A	334.7	Illite	0.157	0.187	0.444	0.474	159
10-02A	334.7	Illite	0.148	0.171	0.459	0.482	161
10-02A	334.7	Illite	0.147	0.172	0.463	0.488	162
10-02A	334.7	Illite	0.152	0.186	0.456	0.49	163
10-02A	334.7	Illite	0.139	0.179	0.463	0.503	166
10-02A	334.7	Illite	0.126	0.18	0.496	0.55	179
10-02A	334.7	Illite	0.153	0.156	0.55	0.553	180
10-02A	334.7	Illite	0.147	0.207	0.557	0.617	197
10-02A	360	Illite	0.135	0.264	0.483	0.612	195
Average Temperature							175
10-03	30	Illite	0.054	0.155	0.406	0.507	167
10-03	42.4	Illite	0.076	0.176	0.458	0.558	181
10-03	42.4	Illite	0.05	0.099	0.438	0.487	162
10-03	42.4	Illite	0.165	0.176	0.422	0.433	148
10-03	42.4	Illite	0.062	0.16	0.472	0.57	184
10-03	42.4	Illite	0.063	0.138	0.485	0.56	182
10-03	42.4	Illite	0.101	0.216	0.403	0.518	170
10-03	131	Illite	0.073	0.232	0.44	0.599	192
10-03	140	Illite	0.053	0.324	0.368	0.639	203
10-03	140	Illite	0.051	0.341	0.465	0.755	234
10-03	140	Illite	0.057	0.327	0.431	0.701	219
10-03	140	Illite	0.059	0.289	0.506	0.736	229
10-03	140	Illite	0.056	0.303	0.328	0.575	186
10-03	244.5	Illite	0.171	0.316	0.359	0.504	167
10-03	244.5	Illite	0.496	1.079	0.158	0.741	230
10-03	244.5	Illite	0.472	1.096	0.11	0.734	228
10-03	244.5	Illite	0.311	0.908	0.202	0.799	246
10-03	250	Illite	0.067	0.255	0.411	0.599	192
10-03	250	Illite	0.117	0.283	0.375	0.541	176

Drill Hole	Depth (m)	Mineral	Fe	Mg	K	x	Temp (°C)
10-03	250	Illite	0.068	0.2	0.414	0.546	178
10-03	250	Illite	0.133	0.309	0.354	0.53	174
10-03	253.7	Illite	0.206	0.185	0.41	0.431	147
10-03	253.7	Illite	0.137	0.142	0.407	0.412	142
10-03	253.7	Illite	0.172	0.208	0.429	0.465	156
10-03	253.7	Illite	0.088	0.551	0.184	0.647	205
10-03	253.7	Illite	0.192	0.182	0.436	0.446	151
10-03	253.7	Illite	0.195	0.279	0.233	0.317	116
10-03	290	Illite	0.106	0.075	0.506	0.537	175
10-03	290	Illite	0.255	0.196	0.47	0.529	173
10-03	290	Illite	0.123	0.274	0.423	0.574	185
10-03	290	Illite	0.101	0.25	0.501	0.65	206
10-03	296	Illite	0.076	0.294	0.394	0.612	195
10-03	296	Illite	0.075	0.257	0.419	0.601	193
10-03	296	Illite	0.071	0.288	0.419	0.636	202
10-03	296	Illite	0.083	0.298	0.396	0.611	195
10-03	347.7	Illite	0.092	0.358	0.404	0.67	211
10-03	347.7	Illite	0.121	0.081	0.465	0.505	167
Average Temperature							186

Table B.5 MR3-2R3-3R2 calculations of alteration minerals within the End Deposit, Thelon Basin, Nunavut, Canada.

Drill Hole	Depth (m)	Mineral	Na	Ca	Fe	Ti	K	Mg	Al	Mn	MR ³	2R ³	3R ²
10-03	70	Chlorite	0.07	0.05	17.51	0.02	0.96	7.77	11.22	0.27	1.13	5.06	8.52
10-03	131	Illite	0.36	0.05	1.81	0	7.98	0.72	17.17	0	8.44	4.37	0.84
10-03	131	Illite	0.35	0.01	2.63	0.17	8.39	0.93	16.72	0	8.76	4.07	1.19
10-03	131	Illite	0.36	0.04	2.48	0.18	8.42	0.88	16.9	0.03	8.86	4.11	1.13
10-03	131	Illite	0.27	0	2.06	0.14	8.67	0.79	17.03	0.01	8.94	4.12	0.95
10-03	42.4	Muscovite	0.06	0.01	2.39	0	8.99	0.59	16.77	0	9.07	3.85	0.99
10-03	42.4	Muscovite	0.04	0.01	2.54	0.14	8.85	0.91	15.85	0.01	8.91	3.54	1.15
10-03	42.4	Muscovite	0.11	0.01	2.24	0.3	8.56	0.94	16.47	0.03	8.69	4.04	1.07
10-03	42.4	Muscovite	0.15	0.01	1.75	0.07	8.47	1	16.24	0.04	8.64	3.84	0.93
10-03	180	Muscovite	0.08	0.11	0.89	0.04	6.5	2.61	12.33	0.03	6.8	2.79	1.18
10-03	180	Muscovite	0.24	0.01	1.99	0.36	8.26	1.3	15.45	0	8.52	3.65	1.10
10-03	180	Muscovite	0.21	0.04	1.86	0.27	7.87	1.46	15.05	0.01	8.16	3.58	1.11
10-03	180	Muscovite	0.06	0.06	0.91	0.02	6.19	2.8	11.81	0	6.37	2.73	1.24
10-03	250	Biotite	0.26	0.01	3.88	0.15	7.57	1.89	16.25	0.03	7.85	4.28	1.93
10-03	250	Chlorite	0.03	0.05	15.89	0.08	1.25	8.1	10.93	0.16	1.38	4.82	8.05
10-03	250	Muscovite	0.31	0	2.37	0.14	8.88	0.51	17.52	0	9.19	4.24	0.96
10-03	250	Biotite	0.05	0.06	11.04	0.11	3.12	6.72	12.1	0.13	3.29	4.46	5.96
10-03	20	Muscovite	0.16	0.04	0.06	0	0.28	0.03	0.9	0	0.52	0.19	0.03
10-03	20	Muscovite	0.29	0.13	0.74	0.02	4.24	0.56	18.01	0	4.79	6.62	0.43
10-03	20	Muscovite	0.17	0.03	17.74	0.15	4.57	0.37	11.3	0.03	4.8	3.33	6.05
10-03	20	Muscovite	2.37	0.03	43.02	0.16	3.12	0.19	8.38	0.02	5.55	1.50	14.41
10-03	20	Muscovite	0.09	0.02	0.89	0.01	4.78	0.48	18.77	0	4.91	6.94	0.46
10-03	20	Muscovite	0.07	0.02	15.59	0.06	1.25	0.11	3.45	0.01	1.36	1.08	5.24
10-03	30	Muscovite	0.07	0.14	0.55	0	4.34	0.85	16.88	0	4.69	6.10	0.47
10-03	30	Muscovite	0.03	0.08	0.75	0.02	4.46	0.94	17.4	0.01	4.65	6.39	0.57
10-03	30	Muscovite	0.03	0.1	0.83	0	5.3	0.85	17.97	0.03	5.53	6.22	0.57
10-03	30	Muscovite	0.03	0.01	0.94	0.02	6.18	0.53	18.52	0.02	6.23	6.16	0.50
10-03	30	Muscovite	0.11	0.12	0.78	0.01	5.47	0.77	18.09	0.04	5.82	6.14	0.53
10-03	30	Muscovite	0.05	0.07	0.72	0.01	4.73	1.02	17.89	0.01	4.92	6.49	0.58

Drill Hole	Depth (m)	Mineral	Na	Ca	Fe	Ti	K	Mg	Al	Mn	MR ³	2R ³	3R ²
10-03	50	Muscovite	0.02	0.04	0.81	0	4.74	0.47	18.69	0.02	4.84	6.93	0.43
10-03	50	Muscovite	0.01	0.04	0.87	0	4.52	0.46	19.03	0	4.61	7.21	0.44
10-03	50	Muscovite	0.01	0.03	0.82	0.09	4.45	0.49	18.73	0	4.52	7.15	0.44
10-03	50	Muscovite	0.02	0.02	0.74	0.04	4.67	0.43	18.88	0	4.73	7.10	0.39
10-03	60	Muscovite	0.05	0.01	2.94	0	5.19	0.61	17.99	0	5.26	6.37	1.18
10-03	60	Muscovite	0.09	0.02	1.91	0	4.83	0.42	19.05	0.05	4.96	7.05	0.79
10-03	60	Muscovite	0.09	0.01	4.12	0.18	4.93	0.96	17	0.01	5.04	6.07	1.70
10-03	30	Muscovite	0.07	0.1	0.71	0.01	8.3	0.98	16.92	0.01	8.57	4.18	0.57
10-03	50	Muscovite	0.25	0	1.79	0.23	8.93	0.8	17.27	0.01	9.18	4.16	0.87
10-03	50	Muscovite	0.04	0.05	0.76	0	8.19	0.52	17.93	0	8.33	4.80	0.43
10-03	60	Muscovite	0.09	0.01	3.04	0.03	9.31	0.64	16.4	0.06	9.42	3.51	1.25
10-03	60	Muscovite	0.12	0	2.63	0.16	9.06	1.12	15.66	0	9.18	3.32	1.25
10-03	60	Muscovite	0.2	0.01	2.38	0.14	9.06	0.93	16.87	0	9.28	3.87	1.10
10-03	70	Illite	0.04	0.07	19.35	0	1.06	4.96	12.35	0.26	1.24	5.56	8.19
10-03	70	Chlorite	0.02	0.05	20.94	0	0.2	8.03	10.75	0.33	0.32	5.22	9.77
10-03	70	Chlorite	0.07	0.18	13.56	0	1.25	5.17	12.38	0.22	1.68	5.35	6.32
10-03	70	Chlorite	0.07	0.09	16.81	0.02	0.5	8.36	10.01	0.32	0.75	4.64	8.50
10-03	70	Chlorite	0	0.02	23.61	0.07	0.07	6.87	11	0.28	0.11	5.48	10.25
10-03	70	Chlorite	0.02	0.03	16.04	0.03	0.33	8.17	11.79	0.22	0.41	5.71	8.14
10-03	70	Muscovite	0.1	0.03	0.17	0	8.07	0.14	10.82	0	8.23	1.30	0.10
10-03	70	Muscovite	0.07	0	0.01	0	9.54	0	10.1	0.01	9.61	0.25	0.01
10-03	80	Sericite	0.1	0.2	0.79	0.03	4.15	2.39	14.08	0.03	4.65	4.73	1.07
10-03	80	Sericite	0.08	0.21	0.98	0.01	3.74	1.99	15.37	0.02	4.24	5.57	1.00
10-03	80	Chlorite	0.03	0.06	12.1	0.07	1.11	8.04	11.91	0.15	1.26	5.36	6.76
10-03	80	Muscovite	0.19	0.01	0.4	0	8.49	0.4	10.32	0.03	8.7	0.81	0.28
10-03	80	Illite	0.08	0.14	0.75	0.05	4.6	1.56	14.96	0.01	4.96	5.03	0.77
10-03	80	Muscovite	0.26	0.04	0.24	0	8.3	0.03	10.77	0.02	8.64	1.07	0.10
10-03	90	Muscovite	0.03	0.29	0.86	0	3.44	1.81	14.48	0	4.05	5.22	0.89
10-03	90	Chlorite	0.01	0.08	2.55	0.08	4.08	1.49	15.14	0	4.25	5.49	1.35
10-03	90	Muscovite	0.04	0.09	1.14	0.1	2.92	1.56	15.85	0.01	3.14	6.41	0.90

Drill Hole	Depth (m)	Mineral	Na	Ca	Fe	Ti	K	Mg	Al	Mn	MR ³	2R ³	3R ²
10-03	90	Muscovite	0.02	0.1	1.36	0	5.23	1.47	15.03	0.02	5.45	4.79	0.95
10-03	90	Muscovite	0.02	0.13	1.89	0.13	3.44	1.71	15.39	0.01	3.72	5.90	1.20
10-03	100	Muscovite	0.08	0.24	1.19	0.01	4.17	1.99	14.59	0	4.73	4.94	1.06
10-03	100	Muscovite	0.07	0.23	1.26	0	4.24	2.03	14.6	0	4.77	4.92	1.10
10-03	100	Muscovite	0.09	0.18	1.06	0	3.91	1.93	14.33	0.01	4.36	4.99	1.00
10-03	100	Muscovite	0.08	0.23	1.2	0.03	4.07	1.84	14.48	0	4.61	4.95	1.01
10-03	100	Muscovite	0.1	0.19	1.1	0.01	3.72	1.66	15.5	0	4.2	5.66	0.92
10-03	100	Muscovite	0.12	0.15	0.77	0	6.82	1.31	14.9	0.03	7.24	3.83	0.70
10-03	100	Muscovite	0.06	0.07	0.52	0.05	5.4	1.02	14.06	0	5.6	4.26	0.51
10-03	100	Muscovite	0.03	0.06	0.79	0	6.9	1.2	15.29	0	7.05	4.12	0.66
10-03	131	Illite	0.07	0.1	1.04	0	4.38	1.44	16.39	0.01	4.65	5.87	0.83
10-03	131	Muscovite	0.09	0.13	2.24	0.01	4.89	1.46	16.67	0	5.24	5.72	1.23
10-03	131	Muscovite	0.02	0.04	1.04	0.02	4.45	2.28	16.41	0.01	4.55	5.94	1.11
10-03	131	Muscovite	0.03	0.01	2.31	0.02	5.08	0.7	17.7	0.04	5.13	6.30	1.02
10-03	131	Muscovite	0.25	0.06	1.74	0	4.95	0.79	18.15	0	5.32	6.42	0.84
10-03	140	Illite	0.09	0.28	0.77	0.01	3.72	2.04	14.19	0.01	4.37	4.92	0.94
10-03	140	Illite	0.03	0.29	0.74	0	4.69	2.13	14.5	0	5.3	4.60	0.96
10-03	140	Illite	0.05	0.28	0.82	0	4.38	2.06	14.65	0	4.99	4.83	0.96
10-03	140	Illite	0.06	0.19	0.86	0.06	5.15	1.83	15.62	0.04	5.59	5.05	0.91
10-03	140	Muscovite	0.13	0.17	0.77	0	3.72	1.67	12.65	0	4.19	4.23	0.81
10-03	140	Illite	0.07	0.29	0.83	0.01	3.39	1.94	14.75	0	4.04	5.36	0.92
10-03	150.2	Muscovite	0.23	0.01	2.09	0.36	5.12	0.76	18.1	0.02	5.37	6.55	0.96
10-03	150.2	Muscovite	0.27	0.01	2.05	0.34	4.32	0.79	18.13	0.03	4.61	6.93	0.96
10-03	150.2	Muscovite	0.27	0.01	2.16	0.28	4.52	0.71	18.46	0.01	4.81	6.97	0.96
10-03	150.2	Muscovite	0.27	0.04	2.28	0.3	5.21	0.84	17.73	0.01	5.56	6.24	1.04
10-03	150.2	Muscovite	0.18	0.02	1.5	0.27	5.89	0.49	11.75	0.02	6.11	2.96	0.67
10-03	150.2	Muscovite	0.04	0.11	0.85	0.02	3.64	1.44	16.78	0.06	3.9	6.45	0.78
10-03	150.2	Muscovite	0.13	0.03	1.25	0.14	4.12	1.15	17.65	0.01	4.31	6.74	0.80
10-03	170	Muscovite	0.05	0.28	1.2	0	3.75	1.8	14.71	0	4.36	5.18	1.00
10-03	170	Muscovite	0.03	0.3	1.15	0.03	4.72	2.03	14.42	0	5.35	4.55	1.06

Drill Hole	Depth (m)	Mineral	Na	Ca	Fe	Ti	K	Mg	Al	Mn	MR ³	2R ³	3R ²
10-03	170	Muscovite	0.04	0.29	1.55	0.02	4.09	1.6	14.73	0.01	4.71	5.02	1.05
10-03	170	Muscovite	0.03	0.26	1.08	0.02	3.73	1.92	14.63	0.03	4.28	5.19	1.01
10-03	170	Muscovite	0.05	0.31	1.06	0.01	3.28	2.18	14.5	0	3.95	5.28	1.08
10-03	42.4	Illite	0.08	0.06	0.72	0	4.41	0.62	18.46	0.03	4.61	6.93	0.46
10-03	42.4	Illite	0.03	0.01	2.46	0.03	4.21	1.15	16.53	0.04	4.26	6.15	1.22
10-03	42.4	Illite	0.07	0.02	1.57	0	4.72	1	17.08	0.03	4.83	6.13	0.87
10-03	42.4	Illite	0.13	0.14	0.88	0.02	4.71	0.83	17.02	0.02	5.12	5.96	0.58
10-03	42.4	Illite	0.04	0.02	1.48	0.01	4.13	1.38	16.71	0.01	4.21	6.26	0.96
10-03	42.4	Illite	0.1	0.06	1.08	0.05	4.58	1.09	16.89	0	4.8	6.07	0.72
10-03	180	Muscovite	0.07	0.15	0.95	0.01	2.79	2.66	13.25	0	3.16	5.05	1.20
10-03	180	Muscovite	0.13	0.28	1.63	0.02	3.44	2.1	13.07	0.01	4.13	4.48	1.25
10-03	250	Illite	0.16	0.19	0.93	0.02	4	1.54	15.51	0.01	4.54	5.50	0.83
10-03	250	Illite	0.1	0.09	1.65	0.01	3.71	1.74	14.99	0.03	3.99	5.51	1.14
10-03	250	Muscovite	0.2	0	2.48	0.24	3.92	1.31	17.12	0	4.12	6.62	1.26
10-03	250	Muscovite	0.33	0	2.35	0.23	6.03	0.67	18.02	0	6.36	5.95	1.01
10-03	250	Illite	0.17	0.16	2.57	0	4.63	1.97	14.06	0	5.12	4.47	1.51
10-03	250	Biotite	0.28	0.01	2.29	0.27	4.29	0.94	17.99	0	4.59	6.84	1.08
10-03	250	Illite	0.12	0.08	0.98	0.02	4.19	1.26	17.05	0.02	4.47	6.30	0.75
10-03	250	Illite	0.14	0.18	1.82	0	3.38	1.83	13.89	0	3.88	5.01	1.22
10-02A	62.4	Muscovite	0.14	0.07	6.65	0.04	1.33	9.79	14.69	0.02	1.61	6.56	5.49
10-02A	62.4	Illite	0.09	0.04	0.69	0.02	4.01	4.94	14.75	0	4.18	5.30	1.88
10-02A	62.4	Chlorite	0.04	0.01	16.9	0.05	0.02	11.27	10.65	0.14	0.08	5.31	9.44
10-02A	62.4	Illite	0.11	0.12	0.53	0.03	4.73	2.44	14.6	0.01	5.08	4.78	0.99
10-02A	62.4	Chlorite	0.15	0.06	8.67	0	0.06	17.13	7.01	0.12	0.33	3.34	8.64
10-02A	210	Chlorite	0.04	0.02	20.26	0.07	0.01	9.07	10.46	0.39	0.09	5.22	9.91
10-02A	250	Chlorite	0.06	0.01	25.23	0.29	0.63	5.84	9.81	0.14	0.71	4.70	10.40
10-02A	250	Chlorite	0.04	0.02	27.34	0.07	0.03	5.51	10.03	0.17	0.11	5.00	11.01
10-02A	202.4	Chlorite	0.07	0.02	20.83	0.03	0.01	8.34	10.17	0.29	0.12	5.04	9.82
10-02A	202.4	Chlorite	0.01	0.03	20.59	0.01	0.02	8.81	10.04	0.29	0.09	4.98	9.90
10-02A	217	Chlorite	0.03	0	24.27	0.05	0.06	6.47	10.39	0.24	0.09	5.18	10.33

Drill Hole	Depth (m)	Mineral	Na	Ca	Fe	Ti	K	Mg	Al	Mn	MR ³	2R ³	3R ²
10-02A	217	Illite	0.17	0.03	0.83	0	7.45	0.5	14.94	0	7.68	3.63	0.44
10-02A	217	Chlorite	0.01	0	24.74	0.03	0.03	6.44	10.42	0.27	0.04	5.21	10.48
10-02A	217	Chlorite	0.03	0.02	24.56	0.05	0.03	6.61	10.22	0.26	0.1	5.09	10.48
10-02A	217	Chlorite	0.01	0.01	23.6	0	0.25	6.23	10.95	0.26	0.28	5.34	10.03
10-02A	217	Illite	0.09	0.12	2.12	0.01	5.52	1.16	15.93	0.01	5.85	5.05	1.10
10-02A	217	Illite	0.06	0.1	1.97	0	5.01	1.16	16.38	0.01	5.27	5.56	1.05
10-03	170.99	Chlorite	0.03	0.02	13.98	0.04	0.09	9.15	11.9	0.27	0.16	5.89	7.80
10-03	170.99	Illite	0.04	0.14	0.79	0.02	3.89	1.88	14.4	0.03	4.21	5.11	0.90
10-03	170.99	Illite	0.04	0.07	1.61	0.02	4.14	1.59	16.2	0.01	4.32	5.95	1.07
10-03	170.99	Illite	0.14	0.05	0.68	0.01	4.82	0.77	18.59	0.06	5.06	6.77	0.50
10-03	170.99	Muscovite	0.19	0	2.84	0.23	4.49	0.81	17.76	0.01	4.68	6.66	1.22
10-03	170.99	Chlorite	0.01	0.02	19.34	0.05	0.14	9.2	10.42	0.39	0.19	5.14	9.64
10-03	244.5	Muscovite	0.24	0	2.2	0.04	4.85	0.66	18.67	0	5.09	6.81	0.95
10-03	244.5	Illite	0.07	0.13	4.22	0.07	3.28	3.27	15.5	0	3.61	5.98	2.50
10-03	244.5	Illite	0.04	0.14	2.45	0	3.6	1.97	15.16	0.02	3.92	5.62	1.48
10-03	244.5	Muscovite	0.25	0.01	2.04	0	5.36	0.7	18.37	0.03	5.63	6.37	0.92
10-03	244.5	Illite	0.03	0.17	6.16	0.06	1.37	5.83	15.45	0	1.74	6.89	4.00
10-03	244.5	Illite	0.03	0.21	5.73	0.13	2.18	4.84	14.92	0.04	2.63	6.21	3.54
10-03	244.5	Illite	0.03	0.26	6.19	0.05	0.97	6.04	15.19	0	1.52	6.86	4.08
10-03	244.5	Illite	0.03	0.18	4	0.09	1.82	5.08	15.85	0.04	2.21	6.87	3.04
10-03	253.7	Illite	0.05	0.02	2.96	0.38	4.12	1.16	16.21	0	4.21	6.19	1.37
10-03	253.7	Illite	0.07	0.05	1.98	0	4.12	0.89	17.14	0	4.29	6.43	0.96
10-03	253.7	Illite	0.05	0.22	1.02	0.01	1.49	4.09	16.66	0	1.98	7.35	1.70
10-03	253.7	Illite	0.06	0.03	2.47	0.05	4.33	1.3	16.58	0.04	4.45	6.09	1.27
10-03	253.7	Illite	0.09	0.39	1.16	0.03	1.7	3.16	16.1	0	2.57	6.78	1.44
10-03	253.7	Illite	0.07	0.02	2.75	0.12	4.39	1.14	16.99	0.01	4.5	6.31	1.30
10-03	253.7	Illite	0.08	0.25	3.37	0.02	0.95	7.24	15.63	0.02	1.53	7.06	3.54
10-03	253.7	Illite	0.13	0.25	2.67	0	2.24	1.66	15.77	0.02	2.87	6.45	1.45
10-03	280	Muscovite	0.27	0	2.72	0.15	4.62	0.76	18.33	0.01	4.89	6.80	1.16
10-03	280	Muscovite	0.24	0.01	2.84	0.2	8.83	0.81	16.98	0.01	9.09	4.05	1.22

Drill Hole	Depth (m)	Mineral	Na	Ca	Fe	Ti	K	Mg	Al	Mn	MR ³	2R ³	3R ²
10-03	280	Muscovite	0.29	0	2.66	0.09	8.47	0.75	17.07	0.02	8.76	4.20	1.14
10-03	280	Muscovite	0.31	0	2.72	0.19	8.72	0.85	16.98	0.01	9.03	4.07	1.19
10-02A	20	Chlorite	0.05	0.02	22.61	0.02	0.03	7.7	9.85	0.27	0.12	4.88	10.19
10-02A	20	Chlorite	0.07	0.12	22.31	0.1	0.06	7.88	9.84	0.26	0.37	4.79	10.15
10-02A	129.4	Muscovite	0.22	0	3.02	0.24	8.87	0.45	16.23	0.04	9.09	3.69	1.17
10-02A	127.4	Illite	0.07	0.09	1.5	0.01	4.43	0.43	18.4	0.03	4.68	6.87	0.65
10-02A	127.4	Chlorite	0.01	0.01	24.69	0.02	0.05	6.29	10.87	0.24	0.08	5.41	10.41
10-02A	129.4	Illite	0.12	0.02	1.07	0.01	4.82	0.53	17.46	0.01	4.98	6.25	0.54
10-02A	129.4	Illite	0.14	0.11	0.56	0.04	6.21	0.22	19.71	0	6.57	6.59	0.26
10-02A	145	Chlorite	0.05	0.01	19.71	0.01	0.02	8.84	10.58	0.49	0.09	5.25	9.68
10-02A	147.2	Muscovite	0.26	0	2.75	0.14	9.15	0.41	16.82	0.05	9.41	3.78	1.07
10-02A	152	Biotite	0.03	0.11	13.74	2.1	6.92	4.56	6.73	0.25	7.17	0.83	6.18
10-02A	152	Biotite	0.01	0.03	6.72	0.72	6.26	7.32	6.64	0.06	6.33	0.52	4.70
10-02A	160	Muscovite	0.15	0.01	6.49	0.44	7.57	1.07	14.9	0.04	7.74	3.80	2.53
10-02A	160	Muscovite	0.21	0	3.56	0.15	9.05	0.51	16.17	0	9.26	3.53	1.36
10-02A	160	Muscovite	0.27	0	3.64	0.25	8.7	0.6	15.88	0.01	8.97	3.58	1.42
10-02A	160	Chlorite	0.14	0.02	22.29	0.07	0.06	4.17	10.91	0.32	0.24	5.37	8.93
10-02A	180	Chlorite	0.07	0.22	20.49	0.14	0.06	4.91	9.38	0.35	0.57	4.48	8.58
10-02A	147.2	Biotite	0.18	0.02	3.71	0.34	5.12	1.02	17.18	0.03	5.34	6.09	1.59
10-02A	147.2	Chlorite	0.01	0.02	19.03	0.14	0.31	8.3	10.29	0.26	0.36	5.04	9.20
10-02A	152	Chlorite	0.01	0.03	8.7	0.02	0.02	16.2	6.75	0.12	0.09	3.34	8.34
10-02A	152	Chlorite	0.02	0.04	9.35	0	0.01	15.62	7.49	0.13	0.11	3.69	8.37
10-02A	20	Chlorite	0.06	0.01	22.95	0.02	0.03	7.67	9.75	0.29	0.11	4.83	10.30
10-02A	20	Chlorite	0.1	0.01	22.01	0.01	0.04	7.88	9.86	0.24	0.16	4.86	10.04
10-02A	20	Chlorite	0.06	0.01	22.42	0.07	0.03	7.73	9.83	0.3	0.11	4.90	10.15
10-02A	20	Sericite	3.17	0.29	0.31	0	5.37	0.06	10.99	0	9.12	0.94	0.12
10-02A	20	Sericite	1.56	0.11	0.55	0	5.44	0.27	14.69	0	7.22	3.74	0.27
10-02A	110	Chlorite	0	0.02	21.31	0.04	0.76	7.51	10.35	0.29	0.8	4.80	9.70
10-02A	110	Chlorite	0.04	0	0.04	0.02	9.51	0	10.15	0	9.55	0.31	0.01
10-02A	110	Muscovite	0.24	0	2	0.25	4.63	0.8	18.14	0.01	4.87	6.76	0.94

Drill Hole	Depth (m)	Mineral	Na	Ca	Fe	Ti	K	Mg	Al	Mn	MR ³	2R ³	3R ²
10-02A	110	Biotite	0.02	0.04	17.97	0.16	2.56	7.01	11.6	0.19	2.66	4.55	8.39
10-02A	110	Chlorite	0.01	0.01	26.56	0	0.01	6.23	8.89	0.41	0.04	4.43	11.07
10-02A	110	Biotite	0.22	0.01	1.8	0.2	4.36	1.04	17.44	0.01	4.6	6.52	0.95
10-02A	110	Muscovite	0.33	0.02	0.15	0	8.56	0.03	10.24	0.02	8.93	0.66	0.07
10-02A	110	Muscovite	0.13	0.19	0.18	0	8.64	0.01	9.61	0.01	9.15	0.23	0.07
10-02A	110	Chlorite	0	0.03	19.97	0.11	1.77	7.37	10.35	0.25	1.83	4.32	9.20
10-02A	110	Muscovite	0.33	0.01	2.01	0.2	8.61	0.76	17.31	0.07	8.96	4.28	0.95
10-02A	110	Muscovite	0	0.01	17.89	0.63	4.15	6.31	10.3	0.21	4.17	3.38	8.14
10-02A	127.4	Chlorite	0	0	23.8	0.06	0.02	3.62	10.58	0.27	0.02	5.31	9.23
10-02A	127.4	Chlorite	0	0.03	23.02	0.27	0.54	3.82	9.45	0.28	0.6	4.56	9.04
10-02A	127.4	Chlorite	0.02	0.09	23	0.31	0.22	3.82	8.95	0.25	0.42	4.42	9.02
10-02A	129.4	Muscovite	0.23	0.01	3.2	0.34	8.79	0.74	15.52	0.01	9.04	3.41	1.32
10-02A	129.4	Chlorite	0.02	0.01	19.85	0.05	0.1	4.4	9.82	0.18	0.14	4.87	8.14
10-02A	129.4	Muscovite	0.19	0	2.96	0.29	9.12	0.61	15.92	0.03	9.31	3.45	1.20
10-02A	250	Chlorite	0.04	0.02	26.22	0.2	0.21	2.97	9.56	0.12	0.29	4.74	9.77
10-02A	250	Chlorite	0.03	0.03	26.55	0.08	0.1	3.01	9.59	0.18	0.19	4.74	9.91
10-02A	250	Chlorite	0.02	0.04	26.26	0	0.03	2.95	9.75	0.15	0.13	4.81	9.79
10-02A	310	Chlorite	0.03	0.03	22.19	0.02	0.01	4.1	10.31	0.29	0.1	5.12	8.86
10-02A	310	Chlorite	0.01	0	22.49	0	0.02	4.04	10.49	0.23	0.03	5.23	8.92
10-02A	310	Chlorite	0	0.01	21.89	0.06	0.05	3.99	10.28	0.28	0.07	5.14	8.72
10-02A	310	Chlorite	0	0.02	21.74	0.03	0.09	3.94	10.4	0.21	0.13	5.15	8.63
10-02A	190	Chlorite	0	0.06	18.46	1.13	3.7	3.45	8.63	0.26	3.82	2.97	7.39
10-02A	334.7	Illite	0.05	0.07	2.15	0.03	5	1.18	15.88	0.01	5.19	5.36	1.11
10-02A	334.7	Illite	0.06	0.07	1.99	0	4.64	1.12	16.48	0	4.84	5.82	1.04
10-02A	334.7	Illite	0.04	0.09	2.17	0	4.54	1.15	16.18	0	4.76	5.71	1.11
10-02A	334.7	Illite	0.05	0.05	2.11	0.01	4.64	1.07	16.59	0	4.79	5.91	1.06
10-02A	147.2	Muscovite	0.31	0	3.47	0.32	8.97	0.48	16.7	0.01	9.28	3.87	1.32
10-02A	147.2	Muscovite	0.28	0.01	3.23	0.26	9.01	0.55	16.24	0.02	9.31	3.60	1.27
10-02A	147.2	Biotite	0.26	0	3.45	0.31	8.85	0.5	16.62	0.04	9.11	3.91	1.33
10-02A	147.2	Muscovite	0.28	0.01	3.3	0.26	8.93	0.45	16.58	0	9.23	3.81	1.25

Drill Hole	Depth (m)	Mineral	Na	Ca	Fe	Ti	K	Mg	Al	Mn	MR ³	2R ³	3R ²
10-02A	80	Muscovite	0.32	0.02	2.13	0.3	8.92	0.75	17.23	0.03	9.28	4.13	0.97
10-02A	80	Muscovite	0.07	0.92	21.52	0.96	0.15	7.18	9.56	0.33	2.06	4.23	9.68
10-02A	80	Muscovite	0.26	0	2.33	0.32	8.76	1.2	16.45	0.03	9.02	3.88	1.19
10-02A	110	Muscovite	0.21	0	4.24	0.16	8.61	1.46	16.53	0.03	8.82	3.94	1.91
10-02A	110	Muscovite	0.33	0	3.37	0.11	8.48	1.17	16.73	0.03	8.81	4.02	1.52
10-02A	152	Chlorite	0.03	0.04	8.49	0	0.01	16.72	6.43	0.15	0.12	3.16	8.45
10-02A	160	Chlorite	0.02	0.2	0.23	0.28	1.48	0.98	4.03	0.01	1.9	1.21	0.41
10-02A	160	Chlorite	0.05	0.01	23.75	0.08	0.05	6.85	10.93	0.27	0.12	5.45	10.29
10-02A	160	Sericite	0.04	0.72	0.23	0.33	0.83	1.3	2.99	0.02	2.31	0.51	0.52
10-02A	180	Chlorite	0.05	0.03	19.01	0.03	0.09	9.5	9.62	0.27	0.2	4.73	9.59
10-02A	180	Chlorite	0.07	0.02	20.27	0.01	0.03	9.07	10.08	0.37	0.14	4.98	9.90
10-02A	202.4	Illite	0.29	0.02	2.51	0.27	4.33	0.86	17.2	0.02	4.66	6.41	1.13
10-02A	202.4	Chlorite	0.09	0.05	20.15	0.04	0.08	8.52	10.29	0.32	0.27	5.03	9.66
10-02A	202.4	Chlorite	0.1	0.03	18.87	0.04	0.19	8.2	11.42	0.27	0.35	5.56	9.11
10-02A	202.4	Illite	0.13	0.04	7.19	0.06	2.83	5.26	13.93	0.21	3.04	5.48	4.22
10-02A	202.4	Illite	0.24	0.03	2.61	0.23	4.28	1.26	16.89	0	4.58	6.27	1.29
10-02A	250	chlorite	0	0.03	26.77	0	0.03	5.58	10.13	0.19	0.09	5.02	10.85
10-02A	250	chlorite	0.04	0.03	25.92	0.24	0.28	5.73	9.79	0.14	0.38	4.83	10.60
10-02A	250	Illite	0.05	0.03	2.91	0	3.9	0.91	16.51	0.02	4.01	6.25	1.28
10-02A	310	Chlorite	0.02	0.02	21.92	0.03	0.04	8.14	10.28	0.22	0.1	5.11	10.09
10-02A	190	Chlorite	0.04	0.04	20.73	0.29	0.68	7.72	9.34	0.27	0.8	4.42	9.57
10-02A	190	Chlorite	0.05	0.03	19.62	0.07	0.15	8.55	10.25	0.37	0.26	5.03	9.51
10-02A	190	Chlorite	0.02	0.02	19.11	0.07	0.07	9.44	10.04	0.35	0.13	4.99	9.63
10-02A	190	Illite	0.05	0.07	0.85	0	3.77	1.72	15.37	0	3.96	5.71	0.86
10-02A	190	Illite	0.08	0.19	1.07	0	3.98	1.23	16.46	0.03	4.44	6.01	0.78
10-02A	190	Illite	0.09	0.14	1.07	0.02	4.02	1.4	16.35	0.02	4.39	5.99	0.83
10-02A	190	Illite	0.08	0.14	0.41	0.03	4.16	2.24	14.53	0	4.52	5.02	0.88
10-02A	334.7	Illite	0.04	0.08	2.1	0	4.54	1.05	16.22	0	4.74	5.74	1.05
10-02A	334.7	Illite	0.04	0.09	1.92	0	5.08	1.17	14.74	0	5.3	4.72	1.03
10-02A	334.7	Illite	0.06	0.11	2.31	0	4.56	1.2	16.45	0.01	4.84	5.81	1.17

Drill Hole	Depth (m)	Mineral	Na	Ca	Fe	Ti	K	Mg	Al	Mn	MR ³	2R ³	3R ²
10-02A	334.7	Illite	0.02	0.06	1.9	0	4.76	0.84	13.71	0	4.9	4.41	0.91
10-02A	334.7	Illite	0.05	0.07	1.79	0.03	4.91	1.11	16.32	0.01	5.1	5.63	0.97
10-02A	360	Illite	0.07	0.04	1.93	0.03	4.83	1.64	15.64	0.04	4.98	5.35	1.20
10-02A	330	Chlorite	0.08	0.05	23.27	0.38	0.12	7.4	9.24	0.19	0.3	4.66	10.29
10-02A	330	Illite	0.12	0.12	1.16	0.03	4.43	1.01	16.57	0.02	4.79	5.91	0.73
10-02A	110	Muscovite	0.25	0	3.2	0.13	8.85	1.16	16.64	0.01	9.1	3.84	1.46
10-02A	110	Muscovite	0	0.01	23.47	0.04	0	7.19	11.37	0.32	0.02	5.70	10.33
10-02A	110	Chlorite	0.03	0.01	23.54	0.05	0.01	7.08	10.76	0.38	0.06	5.38	10.33
10-02A	62	Chlorite	0.04	0.01	16.19	0.03	0.06	11.53	10.42	0.17	0.12	5.17	9.30
10-02A	62	Chlorite	0.04	0.03	16.75	0.01	0.06	11.26	10.16	0.21	0.16	5.01	9.41
10-02A	202.4	Illite	0.21	0	2.48	0.26	4.81	0.67	17.89	0.05	5.02	6.57	1.07
10-02A	202.4	Illite	0.29	0.06	2.44	0.27	4.67	0.75	17.43	0.03	5.08	6.31	1.07
10-02A	330	Illite	0.06	0.12	2.43	0.02	4.08	2.23	14.63	0.05	4.38	5.14	1.57
10-02A	435	Chlorite	0.04	0.07	16.95	0.25	0.43	5	9.9	0.31	0.61	4.77	7.42
10-02A	435	Muscovite	0.38	0.01	1.12	0.28	8.73	0.34	17.74	0.03	9.13	4.45	0.50
10-02A	435	Muscovite	0.41	0.01	1.11	0.3	8.8	0.33	17.81	0.02	9.23	4.44	0.49
10-02A	435	Chlorite	0.04	0.04	17.77	0.13	0.19	4.93	9.59	0.29	0.31	4.71	7.66
10-02A	435	Muscovite	0.39	0	1.25	0.31	8.55	0.4	17.2	0.04	8.94	4.29	0.56
10-02A	435	Muscovite	0.34	0.01	1.26	0.23	8.61	0.46	17.25	0.02	8.97	4.26	0.58
10-02A	330	Muscovite	0.14	0.1	1.54	0	8.16	0.59	15.97	0	8.5	3.74	0.71
10-02A	330	Muscovite	0.23	0.13	1.24	0.01	8.11	0.55	16.1	0.01	8.6	3.76	0.60
10-02A	330	Muscovite	0.18	0.16	1.12	0	7.82	0.56	15.93	0.01	8.32	3.81	0.56

Table B.6 Si and Al apfu content of muscovite and illite within the End Deposit, Thelon Basin, Nunavut, Canada.

Drill Hole	Depth (m)	Si	Al
END-10-02A	50	3.69	2.1
END-10-02A	50	3.316	2.558
END-10-02A	50	3.26	2.614
END-10-02A	62	3.645	1.98
END-10-02A	62	3.562	2.185
END-10-02A	62	3.611	2.061
END-10-02A	62	3.523	2.236
END-10-02A	62	3.526	2.186
END-10-02A	80	3.286	2.062
END-10-02A	80	3.169	2.499
END-10-02A	80	3.135	2.601
END-10-02A	110	3.77	1.643
END-10-02A	110	3.151	2.622
END-10-02A	110	3.247	2.628
END-10-02A	110	3.134	2.625
END-10-02A	110	3.103	2.561
END-10-02A	110	3.083	2.586
END-10-02A	110	3.046	2.555
END-10-02A	110	3.33	2.519
END-10-02A	127.4	3.316	2.639
END-10-02A	129.4	3.394	2.531
END-10-02A	129.4	3.164	2.84
END-10-02A	129.4	3.213	2.43
END-10-02A	129.4	3.174	2.536
END-10-02A	129.4	3.174	2.536
END-10-02A	147.2	3.172	2.531
END-10-02A	147.2	3.161	2.579
END-10-02A	147.2	3.144	2.546
END-10-02A	147.2	3.177	2.506
END-10-02A	160	3.189	2.495
END-10-02A	160	3.191	2.47
END-10-02A	160	3.108	2.384
END-10-02A	160	3.291	2.673
END-10-02A	190	3.581	2.204
END-10-02A	190	3.508	2.313
END-10-02A	190	3.473	2.371
END-10-02A	202.4	3.326	2.457
END-10-02A	202.4	3.245	2.59
END-10-02A	202.4	3.227	2.616
END-10-02A	202.4	3.197	2.669

END-10-02A	202.4	3.02	2.196
END-10-02A	202.4	3.93	1.684
END-10-02A	250	3.441	2.379
END-10-02A	330	3.401	2.461
END-10-02A	330	3.375	2.288
END-10-02A	330	3.398	2.384
END-10-02A	330	3.395	2.374
END-10-02A	330	3.397	2.396
END-10-02A	330	3.187	2.622
END-10-02A	334.7	3.471	2.317
END-10-02A	334.7	3.435	2.38
END-10-02A	334.7	3.445	2.355
END-10-02A	334.7	3.421	2.397
END-10-02A	334.7	3.447	2.327
END-10-02A	334.7	3.439	2.374
END-10-02A	334.7	3.416	2.389
END-10-02A	334.7	3.447	2.356
END-10-02A	334.7	3.478	2.297
END-10-02A	360	3.47	2.268
END-10-02A	435	3.143	2.688
END-10-02A	435	3.149	2.66
END-10-02A	435	3.111	0.026
END-10-03	20	3.228	2.765
END-10-03	20	3.252	2.723
END-10-03	30	3.346	2.566
END-10-03	30	3.309	2.605
END-10-03	30	3.44	2.575
END-10-03	30	3.264	2.658
END-10-03	30	3.343	2.586
END-10-03	30	3.051	2.857
END-10-03	30	3.295	2.506
END-10-03	42.4	3.464	2.364
END-10-03	42.4	3.431	2.375
END-10-03	42.4	3.393	2.467
END-10-03	42.4	3.41	2.451
END-10-03	42.4	3.321	2.65
END-10-03	42.4	3.362	2.535
END-10-03	42.4	3.293	2.392
END-10-03	42.4	3.235	2.47
END-10-03	42.4	3.26	2.472
END-10-03	42.4	3.22	2.54
Drill Hole	Depth (m)	Si	Al
END-10-03	50	3.31	2.682
END-10-03	50	3.285	2.713

END-10-03	50	3.287	2.699
END-10-03	50	3.281	2.708
END-10-03	50	3.238	2.64
END-10-03	50	3.151	2.606
END-10-03	60	3.26	2.607
END-10-03	60	3.201	2.761
END-10-03	60	3.233	2.526
END-10-03	60	3.245	2.404
END-10-03	60	3.192	2.514
END-10-03	60	3.143	2.573
END-10-03	80	3.674	1.99
END-10-03	80	3.587	2.159
END-10-03	80	3.599	2.16
END-10-03	90	3.639	2.11
END-10-03	90	3.555	2.262
END-10-03	90	3.524	2.203
END-10-03	90	3.469	2.287
END-10-03	90	3.476	2.277
END-10-03	100	3.676	2.035
END-10-03	100	3.631	2.066
END-10-03	100	3.593	2.182
END-10-03	100	3.611	2.094
END-10-03	100	3.622	2.094
END-10-03	100	3.426	2.313
END-10-03	100	3.377	2.397
END-10-03	100	3.358	2.461
END-10-03	131	3.437	2.328
END-10-03	131	3.438	2.388
END-10-03	131	3.317	2.553
END-10-03	131	3.216	2.688
END-10-03	131	3.244	2.531
END-10-03	131	3.183	2.614
END-10-03	131	3.16	2.593
END-10-03	131	3.144	2.579
END-10-03	131	3.134	2.578
END-10-03	140	3.667	2.073
END-10-03	140	3.676	2.034
END-10-03	140	3.617	2.09
END-10-03	140	3.609	2.085
END-10-03	140	3.513	2.224
END-10-03	140	3.654	2.059
END-10-03	150.2	3.375	2.497
END-10-03	150.2	3.432	2.428
END-10-03	150.2	3.227	2.659

END-10-03	150.2	3.246	2.627
END-10-03	150.2	3.17	2.629
END-10-03	150.2	3.198	2.636
END-10-03	150.2	3.221	2.508
END-10-03	170	3.671	0.072
END-10-03	170	3.649	2.073
END-10-03	170	3.632	2.101
END-10-03	170	3.648	2.073
END-10-03	170	3.565	2.17
END-10-03	180	3.786	1.723
END-10-03	180	3.719	1.812
END-10-03	180	3.698	1.946
END-10-03	180	3.523	2.043
END-10-03	180	3.316	2.329
END-10-03	244.5	3.512	2.193
END-10-03	244.5	3.191	2.7
END-10-03	244.5	3.136	2.422
END-10-03	244.5	2.904	2.553
END-10-03	244.5	2.893	2.495
END-10-03	244.5	2.802	2.478
END-10-03	244.5	2.722	2.579
END-10-03	244.5	3.194	2.72
END-10-03	250	3.552	2.193
END-10-03	250	3.424	2.437
END-10-03	250	3.547	2.086
END-10-03	250	3.593	2.109
END-10-03	250	3.488	2.307
END-10-03	250	3.346	2.452
END-10-03	250	3.267	2.584
END-10-03	250	3.181	2.658
END-10-03	250	3.11	2.666
END-10-03	250	3.081	2.511
END-10-03	253.7	3.416	2.451
END-10-03	253.7	3.408	2.381
END-10-03	253.7	3.414	2.338
END-10-03	253.7	3.358	2.444
END-10-03	253.7	3.395	2.387
END-10-03	253.7	3.212	2.527
END-10-03	253.7	3.144	2.57
END-10-03	253.7	2.752	2.55
END-10-03	280	3.218	2.649
END-10-03	280	3.139	2.606
END-10-03	280	3.126	2.597
END-10-03	280	3.109	2.605

END-10-03	290	3.544	2.189
END-10-03	290	3.539	2.197
END-10-03	290	3.416	2.314
END-10-03	290	3.208	2.729
END-10-03	290	3.14	2.174
END-10-03	296	3.488	2.301
END-10-03	296	3.487	2.313
END-10-03	296	3.447	2.347
END-10-03	296	3.461	2.323
END-10-03	347.7	3.555	2.131
END-10-03	347.7	3.126	2.691
END-10-03	347.7	3.157	2.738

Table B.10 Oxide weight percentage of metamorphic minerals from the End Deposit, Thelon Basin, Nunavut, Canada.

Drill Hole	Depth (m)	Mineral	Na2O	SiO2	CaO	Fe2O3	TiO2	K2O	MnO	MgO	Al2O3	Total
END-10-02A	40	Epidote	0.01	37.89	23.59	11.33	0.06	0.01	0.08	0	24.72	97.74
END-10-02A	40	Epidote	0.01	37.82	23.4	10.8	0.04	0.03	0.27	0	25.24	97.78
END-10-02A	40	Epidote	0.01	38.1	23.74	11.55	0	0.02	0.07	0	24.33	98.05
END-10-02A	40	Epidote	0	38.64	22.42	13.37	0.07	0.54	0.02	0.16	23.23	98.5
END-10-02A	40	Epidote	0	38.21	23.73	12.15	0.04	0.01	0.05	0	24.34	98.76
END-10-02A	40	Epidote	0	36.99	23.27	14.4	0.54	0.02	0.08	0.09	21.55	97.1
END-10-02A	40	Epidote	0	37.75	23.19	11.02	0.05	0.01	0.34	0	25.22	97.7
END-10-02A	40	Epidote	0.02	38.11	23.88	11.59	0.03	0.02	0.05	0	24.54	98.39
END-10-02A	40	Epidote	0.01	37.58	23.29	11.17	0.05	0.01	0.33	0	24.66	97.14
END-10-02A	110	Epidote	0.04	37.13	22.08	12.45	0.06	0.01	0.27	0.84	23.55	100
END-10-02A	110	Epidote	0	37.93	23.44	13.36	0.11	0.05	0.14	0	23.35	100
END-10-02A	250	Almandine	0.01	37.37	7.13	37.2	0.09	0.01	1.3	0.58	20.72	104.45
END-10-02A	250	Almandine	0.01	36.86	6.37	37.56	0.07	0	1.47	0.64	20.85	103.83
END-10-02A	250	Almandine	0	37.03	6.11	37.67	0.1	0.05	1.17	0.75	20.74	103.65
END-10-02A	250	Almandine	0.02	36.76	6.73	37.49	0.08	0.01	0.72	0.77	20.76	103.46
END-10-02A	250	Almandine	0.02	36.77	6	37.67	0.03	0	1.28	0.79	20.47	103.12
END-10-02A	360	Epidote	0.03	36.82	21.24	14.11	0.24	0.03	0.18	0.99	22.17	100
END-10-02A	360	Epidote	0	37.5	22.84	15.25	0.13	0.02	0.26	0	22.24	100

Appendix C

X-Ray Diffraction (XRD)

Fig. C.1 X-Ray Diffraction profile of muscovite above alteration halo within the END deposit, Thelon Basin, Nunavut, Canada (END-10-03-40).

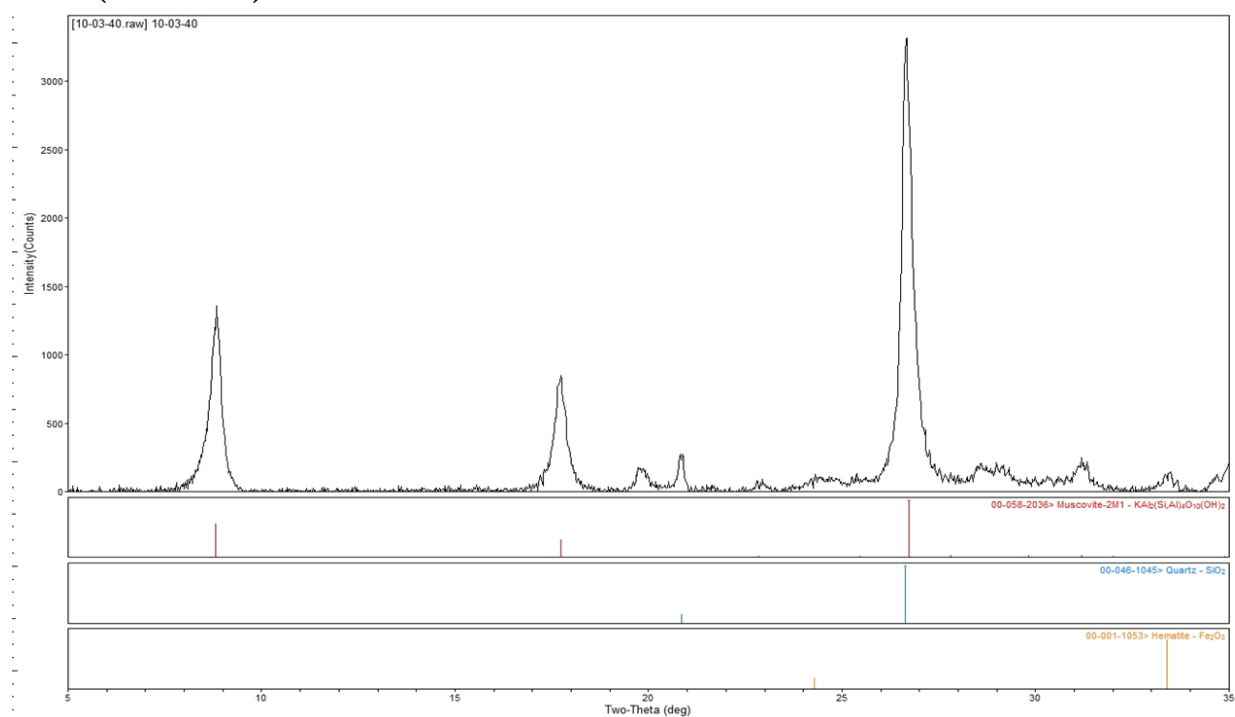


Fig. C.2 X-Ray Diffraction profile of muscovite distal to END deposit, Thelon Basin, Nunavut, Canada (END-10-02A-263.2).

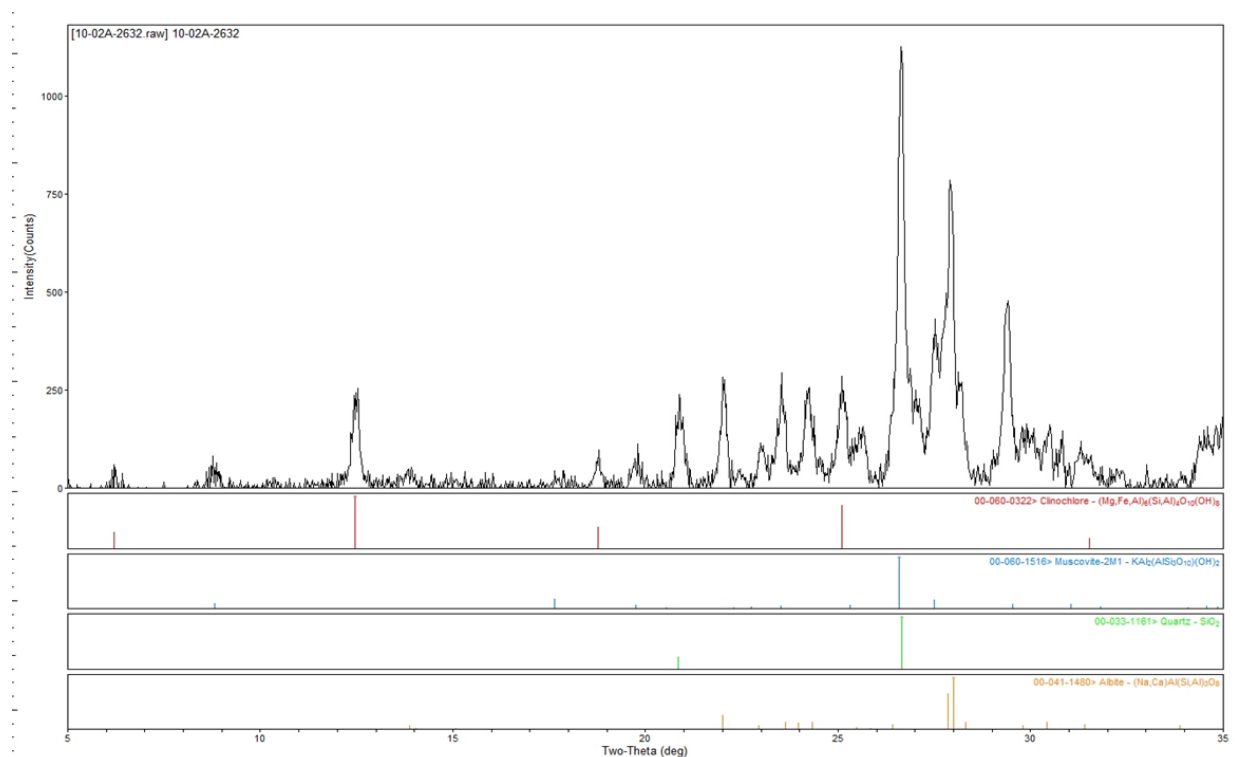
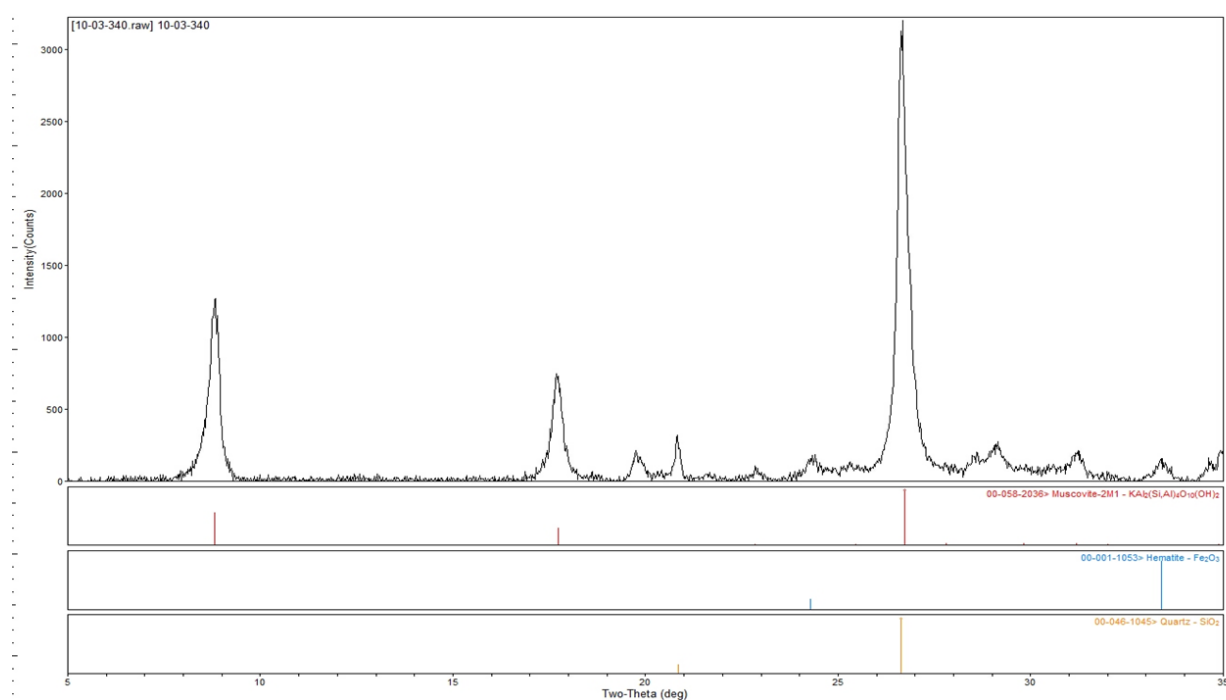


Fig. C.3 X-Ray Diffraction profile of muscovite from below of alteration halo of END deposit, Thelon Basin, Nunavut, Canada (END-10-03-340).



Appendix D
Secondary Ion Mass Spectrometry (SIMS)

Table D.1 : U-Pb and Pb-Pb ratios from SIMS with corresponding Pb-Pb ages of uraninite from the End Deposit, Thelon Basin, Nunavut, Canada.

Sample-ID	DDH ID	Depth (m)	Style of Mineralization	²⁰⁶ Pb/ ²⁰⁴ Pb	²⁰⁷ Pb/ ²⁰⁶ Pb	²⁰⁶ Pb/ ²³⁸ U	²⁰⁷ Pb/ ²³⁵ U	* ²⁰⁶ Pb/ ²³⁸ U	* ²⁰⁷ Pb/ ²³⁵ U	**Pb-Pb Age
09-04-340.5-01	END-09-04	340.5	Vein-type (U2)	49779	0.08075	0.16117	0.10476	1.13519	1.72591	1215
09-04-340.5-02	END-09-04	340.5	Vein-type (U2)	40232	0.08144	0.17741	0.11473	1.26016	1.91969	1232
09-04-340.5-03	END-09-04	340.5	Vein-type (U2)	91468	0.08365	0.26961	0.16930	1.93403	2.97844	1283
09-04-340.5-04	END-09-04	340.5	Vein-type (U2)	83637	0.08386	0.25767	0.16243	1.85339	2.85049	1288
09-04-340.5-05	END-09-04	340.5	Vein-type (U2)	63830	0.08181	0.19555	0.12574	1.38677	2.11683	1240
09-04-340.5-07	END-09-04	340.5	Vein-type (U2)	25901	0.08044	0.09938	0.06584	0.69675	1.05210	1206
09-04-340.5-08	END-09-04	340.5	Vein-type (U2)	16951	0.07617	0.07819	0.05214	0.52831	0.79569	1099
10-03-222.4-01	END-10-03	222.4	Infill-type (U3b)	6211	0.07654	0.03974	0.02571	0.26175	0.40331	1107
10-03-222.4-02	END-10-03	222.4	Infill-type (U3b)	6263	0.07705	0.04500	0.02910	0.29926	0.46117	1120
10-03-222.4-03	END-10-03	222.4	Infill-type (U3b)	7578	0.07629	0.04493	0.02905	0.27680	0.42652	1102
10-03-222.4-04	END-10-03	222.4	Infill-type (U3b)	6497	0.07760	0.03694	0.02391	0.24513	0.37767	1137
10-03-222.4-05	END-10-03	222.4	Roll Front (U3c)	6121	0.07837	0.02748	0.01781	0.18700	0.28803	1155
10-03-222.4-07	END-10-03	222.4	Roll Front (U3c)	6462	0.07688	0.04444	0.02874	0.29346	0.45223	1118
10-03-222.4-08	END-10-03	222.4	Infill-type (U3b)	5674	0.07164	0.03876	0.02508	0.25773	0.39711	975
10-03-222.4-09	END-10-03	222.4	Infill-type (U3b)	5648	0.07607	0.03840	0.02485	0.25037	0.38574	1097
10-03-217.6-01	END-10-03	217.6	Roll Front (U3c)	3269	0.06742	0.01670	0.01160	0.10082	0.14842	851
10-03-217.6-03	END-10-03	217.6	Roll Front (U3c)	2812	0.06736	0.01463	0.01016	0.08926	0.13138	849
10-03-217.6-04	END-10-03	217.6	Roll Front (U3c)	2897	0.06706	0.01820	0.01263	0.11057	0.16280	840
10-03-217.6-05	END-10-03	217.6	Roll Front (U3c)	671	0.06308	0.01433	0.00996	0.08129	0.11962	711
10-03-217.6-06	END-10-03	217.6	Roll Front (U3c)	398	0.06704	0.00833	0.00580	0.05192	0.07637	839
10-03-217.6-07	END-10-03	217.6	Roll Front (U3c)	141	0.06445	0.00320	0.00224	0.01816	0.02670	755
10-03-223.3-01	END-10-03	223.3	Disseminated (U1)	906	0.08417	0.00712	0.00496	0.05499	0.08088	1295
10-03-223.3-03	END-10-03	223.3	Disseminated (U1)	289	0.07830	0.00468	0.00326	0.03313	0.04872	1151
10-03-223.3-04	END-10-03	223.3	Disseminated (U1)	352	0.07298	0.01006	0.00700	0.07094	0.10438	1013
10-03-223.3-07	END-10-03	223.3	Disseminated (U1)	2120	0.08980	0.01214	0.00844	0.09854	0.14505	1422
10-03-223.3-08	END-10-03	223.3	Disseminated (U1)	2176	0.09044	0.01185	0.00824	0.09689	0.14262	1435
10-03-223.3-09	END-10-03	223.3	Disseminated (U1)	1126	0.08840	0.01037	0.00722	0.08270	0.12170	1390
10-03-244.5_02	END-10-03	244.5	Infill-type (U3b)	7313	0.06398	0.02642	0.01829	0.13047	0.22316	740
10-03-244.5_03	END-10-03	244.5	Infill-type (U3b)	7973	0.06299	0.02566	0.01776	0.12511	0.21398	705
10-03-244.5_04	END-10-03	244.5	Infill-type (U3b)	7880	0.06197	0.02814	0.01947	0.13510	0.23107	671
10-03-244.5_06	END-10-03	244.5	Infill-type (U3b)	6439	0.06379	0.02757	0.01908	0.13759	0.23533	735
10-03-244.5_07	END-10-03	244.5	Infill-type (U3b)	8079	0.06929	0.03706	0.02557	0.19963	0.34142	908
10-03-244.5_09	END-10-03	244.5	Infill-type (U3b)	4590	0.06906	0.01641	0.01139	0.07800	0.13341	901
10-03-203A_01	END-10-03	203	Foliation Parallel (U3a)	722	0.07448	0.00329	0.03260	0.01261	0.08110	1055
10-03-203A-02	END-10-03	203	Foliation Parallel (U3a)	821	0.07662	0.00392	0.03993	0.01297	0.08566	1111
10-03-203A-03	END-10-03	203	Foliation Parallel (U3a)	832	0.07363	0.00164	0.01596	0.01165	0.07074	1031
10-03-203A-04	END-10-03	203	Foliation Parallel (U3a)	788	0.07069	0.00475	0.04476	0.01346	0.08867	948

Errors associated with measurements are <10% for ²⁰⁶Pb/²⁰⁴Pb and <1% for ²⁰⁷Pb/²⁰⁶Pb, ²⁰⁶Pb/²³⁸U & ²⁰⁷Pb/²³⁵U

*Corrected "true" values using $R_{true} = a \cdot R_{sims}^2 + b \cdot R_{sims}$

**Pb-Pb ages determined using equation [1] ($^{207}Pb/^{206}Pb = ^{235}U/^{238}U \cdot e^{\lambda_{235}t} - 1 / e^{\lambda_{238}t} - 1$; Nier et al., 1941).

Appendix E
 $^{40}\text{Ar} / ^{39}\text{Ar}$ Analysis

Table E.1 ⁴⁰ Ar- ³⁹ Ar of Muscovite from 10-02A-263.2, from the End Deposit, Thelon Basin, Nunavut, Canada.																			
Relative Isotopic abundances (fAmps)																			
Power	Ar40	±	Ar39	±	Ar38	±	Ar37	±	Ar36	±	Ca/K	±	Cl/K	±	⁴⁰ Ar*/ ³⁹ Ar(K)	±	⁴⁰ Ar*	Age	±
(%)		(1σ)		(1σ)		(1σ)		(1σ)		(1σ)		(1σ)		(1σ)		(1σ)	(%)	(Ma)	(1σ)
0.10	6.3502	0.0676	0.1174	0.0573	0.0478	0.0294	0.0246	0.0289	0.0016	0.0007	7.026	9.045	1.140	0.936	50.475	25.40 8	93.22	1191.7	439.0
0.20	33.0243	0.0704	0.5835	0.0685	0.0525	0.0278	0.0865	0.0293	0.0023	0.0008	4.970	1.798	0.224	0.143	55.662	6.730	98.27	1279.2	110.8
0.30	684.2681	0.1142	10.5131	0.0640	0.1324	0.0315	0.3258	0.0258	0.0309	0.0010	1.037	0.083	0.000	0.009	64.218	0.402	98.73	1414.8	6.1
0.40	1361.9060	0.1661	20.1696	0.0625	0.2011	0.0328	0.6082	0.0277	0.0377	0.0012	1.010	0.047	-0.007	0.005	66.965	0.214	99.24	1456.3	3.2
0.50	2627.6140	0.2166	36.9735	0.0643	0.4436	0.0298	1.3158	0.0267	0.0733	0.0013	1.193	0.025	-0.002	0.002	70.486	0.126	99.24	1508.0	1.8
0.60	2615.5760	0.2236	38.0875	0.0623	0.3956	0.0300	1.1834	0.0286	0.0612	0.0013	1.042	0.026	-0.006	0.002	68.195	0.115	99.37	1474.5	1.7
0.70	2228.0710	0.1877	38.1172	0.0701	0.4275	0.0308	0.7780	0.0298	0.0475	0.0012	0.685	0.027	-0.004	0.002	58.066	0.110	99.42	1318.3	1.8
0.80	1059.0750	0.1515	18.5173	0.0629	0.2339	0.0280	0.3683	0.0270	0.0198	0.0010	0.668	0.049	0.001	0.004	56.860	0.199	99.49	1298.8	3.2
0.90	211.1467	0.0817	4.1959	0.0578	0.0533	0.0295	0.1998	0.0261	0.0000	0.0008	1.602	0.213	0.002	0.021	50.364	0.717	100.13	1189.8	12.4
1.00	104.7629	0.0786	2.2169	0.0618	0.0559	0.0336	0.0897	0.0272	0.0054	0.0009	1.363	0.419	0.036	0.045	46.566	1.340	98.59	1122.9	24.0
2.50	772.8208	0.1306	12.9204	0.0615	0.1359	0.0314	0.6139	0.0254	0.0753	0.0015	1.601	0.067	-0.008	0.007	58.127	0.287	97.23	1319.3	4.6
5.00	8.8737	0.0648	0.2252	0.0610	-0.0768	0.0286	0.0608	0.0265	-0.0008	0.0008	9.129	4.747	-1.024	0.471	40.842	11.43 5	103.42	1017.1	217.7

*J=0.018541 1σ = 2.2x10⁻⁵

Table E.2 ⁴⁰ Ar- ³⁹ Ar of Muscovite from 10-03-40, from the End Deposit, Thelon Basin, Nunavut, Canada.																			
Relative Isotopic abundances (fAmps)																			
Power	Ar40	±	Ar39	±	Ar38	±	Ar37	±	Ar36	±	Ca/K	±	Cl/K	±	⁴⁰ Ar*/ ³⁹ Ar(K)	±	⁴⁰ Ar*	Age	
(%)		(1 σ)		(1 σ)		(1 σ)		(1 σ)		(1 σ)		(1 σ)		(1 σ)		(1 σ)	(%)	(Ma)	(1 σ)
0.10	0.0979	0.0653	-0.0349	0.0593	-0.0146	0.0337	-0.0165	0.0265	0.0006	0.0008	18.811	44.856	1.192	3.534	3.019	8.746	-	107.06	276.7
0.20	133.5480	0.0699	1.7352	0.0602	0.0643	0.0277	-0.0300	0.0286	0.0026	0.0008	-0.686	0.658	0.071	0.047	76.392	2.713	99.39	1590.4	37.5
0.30	4542.4730	0.2891	63.1291	0.0723	0.7816	0.0291	-0.0231	0.0264	0.0650	0.0016	-0.015	0.017	0.000	0.001	71.572	0.090	99.58	1522.4	1.3
0.40	11589.4800	0.4240	160.5697	0.0671	1.9800	0.0316	0.0967	0.0271	0.1097	0.0017	0.023	0.007	0.000	0.001	71.899	0.045	99.72	1527.1	0.6
0.50	15169.5400	0.5424	200.2202	0.0767	2.3947	0.0304	0.0424	0.0254	0.0881	0.0019	0.008	0.005	-0.001	0.000	75.553	0.045	99.83	1578.7	0.6
0.60	13967.0400	0.5899	179.6816	0.0874	2.0894	0.0299	0.0892	0.0269	0.0598	0.0015	0.019	0.006	-0.002	0.000	77.551	0.052	99.87	1606.4	0.7
0.70	9709.2900	0.5076	125.6533	0.0684	1.4983	0.0283	0.0520	0.0292	0.0328	0.0012	0.016	0.009	-0.001	0.001	77.110	0.055	99.90	1600.3	0.8
0.80	9436.2910	0.4022	126.0476	0.0768	1.5443	0.0302	-0.0050	0.0281	0.0246	0.0012	-0.002	0.009	0.000	0.001	74.724	0.057	99.92	1567.2	0.8
0.90	3827.6220	0.2981	53.0247	0.0707	0.6191	0.0339	0.0751	0.0261	0.0080	0.0010	0.056	0.020	-0.002	0.002	72.066	0.104	99.94	1529.5	1.5
1.00	1465.1470	0.1699	21.1950	0.0576	0.3240	0.0301	-0.0149	0.0276	0.0054	0.0009	-0.029	0.052	0.009	0.004	68.974	0.195	99.89	1484.7	2.9
2.50	794.1326	0.1349	14.6071	0.0639	0.2269	0.0323	0.0761	0.0273	0.0091	0.0009	0.207	0.075	0.009	0.007	54.135	0.244	99.68	1252.7	4.1
5.00	145.3346	0.0762	7.4430	0.0627	0.1978	0.0328	0.0212	0.0254	0.0157	0.0011	0.113	0.138	0.040	0.013	18.890	0.169	96.84	541.1	4.2

*J=0.0185183 1σ = 2.10x10⁻⁵

Table E.3 ⁴⁰ Ar- ³⁹ Ar of Muscovite from 10-03-340, from the End Deposit, Thelon Basin, Nunavut, Canada.																			
Relative Isotopic abundances (fAmps)																			
Power	Ar40	±	Ar39	±	Ar38	±	Ar37	±	Ar36	±	Ca/K	±	Cl/K	±	⁴⁰ Ar*/ ³⁹ Ar _(K)	±	⁴⁰ Ar*	Age	±
(%)		(1σ)		(1σ)		(1σ)		(1σ)		(1σ)		(1σ)		(1σ)		(1σ)	(%)	(Ma)	(1σ)
0.20	193.8139	0.0868	2.9044	0.0615	0.0135	0.0316	0.0180	0.0280	0.0050	0.0008	0.242	0.380	-0.023	0.032	66.161	1.436	99.24	1439.9	21.5
0.30	2795.1930	0.2215	42.2947	0.0667	0.5634	0.0310	0.0030	0.0260	0.0477	0.0012	0.002	0.024	0.003	0.002	65.684	0.116	99.50	1432.7	1.7
0.40	5942.2050	0.3238	88.6699	0.0620	1.0446	0.0295	-0.0177	0.0270	0.0530	0.0013	-0.008	0.012	-0.002	0.001	66.765	0.067	99.74	1448.9	1.0
0.50	7272.3510	0.4051	105.4624	0.0708	1.1814	0.0305	0.0925	0.0287	0.0422	0.0013	0.034	0.011	-0.003	0.001	68.766	0.067	99.83	1478.5	1.0
0.60	6433.3550	0.3436	92.9226	0.0745	1.1275	0.0278	0.0648	0.0277	0.0249	0.0011	0.027	0.012	0.000	0.001	69.081	0.074	99.89	1483.1	1.1
0.70	5100.5850	0.3363	75.2955	0.0734	0.9723	0.0301	0.0229	0.0265	0.0131	0.0011	0.012	0.014	0.002	0.001	67.617	0.082	99.92	1461.6	1.2
0.80	3136.6600	0.2259	48.0961	0.0717	0.5083	0.0273	0.0016	0.0261	0.0082	0.0009	0.001	0.022	-0.005	0.002	65.095	0.109	99.92	1423.8	1.7
0.90	839.6901	0.1296	13.8648	0.0649	0.2009	0.0300	0.0603	0.0263	0.0047	0.0008	0.171	0.075	0.006	0.006	60.406	0.293	99.84	1351.5	4.6
1.00	241.7424	0.0909	4.5463	0.0679	0.0418	0.0291	0.0408	0.0269	0.0010	0.0008	0.353	0.235	-0.009	0.019	53.069	0.814	99.90	1232.1	13.7
2.50	272.6954	0.0815	8.1993	0.0629	0.2145	0.0284	0.0083	0.0265	0.0188	0.0010	0.040	0.128	0.039	0.010	32.548	0.260	97.97	848.9	5.4
5.00	2990.0630	0.2170	40.1475	0.0634	0.5366	0.0322	0.0130	0.0252	0.0686	0.0015	0.012	0.025	0.002	0.002	73.893	0.131	99.32	1552.2	1.8

*J=0.018541 1σ = 2.2x10⁻⁵