NRC Research Press

ARTICLE

Depositional timing of Neoarchean turbidites of the Slave craton—recommended nomenclature and type localities

Rasmus Haugaard, Luke Ootes, Larry M. Heaman, Michael A. Hamilton, Barry J. Shaulis, and Kurt Konhauser

Abstract: Two temporally distinct Neoarchean turbidite packages are known to occur in the Slave craton. The older is a greywacke–mudstone succession that includes the renowned Burwash Formation (ca. 2661 Ma). In this study, a previously undated tuff bed is demonstrated to have crystallized at ca. 2650.5 ± 1.0 Ma refining the deposition age of these turbidites between ca. 2661 and 2650 Ma. The younger turbidites are locally distinctive as they contain interstratified banded iron formation (BIF). Previous work demonstrated that the younger turbidites were deposited between ca. 2640 and 2615 Ma, based entirely on maximum depositional ages from detrital zircons. A ~3 cm thick felsic to intermediate tuff bed was discovered interbedded with these BIF-bearing turbidites. The tuff bed contains a single age population of zircon with a crystallization age of 2620 ± 6 Ma defining the depositional timing of these BIF-bearing turbidites. New U–Pb detrital zircon dates from extensive turbidite sequences in the eastern and central part of the Slave craton are also presented. We use the new and previously published results to recommend nomenclature for these extensive sedimentary rocks in the Slave craton. The ca. 2661–2650 Ma turbidites remain part of the previously ascribed Duncan Lake Group. The younger ca. 2620 Ma turbidites are assigned to the new Slemon Group. Where robust age-data exist, we recommend formation names and include type localities for each.

Résumé : La présence de deux paquets de turbidites néoarchéennes temporellement distincts dans le craton des Esclaves est déjà connue. Le plus ancien de ces paquets consiste en une succession de grauwackes–mudstones qui comprend la réputée Formation de Burwash (env. 2661 Ma). Il est démontré qu'un lit de tuf jusqu'ici non daté a cristallisé il y a environ 2650,5 ± 1,0 Ma, ce qui ressert la fourchette d'âges pour le dépôt de ces turbidites entre env. 2661 Ma et 2650 Ma. Les turbidites plus jeunes se distinguent localement par la présence de fer rubané interstratifié. Des travaux antérieurs ont démontré que les turbidites plus jeunes ont été déposées entre env. 2640 Ma et 2615 Ma, sur la seule base d'âges de dépôt maximums obtenus de zircons détritiques. Un lit de tuf felsique à intermédiaire de ~3 cm d'épaisseur a été découvert intercalé dans ces turbidites à fer rubané. Le lit de tuf renferme une seule population d'âges de zircons présentant un âge de cristallisation de 2620 ± 6 Ma qui définit le moment du dépôt de ces turbidites à fer rubané. De nouveaux âges U–Pb sur zircons détritiques provenant de vastes séquences de turbidites dans la partie est et centrale du craton des Esclaves sont également présentés. Nous utilisons les nouveaux résultats ainsi que des résultats déjà publiés pour recommander une nomenclature pour ces roches sédimentaires répandues dans le craton des Esclaves. Les turbidites d'environ 2661 Ma à 2650 Ma font toujours partie du Groupe du lac Duncan déjà défini. Les turbidites plus jeunes (env. 2620 Ma) sont affectées au nouveau Groupe de Slemon. Pour les cas où des données robustes sur les âges sont disponibles, nous recommandons des noms de formation et incluons des localités types pour chacune. [Traduit par la Rédaction]

Introduction

The nature of Archean tectonics is often surmised in part from the preserved igneous record, particularly from the geochemistry of basalts, komatiites, and tonalite–trondhjemite–granodiorite (TTG) gneisses/plutons (Kröner and Layer 1992; Fan and Kerrich 1997; Arndt et al. 2001; Sharma and Pandit 2003; Condie 2004; Bédard et al. 2013); geophysical experiments (e.g., Chen et al. 2009); and mineral inclusions in diamonds from the subcontinental lithosphere (e.g., Shirey and Richardson 2011). The accumulation of Archean clastic sedimentary rocks reflects orogenic uplift, erosion, and basin filling; however, due to post-depositional metamorphic and structural overprinting, they remain under studied. Further to this, and unlike strata in later Proterozoic and Phanerozoic orogens, Archean sedimentary rocks lack fossils, and thick siliciclastic accumulations generally lack any kind of unique stratigraphic marker horizon (e.g., Nisbet 1987). As such, basin models and tectono-stratigraphic correlations within and between Archean cratons remain, for the most part, subjective.

The use of U–Pb zircon geochronology in tuff beds, or detrital zircons in clastic sedimentary rocks, has evolved as the most useful approach to help establish the timing of deposition of Archean sedimentary rocks and construct more robust regional correlations (e.g., Davis et al. 1990; Fedo et al. 2003; Ferguson et al. 2005; Kositcin et al. 2008; Ootes et al. 2009; Rasmussen and Fletcher 2010; Cawood et al. 2012). However, this is wrought with chal-

Received 8 June 2016. Accepted 1 August 2016.

Paper handled by Editor Ali Polat.

R. Haugaard, L.M. Heaman, B.J. Shaulis, and K. Konhauser. Department of Earth and Atmospheric Sciences, University of Alberta, Edmonton, AB T6G 2E3, Canada.
L. Ootes.* Northwest Territories Geological Survey, Box 1320, Yellowknife, NT X1A 2R3, Canada; Arctic Institute of North America, University of Calgary, 2500 University Drive NW, Calgary, AB T2N 1N4, Canada.
M.A. Hamilton. Jack Satterly Geochronology Laboratory, Department of Earth Sciences, University of Toronto, Toronto, ON M5S 3B1, Canada.
Corresponding authors: Ramsus Haugaard (email: rasmus@ualberta.ca); Luke Ootes (email: luke.ootes@gov.bc.ca).
*Current address: British Columbia Geological Survey, Box 9333, Stn Prov Govt, Victoria, BC V8W 9N3, Canada.

Can. J. Earth Sci. **54**: 15–32 (2017) dx.doi.org/10.1139/cjes-2016-0098

lenges due to a number of reasons, namely (*i*) the vast majority of Archean sedimentary rocks represent a mixture of polycyclic sedimentary products, (*ii*) synchronous felsic volcanic rocks may not exist (e.g., tuff beds are absent), and (*iii*) certain sedimentary processes (e.g., turbidity currents) may have reworked the products of volcanic ash-fall events, thus altering their original chronostratigraphic significance. Detrital zircons also provide an imperfect record, as maximum depositional ages may not reflect the youngest single zircon or population of zircons in a sample, which could be millions to hundreds of million years older than the actual deposition age. By combining the two approaches, however, some of the challenges with regional correlations and depositional environments can be resolved.

Greywacke–mudstone sedimentary rocks, deposited by turbidity currents in a below-wave-base environment, are common in Archean supracrustal successions (e.g., Lowe 1980; Barrett and Fralick 1989; Eriksson et al. 1994; Haugaard et al. 2013). Within the Slave craton, the Yellowknife Supergroup contains some of the largest and best-preserved Archean turbidite deposits in the world (Henderson 1970, 1972; Padgham and Fyson 1992; Ferguson et al. 2005). The overall supracrustal stratigraphy consists of approximately 70% of these sedimentary rocks, which is unique amongst Archean cratons (vs. Superior and Yilgarn for example), providing insight into diverse Archean tectonic processes (Padgham and Fyson 1992). The Slave craton turbidites are often monotonous, but Ootes et al. (2009) have divided them into an older and younger package (I and II). The older includes the well-known Burwash Formation, which is spectacularly preserved in the south-central part of the craton (e.g., Henderson 1970, 1972; Ferguson et al. 2005) and contains a number of interbedded tuff beds that have been dated at ca. 2661 Ma (Bleeker and Villeneuve 1995; Ferguson 2002; Ferguson et al. 2005). The younger are locally distinctive as they contain interstratified banded iron formation (BIF); detrital zircon ages indicate these turbidites have maximum deposition ages younger than ca. 2640 Ma and were deposited more than 20 million years after the Burwash Formation (Pehrsson and Villeneuve 1999; Bennett et al. 2005; Ootes et al. 2009). The recognition that the younger turbidites are associated with BIF has fundamental importance for (*i*) establishing a provenance record for the turbidites; (*ii*) establishing regional correlations across the craton, which are critical in evaluating postulated tectonic evolution models (e.g., Davis et al. 2003; Helmstaedt 2009); and (*iii*) temporally constraining BIF deposition, allowing insight into the nature of early sea water and by analogy atmospheric and biospheric conditions at that time (e.g., Bekker et al. 2010; Haugaard et al. 2013, 2016).

To further evaluate the extent and absolute timing of the turbidite depositional events, we report a new, conventional (isotope dilution) U–Pb zircon crystallization age determination for a previously undated tuff bed in the type locality of the Burwash Formation, and the first U–Pb zircon eruption age from a tuff bed that is intercalated with the younger BIF-bearing turbidites (determined via laser ablation ICP-MS). Furthermore, we present new U–Pb detrital zircon maximum depositional ages from three turbidite sequences across the Slave craton; these results complement the tuff dates, augment provenance information from previous Slave craton detrital zircon age studies, and establish new maximum age limits for deposition.

Turbidites in the Slave craton have previously been assigned to the Duncan Lake Group, with the Burwash Formation as the type locality (Henderson 1970, 1972). The results of this and previous studies now demonstrate enough evidence to clearly distinguish the younger BIF-bearing turbidites from the older Duncan Lake Group. As such, we recommend new nomenclature, referring to these younger turbidites as the Slemon Group and recommend the use of a number of formation names and their type localities across the craton.

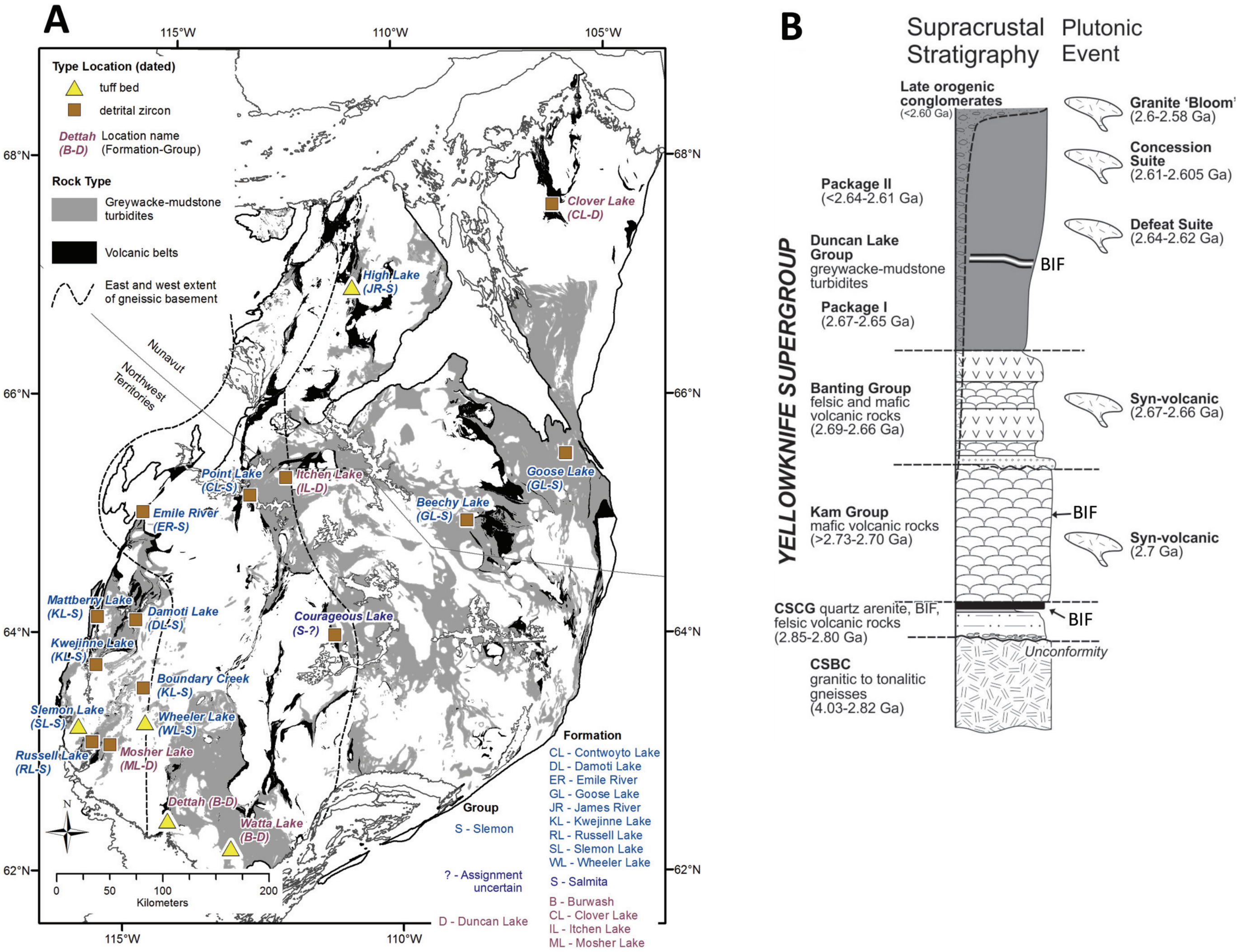
Geological setting

The Archean Slave craton is well known for hosting the oldest bedrock exposure in the world, the Acasta gneiss (e.g., Reimink et al. 2014, 2016), ca. 2.7 Ga greenstone belts and orogenic gold (e.g., Bleeker and Hall 2007; Ootes et al. 2011), and kimberlite-hosted diamond deposits (e.g., Heaman and Pearson 2010). However, the Slave craton is relatively unique as the supracrustal rock record is dominated by large and extensive Neoarchean turbidite successions deposited over a minimum area of about 32 000 km^2 (Henderson 1970, 1972; Ferguson et al. 2005; Bleeker and Hall 2007; Ootes et al. 2009). The turbidite sequences are part of the Duncan Lake Group of the Yellowknife Supergroup (Fig. 1; Henderson 1970) and were deposited on top of or adjacent to older volcanic-dominated supracrustal rocks, namely the ca. 2740–2700 Ma Kam Group and the ca. 2660 Ma Banting Group (e.g., Helmstaedt and Padgham 1986; Isachsen and Bowring 1997). The turbidites include the archetypal, up to 5 km thick, Burwash Formation (Henderson 1970, 1972; Ferguson et al. 2005).

Felsic tuff beds are preserved within the Burwash Formation turbidites and have been dated by the isotope dilution – thermal ionization mass spectrometry (ID–TIMS) U–Pb zircon method, providing a robust constraint on the time of turbidite deposition at 2661 ± 2 Ma (Bleeker and Villeneuve 1995; Ferguson 2002). While the greywacke–mudstone turbidites are commonly monotonous, they are locally distinctive as they contain interstratified oxide-silicate BIF and were historically considered correlative to the Burwash Formation (e.g., Bostock 1980, Padgham 1992; Henderson 1998; Jackson 2001). The advent of U–Pb detrital zircon studies that utilize micro-analytical techniques allowed for statistically robust maximum deposition ages to be determined from turbidites in the central and western parts of the craton. That work showed that some of the turbidites, particularly those with interbedded BIF, were deposited 30 million years after the "BIF-free" Burwash Formation (Pehrsson and Villeneuve 1999; Bennett et al. 2005; Ootes et al. 2009). The three most precise maximum deposition ages from the young turbidites include a concordant 2629 ± 2 Ma date, determined by U–Pb zircon (ID–TIMS) from a Damoti Lake sample (Pehrsson and Villeneuve 1999), a concordant 2620 ± 5 Ma date, determined by U–Pb zircon ID–TIMS from a Beechey Lake sample (Villeneuve et al. 2001), and a 2625 ± 6 Ma weighted mean age, determined from multiple analyses on single zircons analyzed using the sensitive high-resolution ion microprobe (SHRIMP) on a sample from Russell Lake (Ootes et al. 2009). Other maximum deposition ages have been determined from a greywacke in the central part of the craton at Point Lake (2615 ± 13 Ma), and from greywackes in the western part of the craton near the Emile River (2637 ± 10 Ma; Ootes et al. 2009), and in the vicinity of Kwejinne Lake (2634 ± 8, 2636 ± 3, and 2637 ± 4 Ma; Bennett et al. 2005, 2012). An age of 2616 ± 3 Ma is reported for turbidites in the High Lake area in the northern Slave craton (Henderson et al. 1995) and a 2612 ± 1 Ma date is reported for a lithic tuff bed within turbidites at Wheeler Lake in the southwestern Slave craton (Isachsen and Bowring 1994); the supporting data for these latter two reported ages has not been published. Other previously reported, less statistically robust maximum deposition age data are summarized in Ootes et al. (2009).

Both the older and younger turbidites have been locally to extensively intruded by granitic plutons. The Defeat Suite plutons have been dated between ca. 2635 and 2620 Ma and they cross-cut isoclinal folds (F_1) in the Burwash Formation (Davis and Bleeker 1999). The Defeat Suite crystallization ages approximate the maximum deposition ages recorded in the younger BIF-bearing turbidites (e.g., Davis et al. 2003; Bleeker and Hall 2007; Ootes et al. 2009). This is a key constraint, indicating that the younger turbidites post-date the F_1 event recorded in the older turbidites. Younger plutonic suites, such as Concession Suite (ca. 2610–2600 Ma) and later granite bloom (ca. 2600–2580 Ma), intrude both the older and

Fig. 1. (A) Geological map of the Slave craton showing the distribution of greywacke–mudstone turbidites and older volcanic belts. Coloured location names refer to the recommend nomenclature in this study. Note the extent of exposed basement, which is from bedrock mapping and Nd isotopes in ca. 2.63–2.58 Ga granitic rocks. The U–Pb age dating of each location is shown in Table 1. Map modified from Bleeker et al. (1999); Davis and Hegner (1992); Bennett et al. (2005); Buse (2006); Yamashita and Creaser (1999). (B) The Neoarchean stratigraphy of the Slave craton. CSCG, Central Slave Cover Group; BIF, banded iron formation. Map and stratigraphy modified after Bleeker (2002) and Ootes et al. (2009). [Colour online.]



younger turbidite packages (e.g., van Breemen et al. 1992; Davis et al. 1994; Davis and Bleeker 1999; Bennett et al. 2005; Ootes et al. 2005). The granite bloom coincided with regional greenschist to granulite facies metamorphism (e.g., Davis and Bleeker 1999; Bethune et al. 1999; Pehrsson et al. 2000; Bennett et al. 2005; Ootes et al. 2005). The depositional setting of the Burwash Formation is thought to be a rifted arc basin (Ferguson et al. 2005), whereas the depositional setting for the younger BIF-bearing turbidites is unclear. Previously proposed depositional models include a passive margin to foreland basin (Pehrsson 2002), an accretionary wedge setting (Bennett et al. 2005), and a continental back-arc basin adjacent to an active Defeat suite magmatic arc (Ootes et al. 2009).

Methods

Approximately 1–1.2 kg of rock material was selected for each of the fine-grained turbidite samples. Each sample was cut down to small chips with a rock saw and divided into three batches that subsequently were crushed in a tungsten carbide puck mill. Each batch was crushed and sieved with a 70 mesh (210 μm) disposable nylon. The <210 μm sieved rock material was processed on a Wilfley table to obtain a heavy mineral concentrate and then, multiple passes (up to 0.4 A) on a Frantz magnetic barrier separator to remove moderately to strongly magnetic grains. The non-magnetic Frantz fraction was then added to a Methylene Iodide heavy liquid with specific gravity of 3.3 g/cm³ for further density separation.

The recovered zircon grains were handpicked, secured in an epoxy mount, and subsequently polished. Due to minimum material recovered from the tuff bed at Slemon Lake, the crushed fraction was wash panned over multiple steps ending in a head fraction, a second head fraction, and a tail fraction before hand picking. The majority of the zircons were found in the first head fraction with only minor in the second head fraction. No zircon grains were recovered in the tail fraction. Cathodoluminescence (CL) imaging of zircon grains was obtained using a scanning electron microscope (Zeiss EVO LS15 EP-SEM) equipped with cathodoluminescent and backscattered detectors.

U–Pb isotopic data for zircon from the turbidite samples and from the Slemon Lake tuff were obtained at the University of Alberta and were acquired using a Nu Plasma I multi-collector inductively coupled plasma mass spectrometer (ICP-MS) coupled to a New Wave laser ablation (LA) system with an operating wavelength of 213 nm and energy density of 2–3 J/cm². Spot diameter was set to 20 μm. Both the full machine parameters and measurement protocols are outlined in Simonetti et al. (2005, 2006). Two zircon standards were analyzed throughout each analytical session; the 1830 Ma LH94-15 zircon (Ashton et al. 1999) was used to correct U–Pb fractionation and an in-house zircon (OG1) with U–Pb ID–TIMS age of 3465.4 ± 0.6 Ma (Stern et al. 2009) was analyzed as a blind standard. The weighted mean $^{207}Pb/^{206}Pb$ ages of the analyzed OG1 standard are presented in the supplementary data (Table S6)[1]. Almost all analytical sessions for OG1 overlap within analytical uncertainty of the accepted ID–TIMS age. However, an exception occurred for the session involving the Courageous Lake greywacke, and this is dealt with below.

U–Pb dating of the Dettah tuff sample was carried out at the Jack Satterly Geochronology Laboratory (JSGL) at the University of Toronto. From a larger sample sawn out of the outcrop, the ~1.5 cm tuff horizon was carefully excised from the enclosing sediments using a thin trim saw (see sample description below). The resulting, clean, isolated slabs, weighing in total approximately 300 g, were reduced using a jaw crusher, followed by grinding briefly in a ring mill. Initial separation of heavy minerals was carried out by multiple passes on a Wilfley table to concentrate zircon. Subsequent work included density separation using methylene iodide, followed by paramagnetic separations with a Frantz isodynamic separator. Approximately 20 zircon grains were recovered in the least magnetic fractions; best optical quality grains were subsequently hand picked under ethanol using a binocular microscope, choosing the freshest, least cracked grains of zircon. Most grains from the Dettah tuff, however, show a relatively high degree of alteration.

Chemical abrasion methods (CA; Mattinson 2005) were used to pretreat the selected Dettah tuff zircons before analysis by ID–TIMS. Zircons were annealed in a quartz crucible at 1000 °C for a period of 48 h. These crystals were then leached briefly in concentrated HF at 200 °C in Teflon bombs (Krogh 1973).

Weights of Dettah tuff zircon grains were estimated from photomicrographs. Estimated weights should be accurate to about ±30%. This affects only U and Pb concentrations, not age information, which depends only on isotope ratio measurements. Annealed and leached zircons were rinsed prior to loading into dissolution capsules, into which a ^{205}Pb-^{235}U spike was added during sample loading. Zircon was dissolved using concentrated hydrofluoric acid (HF) in Teflon bombs at 200 °C (Krogh 1973) and subsequently redissolved in 3N HCl to promote equilibration with the spike. U and Pb were separated from the solutions using 50 μL anion exchange columns (Krogh 1973). Mixed purified U and Pb solutions were loaded directly onto Re filaments using silica gel and analyzed with a VG354 mass spectrometer in single (Daly) collector, pulse-counting mode. Dead time of the measuring system during this time was 20 ns. The mass discrimination correction for the Daly detector was constant at 0.07%/AMU. Daly characteristics were monitored using the SRM982 Pb standard. Thermal mass discrimination corrections were 0.10 ± 0.03%/AMU. Laboratory blanks at the JSGL are typically less than 1 pg for Pb and 0.1 pg for U.

Sample description and results

All U–Pb zircon data tables are presented in Tables S1–S5[1], and the results of the LA–ICP-MS standards are presented in Table S6[1].

Tuff bed — Slemon Lake turbidites

An ~3 cm thick, fine- to very fine-grained, felsic to intermediate tuff bed occurs within the greywacke–mudstone turbidites at Slemon Lake in the southwestern Slave craton (Figs. 1, 2A–2C; Table 1). In this area, the turbidites show evidence of three generations of ductile deformation, preserved as folds and foliations and were metamorphosed to greenschist facies (Fyson and Jackson 1991; Jackson 2001). The turbidites are BIF-bearing and a well-exposed ~0.8–1.2 m thick BIF is preserved ~1 m below the tuff bed (Fig. 2D). The greywacke hosting the tuff bed is finely laminated and contains a high fraction of biotite and fine-grained quartz. The tuff bed is traceable for about 15 m along strike on relatively flat glacially polished outcrop, and it is readily distinguished by having a bleached yellow weathered colour relative to the darker greywacke (Figs. 2A and 2B). The bed has a relatively sharp depositional base and a more disturbed upper contact with the greywacke (Fig. 2B). The upper contact represents well-developed load structures (flames) as a result of soft sediment deformation (white arrows Fig. 2B). The tuff is composed of randomly distributed fine-grained broken quartz fragments set in a very fine-grained quartz, biotite, chlorite, and K-feldspar matrix (Fig. 2C). A weak foliation is defined by biotite and chlorite. The texture and mineralogy is clearly different than the hosting greywacke and together with the similar zircon population (see below), it shows that only minor reworking (e.g., erosion, soft sediment deformation) of the bed took place. This could be ascribed to the fact that the tuff bed was found within a fine-grained mud-rich greywacke, which indicate that the tuff bed represents a submarine ash-settling event during a period of only weak turbidite deposition.

A sample of the tuff bed was collected and separated from surrounding greywacke and mudstone prior to crushing. Zircons are relatively scarce in the tuff bed, compared to the zircon abundance in greywacke samples. The individual zircons are ~50–80 μm in size and are mostly subhedral with a stubby to weakly prismatic habit (Fig. 2E). The colour ranges from colourless to pale pink to brown. They are relatively free of inclusions and have only minor growth zonations, as indicated by electron backscatter imaging (Fig. 2E). The zircons were analyzed by LA–MC–ICP-MS and all of the zircon grains analyzed (n = 17) are modestly discordant and a regression line through the data yields an upper intercept age of 2617.2 ± 4.7 Ma (MSWD = 1.08) and a lower intercept of 6 ± 28 Ma (Fig. 3A). A weighted mean $^{207}Pb/^{206}Pb$ age calculation yields an indistinguishable date of 2616.6 ± 3.5 Ma (Fig. 3B). When considering only the six most concordant grains in the data set (<7.3% discordant), a best-fit discordia line yields an upper intercept age of 2620.4 ± 5.7 Ma (lower intercept at 0 Ma); identical to the weighted mean $^{207}Pb/^{206}Pb$ date of 2620.4 ± 5.5 Ma (MSWD = 1.03) for these same grains (Figs. 3C and 3D). We interpret that the tuff bed was deposited at 2620 ± 6 Ma, which is also the timing of deposition of the interleaved turbidites.

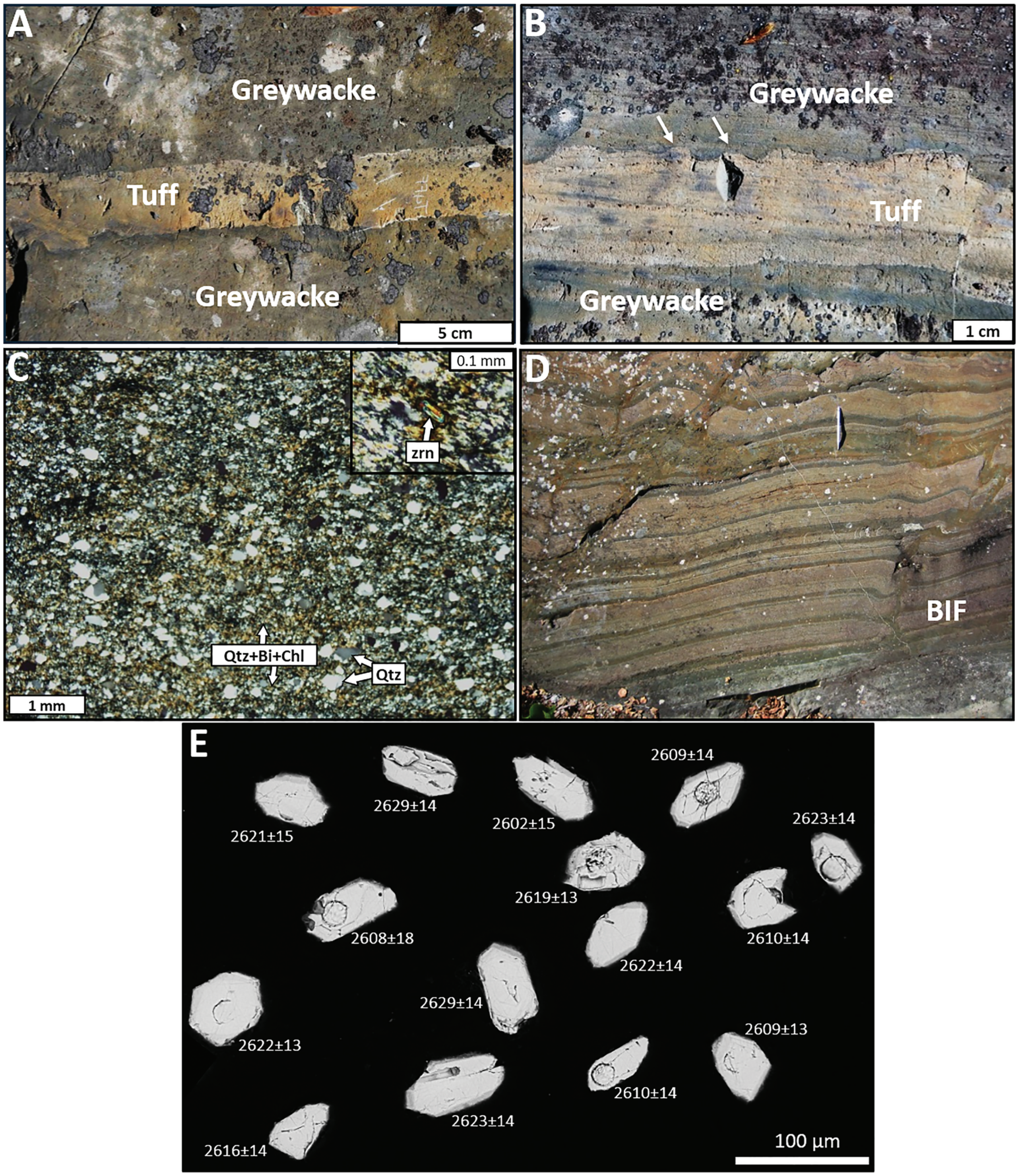
Tuff bed — Burwash Formation turbidites (Dettah)

On the northeast side of Yellowknife Bay, between Yellowknife Bay and Hay Lake, outcrops of the Burwash Formation turbidites are exposed along the road between the Ingraham Trail and the town of Dettah (Fig. 1). In this area, the turbidites also preserve evidence of three generations of ductile deformation, preserved as folds and foliations and were metamorphosed to greenschist facies (Henderson 1970, 1972). One of these outcrops contains distinctive yellow-tan weathered tuff beds interstratified with the turbidites (Fig. 4; Table 1; also see Stop 33 in Bleeker et al. 2007). At this location, the turbidite beds are west-striking, steeply dipping, upright (younging to the north), and they progressively change from 1 m thick sand-dominated beds to 5 cm thick mud-dominated beds over 30 m across strike. Within the thinner, mud-dominated beds at the north end of the outcrop occur four tuff beds that are traceable for ~7 m along strike (Fig. 4). The main tuff bed is

---

[1] Supplementary data are available with the article through the journal Web site at http://nrcresearchpress.com/doi/suppl/10.1139/cjes-2016-0098.

Fig. 2. Slemon Lake tuff bed. (A, B) Field photographs of the tuff bed interbedded in a greywacke. The contact between tuff and greywacke is characterized by a sharp base and a more uneven upper contact with load structures developed as a result of soft sediment deformation (arrows in B). (C) Crossed polarized photomicrograph of the tuff showing randomly dispersed fragmented quartz crystals set in a more fine-grained biotite (Bi) + chlorite (Chl) + quartz (Qtz) groundmass. Inset shows a well-crystallized prismatic zircon (zrn). (D) Field photograph of the banded iron formation (BIF) at Slemon Lake immediately 1 m underneath the tuff bed. (E) Backscatter image of relatively unzoned zircons from the tuff bed at Slemon Lake. [Colour online.]



1.5–2 cm thick, and the other three are <5 mm thick (Figs. 4A and 4B). The tuff beds are all intercalated with the mudstone facies, indicating primary settling of ash particles on the ocean floor. All the beds have a relatively sharp base and local evidence for load structures (flames) along the upper contact with the overlying mudstones (Figs. 4A–4C). These flames have been slightly accentuated by a high-angle second generation foliation (Figs. 4A–4C). The preservation of the tuff and mudstone must represent a period of quiescence and a return to turbidity-driven deposition as evident by the capping greywacke bed.

The tuff beds are comprised of euhedral quartz grains (~0.2–0.3 mm) set in a very fine-grained groundmass of quartz, chlorite, and mica (Fig. 4C). Recovered zircons (Fig. 4D; Table S2[1]) from the thickest bed define a homogeneous-looking population, predominantly occurring as variably clear to cloudy colourless to pale grey-brown, elongate slender prisms (up to 5:1 length:breadth). All zircon grains show some degree of alteration, cracks, and the presence of apatite and opaque mineral inclusions.

Isotopic results from ID–TIMS analysis of single grain zircon fractions from the Dettah tuff are provided in Table S2[1]. Data from

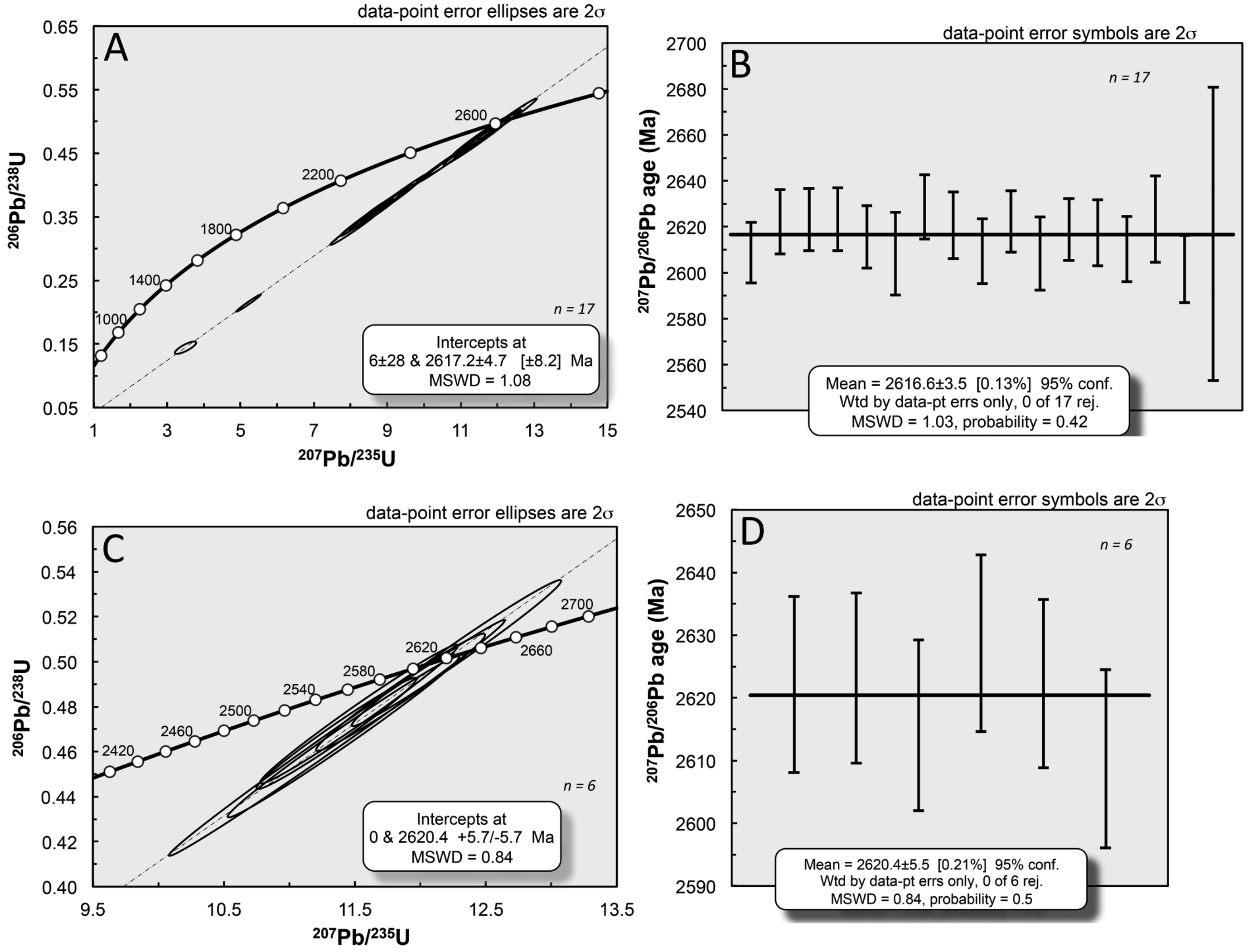
Published by NRC Research Press

Table 1. Summary of age constraints on the depositional timing of turbidites in the Slave craton.

Name and location	Latitude, longitude	Lithology	Deposition age (Ma)	Method	Reference	Interpretation	Suggested formation name	Suggested group name
Watta Lake, southwestern Slave craton	62°16′53″N, 113°6′38″W	Tuff	2661±2	TIMS	Bleeker and Villeneuve (1995)	Crystallization age of tuff	Burwash Formation (type locality)	Duncan Lake Group
Dettah, southwestern Slave craton	62°29′25″N, 114°17′13″W	Tuff	2650.5±1	ID–TIMS	This study	Crystallization age of tuff	Burwash Formation (type locality)	Duncan Lake Group
Itchen Lake, east of Point Lake, central Slave craton	65°25′8″N, 112°15′7″W	Greywacke (turbidite)	2658±8 (DZ, max. deposition age)	SHRIMP (*n*=60)	Ootes et al. (2009)	Weigted mean age of youngest grain	Itchen Lake Formation	Duncan Lake Group
Mosher Lake, southwestern Slave craton	63°5′55″N, 115°25′43″W	Greywacke (turbidite)	2651±6 (DZ, max. depositon age)	SHRIMP (*n*=58)	Ootes et al. (2009)	Weigted mean age of youngest grain	Mosher Lake Formation	Duncan Lake Group
Clover Lake, Hope Bay belt, northeastern Slave craton	67°40′07″N, 106°27′33″W	Rhyolite	2662.7+3.4/–2.8 (min. deposition age)	TIMS (*n*=5)	Sherlock et al. (2012)	Crystallization age of rhyolite body intruding wet turbidite sediment	Clover Lake Formation	Duncan Lake Group
Slemon Lake, southwestern Slave craton	63°23′95″N, 116°04′55″W	Tuff	2620±6	LA–ICP-MS (*n*=17)	This study	Crystallization age of tuff, weighted mean of six concordant grains	Slemon Lake Formation (type locality)	Slemon Group
Goose Lake, eastern Slave craton	65°33′59″N, 112°32′48″W	Greywacke (turbidite)	2621±18 (DZ, max. depositon age)	LA–ICP-MS (*n*=61)	This study	Youngest zircon	Goose Lake Formation	Slemon Group
Beechey Lake, eastern Slave craton	65°05′27″N, 108°14′25″W	Greywacke (turbidite)	2620±5 (DZ, max. deposition age)	TIMS (*n*=6)	Villeneuve et al. (2001)	Youngest zircon	Goose Lake Formation	Slemon Group
Courageous Lake, central Slave craton	64°05′45″N, 111°14′30″W	Greywacke (turbidite)	2635±7 (DZ, max. depositon age)	LA–ICP-MS (*n*=69)	This study	Weighted mean age of youngest four grains	Salmita Formation	Slemon Group*
Point Lake, central Slave craton	65°15′49″N, 112°58′4″W	Ferruginous clastic sediment (turbidite)	2608±6 (DZ, max. depositon age)	LA–ICP-MS (*n*=43)	This study	Weighted mean age of youngest five grains	Contwoyto Lake Formation	Slemon Group
Damoti lake, west-southwestern Slave craton	64°9′60″N, 115°5′59″W	Greywacke (turbidite)	2629±2 (DZ, max. depositon age)	TIMS (*n*=15)	Pehrsson and Villeneuve (1999)	Youngest concordant grain	Damoti Lake Formation	Slemon Group
Kwejinne Lake area, southeastern Slave craton	~63°46′00″N, 115°47′55″W	Greywackes (turbidites)	2634±8, 2636±3, 2638±4 (DZ, max. depositon ages)	LA–ICP-MS (*n*=100, 79, 68)	Bennett et al. (2005, 2012)	Age defined by regression of selected discordant grains	Kwejinne Lake Formation	Slemon Group
Emile River, western Slave craton (Acasta area)	65°4′45″N, 115°5′43″W	Greywacke (turbidite)	2637±10 (DZ, max. depositon age)	SHRIMP (*n*=66)	Ootes et al. (2009)	Weighted mean age of youngest grains	Emile River Formation	Slemon Group
Wheeler Lake, southwestern Slave craton	63°18′29″N, W114°47′53″W	Presumably tuff (analytical data not published)	2612±2	TIMS (*n*=?)	Isachsen and Bowring (1994)	Age reported without supporting analytical data	Wheeler Lake Formation	Slemon Group
High Lake, northern Slave craton	67°2′00″N, 110°54′20″W	Porphyritic dacite body between greywacke and mudstone facies	2616±3	TIMS (*n*=4)	Henderson et al. (1995)	Age reported without supporting analytical data	James River Formation	Slemon Group

*Tentatively assigned to the Slemon Group. See text for further explanations.

Fig. 3. LA–MC–ICP-MS U–Pb zircon results for the Slemon Lake tuff bed. (A) U–Pb concordia diagram showing a straight line through all the zircons (*n* = 17) plotted. (B) Weighted mean ^{207}Pb/^{206}Pb age of 2616.6 ± 3.5 Ma of the zircons plotted in (A). (C) U–Pb concordia diagram of the six most concordant grains from the sample. (D) Weighted mean ^{207}Pb/^{206}Pb age of 2620.4 ± 5.5 Ma of the six concordant grains. This date defines the crystallisation age of the tuff bed and constrains the depositional timing of the turbidites and the interbedded banded iron formation (BIF). See text for further explanations.



three individual fractions show relatively low to medium concentrations of U (~85–190 ppm), and moderate Th/U ratios (~0.82–0.88), which are typical for magmatic, igneous grains crystallized from felsic magma systems. Total measured common Pb is at the sub-picogram level. Analytical results range from being 1.0%–1.6% discordant to slightly (0.6%) reverse discordant. Model ^{207}Pb/^{206}Pb ratios, however, range narrowly between 2650.1 and 2651.0 Ma. Free regression of the three data points results in an upper intercept age of 2650.4 ± 1.0 Ma with a lower intercept within error of the origin; we therefore choose to anchor the regression at 0 Ma, equivalently accepting a calculated weighted average ^{207}Pb/^{206}Pb age for all three analyses at 2650.5 ± 1.0 Ma (2σ; MSWD = 0.3, 73% probability of fit, Fig. 4E). We interpret this to represent a robust estimate of the eruption and deposition age of the ash.

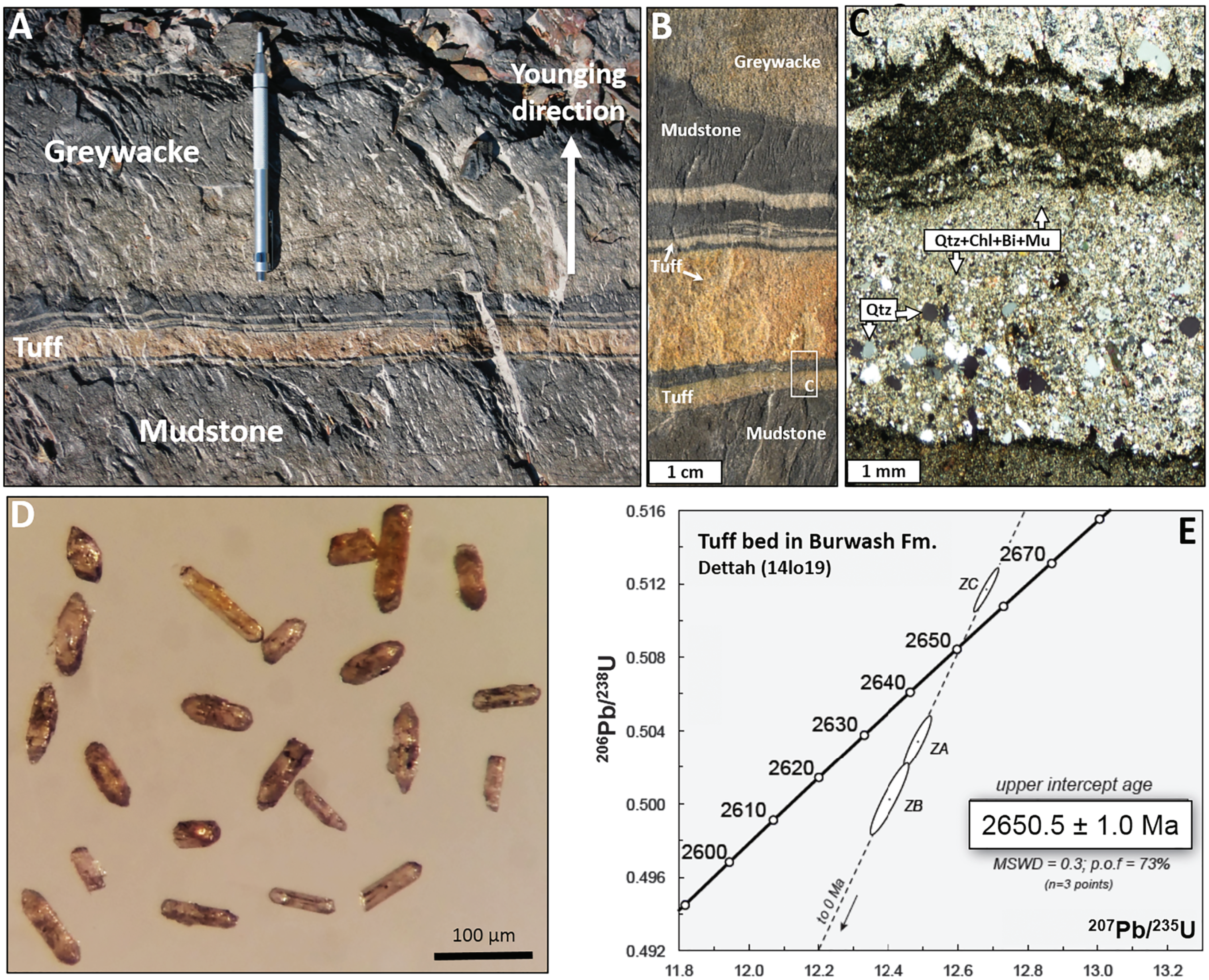
Greywacke beds — Goose Lake and Courageous Lake turbidites

Greywacke samples from Goose Lake in the east and Courageous Lake in the east-central part of the Slave craton (Fig. 1) share typical textural and mineralogical features. They are fine- to medium-grained (~0.2–0.5 mm), and contain quartz, biotite, chlorite, K-feldspar, and minor plagioclase. The existence of biotite and chlorite, but no garnet, in these samples indicates they were metamorphosed within the biotite zone of greenschist facies.

A 0.8 m thick piece of drill core intersection of greywacke (RH18140) from the bottom part of a 100.4 m deep drill hole (#12GSE140) was collected at Goose Lake (Figs. 1A and 5A). The sample underlies the base of the lowest BIF horizon and is part of a ~4 m thick BIF-bearing greywacke–mudstone unit (Fig. 5A). This is the lowest stratigraphy tested by drilling and therefore likely represents the oldest interval of the drilled part of Goose Lake turbidites. The detrital zircons from the greywacke are euhedral to subhedral with a rounded to subrounded to prismatic habit (Fig. 5B). They range between 30 and 180 μm in size and vary in colour from clear to pale pink to brown and dark brown, with few having a cloudy appearance. Growth (oscillatory) zoning and mineral inclusions are common (Fig. 5B). Selected zircons were analyzed by LA–MC–ICP-MS.

The Goose Lake U–Pb detrital zircon results reveal variable zircon populations, representing multiple sources (Fig. 5C). The analyzed zircons fall mostly in the age range of ca. 2760–2660 Ma, with probability peaks at ca. 2700 and 2670 Ma (Fig. 5D), consistent with derivation from the underlying volcanic rocks (van Breemen

Fig. 4. The Dettah tuff bed in the Burwash Formation, northeast of Yellowknife Bay (see also Bleeker et al. 2007, p. 163), exposed along the road between the Ingraham Trail and the town of Dettah. (A) Field photograph of the tuff bed. (B) Close-up image of the tuff bed in (A). Note the ultra-fine lamina of ash within the mudstone facies. The zircons extracted for this study are from the thickest tuff bed shown. (C) Photomicrograph (crossed polarized light) of the tuff bed showing bimodal distribution of quartz (Qtz) grains in a fine-grained chlorite (Chl), biotite (Bi), and muscovite (Mu) groundmass. (D) Photomicrograph of selected zircon grains from the tuff bed. (E) U–Pb concordia plot showing ID–TIMS data for three single-grain zircon fractions (ZA, ZB, ZC) from the Dettah tuff. Error ellipses and age calculation are shown at the 2σ level of uncertainty. The weighted average $^{207}Pb/^{206}Pb$ age (and anchored upper intercept age) for these three fractions from the tuff is 2650.5 ± 1.0 Ma. [Colour online.]

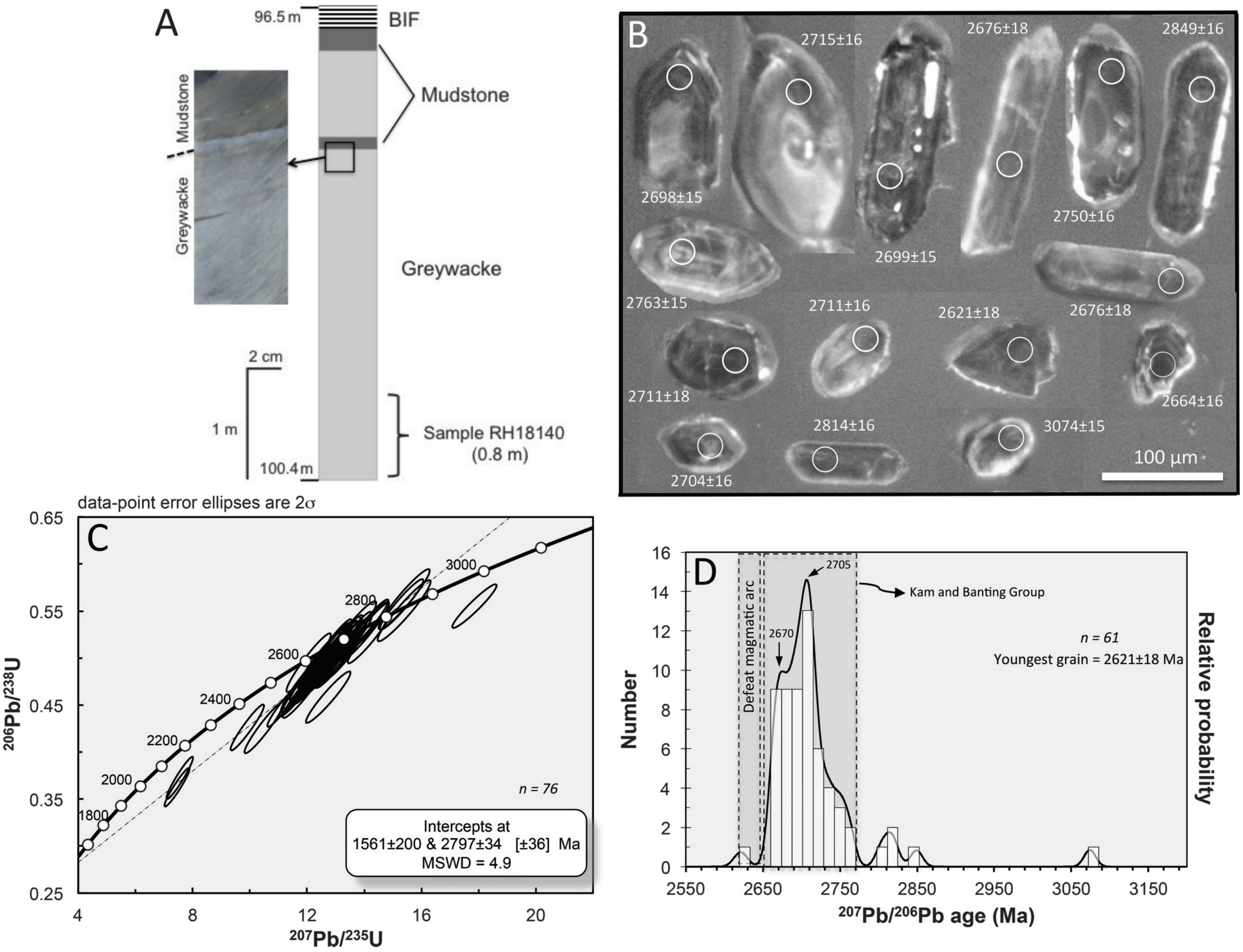


et al. 1992; Isachsen and Bowring 1994, 1997; Villeneuve et al. 2001; Sherlock et al. 2012). Five older grains also occur within the sample (3074 ± 15, 2849 ± 16, 2820 ± 16, 2814 ± 16, and 2803 ± 15 Ma; Figs. 5B and 5D). The youngest detrital zircon grain at Goose Lake yields a $^{207}Pb/^{206}Pb$ age of 2621 ± 18 Ma (1.3% discordance, Figs. 5B and 5D), which is interpreted as the maximum deposition age of the sample.

A greywacke sample (13AB2206A) was collected from outcrop south of Courageous Lake and east of Matthews Lake (Fig. 6A), where the turbidites were deposited on 2671 +5/−4 Ma felsic volcanic rocks and are intruded by 2613 +6/−5 Ma granitic rocks (Moore 1956; Dillon-Leitch 1981; Villeneuve 1993). These turbidites lack interbedded BIF. The sample was collected from the coarsest greywacke near the base of the turbidite succession, just above the contact with the underlying rhyolite and basalt (Fig. 6A). The zircons recovered are morphologically similar by description to those from the Goose Lake sample, and they range from 30 to 120 µm in their longest dimension, with a fraction of the recovered zircons being highly fragmented (Fig. 6B). Selected zircons were analyzed by LA–MC–ICP-MS.

The U–Pb detrital zircon results from the Courageous Lake sample reveals variable age populations (although less scattered than for Goose Lake) representing multiple sources (Fig. 7A). All of the analyzed grains are <10% discordant, reflecting minimum Pb loss in these sediments. The results indicate that 61 out of 69 grains have ages between ca. 2735 and 2660 Ma (Fig. 7B). There are three probability peaks within this interval at ca. 2720, 2685, and 2665 Ma (Fig. 7B). The youngest grain at Courageous Lake is 2626 ± 14 Ma (9.7% discordance) and the oldest is 2813 ± 13 Ma (5% discordance) (Figs. 6B and 7B). The weighted average of the four youngest grains yields a $^{207}Pb/^{206}Pb$ age of 2635 ± 7 Ma (MSWD = 1.12; Fig. 7C). This age may be on the young side as the measurements on the OG1

Fig. 5. Goose Lake greywacke. (A) Illustration of the Goose Lake core sample showing greywacke–mudstone turbidites associated with banded iron formation (BIF). The sample in this study was obtained from the lower part of the lower greywacke. (B) Cathodoluminescence images of the selected zircon grains. (C) LA–MC–ICP-MS U–Pb detrital zircon results showing U–Pb concordia diagram of all the zircons analyzed. (D) Histogram with probability curve for the detrital zircons (<10% discordance). Note the youngest grain at 2621 ± 18 Ma (1.3% discordance) and the >2800 Ma grains that suggest the existence of older basement lithologies. A large part of the zircons correlate in age with Kam and Banting Group detritus.



standard during this analytical session yield a weighted average of 3455.5 ± 4.3 Ma, which falls outside the analytical uncertainty of the 3465.4 ± 0.6 Ma (TIMS) age of OG1 (see Table S2[1]).

Ferruginous bed — Point Lake turbidites

Within the turbidites on the northeast side of Point Lake, 1–5 cm thick beds of mafic to intermediate clastic sediments are found intercalated with BIF up to 0.5 m thick (Figs. 8A and 8B). The sedimentary beds differ from the greywackes in that they have about 25%–30% modal content of coarse-grained ferrohornblende throughout. Still, they contain randomly dispersed biotite flakes and fragmented quartz and, occasionally, feldspar laths. These beds are concordant and folded and deformed together with the BIF units (Fig. 8A). They contain approximately the same concentration of zircon as the more typical greywackes. The zircons range from ~80 to 150 μm in size (Fig. 8C) and from clear and colorless to pale and medium brown in colour. The pale brown zircons often show a cloudy appearance. A major population of zircons shows well-developed oscillatory zonation patterns with an elongated prismatic to stubby habits (Fig. 8C). Fragmentation and intense corroded edges of some of the zircons can also be viewed in Fig. 8C.

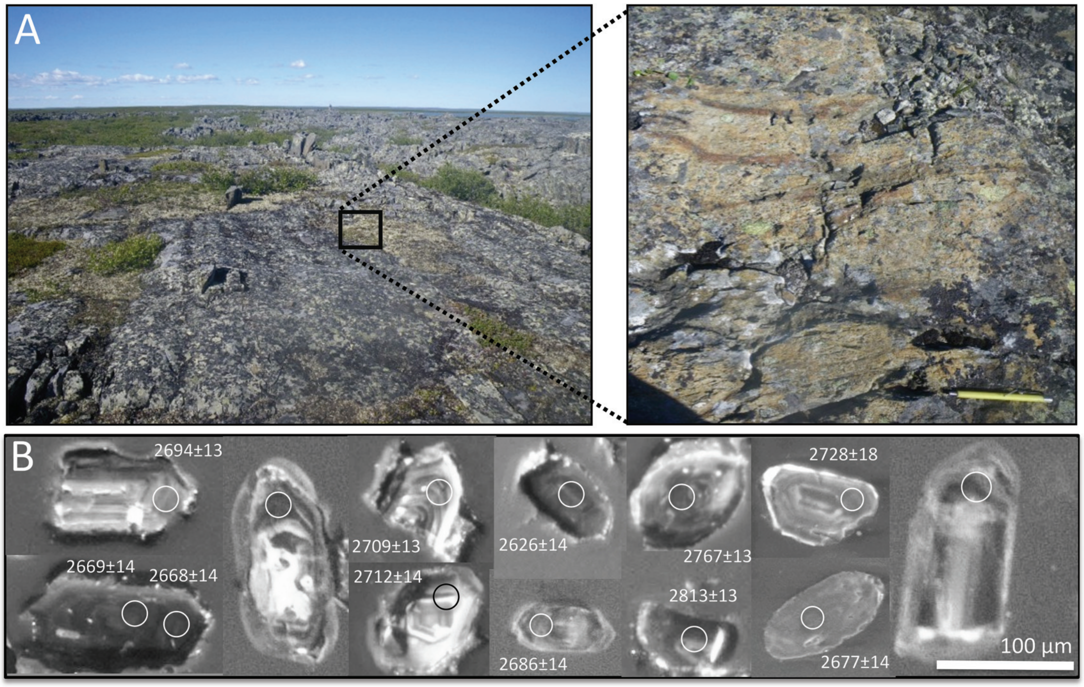
The U–Pb detrital zircon results are plotted in Figs. 9A and 9B and reveal a zircon population that is generally younger than those in the Goose Lake and Courageous Lake greywacke samples. Most of the zircons have dates that fall into two major age populations that correlate well with the timing of Kam and Banting Group volcanism. In addition, there is a younger age peak at ~2610 Ma (Fig. 9B). The five youngest (<10% discordant) grains all overlap within uncertainties (Fig. 9C) and have a weighted mean ^{207}Pb/^{206}Pb age of 2608 ± 6 Ma (MSWD = 0.97; Fig. 9D).

Discussion

Recommended nomenclature for Neoarchean turbidites of the Slave craton

There is now enough age control to clearly separate the older turbidites from the younger BIF-bearing turbidites in the Slave craton. The Burwash Formation was deposited between ca. 2661 and 2650 Ma, as determined from crystallization ages of tuff beds

Fig. 6. Courageous Lake greywacke. (A) Field photographs of the greywacke sample collected from the Courageous Lake turbidites. (B) Cathodoluminescence images of the selected zircon grains. [Colour online.]



intercalated with the greywacke–mudstone turbidites (Figs. 3 and 4; Bleeker and Villeneuve 1995; Ferguson et al. 2005). The F_1 structures identified in the Burwash Formation turbidites are cross-cut by Defeat Suite plutons between 2635 and 2620 Ma (Fig. 10; Davis and Bleeker 1999). The new 2620 ± 6 Ma tuff bed crystallization age in the younger BIF-bearing turbidites (Figs. 2 and 3) indicate these sedimentary rocks either post-date or were deposited synchronously with the intrusion of the Defeat Suite plutons; these sedimentary rocks were deposited after uplift and crustal shortening of the older Burwash Formation turbidites. These two chronologically distinct turbidite sequences, therefore, represent separate depositional basins (Ootes et al. 2009).

We recommend a new nomenclature for these two distinct turbidite sequences and their type localities. In Phanerozoic, or flat lying Precambrian stratigraphy, the nomenclature of a formation or group generally requires a base, top, and type-section. However, such constraints are rarely preserved in Archean stratigraphy; the voluminous nature of the turbidites in the Slave craton and the multiple generations of structural overprinting generally make such criteria impossible to identify. In addition, without a base or top, a measured section is only a minimal assumption of the overall thickness of a unit. Instead, for the turbidites in the Slave craton, we champion that sample locations that have been dated should be considered the type locality for the turbidites in question, and the formation name assigned should be tied to the dated location and any turbidites traceable from that location. If the location has not been dated it should not be formally considered.

We recognize formations that can be correlated with the Burwash Formation and assign these to the Duncan Lake Group (Henderson 1972; Helmstaedt and Padgham 1986). Utilizing new and previously published tuff crystallization ages and detrital zircon maximum deposition ages we recommend the young BIF-bearing turbidites be referred to as the Slemon Group and upgrade type localities with recommended formation names (Figs. 1A and 10; Table 1).

Duncan Lake Group

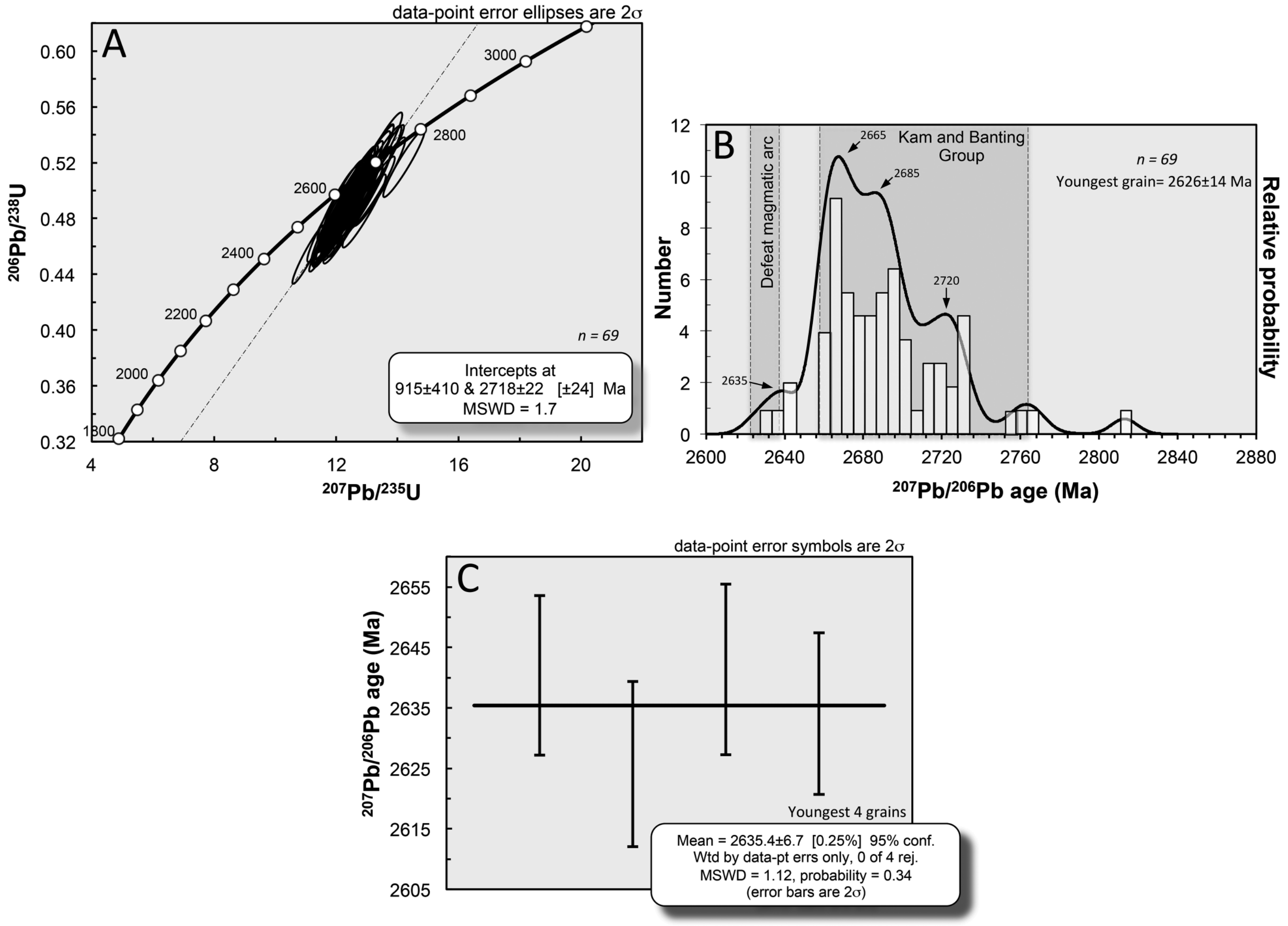
The Duncan Lake Group terminology first appeared in Henderson (1975) and was used to refer to all of the sedimentary rocks that overlay the Kam Group volcanic rocks at Yellowknife. This included the Burwash Formation and Jackson Lake Formation (Henderson 1970). Although Henderson considered these sedimentary rocks to be older than the Banting Group volcanic rocks, however, Helmstaedt and Padgham (1986) recognized that these sedimentary rocks are in fact younger than, or laterally equivalent to, the Banting Group. Furthermore, they established that the Jackson Lake Formation conglomerates and sandstones are considerably younger and therefore should not be included as part of the Duncan Lake Group. Subsequent U–Pb zircon dating has further corroborated this latter interpretation (e.g., Isachsen et al. 1991). Therefore, the Duncan Lake Group and the Burwash Formation specifically refer to the thick accumulation of turbidites east of Yellowknife Bay of Great Slave Lake (e.g., Henderson 1970, 1975; Ferguson et al. 2005).

Burwash Formation

The archetype of the Duncan Lake Group is the renowned Burwash Formation, which has been investigated in detail on the eastern side of Yellowknife Bay of Great Slave Lake (Henderson 1970, 1972) and in the Hearne Lake area (Ferguson et al. 2005; Fig. 1A). The Burwash Formation, which is estimated to be ~4.5–5 km in thickness (Henderson 1970), forms a large synclinorium between Yellowknife and the Sleepy Dragon Complex to the east, and continues south and potentially east of this basement culmination (e.g., Stubley 2005). The type section is south of Burwash Point in Yellowknife Bay where each turbidite cycle (greywacke–mudstone) is on average ~0.3–0.4 m thick (Henderson 1970).

Although the date of ca. 2650.5 Ma from the Dettah tuff bed in this study (Fig. 4E) is younger than the 2661 Ma presented by Bleeker and Villeneuve (1995), it is still comparable. Noteable is that our 2650.5 Ma age is very close to the detrital zircon maximum deposition age obtained from the turbidites at Mosher Lake (Ootes et al. 2009), and collectively these dates show that the turbidites are relatively close temporally to the upper part of Duncan Lake Group (Fig. 10; Table 1).

Fig. 7. Courageous Lake greywacke showing the LA–MC–ICP-MS U–Pb detrital zircon results. (A) U–Pb concordia diagram showing all the zircons analyzed. (B) Histogram with probability curve for the detrital zircons (<10% discordance). Note the high frequencies of Banting Group detritus. (C) The weighted mean $^{207}Pb/^{206}Pb$ age of the four youngest grains is 2635 ± 6.7 Ma, which we define as the maximum deposition age and likely these zircons are source from the Defeat magmatic arc.



Clover Lake Formation

A succession of turbiditic sedimentary rocks that occur just north of Clover Lake in the Hope Bay greenstone belt has been described by Sherlock et al. (2012; Fig. 1A). The sedimentary sequence there contains well-bedded greywacke and mudstone facies occasionally with conglomerates containing locally derived clasts. The sedimentary succession has been intruded and is interbedded with the Clover Lake felsic volcanic suite, primarily calc-alkaline flow-banded rhyolites. These rhyolites show distinct contact textures that suggest emplacement of the volcanics into unlithified wet sediment. A U–Pb ID–TIMS age for one of the rhyolite flows in this section is 2662.7 +3.4/−2.8 Ma, which is viewed as the minimum age of the turbidites in the Hope Bay greenstone belt (Sherlock et al. 2012). On this basis, we recommend the use of Clover Lake Formation and assign this formation to the Duncan Lake Group (Fig. 1A; Table 1).

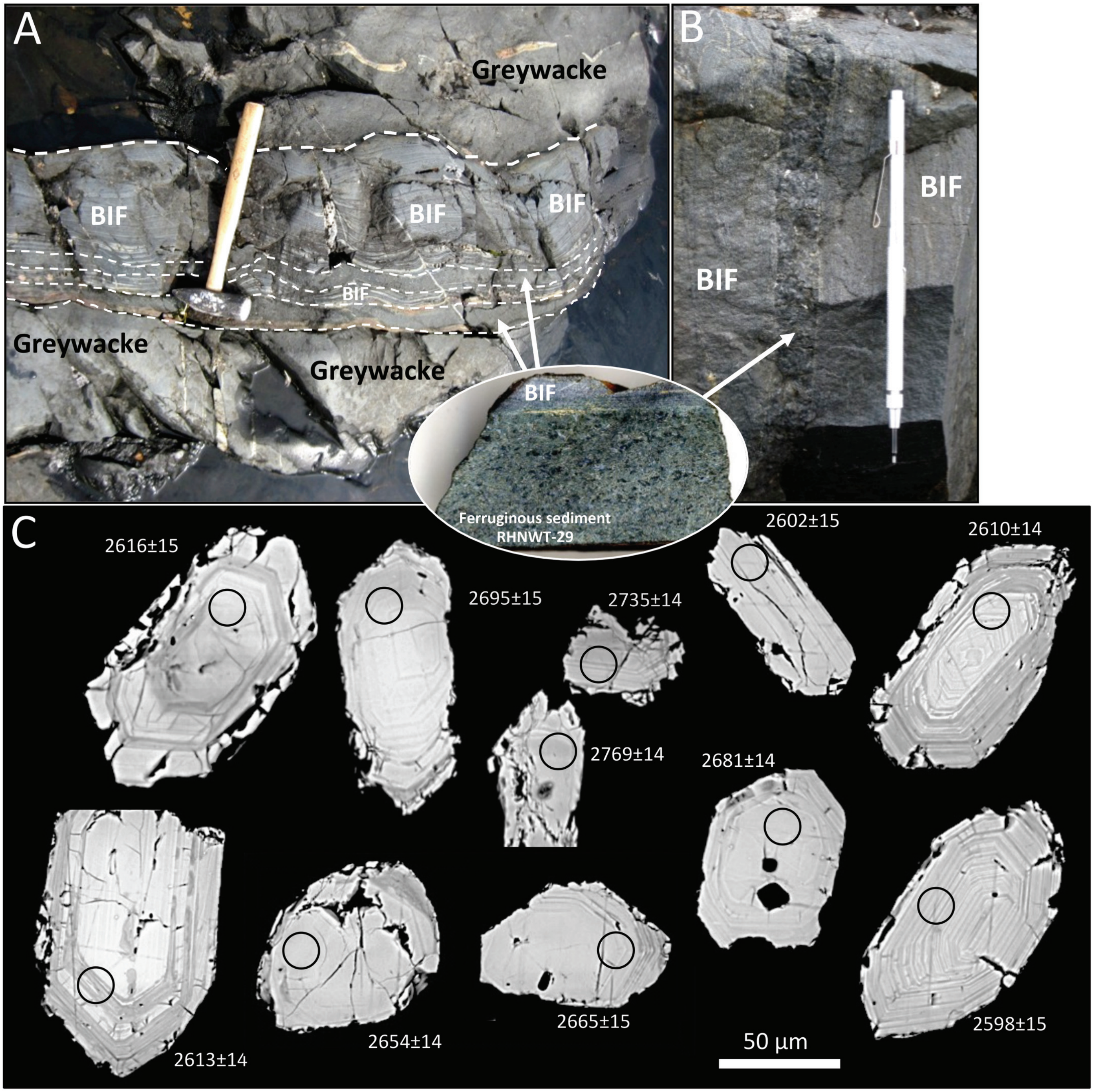
Itchen Lake Formation

The Itchen Formation was named by Bostock (1980) to refer to greywacke–mudstone turbidites in the central part of the Slave craton that do not contain BIF (Bostock 1980; Henderson 1998; Fig. 1A). Bostock (1980) interpreted that the Itchen Formation was younger than the Contwoyto Formation, because the latter is more proximal to the underlying volcanic belts. Ootes et al. (2009) analyzed 58 detrital zircons by the U–Pb SHRIMP method and determined a maximum deposition age of 2658 ± 8 Ma for the Itchen Formation, indicating that the Itchen Formation is likely older than the BIF-bearing Contwoyto Formation. We recommend the Itchen Formation be, from here forward, recognized as the Itchen Lake Formation, and the type locality be the location of the greywacke sampled for detrital zircon analyses (Ootes et al. 2008, 2009). Based on the maximum deposition age, we tentatively retain the Itchen Lake Formation within the Duncan Lake Group, although it should be recognized that the nature of detrital zircon results allows this formation to potentially be younger.

Mosher Lake Formation

Greywacke–mudstone turbidites are well preserved at Mosher Lake in the southwestern Slave craton (Ootes and Pierce 2005; Ootes et al. 2006, 2008, 2009; Fig. 1A). A total of 58 detrital zircons from a greywacke sample were dated by the U–Pb SHRIMP method and the youngest yielded a maximum deposition age of 2651 ± 6 Ma (Ootes et al. 2006, 2009). These turbidites do not contain interbedded BIF. We recommend referring to these turbidites as the Mosher Lake Formation and the type locality should be considered the location for the detrital zircon sample (Ootes et al. 2006, 2008, 2009). Based on the maximum deposition age, we tentatively assign these turbidites to the Duncan Lake Group (Fig. 10; Table 1). Although the nature of detrital zircon results allow that these turbidites could be younger (Ootes et al. 2009), structural

Fig. 8. Point Lake ferruginous sediment. (A, B) Field photograph of the Point Lake coarse-grained ferruginous sediment beds within the turbidite-BIF sequence. (C) Backscatter image of representative zircons from the ferruginous sediment beds. The grains are well-zoned but occasionally intensively fragmented and corroded. [Colour online.]



data presented in Fyson and Jackson (1991) establish that these turbidites contain a deformation fabric that pre-dates fabrics preserved in the Slemon Lake Formation turbidites (see below) that occur to the west at Russell and Slemon lakes.

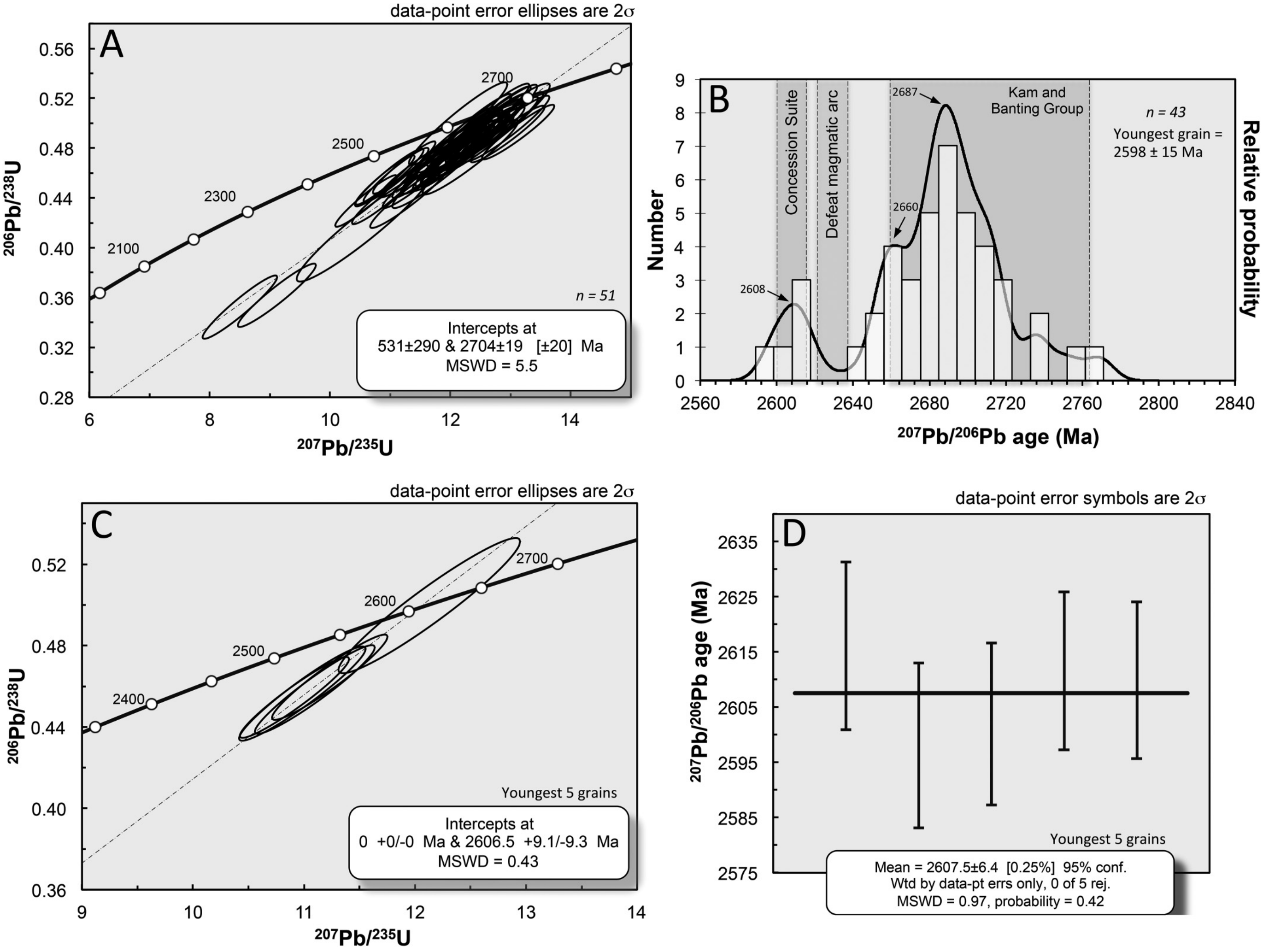
The Slemon Group

Slemon Lake Formation

The Slemon Lake tuff, with its single-age zircon population, record coeval volcanic input into the chemical and clastic sediment dominated basin at 2620 ± 6 Ma (Figs. 2 and 3). This date is the best estimate of the age of this tuff bed and constrains the depositional timing of the turbidites and the interbedded BIF. This is the only tuff bed discovered and dated in the younger BIF-bearing turbidites in the craton. We recommend referring to these as the Slemon Lake Formation, and this locality should also be considered as the type locality for the young BIF-bearing turbidite sequences in the suggested Slemon Group (Figs. 1A and 10; Table 1). The age is synchronous with or slightly late, relative to the ages of the Defeat Suite plutons (Davis and Bleeker 1999) and likely the precursor sediment was pyroclastic ash derived from Defeat-related volcanism in the hinterland of the basin.

These BIF-bearing turbidites continue eastward to Russell Lake (Jackson 2001; Fig. 1A) where detrital zircon from a greywacke

Fig. 9. LA–MC–ICP-MS U–Pb detrital zircon results from the Point Lake ferruginous sediment. (A) U–Pb concordia diagram showing all the zircons analyzed. (B) Histogram with probability curve for the detrital zircons (<10% discordance). In addition to the high input of Banting Group detritus, note the probability peak at 2608 Ma, which indicate detrital input from the differentiated Concession Suite magmatic rocks. (C) U–Pb concordia diagram of the youngest five grains. (D) The weighted mean $^{207}Pb/^{206}Pb$ age for the five grains is 2607.5 ± 6.4 Ma, which could suggest the existence of an even younger turbidite-BIF sequence in the craton.



sample has yielded a maximum deposition age of 2625 ± 6 Ma (Ootes et al. 2006, 2008, 2009). This further demonstrates that these laterally extensive deposits were all formed after uplift and deformation of the turbidite formations in the Duncan Lake Group.

Goose Lake Formation (Goose Lake)

The youngest detrital zircon age of 2621 ± 18 Ma (1.3% discordance, Figs. 5B and 5D) for the Goose Lake greywacke is the only grain of that age that has been recovered from the sample. This date is, however, consistent with another concordant detrital zircon date of 2620 ± 5 Ma (ID–TIMS) reported by Villeneuve et al. (2001) from a greywacke in the Beechey Lake turbidites on the western flank of the Back River volcanic complex (Fig. 1A). Furthermore, euhedral to subhedral zircons from a fine-grained felsic sill that intruded the Beechey Lake turbidites yielded an upper intercept at 2637 +8/−6 Ma placing a minimum age on the deposition of these turbidites (Villeneuve et al. 2001). However, this best fit regression was determined on four zircon fractions, none of which were concordant or had overlapping 95% confidence error ellipses (Fig. 4; Villeneuve et al. 2001).

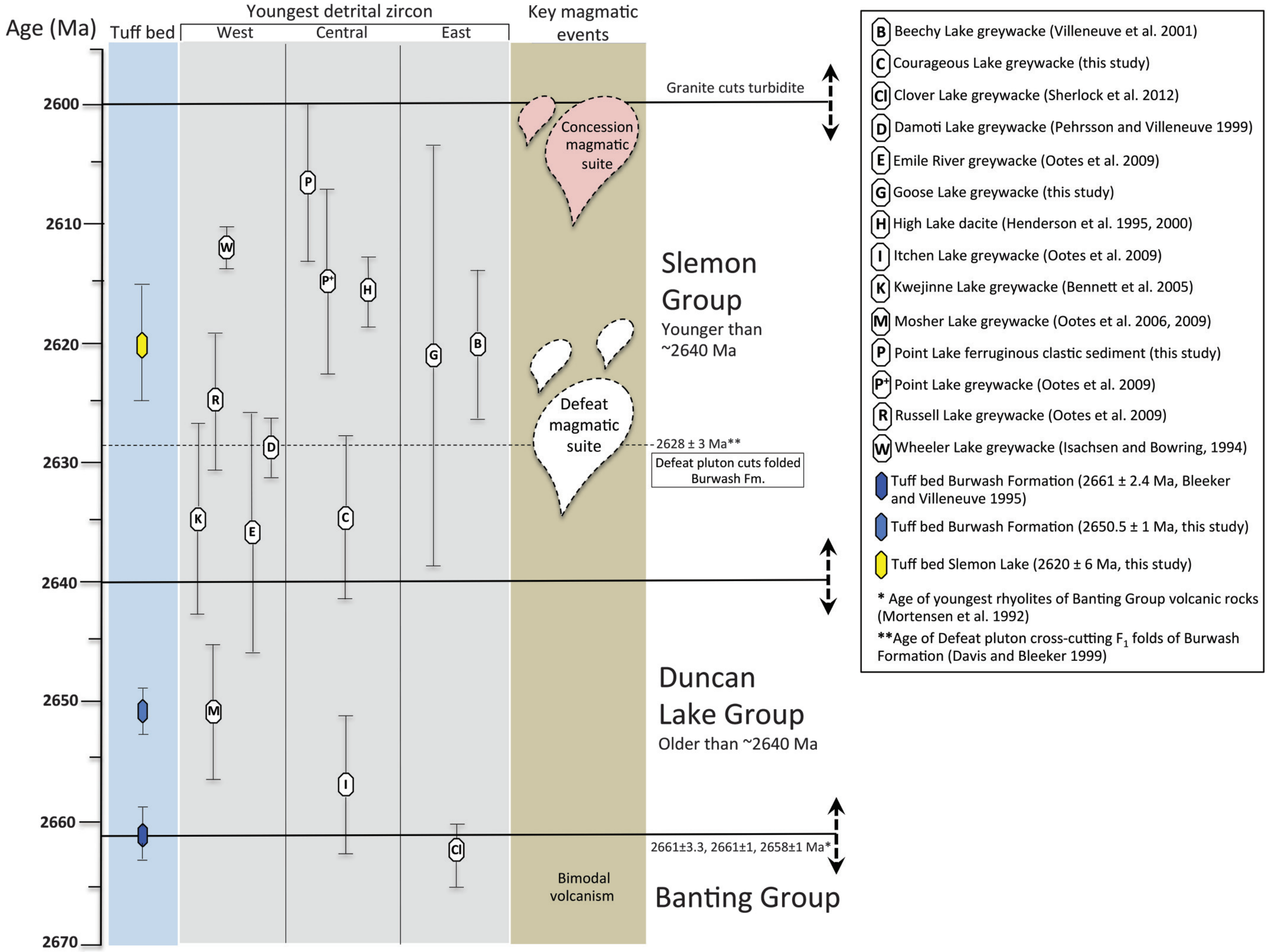
Nevertheless, the U–Pb zircon dates from Beechey Lake together with the 2621 ± 18 Ma age from Goose Lake confirm the belonging of these BIF-bearing turbidites to the suggested Slemon Group and furthermore correlate the eastern turbidite-BIF sequences with the ones from the central and western Slave craton (Fig. 1A).

We recommend that the BIF-bearing turbidites in the Goose Lake area be referred to as the Goose Lake Formation (Fig. 10; Table 1). While the Mesoarchean Central Slave Cover Group and the Mesoarchean to Hadean Central Slave Basement Complex rocks are not known to be preserved in the eastern part of the craton (Bleeker et al. 1999), the five zircon grains from Goose Lake dated between 3074 ± 15 and 2803 ± 15 Ma (Fig. 5D) indicate that older basement was exposed in the source region.

Salmita Formation (Courageous-MacKay lakes)

In the central part of the Slave craton, greywacke–mudstone turbidites were deposited stratigraphically on top of the Courageous-MacKay lakes greenstone belt (Fig. 1A). These turbidites continue well to the east where they may be correlative to the Beechey Lake turbidites that overly the Hackett River greenstone belt (Villeneuve

Fig. 10. Composite U–Pb ages for turbidites in the Slave craton with the recommended revised nomenclature for the Duncan Lake Group (Henderson 1970, 1972; Helmstaedt and Padgham 1986; Ferguson 2002; Ferguson et al. 2005) and the proposed Slemon Group (this study). See text for further explanations. [Colour online.]



et al. 2001; Stubley 2005; Fig. 1A). The detrital zircon age populations for the Courageous Lake sample represent multiple sources with a dominant input of detritus at ca. 2720, 2685, and 2665 Ma (Fig. 7B). These ages are consistent with the timing of volcanism in the underlying volcanic belt and volcanic rocks preserved elsewhere in the craton (van Breemen et al. 1992; Isachsen and Bowring 1997; Sherlock et al. 2012).

The youngest zircon grain identified in the sample is 2626 ± 14 Ma, although it is modestly discordant (9.7% discordance, Figs. 6B and 7B). The weighted average of the four youngest grains yields a $^{207}Pb/^{206}Pb$ age of 2635 ± 7 Ma (Fig. 7C). This age may be on the young side since the measurements on the OG1 standard during this data acquisition yield a weighted average of 3455.5 ± 4.3 Ma, which fall outside the analytical uncertainty of the 3465.4 ± 0.6 Ma (TIMS) age of OG1 (see Table S6[1]). However, we tentatively assign these turbidites as part of the younger Slemon Group. As many of the local geographic names are generally assigned to other stratigraphic units in the area, we recommend the turbidites at this locality be referred to as the Salmita Formation, in recognition of the past-producing Salmita gold mine that is located just to the southwest of the sampled location.

Contwoyto Lake Formation (Point Lake)

These BIF-bearing turbidites are exposed on the northern and eastern side of Point Lake (Henderson 1998; Fig. 1A). The use of the name Contwoyto Formation was used by Bostock (1980) who pointed out the occurrence of interbedded BIF, which distinguished these turbidtites from the higher metamorphic-grade turbidites that were assigned to the Itchen Formation further east (see Henderson 1998). However, Bostock (1980) believed the Contwoyto Formation to be older than Itchen Formation due to its more proximal nature to volcanic belts. Using detrital zircons, Ootes et al. (2009) suggested the BIF-bearing Contwoyto Formation is actually younger than the BIF-absent Itchen Formation. We recommend the name Contwoyto Lake Formation for BIF-bearing turbidites in this area, which is defined by the detrital zircon maximum deposition age of 2608 ± 6 Ma (Fig. 9D), and the previously reported youngest identified detrital zircon grain at 2615 ± 13 Ma (Ootes et al. 2009; Fig. 10; Table 1). As such, we recommend the name Contowyto Lake Formation for these BIF-bearing turbidites at Point Lake.

The ferruginous clastic sediment sample in this study contains a dominant zircon population (ca. 2720–2660 Ma), likely of Banting or Kam Group affinity (Fig. 9B). There is a probability trough at ca. 2640–2620 Ma, indicating only minimum input from the Defeat Suite (Fig. 9B). The youngest population, at ca. 2610 Ma, indicates a minor proportion of the zircons (n = 5) may have been derived from the monzodioritic to granodioritic Concession Suite plutons (Davis et al. 1994; Figs. 9B, 9C, 9D, and 10). The BIF-bearing turbidites of the Contwoyto Lake Formation either represent the upper part of Slemon Group turbidites or may be a separate package of even younger turbidites.

Damoti Lake Formation

At Damoti Lake (Fig. 1A), greywacke–mudstone turbidites with interbedded BIF was informally named the Damoti formation by Pehrsson and Villeneuve (1999). They dated 15 detrital zircons by the ID–TIMS method and discovered a single concordant grain at 2629 ± 2 Ma, and interpreted this as the maximum deposition age of the sample (Fig. 10; Table 1). This was the first demonstration of turbidites that were clearly younger than the 2661 Ma Burwash Formation of the Duncan Lake Group. We therefore recommend the BIF-bearing turbidites in the Damoti Lake area to be referred to as the Damoti Lake Formation, with the type locality being the sample location of Pehrsson and Villeneuve (1999; Table 1).

Kwejinne Lake Formation

North of Slemon Lake and along the Snare and Emile rivers in the western Slave craton, greywacke–mudstone turbidites are extensively preserved (Fig. 1A). At Kwejinne Lake, Bennett et al. (2005) collected a greywacke sample and dated 100 detrital zircons by the LA–ICP-MS method, the youngest concordant grain of which yielded a maximum deposition age of 2633 ± 9 Ma. The five youngest grains yielded a weighted average $^{207}Pb/^{206}Pb$ age of 2634 ± 8 Ma. These greywackes do not contain interbedded BIF, but they do continue to the east where they are preserved at higher metamorphic grades. There they are preserved as migmatites and contain abundant BIF enclaves. Detrital zircon cores were dated by Bennett et al. (2012) and the youngest of 68 analyses yielded a maximum deposition age of 2636 ± 3 Ma. Northwest of Kwejinne Lake, along the Emile River at Mattberry Lake, Archean greywacke–mudstone turbidites underlie Proterozoic quartzite and quartz pebble conglomerate and both were deformed together in the Proterozoic (Fyson and Jackson 2008; Jackson 2008; Bennett et al. 2012). Detrital zircons from the Archean greywacke were dated by the LA–ICP-MS method by Bennett et al. (2012) and the youngest grains of 79 analyses indicate a maximum deposition age of 2637 ± 4 Ma.

All three of the above samples share similar maximum deposition ages and are proximal to Kwejinne Lake, and we therefore recommend they be referred to as the Kwejinne Lake Formation (Fig. 10; Table 1). The type locality should be considered the location at Kwejinne Lake dated by Bennett et al. (2005). While the maximum deposition ages are younger than the ca. 2661 Ma Burwash Formation of the Duncan Lake Group, the maximum deposition ages are comparable to the oldest Defeat Suite plutons (Davis and Bleeker 1999). These turbidites locally contain interbedded BIF and occur along strike of the Slemon Lake Formation, and because they are younger than the youngest detrital zircons dated, we assign these to the Slemon Group.

Emile River Formation

In the western Slave craton, north of the Damoti Lake Formation, turbidites with interbedded BIF occur within the core of a Central Slave Basement Complex-bounded synclinorium (Ootes et al. 2008; Fig. 1A). Ootes et al. (2009) dated 66 detrital zircons from a greywacke sample by the SHRIMP method, and they determined a maximum deposition age of 2637 ± 10 Ma (Fig. 10). We recommend these turbidites be referred to as the Emile River Formation (Table 1) with the type locality being the detrital zircon sample location in Ootes et al. (2008, 2009). As these turbidites contain interbedded BIF and have a maximum deposition age distinctly younger than the 2661 Ma deposition age of Burwash Formation of the Duncan Lake Group, we tentatively recommend these be assigned to the Slemon Group (Table 1).

Wheeler Lake Formation

Isachsen and Bowring (1994) report an age from a tuff, interbedded with BIF-bearing turbidites east of Wheeler Lake, of 2612 ± 1 Ma (Fig. 1A). Ootes et al. (2009) dismissed this and interpreted that it was likely an intrusive sill that was dated in that study as the sample location could not be confirmed in the field and many porphyry sills occur in the area (Ootes and Pierce 2005). However, since that time it has been confirmed that it was in fact a tuff bed that was sampled near Wheeler Lake and dated in that study (W. Fyson, personal communication, 2010). Due to the new results from the Contowyto Lake Formation (above), the ca. 2612 Ma deposition age for the BIF-bearing Wheeler Lake turbidites is considered as permissible. We recommend referring to the turbidites in the Wheeler Lake area (Brophy 1995; Ootes and Pierce 2005) as the Wheeler Lake Formation (Table 1). The type locality for these should be considered as the location dated by Isachsen and Bowring (1994), on the southeast side of Wheeler Lake (Figs. 1A and 10).

James River Formation (High Lake)

In the northern Slave craton, in the vicinity of High Lake, slates, siltstones, and greywackes overly older volcanic belts (Jackson 1985; Henderson et al. 1995, 2000; Fig. 1A). The mudstones and siltstones have long been considered to be younger than the greywackes and Henderson et al. (2000) indicate a deposition age (their unit Asl) of ca. 2616–2612 Ma. However, numerous plutons of similar age occur throughout the area and it is not clear from that work what was dated, felsic dykes or concordant sills, or interbedded felsic volcanic layers (Henderson et al. 2000). In addition, no interbedded BIF have been reported from these sedimentary rocks. Therefore, we cautiously assign these sedimentary rocks to the Slemon Group. Regardless of their age, we recommend they be referred to as the James River Formation (Table 1). The type locality should be considered the location with reported date from a concordant dacitic porphyry body at 2616 ± 3 Ma (Henderson et al. 1995).

Composite stratigraphy

Depositional ages and field relations among the turbidites in the Slave craton show that these can be separated into at least two separate packages: an older (>2640 Ma) Duncan Lake Group and a younger (<2640 Ma) Slemon Group (Fig. 10; Table 1). Since the older turbidites are uplifted, folded, and later cut by the ca. 2628 Ma Defeat pluton, we arbitrary put the border between the two groups at 2640 Ma, as illustrated in Fig. 10. This age may be slightly older or younger. The backbone of this new stratigraphy is the depositional ages of the tuff beds interbedded with the greywacke–mudstone turbidites. The Burwash Formation of the Duncan Lake Group was deposited between ca. 2661 and 2650 Ma, whereas the newly discovered 2620 ± 6 Ma tuff bed defines the age of a younger BIF-bearing turbidite package at Slemon Lake, referred to as the Slemon Group here. This age indicates that these turbidites either post-date or were deposited synchronously with the intrusion of the ca. 2635–2620 Ma Defeat Suite plutons (Fig. 10). These younger turbidites of the Slemon Group were deposited after uplift and crustal shortening of the older Burwash Formation turbidites. The is furthermore supported in the detrital zircon record of the Slemon Group (Figs. 5D, 7B, and 9B; figs. 5 and 8 in Ootes et al. 2009) that shows only a minor input of synchronous zircons derived from juvenile (~2620 Ma) sources. Rather, the greywackes of the Slemon Group contain detrital zircons that are similar in age to zircons in the older volcanic belts, indicating further uplift and erosion of those belts, or recycling of the Duncan Lake Group sediment into the Slemon Group turbidite-BIF basin.

Future considerations

It is evident from the above that the Point Lake date, along with the Wheeler Lake and High Lake dates (Isachsen and Bowring

1994; Henderson et al. 1995), may represent an even younger event of turbidite-BIF depoition and therefore we cannot exclude the potential existence of a third package of turbidites within the craton. Collectively, these dates may reflect minor contribution from the younger (2610–2600 Ma) Concession Suite. Unfortunately, however, the data from High Lake and Wheeler Lake is reported without supporting analytical data. Consequently, the young dates from these locations need further confirmation as these could also represent the upper components of the Slemon Group depositional basin; therefore, without further evidence, they are currently included within the Slemon Group.

Locating tuff beds within greywacke–mudstone turbidites is challenging as these beds are volumetrically minor and often only are a few centimeters thick. However, their importance in constraining the Neoarchean stratigraphy of the Slave craton, and other Archean cratons, is crucial for resolving regional stratigraphic relationships. Finding additional tuff beds and younger clastic sedimentary units in these sections will help to better-constrain the deposition ages and duration of sedimentation in many turbidite sequences in the craton. For example, the 2620 ± 6 Ma crystallization age of the tuff bed at Slemon Lake presented in this study provides a critical date and horizon in further establishing previously unknown younger stratigraphic relationships in these turbidite basins and evaluating tectonic processes across the Slave craton.

The results of this study imply that an unconformity should exist somewhere between the Duncan Lake Group and the Slemon Group. Although these extensive turbidite deposits often are monotonous and indistinct, future fieldwork and bedrock mapping should emphasize the importance of finding this internal Slave craton boundary that likely exists as an angular unconformity.

The Burwash Formation of the Duncan Lake Group has been well studied (Henderson 1970, 1972; Yamashita and Creaser 1999; Ferguson et al. 2005), but the petrology of the Slemon Group has not been investigated to the same extent. Thorough sedimentologically focussed petrological work comparing the Duncan Lake and Slemon groups is recommended. In addition to the now-identified BIF association with the younger Slemon Group, such study should further reveal any petrological differences between these temporally distinct turbidite sequences. This would not only have profound importance on the crustal composition and tectonic development of the craton but would also help to characterize the depositional basins that accumulated these extensive turbidite deposits during the Neoarchean.

Conclusions

The U–Pb zircon results for tuff and greywacke samples investigated in this study refine the depositional ages for Neoarchean turbidite packages in the Slave craton. A tuff bed occurs within the BIF-bearing turbidites at Slemon Lake, and yields a U–Pb zircon depositional age of 2620 ± 6 Ma. For the first time, this date constrains the depositional age for the younger BIF-bearing turbidites in the southwest of the Slave craton. A previously undated tuff bed in the Burwash Formation turbidites yields a U–Pb zircon age of 2650.5 ± 1.0 Ma. This new age is ~10 million years younger than previously reported tuff ages from the Burwash Formation, indicating a longer depositional time-frame than previously considered.

At Goose Lake in the eastern Slave craton, the youngest zircon grain yields an age of 2621 ± 18 Ma (1.3% discordant). These are BIF-bearing turbidites and for the first time the depositional timing of turbidites can be linked from west to east across the craton. At Courageous Lake, turbidites yield a maximum deposition age of 2635 ± 7 Ma. At Point Lake, coarse-grained mafic to intermediate sediment beds are intercalated with the BIF unit. The detrital zircons obtained from these beds define a maximum depositional age of 2608 ± 6 Ma, supporting that these either are distinctly younger than the ca. 2620 Ma BIF-bearing turbidites or are higher in the stratigraphic sequence.

The two new tuff ages, in concert with previously published data, allow the breakout of the younger BIF-bearing turbidite sequence from the Duncan Lake Group. The ca. 2661–2650 Ma Burwash Formation remains the archetype of the Duncan Lake Group, and we propose the Itchen Lake Formation, Mosher Lake Formation, and Clover Lake Formation should also be included within this group. The type localities for the formations are the dated sample locations. We propose that the demonstrably younger BIF-bearing turbidites be referred to as the Slemon Group. The archetypal locality for the Slemon Group is the tuff sample site in the proposed Slemon Lake Formation. Using maximum deposition ages that are comparable and younger than the crystallization age of the tuff, we recommend a number of other formation names, their type localities being the sections with dated sample locations. Further petrological work on these two groups is recommended to help resolve depositional environments, and to further help the understanding of Archean tectonic processes.

Acknowledgements

We gratefully acknowledge the help from Birger Rasmussen and Bryan Krapež for providing field assistance at Slemon Lake; Mark Labbe, Joshua Davies, and Jesse Reimink for support during sample preparation; Josh Davies and Jesse Reimink for discussions on zirconology; and Andy DuFrane for great help on the ICP-MS. Pilot Samantha Merritt provided excellent field support. Lastly, Rachel Abbott, Francois Berniolles, and Dave Smith of Sabina Gold and Silver Corporation provided great help at Goose Lake drill camp. This work was funded by Polar Continental Shelf Program (PCSP project number 65412) to R.H. and L.O., the Natural Sciences and Engineering Research Council of Canada (NSERC) to K.K. and L.M.H., the Northwest Territories Geological Survey, Sabina Gold and Silver Cooperation, the Circumpolar/Boreal Alberta Research Grants (C/BAR) program of the CCI-Canadian Circumpolar Institute (Grant #CG428). This is NWT Geological Survey Contribution #0098.

References

Arndt, N.T., Bruzak, G., and Reischmann, T. 2001. The oldest continental and oceanic plateaus: Geochemistry of basalts and komatiites of the Pilbara Craton, Australia. Geological Society of America Special Papers, **352**: 359–387. doi:10.1130/0-8137-2352-3.359.

Ashton, K.E., Heaman, L.M., Lewry, J.F., Hartlaub, R.P., and Shi, R. 1999. Age and origin of the Jan Lake Complex: a glimpse at the buried Archean craton of the Trans-Hudson Orogen. Canadian Journal of Earth Sciences, **36**: 185–208. doi:10.1139/e98-038.

Barrett, T.J., and Fralick, P.W. 1989. Turbidites and iron formations, Beardmore-Geraldton, Ontario: application of a combined ramp/fan model to Archaean clastic and chemical sedimentation. Sedimentology, **36**: 221–234. doi:10.1111/j.1365-3091.1989.tb00604.x.

Bédard, J.H., Harris, L.B., and Thurston, P.C. 2013. The hunting of the snArc. Precambrian Research, **229**: 20–48. doi:10.1016/j.precamres.2012.04.001.

Bekker, A., Slack, J.F., Planavsky, N., Krapež, B., Hofmann, A., Konhauser, K.O., and Rouxel, O.J. 2010. Iron formation: The sedimentary product of a complex interplay among mantle, tectonic, oceanic, and biospheric processes. Economic Geology, **105**: 467–508. doi:10.2113/gsecongeo.105.3.467.

Bennett, V., Jackson, V.A., and Rivers, T. 2005. Geology and UPb geochronology of the Neoarchean Snare River terrane: tracking evolving tectonic regimes and crustal growth mechanisms. Canadian Journal of Earth Sciences, **42**: 895–934. doi:10.1139/e04-065.

Bennett, V., Rivers, T., and Jackson, V.A. 2012. A compilation of U–Pb zircon primary crystallization ages from Paleoproterozoic southern Wopmay Orogen, Northwest Territories. Northwest Territories Geoscience Office, NWT Open Report 2012-003, 157 p.

Bethune, K.M., Villeneuve, M.E., and Bleeker, W. 1999. Laser $^{40}Ar/^{39}Ar$ thermochronology of Archean rocks in Yellowknife Domain, southwestern Slave Province: insights into the cooling history of an Archean granite-greenstone terrane. Canadian Journal of Earth Sciences, **36**: 1189–1206. doi:10.1139/e99-006.

Bleeker, W. 2002. Archaean tectonics: a review, with illustrations from the Slave craton. *In* The early earth: physical, chemical and biological development. *Edited by* C.M.R. Fowler, C.J. Ebinger, and C.J. Hawkesworth. Geological Society of London Special Publications, **199**: 151–181. doi:10.1144/GSL.SP.2002.199.01.09.

Bleeker, W., and Hall, B. 2007. The Slave Craton: Geological and Matallogenic Evolution. *In* Mineral Deposits of Canada: A synthesis of major Deposit-types, District Metallogeny, the evolution of geological provinces, and exploration methods. *Edited by* W.D. Goodfellow. Geological Society of Canada, Mineral deposit division, Special Publication, **5**: 849–879.

Bleeker, W., and Villeneuve, M.E. 1995. Structural studies along the Slave portion of the SNORCLE transect. *In* Slave–Northern Cordillera Lithospheric Evolution (SNORCLE) Transect and Cordilleran Tectonics Workshop. *Edited by* F. Cook and P. Erdmer. Lithoprobe Report, **44**: 8–13.

Bleeker, W., Ketchum, J.W., and Davis, W.J. 1999. The Central Slave Basement Complex, Part II: age and tectonic significance of high-strain zones along the basement-cover contact. Canadian Journal of Earth Sciences, **36**: 1111–1130. doi:10.1139/e99-007.

Bleeker, W., LeCheminant, T., Davis, W.J., Buchan, K., Ketchum, J., Sircombe, et al. 2007. Transect across the southwestern Slave craton: from Phanerozoic platform edge to the core of the Yellowknife Supracrustal Domain. Geological Association of Canada, Field Trip Guide Book A1, 232 p.

Bostock, H.H. 1980. Geology of the Itchen Lake area, District of Mackenzie. Geol. Surv. Can. Mem. 391, 101 p.

Brophy, J.A. 1995. Additional evidence for syngenetic gold enrichment in amphibolitic banded iron-formation, Slave Province. *In* Exploration Overview 1995. NWT Geological Mapping Division, Department of Indian Affairs and Northern Development, pp. 3/6–3/7.

Buse, S. 2006. A field, geochemical and geochronological perspective on the origin of granitoids and mafic volcanic rocks in the Wecho River area and the nature of ancient crust in the southwestern Slave Province, NWT. MS dissertation, Carleton University, Ottawa.

Cawood, P.A., Hawkesworth, C.J., and Dhuime, B. 2012. Detrital zircon record and tectonic setting. Geology, **40**: 875–878. doi:10.1130/G32945.1.

Chen, C.W., Rondenay, S., Evans, R.L., and Snyder, D.B. 2009. Geophysical detection of relict metasomatism from an Archean (~3.5 Ga) subduction zone. Science, **326**: 1089–1091. doi:10.1126/science.1178477.

Condie, K.C. 2004. Supercontinents and superplume events: distinguishing signals in the geologic record. Physics of the Earth and Planetary Interiors, **146**: 319–332. doi:10.1016/j.pepi.2003.04.002.

Davis, D.W., Pezzutto, F., and Ojakangas, R.W. 1990. The age and provenance of metasedimentary rocks in the Quetico Subprovince, Ontario, from single zircon analyses: implications for Archean sedimentation and tectonics in the Superior Province. Earth and Planetary Science Letters, **99**: 195–205. doi:10.1016/0012-821X(90)90110-J.

Davis, W.J., and Bleeker, W. 1999. Timing of plutonism, deformation, and metamorphism in the Yellowknife Domain, Slave Province, Canada. Canadian Journal of Earth Sciences, **36**: 1169–1187. doi:10.1139/e99-011.

Davis, W.J., and Hegner, E. 1992. Neodymium isotopic evidence for the tectonic assembly of Late Archean crust in the Slave Province, northwest Canada. Contribution to Mineralogical Petrology, **111**: 493–504. doi:10.1007/BF00320904.

Davis, W.J., Fryers, B.J., and King, J.E. 1994. Geochemistry and evolution of late Archean plutonism and its significance to the tectonic development of the Slave craton. Precambrian Research, **67**: 207–241. doi:10.1016/0301-9268(94)90011-6.

Davis, W., Jones, A., Bleeker, W., and Grütter, H. 2003. Lithosphere development in the Slave craton: a linked crustal and mantle perspective. Lithos, **71**: 575–589. doi:10.1016/S0024-4937(03)00131-2.

Dillon-Leitch, H.C.H. 1981. Volcanic stratigraphy, structure and metamorphism in the Courageous-MacKay Lake greenstone belt, Slave Province, Northwest Territories. Unpublished M.Sc. thesis, University of Ottawa, Ottawa, ON, 169 p.

Eriksson, K.A., Krapez, B., and Fralick, P.W. 1994. Sedimentology of archean greenstone belts: Signatures of tectonic evolution. Earth-Science Review, **37**: 1–88. doi:10.1016/0012-8252(94)90025-6.

Fan, J., and Kerrich, R. 1997. Geochemical characteristics of aluminum depleted and undepleted komatiites and HREE-enriched low-Ti tholeiites, western Abitibi greenstone belt: A heterogeneous mantle plume-convergent margin environment. Geochimica et Cosmochimica Acta, **61**: 4723–4744. doi:10.1016/S0016-7037(97)00269-X.

Fedo, C.M, Sircombe, K.N., and Rainbird, R.H. 2003. Detrital zircon analysis of the sedimentary record. Reviews in Mineralogy and Geochemistry, **53**: 277–303. doi:10.2113/0530277.

Ferguson, M.E. 2002. Sedimentology and tectonic setting of the late Archean Burwash Formation, southern Slave Province. MS dissertation, Dalhousie University, Halifax.

Ferguson, M.E., Waldron, J.W., and Bleeker, W. 2005. The Archean deep-marine environment: turbidite architecture of the Burwash Formation, Slave Province, Northwest Territories. Canadian Journal of Earth Sciences, **42**: 935–954. doi:10.1139/e04-070.

Fyson, W.K., and Jackson, V.A. 1991. Reorientation of structures near granitic plutons and orthogonal lineaments, Russell Lake supracrustal domain, southwestern Slave Province. Canadian Journal of Earth Sciences, **28**: 126–135. doi:10.1139/e91-011.

Fyson, W.K., and Jackson, V.A. 2008. Images of an unconformity, Mattberry Lake, NWT. Northwest Territories Geological Survey, NWT Open Report 2008-004, 27 p.

Haugaard, R., Frei, R., and Stendal, H. 2013. Petrology and geochemistry of the ~2.9 Ga Itilliarsuk banded iron formation and associated supracrustal rocks, West Greenland: Source characteristics and depositional environment. Precambrian Research, **229**: 150–176. doi:10.1016/j.precamres.2012.04.013.

Haugaard, R., Ootes, L., Creaser, R.A., and Konhauser, K.O. 2016. The nature of Mesoarchaean seawater and continental weathering in 2.85 Ga banded iron formation, Slave craton, NW Canada. Geochimica et Cosmochimica Acta, **194**: 34–56. doi:10.1016/j.gca.2016.08.020.

Heaman, L.M., and Pearson, D.G. 2010. Nature and evolution of the Slave Province subcontinental lithospheric mantle. Canadian Journal of Earth Sciences, **47**: 369–388. doi:10.1139/E09-046.

Helmstaedt, H. 2009. Crust–mantle coupling revisited: The Archean Slave craton, NWT, Canada. *In* Proceedings of the 9th International Kimberlite Conference. *Edited by* S. Foley, S. Aulbach, G. Brey, H. Grütter, H. Höfer, D. Jacob, V. Lorenz, T. Stachel, and A. Woodland. Lithos, **112**: 1055–1068. doi:10.1016/j.lithos.2009.04.046.

Helmstaedt, H., and Padgham, W.A. 1986. A new look at the stratigraphy of the Yellowknife Supergroup at Yellowknife, NWT: implications for the age of gold-bearing shear zones and Archean basin evolution. Canadian Journal of Earth Sciences, **23**: 454–475. doi:10.1139/e86-049.

Henderson, J.B. 1970. Stratigraphy of the Yellowknife Supergroup, Yellowknife Bay–Prosperous Lake Area, District of Mackenzie. Geological Survey Canadian Paper, 70-26.

Henderson, J.B. 1972. Sedimentology of Archean turbidites at Yellowknife, Northwest Territories. Canadian Journal of Earth Sciences, **9**: 882–902. doi:10.1139/e72-071.

Henderson, J.B. 1975. Sedimentology of the Archean Yellowknife Supergroup at Yellowknife, District of Mackenzie. Geological Survey of Canada, Bulletin 246, 62 p.

Henderson, J.B. 1998. Geology of the Keskarrah Bay area, District of Mackenzie, Northwest Territories. Geological Survey of Canada Bulletin 527, 122 p.

Henderson, J.R., Kerswill, J.A., Henderson, M.N., Villeneuve, M., Petch, C.A., Dehls, J.F., and Okeefe, M.D. 1995. Geology, geochronology, and metallogeny of High Lake greenstone belt, Archean Slave Province, Northwest Territories. Geological Survey of Canada Current Research 1995-C, 97–106.

Henderson, J.R., Henderson, M.N., Kerswill, J.A., and Dehls, J.F. 2000. Geology, High Lake greenstone belt, Nunavut. Geol. Surv. Can. Map 1945A, scale 1:100 000.

Isachsen, C.E., and Bowring, S.A. 1994. Evolution of the Slave craton. Geology, **22**: 917–920. doi:10.1130/0091-7613(1994)022<0917:EOTSC>2.3.CO;2.

Isachsen, C., and Bowring, S. 1997. The Bell Lake group and Anton Complex: a basement-cover sequence beneath the Archean Yellowknife greenstone belt revealed and implicated in greenstone belt formation. Canadian Journal of Earth Science, **189**: 169–189. doi:10.1139/e17-014.

Isachsen, C.E., Bowring, S.A., and Padgham, W.A. 1991. U–Pb zircon geochronology of the Yellowknife volcanic belt, NWT, Canada: new constraints on the timing and duration of greenstone belt magmatism. Journal of Geology, **99**: 55–67. doi:10.1086/629473.

Jackson, V.A. 1985. Geology of the Keskarrah Bay area, parts of NTS areas 86 H/6 and 86 H/7. Northwest Territories Geoscience Office EGS 1985-8:1 map, scale 1:50 000.

Jackson, V.A. 2001. Report on the geology of the northern Russell Lake area (85O=4). Northwest Territories Geoscience Office, EGS 2001–03, 90 p.

Jackson, V.A. 2008. Preliminary geological map of part of the South Wopmay orogen (parts of NTS 86B and 86C; 2007 updates); descriptive notes to accompany 1:100 000 scale map. Northwest Territories Geological Survey, NWT Open Report 2008-007, 53 p. and 1 map, scale 1:100 000.

Kositcin, N., Brown, S.J.A., Barley, M.E., Krapež, B, Cassidy, K.F., and Champion, D.C. 2008. SHRIMP U–Pb zircon age constraints on the Late Archaean tectonostratigraphic architecture of the Eastern Goldfields Superterrane, Yilgarn Craton. Western Australia. Precambrian Research, **161**: 5–33. doi:10.1016/j.precamres.2007.06.018.

Krogh, T.E. 1973. A low contamination method for hydrothermal decomposition of zircon and extraction of U and Pb for isotopic age determinations. Geochimica et Cosmochimica Acta, **37**: 485–494. doi:10.1016/0016-7037(73)90213-5.

Kröner, A., and Layer, P.W. 1992. Crust Formation and Plate Motion in the Early Archean. Science, **256**(5062): 1405–1411. doi:10.1126/science.256.5062.1405. PMID:17791608.

Lowe, D.R. 1980. Archean sedimentation. Annual Review of Earth and Planetary Sciences, **8**: 145–167. doi:10.1146/annurev.ea.08.050180.001045.

Mattinson, J. 2005. Zircon U–Pb chemical abrasion (CA–TIMS) method: Combined annealing and multi-step partial dissolution analysis for improved precision and accuracy of zircon ages. Chemical Geology, **220**: 47–66. doi:10.1016/j.chemgeo.2005.03.011.

Moore, J.C.G. 1956. Courageous-Matthews lakes area, District of Mackenzie, Northwest Territories. Geological Survey of Canada, Memoir, **283**: 52 (4 sheets).

Mortensen, J.K., Henderson, J.B., Jackson, V.A., and Padgham, W.A. 1992. U–Pb geochronology of the Yellowknife Supergroup felsic volcanic rocks in the Russell Lake and Clan Lake areas, southwestern Slave Province, Northwest

Territories. *In* Radio-genic age and isotopic studies: Report 5. Geological Survey of Canada, Paper **91**(2): 1–7.

Nisbet, E.G. 1987. The young Earth: An introduction to Archaean Geology. Allen and Unwin, Boston, pp. 402.

Ootes, L., and Pierce, K. 2005. Digital geological atlas of the Wecho River area. Northwest Territories Geoscience Office, NWT Open File 2005-03 map, scale 1:100 000.

Ootes, L., Buse, S., Davis, W.J., and Cousens, B.C. 2005. U–Pb ages from the northern Wecho River area, southwestern Slave Province, Northwest Territories: constraints on late Archean plutonism and metamorphism. Geological Survey of Canada Current Research, 2005-F2, 13 p.

Ootes, L., Davis, W.J., and Jackson, V.A. 2006. Two turbidite sequences in the Russell Lake–Mosher Lake area: SHRIMP U–Pb detrital zircon evidence and correlations in the southwestern Slave craton, Northwest Territories. Geological Survey Canada Current Research, 2006-A7, 15 p.

Ootes, L., Davis, W.J., Bleeker, W., and Jackson, V.A. 2008. Geologic overview of greywacke samples collected from the western Slave craton. Northwest Territories Geoscience Office, NWT Open Report 2008-012, p. 14.

Ootes, L., Davis, W.J., Bleeker, W., and Jackson, V.A. 2009. Two Distinct Ages of Neoarchean Turbidites in the Western Slave Craton: Further Evidence and Implications for a Possible Back-Arc Model. The Journal of Geology, **117**(1): 15–36. doi:10.1086/593319.

Ootes, L., Morelli, R., Lentz, D.R., Falck, H., Creaser, R.A., and Davis, W.J. 2011. The timing of Yellowknife gold mineralization: a temporal relationship with crustal anatexis? Economic Geology, **106**: 713–720. doi:10.2113/econgeo.106.4.713.

Padgham, W. 1992. Mineral deposits in the Archean Slave Structural Province; lithological and tectonic setting. Precambrian Research, **58**: 1–24. doi:10.1016/0301-9268(92)90110-A.

Padgham, W.A., and Fyson, W.K. 1992. The Slave Province: a distinct Archean craton. Canadian Journal of Earth Sciences, **29**: 2072–2086. doi:10.1139/e92-165.

Pehrsson, S.J. 2002. The 2.27–2.63 Ga Indin Lake supracrustal belt: an Archaean marginal basin–foredeep succession preserved in the western Slave Province, Canada. *In* Precambrian sedimentary environments: a modern approach to ancient depositional systems. *Edited by* W. Altermann and P. Corcoran. Special Publication International Association of Sedimentology, **33**: 123–152.

Pehrsson, S., and Villeneuve, M. 1999. Deposition and imbrication of a 2670–2629 Ma supracrustal sequence in the Indin Lake area, southwestern Slave Province, Canada. Canadian Journal of Earth Sciences, **36**: 1149–1168. doi:10.1139/e99-017.

Pehrsson, S.J., Chacko, T., Pilkington, M., Villeneuve, M.E., and Bethune, K. 2000. Anton terrane revisited: late Archean exhumation of a moderate-pressure granulite terrane in the western Slave Province. Geology, **28**: 1075–1078. doi:10.1130/0091-7613(2000)28<1075:ATRLAE>2.0.CO;2.

Rasmussen, B., and Fletcher, I.R. 2010. Dating sedimentary rocks using in situ U–Pb geochronology of syneruptive zircon in ash-fall tuffs <1 mm thick. Geology, **38**(4): 299–302. doi:10.1130/G30567.1.

Reimink, J.R., Chacko, T., Stern, R.A., and Heaman, L.M. 2014. Earth's earliest evolved crust generated in an Iceland-like setting. Nature Geoscience, **7**: 529–533. doi:10.1038/ngeo2170.

Reimink, J.R., Chacko, T., Stern, R.A., and Heaman, L.M. 2016. The birth of a cratonic nucleus: Lithogeochemical evolution of the 4.02-2.94 Ga Acasta Gneiss Complex. Precambrian Research, **281**: 453–472. doi:10.1016/j.precamres.2016.06.007.

Sharma, R., and Pandit, M. 2003. Evolution of early continental crust. Current Science, **84**(8): 1–7.

Sherlock, R.L., Shannon, A., Hebel, M., Lindsay, D., Madsen, J., Sandeman, H., et al. 2012. Volcanic stratigraphy, geochronology, and gold deposits of the archean hope bay greenstone belt, Nunavut, Canada. Economic Geology, **107**: 991–1042. doi:10.2113/econgeo.107.5.991.

Shirey, S.B., and Richardson, S.H. 2011. Start of the Wilson cycle at 3 Ga shown by diamonds from subcontinental mantle. Science, **333**: 434–436. doi:10.1126/science.1206275. PMID:21778395.

Simonetti, A., Heaman, L.M., Hartlaub, R.P., Creaser, R.A., MacHattie, T.G., and Böhm, C. 2005. U–Pb zircon dating by laser ablation–MC–ICP-MS using a new multiple ion counting Faraday collector array. Journal of Analytical Atomic Spectrometry, **20**: 677–686. doi:10.1039/b504465k.

Simonetti, A., Heaman, L.M., Chacko, T., and Banerjee, N.R. 2006. In situ petrographic thin section U–Pb dating of zircon, monazite, and titanite using laser ablation–MC–ICP-MS. International Journal of Mass Spectrometry, **253**: 87–97. doi:10.1016/j.ijms.2006.03.003.

Stern, R.A., Bodorkos, S., Kamo, S.L., Hickman, A.H., and Corfu, F. 2009. Measurement of SIMS Instrumental Mass Fractionation of Pb Isotopes During Zircon Dating. Geostandards and Geoanalytical Research, **33**(2): 145–168. doi:10.1111/j.1751-908X.2009.00023.x.

Stubley, M.P. 2005. Slave Craton: interpretive bedrock compilation. Northwest Territories Geoscience Office, NWT-NU Open File 2005-01: Digital files and 2 maps.

Van Breemen, O., Davis, W.J., and King, J.E. 1992. Temporal distribution of granitoid plutonic rocks in the Archean Slave Province, northwest Canadian Shield. Canadian Journal of Earth Sciences, **29**: 2186–2199. doi:10.1139/e92-173.

Villeneuve, M.E. 1993. Preliminary geochronological results from the Winter Lake-Lac de Gras Slave Province NATMAP project, Northwest Territories. *In* Radiogenic Age and Isotopic Studies: Report 7. Geological Survey of Canada, Paper **93**(2): 29–38.

Villeneuve, M., Lambert, L., van Breemen, O., and Mortensen, J. 2001. Geochronology of the Back River volcanic complex, Nunavut-Northwest Territories. Geological Survey of Canada Current Research 2001-F2, 8 p.

Yamashita, K., and Creaser, R.A. 1999. Geochemical and Nd isotopic constraints for the origin of late Archean turbidites from the Yellowknife area, Northwest Territories, Canada. Geochimica et Cosmocimica Acta, **63**: 2579–2598. doi:10.1016/S0016-7037(99)00167-2.