Chapter 28

The Assean Lake Complex: Ancient Crust at the Northwestern Margin of the Superior Craton, Manitoba, Canada

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Chapter Outline

1. INTRODUCTION

The Superior Craton, which forms a substantial portion of the ancient core of North America, represents the largest known Archean craton (Fig. 28.1). Rare Paleoarchean crustal remnants in the Superior Craton are relatively small and invariably highly deformed (Böhm et al., 2000a; Bickford et al., 2004; David et al., 2009; Cates et al., 2013; O'Neil et al., 2013). This is possibly because of extensive Neoarchean crustal formation, recycling, and polyphase tectono-metamorphism that resulted from (proto-)plate tectonic processes (e.g., Card and Ciesielski, 1986; Card, 1990; Thurston et al., 1991; Williams et al., 1992; Lin, 2005; Percival et al., 2006). Despite these problems, evidence for a Paleoarchean component to the northwest margin of the Superior Craton was identified by Böhm et al. (2000a) in the Assean Lake area of north-central Manitoba, Canada. Further studies (e.g., Böhm et al., 2003; Hartlaub et al., 2006) have

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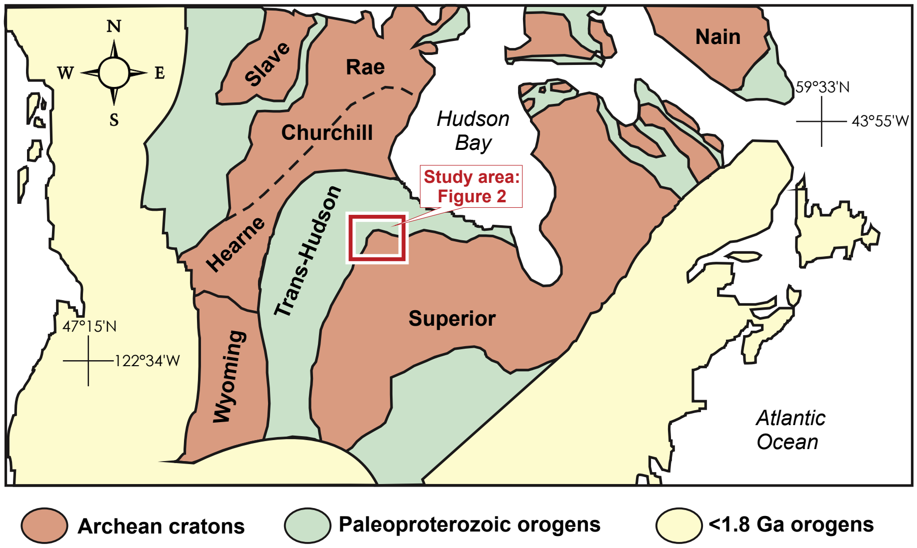

FIGURE 28.1 Simplified geological map of part of North America highlighting the major Archean cratons and Proterozoic orogenic belts.

advanced the knowledge of this ancient region and produced a significant database of mineral and whole-rock isotopic information summarized in this paper.

An initial tectonic model (Corkery and Lenton, 1990) indicated that a regionally extensive high-strain zone running through Assean Lake marks the suture between Archean high-grade crustal terranes of the Superior Craton to the southeast and Paleoproterozoic rocks of the Trans-Hudson Orogen to the northwest (Figs. 28.1 and 28.2). Detailed geological remapping (Böhm, 1997b, 1998; Böhm and Corkery, 1999), combined with isotopic and geochemical studies (Böhm et al., 2000a, 2003; Hartlaub et al., 2006), led to a reinterpretation of the crust immediately north of the Assean Lake high-strain zone as Mesoarchean and/or Paleoarchean.

This paper describes the age and extent of this ancient crust, defined herein as the Assean Lake Complex (ALC). We describe the Paleoarchean and Eoarchean components of the ALC and examine the relationship of this ancient crustal complex to surrounding crustal domains and include new U–Pb zircon age and whole-rock Nd and Hf isotopic data that further elucidate the antiquity of the ALC and cement the interpretation that it comprises exotic crustal material amalgamated to neighboring high-grade terranes during, or after, the 2.68–2.70 Ga assembly of the northwest Superior Craton (Davis et al., 1988; Davis and Amelin, 2000; Percival et al., 2006).

2. PRINCIPAL GEOLOGICAL ELEMENTS OF THE NORTHWESTERN SUPERIOR CRATON MARGIN

The study area straddles the boundary between the Archean Superior Craton and the c.1.90–1.84 Ga arc and marginal basin rocks of the Trans-Hudson Orogen, which represents the remains of 1.83–1.76 Ga ocean closure and orogeny (Corrigan et al., 2005; Ansdell, 2005). Within the northwestern part of the Superior Craton (Fig. 28.2), the Pikwitonei Granulite Domain and Split Lake Block (Böhm et al., 1999) are separated by the Aiken River deformation zone but comprise similar, variably retrogressed, and reworked granulite-grade rocks. To the north and west of these domains is the Superior Boundary Zone, which is composed of complexly interleaved Archean rocks of the Superior Craton and its cover sequences, Paleoproterozoic rocks related to the Trans-Hudson Orogen, and Mesoarchean to Paleoarchean rocks of the ALC.

The region has been geologically subdivided based on differences in structural trend, aeromagnetic signature, metamorphic grade, lithological nature, and age (e.g., Böhm et al., 2000a; Zwanzig and Böhm, 2004; Coyle et al., 2004). An economically important component of the Superior Boundary Zone is the Thompson Nickel Belt (Peredery et al., 1982; Bleeker, 1990; Machado et al., 1990; Layton-Matthews et al., 2007), one of the most prolific magmatic nickel-copper sulfide districts in the world. The nature and age of the prominent and extensive boundary between the ALC and the Split Lake Block, the Assean Lake deformation zone (Fig. 28.2), has been unclear; the discovery of Archean rocks north of this boundary has opened the question of how far north Archean rocks may extend and possibly underlie Paleoproterozoic rocks of the Trans-Hudson Orogen north of the ALC.

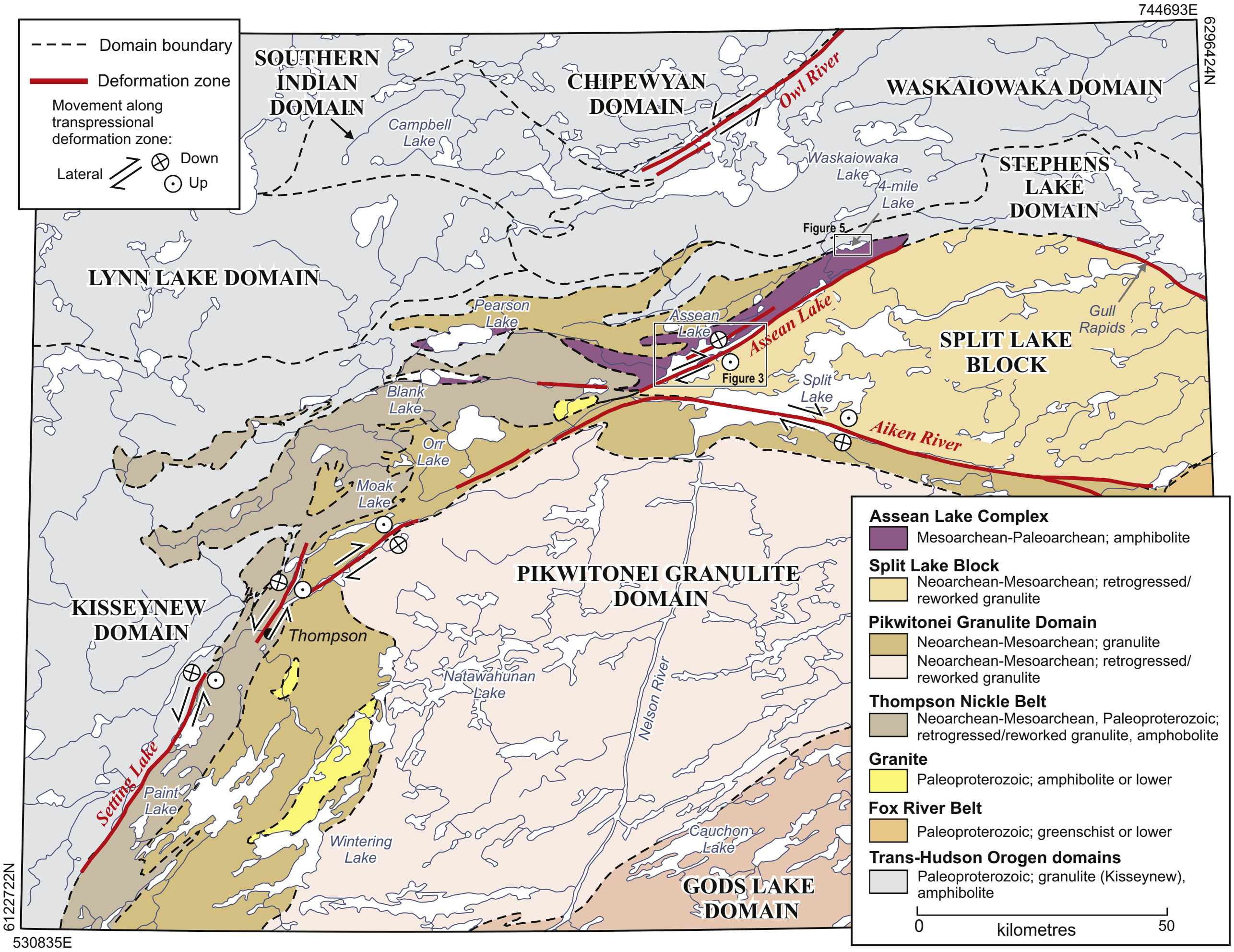

FIGURE 28.2 Tectono-metamorphic map of the Superior Boundary Zone region in north-central Manitoba, outlining the principal geological domains including their ages and metamorphic grades, as well as principal movements along main deformation zones (Kuiper et al., 2011a).

The following paragraphs summarize composition, structures, metamorphism, and available isotopic age constraints for each of the principal geological elements adjacent to the ALC.

2.1 Pikwitonei Granulite Domain

The Pikwitonei Granulite Domain is interpreted to represent the middle to deep crustal levels of an Archean granite-greenstone terrane (Green et al., 1985). Vestiges of supracrustal belts (Weber, 1978, 1983; Böhm, 1998) remain, but a tonalite–trondhjemite–granodiorite (TTG) suite of orthopyroxene-bearing tonalite and granodiorite dominate. Some tonalite gneisses may have 3.0 Ga or older crystallization ages, but most were emplaced around 2.7 Ga (Heaman et al., 1986, 2011; Böhm, 1998; Böhm et al., 1999). The area around Orr Lake (Fig. 28.2), formerly referred to as the Orr Lake Block (Lenton and Corkery, 1981; Böhm et al., 2000a), represents a structural and lithological complex hosting a number of terrane fragments. These fragments may include the northeast extension of the Thompson Nickel Belt, variably retrogressed rocks of the Pikwitonei Granulite Domain, Paleoproterozoic intrusive and sedimentary rocks of the Trans-Hudson Orogen, and possibly fragments of the ancient ALC (Zwanzig and Böhm, 2002).

Based on field relationships, petrography, and U–Pb geochronology, there is an indication of two, and possibly three, high-grade Archean deformational and metamorphic episodes in the Pikwitonei Granulite Domain (Weber and Scoates, 1978; Hubregtse, 1980; Heaman et al., 1986; Couëslan and Guevara, 2015). Geochronological studies indicate, however, that these events may be diachronous across the region (Heaman et al., 1986, 2011; Mezger et al., 1990). A 2695 ± 2 Ma orthopyroxene-bearing granitic dike is the first indication of localized granulite conditions. Complex metamorphic zircon populations from felsic and mafic granulites suggest amphibolite-grade metamorphism at c.2705−2692 Ma, followed by granulite-grade metamorphism from 2683 to 2665 Ma, and possibly also at c.2657 Ma, followed by localized amphibolite facies retrogression at c.2636 Ma (Heaman et al., 1986, 2011; Böhm et al., 1999). Estimates of peak pressure and temperature conditions during granulite-facies metamorphism are approximately 6.7−7.3 kbar and 730−770°C in the southeast and approximately 7.0−7.8 kbar and 780−840°C in the northwest Pikwitonei Granulite Domain (Mezger et al., 1990). U−Pb zircon ages of c.2629 and 2598 Ma from post-granulite pegmatite in the Cauchon Lake area (Fig. 28.2; Mezger, unpublished data, 1990) are additional evidence that metamorphic conditions reached amphibolite grade shortly after granulite facies. The presence of orthopyroxene−sillimanite and sapphirine-bearing rocks at Partridge Crop, Natawahunan Lake, and at Sipiwesk Lake (south of Wintering Lake outside of Fig. 28.2) — indicates that high-grade metamorphism reached maximum intensity at these locations (Arima and Barnett, 1984; Macek, 1989; Couëslan et al., 2013; Couëslan, 2016a).

2.2 Split Lake Block

The Split Lake Block is a tectonic lens of variably retrogressed and reworked Superior Craton margin rocks bounded by the Assean Lake and Aiken River deformation zones (Fig. 28.2; Corkery, 1985; Böhm et al., 1999). These deformation zones have been interpreted to represent Neoarchean structures reactivated by Paleoproterozoic tectonism (Böhm et al., 2000a, 2003; Downey et al., 2009; Kuiper et al., 2011a,b). The Split Lake Block is dominated by medium- to coarse-grained granoblastic gneisses, which contain hypersthene, diopside, and their retrogressed equivalents. Although the metamorphic and lithological character of this domain is similar to the Pikwitonei Granulite Domain, the Split Lake Block has been retrogressed and hydrated to a greater degree. Field and petrographic studies (Haugh, 1969; Corkery, 1985; Hartlaub et al., 2004) indicate that the gneisses of the Split Lake Block consist primarily of metaigneous protoliths of gabbroic to granitic composition. Tonalite and granodiorite are the most volumetrically dominant.

Böhm et al. (1999) report three periods of Archean magmatism in the Split Lake Block: (1) pre-2.9 Ga granodiorite to tonalite magmatism, which is considered to be part of the basement; (2) a possible period of 2841 ± 2 Ma tonalite magmatism; and (3) granite intrusion at 2708 ± 3 Ma. Similarly, granodiorite rocks at the northeast edge of the Split Lake Block at Gull Rapids (Fig. 28.2) are c.3.16 and 2.86 Ga and form the basement of a c.2.70 Ga mafic volcano-sedimentary sequence that contains 2.71 to 3.35 Ga zircon detritus (Bowerman et al., 2004; Downey et al., 2009).

Similar to the Pikwitonei Granulite Domain, three high-grade metamorphic events are recognized in the Split Lake Block (Corkery, 1985). Two of these events occurred within a short time span of about 10 My (Böhm et al., 1999). Based on the age of metamorphic zircon overgrowth from enderbite, the older event resulted in hornblende granulite-grade metamorphism at 2705 ± 2 Ma, closely linked to granite magmatism at 2708 ± 3 Ma. A younger granulite-grade peak metamorphic event is constrained at $2695 + 4/-1$ Ma based on the age of orthopyroxene-bearing leucosome isolated from mafic gneiss. The youngest significant metamorphic event is localized c.2620 Ma amphibolite-grade retrogression (Corkery, 1985; Böhm et al., 1999).

2.3 Thompson Nickel Belt

The Thompson Nickel Belt, which is mainly exposed southwest of Moak Lake (Fig. 28.2), includes variably reworked, c.2.7 Ga (Machado et al., 1987) Archean basement gneiss, Ospwagan Group rocks of probable 2.1−1.89 Ga age (Zwanzig, 2005), and c.1.88 Ga ultramafic bodies (Hulbert et al., 2005; Heaman et al., 2009; Scoates et al., 2017). The Ospwagan Group is interpreted as platform to marginal basin siliciclastic and chemical sedimentary sequence overlain by mafic volcanic rocks and intruded by felsic to ultramafic Paleoproterozoic bodies (Zwanzig et al., 2007). The Thompson Nickel Belt contains significant nickel-copper mineralization that has resulted in intense exploration and a wealth of geological and geophysical information (e.g., Bleeker, 1990; Macek et al., 2006; Zwanzig et al., 2007; Layton-Matthews et al., 2007; Couëslan et al., 2013). Nickel-copper deposits in the belt are hosted by the Ospwagan Group supracrustal succession and are generally associated with ultramafic bodies in contact with sulfide-bearing metasedimentary units (Bleeker, 1990).

2.4 Trans-Hudson Orogen

North and west of Assean Lake, a belt-like pattern, which is continuous with Trans-Hudson Orogen subdivisions to the west, was identified by Lenton and Corkery (1981). The belts are defined by alternating east- and southeast-trending belts dominated by plutonic (e.g., Chipewyan, Waskaiowaka) and supracrustal (Kisseynew, Lynn Lake, Southern Indian) domains (Fig. 28.2). The crust north and west of the ALC preserves prograde amphibolite metamorphic assemblages, whereas the northwestern most portion of the Thompson Nickel Belt and the Paleoproterozoic Kisseynew domain attained granulite-grade conditions. Metasedimentary rocks north and west of the ALC can be correlated with Burntwood Group graywacke and Sickle Group arkose of the Kisseynew domain (Fig. 28.2; Zwanzig, 1990). C. 50 km northwest of Assean Lake, the presence of abundant c.2.45 Ga detrital zircons in a metagraywacke at Campbell Lake (Fig. 28.2; Hartlaub et al., 2004) is consistent with derivation from the Sask Craton (Ashton et al., 1999), an Archean microcontinent that may underlie much of the Trans-Hudson Orogen northwest of the ALC in Manitoba and Saskatchewan.

North of the ALC and the Split Lake Block are Paleoproterozoic rocks of the Stephens Lake Domain (Fig. 28.2). Graywacke- and arkose-derived paragneisses of middle to upper amphibolite grade form the principal rock types in this domain (Haugh and Elphick, 1968; Corkery, 1985). The paragneisses contain minor amounts of amphibolite and quartzite, and the entire package is intruded by tonalite to granite and derived migmatitic gneiss. Metagraywacke and layered granodiorite gneisses from the east end of Stephens Lake have Nd-depleted−mantle model ages of 1.95 and 2.1 Ga, respectively (Böhm et al., unpublished data, 2000). The fact that both para- and orthogneisses in the area are derived from Paleoproterozoic material is consistent with the interpretation that the Stephens Lake Domain represents the far eastern extension of the Kisseynew Domain of the Trans-Hudson Orogen.

3. GEOLOGY OF THE ASSEAN LAKE COMPLEX

Shoreline exposures at Assean Lake (Figs. 28.2 and 28.3) were first recognized as the "Assean Lake series" of sedimentary and volcanic rocks by Dawson (1941). The name was subsequently modified to "Assean Lake Group" (Mulligan, 1957) and expanded to include sedimentary and volcanic rocks of the Ospwagan Group of the Thompson Nickel Belt. Haugh (1969) remapped the Assean Lake area and defined three subareas divided by extensive zones of cataclasis. Lithologies such as gray biotite gneiss, lit-par-lit gneiss, pelitic schist, amphibolite, gneissic granite, and gabbro were interpreted to be continuous, identical, and age-equivalent extensions of rocks in the Ospwagan Lake area southwest of Thompson (Haugh, 1969).

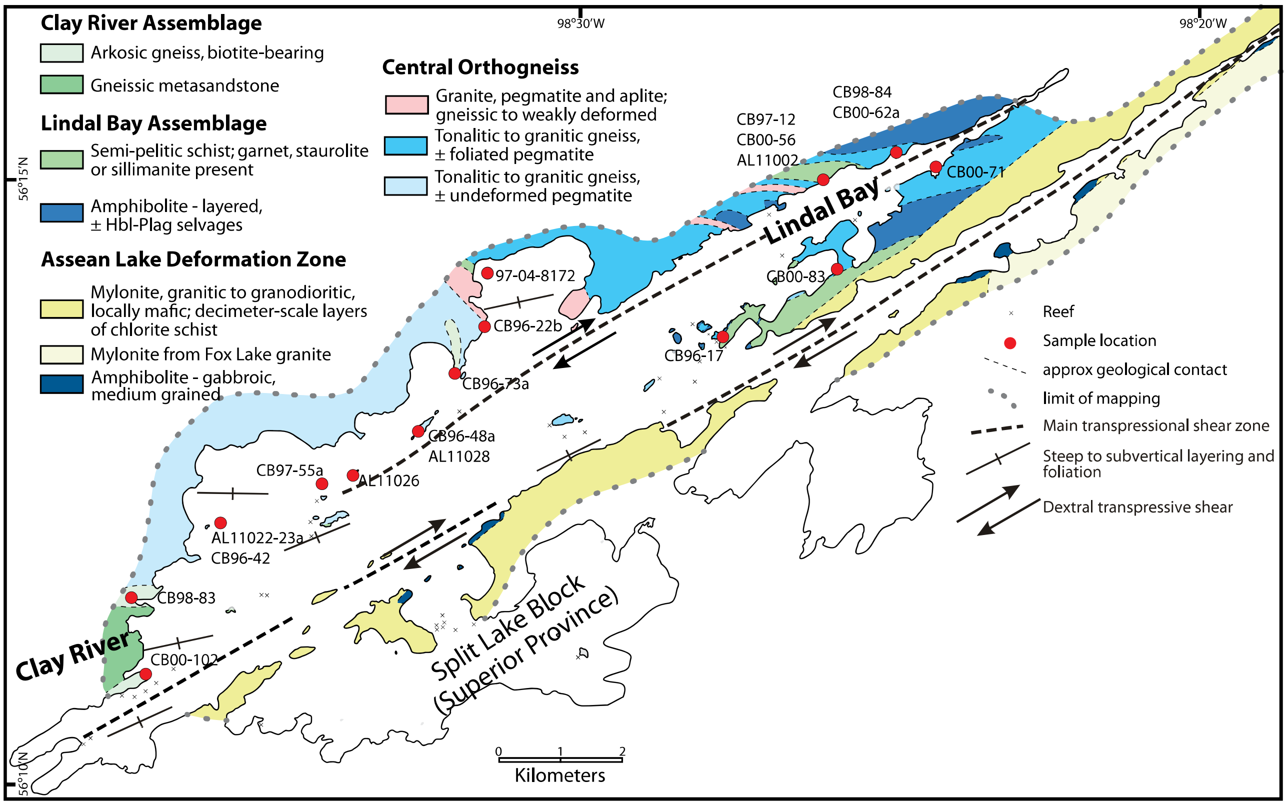

FIGURE 28.3 Schematic geological map of the Assean Lake area, showing locations of Nd isotope and U−Pb geochronology samples listed in Table 28.1.

TABLE 28.1 Sample Locations and Lithology

Sample	Lithology	Locality	UTM East NAD83 Z14	UTM North NAD83 Z14
CB96-17	Quartzofeldspathic gneiss	Central Assean Lake	656886	6234446
CB96-22b	Granodiorite gneiss	North Assean Lake	653136	6234546
CB96-42	Biotite granodiorite gneiss	West Assean Lake	648746	6231346
CB96-48a	Garnet biotite (ortho)gneiss	Northwest Assean Lake	652026	6232816
CB96-73a	Tonalite gneiss	Assean Lake	652826	6233726
CB97-12	Metagraywacke	Northeast Assean Lake	659016	6236476
CB97-55a	Biotite granodiorite gneiss	Northwest Assean Lake	649146	6232596
CB98-14	Layered tonalite gneiss	Blank Lake	603765	6226126
CB98-21	Leucogranite gneiss	Four Mile Lake	682316	6253476
CB98-24	Quartzofeldspathic granite gneiss	Four Mile Lake	680246	6253626
CB98-83	Pelitic graywacke migmatite	West Assean Lake	647286	6230076
CB98-84	Granite augen gneiss	Northeast Assean Lake	659986	6236416
CB00-56	Metagraywacke	Northeast Assean Lake	659016	6236476
CB00-62a	Granite augen gneiss	Northeast Assean Lake	659986	6236416
CB00-71	Granodiorite gneiss	Northeast Assean Lake	659386	6236456
CB00-83	Pelitic metagraywacke	East Assean Lake	658966	6235826
CB00-102	Quartzarenite gneiss	West Assean Lake	647516	6228926
12-01-217	Granodiorite gneiss	Pearson Lake	604071	6233709
97-04-8172	Metagraywacke	North Assean Lake	653204	6235247
AL11002	Metagraywacke	Northeast Assean Lake	659016	6236476
AL11023a	Tonalite gneiss	West Assean Lake	648746	6231346
AL11022	Biotite granodiorite gneiss	West Assean Lake	648746	6231346
AL11026	Tonalite gneiss	West Assean Lake	650386	6232081
AL11028	Tonalite gneiss	Northwest Assean Lake	652026	6232816

While regional studies at the northwestern Superior Craton margin helped to place the Assean Lake area into a regional context (Corkery, 1985; Corkery and Lenton, 1990), geological remapping of the Assean Lake area (Böhm, 1997a,b) and associated radiogenic isotope studies (Böhm et al., 2000a) led to the discovery of a pre-3.0 Ga origin for the ALC and revealed that the supracrustal rocks of the ALC are unrelated to the Ospwagan Group supracrustal rocks, despite their similar composition and metamorphic grade (Böhm et al., 2003).

Subsequent studies (Böhm et al., 2003; Hartlaub et al., 2005, 2006) provided more than a dozen, exclusively Mesoarchean and older U–Pb ages for the ALC, and a significant database of Nd isotope data. These data, combined with numerous complementary studies in the northwest Superior Craton (e.g., Bowerman et al., 2004; Hartlaub et al., 2004; Kuiper et al., 2011a, 2004a,b; Zwanzig and Böhm, 2004), provide the basis for the tectonic analysis described herein. Rock types and locations of all analyzed samples of the ALC and adjacent crustal domains are summarized in Table 28.1.

3.1 Structural Domains of the Assean Lake Area

The exposed ALC is an assembly of 090°–110 degrees trending crustal segments with moderately to well-developed subvertical tectonic fabrics in all lithological units that have been overprinted by 060 degrees trending deformation zones (Figs. 28.2 and 28.3). Rocks of the ALC can only locally be traced into lower strain equivalents, making protolith determination in the high-strain zones difficult. The most prominent structure of the Assean Lake area is the steeply southeast-dipping Assean Lake deformation zone, which marks the southern boundary of the ALC (Figs. 28.2 and 28.3). It contains mylonite, protomylonite, and some ultramylonite of various compositions that can be traced for more than 10 km to the northeast into Little Assean Lake (Böhm, 1997a) and along which a main dextral southeast-side up transpressive component has been recognized based on asymmetric folds and sheath folds, shear sense indicators, and lineations (Kuiper et al., 2004a). The latest movement may have been dextral, without a dip-slip component, as indicated by local, more brittle Riedel faults (Kuiper et al., 2011a).

To the northeast, dextral, southeast-side up structures along a cataclastic zone in the Lindal Bay area may be related to movement along the Assean Lake deformation zone (Kuiper et al., 2004a, 2011a). The ALC to the northwest of the Assean Lake deformation zone is deformed by moderately east-plunging, open to isoclinal folds (Kuiper et al., 2004a). Folds in the Split Lake Block may be genetically related to the ones in the ALC (Kuiper et al., 2004b, 2011b). If true, the ALC was juxtaposed with the Split Lake Block of the Superior Craton prior to this folding event.

3.2 Lithotectonic Assemblages of the Assean Lake Complex

Supracrustal rocks in the ALC are subdivided into the Clay River assemblage of migmatitic metasedimentary rocks in the southwest and a northeast volcano-sedimentary package termed the Lindal Bay assemblage (Fig. 28.3). The Clay River and Lindal Bay assemblages are separated and intruded by abundant orthogneiss ranging in composition from tonalite to granite (central orthogneiss domain).

3.2.1 Clay River Assemblage

At the western end of Assean Lake, a graywacke protolith is well established for upper amphibolite-grade garnet $\pm$ sillimanite $\pm$ cordierite gneiss, whereas strongly recrystallized, migmatized, and injected quartz-rich rocks were previously interpreted as orthogneiss. Minor garnetiferous pegmatite, amphibolite, white-weathering feldspathic biotite gneiss, and silicate facies iron formation are locally present. Metasandstone is gneissic and highly variable in quartz content. Compositional layering in these rocks, and interlayering with amphibolite, is interpreted as primary sedimentary and volcanic layering that has been enhanced by the development of in situ and injection mobilizate.

3.2.2 Central Felsic Intrusive Rocks (Orthogneiss Domain)

The area between the Clay River and Lindal Bay assemblages is dominated by a sequence of tonalite to granodiorite and derived gneisses (Fig. 28.3). These felsic intrusive rocks are variably layered because of injection by later pegmatites along the metamorphic fabric. The felsic intrusive rocks are predominantly structurally conformable with most supracrustal units, but in rare cases, intrusive contacts crosscut the principal layering in metasedimentary and mafic volcanic rocks. Lenses of paragneiss and amphibolite in orthogneiss are common and provide further evidence that the central orthogneisses intruded the Clay River and Lindal Bay supracrustal rocks.

3.2.3 Lindal Bay Assemblage

The Lindal Bay area of northeast Assean Lake (Fig. 28.3) is dominated by mafic to intermediate metavolcanic and semipelitic metasedimentary rocks. As in the Clay River assemblage, lithological units can be defined but stratigraphic relationships are difficult to determine because of the complex structural overprinting and lack of continuous outcrop. On the south shore of Lindal Bay, metasedimentary rocks predominate, but interlayered iron formation and amphibolite are also present. On the north shore of the bay, 090°−110 degrees trending amphibolite-grade mafic to intermediate volcanic rock and subordinate graywacke are exposed. The mafic volcanic rocks vary from fine- to medium-grained and range from massive to layered at a centimeter scale. In several locations the layering can be interpreted as flattened remnants of volcanic pillows. The mafic volcanic rocks are predominantly basaltic, with subordinate andesitic to dacitic and ultramafic compositions (Böhm et al., 2003). The ultramafic rocks occur as rare, isolated outcrops; their age relationship to the paragneiss sequence is uncertain. North to northeast-trending mafic dikes may be coeval with, and appear to be feeders to the mafic volcanic rocks. The intermediate and mafic volcanic rocks are geochemically similar to modern ocean floor basalts, but they have slightly enriched rare-earth element and Th contents and are depleted in Nb (Böhm et al., 2003). Together, this may indicate an enriched mantle component or a volcanic arc setting.

Metasedimentary rocks of the Lindal Bay assemblage are generally highly strained, thinly bedded semipelitic gneisses interlayered with quartzarenite, silicate facies iron formation, and mafic lithic and psammitic graywacke. Staurolite in semipelitic gneiss indicates middle amphibolite facies peak metamorphic conditions. Both sequences, however, seem to be intruded by tonalite–granodiorite orthogneiss, granite, and pegmatite associated with the central orthogneiss domain. No basement to the supracrustal rocks has been located at Assean Lake.

3.3 Tracer Isotopic Constraints on the Antiquity of the Assean Lake Complex

3.3.1 Whole-Rock Sm–Nd Isotopic Results

Rocks of the Assean Lake area were initially interpreted as the Paleoproterozoic Kisseynew Domain based on paragneiss composition, metamorphic grade, and location north of the Split Lake Block, Superior Craton (e.g., Corkery and Lenton, 1990). To test this assumption, a Sm–Nd isotope study was commenced on felsic igneous and metasedimentary gneiss samples at Assean Lake (Böhm et al., 2000a). Table 28.2 provides a compilation of previously published (Böhm et al., 2000a, 2003) and new Sm–Nd isotopic data for the ALC, with Nd-depleted mantle model ages (T_{DM}) ranging from ~3.5 to over 4.1 Ga. Results from orthogneiss samples primarily range between 3.5 and 3.7 Ga, but a few samples have Nd model ages ≥4.0 Ga. All ALC felsic gneisses yield model ages significantly older than their Mesoarchean U–Pb crystallization ages (Table 28.2), indicating involvement of ancient crust in the formation of these gneisses. Similarly, metasedimentary rocks yielded Nd model ages between 3.5 Ga (metaarenite) and 3.9 Ga (metagraywacke).

TABLE 28.2 Summary of Nd Isotopic and U–Pb Geochronological Data of Rocks of the Assean Lake Complex

Sample	Analytical Methods	U–Pb Age (Ma)	Error 2σ Abs.	Mineral[a]	Nd Model Age (Ga)[b]	Isotopic Ratios		Error 2σ Abs.	Age Interpretation
						$^{147}Sm/^{144}Nd$	$^{143}Nd/^{144}Nd$		
CB96-17	ID-TIMS			wr	3.49	0.1276	0.511162	0.000005	Model[1]
CB96-22b	ID-TIMS			wr	3.72	0.1242	0.510951	0.000010	Model[2]
CB96-42	ID-TIMS	3191	5	zc					Igneous?[1]
	ID-TIMS			wr	4.15	0.1283	0.510811	0.000009	Model[1]
CB96-48a	LA-MC-ICPMS	3169	10	zc					Igneous[3]
	ID-TIMS			wr	3.71	0.1203	0.510861	0.000008	Model[1]
CB96-73a	SHRIMP	3180	6	zc					Igneous[1]
	SHRIMP	2680	5	zc					Metamorphic[1]
	ID-TIMS			wr	3.61	0.1076	0.510615	0.000010	Model[2]
CB97-12	SHRIMP	3278	19	zc					Min. detrital[1]
	ID-TIMS			wr	3.84	0.1151	0.510615	0.000010	Model[2]
	ID-TIMS	2636	10	mz					Metamorphic[1]
CB97-55a	ID-TIMS			wr	3.54	0.0898	0.510251	0.000007	Model[2]
CB98-14	ID-TIMS			wr	3.57	0.1058	0.510598	0.000011	Model[2]
CB98-21	LA-MC-ICPMS	3206	4	zc					Igneous[3]
	ID-TIMS			wr	3.5	0.0968	0.510443	0.000007	Model[4]
CB98-24	LA-MC-ICPMS	~3100		zc					Igneous[1]
	ID-TIMS			wr	3.7	0.1223	0.510914	0.000006	Model[2]

Continued

TABLE 28.2 **Summary of Nd Isotopic and U–Pb Geochronological Data of Rocks of the Assean Lake Complex—cont'd**

Sample	Analytical Methods	U–Pb Age (Ma)	Error 2σ Abs.	Mineral[a]	Nd Model Age (Ga)[b]	Isotopic Ratios $^{147}Sm/^{144}Nd$	Isotopic Ratios $^{143}Nd/^{144}Nd$	Error 2σ Abs.	Age Interpretation
CB98-83	SHRIMP	2607	17	zc					Metamorphic[1]
	ID-TIMS	2444	2	mz					Metamorphic[1]
	ID-TIMS	3202	5	zc					Min. detrital[1]
	ID-TIMS			wr	3.74	0.1219	0.510881	0.000006	Model[2]
CB98-84	ID-TIMS			wr	4.15	0.1467	0.511315	0.000007	Model[2]
	ID-TIMS	~2620		zc + mz					Metamorphic[1]
CB00-56	LA-MC-ICPMS	3165	27	zc					Metamorphic?[5]
CB00-62a	ID-TIMS			wr	3.56	0.1003	0.510478	0.000007	Model[1]
CB00-71	ID-TIMS			wr	3.5	0.1206	0.510993	0.000010	Model[1]
CB00-83	ID-TIMS			wr	3.73	0.1194	0.510824	0.000009	Model[1]
CB00-102	ID-TIMS			wr	3.47	0.1175	0.510939	0.000009	Model[1]
12-01-217	ID-TIMS	3185	7	zc					Igneous?[6]
97-04-8172	ID-TIMS	~3180	19	zc					Min. detrital[3]
AL11002	Cameca IMP[d]	3160							Min. detrital[d]
AL11023a	Cameca IMP[d]	3182	12	zc					Igneous[d]
	ID-TIMS[c]			wr	3.56	0.1190	0.510919	0.000001	Model[d]
AL11022	ID-TIMS[c]			wr	3.64	0.1260	0.511039	0.000001	Model[d]
AL11026	ID-TIMS[c]			wr	3.69	0.1520	0.511643	0.000001	Model[d]
AL11028	ID-TIMS[c]			wr	3.49	0.1091	0.510737	0.000002	Model[d]
AL11028 (duplicate)				wr	3.48	0.1091	0.510740	0.000001	Model[d]

See Cates and Mojzsis (2007) for analytical procedures. See the following references for original publication data and procedures: [1]Böhm et al. (2003); [2]Böhm et al. (2000a); [3]Hartlaub et al. (2005); [4]Böhm et al. (2000a,b); [5]Hartlaub et al. (2006); [6]Zwanzig and Böhm (2002).
[a]*mz, monazite; wr, whole rock; zc, zircon.*
[b]*Depleted mantle Nd model ages calculated assuming present-day εNd value of +9.*
[c]*See Table 28.3 for details on Sm–Nd analytical procedures for these samples.*
[d]*New analyses. Zircon U–Pb analyses preformed at the UCLA National Ion Microprobe facility on the CAMECA ims1270.*

Together, these exclusively ≥3.5 Ga Nd model ages provide strong isotopic evidence for a Paleoarchean and possibly older source for the crustal material at Assean Lake and imply that the suture between the Trans-Hudson Orogen and Archean basement (ALC, Superior Craton) is northwest of the ALC (Böhm et al., 2000a). The Nd model ages from the ALC are generally older than those from any of the adjacent domains. In the Pikwitonei Granulite Domain and the Split Lake Block, Nd model ages are predominantly 2.9–3.3 Ga. The Thompson Nickel Belt has a broader range of model ages ranging from ~2.5 to 3.5 Ga, which most likely represent a mix of Archean and Proterozoic crustal components (Böhm et al., 2000b, 2007; Zwanzig and Böhm, 2002). North of the ALC, a mix of model ages from 2.1 to 3.4 Ga likely indicates a transition zone of variably reworked Archean crust and contaminated juvenile Paleoproterozoic sedimentary and intrusive rocks (Böhm et al., 2000a,b, 2007).

Nd model ages as old as 3.6 Ga do occur in the northwest Superior Craton, but they are rare (Böhm et al., 2000a). Model ages greater than 3.6 Ga elsewhere in the Superior Craton have thus far only been found in the Inukjuak domain of northwestern Québec, where multiple examples of >3.5 Ga igneous rocks, orthogneisses and metasediments have been found (Caro et al., 2016; Cates et al., 2013; O'Neil et al., 2013; Roth et al., 2013).

3.3.2 Combined Whole-Rock Sm–Nd and Lu–Hf Isotopic Results

New high-precision whole-rock Sm–Nd and Lu–Hf isotopic analyses were undertaken on four orthogneiss samples from the ALC (Table 28.3). Lu–Hf isotope data are consistent with the Sm–Nd data, providing evidence against disturbances of the isotope systematics. The Hf T_{DM} are 3.4–3.5 Ga and slightly younger than the 3.5–3.6 Ga Nd model ages for the same samples. Similarly, initial εHf are slightly lower than εNd calculated at 3.2 Ga (based on zircon U–Pb of ALC orthogneisses; Table 28.2), with near chondritic, but still mostly negative εHf, and slightly more negative εNd (Table 28.3). Furthermore, we obtained additional information from new ^{142}Nd analyses on the same samples (Table 28.3). ^{142}Nd is the daughter of the now extinct ^{146}Sm, and the presence of an anomaly (positive or negative) would indicate the preservation and incorporation of an isolated crustal or mantle source older than at least 4.1 Ga (Caro, 2011). As some of the ALC model ages point to Eoarchean–Hadean ages, and terranes elsewhere containing ancient gneisses with both negative and positive ^{142}Nd anomalies are known (Boyet et al., 2003; Caro et al., 2006; O'Neil et al., 2013; Caro et al., 2016), it was deemed worthy to test whether some of the most ancient model ages may be associated with ^{142}Nd anomalies. The ^{142}Nd signature for the ALC is, however, within error of the terrestrial value of ± 4 μ^{142}Nd (Table 28.3). As such, it is probable that the Eoarchean model ages are not the result of assimilation of very ancient material. However, the absence of an anomaly may be the result of only modest assimilation, which would dilute the ^{142}Nd signal.

3.3.3 Zircon Lu–Hf Isotopic Results

To more fully explore the nature of crustal material in the area, Hartlaub et al. (2006) obtained in situ laser ablation analyses for Hf isotope compositions from Paleoarchean detrital zircons from the ALC. The majority of these zircons yielded negative ε_{Hf} values between -2 and -10 when compared with the CHUR values of Blichert-Toft and Albarède (1997). These ε_{Hf} values indicate that Assean Lake detrital zircons are derived from evolved, reworked crust and fall within the array of ε_{Hf} values defined by both older and younger zircons from Jack Hills, Australia, the Acasta gneisses, Canada, and the Beartooth Mountains, Montana (Amelin et al., 1999, 2000; Harrison et al., 2005, 2008; Iizuka et al., 2015; Bell et al., 2014; Hartlaub et al., 2006; Mueller and Wooden, 2012; Guitreau et al., 2012, 2014). The zircon Hf isotope results from Assean Lake further support the interpretation that there was significant Hadean crust formation (see also Cavosie et al., this volume, and Kamber, this volume).

3.4 U–Pb Age Constraints of the Assean Lake Complex

U-Pb age data for orthogneisses from the ALC (Böhm et al., 2000a, 2003) provide evidence for a major magmatic event at c.3.1–3.2 Ga, with minor c.3.5 Ga crustal inheritance. Several analyzed felsic intrusive samples yielded well-constrained zircon ages around 3.17–3.18 Ga (Table 28.2; Böhm et al., 2003), including a U–Pb concordia age of 3182 ± 12 Ma based on the seven most concordant zircon ages (MSWD of concordance 2.4) for a new orthogneiss sample also analyzed for combined Nd and Hf isotopes (sample AL11023a; Tables 28.2 and 28.3; Fig. 28.4). Mesoarchean ages for felsic intrusive rocks are less common in the adjacent high-grade terranes of the northwest Superior Craton. The Split Lake Block, for example, is dominated by Neoarchean igneous rocks (e.g., Heaman et al., 2011). One exception is the Gull Rapids area at the northeast margin of the Split Lake Block, c. 100 km to the east of the ALC in a tectonically similar area along the margin of the Superior Craton (Fig. 28.2). At Gull Rapids, a c. 3 km thick exposed supracrustal package structurally lies on top of c.3.16 Ga orthogneiss (Bowerman et al., 2004). Paragneiss in this package is dominated by Neoarchean zircon detritus, mostly younger than 2.9 Ga but with rare zircons as old as 3.35 Ga. The supracrustal rocks at Gull Rapids were likely deposited at c.2.71 Ga based on the youngest detrital zircons and c.2.68 Ga crosscutting leucogranite dikes (Bowerman et al., 2004). Metasedimentary rocks at Assean Lake, in comparison, have zircons interpreted as detrital exclusively older than 3.18 Ga (Table 28.2; Fig. 28.4; Böhm et al., 2003).

In the central Split Lake Block c. 30 km west of Gull Rapids, garnet–sillimanite–biotite paragneiss contains detrital zircons that range in age from c.2.7 to 3.8 Ga (Hartlaub et al., 2005). This unit underwent Neoarchean high-grade metamorphism that, combined with the detrital ages, indicates sedimentation around 2.70 Ga. The abundance of Meso- and Paleoarchean detrital zircon in this sample may suggest that the source terrane likely included the ALC and/or its

TABLE 28.3 Summary of New Paired Whole-Rock Lu–Hf and Sm–Nd Isotopic Results for Select Orthogneiss Samples of the Assean Lake Complex

Sample	[Sm][a]	[Nd][a]	^{147}Sm/^{144}Nd	2σ	^{143}Nd/^{144}Nd	2σ	$\varepsilon_{Nd(t)}$[b,c]	2σ[e]	T_{DM} (Ga)[f]	^{142}Nd/^{144}Nd	2σ	μ^{142}Nd	2σ	[Lu][a]	[Hf][a]	^{176}Lu/^{177}Hf[b]	2σ	^{176}Hf/^{177}Hf	2σ	$\varepsilon_{Hf(t)}$[b,d]	2σ[f]	T_{DM} (Ga)[f]
AL11022	8.1	38.9	0.1260	6E-04	0.511039	1E-06	−2.2	0.3	3.64	1.141840	2.1E-06	2.8	1.8	0.57	7.8	0.01039	2E-05	0.281307	5E-06	−1.6	0.3	3.53
AL11023a	3.3	16.8	0.1190	6E-04	0.510919	1E-06	−1.6	0.3	3.56	1.141832	2.8E-06	−4.2	2.4	0.27	4.1	0.00948	2E-05	0.281276	4E-06	−0.7	0.3	3.48
AL11026	9.2	36.5	0.1520	8E-04	0.511643	1E-06	−1.1	0.3	3.69	1.141836	2.4E-06	−1.0	2.1	0.53	7.3	0.01039	2E-05	0.281375	4E-06	0.8	0.3	3.42
AL11028	3.7	20.4	0.1091	5E-04	0.510737	2E-06	−1.1	0.2	3.49	1.141834	3.5E-06	−2.4	3.0	0.28	4.2	0.00947	2E-05	0.281307	4E-06	0.4	0.3	3.43
AL11028 duplicate			0.1091	5E-04	0.510740	9E-07	−1.0	0.2	3.48	1.141838	2.1E-06	0.9	1.8	–	–	–	–	–	–	–	–	–

Sm–Nd isotope chemistry and measurements were done at ETH Zurich according to procedures described in Caro et al. (2006) and Roth et al. (2013). Lu–Hf isotope chemistry and measurements were done at Laboratoire de Géologie de Lyon according to procedures described in Blichert-Toft (2001).

[a] *Concentrations are given in ppm.*

[b] *$t = 3.2$ Ga.*

[c] *CHUR parameters used to calculate εNd and εHf are from Bouvier et al. (2008) and Iizuka et al. (2015), respectively.*

[d] *CHUR parameters used to calculate ε_{Hf} are from Iizuka et al. (2015). 176Lu decay constant used in age corrections is given by Scherer et al. (2001).*

[e] *Errors have been propagated using the algorithms provided in Ickert (2013).*

[f] *Depleted mantle model ages were calculated assuming present-day εNd and εHf values of +9 and + 17, respectively, and a DM age of 4560 Ma.*

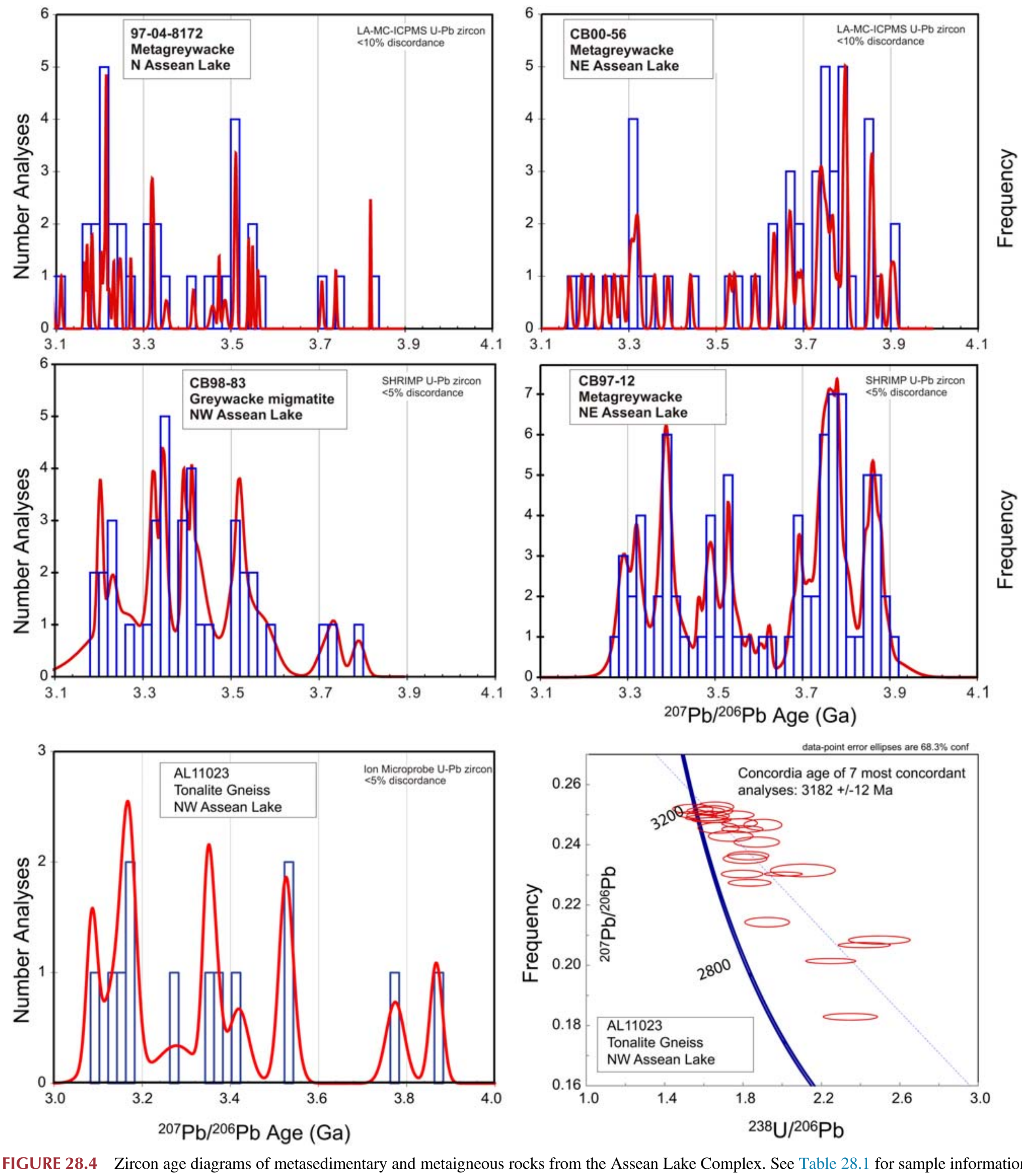

FIGURE 28.4 Zircon age diagrams of metasedimentary and metaigneous rocks from the Assean Lake Complex. See Table 28.1 for sample information and Table 28.2 for analytical procedures. Zircon ages of metasedimentary samples are presented as histograms of least discordant analyses to identify detrital populations. Zircon ages of metaigneous sample AL11023 are both presented in a histogram and in a Tera–Wasserburg diagram, the latter illustrating linear regression of all analyses resulting in a discordia upper intercept age of 3231 ± 47 Ma and a concordia age of 3182 ± 12 Ma based on the seven most concordant analyses interpreted as crystallization age.

cryptic basement. By comparison, more than half of the zircon detritus in the Assean Lake paragneiss samples yielded Paleoarchean ages of between 3.5 and 3.9 Ga (Fig. 28.4; Böhm et al., 2003; Hartlaub et al., 2006), confirming the ancient provenance of these paragneisses as suggested by the c.3.5–3.9 Ga Nd model ages. No exposures of Paleoarchean basement rocks, however, seem to be preserved or have been located at Assean Lake.

Internal and external morphologies of these zircons are described in Böhm et al. (2003), where it is pointed out that cores of both detrital and inherited Paleoarchean crystals are typically structureless or show weak, patchy zoning, whereas Mesoarchean igneous zircon growth domains and Neoarchean metamorphic zircon rims typically display oscillatory zoning. Although the timing of metamorphism at Assean Lake is not yet fully understood, 3.14, 2.68, and 2.61 Ga metamorphic zircon overgrowth ages have been documented (Böhm et al., 2003; Hartlaub et al., 2005). In addition, an even older metamorphic event around 3.5 Ga is recorded in metamorphic or altered domains of some Paleoarchean zircons from a metagraywacke at northeast Assean Lake (sample CB97-12; Fig. 9d in Böhm et al., 2003). 3.5 Ga is also the age of xenocrystic zircon in 3.18 Ga tonalite–granodiorite gneiss from north Assean Lake (sample CB96-73a in Böhm et al., 2003).

A c.2.68 Ga amphibolite-grade metamorphic overprint of the Assean Lake orthogneisses occurred contemporaneously with peak metamorphic conditions, related partial melting, and voluminous injection of leucocratic granitic magma in the nearby Split Lake Block (Heaman et al., 1986, 2011; Böhm et al., 1999; Hartlaub et al., 2004; Bowerman et al., 2004). This is the earliest temporal link of metamorphism between the two terranes across the Assean Lake deformation zone.

In addition to the zircon age data, U–Pb ages of monazite extend the record of metamorphic mineral growth in the ALC. Several Neoarchean and Paleoproterozoic ages of monazite growth have been identified (Fig. 10 in Böhm et al., 2003), including concordant ages at c.2630, 2444, and 1810 Ma. While the 2630 and 1810 Ma monazite ages can directly be correlated with regional peak metamorphism during the late-stage Kenoran (Böhm et al., 1999) and Hudsonian orogenies, respectively, the 2444 Ma monazite age from a metagraywacke migmatite at northwest Assean Lake (sample CB98-83 in Böhm et al., 2003) may be correlated with c.2.45 Ga peak metamorphic and igneous activities in the Sask Craton (Ashton et al., 1999).

4. EXTENT OF THE MESOARCHEAN ASSEAN LAKE COMPLEX

Mapping, isotopic, and age data combined with high-resolution aeromagnetic data (Coyle et al., 2004) indicate that the Mesoarchean ALC is a crustal slice up to 10 km wide, with a strike length of at least 50 km (Fig. 28.2). The ALC is centered on Assean Lake and extends along the northern side of the Assean Lake deformation zone, along which the ALC and the Split Lake Block are juxtaposed.

4.1 Eastern Extent of the Assean Lake Complex

Apetowachakamasik Lake (Four Mile Lake; Fig. 28.5), which is located north of the Split Lake Block and approximately 30 km east-northeast of Assean Lake (Fig. 28.2), contains upper amphibolite-grade igneous rocks of Mesoarchean age (Hartlaub et al., 2005). The first hint for potentially Paleoarchean rocks exposed at Four Mile Lake was a c.3.7 Ga Nd model age for a quartzofeldspathic gneiss interpreted as granitic (sample 98-24; Böhm et al., 2000a). Follow-up mapping and isotopic work by Hartlaub et al. (2005) showed that the boundary between Paleoproterozoic sedimentary rocks of the Trans-Hudson Orogen and Mesoarchean rocks most likely associated with the ALC runs approximately east-west through the center of Four Mile Lake (Fig. 28.5). Moreover, aeromagnetic data of the Assean Lake area (Coyle et al., 2004) display continuous east-northeast, weak, narrow linear magnetic anomalies from Assean Lake into the Four Mile Lake area.

The north shore of Four Mile Lake is predominantly greenschist facies conglomerate and sandstone, whereas a mixed suite of upper amphibolite facies Archean granite gneiss with injected leucogranite is exposed along the south shore (Fig. 28.5; Hartlaub et al., 2005). Orthogneiss is composed of granite to granodiorite paleosome and leucogranite neosome. Mafic, biotite-rich enclaves that may represent xenoliths of older rock or disrupted dikes are locally abundant. A sample of pink, medium- to coarse-grained granite gneiss is dominated by 3206 ± 4 Ma zircon prisms interpreted to record the crystallization age of the granite (sample CB98-21 in Table 28.2; Hartlaub et al., 2005). A single c.2.7 Ga metamorphic zircon and a single c.3.6 Ga xenocrystic zircon were also identified in this sample. A sample of migmatitic, quartzofeldspathic leucogranite, which may represent a large segregation of neosome from the gneiss, has a complex zircon population dominated by c.3.1 Ga zircons interpreted to record granite crystallization (sample CB98-24 in Table 28.2; Hartlaub et al., 2005). Older zircons with $^{207}Pb/^{206}Pb$ ages between 3.2 and 3.8 Ga are interpreted to be xenocrystic and may have been derived, at least in part, from the mafic enclaves that are present in the sampled outcrop.

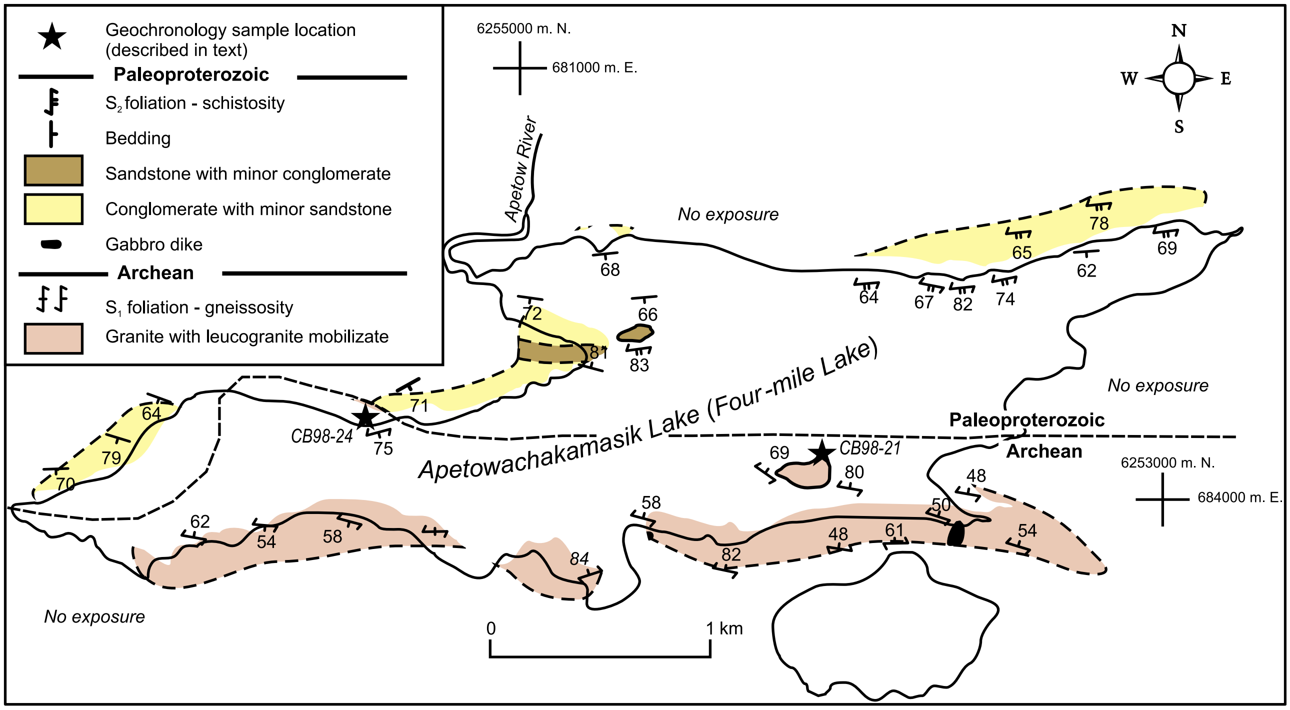

FIGURE 28.5 Simplified geology of Apetowachakamasik Lake (Four Mile Lake).

4.2 Northern and Western Extent of the Assean Lake Complex

Exposures along the south shore of Blank Lake, located approximately 50 km west of Assean Lake (Fig. 28.2), are dominated by migmatitic, layered tonalite–granodiorite gneiss including various amounts of amphibolite (metagabbro) lenses. A sample of hornblende-biotite granodiorite gneiss yielded a Nd model age of c.3.6 Ga (sample 98-14; Böhm et al., 2000a), interpreted to indicate a Meso- or Paleoarchean age for the granodiorite gneiss precursor and possibly an indication for ALC-type Mesoarchean orthogneiss at Blank Lake.

C. 10 km north of Blank Lake, Pearson Lake (Fig. 28.2) lies along strike of the intersection of the northeast-trending Superior Boundary Zone and the southwestern extension of the regional Owl River lineament, the latter presumably separating mixed Archean and Paleoproterozoic crust to the south from dominantly Paleoproterozoic crust to the north (Böhm et al., 2000a). Granodiorite gneiss, the dominant unit at Pearson Lake (Zwanzig et al., 2001), yielded a zircon U–Pb age of 3185 ± 7 Ma (sample 12-01-217 in Table 28.2). This age is interpreted as the time of granodiorite crystallization (Zwanzig and Böhm, 2002), coeval with felsic magmatism at Assean Lake. The Mesoarchean orthogneiss at Pearson Lake is interleaved with Paleoproterozoic- to Neoarchean-derived paragneiss in the north and is in fault contact with predominantly Paleoproterozoic-derived graywacke migmatite of the Kisseynew Domain to the south (Fig. 28.2; Zwanzig and Böhm, 2002).

About 1 km north of Assean Lake, a single exposure of highly strained, feldspar augen granodiorite–tonalite gneiss occurs at Pukitawaw Lake (not identified on Figs. 28.2 and 28.3). Nd isotopic analysis of a sample of this exposure yielded a T_{DM} of c.3.4 Ga, slightly younger than those obtained at Assean Lake (Böhm et al., 2000a, 2003, 2007). However, ID-TIMS U–Pb age dating of four abraded single-grain zircons resulted in slightly (<2%) discordant analyses with a mean $^{207}Pb/^{206}Pb$ age and concordia upper intercept age of c.2.70 Ga (Böhm, unpublished data, 2001). Due to the consistent $^{207}Pb/^{206}Pb$ ages, we interpret the 2.70 Ga age to represent the timing of felsic magmatism at Pukitawaw Lake. This age is similar to that of prevalent Neoarchean magmatism in the Split Lake Block and the Pikwitonei Granulite Domain. Consequently, Pukitawaw Lake may represent a sliver of Split Lake Block–related crust along the northern margin of the ALC (Fig. 28.2). This sliver could also represent an allochthonous block that was thrust over the ALC, or the ALC was thrust part ways onto the Split Lake Block. Regardless; the exposed ALC likely extends less than a kilometer to the north of Assean Lake.

4.3 The Assean Lake Complex−Split Lake Block Connection

4.3.1 Supracrustal Rocks

Unlike the ALC, supracrustal rocks are rare in the Split Lake Block, primarily occurring as mafic granulite with thin interlayered horizons of pelite (Bowerman et al., 2004; Hartlaub et al., 2005). Mafic granulite in the Split Lake Block is fine- to medium-grained and locally displays compositional layering. Orthopyroxene ± garnet melt segregations comprise up to 5% of this unit. The fine- to medium-grained nature and local compositional layering of the mafic granulite may indicate that its protolith was a mafic volcanic rock. Local garnet-rich horizons may represent iron-rich interflow sediments. Whole-rock geochemistry indicates a primitive MORB-like signature (Hartlaub et al., 2004). As in the ALC, pelite in the Split Lake Block consists of well-layered quartz, feldspar, biotite, garnet, and sillimanite with trace sulfides ± graphite. Although detrital zircons from pelite from both the Split Lake Block (Hartlaub et al., 2005) and the ALC (Böhm et al., 2003; Hartlaub et al., 2006; Table 28.2) contain ancient (>3.6 Ga) grains, the youngest detrital grains in pelite from the Split Lake Block are c.2.70 Ga, whereas the youngest detrital zircons in the ALC are c.3.18 Ga. Although volcanic rocks have not been directly dated in either the ALC or the Split Lake Block, the youngest detrital zircons place a maximum age of c.3.18 Ga on supracrustal rocks of the ALC and c.2.70 Ga for the Split Lake Block. The presence of diverse detrital zircon age populations in sediments indicates that sediments in both the ALC and the Split Lake Block were derived by erosion of continental-type crust.

4.3.2 Felsic Plutonism

Although sediments in the ALC and Split Lake Block were deposited at different times, both regions share c.3.16−3.20 Ga Mesoarchean plutonism (Böhm et al., 2003; Hartlaub et al., 2004; Bowerman et al., 2004). In the ALC, this predominant phase of plutonism is considered intrusive into the supracrustal package, whereas rare plutons in the Split Lake Block are considered basement to the supracrustal rocks. The >3.5 Ga model ages (Böhm et al., 2000a) of the 3.16−3.18 Ga orthogneisses in the ALC suggest that felsic magmatism in the ALC involved Paleoarchean crustal material, some of which may be represented by ancient detritus in the sedimentary rocks. The c.3.2 Ga period of magmatism built the ALC into a Mesoarchean protocontinent. Mesoarchean crust of the Split Lake Block may have formed contemporaneously to the ALC as a separate protocontinent and stitched to it later. Alternatively, the Mesoarchean basement of the northwest Superior Craton may be an extension of the ALC.

5. POTENTIAL SOURCE MATERIAL FOR THE ASSEAN LAKE COMPLEX

Ancient rocks occur elsewhere around the margins of the Superior Craton (see Chapters 16 and 27). At the southwest margin of the Superior Craton, the Minnesota River Valley terrane (Goldich and Hedge, 1974; Chapter 27) contains a suite of poorly exposed but complex gneisses. U−Pb SHRIMP results by Bickford et al. (2004), confirmed by high-precision ID-TIMS analyses of Schmitz et al. (2006), indicate that the early gneisses formed at c.3.5 Ga and were metamorphosed and injected by tonalite at c.3.3−3.4 Ga. However, a more ancient source of detrital zircons as in the ALC appears to be absent in the younger Minnesota River Valley sediments that have age distribution peaks at 3520, 3380, 3140, and 2600 Ma (Bickford et al., 2004). Thus it is unlikely that the Minnesota River Valley terrane was the source of ancient material for the ALC.

The Nuvvuagittuq supracrustal belt (NSB; Chapter 16) is located at the Superior Craton margin in northwestern Québec and like the ALC contains ancient detrital components and ancient model ages. The NSB, however, is characterized by >3.75 Ga volcanic and intrusive ultramafic to mafic rocks, with subordinate similarly-aged sedimentary rocks. These were intruded by c.3.75, 3.65, 3.50, and 2.7 Ga felsic rocks of typical TTG composition (Cates and Mojzsis, 2007; Cates et al., 2013; O'Neil et al., 2008, 2012, 2013, Chapter 16). The dramatically different depositional ages of the respective sedimentary units and the different ages of felsic intrusions preclude a direct link between the NSB and ALC but do not rule out that the NSB could potentially have been a source for the ALC. Notably, despite the ALC sediments themselves being significantly younger, the oldest ALC detrital zircons are older that those found in the NSB (3.85 vs. 3.78 Ga). Furthermore, if the NSB and ALC shared source materials, one would expect to see common detrital zircon populations at 3.65 and 3.50 Ga, which, however, are absent in the ALC (Fig. 28.4). Additionally, the NSB and ALC do not share an isotopic history. Compared with the ALC, the NSB has overall older model ages of ≥3.8 Ga and preserves evidence for the large-scale incorporation of Hadean crust based on pervasively negative ^{142}Nd anomalies, a signature that appears to be missing in the ALC. Thus the NSB unlikely represents a detrital source for the ALC.

The only known location with exposed c.4.0 Ga felsic crust is the Acasta gneiss of the Northwest Territories, Canada (Bowring and Williams, 1999, Mojzsis et al., 2014; Reimink et al., this volume). Detrital ALC and igneous Acasta gneiss zircons share similarly negative εHf values (down to −10), which may suggest the Acasta gneiss as a potential source for the ALC. However, a large proportion of ALC zircon detritus is c.3.7−3.86 Ga (Fig. 28.4), a period with minor representation in the Acasta gneiss zircon record (Reimink et al., 2016), but may be recapitulated in the Beartooth Mountain (Montana) zircons (Maier et al., 2012).

Thus, a local derivation for ancient detritus at Assean Lake is most consistent with the 3.5−4.1 Ga Nd and Hf model ages of both the sedimentary and orthogneiss components of the ALC. Although all recorded Nd model ages for the ALC are ≥3.5 Ga, the wide range of values indicates that the Nd model ages represent mixtures of variably ancient material that was tapped as both a source for detrital material and incorporated in 3.2 Ga plutonism that intruded into the sediments.

6. CONCLUDING REMARKS

The ALC represents an ancient crustal assemblage at the Superior Craton margin. The presence of 3.2−3.85 Ga detritus in metasedimentary rocks and ≥4.0 Ga Nd model ages of igneous rocks of the ALC suggests involvement of Eoarchean and possibly Hadean crustal components during c.3.2 Ga protocontinent formation of the ALC. Although not preserved or identified at surface, ≥4.0 Ga crust may have acted as a protocontinent nucleus that underwent significant growth in the Mesoarchean. Mesoarchean crust in the adjacent Split Lake Block of the northwest Superior Craton may have formed contemporaneously with the ALC.

The lack of shared Neoarchean and older isotopic and tectono-metamorphic characteristics of the ALC and adjacent crustal domains of the northwest Superior Craton, however, suggests that the amalgamation of the ALC to the margin of the Superior Craton occurred after c.3.2 Ga ALC formation and during or after c.2.70 Ga granulite facies metamorphism in the Split Lake Block and Pikwitonei Granulite domains, and cements the interpretation that the ALC remains a so far unique, exotic ancient crustal terrane on the margin of the Superior Craton.

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