Revising the igneous stratigraphy in the eastern Aileron Province: Implications for the geodynamic setting between ca 1.81–1.71 Ga

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Background

The Aileron Province preserves a succession of Palaeoproterozoic metasedimentary and meta-igneous rocks that formed at the southern margin of the North Australian Craton between ca 1.86–1.70 Ga (**Figure 1**, Scrimgeour 2013). Building on the earlier work of Warren (1989), Zhao (1994) and Zhao and McCulloch (1995), regional mapping studies by the Northern Territory Geological Survey (NTGS) since 2007 have significantly revised previous understanding of Palaeoproterozoic magmatism in the eastern Aileron Province. New mapping has improved knowledge of unit spatial extent, and new large geochemical and isotopic datasets, in conjunction with complementary age data for both felsic and mafic intrusive rocks, have been used to revise igneous stratigraphy and better understand source region and geodynamic setting in space and time. This has been accompanied by studies focused on identifying direct links between specific magmatic events and mineralisation, as well as magmatic rocks that might provide metal and sulfur sources in the eastern Aileron Province, thus improving knowledge of the resource potential of the province (eg Whelan *et al* 2012a, 2013, McGloin and Weisheit 2015, 2021, McGloin *et al* 2016, 2018, Simmons and McGloin 2020, Reno *et al* 2021, McGloin and Weisheit in review). The following is an overview of magmatism in the eastern Aileron Province between ca 1.81–1.71 Ga; it incorporates the datasets presented in Whelan *et al* (2011a,b, 2012b) for western ILLOGWA CREEK[3]. Whelan *et al* (2011a, 2012b) identified several periods of magmatism during this time and interpreted a changing geodynamic regime at a convergent margin where the oldest magmatism is bimodal and juvenile, while the youngest is dominantly felsic and derived from reworked and isotopically evolved crust. This study builds on that work and looks beyond ILLOGWA CREEK to the magmatic rocks exposed to the north in ALCOOTA and HUCKITTA, with a focus on igneous activity at ca 1.81–1.80 Ga, ca 1.79–1.77 Ga, ca 1.76–1.74 Ga and ca 1.73–1.71 Ga.

Ca 1.81–1.80 Ga magmatism

Summary of rock units and lithologies

Black Label Suite

Magmatism between ca 1.81–1.80 Ga in the eastern Aileron Province is represented by the Black Label Suite (Beyer *et al* in prep a). The current definition of this suite is based on outcrops in eastern ALCOOTA and DNEIPER (HUCKITTA), but with further work could be extended to include intrusive rocks of this age recognised in western ALCOOTA, BARROW CREEK and NAPPERBY (**Figure 1**, Scrimgeour 2013 and references therein). The Black Label Suite is composed of predominantly felsic rocks with subordinate mafic rocks. Intimate magma mingling textures between mafic and felsic compositions exposed in some outcrops in DNEIPER indicate that these intrusive rocks are comagmatic and coeval (**Figure 2a**). The mafic rocks are hornblende–plagioclase±clinopyroxene±orthopyroxene±biotite metadolerites; the felsic rocks include biotite granite and granodiorite, hornblende±biotite granite, leucogranite, and rare clinopyroxene–hornblende tonalite. The felsic intrusive rocks are generally rich in mafic minerals (10–20 vol% of the mineral mode) and are strongly foliated to locally gneissic; mafic microgranular enclaves are common in some units.

Geochemical characteristics and implications for geodynamic setting

The Black Label Suite is strongly bimodal, with rare intermediate compositions. The mafic component of the suite is dominated by rocks with calc-alkaline basalt/gabbro to basaltic andesite/gabbroic diorite compositions (**Figure 3a**). On a rare earth element (REE) plot, these rocks display moderate light REE (LREE)-enrichment and shallow negative Eu anomalies, indicative of plagioclase fractionation; Mg# are <65, supporting these as probable (fractionated) liquids (Glass 2005). The felsic rocks have silica contents largely between 64–72 wt% SiO_2, with a narrow range in Al_2O_3 abundances of 13–14 wt%. On an alumina saturation index plot, they classify as metaluminous to weakly peraluminous, suggesting an I-type composition (**Figure 4a**). This is supported by the presence of primary igneous hornblende in some constituent units of the suite. Potassium contents are generally between 3–5 wt% K_2O and indicate that these are high-K (calc-alkaline series) rocks.

Trace element chemistry for the mafic rocks indicates depletion in Nb and Ta relative to Th and La, pronounced negative P anomalies, and shallow negative Zr, Hf and Ti anomalies, all characteristics typical of continental arc basalts (**Figure 5a**). This is also illustrated in **Figure 6a**, which shows these rocks plotting in the field for calc-alkaline rocks from active continental margins. The felsic rocks are largely ferroan to less commonly magnesian and predominantly calc-alkalic in composition (**Figure 7a, b**). Unlike the mafic rocks, the felsic intrusive rocks do not resemble those typical of convergent margins, ie Cordilleran batholiths (see grey fields in **Figures 7a, b**), which are most commonly magnesian, and where ferroan rocks are always peraluminous (Frost *et al* 2001). The felsic rocks of the

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[3] Names of 1:250 000 and 1:100 000 mapsheets are shown in large and small capital letters respectively, eg ILLOGWA CREEK, DNEIPER

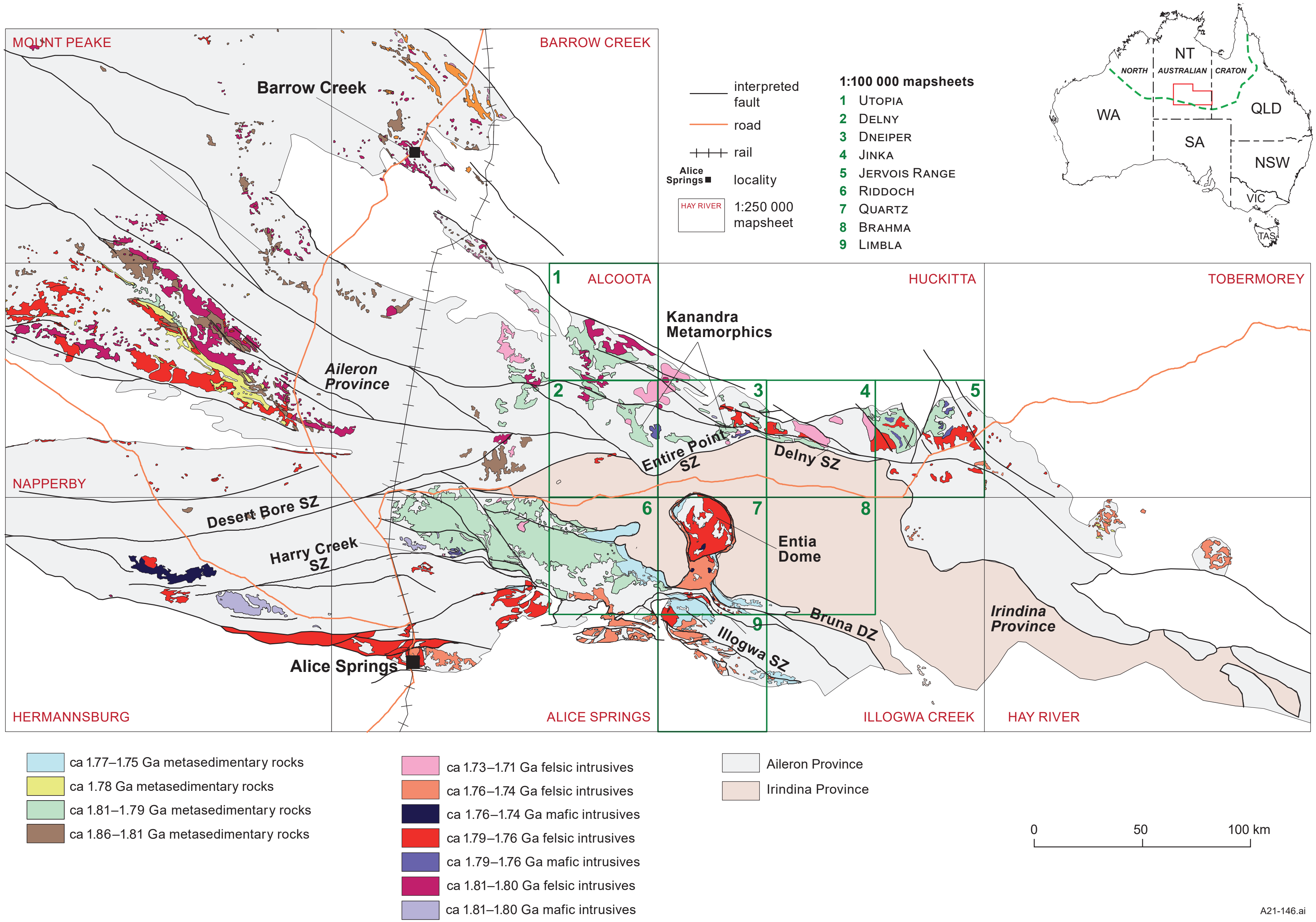

Figure 1. Generalised outcrop geology map of the central and eastern Aileron Province in selected 1:250 000 and 1:100 000 mapsheets. Modified after Figures 12.2 and 29.2 in Scrimgeour (2013) and Figure 12 in Weisheit *et al* (2019). SZ = shear zone, DZ = Detachment Zone.

Figure 2. Outcrop photos of selected rocks from this study. (**a**) Magma mingling textures between mafic and felsic intrusive rocks of the ca 1.81–1.80 Ga Black Label Suite. (**b**) Intrusive contact between felsic (left) and mafic (right) intrusive rocks of the ca 1.79–1.77 Ga Casper Suite (Baikal Supersuite). (**c**) Granitic gneiss of the ca 1.77 Ga Lionel Suite (Almbulbinya Supersuite). (**d**) Ca 1.78 Ga Carmencita Metadolerite with well-developed leucosome. (**e**) Porphyritic granite of the ca 1.75 Ga Bruna Suite. (**f**) Leucogranite of the ca 1.75 Ga Tarlton Bore Granite. (**g**) Garnet-biotite granitic gneiss of the ca 1.72 Ga Alkara Suite. (**h**) Porphyritic biotite granite of the ca 1.73–1.71 Ga Sainthill Suite. Pen is 15 cm long and hammer is 30 cm long.

Black Label Suite may be more akin to A-type granitoids, which are iron-enriched, although these are generally alkalic rather than calc-alkalic. Frost and Frost (2011) note that metaluminous, ferroan, calc-alkalic intrusions are uncommon, with the best example being granophyres associated with the Skaergaard intrusion in Greenland, thought to have formed through low-pressure differentiation of tholeiitic magmas in an extensional environment. Isotopic data in support of a juvenile source for the Black Label Suite comes from whole rock Sm–Nd and zircon Hf isotopes, both of which indicate a large component of depleted mantle in the source region (Beyer *et al* 2013, in prep c).

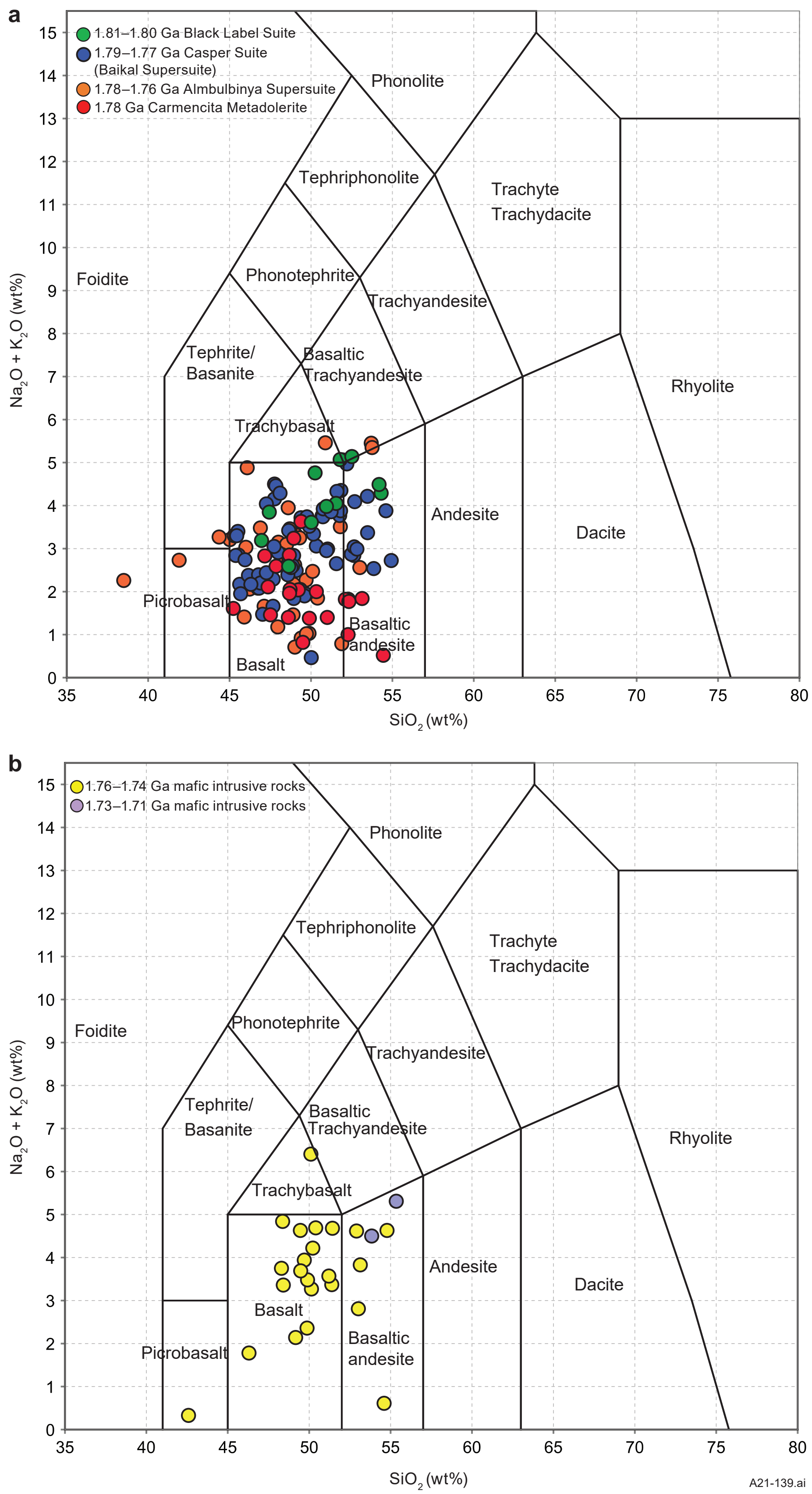

Figure 3. Total alkalis versus SiO_2 (TAS) diagram for mafic rocks. (**a**) Ca 1.81–1.80 Ga Black Label Suite, 1.79–1.77 Ga Baikal Supersuite (Casper Suite), ca 1.78–1.76 Ga Almbulbinya Supersuite (Lionel and Huckitta suites) and ca 1.78 Ga Carmencita Metadolerite.
(**b**) Ca 1.76–1.74 Ga intrusive rock units (Bruna and Atneequa suites, Leaky Norite, Harding Metagabbro) and ca 1.73 Ga Oodnarta Diorite. Figure after Le Maitre *et al* (1989).

Ca 1.79–1.76 Ga magmatism

Summary of rock units and lithologies

Baikal Supersuite

The Baikal Supersuite is the dominant igneous unit recognised in Jervois Range and Jinka (HUCKITTA); outcrop is largely restricted to north of the Delny Shear Zone (**Figure 1**, Weisheit *et al* 2019, Reno *et al* in prep). The Supersuite consists of the Molyhil, Casper and Fosters suites, which are composed of variably metamorphosed intrusive rocks with igneous protoliths ranging from granite through to gabbro. The Molyhil Suite is a package of ca 1.79 Ga felsic orthogneiss and migmatitic orthogneiss with granite protoliths. The suite contains lithologies that are biotite-bearing or hornblende±biotite-bearing with

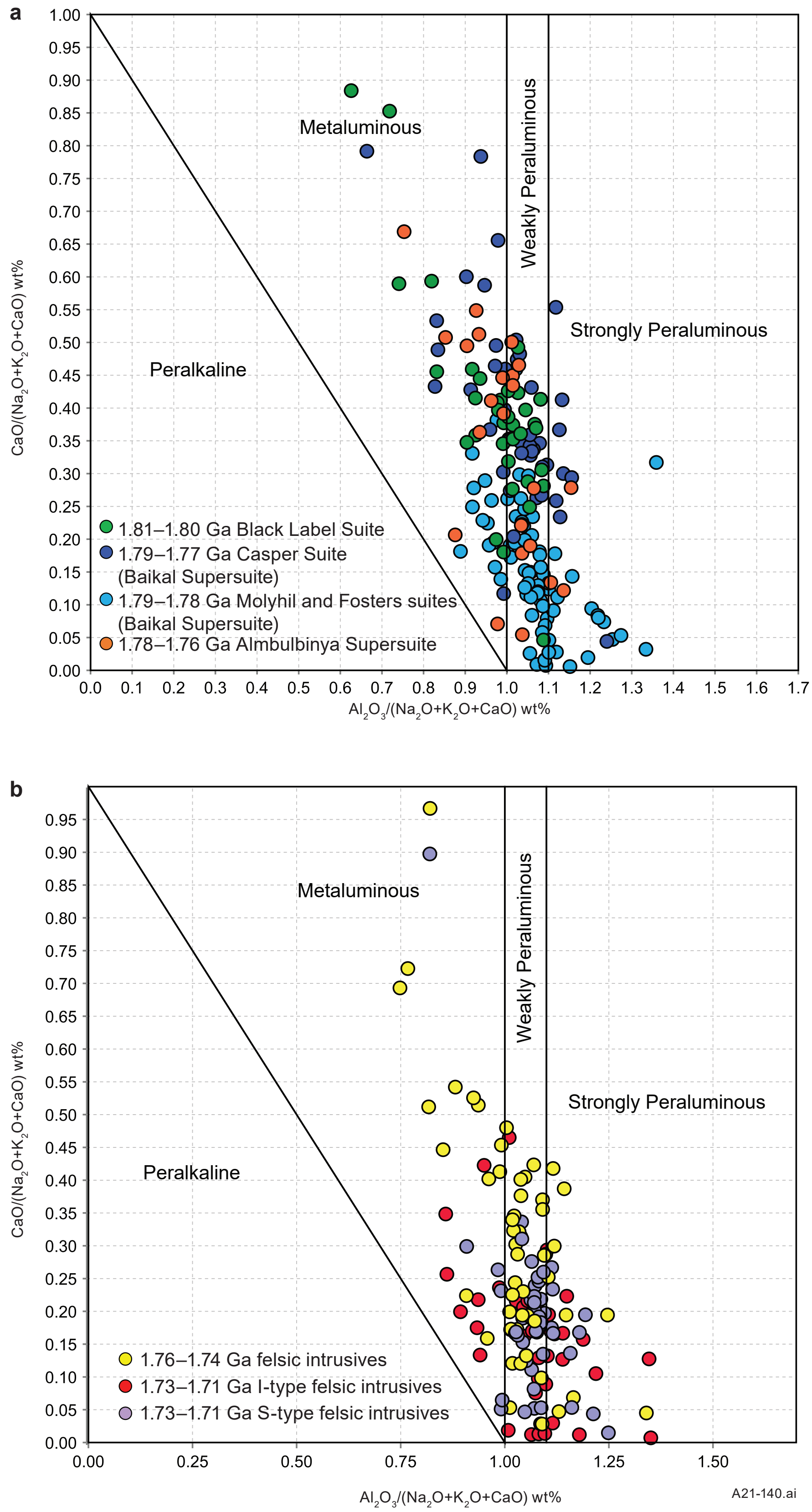

Figure 4. Alumina saturation index plots for felsic and intermediate rocks. (**a**) Ca 1.81–1.80 Ga Black Label Suite, ca 1.79–1.77 Ga Baikal Supersuite (Molyhil, Casper and Fosters suites) and ca 1.78–1.76 Ga Almbulbinya Supersuite (Lionel and Huckitta suites, Atniempa, Inkamulla and Aremra granodiorites). (**b**) Ca 1.76–1.74 Ga intrusive units (Bruna and Atneequa suites, Gidyea and Tarlton Bore granites, Boundary Igneous Complex) and ca 1.73–1.71 Ga intrusive units (Alkara and Sainthill suites, Woodgreen and Mollie granite complexes, Mount Swan and Aleeltara granites). Figure after Barton and Young (2002).

mafic minerals typically comprising between 5–10 vol% of the mineral mode. The Fosters Suite consists of foliated leucogranite and biotite granite emplaced at ca 1.78 Ga. The Casper Suite is bimodal and comprises foliated to gneissic felsic and mafic intrusive rocks with magmatic ages between ca 1.79–1.77 Ga. The felsic intrusive rocks are largely granodiorites with subordinate granite and tonalite; intermediate rocks are volumetrically minor and

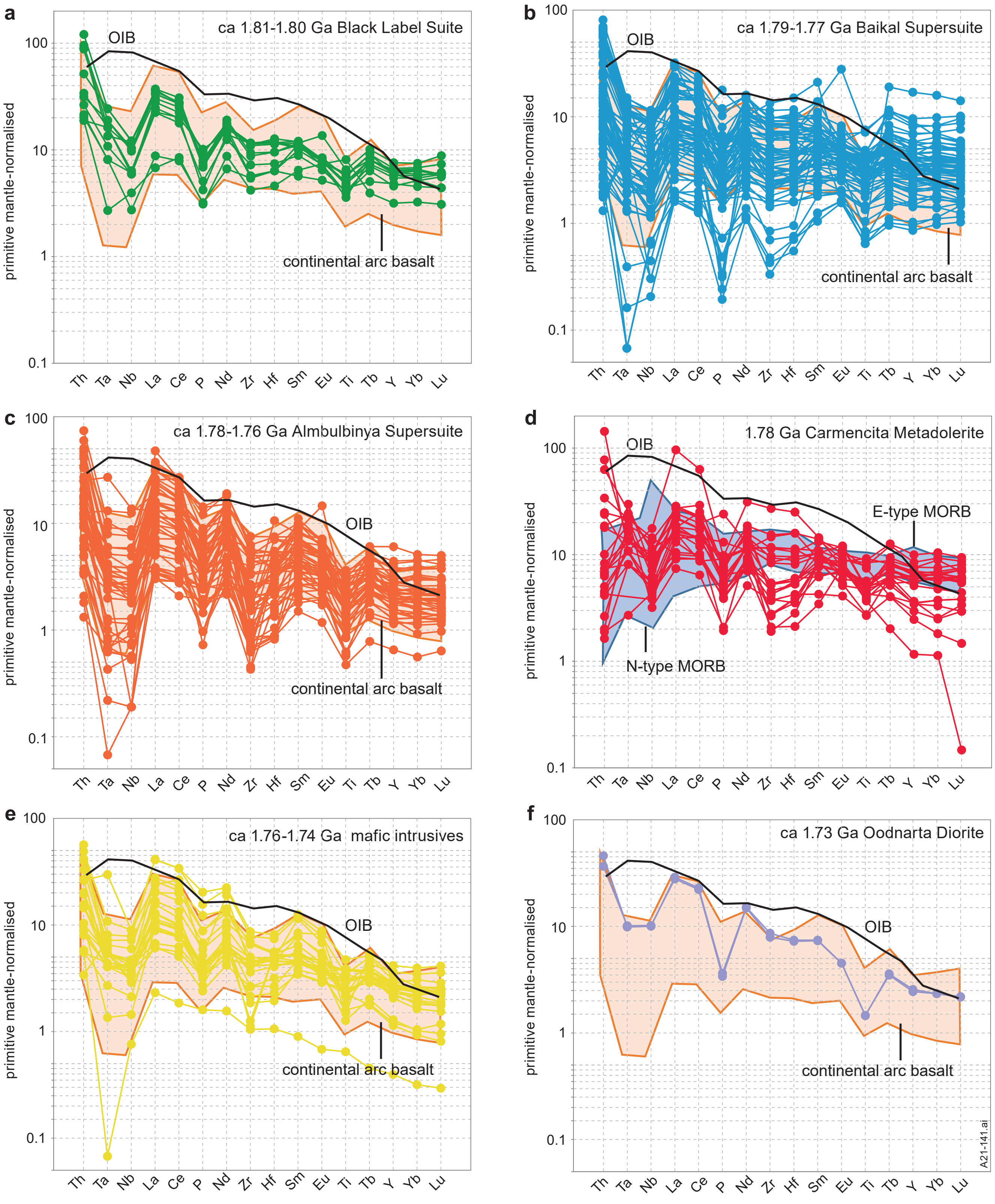

Figure 5. Primitive mantle-normalised incompatible element plots for mafic rocks. (**a**) Ca 1.81–1.80 Ga Black Label Suite. (**b**) 1.79–1.77 Ga Baikal Supersuite (Casper Suite). (**c**) Ca 1.78–1.76 Ga Almbulbinya Supersuite (Lionel and Huckitta suites). (**d**) Ca 1.78 Ga Carmencita Metadolerite (**e**) Ca 1.76–1.74 Ga intrusive rock units (Bruna and Atneequa suites, Leaky Norite, Harding Metagabbro). (**f**) Ca 1.73 Ga Oodnarta Diorite (normalising values from McDonough and Sun 1995). Fields for continental arc basalts: N-type to E-type MORB, and OIB (ocean island basalt) line after Xia and Li (2019).

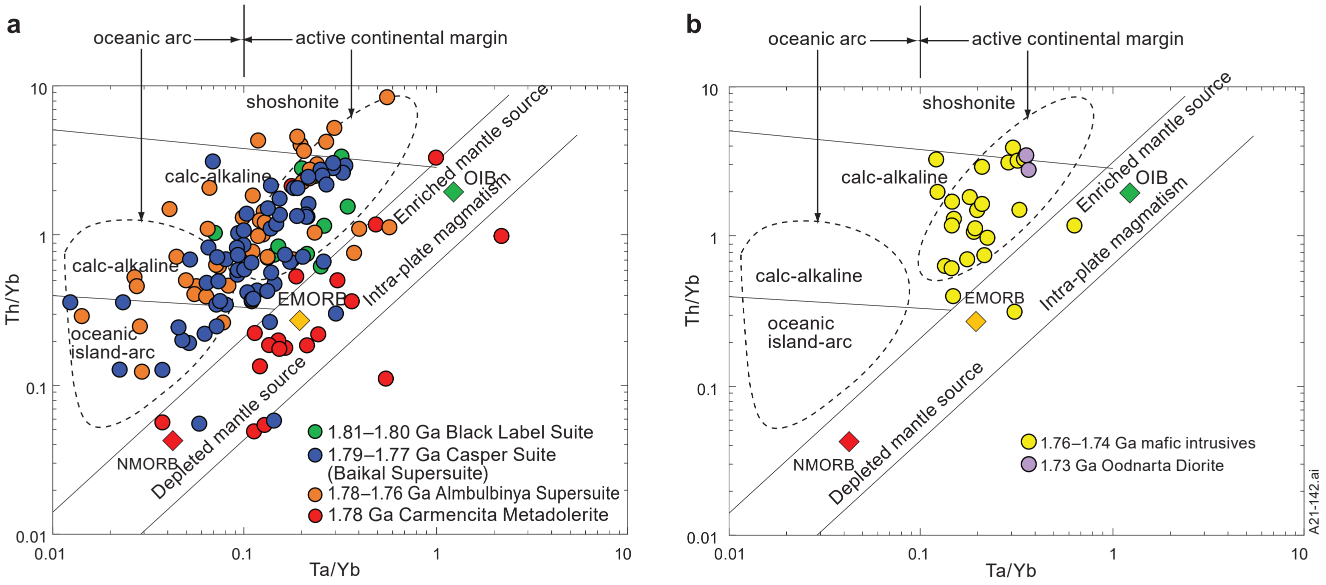

Figure 6. Bivariate trace element plots showing Ta/Yb versus Th/Yb for mafic rocks. (**a**) Ca 1.81–1.80 Ga Black Label Suite, 1.79–1.77 Ga Baikal Supersuite (Casper Suite) and ca 1.78–1.76 Ga Almbulbinya Supersuite (Lionel and Huckitta suites). (**b**) Ca 1.76–1.74 Ga intrusive rock units (Bruna and Atneequa suites, Leaky Norite, Harding Metagabbro) and ca 1.73 Ga Oodnarta Diorite. Figure modified after Pearce (1982, 1983). N-MORB, E-MORB, and OIB are shown for reference (McDonough and Sun 1995).

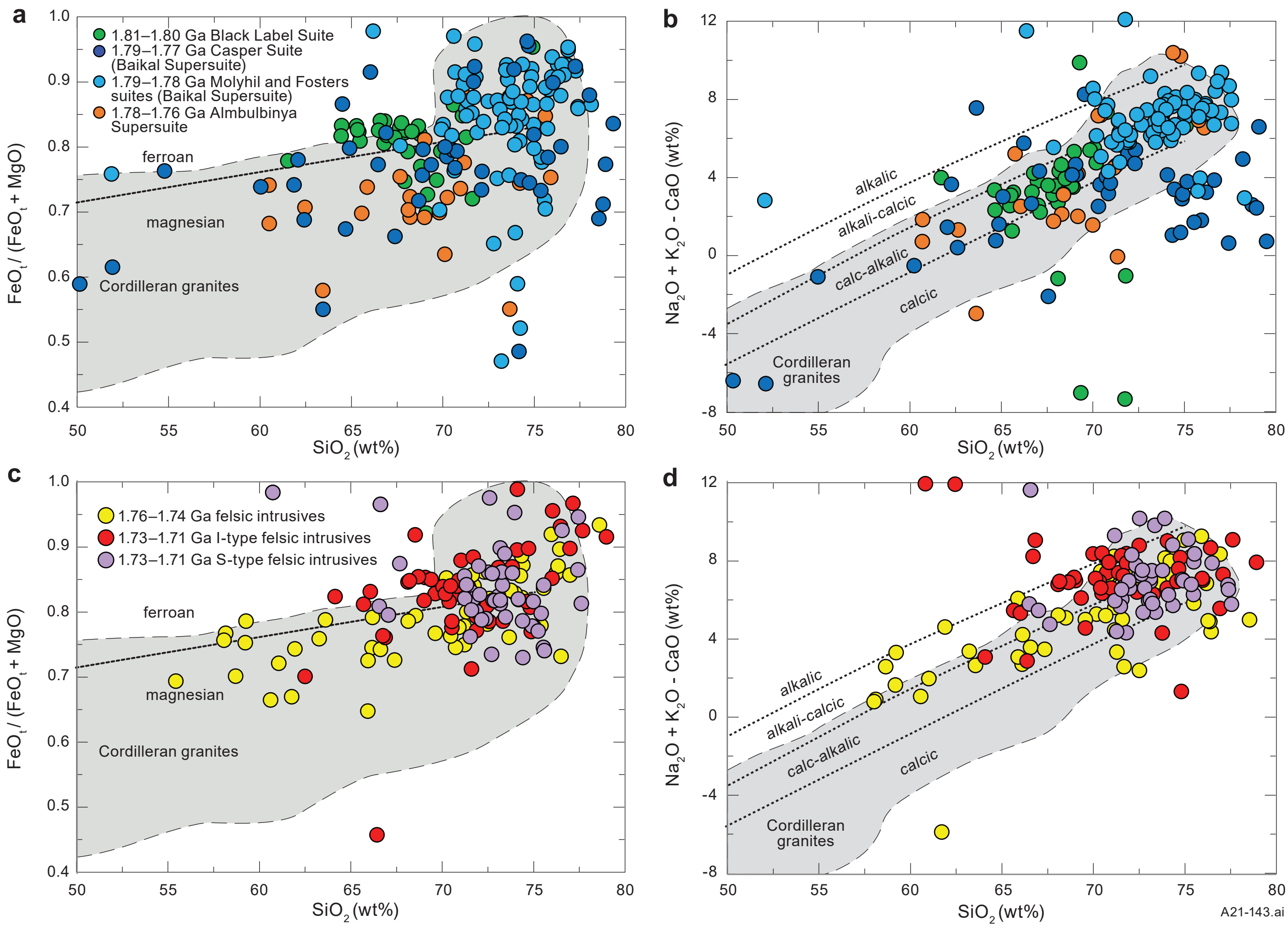

Figure 7. Granite classification plots. (**a**) FeO$_t$/(FeO$_t$ + MgO) versus SiO$_2$. (**b**) Na$_2$O + K$_2$O – CaO versus SiO$_2$ for felsic and intermediate rocks from the ca 1.81–1.80 Ga Black Label Suite, ca 1.79–1.77 Ga Baikal Supersuite (Molyhil, Casper and Fosters suites) and ca 1.78–1.76 Ga Almbulbinya Supersuite (Lionel and Huckitta suites, Atniempa, Inkamulla and Aremra granodiorites). (**c**) FeO$_t$/(FeO$_t$ + MgO) versus SiO$_2$. (**d**) Na$_2$O + K$_2$O – CaO versus SiO$_2$ for felsic and intermediate rocks from ca 1.76–1.74 Ga intrusive units (Bruna and Atneequa suites, Gidyea and Tarlton Bore granites, Boundary Igneous Complex) and ca 1.73–1.71 Ga intrusive units (Alkara and Sainthill suites, Woodgreen and Mollie granite complexes, Mount Swan and Aleeltara granites). Boundaries for worldwide Cordilleran granites (solid grey) shown for reference. Both diagrams are modified after Frost *et al* (2001).

include diorite, monzodiorite, and quartz monzodiorite (**Figure 2b**). Mineral assemblages range from leucocratic with only minor biotite to more biotite-rich lithologies; hornblende is rare. Mafic microgranular enclaves are noted in some units of the Casper Suite. The mafic rocks are hornblende–plagioclase and hornblende–plagioclase–clinopyroxene±orthopyroxene metadolerites. Magma mingling textures between mafic and felsic lithologies are rare. Mafic rocks of the Baikal Supersuite have been identified as important sources of heat, fluids, and metals; they can be directly linked with base metal (McGloin *et al* 2016, 2018, McGloin and Weisheit 2015, 2021) and Fe–Ti–V(–Au–PGE) orthomagmatic mineralisation in eastern HUCKITTA (Freeman 1986, Hussey 2012).

Almbulbinya Supersuite

The Almbulbinya Supersuite is the dominant lithostratigraphic unit exposed in the Aileron Province where it outcrops in Quartz (ILLOGWA CREEK), with minor outcrop extending north into Dneiper (HUCKITTA); unnamed granodiorite and granite exposed in Limbla may also be part of this Supersuite (**Figure 1**, Whelan *et al* in prep, Whelan *et al* 2011b). The Supersuite comprises the Atniempa Granodiorite, Inkamulla Granodiorite, Lionel Suite (former Entia Gneiss of Joklik 1955, and Entia Gneiss Complex of Sivell and Foden 1988), Aremra Granodiorite, and Huckitta Suite (former Huckitta Granodiorite of Joklik 1955). The Supersuite was emplaced between ca 1.78–1.76 Ga and is composed of variably metamorphosed intrusive rocks with igneous protoliths ranging in composition from gabbro through to granite; the dominant lithology is granodiorite. The Atniempa Granodiorite is a ca 1.78 Ga hornblende±biotite granodiorite that is gneissic to locally migmatitic. The Inkamulla Granodiorite consists of foliated to gneissic biotite granite and hornblende–biotite granodiorite emplaced at ca 1.77 Ga. The Lionel Suite makes up the bulk of the igneous rocks exposed in the Entia Dome (**Figure 1**). This suite comprises a variety of orthogneisses, with compositions including gabbro, tonalite, granodiorite, and granite; emplacement age for the protoliths is ca 1.77 Ga. Felsic lithologies include biotite±muscovite granitic gneiss and hornblende–biotite granodioritic and tonalitic gneiss (**Figure 2c**). The mafic rocks include mafic amphibolite and metagabbro. The Aremra Granodiorite is a ca 1.76 Ga foliated hornblende–biotite granodiorite with subordinate diorite and quartz diorite, which are locally gneissic. The ca 1.76 Ga Huckitta Suite is exposed in the central Entia Dome and consists of foliated to gneissic biotite±hornblende granite and hornblende–biotite granodiorite with minor undeformed gabbronorite exposed in low strain zones in the core of the main granite–granodiorite intrusion.

Salthole Gneiss

The Salthole Gneiss occurs in southern Quartz, with minor outcrop interpreted to extend into Limbla and Riddoch (ALICE SPRINGS). The gneiss comprises strongly mylonitic and retrogressed biotite–chlorite and muscovite–biotite schistose gneiss. The Salthole Gneiss is interpreted to have igneous protoliths of granitic to granodioritic composition that were emplaced at ca 1.79 Ga (Kositcin *et al* 2011).

Denara Orthogneiss

The Denara Orthogneiss is a ca 1.78 Ga migmatitic orthogneiss that outcrops south of the Delny Shear Zone in southern HUCKITTA (**Figure 1**, Weisheit *et al* 2019). The orthogneiss is compositionally layered with biotite±garnet-bearing melanosomes and biotite±garnet±hornblende-bearing leucosomes. Protoliths to the orthogneiss are largely granite with subordinate granodiorite; local outcropping bodies of garnet–leucogranite are interpreted as migrated melt derived from anatexis of the orthogneiss.

Carmencita Metadolerite

The Carmencita Metadolerite is a voluminous granulite-facies mafic unit that outcrops mainly in Dneiper (and to a lesser extent Jinka) and continues west into ALCOOTA (Beyer *et al* in prep b). The metadolerite typically occurs as lenses and boudins within metasedimentary rocks of the ca 1.80 Ga Kanandra Metamorphics. Typical Carmencita Metadolerite consists of fine- to medium-grained clinopyroxene–orthopyroxene–plagioclase mafic granulite with variable amounts of hornblende; leucosome is variably developed (**Figure 2d**). The igneous precursor to the metadolerite is interpreted to have a minimum crystallisation age of ca 1.78 Ga (Beyer *et al* 2013).

Geochemical characteristics and implications for geodynamic setting

There is significant overlap in the chemical compositions of the constituent units/suites of the Baikal and Almbulbinya supersuites, particularly between the Casper Suite (Baikal Supersuite) and the Almbulbinya Supersuite as a whole. These latter two igneous packages are broadly bimodal, although, unlike the Black Label Suite, contain a small volume of intermediate rocks. The mafic components are largely calc-alkaline basalt/gabbro with subordinate basaltic andesite/gabbroic diorite (**Figure 3a**). On a REE plot, the mafic rocks from the Almbulbinya Supersuite display weak to moderate LREE-enrichment and flat to gently-sloping HREE. They generally lack Eu anomalies and this, plus their generally low Al_2O_3 content (<19 wt%) and high Mg# (>65), indicates that these are potential parental liquids (Glass 2005). The Casper Suite mafic rocks have similar shaped REE patterns to those in the Almbulbinya Supersuite but have variably negative and positive Eu anomalies, which, coupled with their higher Al_2O_3 and lower Mg#, indicates both plagioclase accumulation and fractionation processes. The felsic and intermediate lithologies of the Casper Suite and Almbulbinya Supersuite have a range in silica contents between 55–78 wt% SiO_2 with the highest silica values seen in the leucogranites of the Casper Suite; silica-rich compositions are generally missing from the Almbulbinya Supersuite. Al_2O_3 contents are highly variable from 11 wt% in the most silica-rich rocks to 23 wt% in those that are silica-poor. On an ASI plot, these rocks classify as metaluminous to strongly peraluminous but are defined as I-type intrusive rocks based on the hornblende present in some of the individual units (**Figure 4a**). An important distinction between the felsic rocks of the Casper Suite and Almbulbinya Supersuite rocks and those of the Black Label Suite is their low-K compositions (<4 wt% K_2O), with the bulk of the felsic-intermediate rocks displaying low-K (tholeiitic) to calc-alkaline affinities.

The felsic rocks of the Molyhil and Fosters suites (Baikal Supersuite) are metaluminous to strongly peraluminous, similar to those of the Casper Suite and Almbulbinya Suite (**Figure 4a**). However, unlike the latter, they are characteristically K-rich (>4 wt% K_2O) with high-K (calc-alkaline series) to shoshonitic affinities. Compared to the low-K to calc-alkaline rocks, they also have narrower ranges in silica and aluminium, with abundances between 70–77 wt% SiO_2 and 11–15 wt% Al_2O_3 respectively. REE patterns for the Molyhil and Fosters suites are fractionated with moderate to strong LREE-enrichment and pronounced negative Eu anomalies. On an incompatible element (ICE) plot, they display relative enrichment in Th and U and have negative anomalies in Ba, Sr, P and Ti. The ca 1.78 Ga Denara Orthogneiss overlaps compositionally with the felsic parts of the Baikal Supersuite and is considered to be comagmatic; the ca 1.79 Ga Salthole Gneiss is chemically similar to the Molyhil Suite and may be related or have the same source.

The mafic rocks from the Baikal and Almbulbinya supersuites have trace element compositions typical of continental arc basalts, with pronounced depletions in Ta and Nb relative to Th and La, pronounced negative P anomalies, and moderate negative anomalies in Zr, Hf and Ti (**Figures 5b, c**). This is also illustrated in **Figure 6a**, which shows the mafic rocks plotting across the fields for calc-alkaline rocks from active continental margins and oceanic arcs. These compositions suggest the mafic rocks were derived via melting of a mantle source contaminated by slab-derived fluids, either in an arc or back arc tectonic regime. The felsic to intermediate rocks of the Baikal Supersuite are mainly alkali-calcic to calc-alkalic and magnesian to ferroan, with the latter dominating at higher SiO_2 contents and peraluminosity (**Figure 7a, b**). These compositions are typical of plutons in the main portion of, or inboard from, Cordilleran batholiths. In comparison, the felsic to intermediate rocks of the Almbulbinya Supersuite are almost uniformly magnesian, largely calc-alkalic to calcic, and similar to plutons in island arcs or those situated in the outboard (or oceanward) portions of Cordilleran batholiths (**Figure 7a, b**). Isotopic data indicates a more juvenile source for the Almbulbinya Supersuite as a whole, with whole rock Sm–Nd and zircon Hf isotopic compositions that range to more radiogenic values than those for the Baikal Supersuite (Whelan *et al* 2011a, 2012b, Beyer *et al* 2013, in prep c).

The Carmencita Metadolerite is chemically distinct from the mafic parts of the Black Label Suite, and Baikal and Almbulbinya supersuites. Compositions are calc-alkaline to tholeiitic, with basalt/gabbro dominating over basaltic andesite/gabbroic diorite. REE patterns are generally characterised by weak to moderate LREE-enrichment, flat to weakly sloping HREE, and weak to moderate negative Eu anomalies. Mg# are <65 and Al_2O_3 contents are typically <19 wt%, suggesting that these are probable fractionated liquids (Glass 2005). Trace element chemistry indicates compositions that are transitional between N-MORB and E-MORB, with variable depletion in Nb relative to Ta and La, and negative anomalies in Zr, Hf and Ti often lacking (**Figure 5d**). This is demonstrated in **Figure 6a**, which shows the metadolerite plotting in the mantle array, confirming the precursor mafic rock was derived from a mixed source with depleted and enriched mantle end members. Isotopic data in support of a juvenile source for the Carmencita Metadolerite comes from whole rock Sm–Nd isotopes, which indicate a large component of depleted mantle in the source region (Beyer *et al* in prep b). However, the LREE-enrichment seen for these rocks also implies a component of continental crust in the source; one possible scenario is these magmas formed in a nascent continental rift setting where mafic melts interacted with crustal wall rock.

Ca 1.76–1.74 Ga magmatism

Summary of rock units and lithologies

Bruna Suite, Leaky Norite, Gidyea Granite, Harding Metagabbro and Atneequa Suite

The Bruna Suite outcrops mainly in Quartz with minor occurrences in Riddoch (**Figure 1**). The suite comprises a large range in lithologies but is dominated by coarse-grained augen gneiss and porphyroblastic feldspar gneiss (which is locally garnet- and muscovite-bearing), leucocratic gneiss, subordinate megacrystic and rapakivi granite, granodiorite, orthopyroxene-garnet granite, and rare gabbro (**Figure 2e**, Whelan *et al* in prep). Hornblende in the felsic rocks is rare (Whelan *et al* 2012). Magmatic ages for the Bruna Suite indicate that it was emplaced between ca 1.76 and ca 1.75 Ga. The Leaky Norite outcrops predominantly in southern Quartz but may also include minor outcrops in Entia Dome. This unit is composed mostly of coarse-grained, layered olivine norite and olivine gabbronorite, with subordinate troctolite and gabbro. Magma mingling textures between the Leaky Norite and Bruna Suite are locally exposed, indicating that these units are comagmatic and coeval. The ca 1.75 Ga Gidyea Granite outcrops in northern ILLOGWA CREEK (Quartz and Brahma). This unit is predominantly a porphyritic to megacrystic biotite granite with abundant coarse-grained K-feldspar phenocrysts; garnet is locally present and rare rapakivi granite is also observed. Whelan *et al* (in prep) note that the Gidyea Granite is compositionally similar to felsic intrusive rocks of the Bruna Suite and suggest it may be comagmatic. The Harding Metagabbro is a pervasively sheared metagabbro to meta-ultramafic rock (websterite and hornblendite) that forms a series of small intrusions in southern Quartz. The Atneequa Suite occurs in northern Limbla and comprises biotite±garnet granite, granodiorite, quartz gabbro, and gabbro; emplacement age is interpreted as ca 1.74 Ga (Whelan *et al* 2011b). Felsic intrusive rocks of the Atneequa Suite are characterised by elevated fluorine and are spatially associated with fluorite–hematite hydrothermal breccia, potassic and silicic alteration, as well as copper ± gold mineralisation, consistent with

IOCG-style systems (Whelan *et al* 2009, 2012a, 2013; Lyons *et al* 2013). Studies focused on characterising the nature of the mineralising fluids and sources for metals and sulfur suggests mineralisation in this area was the result of interaction between highly saline basinal brines and copper-, sulfur- and fluorine-bearing magmatic rocks of the Atneequa Suite during the Palaeozoic (McGloin *et al* 2018).

Tarlton Bore Granite and Boundary Igneous Complex
The Tarlton Bore Granite and Boundary Igneous Complex outcrop predominantly in Jervois Range, with minor outcrop in Jinka (**Figure 1**, Weisheit *et al* 2019, Reno *et al* in prep). These units are poorly exposed and intrusive relationships with other units are generally not seen. The Tarlton Bore Granite is a strongly weathered and altered leucogranite, which is foliated and locally porphyritic (**Figure 2f**). The Boundary Igneous Complex consists of a variety of foliated rock types, including biotite granodiorite, biotite granite with abundant K-feldspar phenocrysts, and leucogranite. Emplacement age for these units is considered to be ca 1.75 Ga.

Geochemical characteristics and implications for geodynamic setting

The ca 1.76–1.74 Ga intrusive rocks in ILLOGWA CREEK form a continuum between mafic and felsic end members with intermediate compositions moderately well-represented. Silica contents range from 43–77 wt% SiO_2 with a small compositional gap between 55–58 wt% SiO_2. The mafic rocks are predominantly calc-alkaline basalt/gabbro with subordinate basaltic andesite/gabbroic diorite; rare picrobasalt/olivine gabbro and trachybasalt/monzogabbro are also noted (**Figure 3b**). REE patterns for the mafic rocks are fractionated with LREE enrichment and moderate HREE depletion, indicating the presence of garnet in the source region. Negative Eu anomalies are weak to absent, but Mg# are generally <65 and Al_2O_3 content <19 wt%, suggesting that these are probable fractionated liquids, albeit at low degrees of fractionation (Glass 2011). The felsic and intermediate intrusive rocks have silica content ranging from 66–77 wt% SiO_2 and alumina abundances largely between 11–17 wt% Al_2O_3. On an ASI plot, the intermediate rocks are predominantly metaluminous compared to the felsic rocks that are mostly weakly peraluminous (**Figure 4b**). The presence of garnet (and lack of appreciable hornblende) in the Bruna Suite and Atneequa Granite suggests that at least some of these intrusive rocks are S-type. In general, these rocks classify as high K (calc-alkaline) to shoshonitic with a strong positive correlation between silica and K_2O contents. REE patterns for these rocks are characterised by LREE-enrichment and weak to moderate negative Eu anomalies. On an ICE plot, they display enrichment in Rb relative to Ba, and negative Nb, Ta, Sr and Ti anomalies. Major and trace element chemistry for the ca 1.76–1.74 Ga intrusive rocks in HUCKITTA largely overlaps that for the felsic rocks in ILLOGWA CREEK. The main difference is that the HUCKITTA rocks are largely peraluminous and I-type (Weisheit *et al* 2019).

Compositions of the ca 1.76–1.74 Ga mafic intrusive rocks overlap with mafic rocks from the Almbulbinya Supersuite, implying a similar source and tectonic setting (**Figures 5e, 6b**). The felsic intrusive rocks from ILLOGWA CREEK and HUCKITTA are magnesian to ferroan for the most silica-rich lithologies, and are largely calcic to calc-alkalic and less commonly alkali-calcic (**Figure 7c,d**). In Cordilleran batholiths, magnesian alkali-calcic plutons are typically found further inboard of the subduction margin than calc-alkalic granitoids, but these compositions are also characteristic of post-orogenic granitoids (Frost *et al* 2001); therefore, it is possible that these later intrusive rocks represent reworking of the older supersuites. This scenario was posited by Whelan *et al* (2012) who presents whole rock Sm–Nd and zircon Lu–Hf isotopic data for the ILLOGWA CREEK rocks that indicate the source was largely reworked crust with only minor juvenile material; Weisheit *et al* (2019) note the same for the counterparts in HUCKITTA.

Ca 1.73–1.71 Ga magmatism

Summary of rock units and lithologies

Alkara and Sainthill suites, Woodgreen and Mollie granite complexes, and Mount Swan Granite
Felsic magmatism between ca 1.73–1.71 Ga in the eastern Aileron Province is widespread in western and central HUCKITTA and eastern ALCOOTA. It is represented by the Alkara and Sainthill suites, Woodgreen and Mollie granite complexes, and Mount Swan Granite (**Figure 1**, Haines and Scrimgeour 2007, Beyer *et al* in prep b, Reno *et al* in prep). These intrusive rocks are interpreted as late syn- to post-tectonic and are generally undeformed except in outcrops within or adjacent to major structures; the exception is the Alkara Suite, which was emplaced during regional granulite facies metamorphism. The Alkara Suite comprises ca 1.73 Ga anatectic biotite±garnet granite, orthogneiss, and migmatitic gneiss, all derived by the partial melting of the Kanandra Metamorphics (**Figure 2g**). Anatectic garnet-rich leucogranite is also noted in the Bleechmore Metamorphics in central ALCOOTA (Beyer *et al* in prep b). The Sainthill Suite is restricted to central HUCKITTA and consists of biotite granite and leucogranite with magmatic ages between ca 1.73 and ca 1.71 Ga; voluminous pegmatite and pegmatitic granite of the Samarkand Pegmatite may be related to this suite (Weisheit *et al* 2019). The biotite granite has variable textures but is dominated by a porphyritic variant that contains abundant coarse-grained K-feldspar phenocrysts (**Figure 2h**). Field evidence indicates that the Sainthill Suite was derived via partial melting of the ca 1.79 Ga Molyhil Suite or equivalents. The Woodgreen and Mollie granite complexes contain a wide variety of felsic rock types emplaced between ca 1.73–1.71 Ga; the main rock types include biotite±garnet granite, biotite-rich granite, and porphyritic leucogranite and biotite granodiorite, the latter with mafic microgranular enclaves. The Mount Swan Granite occurs in eastern ALCOOTA and western HUCKITTA and is a ca 1.72 Ga hornblende–biotite granite with abundant K-feldspar phenocrysts (Freeman 1986, Beyer *et al* in prep b). There is growing evidence that

widespread epigenetic copper ± tungsten ± molybdenum mineralisation in central Australia is associated with this magmatic event, such as at the Molyhil W–Mo deposit in central HUCKITTA but also further afield in the Davenport Province (eg Juggler prospect) and Warramunga Province (Hatches Creek and Mosquito Creek tungsten fields and Tennant Creek mineral field; McGloin *et al* 2020, Reno *et al* 2021, McGloin and Weisheit in review).

Aleeltara Granite, Oodnarta Diorite and unnamed granite
Minor igneous activity at ca 1.73 Ga is recognised in western ILLOGWA CREEK as felsic and mafic magmatism. Felsic lithologies include foliated to gneissic biotite granite and leucogranite of the ca 1.73 Ga Aleeltara Granite and unnamed ca 1.73–1.72 Ga quartz-rich tourmaline–muscovite granite and leucogranite exposed largely in northwest LIMBLA; rare alkaline magmatism is represented by ca 1.72 Ga alkali feldspar syenite in central LIMBLA (Whelan *et al* 2011b). Mafic lithologies are restricted to central QUARTZ where dykes and plugs of quartz diorite and quartz gabbro of the 1.73 Ga Oodnarta Diorite intrude the Bruna Suite.

Geochemical characteristics and implications for geodynamic setting

Magmatism between ca 1.73–1.71 Ga in the eastern Aileron Province is predominantly felsic in nature, with mafic rocks generally restricted to western ILLOGWA CREEK. The felsic rocks can be separated into two compositional types: I-types with biotite±hornblende, and S-types with garnet±biotite or tourmaline–muscovite. The I-type granites include those in the Sainthill Suite, Woodgreen and Mollie granite complexes, and the Mount Swan Granite. The S-type granites are those of the Alkara Suite and the Aleeltara Granite. Overall these two compositional types have similar chemistry with strong overlap in most major elements. On an ASI plot, compositions range from metaluminous (I-type) to strongly peraluminous (S-type), but there is considerable variability with some I-types having strongly peraluminous compositions (**Figure 4b**). In general, these intrusive rocks are potassium-rich (>4 wt% with up to 12 wt% K_2O) and classify as high-K (calc-alkaline) to shoshonite series rocks. REE patterns are strongly fractionated, with LREE enrichment, sloping HREE and deep negative Eu anomalies, suggesting that plagioclase fractionation played an important role in their formation. On an ICE plot, they display enrichment in Rb and Th relative to Ba, and negative Nb, Ta, Sr, P and Ti anomalies.

Compositions of the ca 1.73–1.71 Ga intrusive rocks are magnesian to ferroan and largely fall within the field for Cordilleran granites in **Figure 7c**. There is similar overlap in **Figure 7d**; however, the I-types tend to lie more in the alkali-calcic field compared to the S-types, which are dominantly calc-alkalic. As the Sainthill Suite is known to have derived via partial melting of the ca 1.79 Ga Molyhil Suite (and equivalents), any “Cordilleran” signature is interpreted as inherited; this is also likely the case for the other I-type intrusive rocks in this age group. The S-type Alkara Suite has similar chemistry; however, this is inferred to be coincidental as its parent rock is known to be metasedimentary. Whole rock Sm–Nd isotopic evidence also supports a crustal origin for the ca 1.73–1.71 Ga felsic intrusive rocks, with radiogenic ε_{Nd} values indicating their sources were reworked and isotopically evolved Palaeoproterozoic basement (Whelan *et al* 2011a, 2012b; Beyer *et al* in prep b, Reno *et al* in prep).

The mafic intrusive rocks of the Oodnarta Diorite classify as basaltic andesites in **Figure 3b** and have compositions that overlap with mafic rocks of the ca 1.76–1.74 Ga group and the Almbulbinya Supersuite (**Figures 5f, 6b**). It is likely that these rocks represent localised melting of the older mafic units.

Magmatic evolution of the eastern Aileron Province and model for geodynamic setting

Based on the information presented herein, the following scenario is proposed for the eastern Aileron Province:

- Extension and attenuation of continental crust (possibly formed in an older subduction regime) at ca 1.81–1.80 Ga with asthenospheric upwelling and low-pressure differentiation of a tholeiitic underplate to produce the mafic magmas of the Black Label Suite and their felsic differentiates. Crustal contamination during ascent through (subduction-modified?) crust was possibly responsible for a relict ‘arc-like’ signature in the mafic rocks.
- Early phase of continent–ocean convergence, slab melting, back-arc basin formation (slab rollback), and mafic upwelling/underplating between ca 1.79–1.77 Ga, with emplacement of bimodal calc-alkaline intrusive rocks of the Baikal Supersuite proximal to the locus of back-arc spreading, ie outboard from the convergent margin. Associated base metal and Ti–V–Fe(–Au–PGE) orthomagmatic mineralisation formed locally, driven by emplacement of mafic intrusive rocks.
- Ongoing continent–ocean convergence between ca 1.78–1.76 Ga, with emplacement of bimodal calc-alkaline intrusive rocks of the Almbulbinya Supersuite proximal to or within the magmatic arc, ie inboard of the convergent margin.
- Upwelling of enriched subcontinental mantle and onset of rift magmatism within the back-arc and emplacement of Carmencita Metadolerite at ca 1.78 Ga.
- Cessation of convergence and arc magmatism between ca 1.76–1.74 Ga and start of a compressive regime, with closure of the back-arc basin, crustal thickening and reworking/melting of older basement to produce I-type and S-type felsic intrusive rocks.
- Crust stabilisation and relaxation, with renewed felsic magmatism in thickened crust between 1.73–1.71 Ga. Associated copper ± tungsten ± molybdenum epigenetic mineralisation formed locally, driven by large-scale emplacement of fractionated granites.

This model supports previous interpretations for a convergent margin in this part of the Aileron Province and provides improved constraints on the extent and timing of subduction-related magmatism in both time and space. Importantly, this model indicates that subduction was in play from ca 1.79–1.76 Ga, and that magmatism during this time can be related back to this convergent system, with no requirement for some intrusive rocks to have formed via melting of older, pre-existing subduction-modified crust as postulated by workers such as Zhao and McCulloch (1995). The model is also supported by the tectonothermal cycle determined for Jervois Range by Weisheit *et al* (2019) and Weisheit (2019), which indicates a possible extensional setting between 1.79–1.76 Ga, then a switch to a transpressional setting between ca 1.75–1.73 Ga, and finally decompression from ca 1.73–1.70 Ga.

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