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Gondwana Research

Re-initiation of plutonism at the Gondwana margin after a magmatic hiatus: The bimodal Permian-Triassic Longwood Suite, New Zealand

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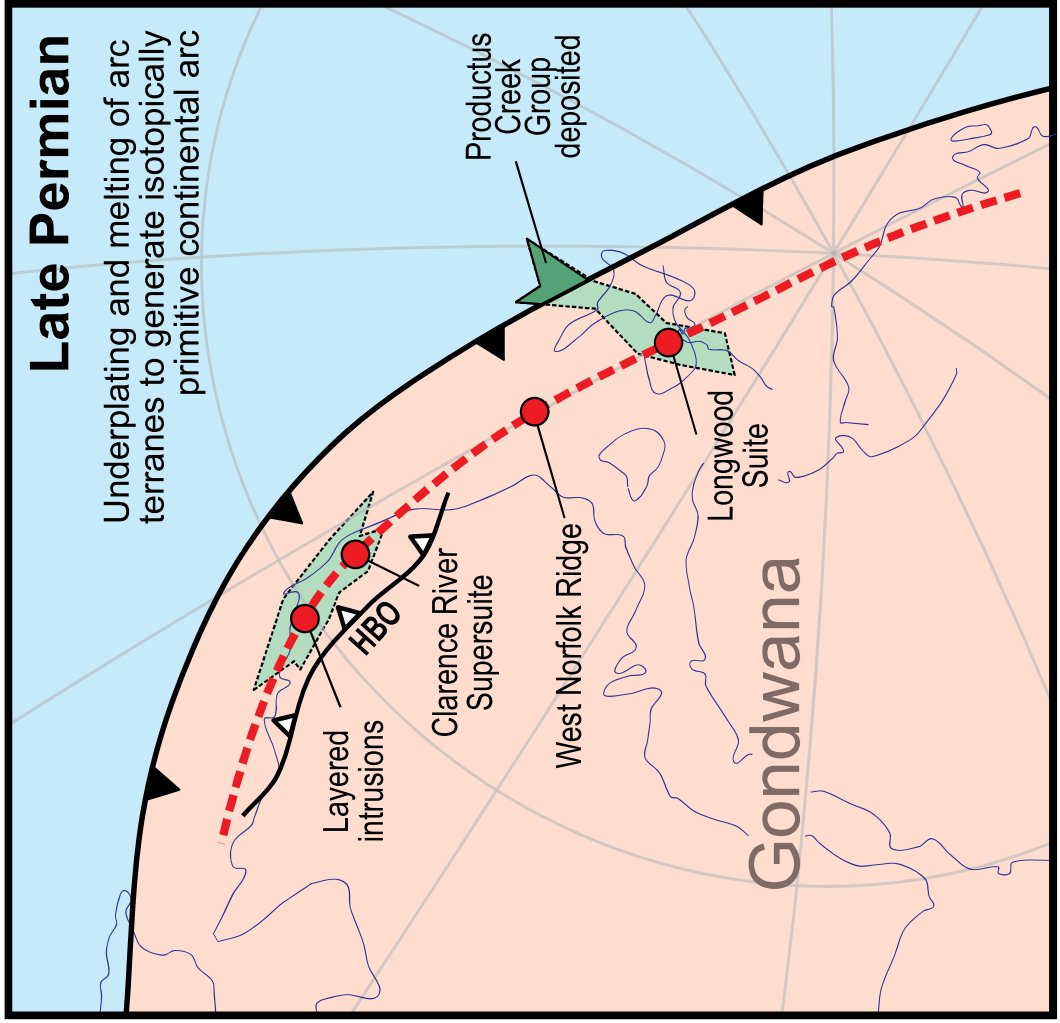
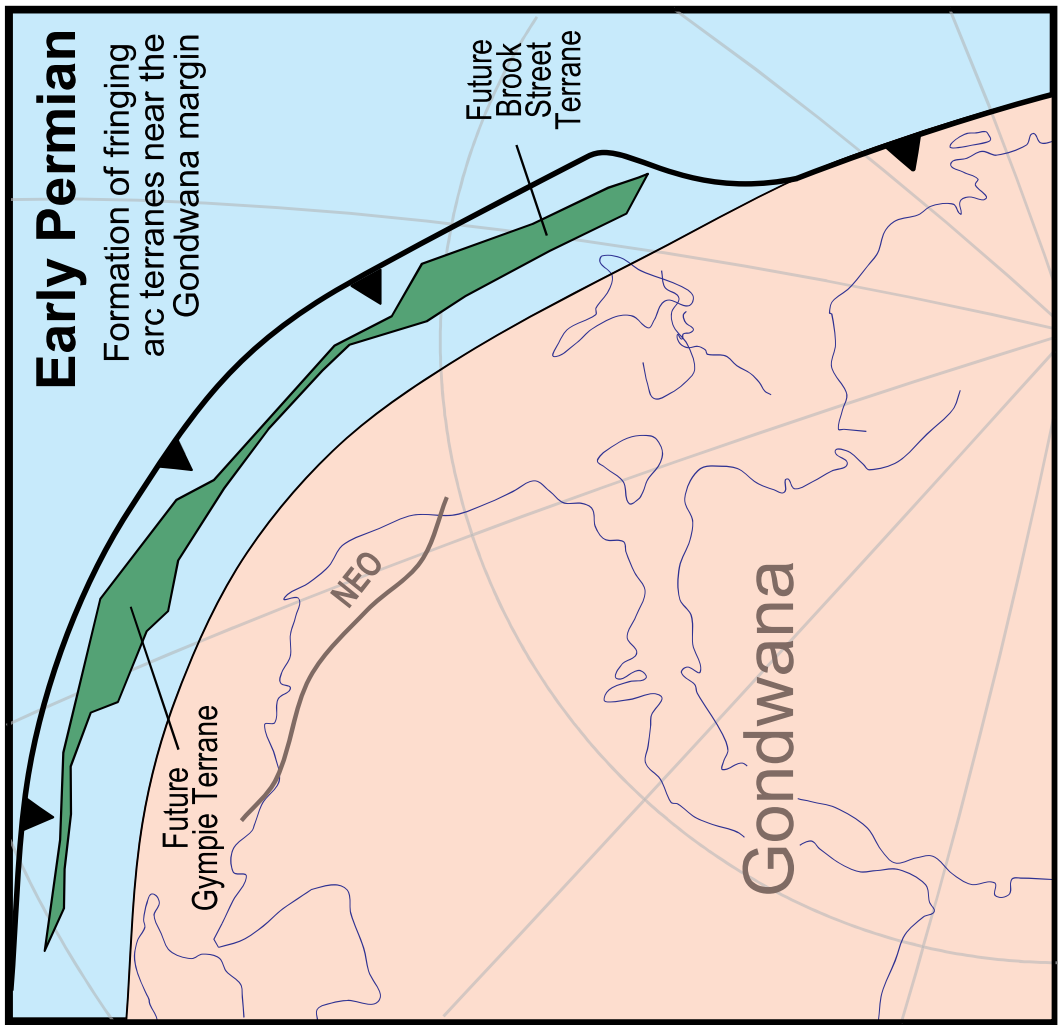
Graphical Abstract





Research Highlights

- The primitive bimodal magmatism of the Longwood Suite occurred from 261-243 Ma
- Granitoid geochemistry requires shallow melting of an amphibolitic residue
- The Longwood Suite has a significantly lower areal addition rate than the later arc
- Thinned Gondwana crust was tectonically underplated by Permian arc lithosphere

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Re-initiation of plutonism at the Gondwana margin after a magmatic hiatus: The bimodal Permian-Triassic Longwood Suite, New Zealand

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Abstract

The Cambrian to Cretaceous Tuhua Intrusives, New Zealand, preserve an igneous record of Phanerozoic subduction and crustal growth at the margin of Gondwana. Within the Tuhua Intrusives, the coeval gabbroic and trondhjemitic intrusions of the c. 261-243 Ma Longwood Suite stand out as being isotopically more primitive and chemically distinct from all other New Zealand plutonic suites. We present new U-Pb crystallization ages, trace element analyses and Sr-Nd isotope compositions of the Longwood Suite. U-Pb SHRIMP zircon ages of 258.5 ± 2.5 Ma, 256.0 ± 1.8 Ma, 247.8 ± 2.7 Ma and 243.2 ± 2.4 Ma obtained from plutons on Ruapuke Island, and a dike at Bluff, affirm the restricted time range and expand the known areal extent of the Longwood Suite. Longwood Suite granitoids are I-type and sodic (K/Na < 0.4), with distinctive low Rb and Nb/Ta, flat rare earth element patterns ($La/Yb_N < 10$), unradiogenic $^{87}Sr/^{86}Sr_{(t)}$ (0.7029 to 0.7032) and radiogenic $\varepsilon^{143}Nd_{(t)}$ (+6.3 to +8.2), compared to the nearby, calc-alkaline, Late Triassic Darran Suite I-type plutons of the Tuhua Intrusives. Stable Nd isotope ratios of Longwood Suite samples are highly variable ($\delta^{146/144}Nd = 233$ ppm) compared to global plutonic rocks ($\delta^{146/144}Nd = 44$ ppm) and reflect the removal of phosphate minerals. Collectively, these geochemical characteristics are consistent with generation of the granitoids by shallow (garnet-absent) melting of an amphibolitic residue, from which we infer relatively thin lithosphere. The Longwood Suite has a maximum areal addition rate of 43 km^2/Ma, substantially less than the subsequent plutonic suites when the magmatic arc was fully established. We suggest a petrotectonic model whereby Gondwana continental margin crust was tectonically underplated by Permian intra-oceanic island arc crust and mantle lithosphere, which subsequently melted to generate the isotopically primitive gabbro and trondhjemite plutons of the Longwood Suite.

1.0 Introduction

Zealandia is Earth's most recently recognized continent (Mortimer and Campbell, 2014; Mortimer et al., 2017), with the oldest known rocks being the Middle Cambrian limestones of the Takaka Terrane and c. 500 Ma plutons of the Jaquiery Suite (Mortimer et al., 2014). No exposed Precambrian crust has been discovered to date, although isotopic evidence suggests more ancient lower crustal and sub-continental lithospheric mantle domains exist at depth (e.g. Liu et al., 2015; McCoy-West et al., 2016; McCoy-West et al., 2013; Turnbull et al., 2021). Despite these hints of ancient lithospheric roots, Zealandia's crustal history is reflective of Cambrian to Early Cretaceous growth and accretion of terranes and batholiths at the southeastern margin of Gondwana, followed by Late Cretaceous continental rifting and breakup, and Cenozoic drift and dispersal as a separate post-Gondwana continent. As such it provides an ideal setting to investigate a range of inter-related crustal growth and stabilisation processes. The Median Batholith (Mortimer et al., 1999b) that bisects Zealandia and represents a long-lived (c. 495-105 Ma), regional arc-root plutonic complex (10,200 km^2) preserves the intrusive record of subduction related magmatism at the Gondwana margin throughout much of the Phanerozoic (e.g. Muir et al., 1996b; Schwartz et al., 2017; Tulloch and Kimbrough, 2003), with age correlative magmatism also observed in the formerly along-strike orogens of Australia and Antarctica (e.g. Allibone et al., 1993; Cawood, 1984; Mortimer et al., 2017). In New Zealand, extensive work has been devoted to identifying and understanding the emplacement history and chemical evolution of several Early Paleozoic and Mesozoic suites, especially in the Fiordland region (e.g. Allibone et al., 2009; Allibone and Tulloch, 2004; Allibone et al., 2007; Decker et al., 2017; Kimbrough et al., 1994; Milan et al., 2017; Muir et al., 1994, 1996a; Muir et al., 1998; Muir et al., 1995; Muir et al., 1996b; Price et al., 2006; Schwartz et al., 2017; Scott and Palin, 2008; Tulloch et al., 2009; Turnbull et al., 2010; Waight et al., 1998a; Waight et al., 1998b). In contrast, the Late Permian to

Middle Triassic rocks of the Longwood Suite, the easternmost suite of the Median Batholith have received relatively little attention (McCoy-West et al., 2014; Mortimer et al., 1999a), with the main focus being on the platinum prospectivity of layered gabbros and peridotites (Ashley et al., 2012; Mortimer et al., 2016; Price et al., 2006; Spandler et al., 2003; Spandler et al., 2000). Of more interest is the fact the Longwood Suite records the re-initiation of Median Batholith magmatism at the south Gondwana margin, after a c. 40 Ma pause, as the result of a major tectonic reorganization.

In this contribution, we present new U-Pb zircon geochronology, trace element systematics, Sr-Nd radiogenic isotope compositions and novel $^{146}Nd/^{144}Nd$ ratios of intrusive rocks from the Foveaux Strait region of southern New Zealand. This combination of radiogenic and stable isotopes allows constraints to be placed on both the sources of the magmatism (i.e. mantle vs. crustal contributions), as well as deciphering magmatic processes (obscured in conventional datasets) involved in their petrogenesis. Building on McCoy-West et al. (2014), these new data refine and improve our knowledge of the time range and spatial extent of the Permo-Triassic Longwood Suite of the Tuhua Intrusives. They affirm that, in terms of geochemical and isotopic parameters, the Longwood Suite is distinctly more primitive than older and younger plutonic suites of the Tuhua Intrusives. The Longwood Suite therefore reflects a unique interplay between tectonics and magma genesis at the Gondwana continental margin which enabled the generation of coeval primitive Na-rich granitoids and layered gabbroids and peridotites.

2.0 Geological Setting

The Paleozoic to Mesozoic geological basement of New Zealand can be divided into two principal components (Landis and Coombs, 1967; Mortimer, 2004; Mortimer et al., 2014): 1)

the Western Province which comprises Early Paleozoic terranes intruded by Early Paleozoic to Late Cretaceous Tuhua Intrusives plutons and batholiths; 2) the Eastern Province which comprises several Permian to Early Cretaceous terranes that represent crustal material accreted to the Gondwana margin from the Permian to Cretaceous. The focus of this paper is on the southeastern Tuhua Intrusives within the Median Batholith. The c. 10,200 km^2 Median Batholith lies along the eastern edge of the Western Province and its Cambrian to Early Cretaceous, composite regional arc-root plutonic complexes preserve a rich intrusive record of subduction related magmatism (Mortimer et al., 1999b). Our study area is the Foveaux Strait region in the southern part of the South Island (Fig. 1). Here, the Median Batholith is composed of two distinct suites: 1) the Longwood Suite (McCoy-West et al., 2014), of Late Permian to Middle Triassic (c. 261-245 Ma) plutonic rocks that vary from ultramafic to felsic in composition, with all analysed rocks possessing isotopically primitive characteristics (McCoy-West et al., 2014; Mortimer et al., 1999a; Nebel et al., 2007; Price et al., 2011; Price et al., 2006; Tulloch et al., 1999); and 2) the Darran Suite (Allibone et al., 2009), which consists of mainly Late Triassic to Early Cretaceous (c. 232-130 Ma) subduction-related I-type plutonic rocks (Allibone et al., 2009; Allibone and Tulloch, 2004; Buriticá et al., 2019; Kimbrough et al., 1994; McCoy-West et al., 2014; Mortimer et al., 1999a; Muir et al., 1998). To the east, the plutonic rocks of the Median Batholith intrude the Permian Brook Street Terrane (Fig. 1). Prior to the dating work of McCoy-West et al. (2014), the Permian plutons now classified as Longwood Suite were regarded as subvolcanic intrusions coeval with Brook Street Terrane magmatism, and/or all the Permian-Jurassic plutons along the Longwood coast were regarded as part of a single subduction-related, I-type batholithic complex (Price et al., 2011).

The Brook Street Terrane consists of mafic to intermediate volcanic and volcaniclastic rocks that are dominated by plagioclase- and clinopyroxene-phyric basalts, and can be

characterized, based on their major and trace element geochemistry, as being an island-arc tholeiitic suite (Houghton, 1981, 1985; Sivell and Rankin, 1983; Spandler et al., 2005). Recent interpretations of sedimentary and geochemical characteristics indicate that the Brook Street Terrane and the Gympie Terrane (an inferred along-strike Australian correlative) probably have some geological connection to the Gondwana margin (Adams et al., 2002; Li et al., 2015; Robertson and Palamakumbura, 2019), instead of having formed in an intra-oceanic setting with very limited input of continental material (Frost and Coombs, 1989; Houghton and Landis, 1989). The biostratigraphic age range of the Brook Street Terrane has most recently been assessed by Campbell (2019): all known Brook Street Volcanics Group fossil localities are Early Permian (c. 295-275 Ma), and the overlying, non-volcanic Productus Creek Group (Landis et al., 1999), a local but highly fossiliferous unit in the Takitimu Mountains (Fig. 1), is latest Early to Late Permian (c. 275-254 Ma).

The Longwood Suite, as first defined by McCoy-West et al. (2014), includes the isotopically primitive ($\varepsilon^{143}Nd_{(t)} = \geq 5.4$; Mortimer et al., 1999a; Nebel et al., 2007; Price et al., 2006) Hekeia Gabbro and Pourakino Trondhjemite intrusions in the Longwood Range, along with plutonic rocks exposed near Oraka Point and on Bluff Peninsula (Fig. 2a-b; Challis and Lauder, 1977; Mortimer et al., 1999a; Price et al., 2006). Previous work has focused mainly on the distribution of rock types and elemental geochemistry, due to the platinum potential of the gabbros (Ashley et al., 2012; Cowden et al., 1990; Mossman, 1973; Spandler et al., 2003). Zircon geochronology confirms the Pourakino Trondhjemite (c. 261-252 Ma; McCoy-West et al., 2014; Tulloch et al., 1999) and Hekeia Gabbro (c. 258-252 Ma; McCoy-West et al., 2014) were emplaced essentially coevally although locally, trondhjemite dikes are seen to cut gabbro. Significant hornblende hornfels contact metamorphism and a sharp intrusive boundary between the volcanic Brook Street Terrane rocks and the aforementioned Longwood Suite plutonic rocks (Mortimer et al., 1999a; Service, 1937) suggests a significant

difference in age. The emplacement depth of the Pourakino Trondhjemite was c. 5-9 km (Mortimer et al., 1999b).

The Darran Suite, consists of mainly Late Triassic to Early Cretaceous (c. 232-130 Ma) subduction-related I-type plutonic rocks (Allibone et al., 2009). Darran Suite plutons (Fig. 1) outcrop throughout eastern Fiordland, in the western Longwood Range, on the Longwood coast, and in northern Stewart Island (Allibone et al., 2009; Allibone and Tulloch, 2004; Kimbrough et al., 1994; McCoy-West et al., 2014; Mortimer et al., 1999a; Muir et al., 1998; Scott and Palin, 2008; Williams and Harper, 1978). The Darran Suite can be distinguished from the more voluminous and younger (c. 129-105 Ma) Separation Point Suite on the basis of the lower Sr/Y of the granitoids (Tulloch and Kimbrough, 2003). Variations in radiogenic isotope (Sr-Nd-Hf) compositions with time are also observed through the Darran and Separation Point suites indicative of an increase in the influence of crustal sources in the migrating Mesozoic subduction arc (Milan et al., 2017; Pickett and Wasserburg, 1989; Schwartz et al., 2021; Turnbull et al., 2021).

Ruapuke Island (Fig. 2c) is a small (16 km^2) low-lying island located between Bluff and Stewart Island in the center of Foveaux Strait (Fig 1). Geologically it is poorly studied with only reconnaissance mapping and petrography undertaken (Watters, 1978; Webster, 1981). Both plutonic rocks and metavolcanic rocks outcrop on the island. The metavolcanic rocks are dominated by hornblende hornfels comparable to those seen near Bluff and were mapped as Brook Street Terrane by Turnbull and Allibone (2003). Across the island, a broader range of plutonic rock types than seen near Bluff are observed. These include tonalite, trondhjemite, hornblende gabbro, and gabbronorite (Webster, 1981). The plutonic rocks of Ruapuke Island have been suggested to be correlatives of either the Anglem Complex, Stewart Island (Watters, 1978) or the Bluff Intrusive Complex (Turnbull and Allibone, 2003). Prior to this work, the only radiometric dating from Ruapuke Island was a K-Ar hornblende age of 222 Ma from a

quartz monzodiorite at South Point (Devereux et al., 1968; age recalculated using decay constants of Steiger and Jäger, 1977).

3.0 Analytical Techniques

A comprehensive description of the analytical techniques implemented herein can be found in the supplementary data, with a brief description provided here. Whole rock geochemistry was conducted at the Arthur Holmes Geochemistry Labs, Durham University. Following a conventional HF-HNO_3 digestion of 200 mg of powder, trace element concentrations were determined using 5 % of this material following established protocols (e.g. Ottley et al., 2003). Following spiking and equilibration with a ^{145}Nd–^{150}Nd double spike (McCoy-West et al., 2017; McCoy-West et al., 2020b), Nd and Sr were separated using well-established chromatographic techniques (e.g. Charlier et al., 2006; McCoy-West et al., 2016). Strontium and Nd isotope measurements were performed using a *Triton Plus* thermal ionization mass spectrometer in static collection mode. Stable Nd isotope ratios are expressed using conventional delta notation, where $\delta^{146}Nd$, is the per mil deviation in the measured $^{146}Nd/^{144}Nd$ relative to the widely measured reference standard JNdi-1. A distinct advantage of the Nd double spike approach implemented here is that it allows $\delta^{146}Nd$ and $^{143}Nd/^{144}Nd$ to be obtained simultaneously from a single measurement (see McCoy-West et al., 2020b for further details), therefore allowing constraints to be placed on both the source or age of a material and the processes involved in its formation. Zircon dating was undertaken at the Australian National University, using SHRIMP-RG and standard operating conditions (e.g. McCoy-West et al., 2014; Muir et al., 1996a). Briefly, Th/U and U/Pb ratios and Pb isotopic compositions were measured in a peak-stepped cycle. Uranium and Th concentrations were normalized using the SL13 zircon (Ireland and Williams, 2003) and U/Pb was normalized using the Temora2 zircon

(Black et al., 2003). Common Pb was removed through projecting to the Concordia (^{207}Pb correction method of Muir et al., 1996a).

4.0 Results

4.1 SHRIMP geochronology

The calculated common Pb corrected ^{206}Pb-^{238}U weighted mean ages of four zircon bearing samples are summarized in Table 1, with the complete U-Th-Pb isotopic compositions presented in Supplementary Data, Table S1. Cathodoluminescence images show that zircon morphology is dependent on the bulk rock composition with the mafic samples containing subhedral to anhedral zircons that display irregular banding or weak zonation (Supplementary Data, Fig. S1 a, c), whereas the more felsic samples contain euhedral to subhedral, predominantly sector zoned zircons (Supplementary Data, Fig. S1 b, d). In all the samples the zircons are relatively coarse grained (c. 100-400 μm) and represent a single igneous crystallization episode with no inherited cores observed. Isotopic compositions are shown graphically in the form of Tera-Wasserburg concordia diagrams in Figure 3 (Tera and Wasserburg, 1972). All mean ages of the zircon populations are reported with propagated two sigma uncertainties.

A gabbroic dike (P82432) crosscutting the Greenhills Complex ultramafic rocks northwest of Bluff, has a calculated ^{206}Pb-^{238}U mean age of 256.0 ± 1.8 Ma (Fig. 3a). Three zircon bearing samples from Ruapuke Island have mean ages varying from c. 259 to 243 Ma, with the crystallization ages becoming younger to the south (Fig. 2c). A hornblende diorite (P32769) from North Head has a calculated ^{206}Pb-^{238}U mean age of 258.5 ± 2.8 Ma; a single analysis with an older concordant age of 289 ± 7 Ma is excluded from the calculated mean (Supplementary Data, Table S1; Fig 3b). A tonalite (OU38374) from the middle of Ruapuke

Island has a ^{206}Pb-^{238}U mean age of 247.8 ± 2.7 Ma. A diorite (OU38336) collected near West Point has a U-Pb mean age of 243.2 ± 2.4 Ma (two analyses with significantly younger ^{206}Pb-^{238}U ages that do not fall onto a mixing line with common Pb, were excluded due to minor Pb loss; Fig. 3c). In all cases the calculated mean ages are within uncertainty of the concordia ages (Fig. 3). Within uncertainty, these new ages fall within the range of previously published crystallization ages of c. 261 to 245 Ma from the Longwood Suite as defined in the nearby Longwood Range (McCoy-West et al., 2014; Price et al., 2006; Tulloch et al., 1999).

4.2 Major and trace element geochemistry

Major and trace element compositions of the igneous rocks investigated here are presented in Supplementary Data, Table S2. Previous work has shown that Brook Street Terrane igneous rocks are dominated by primitive basaltic and basaltic andesites (SiO_2 = 50.7 ± 3.9 wt % and MgO = 6.2 ± 2.4 wt % (1 s.d.); n = 70; Nebel et al., 2007; Robertson and Palamakumbura, 2019; Spandler et al., 2005). Our new trace element analyses confirm that Brook Street Terrane amphibolite and granofels samples from Ruapuke Island have similar compositions to these (Fig. 4). They all display moderate enrichment relative to chondrites ($Ce_{(N)}$ = 9-34) but possess flat chondrite normalized REE patterns ($La/Yb_{(N)}$ = 0.83-1.47; Fig. 4a). Primitive-mantle-normalized multi-element diagrams have positive U, Pb and Sr anomalies with strong negative depletion Nb, and Zr-Hf (Fig. 4b).

Reference samples of the Pourakino Trondhjemite of the Longwood Suite in the Longwood Range are dominated by plagioclase and quartz with (by definition) minimal alkali feldspar (Supplementary Data, Fig. S2a), whereas the younger Hollyburn Intrusives (Darran Suite) have notably higher ratios of alkali feldspar to plagioclase. Another way of showing the same thing is on an anorthite-albite-orthoclase normative diagram (Supplementary Data, Fig. S2b), in which the Pourakino Trondhjemite (Longwood Suite) is

dominated by orthoclase-poor trondhjemites and tonalites, and the Darran Suite by more orthoclase-rich granodiorites and granites. On Ruapuke Island both orthoclase-poor and -rich compositions exist, indicating that both plutonic suites are present.

Trondhjemitic and gabbroic Longwood Suite reference samples from the Longwood Range both possess relatively flat REE element patterns ($La/Yb_{(N)}$ = 0.37-3.8; Fig. 4c) that vary from slightly depleted to slightly enriched in LREE ($La/Sm_{(N)}$ = 0.23-3.1). Most samples also possess flat middle(M) REE to heavy(H) REE ($Gd/Yb_{(N)}$ = 1.2-1.8), except sample P81173 a trondhjemite dike which has a convex REE pattern ($Gd/Yb_{(N)}$ = 0.77; Fig. 4c). Multielement patterns of these samples are highly variable due to their major element composition (i.e. SiO_2 = 45-74 wt. %) and possibly also due to variable crystal accumulation in some gabbros, but most show negative depletion of Zr-Hf and Nb, and positive Pb and Sr anomalies (Fig. 4d), again P81173 is anomalous with a strong positive Hf not seen in the other samples. The samples from Ruapuke Island analysed here possess similar compositions to Longwood Suite rocks with relatively flat REE patterns ($La/Yb_{(N)}$ = 18; Fig. 4e), and unremarkable multielement patterns, although clear negative Zr-Hf depletions are observed in all samples (Fig. 4f). To compare Longwood Suite with older Tuhua Intrusives suites, we analysed a sample of Riwaka granite (c. 364 Ma, Devonian) from the northern South Island (Turnbull et al., 2017). The Riwaka Granite is different in that it is LREE enriched ($La/Yb_{(N)}$ = 18; Fig. 4e) and displays large enrichments in a range of very incompatible elements (e.g. Rb, U, Th; Fig. 4f).

4.3 Radiogenic Sr-Nd isotopes

Isotopic compositions of 17 samples are presented in Table 2. New analyses of plutons and dikes from the Hekeia Gabbro and Pourakino Trondhjemite all have primitive isotope compositions with unradiogenic $^{87}Sr/^{86}Sr_{(t)}$ of < 0.7033 and radiogenic $\varepsilon^{143}Nd_{(t)}$ > +6 (Fig. 5), consistent with previous analyses of the Longwood Suite in the same area (Mortimer et al.,

1999a; Price et al., 2006; Tulloch et al., 1999). The dike from the Greenhills Intrusive Complex (P82432) dated here at 256.0 ± 1.8 Ma also has an isotope composition ($^{87}Sr/^{86}Sr_{(t)}$ = 0.7032; $\varepsilon^{143}Nd_{(t)}$ = +8.0−8.2) that matches other Longwood Suite rocks. Four samples from Ruapuke Island, which vary from gabbroic to tonalitic, present comparable unradiogenic Sr and radiogenic Nd ($^{87}Sr/^{86}Sr_{(t)}$ = 0.7029-0.7032; $\varepsilon^{143}Nd_{(t)}$ = +6.3−7.7). Combined with the U-Pb ages, the Sr and Nd isotope data establish an important correlation of these Ruapuke Island plutons to the Longwood Suite (Fig. 6). The Riwaka Granite has significantly more radiogenic Sr and unradiogenic Nd ($^{87}Sr/^{86}Sr$ = 0.7095; $\varepsilon^{143}Nd$ = -3.1 to -3.3) than Longwood Suite magmas, instead being closer in composition to the older Devonian-Carboniferous magmatic suites (Supplementary Data, Fig. S3; Muir et al., 1998; Muir et al., 1996b; Tulloch et al., 2009).

Our new samples of Brook Street Terrane in southern South Island possess radiogenic $\varepsilon^{143}Nd_{(t)}$ > +6, in agreement with previous analyses (Fig. 6; Adams et al., 2005; Frost and Coombs, 1989; Nebel et al., 2007), and generally unradiogenic $^{87}Sr/^{86}Sr_{(t)}$ of <0.7033, although two of the samples display more radiogenic Sr compositions (P84061: $^{87}Sr/^{86}Sr_{(t)}$ = 0.7037; P32787: $^{87}Sr/^{86}Sr_{(t)}$ = 0.7044). The samples from Ruapuke Island also show primitive isotope compositions with $^{87}Sr/^{86}Sr_{(t)}$ <0.7030 and $\varepsilon^{143}Nd_{(t)}$ >+8 (Fig. 5).

4.4 Stable Nd isotopes

No correlations are observed between $\delta^{146}Nd$ and either Nd concentration or $^{143}Nd/^{144}Nd$ (Supplementary Data, Fig. S4). Samples of Brook Street Terrane from both the southern South Island and Ruapuke Island possess a restricted range of $\delta^{146}Nd$ from −0.053 ‰ to −0.027 ‰ ($\delta^{146}Nd$ = 26 ppm), despite possessing a wide range of Nd concentrations from 6.1 to 18.8 ppm (Supplementary Data, Fig. S4; Table 2). This range is comparable with previously measured $\delta^{146}Nd$ compositions of basaltic igneous rocks (Fig. 7; McCoy-West et al., 2021; McCoy-West et al., 2017, 2020a; McCoy-West et al., 2020b) and within

uncertainty of the average composition of bulk silicate Earth ($\delta^{146}Nd = -0.024 \pm 0.031$ ‰; McCoy-West et al., 2021). The plutonic rocks from Ruapuke Island also possess a restricted range of $\delta^{146}Nd$ with values from −0.051 ‰ to −0.015 ‰ ($\delta^{146}Nd$ = 36 ppm; Fig. 6). Nd stable isotope compositions of samples in the Longwood Suite are significantly more variable with $\delta^{146}Nd$ ranging from −0.075 ‰ to +0.158 ‰ ($\delta^{146}Nd$ = 223 ppm; Fig. 6), although most of this variability is restricted to samples with low Nd concentrations < 2.8 ppm (Supplementary Data, Fig. S4). Two notable samples are a Pourakino Trondhjemite dike sample (P81173: $\delta^{146}Nd = 0.149 \pm 0.023$ ‰; n = 2) and Hekeia Gabbro sample (P82430: $\delta^{146}Nd = 0.057 \pm 0.023$ ‰; n = 2), with the former possessing the heaviest $\delta^{146}Nd$ observed so far in terrestrial magmatic rocks. Large fractionations in $\delta^{146}Nd$ are observed at both high and low Mg# and SiO_2 contents (Fig. 7). While samples with low P_2O_5 contents (< 0.08 wt %) generally display variations from the bulk silicate Earth $\delta^{146}Nd$ composition (Fig. 7c).

5.0 Discussion

5.1 Ruapuke Island geology

Despite its small 16 km^2 size, Ruapuke Island has a complex geologic history (Webster, 1981), with rocks spanning at least c. 60 Ma (this study). Like the Longwood Range and Bluff area, it is one of the few places in New Zealand where an unfaulted intrusive boundary between the Brook Street Terrane and Median Batholith is exposed. Metavolcanic hornblende hornfels rocks correlated with Greenhills Group (Brook Street Terrane) outcrop on the eastern side of Ruapuke Island, with a widespread intermingled zone (up to 1 km wide) where the leucotonalite that dominates the island intrudes the hornblende hornfels (Fig. 2c; Webster, 1981). Two samples of the hornblende hornfels show isotope compositions more primitive than Longwood Suite with $^{87}Sr/^{86}Sr_{(t)} = 0.7028$-$0.7029$ and $\varepsilon^{143}Nd_{(t)} = +8.5$ confirming their links to the broader Brook Street Terrane (Table 2; Fig. 5). As mapped by

Webster (1981), the majority of Ruapuke Island is dominated by tonalite, a sample of which we have U-Pb dated at 247.8 ± 2.7 Ma (Table 1; Fig. 3). Two more mafic plutons from the coast of Ruapuke Island are older and younger, with a hornblende gabbro from North Head dated at 258.5 ± 3.0 Ma (which is with uncertainty of magmatism in the Bluff Intrusive Complex), and a diorite from West Point dated at 243.2 ± 2.5 Ma (Fig. 2c). These samples also possess unradiogenic Sr and radiogenic Nd ($^{87}Sr/^{86}Sr_{(t)} < 0.7033$; $\varepsilon^{143}Nd_{(t)} > +6.3$) comparable compositions to Longwood Suite samples from the mainland and are now included in this suite based on their age and isotopic similarity. A geochemically distinct quartz monzodiorite outcrops in the southern portion of the Ruapuke Island (Fig. 2c), and gave the aforementioned K-Ar hornblende age of 222 Ma. It also has a distinctly lower $\varepsilon^{143}Nd_{(t)}$ of +4.2 (Tulloch, 2001) than rocks of the Longwood Suite. Both the 222 Ma age (which we interpret as approximating an unreset cooling age) and geochemistry confirm it is part of the Darran Suite (Fig. S2 and see section 5.3 for further discussion). The four dated samples from Ruapuke Island varying from c. 259 to c. 222 Ma, and become progressively younger to the south (Fig. 2c). This age progression is comparable to what is observed from east to west in the Longwood Range and nearby coast (see Figure 2 in McCoy-West et al., 2014), although the Longwood Range has been rotated due to the large scale regional deformation of New Zealand's lithostratigraphic terranes associated with oroclinal bending (Mortimer, 2014; see Figs. 1 or 8).

5.2 Improved understanding of the timing and extent of the Longwood Suite

Despite the protracted history of the Median Batholith (c. 495-105 Ma), the Longwood Suite is unique in that it possesses primitive Sr-Nd isotope compositions (Fig. 5; $^{87}Sr/^{86}Sr_{(t)} = \leq 0.7033$; $\varepsilon^{143}Nd_{(t)} = \geq 5.4$) combined with radiogenic $^{176}Hf/^{177}Hf$ (Nebel et al. 2007), which

reflects direct extraction from the mantle with limited or no input (contamination) from crustal reservoirs. In this respect it differs from both older and younger plutonic suites (Fig. 9) that spatially, lie within the outcrop envelope of the Median Batholith further to the south and west (e.g. Stewart Island and Fiordland see Fig. 1). As originally defined, the Longwood Suite (McCoy-West et al., 2014) included the Late Permian to Middle Triassic (c. 261-245 Ma) isotopically primitive plutonic bodies (e.g. Hekeia Gabbro and Pourakino Trondhjemite; Fig. 2) in the Longwood Range, as well plutons of comparable age of the Bluff Intrusive Complex. A gabbroic dike (P82432) from the Greenhills Intrusion, Bluff Intrusive Complex, dated here at 256.0 ± 1.8 Ma, agrees within uncertainty with previous ages of the nearby Flat Hills Intrusion of 256.3 ± 4.0 Ma (^{238}U-^{206}Pb bulk age; Kimbrough et al., 1992) and 259.1 ± 4.4 Ma (Price et al., 2006). Furthermore, the Sr-Nd isotope composition of this sample ($^{87}Sr/^{86}Sr_{(t)}$ = 0.7032; $\varepsilon^{143}Nd_{(t)}$ = 8.0-8.2) confirms for the first time an isotopic as well as age correlation between these distinct plutonic bodies in Longwood Range and Bluff areas (≥30 km apart). Despite considerable geochemical (SiO_2 = 47.9 to 63.7 wt %) and lithologic variability (gabbro to leucotonalite), all of the Ruapuke samples analysed possess primitive Sr-Nd isotope compositions (Fig. 5; $^{87}Sr/^{86}Sr_{(t)}$ = 0.7029-0.7032; $\varepsilon^{143}Nd_{(t)}$ = 6.3-7.7), confirming their assocation with the Longwood Suite. The three dated plutonic rocks from Ruapuke Island have U-Pb zircon crystallization ages ranging from 258.5 ± 3.0 Ma to 243.2 ± 2.5 Ma (Table 1; Fig. 3), which are comparable to, but extend to a slightly younger age, than the existing geochronology of the Longwood Suite (McCoy-West et al., 2014; Mortimer et al., 1999a; Price et al., 2006; Tulloch et al., 1999). Consequently, we now propose an age range of c. 261-243 Ma for the Longwood Suite. The inclusion of samples from Ruapuke Island slightly broadens the extent of the Longwood Suite plutonism in both time (c. 2 Ma) and space, with the outcrop strike length of the Longwood Suite now c. 25 km further southeast (Fig. 8). Although this may seem a minor point, in this paper we have increased the

number of dated Longwood Suite samples by c. 40 %, and those with isotopic fingerprinting by c. 56 %. Further afield, and as discussed below (Section 5.7), Permian to Triassic I-type plutonic rocks of the New England Orogen, Australia may be related (e.g. Bryant et al., 1997).

5.3 Distinguishing the Longwood and Darran suites

The complexity of the Median Batholith, where multiple episodes of plutonism occur in close proximity, means that both age and geochemical relationships are used to define plutonic suites (e.g. Allibone et al., 2009; Tulloch et al., 2009). Samples from the Longwood and Darran suites are present in the inland Longwood Range, along the Longwood coast and on Ruapuke Island (Fig. 2). Furthermore, the ages of the two suites (see Fig. 8b and Supplementary Data, Fig. S5) are only locally separated by c. 11 Ma (243.2 ± 2.4 to 232 ± 1.5 Ma; herein and McCoy-West et al., 2014, respectively) and by only c. 4 Ma if the 238.7 ± 2.4 Ma Mt. Edgar Diorite Darran Suite age of Ringwood et al. (2021) is used. The Longwood Suite ($\varepsilon^{143}Nd_{(t)}$ = +6.78 ± 1.46; 2 s.d. n = 31) can be easily distinguished from the Darran Suite ($\varepsilon^{143}Nd_{(t)}$ = +3.68 ± 1.33; 2 s.d. n = 38) based on their distinct radiogenic Nd isotope compositions (Fig. 10a). However, isotopic analyses are only available for a small proportion of samples, so we have investigated a range of other geochemical criteria, which can be used to distinguish Longwood from Darran rocks. Longwood Suite samples have distinctive flat REE patterns (Fig. 4) and at comparable SiO_2 have lower $La/Sm_{(N)}$ than samples from the Darran Suite (Fig. 10b). When focussing only on granitoids ($SiO_2 \geq 64$ wt %) the Longwood samples have significantly lower K/Na (≤ 0.4; Fig. 10c) and Rb (≤ 10; Fig. 10d) than Darran rocks with similar SiO_2. Interestingly, the Longwood Suite samples also possess distinctive low Nb/Ta (≤ 5; n = 6), which is not observed elsewhere in the plutonic record of the Median Batholith (Fig. 9d). Another widely used parameter to distinguish between plutonic suites is

Sr/Y (e.g. Allibone et al., 2007; Tulloch and Kimbrough, 2003), which has been taken as being indicative of the depth of melting (i.e. high Sr/Y is consistent with a deeper garnet bearing melting region; Moyen, 2011). Although extremely variable (Fig. 9b: note the log scale), most granitoids from the younger Separation Point Suite are dominated by high Sr/Y ($\geq$ 40 after Drummond and Defant, 1990) with a median Sr/Y of 125 (Sr/Y = 11-829; n = 112), whereas most Darran Suite granitoids have significant lower Sr/Y with an median value of 24 (Sr/Y = 2-329; n = 105). The high-Na granitoids of the Longwood Suite appear intermediate between these two suites with Sr/Y ranging from 39 to 342 and a median value of 76 (n = 18; Fig. 9b). This excludes the chemically distinct high-K (K/Na >1.5) Oraka Point granites that have significantly lower Sr/Y values of 8-9 (n = 2).

Previous researchers have used Sr/Y to calculate crustal thickness (e.g. Chapman et al., 2015; Profeta et al., 2015), however, the observation of intermediate Sr/Y in the Longwood Suite suggests this parameter is not always a reliable proxy for melting depth. As well as their intermediate Sr/Y Longwood Suite magmas also possess very low $La/Yb_{(N)} < 10$, and significantly flatter REE patterns than comparable rocks in the Darran Suite (Fig. 4c and 10b) and Tuhua Intrusives (Fig. 9c). When calculating crustal thickness (after Profeta et al., 2015 using rocks with SiO_2 = 55 to 68 wt %) based on median $La/Yb_{(N)}$ and Sr/Y results in disparate crustal thickness estimates of c. 27 km and > 60 km, respectively. Mantle and Collins (2008) tracked Ce/Y in basaltic samples through time in New Zealand to reconstruct Moho depth (see Figure 3 therein), with the results suggesting a minimum in crustal thickness of <25 km around 260 Ma, which agrees much better with the $La/Yb_{(N)}$) crustal thickness estimate. Aluminium in hornblende geobarometry by Mortimer et al. (1999a)indicated Pourakino Trondhjemite emplacement depths of 5-9 km. Therefore, we advocate caution when applying Sr/Y in isolation to reconstruct crustal thickness.

5.4 Using Stable Nd isotopes to constrain magmatic petrogenesis

Unlike radiogenic isotope systems, stable isotope compositions are time-independent tracers of the processes a sample has experienced and thus may provide unique insights into the petrogenesis of igneous rocks (e.g. Dauphas et al., 2009; McCoy-West et al., 2019; Savage et al., 2011). Due to its high molar mass, and monovalent nature at magmatic temperatures, fractionations of Nd stable isotopes would be predicted to be small. Although the application of Nd stable isotopes remains in its infancy, resolvable fractionations in igneous rocks are widespread (McCoy-West et al., 2021; McCoy-West et al., 2017, 2020a; McCoy-West et al., 2020b). A global compilation of magmatic rocks including mid-ocean ridge, ocean island and island arc basalts possess Nd stable isotope compositions from −0.061 ‰ to +0.022 ‰ (δ^{146}Nd = 83 ppm), with the average composition of the bulk silicate Earth calculated as δ^{146}Nd = −0.024 ± 0.031 ‰ (2 s.d.; n = 80; McCoy-West et al., 2021). The Brook Street Terrane consists of basaltic volcanic and volcaniclastic rocks (e.g. Frost and Coombs, 1989; Spandler et al., 2005), all measured samples possess a restricted range of δ^{146}Nd from −0.053‰ to −0.027 ‰ (δ^{146}Nd = 26 ppm; n = 6; Fig. 6), which is indistinguishable from the composition of the bulk silicate Earth. The relatively invariant δ^{146}Nd composition of these basaltic metasediments (i.e. hornfels) is consistent with contact metamorphism having had no resolvable effect on their Nd stable isotope compositions.

In contrast, the plutonic rocks of the Longwood Suite are significantly more variable with δ^{146}Nd ranging from −0.075 ‰ to +0.158 ‰ (δ^{146}Nd = 223 ppm; n = 10; Fig. 6). This range is substantially larger than that seen previously in plutonic rocks (δ^{146}Nd = 44 ppm; McCoy-West et al., 2017) or oceanic gabbros from Hole 735B which, although variable, extend towards isotopically light compositions (i.e. to –0.127 ‰; δ^{146}Nd = 101 ppm; Fig. 6). Due to the incompatible nature of Nd in the dominate silicate phases involved in mafic magmatic processes ($D_{Nd} \leq 0.01$ to 0.4; McCoy-West et al., 2021), no resolvable effects of magmatic

differentiation (between 50 and 70 wt % SiO_2) are observed on Nd stable isotope compositions (McCoy-West et al., 2021; McCoy-West et al., 2017, 2020a). Instead the light $\delta^{146}Nd$ values observed in the oceanic gabbros were attributed to kinetic isotope fractionation, as the result of diffusion across disequilibrium boundaries, during repeated melt migration through the oceanic crust (McCoy-West et al., 2020a). No petrologic evidence exists for repeated melt percolation in the Longwood Suite rocks. However, the crystallization of REE-bearing accessory phases (e.g. monazite, allanite, xenotime, titanite or apatite), which can incorporate significant concentrations of LREE (up to 1000 fold enrichment; Exley, 1980; Hoskin, 2000) could generate stable isotope fractionations as suggested previously (McCoy-West et al., 2017; McCoy-West et al., 2020b). The crystallization of monazite, or other trace phases, is predicted to preferentially sequester light Nd isotopes, due to the effect of variations in Nd coordination environment between the accessory minerals and silicate melt. In the Longwood Suite rocks, larger fractionations of $\delta^{146}Nd$ from the composition of the bulk silicate Earth are observed in both the most primitive and evolved plutonic rocks (e.g. low and high SiO_2 and Mg#; Fig. 7), however, all samples with variable $\delta^{146}Nd$ have low P_2O_5 contents (< 0.08 wt %; Fig. 7c), which is reflective of the prior removal of phosphate minerals. For example, the heaviest sample (P81173; $\delta^{146}Nd$ = +0.158 ‰) is a highly evolved (SiO_2 > 74 wt %) narrow trondhjemite dike with very low P_2O_5 (0.02 wt %), hence we infer that the crystallization and settling of monazite ([Ce,La,Nd,Th]PO_4) in the primary magma chamber, would leave the residual melt isotopically heavy explaining the dike's composition. In exploring such fractionation processes, geochemistry is a better tool than modal petrography; monazite is only ever an accessory phase and would, in the case of P81173, have been removed prior to crystallization of the trondhjemite. Further investigations of comagmatic samples that fractionate REE-bearing accessory minerals are clearly warranted.

5.5 Magmatic flux rates

The rate and duration over which new cogenetic material is added to a magmatic arc ultimately has implications for the tectonic processes that generated the magmas (e.g. Milan et al., 2017; Paterson et al., 2011). Calculations of the volume addition and flux rates of plutons and suites are highly dependent on, and vulnerable to, assumptions on age range, areal extent and intrusive depth. Nonetheless, we here make areal addition rate estimates for the Longwood Suite (Table 3), based on mapped areas of plutons and their ages (Mortimer et al., 2016; Turnbull and Allibone, 2003; this study). Note that we use areal addition rates (km^2/Ma) not the more speculative volume addition rates (km^3/Ma) which make assumptions on crustal thickness and vertical pluton extent. In the inland Longwood Range and nearby coast, the 258-245 Ma Hekeia Gabbro is c. 99 km^2 in area, the 261-253 Ma Pourakino Trondhjemite 65 km^2, and the 232-203 Ma Darran Suite plutons 83 km^2 (Fig. 2a). Taken at face value, these GIS-calculated areas and age ranges give areal addition rates of 10 km^2/Ma and 3 km^2/Ma for Longwood and Darran suites, respectively. Further afield, the 24 km^2 Bluff Intrusive Complex is almost all gabbroic and peridotitic (Fig. 2b). Ruapuke Island is dominated by 10.9 km^2 of Longwood Suite granitoids, with a further c. 1.1 km^2 of Longwood Suite gabbroids and only 0.7 km^2 of Darran Suite rocks (Fig. 2c). Applying the wider age range of 261-243 Ma (= 18 Ma) to the wider (but still onland area) of 201 km^2 gives an areal addition rate of 11 km^2/Ma for the entire onland Longwood Suite as presently known. However, the presence of semi-continuous positive magnetic anomalies in Foveaux Strait (Thomson Aviation, 2020) can be used to infer a greater undersea areal extent of the Longwood Suite between the Longwoods and Ruapuke Island, perhaps c. 770 km^2 which would yield an areal addition rate as high as 43 km^2/Ma. In Fiordland, areal addition rates of 67 km^2/Ma, and 105-375 km^2/Ma have been calculated for the 167-127 Ma part of the Darran Suite and the 125-115 Ma Separation Point Suite, respectively (Milan et al., 2017).

Notwithstanding the uncertainties in these calculations, they demonstrate that the Longwood Suite is in fact a very low flux event for this portion of the Gondwana margin.

5.6 Trondhjemite petrogenesis

The Longwood Suite preserves the coeval emplacement of primitive ultramafic-mafic and felsic plutons. Bimodal magmatism is usually a feature of extensional and/or rift tectonic settings and is generally absent in convergent margin magmatism (e.g. Wilson, 1989). As shown in Figure 6 of Mortimer et al. (1999a), Hekeia Gabbro plagioclase and olivine compositions are broadly similar to those in other gabbros from global arc cumulates. The trace element composition of the Pourakino Trondhjemite are also comparable to those of global arc granitoids (i.e. Fig. 10d). Price et al. (2011) strongly emphasized the I-type nature of the Permian and Triassic Longwood and Darran suites along the Longwood coast.

Longwood Suite plutons possess extremely primitive radiogenic isotope compositions indicative of extraction from the mantle with limited to no crustal input ($\varepsilon^{143}Nd_{(t)} > +5.5$; $^{87}Sr/^{86}Sr_{(t)} < 0.7032$; Fig. 5). However, the low Mg-number (Mg# ≤ 0.35) and Ni concentrations (≤ 10 ppm) of the Pourakino Trondhjemite, which are not in equilibrium with the mantle, confirm these melts do not represent direct extraction from the mantle. This characteristic is consistent with the well-established paradigm that trondhjemites are generated by partial melting of metamorphosed mafic rocks (e.g. Barker and Arth, 1976). It is noteworthy that the Pourakino Trondhjemite is 40 % by area of the Longwood Suite, thus a large volume of mafic protolith would have needed to have partially melted to yield such a large pluton. Similar to most other Phanerozoic trondhjemites (Tate et al., 1999; Wolf and Wyllie, 1994), the Pourakino Trondhjemite possesses extremely flat REE patterns (e.g. $La/Yb_N < 10$; $La/Sm_N < 5$; see Fig. 4) consistent with shallow melting in the absence of

residual garnet (Bryant et al., 1997; Gromet and Silver, 1987). Although the presence of garnet will be composition dependent, dehydration melting experiments are consistently garnet absent at < 0·8 GPa (c. 28 km; Rapp et al., 1991; Rushmer, 1991). Another striking feature of the Pourakino Trondhjemite is the distinctive low Nb/Ta ≤ 5 seemingly caused by low Nb values (Fig. 9). Due to their comparable geochemical behaviour, the fractionation of Nb from Ta during magmatic differentiation is unlikely and thus is probably a magma source signature. Experimental work has demonstrated that Nb/Ta fractionation is possible when residual (paragasitic) amphibole is present in the melting region (Li et al., 2017; Tiepolo et al., 2001). Alternatively, the low Nb/Ta could be inherited directly from the precursor (Rapp et al., 2003), although most samples of the Brook Street Terrane possess near-chondritic Nb/Ta with only a few samples having low Nb/Ta < 5 (3/18; this paper and Spandler et al., 2005), making melting in the amphibole stability field the most likely scenario. All of the aforementioned geochemical characteristics, in combination with a shallow Moho at 260 Ma (Mantle and Collins, 2008), are consistent with generation of the Pourakino Trondhjemite by shallow melting (< 28 km) of an amphibolitic residue at the base of a thinned lithosphere.

5.7 Gondwana margin correlations and tectonic model

Permian and Triassic intrusions are also present along strike from the South Island (see Fig. 11) in the New England Orogen of eastern Australia (Cawood et al., 2011a; Cawood, 1984; Donchak et al., 2013; Rosenbaum, 2018). Early Permian (c. 295-280 Ma) New England granitoids are mainly S-type (Shaw et al., 2011) and are deformed around an oroclinal bend in the orogen (Bryant et al., 1997; Cawood et al., 2011b; Jessop et al., 2019). In contrast, Middle Permian to Middle Triassic (c. 270-235 Ma) granitoids, including the Clarence River Supersuite of Shaw and Flood (1981) form post-bending linear belts that were

intruded during a protracted compression phase (c. 270-260 Ma) of the Hunter-Bowen orogeny, part of the broader Gondwanide Orogeny (Cawood et al., 2011a; Cawood, 2005; Jessop et al., 2019). Some (but not all) of the Clarence River Supersuite plutons possess zircons with exceptionally primitive mantle-like $\varepsilon^{176}Hf$ values (Kemp et al., 2009; Shaw et al., 2011), which are correlated with their whole rock Sr-Nd isotope compositions (up to $\varepsilon^{143}Nd = +6$; Bryant et al., 1997; Hensel et al., 1985). This pulse of primitive east Australian magmatism is analogous to that observed in Zealandia. Mortimer et al. (2011) also noted that the platinum prospectivity of the layered Hekeia Gabbro was shared by some Late Permian to Middle Triassic layered mafic intrusions (Fig. 11b) in the northern New England orogen (e.g. Wateranga (244 Ma), Eulogie Park and Bucknalla intrusions; Donchak et al., 2013; Talusani et al., 2005). Additional evidence of mantle-dominated magmatism relatively uncontaminated by continental crust or lithosphere is seen in other geochemical datasets of the Permian Gondwana margin. These include the distinctive low Ce/Y ratios in basaltic and gabbroic rocks (Mantle and Collins, 2008), a c. 247 Ma granodiorite with $\varepsilon^{143}Nd_{(t)} = 6.4$ from the West Norfolk Ridge (Mortimer et al., 1998), and elevated $\varepsilon^{176}Hf$ seen in detrital zircons shed from the Gondwana margin (Campbell et al., 2020; Nelson and Cottle, 2017).All of these datasets, as well as the aforementioned characteristics of the New Zealand and Australian plutons, indicate that Gondwanan rocks and zircons of pre- and post-Permian age are isotopically less primitive than those of Permian age.

Based on these studies and our own observations we propose a mechanism whereby, in the Permian, pre-existing Gondwana subcontinental lithospheric mantle was replaced by crust and mantle of the Brook Street Terrane, and its Australian equivalent, the Gympie Terrane (Fig. 11a). This Early Permian time interval (c. 300-260 Ma) corresponds to an episode of inferred transpression, oroclinal bending, terrane accretion and stepping out of the continent-ocean boundary in the New England orogen (Cawood et al., 2011b; Rosenbaum, 2018;

Veevers, 2004). As revealed in Figure 8, it was also a pronounced magmatic lull or gap in the Median Batholith (Zealandia part of Gondwana). That a period of seemingly no plutonism was preceded by the A-type Foulwind Suite (Tulloch et al., 2009) suggests that the Zealandia segment of Gondwana, was not necessarily a convergent margin during that interval but that it lay offshore, east of a parautochthonous Gympie-Brook Street arc (e.g. Li et al., 2015; Robertson and Palamakumbura, 2019). From the Late Permian (c. 260 Ma) onwards a new, convergent, phase of Gondwana margin development began (Fig.11b). We propose that this convergence caused tectonic underplating of the Brook Street Terrane and Gympie Terrane mafic arc crust and underlying mantle under the Gondwana margin. Melting of the underplated mantle would have given rise to the Hekeia Gabbro, and melting of the underplated mafic crust would produce the Pourakino Trondhjemite. The Late Permian Productus Creek Group of the Brook Street Terrane was still being deposited in the early stages of the underplating (Fig. 11b). The new Late Permian-Middle Triassic magmatic arc was emplaced across the previously formed oroclinal bend and was broadly co-eval with the compressional Hunter-Bowen Orogeny(Cawood et al., 2011b; Rosenbaum, 2018). The isotopically primitive, largely bimodal plutonism of the Longwood Suite was relatively short-lived and, as the magmatic arc matured, migrated, and thickened, became supplanted by more 'normal' gabbro-diorite-granodiorite-granite Darran Suite magmatism.

5.8 Episodicity and growth of the Cordilleran Median Batholith

It has long been noted (e.g. Mortimer et al., 1999b; Price et al., 2006; Tulloch and Kimbrough, 2003) that the axis of Mesozoic continental magmatism, as defined by pluton crystallization ages, migrated west in southern South Island from the Triassic to Early Cretaceous. As more plutons have been dated it has been possible to go from a very

provisional picture of magmatic pulses and gaps (e.g. see Figure 4 in Mortimer et al., 1999b) to more a complete picture of magma flux rates (e.g. see Figure 3 in Ringwood et al., 2021). The establishment of the Late Permian Longwood Suite (McCoy-West et al. 2014; this paper) defines even longer spatial and temporal baselines, and wider isotopic and geochemical variations in this across-strike migration of continental arc volcanism than has previously been recognized in New Zealand (Fig. 8; cf. Chapman et al., 2017) .

Plutons of the 350-342 Ma I-type Tobin Suite are interpreted to represent continental arc magmatism (Tulloch et al., 2009). As yet no clearly subduction-related plutons in New Zealand's Median or other batholiths have been dated in the interval 342-261 Ma. The presence of scattered plutons of the anorogenic A-type Foulwind Suite (Fig. 8b; c. 330-305 Ma) reaffirms that for c. 80 Ma. there was seemingly no magmatic record of subduction under the Zealandia part of the Gondwana supercontinent margin. The re-initiation of isotopically primitive Longwood Suite continental arc magmatism at c. 261 Ma was thus an episode of major tectonomagmatic change. The isotopically primitive nature of the Longwood Suite (Fig. 5) fits with its easterly position (Fig. 8a) in as much as deeper domains of radiogenic crust would be thin or absent. The slightly more isotopically evolved (yet younger) Darran Suite, lying to the west might have interacted with a different and distinct lower crustal block within its source region (cf. Chapman et al., 2017).

With the eastward growth of the Eastern Province accretionary wedge in the Mesozoic, a westward migration of subduction-related co-eval magmatism (Longwood to Darran to Separation Point suites; Fig. 8a) had to have been accompanied by a long-term shallowing of the dip of the subducting slab. The role of deep crustal domains in the overriding Gondwana plate as controls on magma chemistry has started to be revealed by recent studies (e.g. Schwartz et al., 2021; Turnbull et al., 2021) and the Longwood Suite will be a useful end-member to incorporate in future interpretations.

6.0 Conclusions

The Late Permian to Middle Triassic Longwood Suite, the easternmost plutonic suite in the Median Batholith, is isotopically more primitive and chemically distinct from both the older and younger suites of the Median Batholith. Our new geochronological and geochemical study of the coeval plutons of leucotonalite (trondhjemites) that intrude layered mafic-ultramafic plutonic complexes of the Longwood Suite confirms and extends earlier interpretations by McCoy-West et al. (2014):

(1) We define new geochemical criteria to characterize Longwood Suite granitoids. Longwood Suite granitoids are I-type and sodic (K/Na < 0.4), with distinctive low Rb and Nb/Ta and notably flat rare earth element patterns ($La/Yb_N < 10$). They also have uniquely unradiogenic $^{87}Sr/^{86}Sr_{(t)}$ (0.7029 to 0.7032) and radiogenic $\varepsilon^{143}Nd_{(t)}$ (+6.3 to +8.2), which clearly distinguishes them from the I-type Darran Suite plutons that intrude them.

(2) New U-Pb zircon crystallization ages of 258.5 ± 2.5 Ma, 256.0 ± 1.8 Ma, 247.8 ± 2.7 Ma and 243.2 ± 2.4 Ma obtained from plutons on Ruapuke Island, and a gabbroic dike at Bluff, supplement previous geochronology. These ages confirm the restricted time range (c. 261-243 Ma) of the Longwood Suite and expand its areal extent south into Foveaux Strait.

(3) Longwood Suite samples have highly variable stable Nd isotope compositions (−0.075 ‰ to +0.158 ‰; $\delta^{146}Nd$ = 233 ppm) compared to previously analysed plutonic rocks ($\delta^{146}Nd$ = 44 ppm), which are indistinguishable from bulk silicate Earth. A Pourakino Trondhjemite dike has the heaviest $\delta^{146}Nd$ observed globally at +0.158 ‰. This heavy composition requires light Nd isotopes to have been sequestered into REE-rich

accessory phases (e.g. monazite), which must have remained trapped in the parental magma chamber.

(4) Despite its primitive character based on onland exposure areas only, the Longwood Suite has a maximum areal magma addition rate of c. 11 km^2/Ma, which is substantially less than the 27-67 km^2/Ma and 105-375 km^2/Ma of the Darran Suite and Separation Point Suite, respectively, when the magmatic arc was fully established.

(5) Prior to primitive Permian magmatism, the Gondwanan lithosphere is inferred to have been thin, as demonstrated by extension and basin development along this segment of the Gondwana margin. This is consistent with the geochemical characteristics of the Pourakino Trondhjemite (i.e. low $La/Yb_{(N)}$ and Nb/Ta) which indicate generation by shallow melting (< 28 km) of an garnet-free amphibolitic residue. In this instance, calculations of crustal thickness using Sr/Y produce highly erroneous results.

(6) Collectively, these unique petrologic and geochemical features point to a special tectonomagmatic setting for petrogenesis and emplacement of the Longwood Suite, effectively the re-initiation of a subduction-related continental arc. We suggest a model for Longwood Suite magmagenesis involving a phase of renewed Gondwana margin tectonic convergence (the Hunter-Bowen orogeny). This convergence led to the tectonic underplating of Permian intra-oceanic island arc crust and mantle under the Gondwana margin. In turn, melting of the underplated arc crust and mantle generated the isotopically primitive Longwood Suite trondhjemite and gabbro plutons.

Collision and underplating of mafic oceanic terranes, including large igneous provinces, with a continental margin is not uncommon in the geological record. Largely bimodal plutonism may be one consequence of such events.

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AUTHOR CONTRIBUTIONS

AMW: Conceptualization, Investigation, Visualization, Formal analysis, Methodology Writing - Original Draft; **NM:** Conceptualization, Visualization, Writing- Original Draft; **KB:** Resources, Funding acquisition; **TI:** Resources, Validation; **PC:** Writing- Reviewing and Editing, Funding acquisition

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Figure captions

Figure 1: Geological map of the southern South Island of New Zealand, modified after Turnbull and Allibone (2003) and McCoy-West et al. (2014). The box in the inset shows the area of the larger map. Areas labelled A, B, C, D refer to maps shown in Figure 2. PGC = Productus Creek Group

Figure 2: Sample locations, ages, and Nd isotope compositions in the context of local geology. (a) Longwood Range (Mortimer et al., 2016). Zircon crystallization ages for the Hekeia Gabbro are from McCoy-West et al. (2014). (b) Bluff area (Turnbull and Allibone, 2003). (c) Ruapuke Island (Webster, 1981). Inferred crystallization age and Nd isotope composition of Darran Suite sample P32760 are taken from Devereux et al. (1968) and Tulloch (2001), respectively. (d) Riwaka area, northwest Nelson (Rattenbury et al., 1998).

Figure 3: Tera-Wasserburg U-Pb zircon concordia plots of SHRIMP analyses of plutonic rocks from the Longwood Suite. (a) Greenhills Intrusion, Bluff Intrusive Complex, Bluff Peninsula; (b-d) Ruapuke Island plutons. Error ellipses are 1 s.d. uncertainties. Both common-Pb corrected ^{206}Pb-^{238}U weighted mean ages (bold) and concordia intercept ages are reported with 2 s.d. uncertainties. The dashed line connects the concordia intercept age with composition of common Pb ($^{207}Pb/^{206}Pb$ = 0.83). Analyses excluded from mean calculations are plotted with white circles and error ellipses.

Figure 4: Rare earth element and multi-element whole rock patterns for igneous rocks from southern New Zealand, chondrite-normalized and primitive mantle-normalized, respectively (Palme and O'Neill, 2014). (a-b) Brook Street Terrane samples, comparative data is taken from Spandler et al. (2005). (c-d) Intrusive Longwood Suite samples from the South Island. Existing data for the Pourakino Trondhjemite (Nebel et al., 2007) and Hollyburn Intrusives, Darran Suite (Price et al., 2006). (e-f) Ruapuke Island Intrusives and the Riwaka Granite, northwest Nelson compared to Longwood Suite.

Figure 5: Age corrected $^{87}Sr/^{86}Sr$ and $\varepsilon^{143}Nd$ of magmatic rocks from southern New Zealand. Plutonic rocks are age corrected to their crystallization ages (Longwoods Suite: 261-243 Ma; Darran Suite: 232-128 Ma; Separation Point Suite: 125-115 Ma), with the age of the Brook Street Terrane samples assumed to be 285 Ma. We regard the Nd isotopic composition as less vulnerable to secondary processes than Sr isotopic composition, and therefore more reliable for comparative purposes. Hollow symbols represent previously published data for the suites analysed here. Previous data sources are as follows: Separation Point Suite (Muir et al., 1998; Muir et al., 1995); Darran Suite (Mortimer et al., 1999a; Muir et al., 1998; Price et al., 2006; Tulloch, 2001; Turnbull et al., 2010); Longwood Suite (Mortimer et al., 1999a; Price et al., 2006; Tulloch et al., 1999); Brook Street Terrane (Adams et al., 2005).

Figure 6: Comparison of $\delta^{146}Nd$ in extrusive and plutonic rocks from the South Island of New Zealand with global magmatic rocks. Data points are plotted with the long-term reproducibility of $\delta^{146}Nd$ (± 0.015‰). The yellow shaded area represents the bulk silicate Earth (BSE) average ($\delta^{146}Nd$ = −0.024 ± 0.031‰ (2 s.d.); McCoy-West et al., 2021). The shaded fields for the Brook Street Terrane and Longwood Suite also reflect ± 2 s.d. from the mean. Box and whisker plots were generated using data from previous studies: plutonic rocks (n = 5; McCoy-West et al., 2017), ocean floor gabbros (n = 7; McCoy-West et al., 2020a); arc basalts (n =12; McCoy-West et al., 2021), mid-ocean ridge basalts (n = 39; McCoy-West et al., 2021; McCoy-West et al., 2017, 2020a).

Figure 7: Variations in $\delta^{146}Nd$ in plutonic rocks from New Zealand and globally. Graphs of $\delta^{146}Nd$ versus SiO_2 (a), Mg# (b), and P_2O_5 (c), respectively. Mg# (Magnesium-number) = molar $Mg/[Mg + Fe^{2+}]$. The yellow shaded area represents the bulk silicate Earth (BSE) average (McCoy-West et al., 2021). The sample denoted by the cross (P32769) has an elevated P_2O_5 relative to the other Longwood Suite samples because it is a hornblende-rich mafic mineral separate, not a conventional whole rock powder. The heavier $\delta^{146}Nd$ compositions of P81173 and P82430 are attributed to the previous removal of monazite and apatite, respectively.

Figure 8: The Longwood Suite in the context of other Tuhua Intrusives suites in the southern South Island. (a) Map showing the approximate position of the Median Batholith magmatic axis at different times. The distribution of individually-dated Darran (triangle), Longwood (circle) and Foulwind (square) samples with U-Pb crystallization ages are shown. (b) Histogram with 5 Ma bins showing the clear age distinction between the Foulwind Suite (n = 6), Longwood Suite (n = 13) and the Darran Suite (n = 48) within the area of the shown map. Probability density plot was generated using the same dataset assuming a minimum error of 3 Ma. Data is sourced from (herein; Kimbrough et al., 1992; Kimbrough et al., 1994; McCoy-West et al., 2014; Muir et al., 1998; Price et al., 2006; Ramezani and Tulloch, 2006, 2009; Schwartz et al., 2021; Scott and Palin, 2008; Tulloch et al., 1999; Tulloch et al., 2009).

Figure 9: Temporal evolution of geochemical signatures in rocks of the Median Batholith from 380 to 100 Ma. (a) $\varepsilon^{143}Nd$ of all rocks independent of SiO_2. Symbols and references for Nd isotope data are the same as Figure 6, with additional Paleozoic data from Muir et al. (1996a), Muir et al. (1998) and Tulloch et al. (2009). A box and whisker plot for previous published data from the Brook Street Terrane is shown. (b-d) To limit the effect of magmatic differentiation only granitoids with >64 wt % SiO_2 are shown for trace element ratios (i.e. gabbros have lots of plagioclase and thus elevated Sr/Y). Additional trace element data is from Muir et al. (1997), Allibone et al. (2007), Scott and Palin (2008), Allibone et al. (2009) and Price et al. (2011). (b) Lines with values represent the median Sr/Y values for the major suites under discussion. Two samples from the Longwood Suite (hollow symbols) are excluded due to their distinct high-K composition. (c) Chondrite normalized (Palme and O'Neill, 2014) La/Yb. (d) Primitive mantle Nb/Ta = 13.8 ± 1.4 (Palme and O'Neill, 2014). The Longwood Suite has the distinctive high $\varepsilon^{143}Nd$ and low $La/Yb_{(N)}$ and Nb/Ta, compared with other suites within the Median Batholith.

Figure 10: Distinction of the Longwood and Darran Suites based on geochemistry. (a) Graph $\varepsilon^{143}Nd_{(t)}$ versus SiO_2 content. Nd isotope data is corrected to the crystallization age of each sample. Data sources are the same as Fig. 6 with additional data from Nebel et al. (2007) and Mortimer et al. (2016). Hollow symbols represent previously published data for the Longwood Suite. (b) $La/Sm_{(N)}$ versus SiO_2, comparative data is from Muir et al. (1998), Nebel et al. (2007) and Price et al. (2011). (c) K/Na versus SiO_2 for granitoids SiO_2 > 64 wt %, calculated using the same dataset presented in Fig. 5. (d) Granite discrimination diagram (granitoids only) Rb concentration versus Y + Nb after Pearce et al. (1984). Longwood Suite magmas have significantly lower $La/Sm_{(N)}$, K and Rb than the younger suites of the Median Batholith.

Figure 11: Schematic model for the generation of the bimodal Longwood Suite gabbros and trondhjemites. (a) Early Permian Gondwana supercontinent margin was mainly passive (no magmatism, see Figure 8b) with formation of parautochthonous mafic intra-oceanic island arc terranes (green). (b) Late Permian tectonic underplating and melting of accreted terranes to generate a new, isotopically primitive, continental arc (red). Reconstructions based on Matthews et al. (2016);

this model draws on elements from Li et al. (2015) and Robertson and Palamakumbura (2019). NEO = New England Orogen; HBO = Hunter-Bowen Orogen.

Table Captions

Table 1: Summary of SHRIMP U-Pb zircon data for intrusive rocks of the Longwood Suite.

See Supplementary Data, Table S1 for complete U-Th-Pb isotopic compositions of the analysed zircons, 3 zircons were excluded for suspected Pb-loss or inheritance. Uncertainty on the mean ages are 2 s.d. and include propagated errors from the Temora standards.

Table 2: Whole rock Rb-Sr, Sm-Nd and Nd stable isotope data

Uncertainties on measured values are 2 standard errors. $\delta^{146}Nd_{(NORM)}$ values have been normalized to JNdi-1 = 0‰ and uncertainties have been propagated. Radiogenic isotope data for the Longwoods Suite is age corrected using absolute crystallization ages (herein; McCoy-West et al., 2014). $ ages have been estimated using nearby samples from the same unit. *Assumed to be 285 Ma, samples represent the lowest stratigraphic portion of the Brook Street Terrane, which is early Permian (c. 296-275 Ma) in age based on biostratigraphy (Campbell, 2019). No direct age constraints exist for the Riwaka Granite but it is probably part of the Paringa Suite (364 Ma; Tulloch et al., 2009) which exist nearby, see supplementary material for further discussion. $\varepsilon^{143}Nd$ was calculated based on measured compositions, with $\varepsilon^{143}Nd = [(^{143}Nd/^{144}Nd_{Sample}/^{143}Nd/^{144}Nd_{CHUR}) -1] \times 10{,}000$; assuming $^{143}Nd/^{144}Nd_{CHUR} = 0.512638$ and $^{147}Sm/^{144}Nd_{CHUR} = 0.1967$ (Jacobsen and Wasserburg, 1984). ^Brook Street Terrane samples with $^{87}Sr/^{86}Sr(t) > 0.7035$ should be interpreted with caution due to potential cryptic seawater contamination. # represents a replicate digestion processed through the chemical separation procedure.

Table 3: Calculated time-averaged areal magma addition rates for the Longwood, Darran and Separation Point suites.

Information for Darran and Separation Point suites in Fiordland from Milan et al. (2017) who, like us, used a time-averaged approach to calculate addition rates. More detailed pluton-specific analysis of magmatic fluxes in Fiordland can be found in Schwartz et al. (2017).

Supplementary Data, Supplementary Data File 1: includes supplementary figures S1-S6 and a detailed description of the analytical techniques and sample information; Supplementary Data File 2: includes supplementary tables S1-S4.

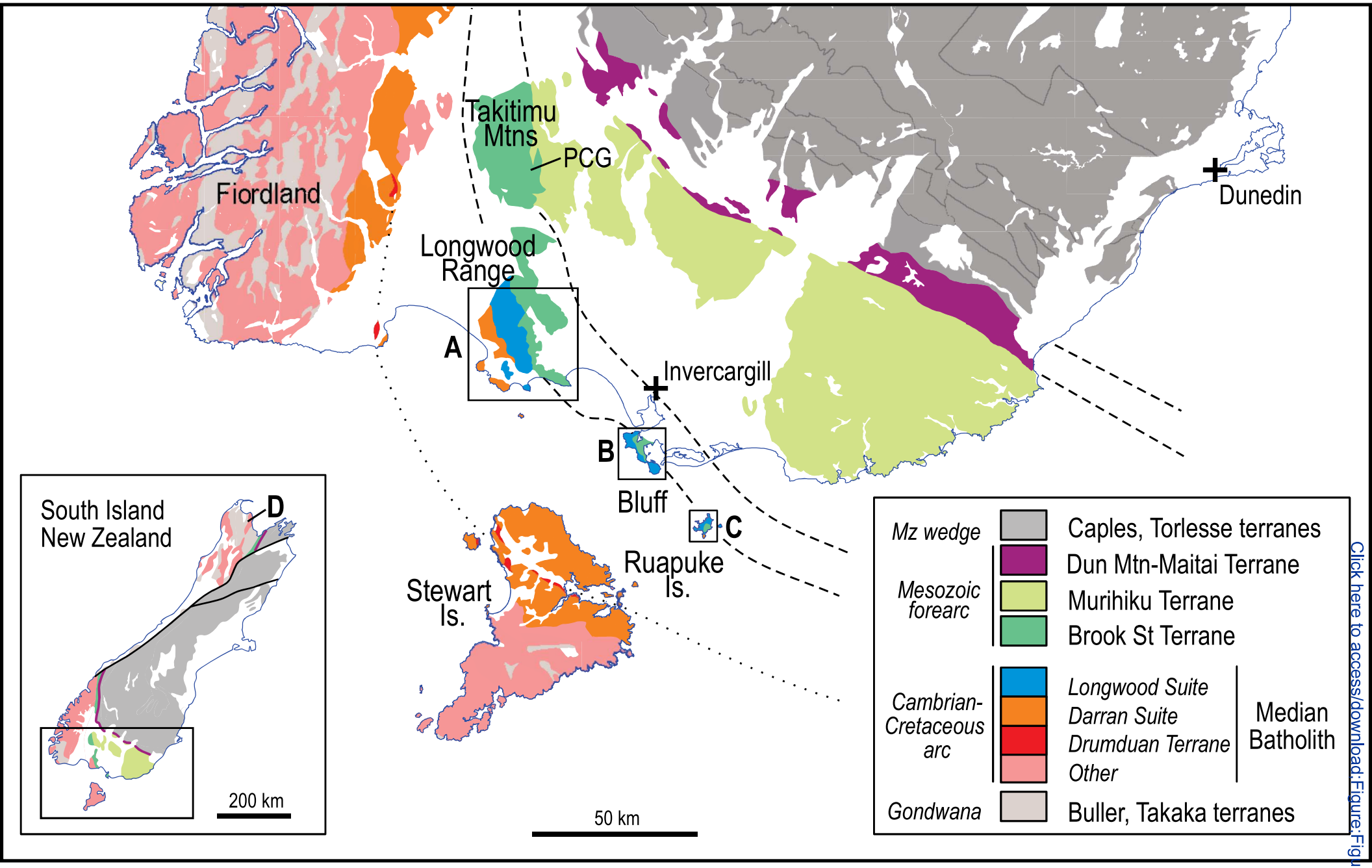

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Figure 2

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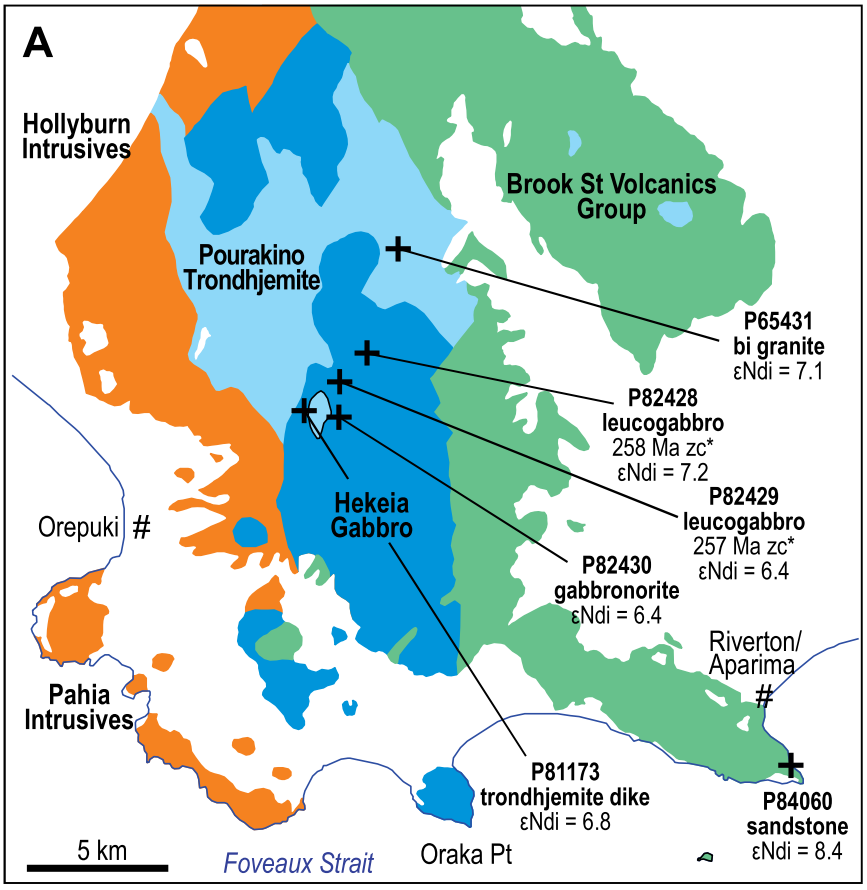

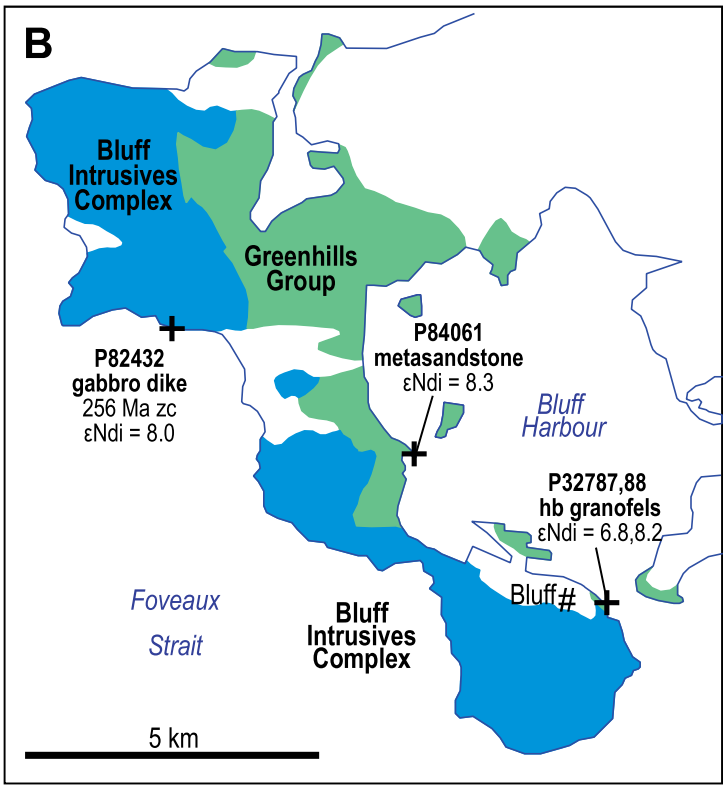

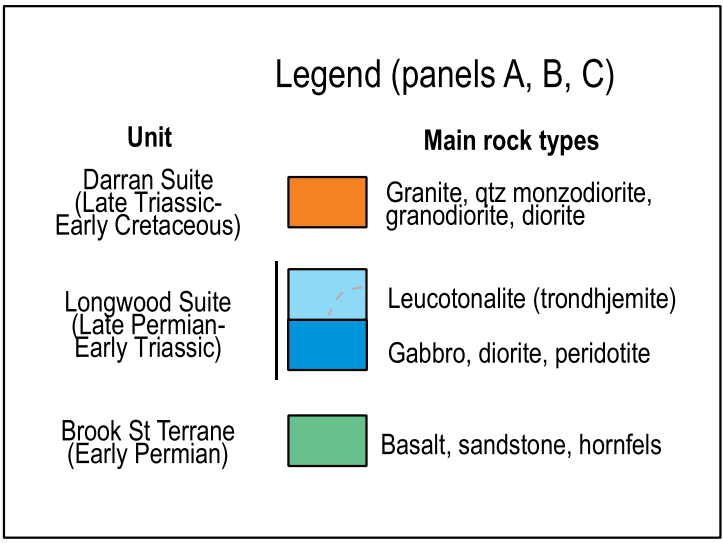

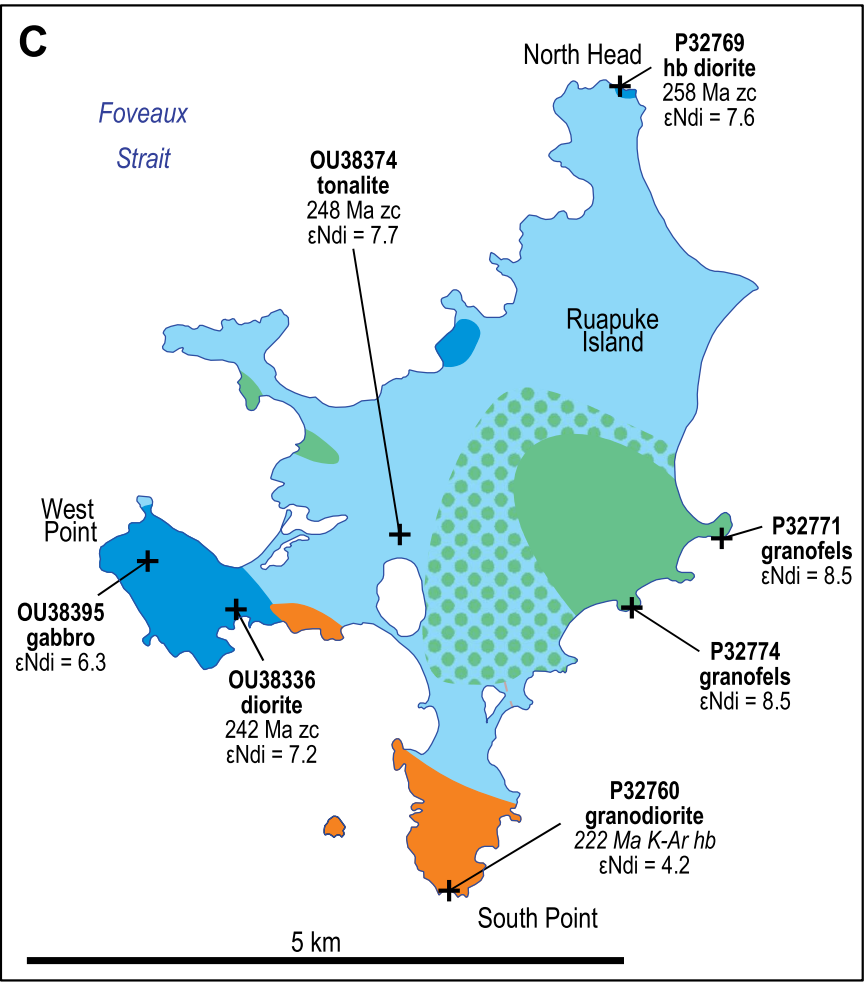

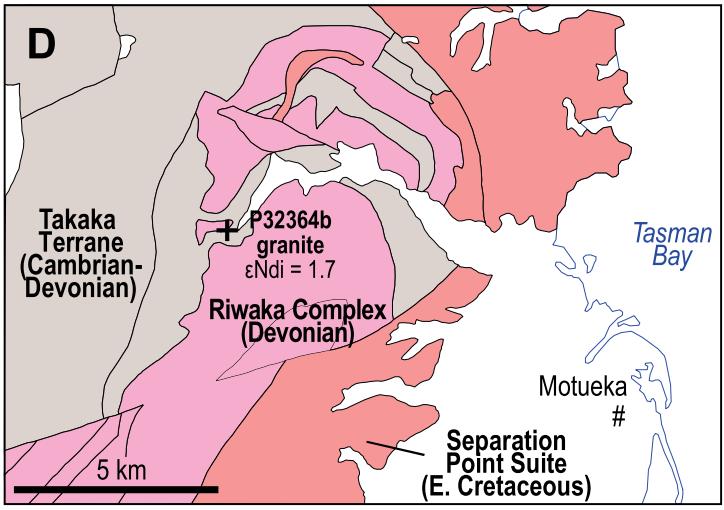

Figure 3

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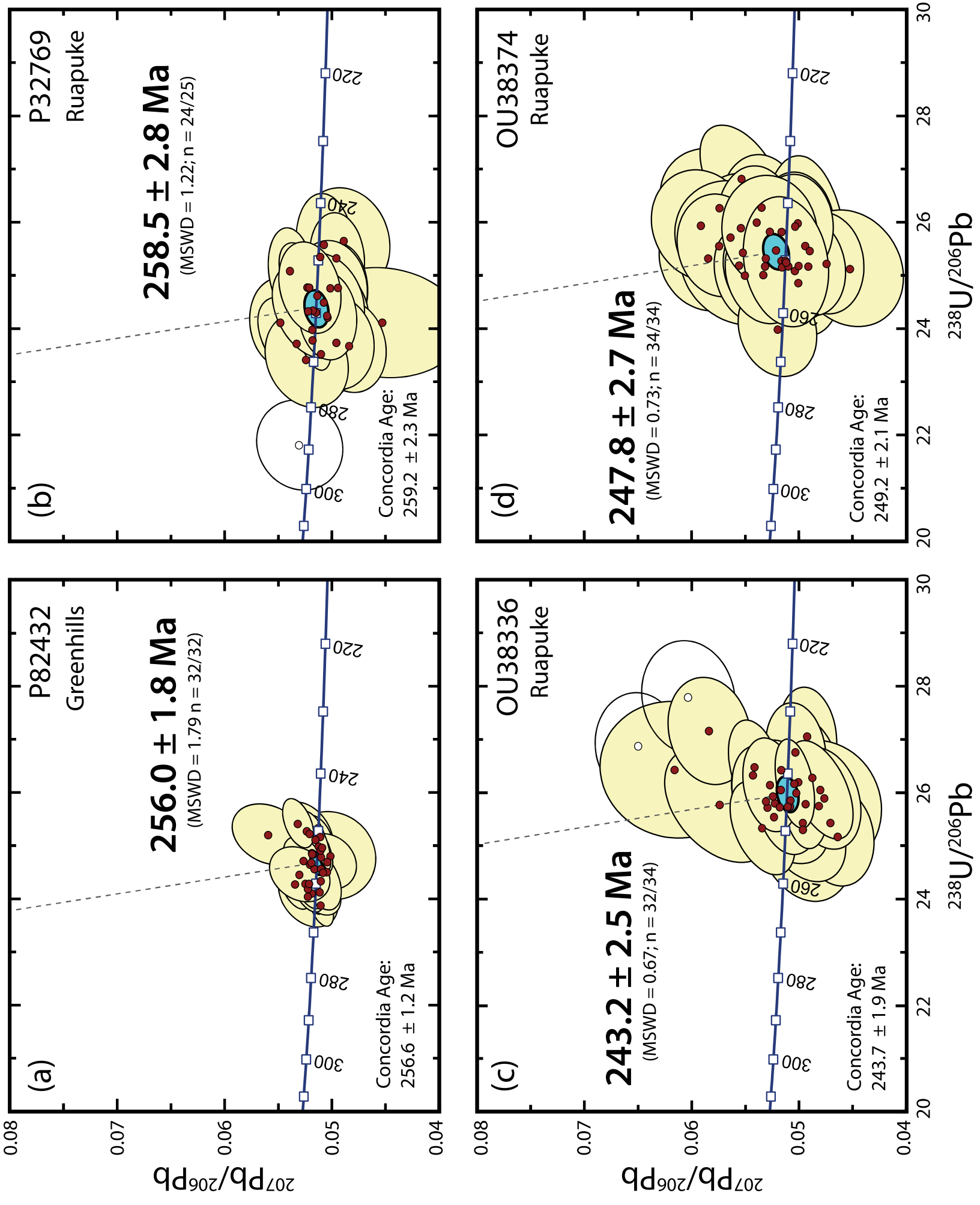

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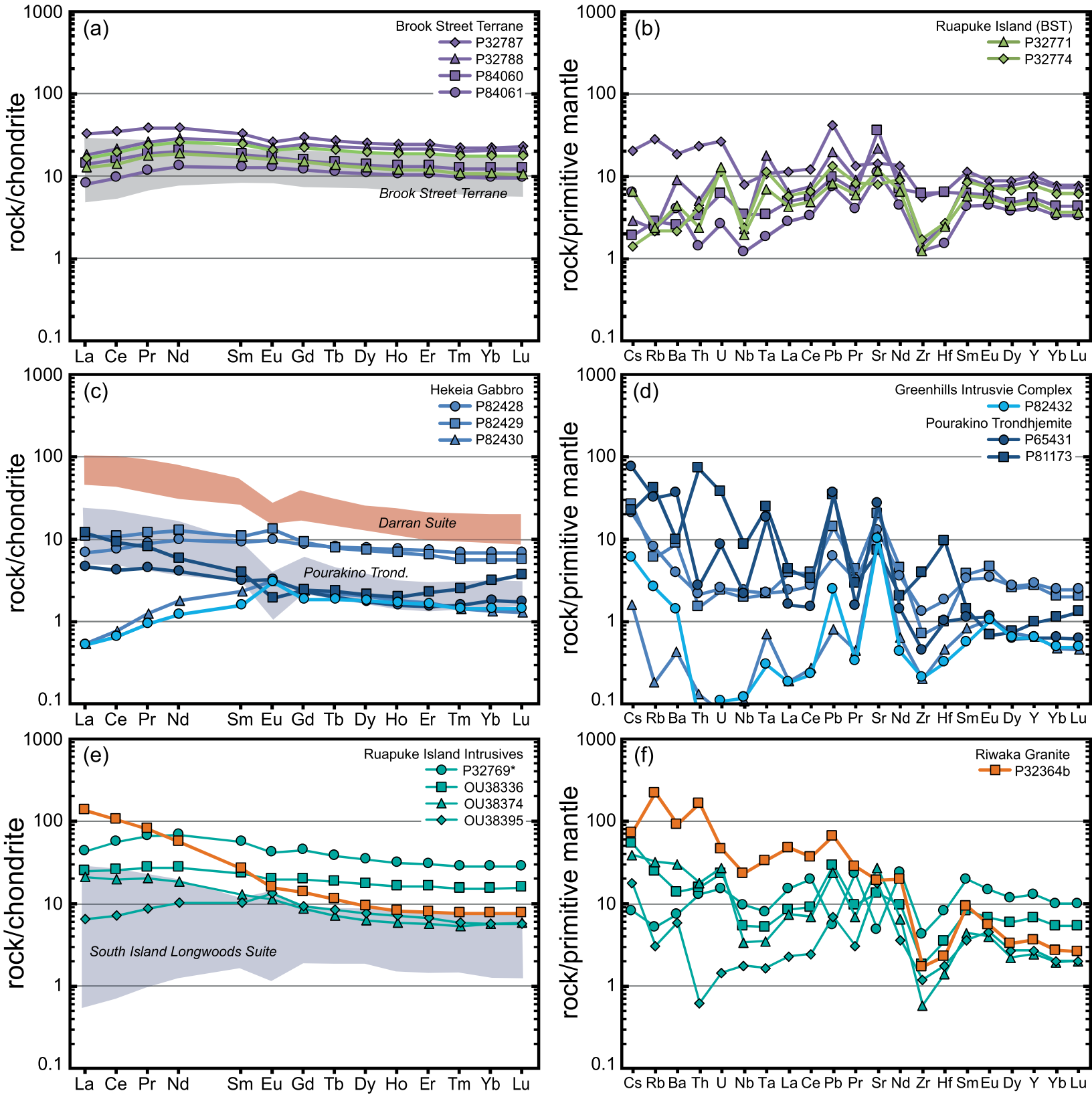

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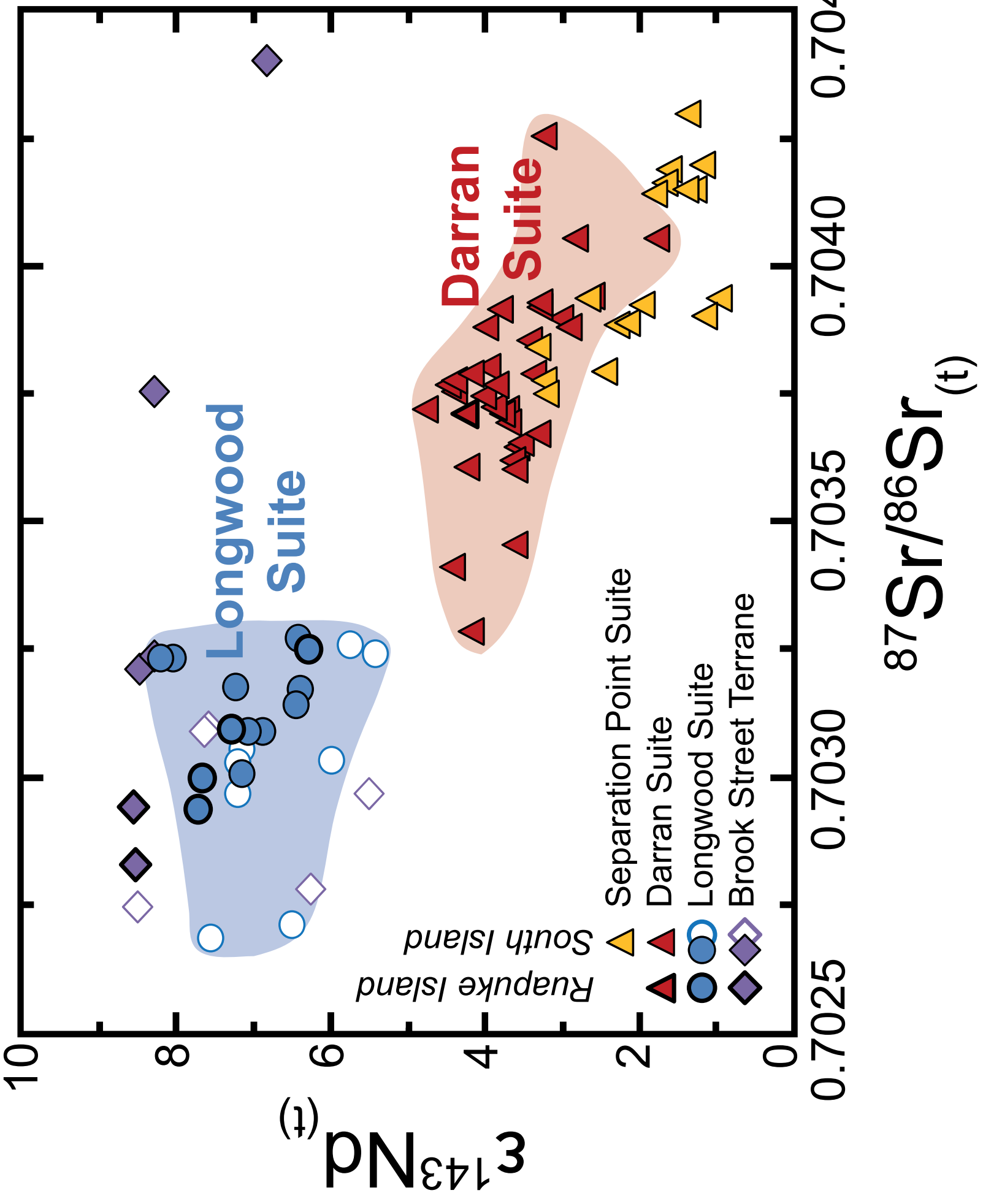

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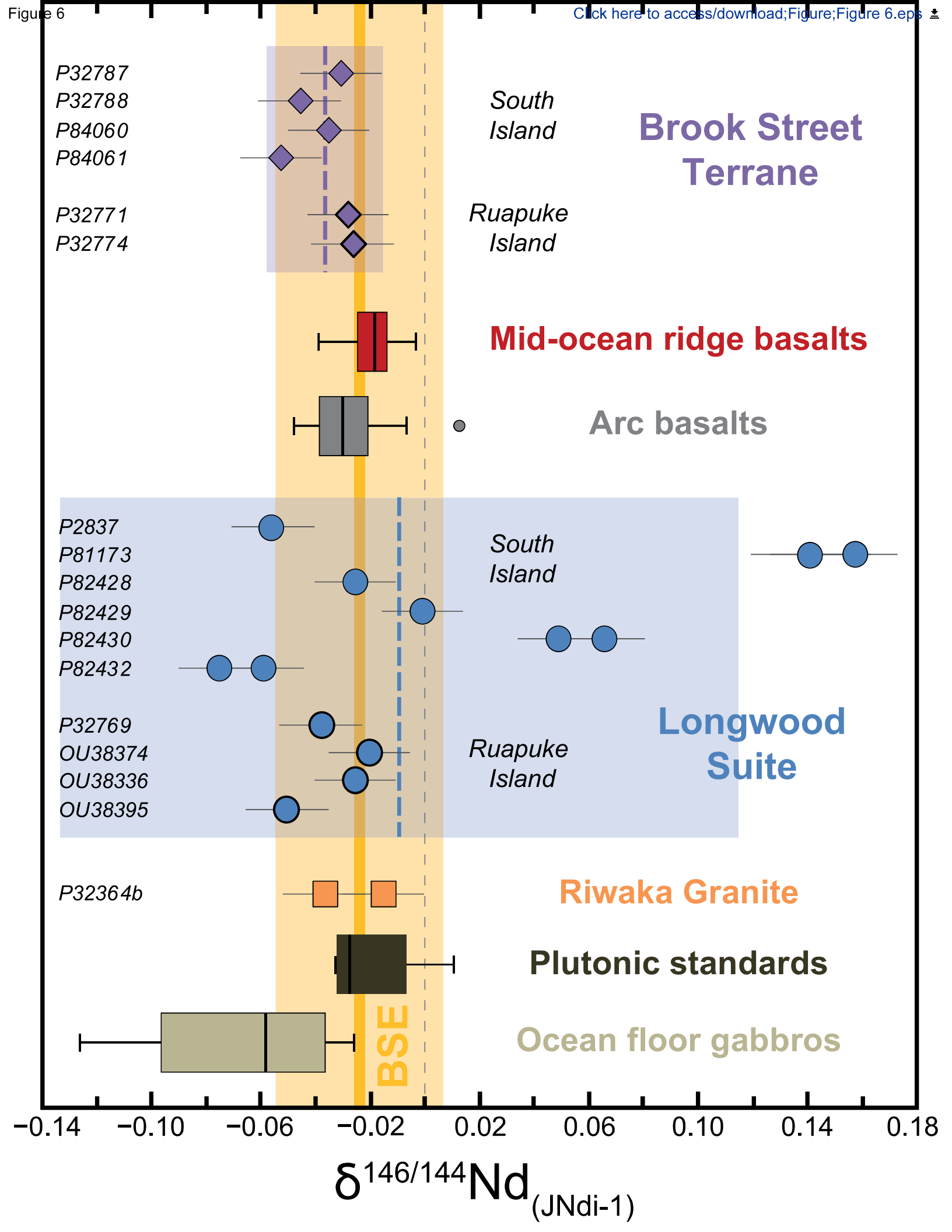

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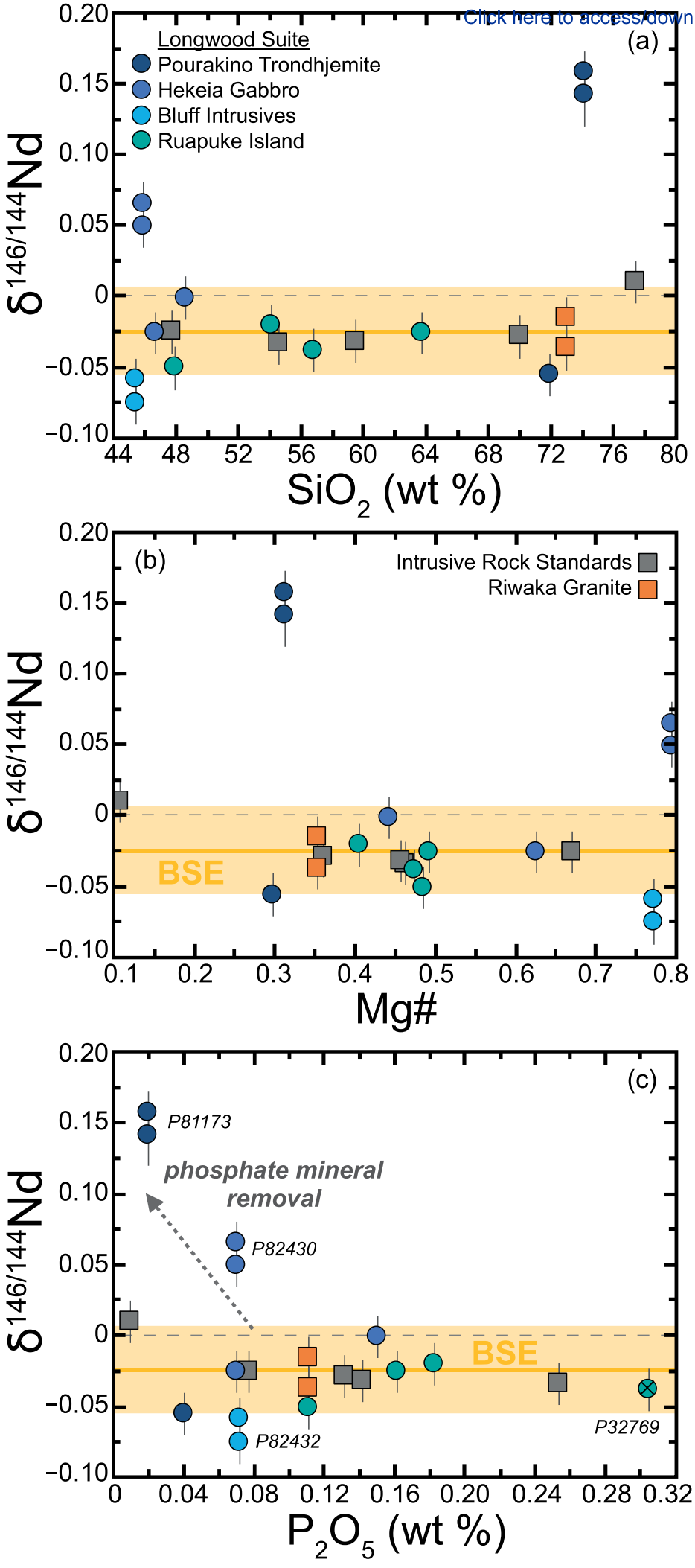

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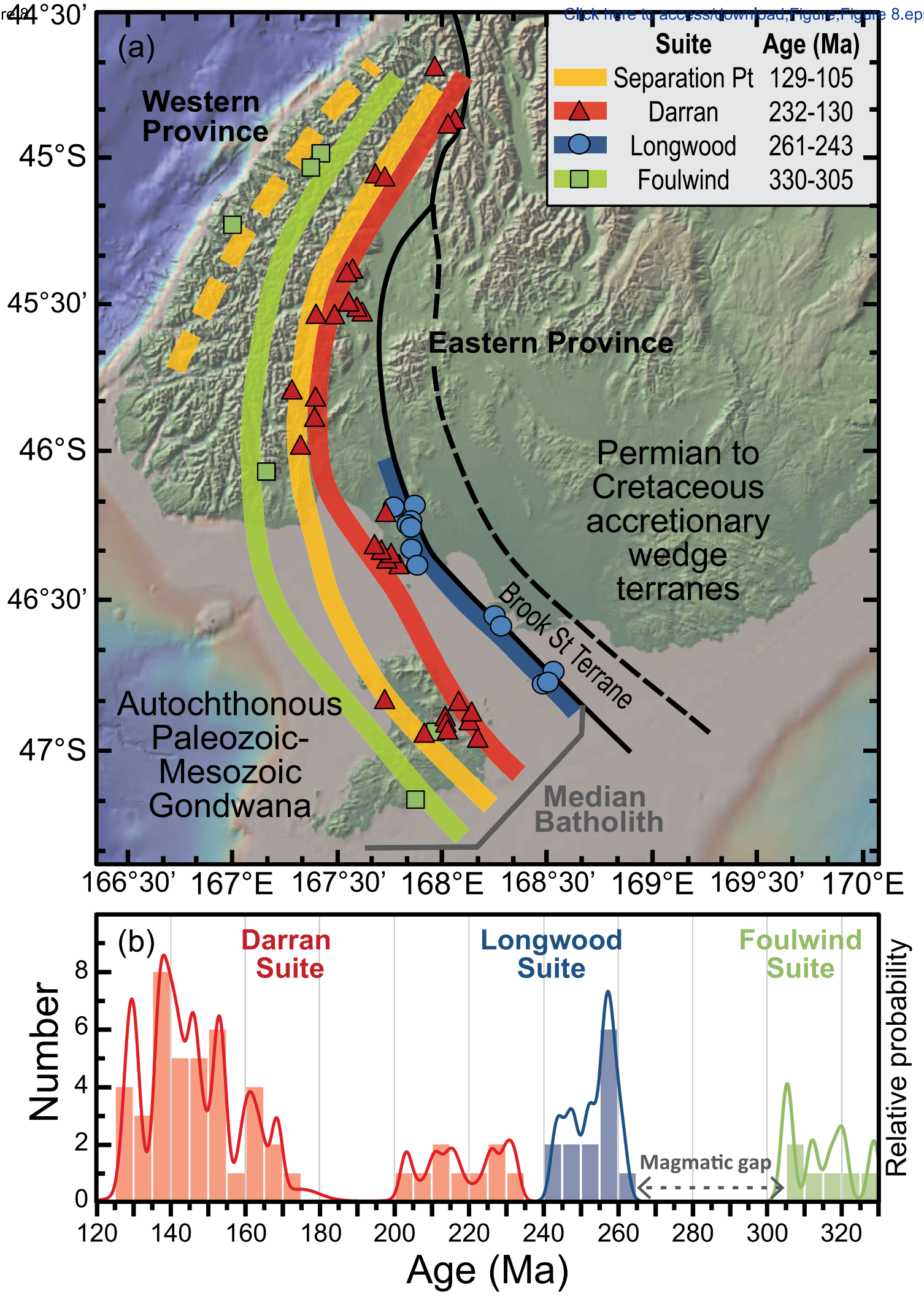

Figure 9

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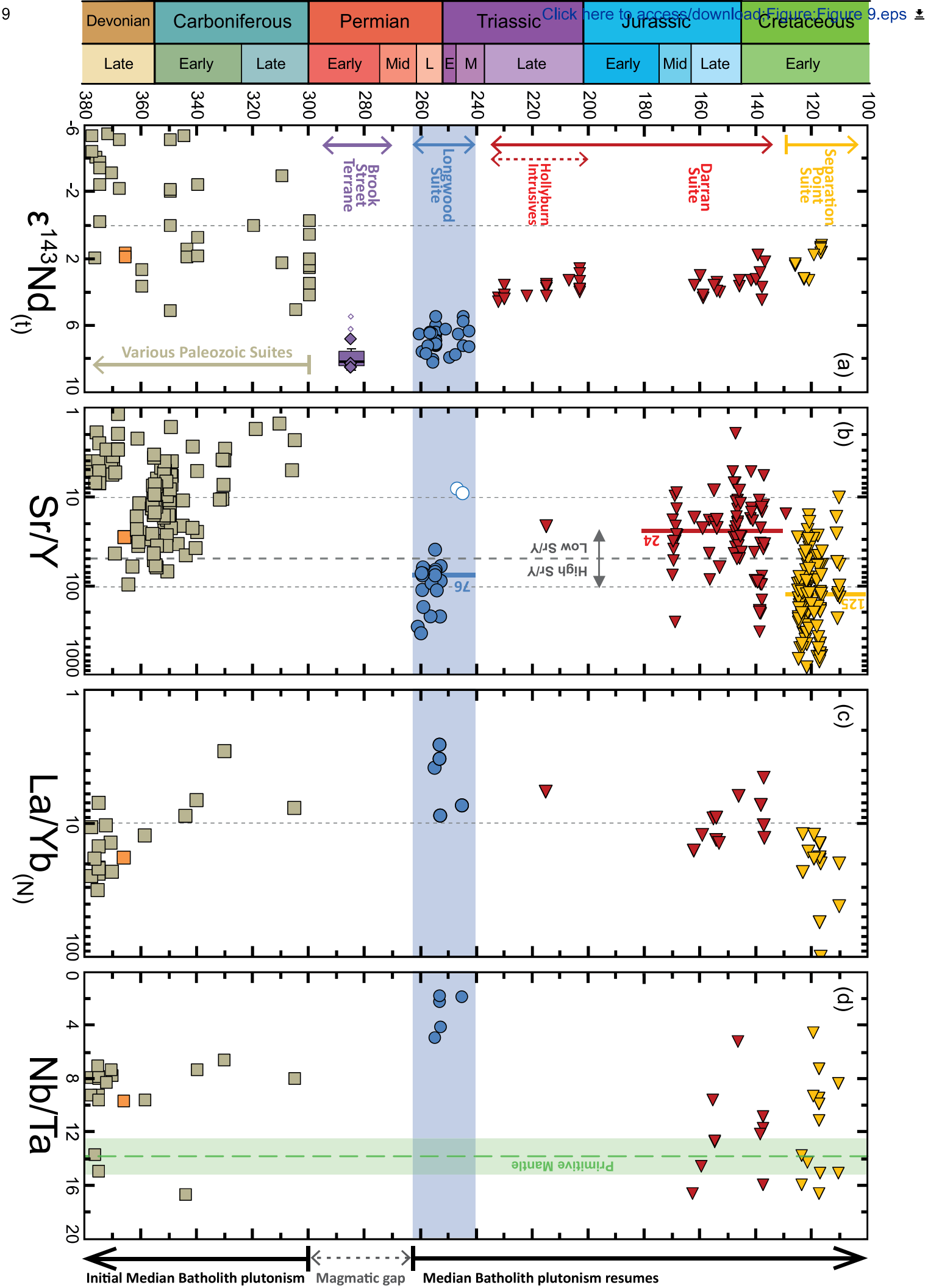

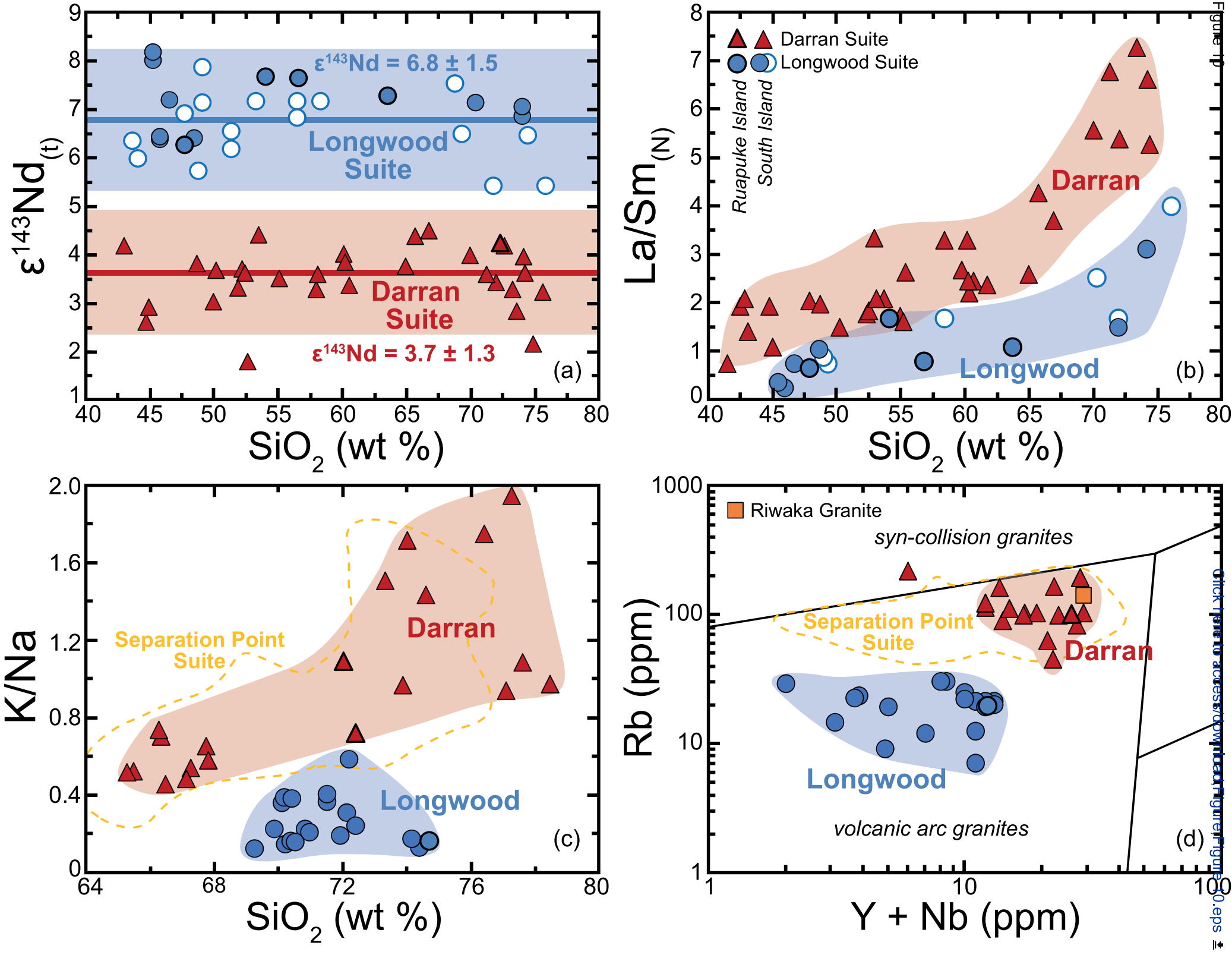

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Figure 11

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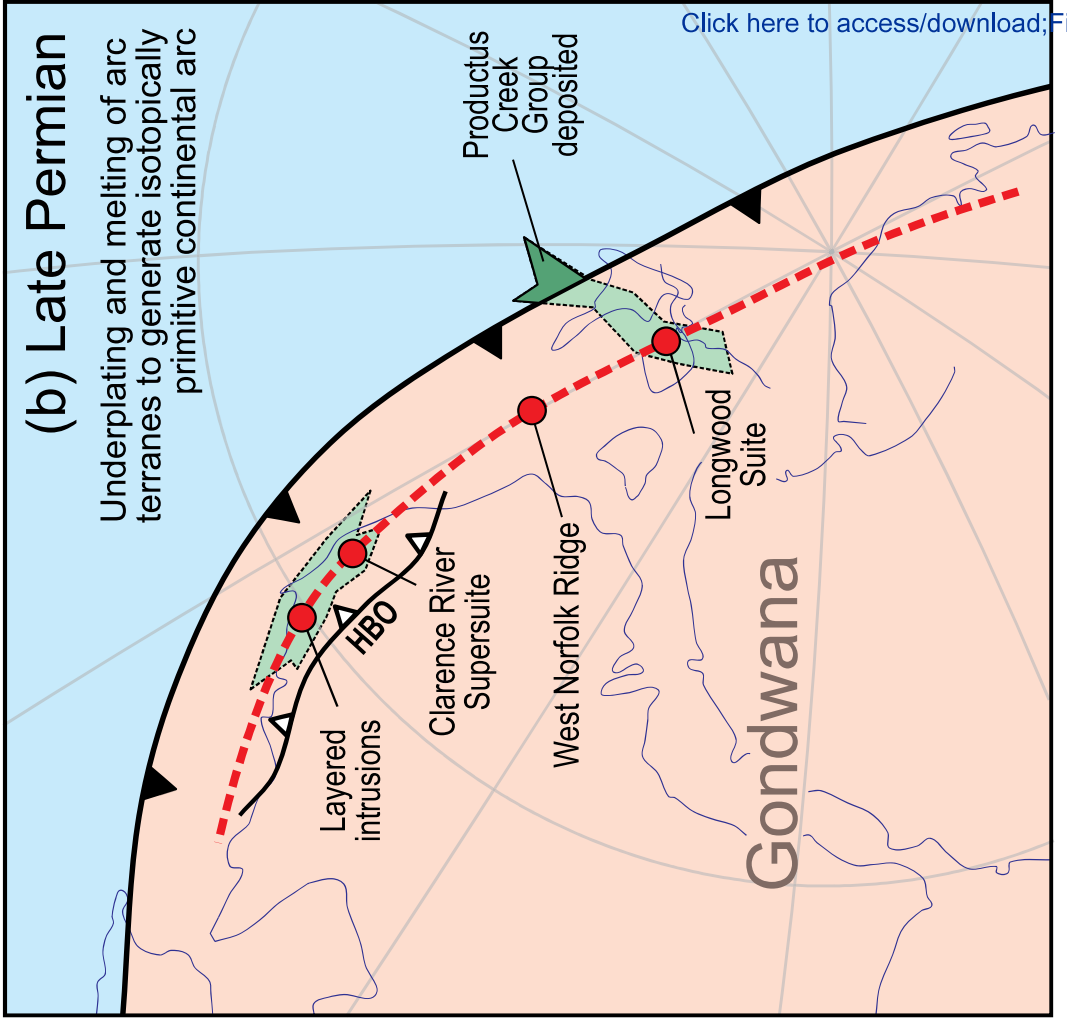

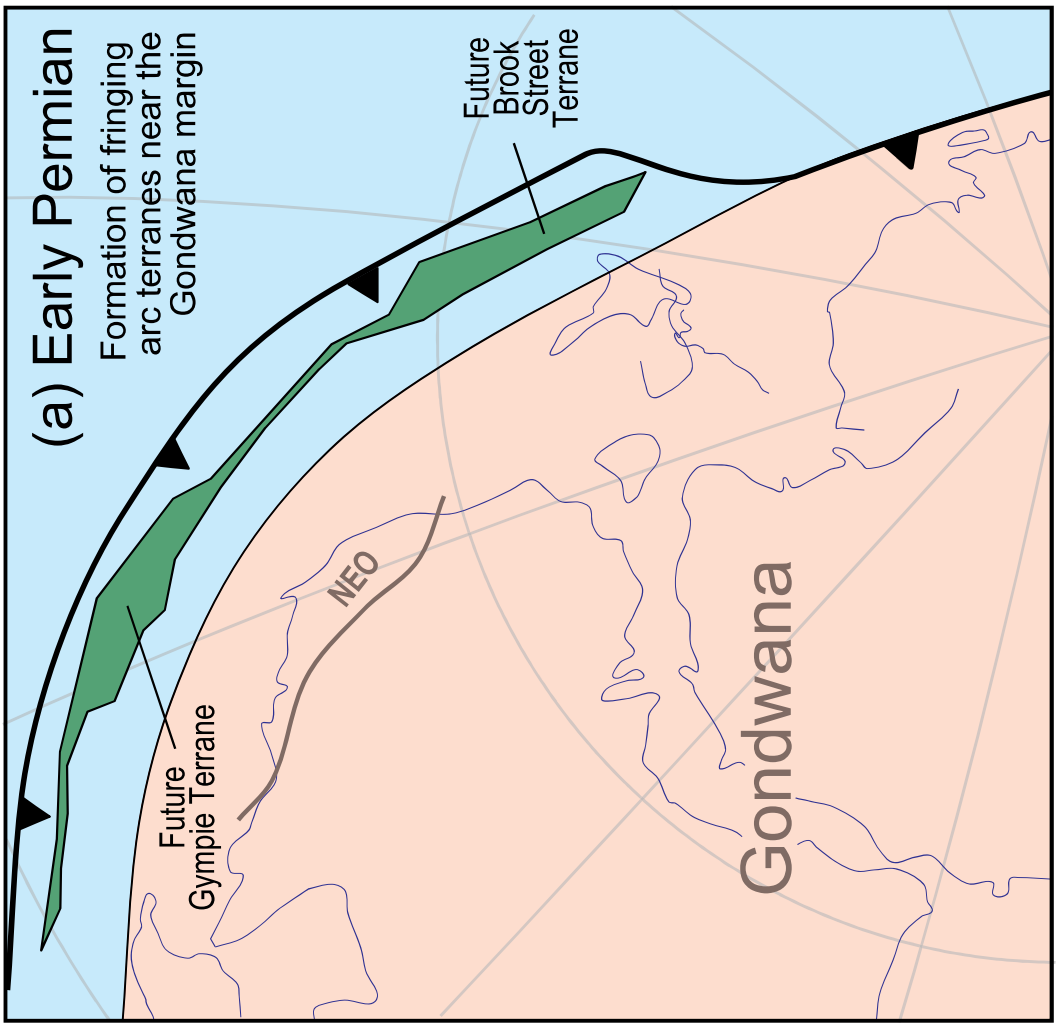

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Table 1: Summary of SHRIMP U-Pb zircon data for intrusive rocks of the Longwood Suite.

Sample	Rock type	Location	Unit	$^{206}Pb/^{238}U$ Mean Age (Ma)	n	MSWD
P82432	Gabbro dike	Green Hills Intrusion, Bluff Peninsula	Bluff Intrusive Complex	256.0 ± 1.8	32/32	1.79
P32769	Diorite	North Head, Ruapuke Island	Ruapuke Intrusive Complex	258.5 ± 2.8	24/25	1.22
OU38336	Diorite	West Point, Ruapuke Island	Ruapuke Intrusive Complex	243.2 ± 2.4	32/34	0.67
OU38374	Tonalite	Waitokariro Lagoon, Ruapuke Island	Ruapuke Intrusive Complex	247.8 ± 2.7	34/34	0.73

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Table 2: Whole rock Rb-Sr, Sm-Nd and Nd stable isotope data

Sample	Unit	Age (Ma)	$^{147}Sm/^{144}Nd$	$^{143}Nd/^{144}Nd$	$^{143}Nd/^{144}Nd_{(t)}$	$\varepsilon^{143}Nd_{(t)}$	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$	$^{87}Sr/^{86}Sr_{(t)}$	Nd (ppm)	$\delta^{146/144}Nd$	$\delta^{148/144}Nd$	$\delta^{146}Nd_{(NORM)}$
Brook Street Terrane													
Southern South Island													
P32787^	Greenhills Group	285*	0.1675	0.512933 ±3	0.51263	6.79	0.1583	0.705040 ±7	0.70442	18.77	-0.027 ±0.005	-0.073 ±0.011	-0.031 ±0.005
P32788	Greenhills Group	285*	0.1839	0.513037 ±3	0.51271	8.25	0.0080	0.703269 ±7	0.70324	13.89	-0.042 ±0.005	-0.071 ±0.012	-0.046 ±0.005
P84060	Brook St Volcanics Group	285*	0.1731	0.513027 ±3	0.51272	8.43	0.0061	0.703237 ±4	0.70321	9.92	-0.032 ±0.005	-0.061 ±0.012	-0.035 ±0.005
P84061^	Greenhills Group	285*	0.1887	0.513047 ±5	0.51271	8.26	0.0169	0.703821 ±4	0.70375	6.14	-0.049 ±0.008	-0.098 ±0.020	-0.053 ±0.009
Ruapuke Island													
P32771	Greenhills Group	285*	0.1761	0.513035 ±2	0.51272	8.48	0.0163	0.702895 ±4	0.70283	8.91	-0.024 ±0.004	-0.030 ±0.010	-0.028 ±0.005
P32774	Greenhills Group	285*	0.1818	0.513047 ±2	0.51272	8.52	0.0216	0.703031 ±3	0.70295	12.18	-0.023 ±0.004	-0.028 ±0.009	-0.027 ±0.004
Longwood Suite													
Southern South Island													
P65431	Pourakino Trond.	255$	0.1520	0.512928 ±2	0.51267	7.12	0.0935	0.703350 ±4	0.70301	1.87	-0.052 ±0.004	-0.098 ±0.011	-0.056 ±0.005
P81173	Pourakino Trond.	255$	0.1332	0.512883 ±13	0.51266	6.85	0.4604	0.704764 ±3	0.70310	2.77	0.145 ±0.022	0.296 ±0.053	0.141 ±0.022
P81173#				0.512893 ±2	0.51267	7.04				2.81	0.161 ±0.003	0.296 ±0.008	0.158 ±0.004
P82428	Hekeia Gabbro	257.6	0.1846	0.512986 ±4	0.51267	7.18	0.0509	0.703366 ±4	0.70318	4.87	-0.022 ±0.008	-0.018 ±0.019	-0.026 ±0.008
P82429	Hekeia Gabbro	256.5	0.1666	0.512915 ±3	0.51264	6.39	0.0230	0.703359 ±5	0.70327	5.81	0.002 ±0.006	-0.006 ±0.014	-0.001 ±0.006

	Hekeia			0.513067				0.703180			0.069	0.111	0.065
P82430	Gabbro	257[$]	0.2575	±3	0.51263	6.37	0.0014	±6	0.70317	0.80	±0.005	±0.012	±0.005
				0.513069				0.703151			0.053	0.097	0.049
P82430#				±3	0.51264	6.42		±4	0.70315	0.73	±0.005	±0.012	±0.005
	Bluff			0.513149				0.703313			-0.055	-0.107	-0.059
P82432	Intrusives	256.0	0.2567	±3	0.51272	8.00	0.0205	±4	0.70324	0.54	±0.006	±0.015	±0.006
				0.513157							-0.072	-0.185	-0.075
P82432#				±4	0.51273	8.17				0.56	±0.006	±0.015	±0.007
Ruapuke Island													
	Ruapuke			0.512968				0.703311			-0.035	-0.049	-0.038
P32769	Intrusives	258.5	0.1610	±2	0.51270	7.61	0.0832	±4	0.70300	32.49	±0.004	±0.010	±0.005
	Ruapuke			0.512932				0.703275			-0.017	-0.031	-0.021
OU38374	Intrusives	247.8	0.1355	±3	0.51271	7.67	0.0938	±4	0.70294	8.95	±0.005	±0.011	±0.005
	Ruapuke			0.512960				0.703610			-0.022	-0.063	-0.026
OU38336	Intrusives	243.2	0.1659	±2	0.51270	7.25	0.1474	±4	0.70310	13.17	±0.004	±0.010	±0.005
	Ruapuke			0.512955				0.703301			-0.047	-0.084	-0.051
OU38395	Intrusives	250[$]	0.1942	±3	0.51264	6.26	0.0140	±4	0.70325	4.96	±0.005	±0.013	±0.006
Paringa Suite													
Northwest Nelson													
	Riwaka			0.512467				0.709524	0.70470		-0.033	-0.066	-0.037
P32364b	Granite	364	0.0916	±3	0.51225	1.55	0.9313	±4		27.18	±0.005	±0.011	±0.005
				0.512481							-0.012	-0.051	-0.015
P32364b#		364		±3	0.51226	1.81				27.49	±0.004	±0.011	±0.005

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Table 3: Calculated time-averaged areal magma addition rates for the Longwood, Darran and Separation Point suites.

Suite and region	Age range (Ma)	Duration (Ma)	Area (km^2)	Magma addition rate (km^2/Ma)
Longwood Suite				
Longwood Range (Hekeia Gabb., Pourakino Tr.)	261-245	16	164	10
Bluff Intrusive Complex, Ruapuke Island	259-243	16	37	2
Total onland exposure	*261-243*	*18*	*201*	*11*
Total including offshore interpolation	*261-243*	18	*770*	*43*
Darran Suite				
Longwood Range (Hollyburn, Pahia intrusives)	232-202	29	83	3
Eastern Fiordland	167-127	40	2700	67
Total onland exposure	*232-130*	*102*	*2783*	*27*
Separation Point Suite				
Eastern Fiordland	125-115	10	1050	105
Western Fiordland	125-115	10	2700	270
Total onland exposure	*125-115*	*10*	*3750*	*375*