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The Longwood Igneous Complex, Southland, New Zealand: A Permo-Jurassic, intra-oceanic, subduction-related, I-type batholithic complex

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ABSTRACT

The Longwood Igneous Complex (LIC) is located in Southland, New Zealand on the eastern side of the Carboniferous to Cretaceous, I-type, Median Batholith. Intrusives of the Complex range in age from Permian to Jurassic and show trace element characteristics typical of subduction-related magmas. Gabbro, gabbroic diorite and basaltic dyke rocks show trace and minor element patterns and isotopic compositions indicating that they represent magmas generated in an intra-oceanic subduction system. Radiometric ages decrease across the LIC from 254 Ma in the east to 142 Ma in the west and mineral chemistry and mineral phase relationships indicate emplacement at depths between 15 and 25 km. Thus the petrology and geochemistry of the LIC provides the basis for evaluating the composition of lower–middle crust assembled above a long lived intra-oceanic subduction system and we estimate this to be andesitic and similar to bulk continental crust.

Rocks of the LIC range in composition from troctolite and gabbro through diorite to trondhjemite and granite. All of the ultramafic rocks and most of the gabbros have petrographic and geochemical features consistent with a cumulate origin and mineral chemistry shows similarities with arc cumulate sequences from elsewhere. Few of the plutonic rocks making up the LIC have direct analogues among modern intra-oceanic volcanic rocks. The latter are the end products and the former the leftovers from magmatic processes that included fractional crystallisation, crustal assimilation and magma mixing and mingling. Longwood intrusions do not represent magma chambers. They formed as crystal cumulates and mushes left over from the processes that generated magmas erupted at the contemporary volcanic arc.

A correlation between decreasing age of emplacement and Sr and Nd isotopic compositions and inheritance in zircons dated by ion probe are indications of crustal recycling. The generation of felsic rocks in the Longwood intra-oceanic arc involved crustal anatexis and, over the 100 million year history of the arc, the crust evolved towards a composition similar to bulk continental crust and average andesite.

Dioritic rocks of the LIC contain abundant mafic enclaves, which are argued to represent fragments of mafic magma, derived by fractional crystallisation from basalt, which was intruded into a hot but solid or near solid diorite. Heating and remobilisation of the dioritic host disrupted and disaggregated the intruding mafic magma to form enclaves and zones of intrusion breccia that show every variation from liquid–liquid to liquid–solid mingling and mixing. They were then further modified chemically and mineralogically by diffusion of H_2O, Na, P, Ba, REE, and, to a lesser extent, Rb.

Mafic dykes occur throughout the Complex and a number of these are composite with compositions ranging from dolerite through andesite to dacite. The components of composite dykes do not define unequivocal linear mixing trends and hybridisation processes that took place within them have only localised significance; mingling and hybridisation in the composite dykes do not appear to have controlled geochemical variation among the major intrusive units of the Complex.

1. Introduction

The Longwood Igneous Complex (LIC) in the southern South Island of New Zealand comprises intrusive igneous rocks, ranging in composition from ultramafic to granite (Bignall, 1987; Challis and Lauder, 1977; Cowden et al., 1990; Price and Sinton, 1978; Rombouts, 1994), which were emplaced in a long-lived intra-oceanic magmatic arc (Mortimer et al., 1999a). Exposures of intrusive rocks from subduction-related magmatic systems are relatively unusual and consequently they provide a rare opportunity to study magma generation and evolution in a subduction setting. More specifically, the Longwood intrusives provide insights into the processes by which I-type granitic

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batholiths are constructed and an opportunity to evaluate the relative contributions of fractional crystallisation, crystal accumulation, magma mixing and mingling and crustal recycling to geochemical variation in an intra-oceanic, subduction-related I-type intrusive suite. Collectively, the Longwood intrusive suite represents a cross-section through sub-arc crust and consequently a means of estimating the composition of crust formed within a long-lived oceanic subduction system.

The geology of the South Island of New Zealand is dominated by two major tectonic provinces with contrasting metamorphic and structural histories and different lithological assemblages (Fig. 1). The Western Province, which is composed of Cambrian–Silurian aged meta-sedimentary rocks cut by Devonian to Carboniferous granitoids, is considered to represent a piece of lithosphere from the Palaeozoic continental margin of Gondwana (Mortimer et al., 1999b). The Eastern Province formed as the result of convergent margin processes and contains arc-volcanic rocks, arc-derived sedimentary sequences, and accretionary complexes of Permian–Cretaceous age (e.g. Adams and Graham, 1996; Adams et al., 1998; Mortimer et al., 1999b; Roser and Korsch, 1999). The boundary between the two provinces was originally considered to be a linear suture between adjoining or paired metamorphic belts and consequently it was termed the Median Tectonic Line (Landis and Coombs, 1967). Further work saw the suture redefined as a broad zone (Bradshaw, 1993; Frost and Coombs, 1989; Kimbrough et al., 1993, 1994; Muir et al., 1998; Williams and Harper, 1978) and most recently Mortimer et al. (1999b) suggested the boundary is stitched by a Median Batholith comprising intrusive rocks ranging in age from Carboniferous to Early Cretaceous (Fig. 1). Price et al. (2006) highlighted the difficulty of differentiating intrusive rocks of the Median Batholith from those of the Eastern and Western Provinces; within each of these tectonic terranes and in the Median Batholith, igneous rocks have the petrological characteristics expected of those formed in subduction settings (e.g. Coombs et al., 1976; Houghton and Landis, 1989; Muir et al., 1998; Spandler et al., 2003). Detailed geochronology provides the only means of assigning specific intrusions to a particular province or to the Median Batholith.

1.1. The geology of the Longwood Igneous Complex (LIC)

The LIC lies within the southern and eastern margin of the Median Batholith, approximately 40 km to the west of Invercargill in the far south of the South Island. It forms a low range of hills (maximum elevation of 804 m at Bald Hill) extending ~35 km northwards from the coast (Fig. 1). The geology, lithologies and age relationships of the LIC have been described in detail by Bignall (1987), Mortimer et al. (1999a), Rombouts (1994) and Price et al. (2006). Inland, the Complex is heavily forested and rocks deeply weathered but Mortimer et al. (1999a) used available outcrop and petrological and geochronological information to develop an interpretative map, which is reproduced here as Fig. 1B. To the east, the oldest intrusives of the Complex are interpreted to have been emplaced into volcanic and volcaniclastic sediments of the Permian Brook Street Terrane with successive intrusive episodes becoming progressively younger to the west. Mortimer et al. (1999a) grouped the intrusive rocks of the Complex into four broad geochronological and petrological units (Fig. 1B): (a) Early to Middle Permian felsic rocks of the Pourakino Trondhjemite; (b) Late Permian to Early Triassic gabbros and diorites of the Hekeia Gabbro; (c) Middle and Late Triassic diorites and granites of the Holly Burn Intrusives; and (d) Late Triassic–Early Jurassic gabbros of the Pahia Intrusives. The age progression from east to west across the Complex is summarised in Fig. 2A, which incorporates data from Mortimer et al. (1999a) and Price et al. (2006). The LIC represents a batholith that was assembled sequentially from east to west beneath an intra-oceanic subduction-related volcanic arc on a 100 million year time scale.

The focus of this paper is on excellent exposures found along the coast between Oraka and Pahia Points (Figs. 1 and 3). These provide a 20 km cross-section through the LIC incorporating all of the intrusive groupings recognised by Mortimer et al. (1999a) except the Pourakino Trondhjemite. At the eastern extremity of the section, at Oraka Point, Late Permian to Early Triassic (245 Ma; Price et al., 2006) gabbroic rocks are bordered by granite to the east and diorite to the south–east and west. The contacts are marked by a mixed or mingled zone, implying that mafic and more felsic magmas co-existed. The middle of the cross section, between Wakaputa Point and Mullet Bay is dominated by dioritic rocks but gabbro also occurs and, as at Oraka Point, contacts tend to be transitional rather than sharp. Diorites from this segment of the cross section give Triassic ages (215–227 Ma; Price et al., 2006). At the western end of the section from Mullet Bay through Pahia Point to Te Wae Wae Bay, gabbroic rocks dominate although ultramafic rocks and diorite also occur and contacts between felsic and mafic rocks are marked by mixed or mingled zones. Pahia Point rocks give Late Triassic to Jurassic ages (203–211 Ma; Price et al., 2006). A leuco-gabbro dyke at Pahia Point gives a SHRIMP zircon age of 142 ± 2 Ma and appears to be related to the Anglem Complex on Stewart Island to the south of the Longwood coast across Foveaux Strait (Price et al., 2006).

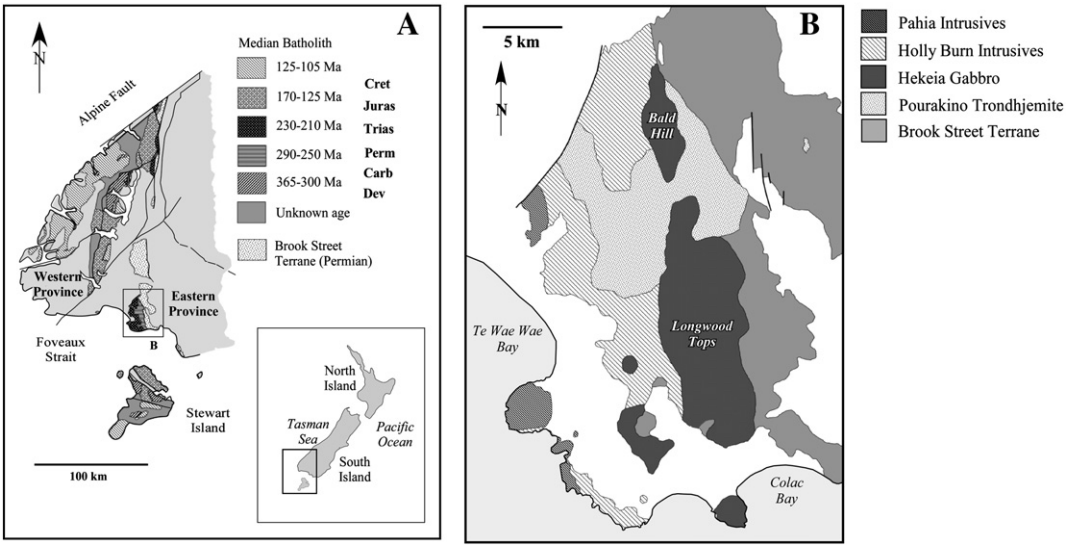

Fig. 1. (A) location of the Longwood Igneous Complex (LIC) in relation to the Median Batholith of South Island, New Zealand (Mortimer et al., 1999a; Muir et al., 1996). (B) Interpretive map showing distribution of plutonic units of the LIC (Mortimer et al., 1999a).