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Kinematic, finite strain and vorticity analysis of the Sisters Shear Zone, Stewart Island, New Zealand

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ABSTRACT

The Sisters Shear Zone (SSZ) on Stewart Island, New Zealand, is a greenschist-facies extensional shear zone active prior to and possibly during the development of the Pacific–Antarctica spreading ridge at ~76 Ma. We report quantitative kinematic and rotation data as well as apatite fission-track (AFT) ages from the SSZ. Early kinematic indicators associated with the NNE-trending stretching lineation formed under upper greenschist-facies metamorphism and show alternating top-to-the-NNW and top-to-the-SSE senses of shear. During progressive exhumation lowermost greenschist-facies and brittle-ductile kinematic indicators depict a more uniform top-to-the-SSE sense of shear in the topmost SSZ just below the detachment plane. Deformed metagranites in the SSZ allow the reconstruction of deformation and flow parameters. The mean kinematic vorticity number (W_m) ranges from 0.10 to 0.89; smaller numbers prevail in the deeper parts of the shear zone with a higher degree of simple shear deformation in the upper parts of the shear zone (deeper and upper parts relate to present geometry). High finite strain intensity correlates with low W_m and high W_m numbers near the detachment correlate with relatively weak strain intensity. Finite strain shows oblate geometries. Overall, our data indicate vertical and possibly temporal variations in deformation of the SSZ. Most AFT ages cluster around 85–75 Ma. We interpret the AFT ages to reflect the final stages of continental break-up just before and possibly during the initiation of sea-floor spreading between New Zealand and Antarctica.

1. Introduction

1.1. Extensional shear zones

Shear zones are arguably the most important deformation structures in the lithosphere. They are the most spectacular expression of the heterogeneity of deformation at all scales. In regions of lithospheric extension shear zones can accommodate tens or hundreds of kilometres of displacement (Foster and John, 1999; Wells et al., 2000; Ring et al., 2001; Thomson and Ring, 2006). Large-scale extension is commonly expressed by the development of metamorphic core complexes (Lister and Davis, 1989), which tectonically separate a mid/lower crustal core in the lower plate from non-metamorphosed sediments in the upper plate. The displacement is usually concentrated into a few tens to a few hundreds of meters thick ductile shear zone at the top of the exhuming metamorphic core. This ductile shear zone is overlain by a brittle detachment fault.

Ramsay and Graham (1970) advocated a model of progressive simple shear for ductile shear zones. Quantitative studies over the last two decades have shown that the deformation in shear zones is more complex and usually involves a coaxial component (Simpson and De Paor, 1993; Northrup et al., 1996; Grasemann et al., 1999; Ring, 1999; Kumerics et al., 2005; Bailey et al., 2007; Ring and Kumerics, 2008). In extensional terrains this pure-shear component is expressed by subvertical coaxial shortening leading to elongating shear zones (stretching faults in the sense of Means, 1989). Sullivan (2008) showed that strain intensity and strain geometry varies very significantly parallel to the tectonic transport direction in the Raft River low-angle extensional shear zone in the Basin and Range province. What is less well investigated are vertical and temporal variations in deformation (strain, rotation, translation) in shallow-dipping extensional shear zones.

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1.2. Metamorphic core complexes in New Zealand

The metamorphic core complexes on the west and south coast of the South Island of New Zealand are generally interpreted as precursors of late Cretaceous Tasman Sea and Southern Ocean rifting (Tulloch and Kimbrough, 1989; Gaina et al., 1998). The most prominent of the New Zealand core complexes is the Paparoa core complex (Fig. 1), which had a major phase of extensional faulting at ~115–110 Ma when the upper amphibolite-facies, in part migmatitic, footwall cooled at rates of ~100 °C Myr^{-1} (Spell et al., 2000; Schulte et al., 2014). The Paparoa core complex is a bivergent core complex characterized by two oppositely dipping and displacing detachments. Modelling work by Gessner et al. (2007) suggests that a bivergent symmetry develops when the lower crust is hot and has a low viscosity during extension and there is a pronounced strength difference between the upper and lower crust. A monovergent core complex, i.e. one that is characterized by a single shear zone/detachment system, develops when the viscosity contrasts between upper and lower crust are less, i.e. the mid/lower crust is stronger. These core complexes usually expose greenschist-facies rocks in their metamorphic core.

Another metamorphic core complex in New Zealand is the Pegasus core complex on Stewart Island (Fig. 2) (Kula et al., 2009). The overall geometry of the Pegasus core complex is not well

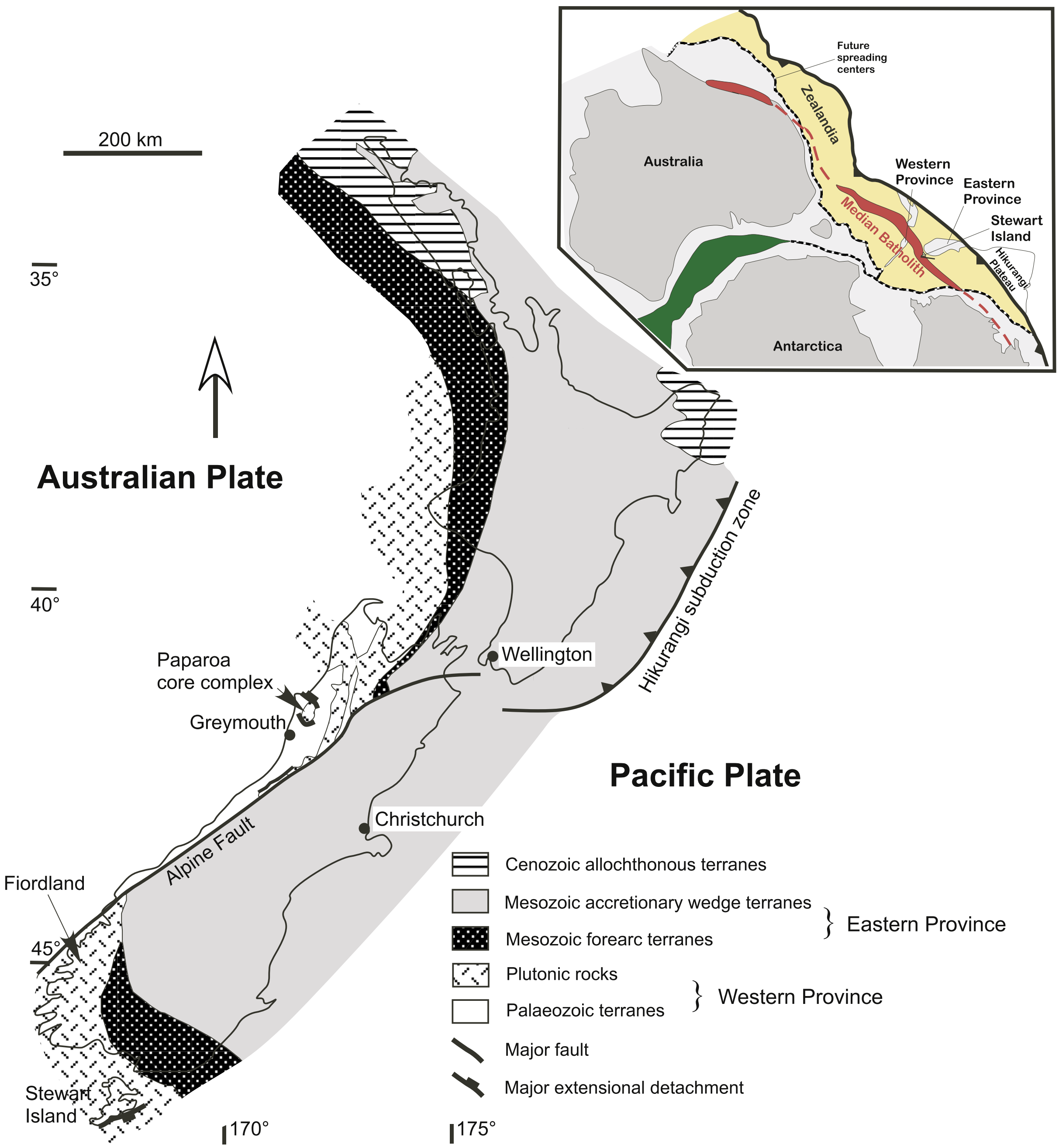

Fig. 1. Simplified terrane map of New Zealand and location of Stewart Island, the latter being made up by plutonic rocks of the Western Province; also shown is Paparoa core complex (inset shows mid Cretaceous subduction system at the eastern margin of Gondwana with Median Batholith magmatic arc; the future South Island of New Zealand is represented in this sketch by Eastern Province and small sliver of Western Province).