Field observations, microstructures, and frictional properties of the Red Island/Karamea shear zone, New Zealand

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Complex fracture networks, increased fluid pressure, and heterogeneous stress states associated with seamount subduction are believed to result in a conditionally stable frictional regime where slow earthquakes and slip can occur (Shaddox & Schwartz, 2019; Sun et al., 2020). However, the geologic expression of this environment is poorly constrained. A well-exposed coastal section near Waimarama, New Zealand, includes an exhumed seamount (Red Island/Karamea) and forearc sediments representative of the source region of shallow slow earthquakes along the northern Hikurangi Subduction Margin.

The exposed hanging wall of the basal thrust zone at Red Island is composed of several lithologies which have accommodated varying degrees of slip. At the base is a scaly red and green montmorillonite-rich gouge with S-C fabric and thin localised slip surfaces. This gouge is comparable to gouges found in large displacement thrust faults throughout the Waimarama coastal section. The montmorillonite-rich gouge is overlain by a pink argillaceous limestone with cleavage defined by alignment of phyllosilicates and coaxial elongation of foraminifera tests. The limestone is overlain by a thin Fe-rich smectite (nontronite) gouge with a shear foliation defined by dark clay seams parallel to the limestone cleavage but locally wrapping around more competent clasts. Widespread hydrothermal alteration of volcanic glass to nontronite has occurred along with the formation of colloform nontronite alteration halos within vesicles that were later infilled with calcite. Clay seams form a thin anastomosing network and nontronite grains and halos are angular with development of weak phacoid structures indicating displacement was relatively low. Multiple generations of foliation parallel and perpendicular calcite extension veins are present in the nontronite shear zone implying periods of high fluid pressure. Veins have been deformed by bedding parallel slip and some foliation parallel veins display crack-seal texture. Finally, the sequence is topped by undeformed mafic lava with pseudo-pillows and concentric calcite filled fractures. This unit is the base of the mafic lava sequence that makes up Red Island.

Friction experiments were conducted to determine the frictional properties of the nontronite-rich gouge and the montmorillonite-rich gouge under P/T conditions representative of the shallow subduction zone as well as to evaluate the effect of pore fluid pressure on frictional stability. Samples were sheared in a hydrothermal rotary shear apparatus at Utrecht University at 1 mm/s for 5 mm, followed by 3 sets of velocity step sequences of 0.3-1-3-10-30 μm/s over 0.6 mm displacement per step. Slide-hold-slide sequences of increasing hold duration (3-10-30-100-300-1000-3000 seconds) followed by 0.6 mm displacement at 1 μm/s were then performed. Experiments were conducted at a temperature of 80°C, a total applied pressure of 200 MPa, and pore fluid pressure of 80 –180 MPa (λ = 0.4, 0.6, and 0.9). The nontronite-rich foliated gouge displays a lower friction coefficient (μ = 0.2 –0.3) - independent of pore fluid pressure - than the montmorillonite-rich gouge (μ = 0.4 –0.6), which displays decreasing frictional strength with increasing pore fluid pressure. Both gouges are consistently velocity strengthening, a frictional behaviour that promotes aseismic creep.

Keywords: seamount, subduction, slow earthquakes, nontronite, Waimarama (NZ), rotary shear friction experiment