

Lateral Migration of Subduction Systems: Progression of the Hikurangi Margin Southwestward Through Increased Plate Coupling to Continuum Compression

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In newly-forming subduction zones on Earth, plates are torn apart and deep fluid generation and chemical element movement set forth, prior to the massive fluid release and arc magmatism of mature subduction. Such zones allow us to test how major fault zone geometries evolve from shallow levels to deep in the lithosphere as well as reveal the role of fluids in promoting rock failure by several mechanisms. Few subduction zones exhibit purely head-on meeting of the plates, but involve a strong proportion of strike-slip movement. Seriously damaging earthquakes in the deep subduction plane itself are well known (Alaska; Chile; Tohoku; Hawkes Bay; Pahiatua), but also occur on related continental strike-slip and thrust earthquakes (San Andreas; Anatolia; Chi-Chi; Murchison; Darfield).

Evolving subduction processes are extant over the transpressional regime of New Zealand (Fig. 1)^{1,2}. Dextral oblique subduction into the Hikurangi trench with relatively weak plate coupling gives way southwestward to the Marlborough (MLB) district of the northern South Island (SI). Here, subduction has migrated southwestward with tighter plate coupling, so that trench parallel deformation in the upper plate is taken up in a broad strike-slip fault system. The MLB region has received much study with geodetic³, passive seismic⁴, MT⁵, structural⁶ and geochemical⁷ methods. Much less understood is the earliest subduction development further SW as the MLB faults converge to the more singular Alpine fault (AF) and the deep continuum compression of the central SI⁸. Obvious Benioff zone seismicity tapers to near zero (at depth) near Culverden, but uppermost mantle eq's further SW may indicate earlier subducted, possibly less hydrated, thick oceanic crust of the Hikurangi Plateau⁹.

Convergence in the central SI is taken up primarily through ductile flow from the deep crust upward to the AF where embrittlement occurs, with some backthrusting⁸. Prograde metamorphism at depth in the root generates fluids which mobilize toward the AF and geophysically mark the main zone of ductile shearing^{10,11}. The fluids break to the surface ~10 km inboard of the AF as they reach the brittle-ductile (B-D) transition along the inclined (~45°) AF ramp, paralleled by a modern band of mesothermal As-Au occurrences^{10,12} (Fig. 2). However, this band converges to the intersection of the AF with the youngest MLB strike-slip fault (the Hope), with the intriguing implication that deep crustal, fluidized ductile flow has taken a vertical trajectory. This is but one example where imageable shearing at depth can trace boundaries representing the transition between distinct domains of major deformation. In MLB proper to the NE, MT imaging revealed the evolution of the main strike-slip faults to broad ductile shearing at depth, suggested a link between fluidized fracture meshes and new fault formation, and explained the source of fluids triggering enigmatic high-angle thrust faulting in the Murchison area⁵ (Fig. 3). These are all slab-sourced fluids, but at a stage of subduction before the hot, circulating mantle wedge has been set up. Agreement with Q_p and V_p/V_s tomography is close⁴.

Comprehending the leading edge of subduction would be advanced if we could trace the evolution of the major zones of deformation from the southern MLB regime into continuum central SI. Especially in the crust, block-bounding shear zones promote the long range interconnection of fluids which then become detectable geophysically^{4,5,10,11}. Correspondence between seismicity and fluidization is key, as fluids can migrate from shears to nearby stressed zones and promote failure⁵. Any relation between growth of MLB faulting southward since Pliocene time and the earthquake potential of the North Canterbury region could be clarified if major crustal weaknesses can be mapped. The NZ SI is ideal for testing these parameters due to the compositional uniformity of the Torlesse Fm crustal column. A powerful experiment would combine MT and passive seismology (Fig. 2,3); the former is sensitive to small amounts of interconnected fluids and has bandwidth to follow structures to near surface, while the latter can map crustal root formation and mantle thickening while confirming the larger crustal fluidized zones. This is a key transition for uncovering the respective roles of fluids generated in subduction versus deep crustal metamorphism in lithospheric deformation.

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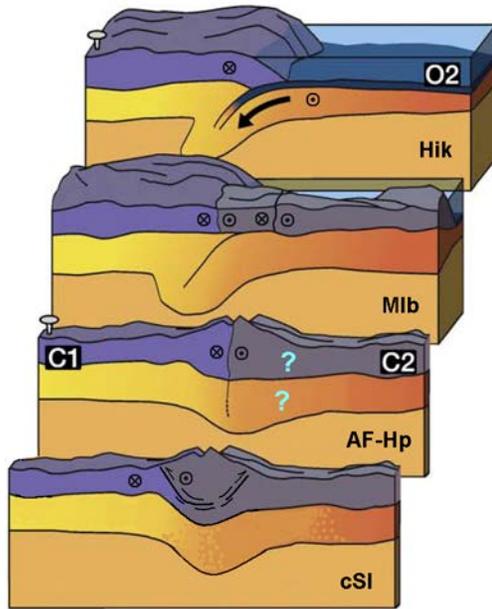


Figure 1. Schematic representation of tectonic transitions from Hikurangi (Hik) subduction, through Marlborough (Mlb) strike-slip, Alpine-Hope (AF-Hp) fault intersection, to central South Island (cSI) compression. Modified from ref. 2.

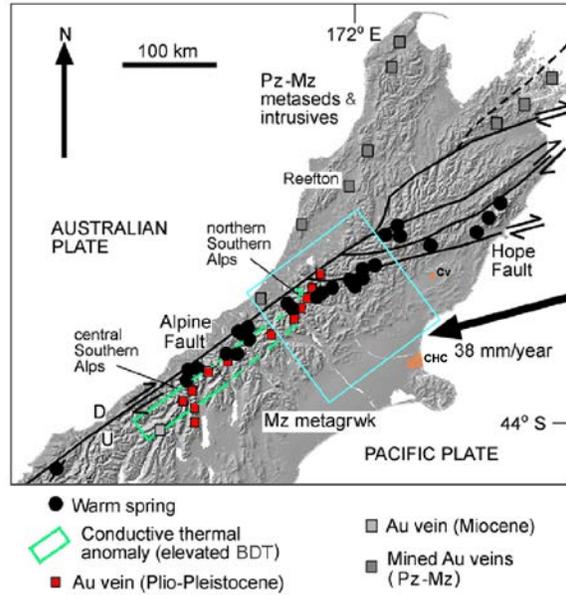


Figure 2. Central and northern South Island oblique compression and strike-slip setting with warm springs and mesothermal gold vein occurrences. Possible MT/passive seismic project area denoted by blue box. Modified from ref. 12.

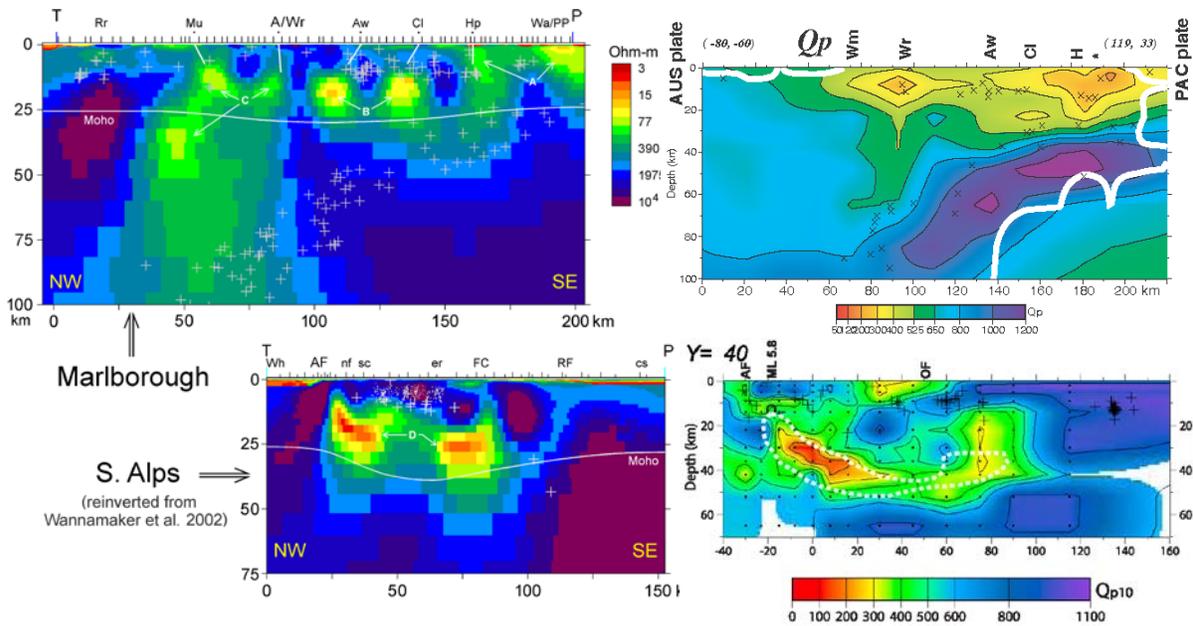


Figure 3. Left: MT electrical resistivity inversion cross sections through the Marlborough and central Southern Alps regions of New Zealand South Island. White lines in MLB section denote downdip projections of major strike-slip or thrust faults. MLB Benioff zone and crustal seismicity of both sections shown as white pluses. Small white dots on cSI section are Arthurs Pass eq's. Labeled resistivity zones discussed in ref. 5. Right: P-wave attenuation cross-sections through MLB and cSI (ref. 11 and 13). Former is ~40 km NE and latter ~75 km SW of respective resistivity models.