Regional Stress and Structural Setting of the 2010-2011 Canterbury earthquake sequence

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Abstract – Earthquake ruptures commonly exploit a varying mixture of inherited discontinuities and comparatively new-formed fault segments that are favourably oriented for reactivation within the prevailing tectonic stress field. The 2010-2011 Canterbury earthquake sequence comprises the September 4, 2010, M_w7.1 Darfield earthquake and the February 22, 2011 M_w6.3 Christchurch major shocks plus associated aftershocks that define a band of seismicity that extends 75 km west-east from the Southern Alps foothills across the Canterbury Plains to the mouth of the Heathcote-Avon estuary at the northern margin of the Banks Peninsula volcanic complex. While seismological and geodetic data suggest complex multiple ruptures (some involving reverse-slip), the M_w7.1 Darfield main shock gave rise to surface strike-slip rupturing for c. 30 km across the Canterbury Plains. Up to 5 m of right-lateral strike-slip occurred along the segmented trace of the subvertical Greendale fault with an enveloping surface trending 085° across the plains in good agreement with teleseismic long-period focal mechanisms. The M_w6.3 Christchurch earthquake at the eastern end of the seismicity band appears to have involved dextral-reverse subsurface rupturing for c. 10 km along an *en echelon* ENE-trending fault segment.

Subsurface information below the Canterbury Plains is sparse and inhomogeneous, but gravity surveys and reflection lines acquired for oil-gas exploration provide 'top-of-basement' maps which show that the broad band of rupturing illuminated by the seismicity lies at the southern boundary of a Late Cretaceous basin (the Rangiora Basin) that terminates abruptly against the Banks Peninsula structural high. The complexity of the structural setting is reflected in the fabric of subsidiary structures revealed by the aftershock distribution which includes: (i) a NE-SW band of predominantly reverse-slip aftershocks trending SW from the western termination of the surface rupture; (ii) a distributed series of comparable NE-SW bands also likely

associated with reverse-slip rupturing; (iii) a broad linear cluster trending NNW from the Darfield epicentre; (iv) a diffuse aftershock lineament trending c. 145-150° from south of the Greendale fault through Norwood and Doyleston to near the mouth of Lake Ellesmere that may represent a conjugate left-lateral strike-slip structure; (v) a sharp ENE-trending lineament extending from St Albans to Waimairi Beach; and (vi) a dense rhomboidal cluster of aftershocks (some with normal-slip mechanisms) at the eastern of the Greensdale rupture and extending south of it, that may define a linking dilational stepover between the major *en echelon* strike-slip fault segments. This last feature is particularly significant because such stepover structures are commonly associated with time-dependent slip transfer from one segment to the next.

Seismological, geodetic and geological stress determinations for the central South Island suggest that maximum compressive stress σ_1 is horizontal and oriented 115±5°. The principal dextral rupture therefore lies at ~30° to inferred regional σ_1, the classic 'Andersonian' orientation for a low-displacement strike-slip fault. This inferred σ_1 trend is also consistent with predominantly reverse-slip reactivation of structures trending NNE-NE along the Southern Alps range-front in a stress field with horizontal $\sigma_1 > \sigma_v = \sigma_2 \sim \sigma_3$. The main strike-slip fault appears unlikely to have large finite displacement and may represent either a fault that is fairly new-formed in the regional stress field, or a composite subvertical existing structure (associated with inherited normal faults?) that is optimally oriented for frictional reactivation.