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Late Quaternary large-scale bedrock defect controlled landslides of eastern North Island, New Zealand: The contrasting roles of tectonic and climatic forcing in landscape evolution

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Bedrock defect controlled landslides are widespread in the Tertiary and Quaternary bedded marine soft rock terrain of the emergent forearc frontal wedge and basin along eastern North Island. The location and frequency of these deep-seated bedrock landslides is somewhat predictable and the slides are a dominant process affecting both sediment fluxes and landscape evolution. Most slides appear to be base level controlled and occur after stream incision has exposed a critical stratigraphic horizon, defined by thin (typically <20mm), comparatively weak and laterally continuous bedding parallel layers. These horizons are of sedimentary origin (e.g. bedding partings; thin sand, clay and volcanic ash horizons) and may have experienced some prior tectonically induced shear displacement (e.g. flexural slip and/or fault shear). The residual strength of these discrete sedimentary horizons (C_r' = 2.6 – 20 kPa, and Φ_r = 2^o – $\sim 20^\circ$) is very low relative to the peak strength of the dominant lithology (C_r' = <300 kPa, and Φ_r= 30^o - 37°), and so define a high strength contrast in the succession. New failures are triggered episodically as deeper critical stratigraphic horizons daylight following stream incision. Failure on multiple near horizontal critical stratigraphic horizons leads to the development of a "stepped" landscape morphology with extensive block slides, while wedge failures dominate catchments with moderately dipping successions. Orthogonal rock defects also partly control the lateral slide boundaries. The slides are triggered by both short- and long-term tectonic (earthquakes; regional

uplift) and climatic (seasonal and glacio-eustatic cycles) forcing.

Large bedrock landslide dams are recognized in a number of catchments (e.g. Ngatapa, Waipaoa, Tutira, Waikaremoana, Ponui). Numerical stability analysis and historical precedent show that the temporal initiation of such landslides is often directly controlled by short-term tectonic forcing (large magnitude earthquakes). Such transient landslide dams block drainages and dramatically alter catchment sediment fluxes for periods ranging up to 10^4 years. Reservoir deposits allow quantification of the degree and timing of perturbations to sediment flux, and provide constraints on variations in catchment sediment yield attributable to long-term glacio-eustatic climatic forcing cycles. The influence of these large slope failures is likely to affect the geomorphic development of catchments over a time scale of $10^4 – 10^5$ years.

We have quantified key material strength and landslide geometry parameters that allow numerical landscape evolution models to include large bedrock failures. Such models are needed to investigate the range of conditions leading to sliding (e.g. uplift rates, incision rates, earthquake recurrence and shaking intensity) and the geomorphic consequences of the failures.