A model of active faulting in New Zealand

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Active fault traces are a surface expression of permanent deformation that accommodates the motion within and between adjacent tectonic plates. We present an updated national-scale model for active faulting in New Zealand, summarise the present understanding of fault kinematics in 15 tectonic domains, and undertake some brief kinematic analysis including comparison of fault slip rates with GPS velocities. The model contains 635 simplified faults with tabulated parameters of their attitude (dip and dip-direction) and kinematics (sense of movement and rake of slip vector); net slip rate; and a quality code. Fault density and slip rates are, as expected, highest along the central plate boundary zone, but the model is undoubtedly incomplete, particularly in rapidly eroding mountainous areas and submarine areas with limited data. The active fault data presented are of value to a range of kinematic, active fault and seismic hazard studies.

Keywords: active fault, New Zealand, tectonic domain, plate boundary, kinematics, slip rate
**Introduction**

Active fault traces are a surface expression of permanent, generally coseismic, deformation. Analyses of large datasets of active fault slip data can therefore provide insights into the kinematics of plate boundary zones. For example, data on the geometry and slip rate of active faults can be converted into tensor estimates of strain or seismic moment rates for comparison with seismicity or geodetic data (e.g., Wesnousky et al. 1982; Holt & Haines 1995; Klein et al. 2009; Stirling et al. 2009). Moreover, such data can be used for developing seismic (e.g., Stirling et al. 1998, 2002, 2012; Peterson et al. 2008) and tsunami (e.g., Berryman 2005; Priest et al. 2009) hazard models. One key to the success of such analyses is having moderately to highly complete active fault datasets with well constrained fault geometries and slip rates, and that include reliable estimates in the uncertainty in the fault kinematic properties.

In New Zealand a rich record of surface or near-surface land and marine active faults are preserved. Reasons for this include: (i) its position straddling the Pacific-Australia plate boundary zone (Fig. 1A); (ii) an historical record, albeit a short one (c. 170 years), of ground-rupturing earthquakes; (iii) good geomorphic and bathymetric expression of faults, reflecting a balance between deformation, erosion, and burial rates; (iv) relatively easy land access to most recognised active fault traces; (v) large areas of forest clearance; (vi) extensive high quality aerial photography coverage; (vii) extensive coverage of marine seismic reflection and multibeam bathymetric datasets; and (viii) a relatively long history of the geological, geodetic, and paleoseismological study of active faults (summarised in the next section). This makes New Zealand an ideal place to study plate boundary kinematics using active fault data.

In this study, we summarise a new nation-wide compilation of active faults that spans the entire New Zealand plate boundary (Fig. 1) and represents our current best understanding of the location, style, and deformation rates of New Zealand active faults. We describe the compilation as a model rather than database because each fault has been mapped at a regional-scale (no better than 1:250,000) as a highly generalised line, with a single set of fault characterisation parameters. Each mapped fault is therefore referred to as a ‘fault zone’ which emphasises the distinction between the simplified fault zones in this model and the more detailed active fault traces and parameters stored in databases such as the GNS Science Active Faults Database of New Zealand (http://data.gns.cri.nz/af/). Fault zone names are often informal. Our model is a significant advance on previous regional or national compilations (summarised below), benefiting from numerous recent (in the last c. 10 years) fault-specific studies, the systematic new mapping of active faults for the entire country at
1:250,000 scale for the QMAP programme (http://www.gns.cri.nz/Home/Products/Maps/Geological-Maps/QMAP.-1-250-000-Geological-Map-of-New-Zealand), and the parallel development of other models that utilise active fault data such as the National Seismic Hazard Model for New Zealand (Stirling et al. 2012). The tabulated characteristics of each fault zone in the model are presented in supplementary file Tables S1 and S2, and comprise: (i) dip; (ii) dip-direction; (iii) sense of movement; (iv) rake; (v) net slip rate; and a quality code. Also provided are regional-scale maps of fault zone locations (supplementary file Figures S1-S9), and digital maps (shapefile, ascii, and kmz files) of the fault zone locations (supplementary files Maps S1, S2 and S3). The derivations of each parameter for individual fault zones are described by Litchfield et al. (2013).

The purposes of this paper are to: (i) describe the model compilation methods; (ii) summarise the general nature and current state of knowledge of kinematics of active fault zones in each of 15 tectonic domains (Fig. 2); (iii) provide some preliminary statistical analysis of key model parameters; (iv) comment on model completeness; and (v) compare geological fault slip data with GPS velocities. We expect that this paper will provide a valuable and up-to-date synthesis upon which more detailed and/or multidisciplinary future plate boundary kinematic investigations can be founded with confidence.

**Previous regional-scale active fault compilations**

The first systematic regional active fault compilation in New Zealand was undertaken by Wellman (1953), who utilised aerial photographs to identify and map Recent and Late Pleistocene South Island faults, including the Alpine, Wairau, Clarence, Kekerengu, and Hope faults. Wellman (1955) then presented the first kinematic analysis of New Zealand active faults in which transcurrent faults were grouped together in a circum-Pacific mobile belt extending northeast across New Zealand, surrounded by a few normal faults. Earthquakes and active faults were noted to be directly related to one another.

From the 1960s onwards, Late Quaternary fault traces were shown (as red lines) on geological maps (e.g., Grindley 1960; Kingma 1962; Lensen 1963), but parameters describing the kinematics of slip on these faults were only mentioned sparsely, if at all, in the texts accompanying these published maps. In the 1970s and 1980s five active fault maps were published as the Late Quaternary Tectonic Map of New Zealand series. This series included the first, and in fact only, published New Zealand-wide active fault paper map (Officers of the Geological Survey 1983). That map shows 31 named active faults and 15
named active folds, but was not accompanied by any fault parameters such as dip, slip rate, or sense of movement.

Over the same period a series of papers summarised the state of knowledge of earth deformation in New Zealand at that time (Lensén 1975; Berryman 1984a,b; Lewis 1984; Walcott 1984; Berryman & Beanland 1988). Some of these papers contain fault parameters (e.g., 35 faults in Berryman & Beanland 1988) or summarise historical surface ruptures (Berryman 1984b; Berryman & Beanland 1988). Most also describe regional variations in fault styles and define a number of tectonic domains for the New Zealand region (also Berryman & Beanland 1991).

The first digital databases of New Zealand active faults were developed in the 1990s. The GNS Science Active Faults Database of New Zealand (http://data.gns.cri.nz/af/) was first developed at 1:250,000 scale and nominally contains faults with evidence of activity in the last 125,000 years (Jongens & Dellow 2003; Litchfield & Jongens 2006). Later, in the late 1990s, it began to be supplemented with data captured at 1:50,000 scale. Much active fault data have also remained archived, if unpublished, in university theses. Significant submarine active fault data has been collected by NIWA at a variety of scales from <1:50,000 to 1:200,000. All of these data have been meticulously perused, compiled, and incorporated into this active fault model.

Since the early 1990s, New Zealand-wide analyses of active faults have been primarily for the purpose of seismic hazard analysis (Stirling et al. 1998, 2002, 2012; Van Dissen et al. 2003). The most recent (2010) update of the New Zealand Seismic Hazard Model (Stirling et al. 2012) was compiled in parallel with the active fault model presented in this paper. The model in this paper however, contains some new material, and is focused more on faulting rates and deformation mechanisms, rather than as sources of past and potentially future earthquakes.

Methods of compilation

Definition of an active fault zone

In the model presented in this paper, a fault zone is defined as active if there is either evidence or inferred evidence for displacement in the past 125,000 years (late Pleistocene). We make an exception for the Taupo Rift (Fig. 1A) however, which is evolving so rapidly that fault zones in the rift are classified as active if there is evidence or inferred evidence for displacement in the past 25,000 years (Villamor & Berryman 2001, 2006a). Thus only faults in the inner, youngest part of the rift are included in this model. As well as representing
timeframes over which we infer that current tectonic regime may be considered stable, these timeframes are convenient in being marked on land by prominent marine or fluvial terraces (Pillans 1990a, 1991) (125,000 years BP). Circa 25,000 years B.P., moreover, coincides with the depositional age of nationally-widespread volcanic eruptive (the Kawakawa/Oruanui Tephra e.g., Wilson 2001; Vandergoes et al. in press) that was deposited across most of northern and central New Zealand. Offshore, many active fault zones beneath the continental shelf are constrained by deformation of the transgressive post-last glacial (<20,000 years BP) marine ravinement surface and associated post-glacial sediments (e.g., Lewis 1971; Nodder 1994; Barnes 1996; Lamarche et al. 2006). Farther offshore, active fault zones can be recognized on the basis of whether or not they displace surfaces that formed since the last interglacial period, and/or considering their prominent geomorphic expression in late Quaternary submarine landscapes (e.g. Barnes 1996; Barnes et al. 2010). In this model we do not include thrust faults of the frontal wedge of the Hikurangi subduction margin, which have been considered to have developed aseismically (Barnes et al. 2010; Stirling et al. 2012).

**Active fault zone traces**

Our compilation maps show the generalised trace (i.e. surface position or projected surface position) of each delineated active fault zone representative of crustal scale deformation (Fig. 1B; supplementary files Figures S1-S9 and Maps S1-S3). The simplified fault zone characterisations presented in this paper are intended primarily to assist regional kinematic and seismic hazard studies, and the more detailed datasets should be consulted for any purposes relating to land-use or engineering development. The simplified fault zones (e.g., Fig. 3), are mostly the same as those used in the 2010 update of the New Zealand National Seismic Hazard Model (Stirling et al. 2012). Where faults are represented in more detailed databases by only one or a few short surface traces, the faults were either: (i) extended along bedrock faults (faults separating different bedrock units, but mapped as inactive) from the GNS Science 1:250,000-scale Geological Map of New Zealand (QMAP); (ii) extended along topographic or bathymetric features, such as range-fronts or submarine ridges; or (iii) merged to reflect minimum threshold earthquake magnitudes for ground-rupturing seismogenic faults. Consideration was also given to likely fault length (e.g., fault zone 170 in Fig. 3A) and subsurface connectivity (e.g., fault zones 230 and 229 in Fig. 3B).

On land ten blind fault zones are recognized. These include buried faults imaged on seismic reflection profiles (Melhuish et al. 1996); those inferred by Jackson et al. (1998) to exist at depth beneath active anticlines near Palmerston North (Fig. 1B); and the mainly blind
fault inferred to have ruptured in the 1931 Napier Earthquake (Hull 1990). Offshore, no differentiation is made here between faults imaged that terminate upward beneath anticlines (i.e., blind faults), and those that break the sea floor to form seafloor scarps.

In the rapidly uplifting (≤ 10 mm/yr) and eroding central Southern Alps (Fig. 1A), geodetic (Beavan et al. 2010a; Wallace et al. 2007) and geologic (Cox & Findlay 1995; Cox & Sutherland 2007; Cox et al. 2012) data indicate that active faults must be present, but their activity cannot be characterised in detail because Late Quaternary scarps and markers are not preserved as a result of rapid erosion in a steep mountainous environment that has been subject to high rates of annual rainfall and repeated glaciations. We address this gap in the data by adding indicative fault zones, typically 5-15 km apart perpendicular to strike, that approximately correspond to the known faults in bedrock as currently mapped (Cox & Barrell 2007; Rattenbury et al. 2010) and which are considered likely, based on structural or geomorphic observations, to have experienced late Quaternary activity (Cox et al. 2012). The names of most of the Southern Alps fault zones (as well as some others in this model, particularly in offshore Bay of Plenty) are informal names that do not necessarily correspond to published active or bedrock fault names.

**Active fault zone parameters**

Active fault zone parameters defined in this model are: (i) dip; (ii) dip-direction; (iii) sense of movement; (iv) rake; (v) net slip rate; and (vi) quality code. Strike is not explicitly tabulated, but can be derived from the fault zone traces. Table 1 provides a description of each parameter and describes in general terms the sources of information used to assign values for each parameter. The quality codes are further defined in Table 2. For the numerical parameters dip, rake, and net slip rate, uncertainties are quantified by providing three values for each, a minimum value, a maximum value, and what is considered to be the best (most likely) value. The minimum and maximum values are inferred to approximate 95% confidence bounds, in a qualitative rather than statistically rigorous way. The best value may in some cases be the mean of several site-specific measurements, or be the median between maximum and minimum values. In other cases, the best value is calculated from the best-constrained site-specific offset and age data, and may return a value anywhere between the maximum and minimum (e.g. for a particular fault zone, a value towards the maximum may be considered most likely). As a result there is not necessarily a symmetrical distribution of uncertainty between maximum and minimum values. Specific details of the derivations of each parameter for individual active fault zones are provided by Litchfield et al. (2013).
Selected Transects of Cumulative Net Slip Rate

To aid with our description of the fault kinematic properties of each tectonic domain in the next section, we have calculated cumulative net slip rates for representative transects across each domain (Fig. 2). The transects were selected to: (i) cross fault zones with the best slip rate data; (ii) be close to perpendicular to the general strike of the fault zones in the domain; and (iii) be close to parallel within each domain (Fig. 2). The cumulative net slip rate (the sum of net slip rates for faults crossing each domain irrespective of fault orientation or rake) is considered to reflect seismic moment release at the surface across the domain (rather than, for instance, horizontal extension or contraction). The cumulative net slip rate uncertainties were calculated from the root mean square of individual fault zone slip rate uncertainties. In addition, the cumulative slip rate was assigned an overall high, medium, or low confidence ranking, which is calculated from the quality codes assigned to each fault zone (high broadly corresponds to code 1, medium to 2, and low to 4; codes 3 and 5 fault zones are not included). We make the assumption that slip rates have been constant over the current period of activity (125,000 or 25,000 years), unless explicitly stated.

Fault kinematics of the tectonic domains

The New Zealand plate boundary can be divided into three main components from north to south: (i) oblique westward subduction of the oceanic Pacific Plate beneath the continental Australian Plate east of the North Island (Hikurangi Margin); (ii) transpression (dextral) and oblique continent-continent convergence in the South Island (South Island continental transpression zone); and (iii) northeastward subduction of the oceanic Australian Plate beneath the continental Pacific Plate southwest of the South Island (Puysegur Margin). Within this overall framework, 15 tectonic domains have been recognised, based on subjective geographic groupings of active faults that have similar geometries and kinematics (Fig. 2). Many of these domains have been defined in previous studies (e.g., Berryman & Beanland 1991; Stirling et al. 2002, 2012) and in particular, the domains in this study are slightly modified from those in the 2010 National Seismic Hazard Model (Stirling et al., 2012). Together, domains 1–6 make up the Hikurangi Subduction Margin, domains 7–12 make up the South Island continental transpression zone; and domains 13–15 make up the Puysegur - Fiordland Margin. The characteristics of the fault zones in each of these domains and the present state of knowledge of domain kinematics (mostly from previous studies) are summarised briefly in the following sections, generally from north to south. Figures 4 and 5
show the fault zones colour-coded by dominant sense of movement and slip rate, respectively.

**Extensional western North Island fault zones (domain 1)**

Domain 1 contains relatively few active fault zones. In the north, two fault zones are the only currently active faults of the Hauraki Rift (Fig. 1B) (Hochstein & Ballance 1993). These north-northwest striking fault zones have normal senses of movement and net slip rates of 0.1–0.3 mm/yr (e.g., M. Persaud, P. Villamor & K. Berryman unpubl. data 2006). Northeast-striking active fault zones in western Taranaki (labelled W on Fig. 1B) appear to have purely normal senses of movement and net slip rates of 0.1–1.5 mm/yr (e.g., Nodder 1994; Townsend et al. 2010; Mouslopoulou et al. 2012). These form the southern part of the mainly submarine Taranaki Basin (Fig. 1A). Farther east, at the western margin of the Wanganui Basin (labelled E on Fig. 1B), a series of north-northeast striking fault zones also have normal senses of displacement, although several have an additional minor component of dextral strike-slip. Net slip rates on individual fault zones are 0.02–0.2 mm/yr (e.g., Pillans 1990b). The Wanganui Basin active faults are interpreted to be bending-moment normal faults on uplifted basement blocks (Pillans 1990b).

A cumulative net slip rate of 3.2 ±0.5/-1.1 mm/yr is calculated along the transect shown in Fig. 2. This rate is significantly higher than the slip rates on fault zones in the Hauraki Rift to the north (maximum 0.3 ± 0.1 mm/yr).

The active tectonics in domain 1 indicates back-arc extension distal to the present day volcanic arc. The Hauraki Rift is largely a relict structure related to the now-extinct Coromandel Volcanic Arc (Hochstein & Ballance 1993; Fig. 1B), and its relict nature may account for the low slip rates on faults there. Roll-back of the Pacific Plate subducted slab and southward motion of the southern termination of subduction and mantle corner flow has been proposed as a mechanism for relatively large slip rates in the southern part of the domain (Giba et al. 2010).

**Extensional Havre Trough – Taupo Rift fault zones (domain 2)**

The southern part of domain 2 is the Taupo Rift (also referred to as the Taupo Fault Belt after Grindley 1960), which is situated within the active volcanic arc, the Taupo Volcanic Zone (e.g., Cole et al. 1995; Rowland & Sibson 2001). Offshore from the Bay of Plenty coast, the Taupo Rift broadens westward into the southern Havre Trough (Fig. 1A) (Wright 1993). In this study, only faults within the southern 100 km of the Havre Trough have been presented.
Fault zones within the Havre Trough - Taupo Rift mostly strike northeast and are typically short (c. 4–33 km) and closely spaced. All appear to have a normal sense of movement (Fig. 4). Net slip rates on individual fault zones are thought to range from 0.05 to 4 mm/yr (Fig. 5), with the highest well-constrained slip rate, at 3.5 mm/yr, in the centre of the Taupo Rift (Villamor & Berryman 2001). A northward increase in extension rates in this domain has been previously recognised, from 2.3 ± 1.2 mm/yr south of Mount Ruapehu (Fig. 1B) (Villamor & Berryman 2006b), to 4.4 +2.4/-1.9 mm/yr near Rotorua (Villamor & Berryman 2001) to 13 ± 6 mm/yr immediately north of the Bay of Plenty coast (Lamarche et al. 2006). This trend is also expressed by a northward increase in cumulative net slip rate for the domain 2 transects shown in Fig. 2.

The Havre Trough is interpreted to be in an incipient phase of distributed and disorganised oceanic crustal accretion and spreading (Wysoczanski et al. 2010). In the Taupo Rift, two areas devoid of fault zones coincide with the locations of two major volcanic centres, the Okataina and Taupo Volcanic Centres (Fig. 1B), where much of the back-arc extension may be locally accommodated by magmatic (e.g., dike intrusion) processes (e.g., Seebeck & Nicol 2009; Cole et al. 2010; Rowland et al. 2010). The northward increase in extension rates is consistent with clockwise rotation of the eastern North Island in response to slab rollback and pinning of the southern edge of subduction against the Chatham Rise (Fig. 1B) (e.g., Beanland & Haines 1998; Wallace et al. 2004, 2007).

**Contractional Kapiti – Manawatu fault zones (domain 3)**

The contractional Kapiti – Manawatu fault zones lie southwest of the Taupo Rift, and northwest of the North Island Dextral Fault Belt. The majority of domain 3 fault zones are steep reverse structures (Fig. 4) which are likely reactivated Pliocene – early Pleistocene normal faults (Lamarche et al. 2005). Many also have blind tips associated with hanging wall anticlines and footwall synclines (Melhuish et al. 1996; Jackson et al. 1998; Lamarche et al. 2005).

Fault zone lengths range from c. 8 to 91 km, but the shortest are likely underestimated because they transect highly erodible Plio-Pleistocene sediments. Net slip rates range from 0.04 to 3.0 mm/yr (Fig. 5), with the highest occurring on the submarine Mascarin Fault (3 +0.5/-2 mm/yr) (Nodder et al. 2007). Cumulative net slip rates increase northwards from 2.5 +0.3/-0.6 to 5.4 +0.6/-1.6 mm/yr (Fig. 2). The lower rate in the south is thought to be due to the fault zones there having a greater dextral component than further northeast and contractional motion partitioned onto reverse faults in the southern Hikurangi subduction
margin forearc (domain 5). This apparent northward increase in slip rate is however inconsistent with geodetic modelling that predicts a northwards decrease in shortening (Wallace et al. 2012).

Domain 3 fault zones uplift the eastern margin of the otherwise subsiding Wanganui Basin (Fig. 1A). The basin has been inferred to be subsiding as a result of high friction on the plate interface, producing a downward pull and flexure of the overriding Australian Plate (Stern et al. 1992). Reverse-slip on these fault zones may also have contributed to subsidence through crustal shortening and lithospheric loading (Lamarche et al. 2005).

**North Island Dextral Fault Belt (domain 4)**

The North Island Dextral Fault Belt (also referred to as the North Island Fault System, Mouslopoulou et al., 2007a) is a c. 470 km long series of fault zones within and along the eastern margin of the North Island’s axial ranges (Fig. 1A). Fault zones at the southern end of the system strike northeast and are predominantly dextral strike-slip at the ground surface (Fig. 4). Further north, the faults become progressively more oblique with an increasing component of extension. Where they intersect and terminate against the eastern margin of the Taupo Rift (domain 2), the northerly-striking faults in the North Island Dextral Fault Belt (domain 4) slip with approximately equal components of dextral and normal slip (Fig. 4) (Mouslopoulou et al. 2007a,b; 2009).

Accompanying the northward change in slip obliquity is a decrease in overall slip rate (Van Dissen & Berryman 1996; Beanland & Haines 1998; Mouslopoulou et al. 2007b) (Figs. 2 and 5). Net slip rates on individual fault zones are up to 11 mm/yr (dextral) in the south (Carne et al. 2011), but are no more than 2.5 mm/yr (dextral-normal) in the north (Mouslopoulou et al. 2007b). The four transects in Fig. 2 show that the cumulative net slip rate decreases northward from 22.3 +1.8/-3.8 to 14.4 ± 1.7, 7.1 +0.3/-0.6, and 6.2 ± 1.1 mm/yr.

The North Island Dextral Fault Belt accommodates much of the margin-parallel (dextral) plate motion (Walcott 1987; Cashman et al. 1992; Van Dissen & Berryman 1996; Beanland & Haines 1998; Mouslopoulou et al. 2007a; Nicol & Wallace 2007). The fault zones are inferred to splay upwards off the Hikurangi subduction thrust and the 1855 rupture of the Wairarapa Fault at the southern end of the system may have involved slip on the subduction interface (Darby & Beanland 1992; Rodgers & Little 2006). The northward decrease in slip rates compliments the northward increasing rates of normal slip across the
adjacent Taupo Rift to the west (southern domain 2), a displacement transfer that is associated with clockwise rotation of the eastern North Island (e.g., Wallace et al. 2004).

The southern end of the North Island Dextral Fault Belt is along strike from strike-slip fault zones of the Marlborough Fault System, but the two are not directly connected beneath Cook Strait (Fig. 1A) (Pondard & Barnes 2010). The discontinuity in Cook Strait separates more northerly-striking fault zones in the North Island Dextral Fault Belt from more easterly-striking fault zones in the northern part of the Marlborough Fault System. This crustal scale hinge or kink between the two dextral-slip fault systems is thought to transfer some of the slip on the Marlborough Fault System northward onto the Hikurangi subduction thrust (Wallace et al. 2012).

**Hikurangi subduction margin forearc (domain 5)**

The Hikurangi subduction margin forearc is a relatively wide domain, extending westward from the seafloor trace of the Hikurangi subduction thrust to the North Island Dextral Fault Belt and the Havre Trough. The majority of the fault zones are thrust faults striking northeast in the submarine accretionary wedge, and are associated with hanging wall anticlines and footwall synclines (e.g., Barnes et al. 2002a, 2010). In the south there are some easterly-striking dextral strike-slip fault zones, while a series of short northeast-striking normal fault zones occur in the northern onshore portion (Fig. 4).

Fault zone lengths range from c. 6 to 146 km, the shortest being the Raukumara Peninsula normal fault zones and the longest the submarine thrust and strike-slip fault zones at the south end of the domain. Net slip rates are estimated to range from c. 0.1 to 5 mm/yr (Fig. 5), with the lowest being the Raukumara Peninsula (Fig. 1B) normal faults (Berryman et al. 2009). The highest slip rate occurs on the Lachlan Fault (4.5 ± 2 mm/yr), a major nearshore thrust fault uplifting Mahia Peninsula (Berryman 1993; Barnes et al. 2002a; Mountjoy & Barnes 2011). Cumulative net slip rates for three transects which cross the entire domain are, from north to south, 13.6 +3.4/-2.5, 9.7 ± 1.6 and 14.4 +2.5/-2.9 mm/yr (Fig. 2).

Uplift of the inner forearc (coastal ranges) is primarily driven by subduction of the buoyant, oceanic, Hikurangi Plateau (Fig. 1A) (Davy 1992; Kelsey et al. 1995; Litchfield et al. 2007), with contributions from sediment underplating and localised upper plate faulting (Walcott, 1987; Reyners et al. 1999, 2006; Nicol et al. 2002; Formento-Trigilio et al. 2003). The fault zones in this domain are interpreted to splay upwards from the subduction thrust (Lewis & Pettinga 1993; Henrys et al. 2006; Barker et al. 2009; Barnes et al. 2010; Pedley et
The southern dextral strike-slip fault zones are inferred to facilitate slip transfer between the northern Marlborough Fault System (domain 8) and either the southern North Island Dextral Fault Belt (domain 4) or the Hikurangi subduction thrust (domain 6) (Wallace et al. 2004, 2012). The normal fault zones in Raukumara Peninsula are interpreted to be shallow, secondary extensional structures formed as a consequence of rapid uplift, and/or trenchward collapse, of the northern forearc (Thornley 1997; Berryman et al. 2009). An absence of consistent along-strike variations in the cumulative slip rates indicate that convergence variability along the margin (Wallace et al. 2004) is largely accommodated by the subduction interface and associated frontal thrusts.

**Hikurangi subduction thrust (domain 6)**

The Hikurangi subduction thrust extends southward from the southern end of oceanic-oceanic crust subduction at the Kermadec Trench (Fig. 1A), where convergence rates exceed 60 mm/yr, to offshore northeastern Marlborough, where plate motion is predominantly transferred to the Marlborough Fault System. The thrust intersects the seafloor along the western edge of the Hikurangi Trough (Fig. 1A), and is expressed by frontal thrust-faulted anticlinal ridges and a proto-thrust zone (Lewis & Pettinga 1993; Barker et al. 2009; Barnes et al. 2010). Following Wallace et al. (2009) and Stirling et al. (2012), the thrust is divided into three sections along strike (Fig. 1B), on the basis of margin characteristics, historical seismicity and the distribution of interseismic coupling and slow slip events (summarised by Wallace et al. 2009). The section boundaries are only approximately located however, because of the relatively low resolution of the location of these changes at depth. The model of Stirling et al. (2012) focused on the seismogenic part of the thrust, for the purposes of seismic hazard modelling, whereas our model addresses all parts of the thrust down-dip from its trace in the Hikurangi Trough.

All sections are inferred to be largely dip-slip, as the thrust takes up a significant proportion of the plate-normal motion (Barnes et al. 1998; Nicol & Beavan 2003; Wallace et al. 2004, 2009; Nicol & Wallace 2007). The concave (e.g., Ansell & Bannister 1996), and in places kinked, profile of the thrust in cross-section (Henrys et al. 2006; Barker et al. 2009) has led us not to assign single dip values to the fault. The full net slip rate on the thrust (i.e., including seismogenic and creeping components) ranges from $54 \pm 6$ mm/yr in the north, $44 \pm 7$ mm/yr in the centre, to $25 \pm 5$ mm/yr in the south (Wallace et al. 2004; Stirling et al. 2012).
**Contractional northwestern South Island fault zones (domain 7)**

Contractional northeast-striking fault zones produce a range and basin topography north and west of the transpressional Alpine Fault. Many of these fault zones are reactivated Mesozoic or early Cenozoic normal faults (Laird 1968; Lihou 1992; Bishop & Buchanan 1995; Ghisetti & Sibson 2006) and many have associated hanging wall anticlines and footwall synclines (Suggate 1987; Nicol & Nathan 2001; Ghisetti & Sibson 2006). Despite their prominent geomorphic expression, only some of these fault systems show evidence for Late Pleistocene activity (Suggate 1987, 1989; Nicol & Nathan 2001), implying that more faults could be potentially active than currently recognised (e.g., Stafford et al. 2008; Sibson & Ghisetti 2010).

Fault zone lengths range from c. 38 to 140 km, based mainly on bedrock geology, and sense of movement is primarily reverse (Fig. 4). Net slip rates are poorly constrained (e.g., Stafford et al. 2008), and generally low (Fig. 5). Cumulative net slip rates across two transects in Fig. 2 are 0.7 ± 0.3 (north) and 1 ± 0.4 (south) mm/yr.

The northwestern South Island fault zones have, through the Late Cenozoic, taken up some of the plate-normal component of continental convergence in the South Island. Deformation is particularly concentrated northwest of a major bend in the Alpine Fault, where some of the reverse fault zones likely form footwall shortcut thrusts and backthrusts to the Alpine Fault (Ghisetti & Sibson 2006).

**Strike-slip Marlborough Fault System (domain 8)**

The Marlborough Fault System is a series of predominantly continental strike-slip fault zones (Fig. 4) in the northern South Island, which link the Hikurangi Subduction thrust (at depth) to the Alpine Fault. Although the majority of fault zones are chiefly dextral strike-slip, several also have measurable dip-slip motion (Fig. 4), most commonly up-to-the-northwest. For example, reverse faults contribute to uplift of the Kaikoura Ranges (e.g., Van Dissen & Yeats 1991; Nicol & Van Dissen 2002) and parts of the continental shelf (Barnes & Audru 1999). A normal component of slip on the Wairau and Cloudy faults create transtensional basins in Cook Strait (Fig. 1A) (Pondard & Barnes 2010), while extension on the Hanmer Fault contributes to localised subsidence of Hanmer Basin along the Hope Fault (Fig. 1B) (Wood et al. 1994) (Fig. 4).

Whilst fault zone lengths range from c. 18 to 145 km, the majority of the structures are elements of longer segmented strike-fault systems (e.g., the Hope Fault, Langridge et al. 2003, which has a total length of c. 300 km as defined here). Net slip rates range from c. 0.1
to 25 mm/yr (Fig. 5), with the highest being the eastern section of the Hope Fault (Langridge et al. 2003). Cumulative net slip rates along transects (Fig. 2) are 23.5 +3.4/-3.7 (southwest) and 37.8 ± 3.4 (northeast) mm/yr, showing a northeastward increase in the transfer of slip from the Alpine Fault to the Marlborough Fault System.

The Wairau Fault, sometimes considered the northern part of the Alpine Fault based on the continuity of the surrounding bedrock and total offset (e.g., Berryman et al. 1992), is included in this domain to reflect its current role in the Marlborough Fault System. Domain 8 lies above the subducted Pacific Plate, but its constituent faults likely intersect the underlying plate interface only in the east, where the interface is shallowest (Reyners & Cowan 1993; Wannamaker et al. 2009; Eberhart-Phillips & Bannister 2010; Wallace et al. 2012). The age of the Marlborough Fault System has been interpreted to decrease southeast-ward, probably reflecting southward migration of the Hikurangi subduction thrust (e.g., Yeats & Berryman 1987; Little et al. 1998; Wallace et al. 2007).

**Contractional North Canterbury fault zones (domain 9)**

Lying southeast of the Marlborough Fault System, this domain is characterised by mixed fault zone orientations and slip types (Fig. 4). In the northeastern, offshore part of the domain, reverse and thrust fault zones with associated hanging wall anticlines and footwall synclines largely verge eastward. They cut Mesozoic basement and possibly splay upwards from the Hikurangi subduction thrust (Barnes et al. 1998; Wallace et al., 2012). Onshore, in the centre of the domain, reverse fault zones with associated hanging wall anticlines and footwall synclines, verge mainly northwest in the coastal region and southeast further inland (Al-Daghastani & Campbell 1995; Nicol et al. 1995; Barnes 1996; Pettinga et al. 2001; Litchfield et al. 2003). Localised northerly and easterly striking fault zones are probably reactivated Cretaceous normal faults (Nicol & Wise 1992; Nicol 1993; Litchfield et al. 2003). The fault zones could extend upward from a mid-crustal detachment identified in microseismicity (Reyners & Cowan 1993; Campbell et al. 2012). Fault zones in the western part of the domain are inferred to be predominantly transpressional (Cox et al. 2012), but some northwest-striking fault zones form complex transfer structures between northeast-striking faults (Abercrombie et al. 2000; Robinson & McGinty 2000). Fault zones in the far west of the domain may splay upwards from the southeast-dipping Alpine Fault (Pettinga et al. 2001). The exact position of the southwest boundary between domains 9 and 11 (in the Southern Alps) is somewhat subjective, but has been defined based on a slight change in
strike (generally more easterly to the north) and sense of movement (some dextral motion to
the north).

Fault zone lengths range from c. 7 to 90 km, with the longest, the Porters Pass – Grey
fault zone, comprising at least two segments (Howard et al. 2005). Slip rates are mostly
poorly constrained; they range from c. 0.1 to 3.5 mm/yr, with the highest rate estimated for
part of the Porters Pass fault (3.5 +0.6/-0.4 mm/yr) (Howard et al. 2005), and the lowest on
submarine faults in the east (Barnes 1996; Barnes et al. 1998) (Fig. 5). Cumulative net slip
rates calculated along transects shown in Fig. 2 decrease northeastward from >5.6 +0.9/-0.6
to 3.1 +1/-0.8 and 2.3 ± 0.7 mm/yr, although the slip rate on the westernmost transect is a
minimum because it includes Southern Alps fault zones with no assigned slip rates.

The North Canterbury fault zones are considered to be relatively youthful (<1 Myr
e.g., Nicol et al. 1994; Barnes 1996; Cowan et al. 1996; Pettinga et al. 2001; Litchfield et al.
2003), and represent an encroachment of plate boundary deformation into the region from
the north. The evolution of this domain means the southeast boundary may be migrating south,
the possibility exists that the faults that ruptured in the 2010-2011 Canterbury Earthquake
Sequence (e.g., Gledhill et al. 2011; Kaiser et al. 2012) could be included in this domain (e.g.,
Campbell et al. 2012) rather than the lower strain domain 11, as proposed here (see below).

**Extensional North Mernoo fault zones (domain 10)**
The North Mernoo fault zones are entirely submarine (Fig. 4) and comprise east-striking fault
zones on the northwestern edge of the submerged continental Chatham Rise (Fig. 1A).

Although mapping is limited by data coverage, the larger structures are inferred to be
between c. 20 and 65 km long (Barnes 1994a). Sense of movement is inferred to be normal
(Fig. 4) with net slip rates, assigned on the basis of low long-term extension (Pliocene-
Quaternary), of c. 0.1 to 0.25 mm/yr (Fig. 5). The cumulative net slip rate across this domain
is 1 ± 0.4 mm/yr (Fig. 2).

The current phase of activity started in the Late Miocene, and involved a reactivation
of Cretaceous and Eocene (normal) fault systems (Barnes 1994b). Two kinematic models to
explain this extension have been proposed. One is minor buckling at the northern end of the
southern Marlborough Fault System, which results in slivers of the Chatham Rise being
spalled off as the Chatham Rise slides past southern Marlborough (Anderson et al. 1993). The
other model invokes flexural extension (bending-moment faulting) of the edge of the
Chatham Rise at the southern end of the Hikurangi Subduction Zone (Barnes 1994a).
**Contractional southeastern South Island fault zones (domain 11)**

Domain 11 is the largest and comprises all of the active faults of onland South Island southeast of the Alpine Fault and south of the North Canterbury fault zones (domain 9) (Fig. 2). The majority of fault zones strike north to northeast, but there is an additional set of northwest-striking faults within much of the domain, producing an orthogonal fault pattern. Many of these structures are range-bounding reverse faults (Fig. 4) with hanging wall anticlines and footwall synclines (e.g., Beanland et al. 1986; Jackson et al. 1996; Markley & Tikoff 2003). Fault zones close to the Alpine Fault have a significant component of dextral strike-slip motion (Sutherland 1995; Ballard 1989; Cox et al. 2012) and there are two predominantly strike-slip fault zones of note. The northwest-striking Wharekuri Fault (Barrell et al. 2009) in the Waitaki Valley (Fig. 1B) is the only dominantly sinistral fault zone in the model, and may facilitate eastward widening of the area of contraction east of the Alpine Fault (see below). The east-striking Greendale Fault in the northeast corner ruptured in the 2010 Darfield Earthquake (e.g., Quigley et al. 2010, 2012; Gledhill et al. 2011) and is likely to be a reactivated Cretaceous normal fault (Browne et al. 2012; Campbell et al. 2012; Ghisetti & Sibson 2012; Jongens et al. 2012).

Fault zone lengths range from c. 15 to 90 km, while the range-bounding reverse fault zones are mostly 20–70 km long. Net slip rates are 0.01 to 2.2 mm/yr (Fig. 5), with the highest being the Fox Peak Fault (2.2 +2.4/-1.8 mm/yr) (Upton et al. 2004). Cumulative net slip rates across the three transects shown in Fig. 2 are >3.9 +3.1/-1.9, 3.9 +1.9/-1.1, and 1.2 ± 0.6 mm/yr from north to south, although the northern (and possibly the central) transect slip rate is a minimum because it includes fault zones within the Southern Alps with no assigned slip rates. Conversely, the central cumulative net slip rate may be a maximum as there is some evidence for the activity of some of these (Beanland & Berryman 1989; Berryman & Beanland 1991), as well as other east Otago (Litchfield & Norris 2000), fault zones to be episodic.

The convergence zone in the north and centre of this domain can be described as an asymmetric two-sided orogen, with the higher rates of erosion in the west (inboard) focusing deformation on the southeast-dipping Alpine Fault (Koons 1990; Norris et al. 1990). Variations in the width of the outboard zone (east) are likely to be a function of lithology, with the widest part in the centre of the domain corresponding to thicker and weaker schistose crust (Upton et al. 2009). Northern outboard fault zones (north of Oamaru; Fig. 1B) likely splay upwards from a mid-crustal shear zone (e.g., Wannamaker et al. 2002; Van
Avendonk et al. 2004), whereas central fault zones (in Otago, the area between approximately Oamaru and Papatowai in Fig. 1B) may splay upwards from a thick ductile lower crust (Upton et al. 2009). Many of the outboard fault zones are reactivated Cretaceous normal faults (Mutch & Wilson 1952; Norris et al. 1987; Ghisetti et al. 2007). Inboard (northwest-dipping) fault zones in the centre and north of the domain are likely to be back-thrusts off the southeast-dipping Alpine Fault (Norris et al. 1987, 1990; Cox & Sutherland 2007).

**Alpine Fault (domain 12)**

The Alpine Fault is a dextral strike-slip fault, defined here to be c. 740 km in length, forming the western (inboard) side of the South Island continental-convergence zone. The fault links the Marlborough Fault System with the Puysegur subduction thrust (Fig. 2).

In this paper, we divide the Alpine Fault into 6 sections (Fig. 1B) based on changes in slip rate and geometry along strike. The southern sections are steeply-dipping to the southeast, almost pure dextral strike-slip (Barnes et al. 2001, 2005), and include the highest net slip rate (31 ± 3 mm/yr) found on the fault (Barnes 2009). The rate decreases northwards to 23 ± 2 mm/yr in south Westland (Sutherland et al. 2006). The central sections, bounding the western side of the Southern Alps, have a moderate dip to the southeast (Davey et al. 1998). Near Aoraki/Mt Cook (Fig. 1B) the dip-slip rate is locally up to 10 mm/yr (Norris & Cooper 2001) and inferred uplift rates to the east of the fault are >8 mm/yr (Batt 2001; Little et al. 2005). The dextral slip rate decreases northwards where slip is transferred onto the Marlborough Fault System, particularly the Hope Fault (Langridge et al. 2010).

The Alpine Fault is inferred to be inherited from an Eocene rift and passive margin that formed during the initiation of the Cenozoic plate boundary through New Zealand (Kamp 1986; Sutherland et al. 2000). It has accrued displacement since the Late Oligocene or Early Miocene as South Tasman ocean crust was subducted beneath Fiordland (Fig. 1A), while continental crust of the Australian Plate (Challenger Plateau; Fig. 1A) acted as an indentor into weaker continental crust to the southeast (Sutherland et al. 2000, 2009). The absence of active faults west of the central Alpine Fault (southern domain 7) provides supporting evidence that the Australian Plate is acting as a rigid indentor.

**Western Fiordland Margin - Caswell High fault zones (domain 13)**

Domain 13 fault zones are entirely submarine and lie west of the southern part of the Alpine Fault. Fault zones form two parallel sets. In the west are a series of normal fault zones along
the edge of the Caswell High (Fig. 1A) and in the east are west-verging reverse fault zones on the east side of the Fiordland Basin (Fig. 4).

Fault zone lengths range from c. 25 to 75 km. Net slip rates, although poorly constrained, are inferred to be low (0.4–3 mm/yr; Fig. 5) on the basis of offset seismic reflectors tied to dated samples (Barnes et al. 2002b). Cumulative net slip rates show a northward decrease in slip rate from 7.4 ± 2.2 to 3.8 ± 1.3 mm/yr (Fig. 2). This decrease continues further north as the zone narrows to just a single fault zone, the Barn Fault, which forms part of a set of submarine, landward-dipping reverse faults which broadly correspond to the South Westland Fault Zone and uplifts Pleistocene marine deposits along the west coast (Sutherland & Norris 1995; Sutherland et al. 2007).

Fault zones in this domain are relatively young, commencing activity in the Pliocene prior to 3 ± 1 Myr, but mostly developed during the Quaternary (Barnes et al. 2002b). The thrust faults form part of a narrow wedge accommodating some of the margin-normal component of plate motion (Delteil et al. 1996; Lebrun et al. 2000; Wood et al. 2000; Barnes et al. 2002b). The Caswell High fault zones are the result of flexural uplift caused by the tight bending of the Australian plate as a result of its subduction beneath Fiordland (Fig. 1A) (Delteil et al. 1996; Malservi et al. 2003). Many of the faults may be reactivated Cretaceous or Eocene normal faults (Sutherland et al. 2000; Wood et al. 2000).

**Puyssegur Ridge – Bank strike-slip fault zones (domain 14)**

Puyssegur Ridge (Fig. 1A), sitting above the Puyssegur subduction thrust, has a faulted gully parallel to the ridge crest that is inferred to be the surface expression of a major strike-slip fault system, the Puyssegur Ridge Fault (Collot et al. 1995). At the northern end of the ridge, at least two splays can be traced into the Snares Trough (Fig. 1B) (Lamarche & Lebrun 2000). North of the Snares Trough, two fault zones extend across and displace wave planation surfaces of probable Quaternary age on Puyssegur Bank (Fig. 1B) (Melhuish et al. 1999).

Fault zone lengths range from c. 66 to 298 km, although it is likely that the Puyssegur Ridge Fault is segmented. The slip rates on these fault zones are unknown, because the age of the wave-cut surface is poorly constrained and the amount of strike-slip displacement cannot be measured on the surface. The rates for these faults are therefore assigned as a portion of the plate convergence rate and cumulative slip rate transects have not been compiled.

The morphology and tectonic setting of Puyssegur Ridge is very similar to Macquarie Ridge to the south, where a structure analogous to the Puyssegur Ridge Fault ruptured with a
dextral strike-slip focal mechanism in the 1989 Macquarie Ridge earthquake ($M_w 8.2$) (Anderson 1990). The northern (Snares) fault zones transfer much of the margin-parallel motion from the Puyssegur Ridge Fault back to the subduction thrust at shallow (<10 km) depths (Lamarche & Lebrun 2000).

**Puyssegur subduction thrust (domain 15)**

The Puyssegur subduction thrust is considered as a single fault zone which dips east from the Puyssegur Trench (Fig. 1A). The seafloor trace extends southward from Resolution Ridge (Fig. 1A), to the Macquarie Ridge Complex (off Fig. 1, to the south) where plate boundary motion is primarily dextral strike-slip (e.g., Massell et al. 2000).

A series of earthquakes on the northern end of the thrust, including the 2009 $M_w 7.8$ Dusky Sound Earthquake, show that the sense of movement on the Puyssegur subduction thrust has a component of dextral strike-slip, and that the azimuth of the slip vector is precisely parallel to that predicted by relative plate motions (Doser et al. 1999; Reyners et al. 2003; Beavan et al. 2010b; Fry et al. 2010). The parallelism of the Dusky Sound Earthquake slip to the plate motion vector further indicates that the thrust takes up the majority of the plate motion, and a net slip rate of $27 \pm 7$ mm/yr has been assigned to reflect this.

Subduction on the Puyssegur subduction thrust initiated at c. 10 Ma along a pre-existing fracture zone within the southeast Tasman oceanic crust, following a major reorganisation of the overall Pacific-Australia plate boundary (Lamarche et al. 1997; Lebrun et al. 2000).

**Discussion**

**Fault zone densities and lengths**

Statistics have been derived for the numbers, densities and lengths of the fault zones in the updated nation-wide model. These numbers are considered to be first-order. They are likely, for example, to comprise fault lengths that are in many cases shorter than the actual lengths due to erosion or burial. Moreover, some domain boundaries (particularly their outer, offshore, edges) are necessarily arbitrary and there has been considerable simplification and interpretation of fault zone traces (e.g., Fig. 3). Nevertheless, we think our compilations reveal some important kinematic features of the New Zealand plate boundary zone, and also highlight issues of potentially unidentified faults, which are discussed further in the model completeness section.
A total of 635 active fault zones or fault zone sections are included in this model (Figs. 1, 4, 5). The majority (416; 66%) are in North Island domains despite the total geographic area of North and South Island domains being similar (Table 3). In part this reflects the large number (196) of closely-spaced fault zones in the Havre Trough - Taupo Rift domain, which contains 47% of North Island fault zones and 31% of the total fault zones (Table 3). Many of the fault zones in this domain are relatively short however, and the domain with the greatest cumulative fault zone length (3265 km) is the contractional southeastern South Island domain (Table 3). Other domains with high fault zone numbers and cumulative lengths are the Hikurangi subduction margin forearc and North Island Dextral Fault Belt (Table 3). Terrestrial and submarine fault zones are similar in abundance to one another: 299 (47%) fault zones are entirely terrestrial, 292 (46%) are entirely submarine, and 44 (7%) cross the coast. Of the entirely submarine fault zones 146 (50%) are in the offshore Taupo Rift and southern Havre Trough.

Translating the number and length of fault zones per domain into density (i.e. dividing the numbers and lengths by domain area), shows that indeed the Havre Trough – Taupo Rift has the greatest density of fault zones, while the North Island Dextral Fault Belt has the longest fault zones per area (aside from the Alpine Fault domain). Other domains of high density are the Kapiti-Manawatu and Marlborough Fault System domains. Not surprisingly, the least-densely faulted domains are situated further away from the main locus of plate boundary strain (excluding the Alpine Fault, and the Hikurangi and Puysegur subduction thrusts). These areas include the western North Island, northwestern South Island, southwestern South Island, and Puysegur Ridge – Bank domains (Table 3). These domains may also contain a larger proportion of unidentified active faults (e.g., Sibson & Ghizetti 2010, Ries et al. 2011), as discussed in the model completeness section below.

**Fault zone kinematics and slip rates**

Figure 4 illustrates that the majority (83%) of fault zones in the model are interpreted to have a predominantly dip-slip sense of movement. Forty six percent are predominantly normal, 38% are predominantly reverse, 17% are predominantly dextral, and there is only 1 dominantly sinistral fault. Figure 4 also reveals how oblique plate boundary convergence is partitioned in the upper plate between domains of primarily dip-slip versus strike-slip faulting that are parallel to one another. However, it should be noted that Figure 4 only shows the dominant sense of movement, whereas many fault zones have an oblique sense of movement (supplementary file Tables S1 and S2).
Figure 5 illustrates that the highest slip rates occur along the northern and central Hikurangi subduction thrust. The transfer of motion from the Alpine Fault onto the Puysegur subduction thrust and the Puysegur Bank – Ridge fault zones in the south, and into the Marlborough Fault System, and ultimately the Hikurangi subduction thrust and southern North Island Dextral Fault Belt, in the north are also clearly shown. Forty-three fault zones have relatively high slip rates (≥5 mm/yr). The combined length of these fault zones is 3448 km, which is 17% of the total length of fault zones in the model (20,618 km).

A total of 226 fault zones (35% of the total length) have moderate (1-5 mm/yr) slip rates, and these are generally close to the major tectonic elements of the plate boundary zone (Fig. 5). Some of the central Southern Alps fault zones may also have moderate slip rates. Fault zones with low (< 1 mm/yr) slip rates (331; 42% of the total length) dominate in areas that are distal to the chief plate boundary elements. The majority of low slip rate fault zones are either reverse or normal (Fig. 4).

The cumulative net slip rates on the transects in Fig. 2 confirm these general patterns of slip rate distribution across the plate boundary zone with the highest slip rates (not including the Alpine Fault and the Hikurangi and Puysegur subduction thrusts) occurring in the Marlborough Fault System, followed by the southern North Island Dextral Fault Belt and the northern Taupo Rift – Havre Trough. Notable along-strike changes in cumulative slip rate occur within single domains. These include the rapid northward decrease in cumulative slip rate along the North Island Dextral Fault Belt, and the parallel northward increase in slip rate across the Kapiti - Manawatu fault zones and the extensional Havre Trough – Taupo Rift. In contrast, the slip rate on the Hikurangi subduction thrust decreases strongly to the southwest, whilst the Alpine Fault rate decreases to the northeast, illustrating a transfer of strain from these first-order plate boundary structures onto second-order fault zones in between.

**Model completeness**

Our model has added significant numbers of active faults to previous New Zealand-wide compilations. However, like other national active fault or fault source databases (e.g., Machette et al. 2004; Yoshioka et al. 2005; Basili et al. 2008; Clark et al. 2012), the model is undoubtedly incomplete. Table 4 summarises our best assessment of the relative level of completeness of each domain and lists the main areas where we consider the model to likely be incomplete. Not surprisingly, the two main areas of likely incompleteness are: (i) rapidly eroding and difficult-to-access mountainous areas; and (ii) some submarine areas where there is currently insufficient knowledge of likely active faulting.
A more quantitative calculation of model completeness is beyond the scope of this study, but a preliminary analysis of 532 fault sources in the 2010 version of the New Zealand National Seismic Hazard Model (Stirling et al. 2012) showed a power-law distribution for faults with slip rates \( \geq 1 \text{ mm/yr} \) (Nicol et al. 2011). Departure from the power-law distribution can be interpreted to indicate that the seismic hazard model (and therefore the model presented in this paper given the overlap) is incomplete at slip rates \( \leq 1 \text{ mm/yr} \). The level of completeness will vary between regions with faults with higher slip rates (e.g., 0.5-1 mm/yr) most likely to be undersampled where they are exceeded by erosion or deposition rates (e.g., the Southern Alps and western Canterbury Plains).

**Comparison of geological and geodetic rates**

The type of fault parameters presented in this model may be used in studies of seismic hazard (e.g., Stirling et al., 2012), kinematic deformation (Beavan et al. 2007; Wallace et al. 2012), and fault interactions (Robinson et al. 2009, 2011; Pondard and Barnes 2010). Comparison of the permanent deformation, revealed by fault slip rates typically measured over thousands to tens of thousands of years, with strains recorded by GPS velocities, measured over the last few decades, places constraints on the spatial distribution, sampling biases and timing of deformation. We present one such comparison, that of regional horizontal deformation for the transects shown in Figure 2. Only mean values are calculated here, but considering the uncertainties in fault zone slip rates in Figure 2, it is only differences of several mm/yr or more that are considered significant. Only horizontal deformation is compared, as a nationwide vertical GPS velocity field is currently unavailable.

Cumulative horizontal fault zone slip rates were obtained by first converting the net slip rates of individual fault zones to horizontal slip rates, and then into transect parallel and normal components. These were then summed for each transect and a resultant vector calculated. Horizontal GPS velocities relative to a fixed Australian plate were calculated from a velocity field produced using a spline-fitting function to 920 site velocities (Beavan 2012). Velocity differences were calculated across each transect (i.e., difference between velocities at the transect endpoints), and were resolved into transect parallel and normal components. The outer edges of the transects in domain 10 and 13 lie outside the current version (4.0) of the GPS velocity field, so velocity differences for those transects could not be calculated.

Inspection of Figure 6 and Table 5 shows that for the majority (37 of 47) of transects, the rates of GPS deformation are higher than the cumulative fault slip rates. This is likely to be for a variety of reasons, including incompleteness in the fault model in some areas (Table
that GPS data includes distributed deformation between the faults in the model and, for the North Island, because elastic strains in the GPS signal are accruing due to (and in the future will likely be converted to) slip on the Hikurangi subduction thrust (Nicol and Wallace 2007). Distributed deformation may take the form of large-scale vertical-axis block rotations, folding associated with fault slip at depth and fault slip that is below the resolution of the present data (i.e. incomplete sampling of fault slip rates). Incomplete sampling may be particularly important for transect-normal deformation (i.e. strike-slip faulting) in domains 1, 2, 7, 9 and 11 where fault slip rates are generally low (e.g., <1 mm/yr), fault piercing points are rare and, for parts of domains 9 and 11, erosion rates are likely to be higher than the slip rates, removing evidence of fault displacements.

In the predominantly strike-slip North Island Dextral Fault Belt and the Marlborough Fault System, cumulative fault slip rates are generally significantly higher (e.g., ~20-100%) than GPS deformation. This difference may partly arise because faults in these domains take up most, if not all, of the margin-parallel plate motion over geological timescales, while contemporary deformation is distributed beyond these relatively narrow domains. For example, geological slip rates are greater than GPS rates in the Marlborough Fault System (33.2 versus 18.8 mm/yr), while GPS rates significantly exceed geological slip rates in domains either side (northwestern North Island and North Canterbury). The total transect-normal deformation across all three domains are similar however, 34.4 (geological slip rates) and 33.1 mm/yr (GPS), respectively. There is no evidence for episodic activity on any fault zones in the North Island Dextral Fault Belt and the Marlborough Fault System, so we infer episodicity is unlikely to account for the higher geological slip rates.

There is a general consistency between the overall sense of motion (contraction or extension) defined by geological and GPS data for nearly all transects (43 of 47 transects). This consistency indicates that the contemporary elastic strains will be largely converted to long-term (thousands to millions of years) permanent deformation in earthquakes (e.g., Nicol and Wallace 2007). Of the four transects with differing geological and GPS sense of movement, three (transect M1 in the North Island Dextral Fault Belt, and the southwestern transects in the Marlborough Fault System and North Canterbury domain) are mainly the result of sensitivity to the orientation of transects. Both fault and GPS deformation is at a high angle and therefore a small change in transect orientation results in transect parallel motion switching from extension to contraction and vice versa. The fourth transect with differing geological and GPS sense of movement is in the western North Island, where the
GPS velocities indicate transect parallel (WNW-ESE) contraction but the fault zones are all clearly extensional. There is currently no clear explanation for this difference.

A final general observation is that fault zone slip is inferred to be transect parallel (i.e., pure normal or reverse) for a number of transects (marked with an * in Figure 6A) whereas the GPS velocities are always oblique. There may be explanations for some of these differences, such as the permanent transect normal motion being taken up by block rotations in the Havre Trough - Taupo Rift, and Alpine Fault locking contributing to the GPS velocities across southeastern South Island transects. However, in other cases it raises the question as to whether fault slip is purely dip slip, or if strike-slip components are unrecognised.

There are clearly drawbacks to this 2 dimensional (transect parallel and normal) comparison, such as the sensitivity of the results to the orientation and endpoints of transects. To further improve understanding of plate boundary kinematics in the future, the approach of Wallace et al. (2004, 2007, 2012) could be applied on a New Zealand scale, whereby GPS velocities, active fault data, and earthquake slip vectors are inverted simultaneously to derive block rotations and degree of interseismic coupling. Alternatively, both datasets can be converted to strain rates for direct comparison (e.g., Holt & Haines 1995; Beanland & Haines 1998; Beavan et al. 2007).

**Summary and conclusions**

A new, regional-scale model of active faulting in New Zealand has been compiled which contains 635 fault zones, including 631 upper crustal fault zones and 4 subduction thrusts. Fault zone traces are available for download in shapefile, ascii and kmz formats (supplementary files Maps S1- S3). One of the biggest additions to this model over previous compilations is the large number of submarine fault zones, which comprise 52% of the total.

Tabulated fault parameters include: (i) dip; (ii) dip-direction; (iii) sense of movement; (iv) rake; (v) net slip rate; and (vi) quality code, and are available for download (supplementary files Table S1 and S2). We endeavoured to obtain, assign, or infer each of these for all faults, with the main exception being slip rates for the central Southern Alps faults, where geomorphic markers are generally absent as a result of high rates of erosion.

The fault zones have been grouped into 15 tectonic domains, comprising subjective geographic groupings of fault zones which have similar kinematics. The current knowledge of kinematics in each domain have been summarised, primarily from previously published work.
The majority (83%) of the fault zones have a dip-slip sense of movement; 46% are normal, 38% are reverse, 17% are dextral, and there is only 1 sinistral fault.

In terms of fault identification and mapping, the model is estimated to be mostly complete for fault zones with slip rates ≥1 mm/yr. Main areas where the model is likely to be incomplete are not surprisingly, areas of rapidly eroding and/or difficult to access hills and mountains, and submarine areas where high resolution seismic and swath data have yet to be collected. Data is also unavailable from the rapidly eroding central Southern Alps, where there are mapped faults but unknown slip rates, such that the southeastern South Island domain has the largest disparities between cumulative fault zone slip rates and differences in horizontal GPS velocity.

The model should be useful for a range of purposes, and an example is provided comparing horizontal cumulative fault slip rates with GPS velocity differences parallel and normal to selected transects crossing each domain. This example has highlighted several differences which could be explored with more sophisticated kinematic modelling and will help target future active fault studies.

Supplementary files:
Table S1: Active fault zone parameters and data source references.
Table S2: Microsoft excel file of the active fault zone parameters.
Figures S1–S8: Index and enlarged maps of the active fault zone traces.
Map S1: Shapefile of the active fault zone traces and parameters (attribute table), in NZTM 2000 projection.
Map S2: Ascii file of the active fault zone traces, in WGS84 projection.
Map S3: Kmz file of the active fault zone traces, in Google Earth coordinate system.

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Figure captions

Figure 1 A, Tectonic setting of New Zealand. The Pacific plate motion vectors relative to the Australian plate are from Wallace et al. (2007) and the coloured bathymetry map is from CANZ (1996). AF is the Alpine Fault, AR is North Island axial ranges, CH is Caswell High, ChP is Challenger Plateau, CR is Chatham Rise, CS is Cook Strait, cSA is central Southern Alps, F is Fiordland, HP is Hikurangi Plateau, HR is Hauraki Rift, HkT is Hikurangi Trough, HvT is Havre Trough, KR is Kaikoura Ranges, KT is Kermadec Trench, PR is Puysegur Ridge, PT is Puysegur Trench, RR is Resolution Ridge, RP is Raukumara Peninsula, TB is Taranaki Basin, TR is the Taupo Rift, WB is Wanganui Basin. B, New Zealand active fault zones (n = 635) compiled for this study. Enlarged maps, on which fault zones are individually numbered for correlation with the fault zone parameter table, are contained in supplementary file Figures S1-S9. Sense of movement is also shown for all faults in supplementary file Figures S1-S9, but is shown for selected faults here; ticks denote the downthrown side of normal fault zones; triangles the upthrown side of reverse fault zones; arrows the sense of movement of strike-slip fault zones. The boundaries between sections of the Hikurangi subduction thrust and the Alpine Fault are denoted with short cross-lines. CVA is Coromandel Volcanic Arc, CaP is Campbell Plateau, E is eastern Taranaki Rift, FB is Fiordland Basin, HB is Hanmer Basin, HR is Hauraki Rift, MtR is Mount Ruapehu, MtC is Mount Cook, O is Oamaru, OVC is Okataina Volcanic Centre, P is Papatowai, PB is Puysegur Bank, PN is Palmerston North, ST is Snares Trough, TVC is Taupo Volcanic Centre, W is western Taranaki Rift.

Figure 2 Major New Zealand tectonic domains, defined primarily by grouping fault zones with similar sense of movements. Black lines are representative transects along which cumulative net slip rates (mm/yr) have been calculated from summing net slip rates on individual fault zones, as labelled. Uncertainties have been calculated from the root mean square of individual fault zone net slip rate uncertainties. H, M, and L are relative confidence rankings, broadly H (high) = most slip rates were calculated from field or seismic reflection data, M (moderate) = most slip rates were assigned from nearby fault zones or consideration of slip rate budgets, L (low) = most slip rates were inferred.

Figure 3 Examples of active fault traces in the GNS Science Active Faults Database (http://data.gns.cri.nz/af/) (red) and the simplified active fault zones compiled for the model presented in this paper (black). A, Simplification of multiple trace normal faults in the central
Taupo Rift. B, Simplification and extension of strike-slip faults, and the addition of an inferred connecting fault (230) in highly erodible hill country, northeast North Island. The map locations are shown on Fig. 1B as dotted rectangles. Numbers refer to the fault zone numbers in supplementary file Table S1.

**Figure 4** Fault zones coloured according to their dominant sense of movement. Domain names are listed in Figure 2.

**Figure 5** Fault zones coloured according to their net slip rate (best estimates). Domain names are listed in Figure 2. The map highlights that the highest slip rates are along the main plate boundary elements, as well as the transfer of deformation between faults such as the Alpine Fault and the Marlborough Fault System.

**Figure 6** Comparison of cumulative horizontal fault zone slip rates (red) and horizontal GPS velocity differences (between transect endpoints) (blue) for selected transects across tectonic domains, shown as vectors (A), transect parallel motion (B), and transect normal motion (C). In A, where the cumulative horizontal fault zone slip rate vectors are shorter than the size of the arrow heads, the arrow heads are not shown, and the asterisks mark vectors which are very close, or exactly parallel to the transects. The vectors are shown relative to a fixed Australian plate.
1. extensional western North Island fault zones
2. extensional Havre Trough - Taupo Rift fault zones
3. contractional Kapiti - Manawatu fault zones
4. North Island Dextral Fault Belt
5. Hikurangi subduction margin forearc
6. Hikurangi subduction thrust
7. contractional northwestern South Island fault zones
8. strike-slip Marlborough Fault System
9. contractional North Canterbury fault zones
10. extensional North Mernoo fault zones
11. contractional southeastern South Island fault zones
12. Alpine Fault
13. western Fiordland Margin - Caswell High fault zones
14. Puysegur Ridge - Bank strike-slip fault zones
15. Puysegur subduction thrust
Cumulative horizontal fault zone slip rates (mm/yr)

GPS horizontal velocity differences (mm/yr)
Table 1 Descriptions of active fault zone parameters compiled in this model (supplementary files Table S1 and S2) and the main methods of data compilation. The derivations of each parameter for individual fault zones are described by Litchfield et al. (2013).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Description</th>
<th>Main methods of compilation:</th>
</tr>
</thead>
</table>
| Dip                | 0 – 90º| Downward inclination of the fault plane from the horizontal. All fault zones are considered to be planar and the best estimate of average dip used. | (i) Obtained from direct measurements in shallow natural or trench exposures, seismic reflection profiles, or multibeam bathymetric data.  
(ii) Inferred from geomorphic expression (e.g., upthrown side) and sense of movement, contiguous fault zones along strike, or from fault zones within the same tectonic domain.  
Uncertainties:  
(i) Obtained from the range of dip values in an exposure or a seismic profile line.  
(ii) Inferred to span reasonable values (generally no more than ±10º-15º). |
| Dip-direction      | N, NE, E, SE, S, SW, W, NW | The geographic octant towards which the fault zone dips.                       | Based on the overall strike of the mapped fault zone, combined with information for dip described above. |
| Sense of movement  | Normal | Dominant, and where applicable, secondary sense (type) of relative movement (slip or displacement) on the fault plane. | (i) Obtained from direct measurements in shallow natural or trench exposures, or seismic reflection profiles.  
(ii) Inferred from geomorphic expression (e.g., topographic or bathymetric scarps, offset channels) and dip, or from more direct data for nearby fault zones of similar strike and/or geological setting. |
| Rake               | 0 – 360º, where:  
360º = 0º = pure dextral  
90º = pure normal  
180º = pure sinistral  
270º = pure reverse | The direction of hanging wall slip, relative to a horizontal line on the fault plane. | (i) Obtained directly from field data (e.g., fault plane striations).  
(ii) Calculated from some combination of H:V ratios (e.g., from offset geomorphic features) and dip, or strike-slip rate and dip-slip rate.  
(iii) Inferred, generally assuming pure dip-slip or strike-slip motion.  
Uncertainties:  
(i) Calculated from the range of field-derived values, H:V ratios, or slip rate components.  
(ii) Inferred values assumed to be reasonable based on other fault zones in the same tectonic domain (generally no more than ±10º).  
Note: Except where multibeam bathymetric data can be used, the expression of strike-slip on submarine fault zones cannot generally be quantified unequivocally in marine seismic reflection data. |
| Slip rate          | mm/yr  | Net (rake-parallel) rate of movement averaged over a time period spanning at | (i) Calculated from strike-slip, vertical, and/or dip-slip rate, dip, and/or rake. The calculated slip rates are generally from offset geologic units (e.g., tephra in a trench) |
least two, but typically many more, ground-rupturing earthquakes. Where fault zones have associated folds, the net slip rate usually includes displacement accommodated by folding. or geomorphic features (e.g., fluvial terrace surfaces or channels), or seismic reflectors (e.g., the post-glacial marine transgression surface).

(ii) Assigned from long-term (millions of years) slip rates, particularly if the rates are broadly consistent with GPS strain rates or a portion of overall plate boundary rates.

(iii) Inferred from:

(a) Geomorphic expression (e.g. scarp height or morphology) in relation to the assumed age of the faulted geomorphic surface.

(b) Slip rates assigned to nearby similar fault zones (e.g., from onshore to offshore fault zones).

(c) Consideration of geomorphic expression combined with a slip rate budget for a particular part of the plate boundary.

| Quality code | 1-5, where 1 is the high quality and 5 is poor. See Table 2 for definitions | Subjective ranking of the relative quantity and type of data available for each fault zone, particularly in regard to calculation of slip rate. | Assigned using the definitions in Table 2. |
Table 2 Definitions of the quality code parameter. The codes are particularly weighted toward the quality of slip rate data.

<table>
<thead>
<tr>
<th>Code number</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Fault zone with high quality field (e.g., trench, dated displaced markers) or marine (e.g., swath, markers with well constrained ages) data.</td>
</tr>
<tr>
<td>2</td>
<td>Fault zone with some constraints from field or marine data; slip rate largely estimated from considering regional slip rate budgets.</td>
</tr>
<tr>
<td>3</td>
<td>Fault zone in offshore Bay of Plenty (northern domain 2 in Fig. 2) with well constrained geometries from swath and seismic data, but slip rate inferred based on distribution of extension rates derived from modelling of onshore GPS data.</td>
</tr>
<tr>
<td>4</td>
<td>Fault zone with few data and slip rates mainly inferred from geomorphic expression (e.g. scarp height and morphology as an indicator of age).</td>
</tr>
<tr>
<td>5</td>
<td>Fault zone within the central South Island (northwestern domain 11 in Fig. 2) that does not have demonstrable activity and hence a slip rate has not been inferred.</td>
</tr>
</tbody>
</table>
Table 3 Number and density of faults in each tectonic domain. The highest values for each are shown in bold.

<table>
<thead>
<tr>
<th>Island</th>
<th>Domain number</th>
<th>Number of fault zones</th>
<th>% of total number of fault zones</th>
<th>Cumulative fault zone length (km)</th>
<th>Domain area (km²)</th>
<th>Density 1 No. of fault zones per km²</th>
<th>Density 2 Length (km) of fault zones per km²</th>
</tr>
</thead>
<tbody>
<tr>
<td>North</td>
<td>1</td>
<td>27</td>
<td>4%</td>
<td>788</td>
<td>110,394</td>
<td>0.0002</td>
<td>0.0071</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>196</td>
<td>31%</td>
<td>3086</td>
<td>42,468</td>
<td><strong>0.0046</strong></td>
<td>0.0727</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>28</td>
<td>4%</td>
<td>684</td>
<td>11,353</td>
<td>0.0025</td>
<td>0.0602</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>63</td>
<td>10%</td>
<td>2224</td>
<td>24,513</td>
<td>0.0025</td>
<td><strong>0.0907</strong></td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>100</td>
<td>16%</td>
<td>3142</td>
<td>92,249</td>
<td>0.0011</td>
<td>0.0341</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>3</td>
<td>0.5%</td>
<td>700</td>
<td>15,533</td>
<td>0.0002</td>
<td>0.0451</td>
</tr>
<tr>
<td></td>
<td>North Totals</td>
<td></td>
<td></td>
<td>416</td>
<td>10,623</td>
<td>0.0014</td>
<td>0.0358</td>
</tr>
<tr>
<td>South</td>
<td>7</td>
<td>9</td>
<td>1%</td>
<td>569</td>
<td>53,337</td>
<td>0.0002</td>
<td>0.0107</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>41</td>
<td>6%</td>
<td>1536</td>
<td>21,023</td>
<td>0.0020</td>
<td>0.0730</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>43</td>
<td>7%</td>
<td>1461</td>
<td>24298</td>
<td>0.0018</td>
<td>0.0601</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>12</td>
<td>2%</td>
<td>482</td>
<td>8,391</td>
<td>0.0014</td>
<td>0.0574</td>
</tr>
<tr>
<td></td>
<td>11</td>
<td>81</td>
<td>13%</td>
<td><strong>3265</strong></td>
<td><strong>151,612</strong></td>
<td>0.0005</td>
<td>0.0215</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>6</td>
<td>1%</td>
<td>741</td>
<td>6,692</td>
<td>0.0009</td>
<td><strong>0.1107</strong></td>
</tr>
<tr>
<td></td>
<td>13</td>
<td>21</td>
<td>3%</td>
<td>945</td>
<td>20,298</td>
<td>0.0010</td>
<td>0.0465</td>
</tr>
<tr>
<td></td>
<td>14</td>
<td>4</td>
<td>1%</td>
<td>553</td>
<td>21,705</td>
<td>0.0002</td>
<td>0.0255</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>1</td>
<td>0.2%</td>
<td>430</td>
<td>10,079</td>
<td>0.0001</td>
<td>0.0427</td>
</tr>
<tr>
<td></td>
<td>South Totals</td>
<td></td>
<td></td>
<td>219</td>
<td>317,497</td>
<td>0.0007</td>
<td>0.0314</td>
</tr>
<tr>
<td>NZ totals</td>
<td></td>
<td>635</td>
<td></td>
<td>20,064</td>
<td>614,017</td>
<td>0.0010</td>
<td>0.0336</td>
</tr>
</tbody>
</table>
Table 4 Summary of our best assessment of domain fault zone mapping completeness.

<table>
<thead>
<tr>
<th>Domain number</th>
<th>Relative level of completeness</th>
<th>Likely main areas where the fault model is incomplete</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Medium</td>
<td>(i) Centre – rapidly eroding areas of soft mudstone</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(ii) South and North – submarine areas where seismic profile analysis has not been undertaken or is incomplete</td>
</tr>
<tr>
<td>2</td>
<td>High</td>
<td>(i) Centre – volcanic centres buried beneath lakes and tephra cover</td>
</tr>
<tr>
<td>3</td>
<td>Medium</td>
<td>(i) North – rapidly eroding areas of soft mudstone and dunefields</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(ii) Far south – submarine areas of strong seafloor erosion</td>
</tr>
<tr>
<td>4</td>
<td>High</td>
<td>(i) Centre – difficult access (steep, forest-covered) areas of moderate erosion and few Late Pleistocene deposits</td>
</tr>
<tr>
<td>5</td>
<td>Medium</td>
<td>(i) North – rapidly eroding areas of soft mudstone and</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(ii) North – submarine areas with less seismic profile coverage</td>
</tr>
<tr>
<td>6</td>
<td>High</td>
<td>(i) Additional fault zone segmentation possible</td>
</tr>
<tr>
<td>7</td>
<td>Low</td>
<td>(i) All onshore areas – difficult access (steep, forest-covered) areas of moderate erosion and few Late Pleistocene deposits</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(ii) All submarine areas</td>
</tr>
<tr>
<td>8</td>
<td>High</td>
<td>(i) Southwest – difficult access and rapidly eroding areas of high rainfall</td>
</tr>
<tr>
<td>9</td>
<td>Medium</td>
<td>(i) Southwest – difficult access and rapidly eroding areas of high rainfall</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(ii) Southeast – submarine areas where seismic profile analysis still needs to be completed</td>
</tr>
<tr>
<td>10</td>
<td>Medium</td>
<td>(i) Everywhere – inadequate density of high resolution seismic data, swath data absent</td>
</tr>
<tr>
<td>11</td>
<td>Medium</td>
<td>(i) Northeast – areas of thick, young alluvium</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(ii) West and southwest – difficult access high rainfall and/or erosion areas</td>
</tr>
<tr>
<td>12</td>
<td>High</td>
<td>(i) Additional fault zone segmentation possible</td>
</tr>
<tr>
<td>13</td>
<td>Medium</td>
<td>(i) Far north – close to coast</td>
</tr>
<tr>
<td>14</td>
<td>Low</td>
<td>(i) Everywhere – absence of high resolution seismic or swath data</td>
</tr>
<tr>
<td>15</td>
<td>High</td>
<td>(i) Additional fault zone segmentation possible</td>
</tr>
</tbody>
</table>
Table 5  Total fault slip rates and GPS velocities for representative transects across each domain (Fig. 2).

<table>
<thead>
<tr>
<th>Domain</th>
<th>Transect</th>
<th>Total Fault Slip Rates</th>
<th>Total GPS Velocities</th>
<th>Differences</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Total Net^2</td>
<td>HTP^3</td>
<td>HTN^4</td>
</tr>
<tr>
<td>1</td>
<td></td>
<td>3.2</td>
<td>-1.3</td>
<td>0.4</td>
</tr>
<tr>
<td>2</td>
<td>N</td>
<td>15.2</td>
<td>-9.1</td>
<td>0.00</td>
</tr>
<tr>
<td>2</td>
<td>M</td>
<td>5.9</td>
<td>-2.9</td>
<td>0.00</td>
</tr>
<tr>
<td>2</td>
<td>S</td>
<td>4.4</td>
<td>-2.3</td>
<td>0.00</td>
</tr>
<tr>
<td>3</td>
<td>N</td>
<td>5.4</td>
<td>1.9</td>
<td>0.00</td>
</tr>
<tr>
<td>3</td>
<td>S</td>
<td>2.5</td>
<td>0.5</td>
<td>0.8</td>
</tr>
<tr>
<td>4</td>
<td>N</td>
<td>6.2</td>
<td>-1.1</td>
<td>3.2</td>
</tr>
<tr>
<td>4</td>
<td>M1</td>
<td>7.1</td>
<td>0.04</td>
<td>6.9</td>
</tr>
<tr>
<td>4</td>
<td>M2</td>
<td>14.4</td>
<td>1.0</td>
<td>13.4</td>
</tr>
<tr>
<td>5</td>
<td>S</td>
<td>22.3</td>
<td>2.4</td>
<td>19.2</td>
</tr>
<tr>
<td>5</td>
<td>N</td>
<td>13.6</td>
<td>9.5</td>
<td>0.04</td>
</tr>
<tr>
<td>5</td>
<td>M</td>
<td>9.7</td>
<td>7.1</td>
<td>0.2</td>
</tr>
<tr>
<td>5</td>
<td>S</td>
<td>14.4</td>
<td>6.7</td>
<td>7.9</td>
</tr>
<tr>
<td>7</td>
<td>N</td>
<td>0.7</td>
<td>0.4</td>
<td>0.00</td>
</tr>
<tr>
<td>7</td>
<td>S</td>
<td>1.0</td>
<td>0.6</td>
<td>0.00</td>
</tr>
<tr>
<td>8</td>
<td>N</td>
<td>37.8</td>
<td>4.0</td>
<td>33.2</td>
</tr>
<tr>
<td>8</td>
<td>S</td>
<td>23.5</td>
<td>0.7</td>
<td>22.5</td>
</tr>
<tr>
<td>9</td>
<td>N</td>
<td>2.3</td>
<td>1.2</td>
<td>1.2</td>
</tr>
<tr>
<td>9</td>
<td>M</td>
<td>3.1</td>
<td>1.4</td>
<td>0.7</td>
</tr>
<tr>
<td>9</td>
<td>S</td>
<td>&gt;3.4\textsuperscript{10}</td>
<td>&gt;1.2\textsuperscript{10}</td>
<td>&gt;3.4\textsuperscript{10}</td>
</tr>
<tr>
<td>10</td>
<td></td>
<td>1.0</td>
<td>-0.6</td>
<td>0.00</td>
</tr>
<tr>
<td>11</td>
<td>N</td>
<td>&gt;3.9\textsuperscript{10}</td>
<td>&gt;1.9\textsuperscript{10}</td>
<td>&gt;1.2\textsuperscript{10}</td>
</tr>
<tr>
<td>11</td>
<td>M</td>
<td>3.9</td>
<td>2.5</td>
<td>0.2</td>
</tr>
<tr>
<td>11</td>
<td>S</td>
<td>1.2</td>
<td>0.2</td>
<td>0.5</td>
</tr>
<tr>
<td>13</td>
<td>N</td>
<td>3.8</td>
<td>1.8</td>
<td>0.00</td>
</tr>
<tr>
<td>13</td>
<td>S</td>
<td>7.4</td>
<td>4.5</td>
<td>0.00</td>
</tr>
</tbody>
</table>
1 N = Northern, M = Middle, S = Southern.
2 These values, with their uncertainties and a confidence ranking, are plotted in Figure 2.
3 HTP = Horizontal Transect-Parallel, negative = extension, positive = contraction.
4 HTN = Horizontal Transect-Normal, negative = sinistral (none), positive = dextral.
5 ND = No Data, as one end of these transects are outside the velocity field.
6 HTP = Horizontal Transect-Parallel, negative = extension, positive = contraction.
7 HTN = Horizontal Transect-Normal, negative = extension, positive = contraction.
8 HTP = Horizontal Transect-Parallel. Absolute differences, so negative is where cumulative fault slip rates > GPS velocities.
9 HTN = Horizontal Transect-Normal. Absolute differences, so negative is where cumulative fault slip rates > GPS velocities.
10 Minimum because the transect crosses central Southern Alps Faults which have no slip rates.