# 3. GEOLOGIC AND TECTONIC SETTING, AND GEOMORPHIC CONDITIONS

## Geological and Tectonic Setting for the Darfield (Canterbury) and Christchurch Earthquakes

The tectonic plate boundary between the Australian (A) and Pacific (P) Plates passes through the South Island of New Zealand, where subduction of the Hikurangi Plateau to the north transitions into a continent-continent collision zone associated with the collision of the Chatham Rise with continental crust of the Australian Plate (Figure 3-1). The Australian and Pacific plates converge obliquely at 48–39 mm/yr in New Zealand. The collision between these plates is accommodated by a distributed zone of active faults extending across the southern North Island and the South Island, each capable of generating large magnitude earthquakes. The Marlborough Fault Zone consists of a series of large, northeast-southwest trending ‘transpressional’ faults that undergo primarily right-lateral displacement with a component of shortening, resulting in localized uplift across the northeastern part of the South Island. These faults ultimately link westward to the Alpine Fault, which accommodates ~70-75% of the total relative plate boundary motion between the A-P Plates with values of 27 ±5 mm/yr of strike-slip and 5–10 mm/yr of dip-slip (see review in Norris and Cooper 2001).

The remaining ~30% of Australian and Pacific plate motion is accommodated by slip on other active faults throughout the Southern Alps and Canterbury Plains such as the Porter’s Pass fault, which has a slip rate of 3-7 mm/yr (3–5 mm/yr; e.g. Cowan et al. 1996; Howard et al. 2005; 7 mm/yr; Wallace et al. 2007). Although there are several mapped structures in this region, both expressed at the surface and ‘hidden’ beneath the surface, that pose a known earthquake hazard to Christchurch (e.g., Hororata fault, Hororata anticline, Springbank fault, Bobby’s Creek fault), the Greendale fault, which was the source of the 2010 Darfield (Canterbury) earthquake, and Port Hills fault, the source of the 22 February 2011 Christchurch earthquake, were not recognized prior to these earthquakes. Neither the generally east-west trending Greendale fault, or the northeast-southwest trending Port Hills fault are associated with distinct geomorphic expression at the surface that could have been recognized prior to the September and February earthquakes (Figure 3-2). No other faults have been mapped at the surface within the volcanic rocks of the Banks Peninsula (Figure 3-3). Additional investigations by GNS and the University of Canterbury will assess the possible presence of other geomorphic features or signals that would indicate the location and activity of faults in the onshore region.

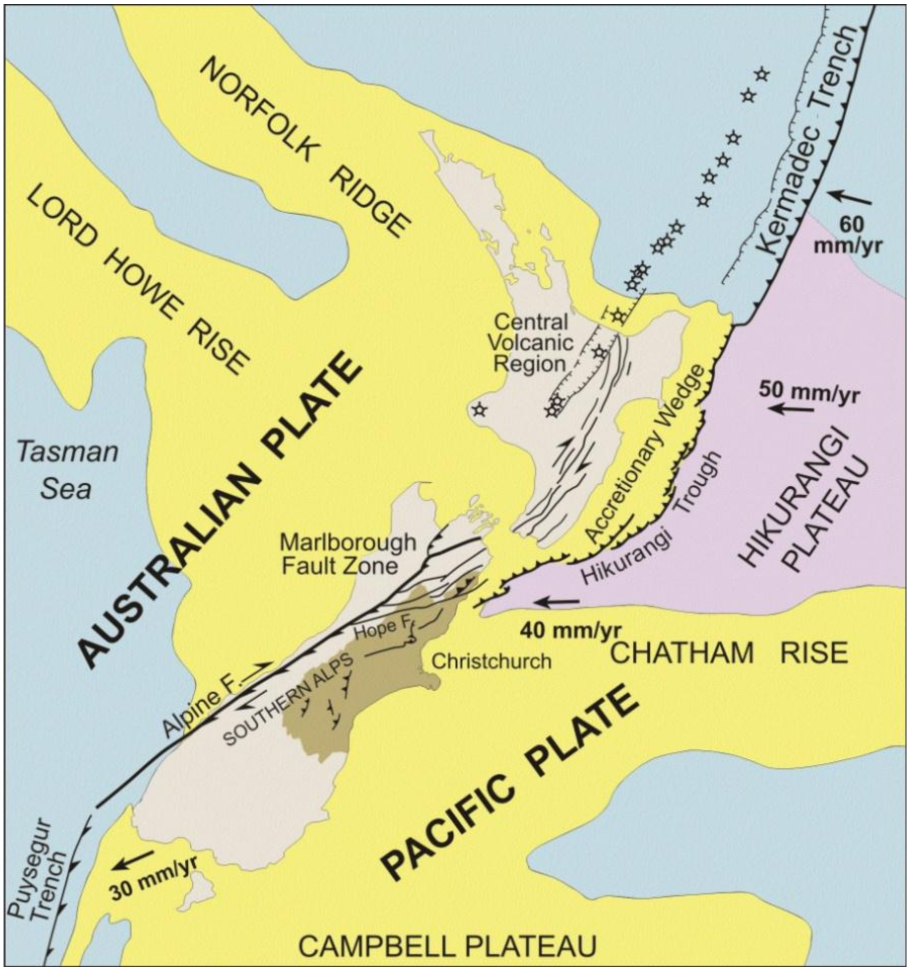


Figure 3-1. Australian-Pacific plate boundary through New Zealand and convergence rates of Pacific Plate relative to Australian Plate. (courtesy of Jarg Pettinga).

Modeling of GPS-derived velocity fields suggests a strain rate of ~2 mm/yr of WNW-oriented permanent contraction for the region east of the Porter's Pass Fault to offshore of Christchurch that hosts the Greendale fault and the Port Hills fault ("Canterbury Block"; Wallace et al., 2007). Some of this slip likely is accommodated by several east-west trending and north-south to northeast-southwest trending active faults present throughout Canterbury and offshore on the Chatham Rise. In a general sense, east-west trending faults tend to be strike-slip dominated faults (e.g., Greendale, Porter's Pass, Bobby's Creek, and Ashley faults) while north-south to northeast-southwest trending faults tend to be oblique slip or reverse-slip dominated faults with smaller components of strike-slip (e.g., Port Hills, Springfield, Springbank, and Hororata faults). As is clear from this recent earthquake, it is important to obtain more information on the locations of all active faults beneath the Canterbury Plains (via geophysical and geological mapping investigations) and earthquake histories of all faults (via paleoseismic analysis) in order to better understand the risk that these structures pose to the Canterbury region (Pettinga et al. 2001). GNS and the University of Canterbury along with other organizations have mobilized extensive efforts to characterize the Port Hills and Greendale faults and other potential faults in the Canterbury Plains and offshore region. (GNS Media Release 3 June 2011). The preliminary results of offshore studies indicate that additional active faults are present offshore of Christchurch (Figure 3-4).

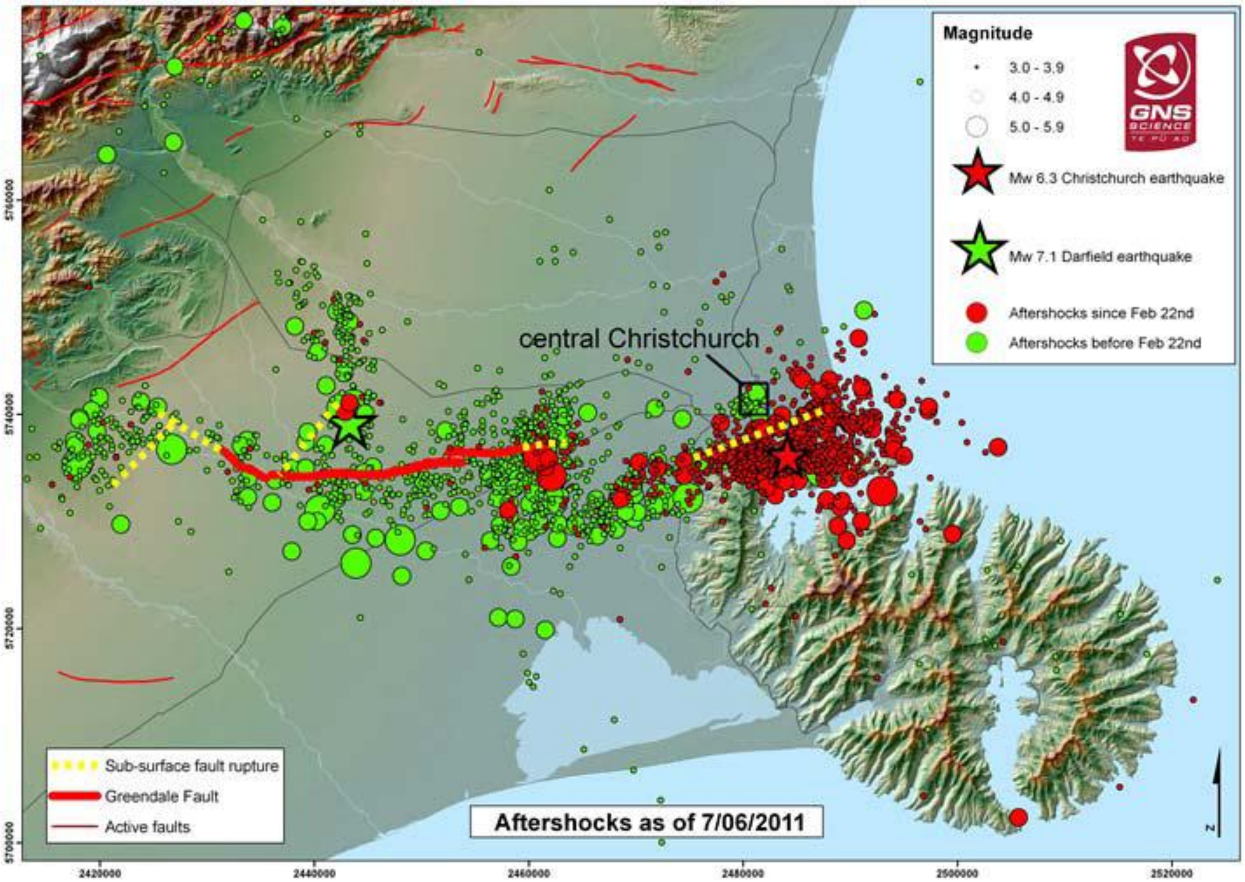


Figure 3-2. Location of active faults in the Canterbury Plains, surface rupture of the Greendale fault, inferred buried trace of the Port Hills fault, and seismicity associated with the 2010 Darfield and 2011 Christchurch earthquakes (from GNS).

**Geology and Geomorphology of the Christchurch Area**

The Canterbury Plains, about 160 km long and of varying width up to about 60 km, are among New Zealand's largest areas of flat land. The plains are the result of overlapping of alluvial fans of glacier-fed rivers issuing from the Southern Alps, the mountain range of the South Island

(Figure 3-3). The relatively rapid uplift of the Southern Alps, compared to the region to the east, resulted in rapid deposition during the late Quaternary and inundation of the Canterbury Plains by alluvial and fluvial deposits. The alluvial gravels underlying the Canterbury Plains typically are at least 500 m thick. The plains are often described as fertile, but the soils are of variable composition. Most are derived from the greywacke of the mountains or from loess (fine sediment blown from riverbeds). In addition, some soils near Christchurch include clay and other materials eroded from Banks Peninsula's volcanic rocks.

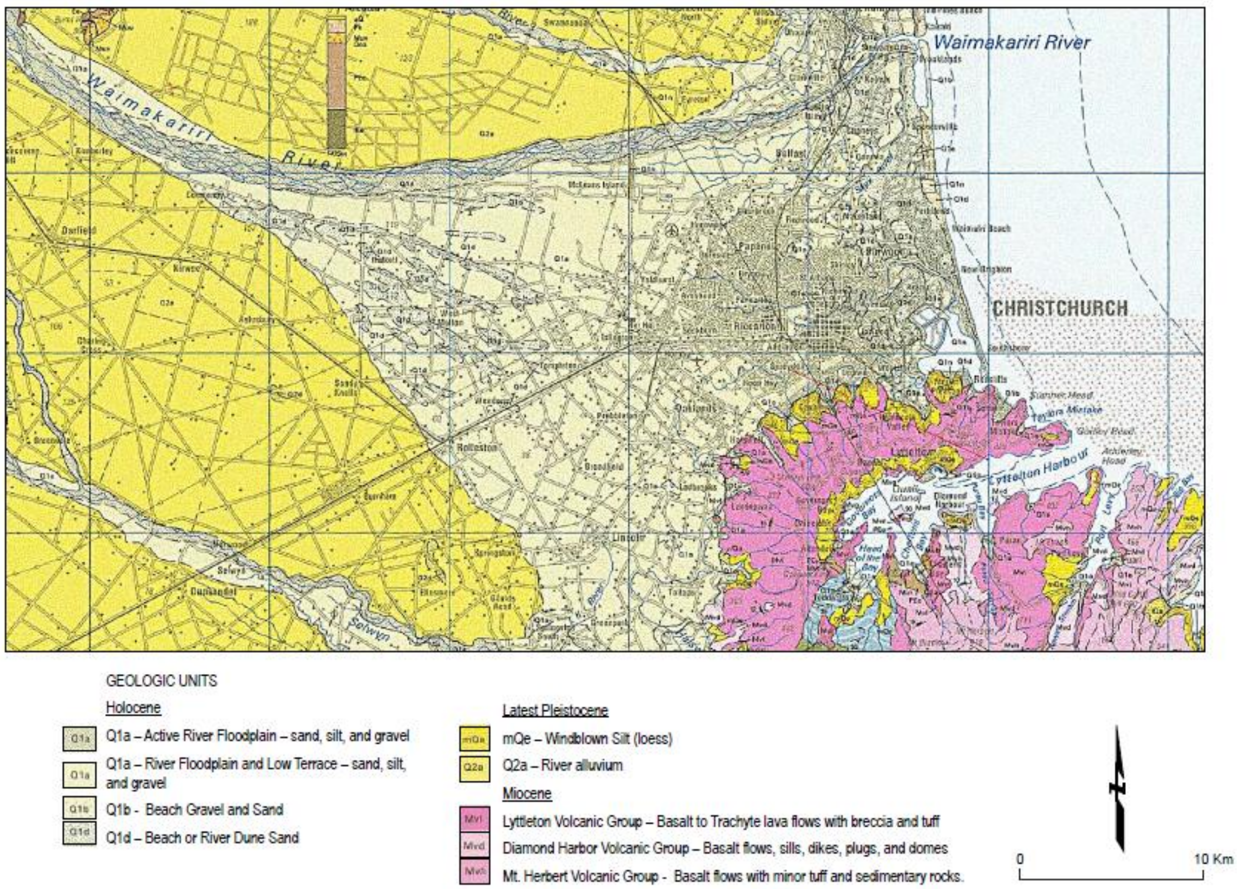


Figure 3-3. Geologic Map of the Canterbury Plains and Christchurch Region, South Island, New Zealand (Forsyth et al., 2008).

The city of Christchurch is located along Pegasus Bay on the eastern margin of the Canterbury Plains, north of the extinct volcanic complex forming Banks Peninsula, and south of the modern channel of the Waimakariri River, one of the major rivers extending east from the Southern Alps across the Canterbury Plains to Kaiapoi (Figure 3-3). The northern part of the Banks Peninsula is composed of the Lyttelton Volcanic Complex, most of which consists of basaltic flows extruded about 10 to 11 million years before present (Ma). Most of these volcanic rocks have variable rock mass quality due to variations in rock strength and variations in the amount or presence of scoria and mafic dikes. The northern part of this volcanic complex, between the southern suburbs of Christchurch and the Port of Lyttleton to the south is known as the Port Hills. These volcanic deposits typically are overlain by loess, a wind-blown silt deposit ranging in thickness from about one meter on the hill slopes to twenty meters in drainages and hollows. (Figures 3-5 and 3-6).

Christchurch lies on the floodplain of the Waimakariri River. The city is underlain by abandoned and infilled channels of the Waimakariri River and two local spring-fed rivers, the Avon and Heathcote Rivers (Figure 3-7). Basement rocks in the area of Christchurch apparently are on the order of 2000 m below present ground surface (Brown et al., 1995). During the late Quaternary glacial maximums, prior to about 18 thousand years ago (ka), sea level was up to 150 m lower than present, and the alluvial plains extended east of the present coast. As sea level rose during the latest Pleistocene and Holocene (post about 15 ka), swamp, estuarine, lagoon, and beach deposits prograded westward across the alluvial plains, and are interbedded with Holocene alluvial deposits (Figure 3-5). Sea level reached the present level about 6,500 years before present, with the coast located about 14 km west of the present location. Since that time, alluvial sand deposition from the Waimakariri River resulted in eastward progradation of the coast to the present location (Figure 3-5; Brown et al., 1995). The post-glacial deposits are about 15 to 40 m thick across the Christchurch area, overlying the Pleistocene gravel deposits (Brown et al., 1995)

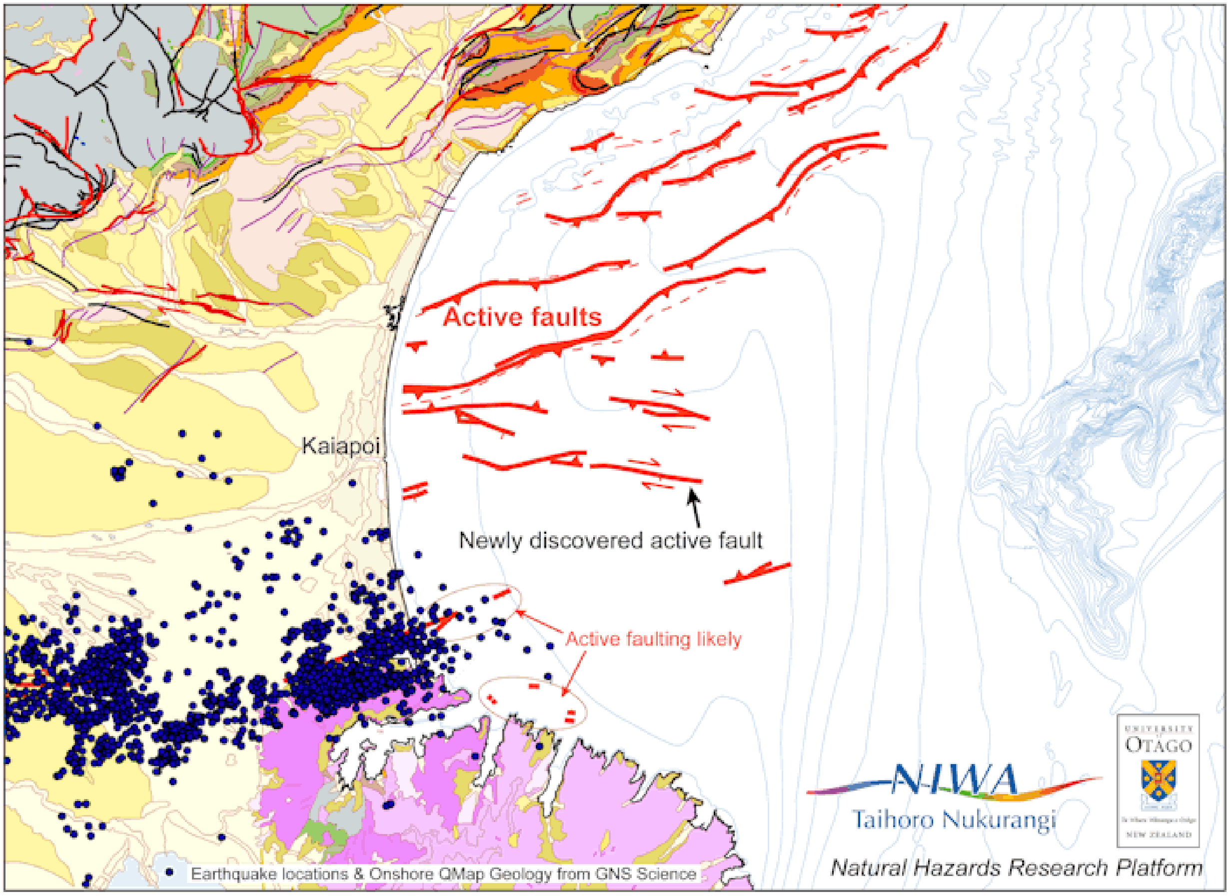


Figure 3-4. Map showing location of sub-marine faults in Pegasus Bay, including preliminary interpreted locations of newly discovered active faults offshore of Christchurch (GNS Media Release 3 June 2011)

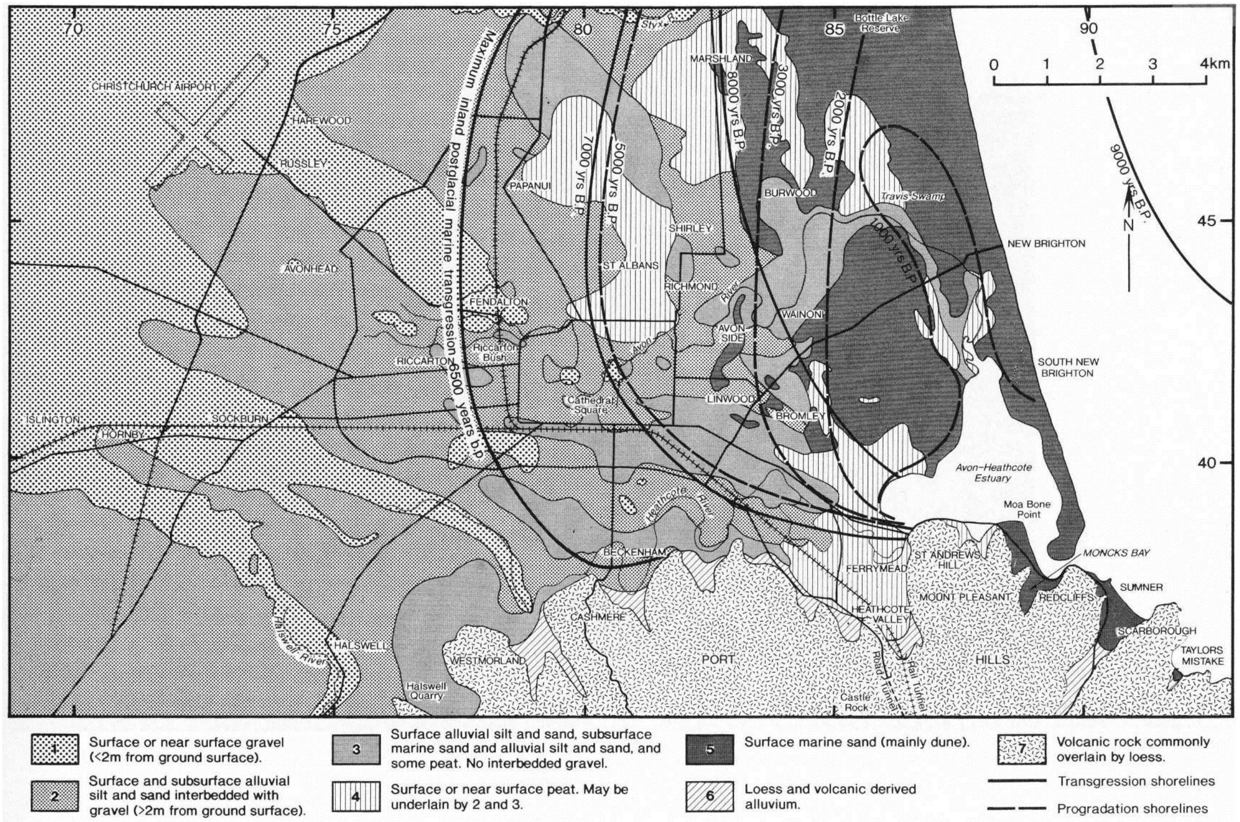


Figure 3-5. Postglacial marine transgression and progradation shorelines, and progradation sediment lithologies (Brown et al., 1995).

Prior to development in the 1800's, most of the city land was low-lying floodplains and swamps behind a series of barrier dunes (composed of fine-grained beach/dune sand), estuaries, and lagoons (underlain by fine-grained deposits) of Pegasus Bay (Figure 3-7). The Waimakariri River regularly flooded Christchurch prior to stopbank construction and river realignment, which began shortly after the city was established in 1850. The original city center apparently was constructed on slightly higher ground compared to areas to the north and west of the city center. Many swamps were drained and filled with sand from coastal dunes to reduce the potential for flooding (Brown et al., 1995). The two main rivers, Avon and Heathcote, which originate from springs in western Christchurch, meander through the city and act as the main drainage system.

Of particular relevance to the liquefaction and lateral spreading that occurred during the Darfield and Christchurch earthquakes are the locations of the present and abandoned paleo channels of the Waimakariri, Heathcote, and Avon Rivers, and the areas of former swamps, as shown on Figure 3-7). These areas are underlain by and filled with young loose and soft sediments, are characterized by shallow groundwater levels (from 1 to 5 meters below ground surface) (Figure

3-5) and were subject to seismically induced ground failure by settlement and lateral spreading during both the Darfield and Christchurch earthquakes as described in following sections.

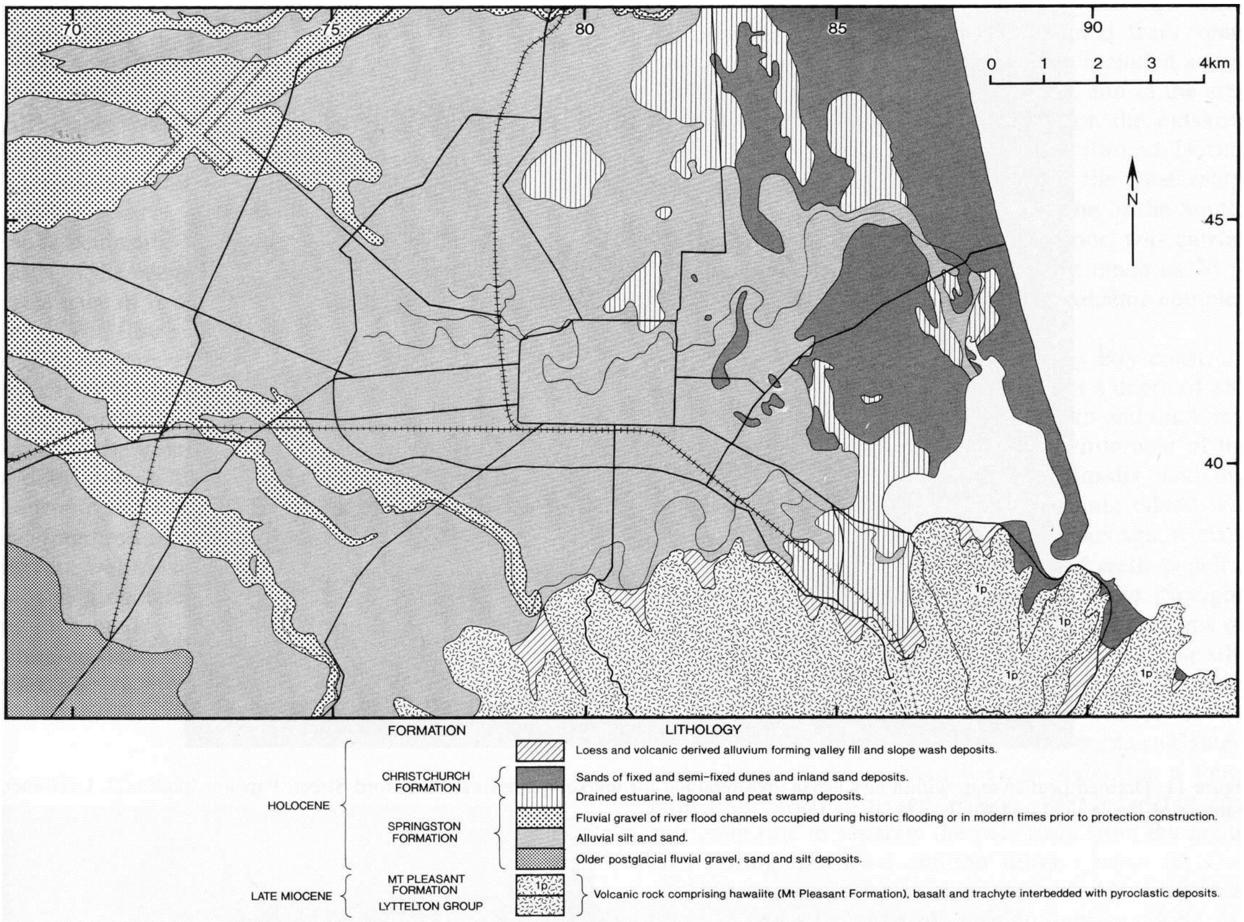


Figure 3-6. Geological map of Christchurch (Brown et al., 1995). Refer to Figure 3-5 for place names.

### Tectonic Deformation Resulting from the Christchurch Earthquake

Preliminary interpretation of earthquake focal mechanisms, aftershocks, and geodetic data show that the Christchurch earthquake occurred on a southeast-dipping fault located beneath the Port Hills of the northern Banks Peninsula. The fault plane identified from geodetic modeling of the rupture and from the distribution of aftershocks projects to the surface in the southern suburbs of Christchurch along the base of the Port Hills. No expression of surface rupture has been identified at the ground surface in the area where the fault would daylight, and no faults have previously been identified in this area within the volcanic deposits of the Port Hills (Figures 3-2, 3-3, and 3-6).

Additional preliminary characterization of the fault that ruptured during the February earthquake provided by GNS includes the following. The fault is modeled as a rectangular plane dipping 65 degrees southeast, trending approximately northeast-southwest, and extending from about 6 km depth to 1 km depth, as constrained by displacement of GPS monuments across the Christchurch region. The survey data indicate that the Port Hills were uplifted by about 15 to 45 cm, while the Christchurch area north of the projection of the fault subsided by about 5 to 15 cm (Figure 3-8).

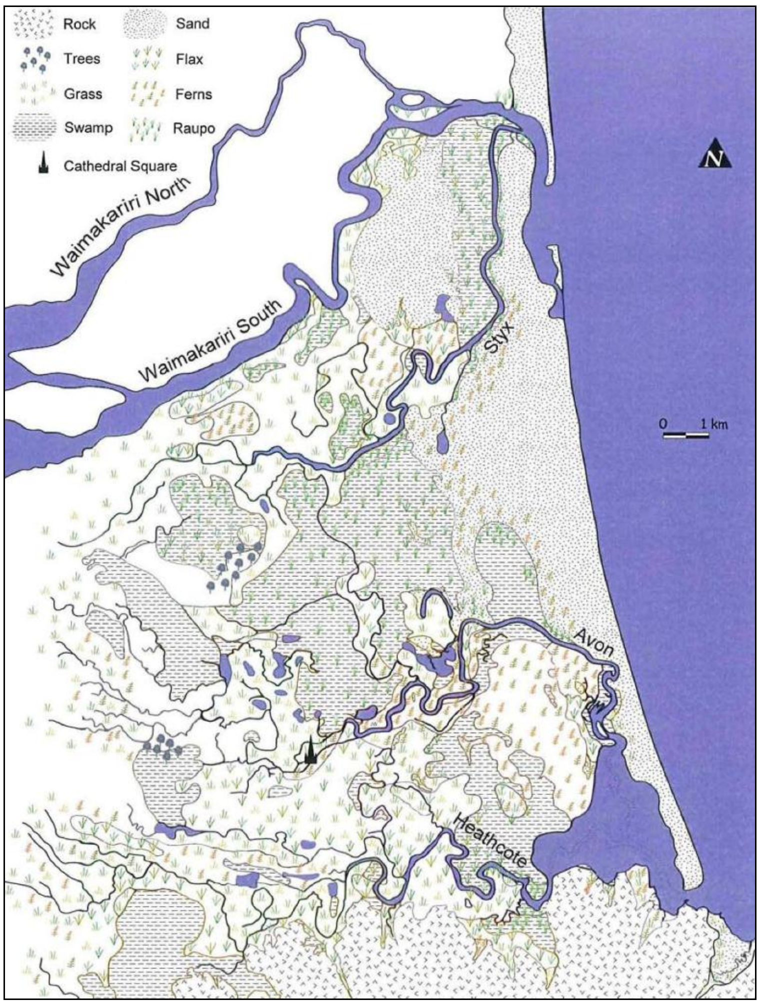


Figure 3-7. Waterways, wetlands, and vegetation cover of the Christchurch region as of 1856. Modified by J. Walter based on a compilation in Wilson (1989), which was based on the Black Map Rural Section cadastral maps of 1856 (from Christchurch City Council, 2003)

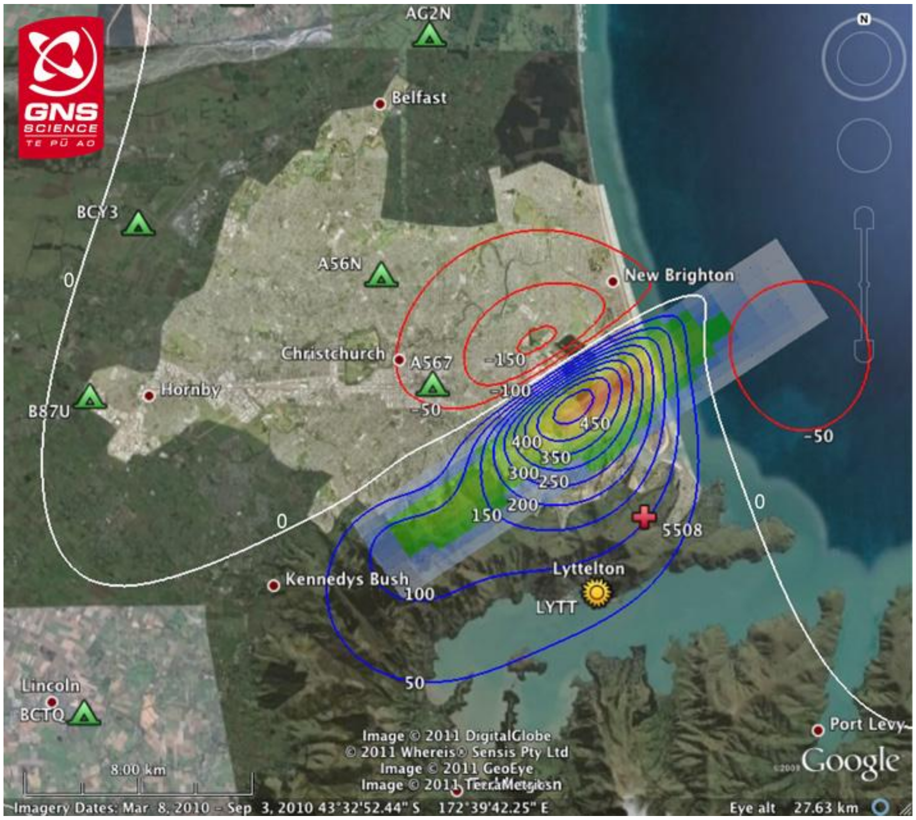


Figure 3-8. Preliminary model of the southeast-dipping fault (rectangular area) that ruptured across the southern part of Christchurch and northern Port Hills during the 22 February 2011 Christchurch earthquake. Colors on the fault plane indicate the amount of slip between the two sides of the fault. The contour lines indicate the amount (in mm) the land has risen (blue contours) or subsided (red contours) due to the slip on the fault. The white line is the contour where there was no change in height. The red, green and yellow colored symbols show some of the GPS stations whose displacements were used to derive the fault slip model (GNS Media Release, April 2011).

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