Active Fault Mapping and Fault Avoidance Zones for Hastings District and environs

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EXECUTIVE SUMMARY

An update of active fault linework and Fault Avoidance Zones is presented for the Hastings District and environs. The district is traversed by sets of active strike-slip, reverse and normal faults that pose a surface rupture hazard to buildings and infrastructure. Following the Ministry for the Environment's (MfE) Guidelines – "Planning for Development of Land on or Close to Active Faults" faults have been mapped to produce fault avoidance zones surrounding the active faults at a scale suitable for cadastral zoning. For life safety purposes, the MfE active fault guidelines focus on: (i) the location and complexity of faulting; (ii) the characterisation of recurrence interval of surface faulting, and (iii) the building importance category with respect to land zonation for a site.

Active fault trace mapping was undertaken in the district using airborne Light Detection and Ranging (LiDAR) hillshade models and Digital Elevation Models (DEMs) and from review of active fault linework by Lee et al. (2011 - the 'QMAP Hawke's Bay' sheet), the New Zealand Active Fault Database and from a regional scale orthophotograph and 10-m DEM. This work builds upon and supersedes previous active fault linework and Fault Avoidance Zones developed for parts of the district by Langridge and Villamor (2007). The fault mapping has been undertaken at scales of c. 1:5000 to 10,000 (LiDAR) and at scales of between 1:50,000 to 1:250,000 (New Zealand Active Fault Database, QMAP).

How accurately the geographic position of a fault trace can be defined is an important factor for deriving the widths of Fault Avoidance Zones. Where LiDAR is available, we have mapped the location of fault traces as either accurate (±10 m), approximate (±25 m), or uncertain (±40 m). Where no LiDAR coverage exists we use QMAP and New Zealand Active Fault Database linework, which is assigned a locational accuracy of ±125 m due to the scale at which it was mapped. Updated fault linework using a regional scale orthophotograph and 10-m DEM have also been assigned an accuracy of ±125 m. A margin of safety buffer of +20 m is added to each fault location buffer.

Fault Avoidance Zones have been defined based on the level of fault location accuracy. These zones range in width from 60 m for accurate (Well-Defined; ±10 x 2 + 20 x 2 m) strike-slip and normal faults, to 290 m for approximately-located QMAP active faults. For reverse faults, the fault location accuracy has been doubled on the hangingwall side of the fault to reflect the increased likelihood of deformation (including folding) on that side of the fault.

Geospatial attributes, including Fault Name, Accuracy, and Recurrence Interval (RI) Class accompany the linework. Recurrence intervals for surface rupture (faulting) have been defined for many of the named faults and fault zones within Hastings District. These include five Recurrence Interval Class I (RI ≤2000 yr) faults (e.g. Mohaka Fault, Patoka Fault) and three RI Class II (>2000-≤3500 yr) faults (e.g. Ruahine Fault; Waiohau Fault) in the district. RI Class III (>3500 to ≤5000 yr) and RI Class IV (>5000 to ≤10,000 yr) are the most common classes of fault activity across the district. Faults from the western margin of Hawke's Bay region are also included in this report.

Tables that relate the Fault Recurrence Interval to the Fault Complexity and Building Importance Category are provided to aid planners to assess the risk attributed to resource and building consent applications.

We recommend that the fault line and Fault Avoidance Zone data presented here as digital geospatial data be adopted by Hastings District Council used as standard practice for planning and consenting in Hastings District, and as per the ‘Hawke’s Bay Joint Hazard Strategy for Local Authority Land Use Planning’ (Plan #4397) that these fault traces be incorporated within DP maps where possible, or within Council GIS databases, in order to set rules for setback distances from active faults, or require proof of consideration of active fault guidelines. These data should supersede previous versions of active fault linework, attributes and Fault Avoidance Zones. We also recommend that active fault linework and Fault Avoidance Zones should be updated every 5-10 years as more LiDAR data becomes available and our understanding of recurrence interval improves. This is particularly important for areas that are undergoing rapid land-use change, such as near the coastline and in the southeastern part of the district, where active faults are currently mapped at smaller scales.

1.0 INTRODUCTION

New Zealand straddles the boundary between the Australian and Pacific tectonic plates (Figure 1.1), where active faults rupture to the Earth's surface during large earthquakes. The area administrated by Hawke's Bay Regional Council (HBRC) lies within one of the more tectonically active parts of this boundary zone. Hawke's Bay Region is underlain by the subducting Pacific plate and is crossed by numerous active faults that can rupture and deform the ground surface, including the Mohaka Fault and Poukawa Fault Zone (Figure 1.1). Previously published data from these faults indicate that some have relatively high rates of activity (i.e. relatively short recurrence intervals, on the order of 1000-5000 years), and are capable of generating large earthquakes (M_w >6.5) associated with large (i.e. metre-scale) single-event ground surface rupture displacements (e.g., Kelsey et al., 1998; Langridge and Villamor, 2007; Langridge et al., 2011).

Surface rupture of an active fault will result in a zone of intense ground deformation as opposite sides of the fault move past or over each other during an earthquake. Property damage can be expected and loss of life may occur where buildings, and other structures, have been constructed across the rupturing fault. The 1931 Hawke's Bay and 2010 Darfield (Canterbury) earthquakes are good examples of the types of effects that can be caused by ground surface rupture along faults, notwithstanding the damage that can occur to man-made built structures in such events (e.g. Hull, 1990; Van Dissen et al., 2011).

1.1 SCOPE OF WORK

The Institute of Geological and Nuclear Sciences Limited (GNS Science) was commissioned by HBRC, to provide an update of mapping of active faults within Hastings District.

The main objective for this work is:

To produce high-quality digital geospatial data and maps suitable for planning use across Hastings District at scales that are relevant to the current and expected future land use requirements. Hastings District has a high number and density of active faults, which are mostly mapped at scales of >1:10,000 (i.e. QMAP – the Geological Map of New Zealand programme at 1:250,000, and the New Zealand Active Fault Database (NZAFD; http://data.gns.cri.nz/af/) (Langridge et al., in press) at 1:50,000 (Figure 1.1). The location of active faults at scales of >1:10,000 have large locational uncertainty and are of limited use for planning purposes.

To improve understanding of faulting hazard and update the quality of fault mapping within Hastings District the scope of work is as follows:

- Provide an up-to-date background on active faulting, focusing on active faults within Hastings District
- Review current fault mapping within Hastings District
- Where airborne LiDAR coverage exists, map and attribute active fault traces at 1:10,000 scale or better.

- In all other areas of Hastings District incorporate new active fault line work and attributes from the recently published QMAP Hawke's Bay (Lee et al., 2011) and review data within the NZAFD (1:50,000 to 1:250,000 scale)[1].
- Produce Fault Avoidance Zones based on the fault line data described above.
- Produce a report for HBRC and present results to Hastings District staff.

Chapter 2 of this report provides a background on what active faults are and discusses their styles of movement, and frequency of movement (recurrence interval). Chapter 3 describes the techniques we used to map the faults and how we developed the attributes, uncertainties and Fault Avoidance Zones for these fault traces, while Chapter 4 provides examples of each style of faulting and the recurrence intervals of important faults in Hastings District. Chapter 5 provides planning and consent tables to help inform decision making by way of several planning case studies regarding active fault classes. Chapter 6 provides a summary of the results of this work and Chapter 7 contains recommendations for the use of this work. The report is accompanied by digital geospatial data including active fault linework and fault avoidance zone (buffers) (Appendix 1).

1.2 MFE GUIDELINES FOR DEVELOPMENT OF LAND ON OR CLOSE TO ACTIVE FAULTS

The Ministry for the Environment (MfE) published guidelines on "Planning for Development of Land on or Close to Active Faults[2] (Kerr at al., 2003, see also King et al., 2003; Van Dissen et al., 2003), hereafter referred to as the MfE Guidelines. The aim of the MfE Guidelines is to assist resource management planners tasked with developing land-use policy and making decisions about development of land on, or near, active faults. The MfE Guidelines provide information about active faults, specifically fault rupture hazard, and promote a risk-based approach when dealing with development in areas that are subject to fault rupture hazard.

The guidelines were developed because:

> *"There is no technology to prevent earthquake damage to buildings built across faults."*
>
> (Kerr et al., 2003)

The main elements of the risk-based approach presented by the guidelines are:

1. Fault characterisation relevant to planning for development across fault lines which focuses on: a) accurate location of faults (including its "fault complexity", i.e., the distribution and deformation of land around a fault line); b) definition of Fault Avoidance Zones, and; c) classification of faults based on their recurrence interval (time interval between large earthquakes on the same fault), which is an indicator of the likelihood of a fault rupturing in the near future.
2. The Building Importance Category, which indicates the acceptable level of risk of different types of buildings within a Fault Avoidance Zone.

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[1] In this study we have not had the scope to review active fault locations using aerial photographs and rely on previous mapping, a regional-scale DEM and orthophotograph outside of areas that have LiDAR coverage.

[2] Throughout the remainder of this report, the Ministry for the Environment's Guidelines will be referred to as the MfE Guidelines.

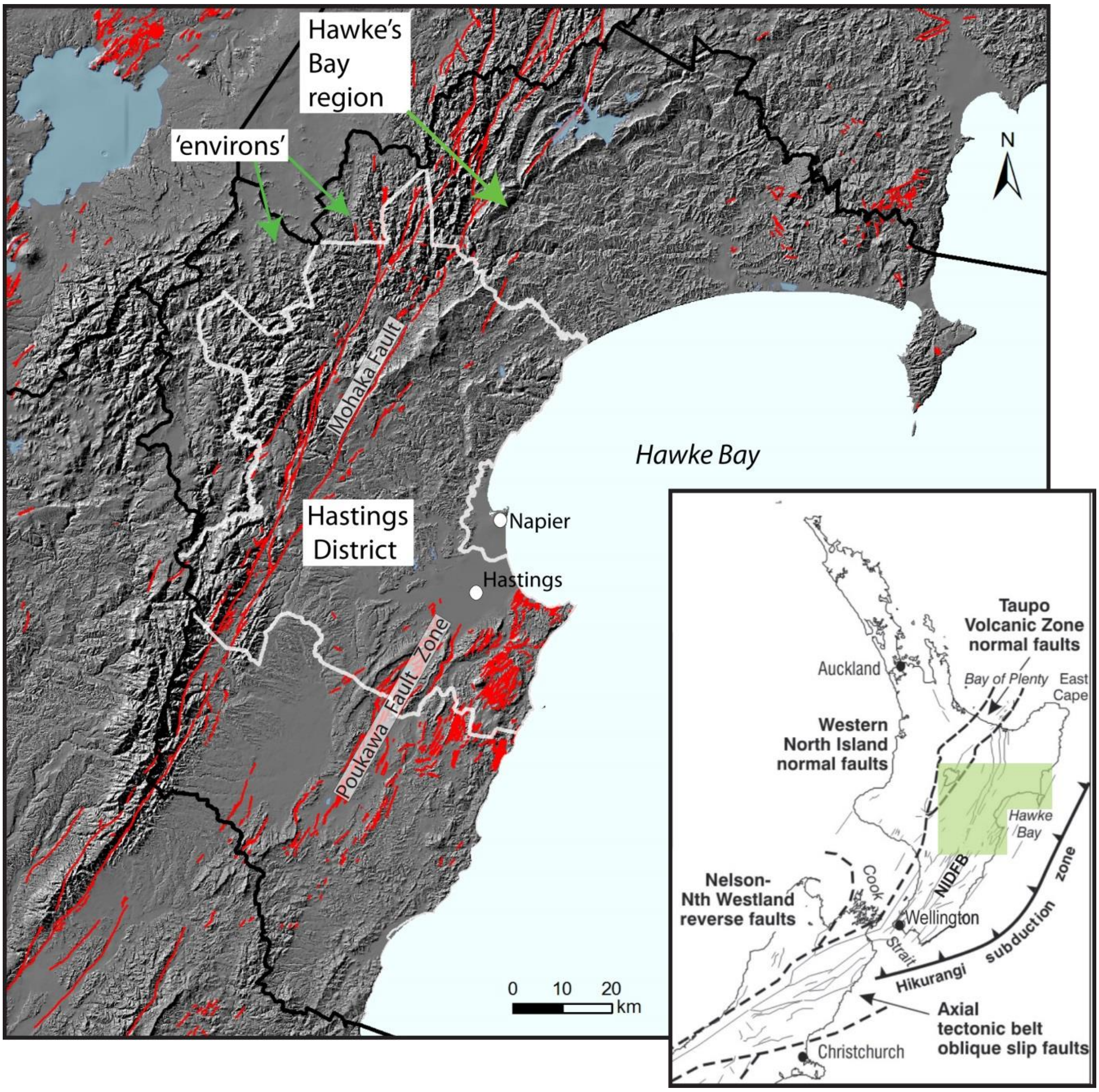

Figure 1.1 Active faults (red) within the Hawke's Bay region (inside black line). The study area of Hastings District is within the white line (excluding Napier City). The study area also encompasses that part of Hawke's bay region along the western and northwestern edge of Hastings District (the 'environs'). Inset: Simplified map of North Island plate tectonic boundary zone. NIDFB = North Island Dextral Fault Belt.

For these reasons our report will focus on aspects of accurate fault location (see section 3.0), fault recurrence interval (see section 3.1) and recommendations pertinent to the guidelines.

The MfE Guidelines also advance a hierarchical relationship between recurrence interval and building importance, such that the greater the importance of a structure, with respect to life safety, the longer the avoidance recurrence interval needs to be for that building to be permissible. For example, only low occupancy or risk structures, such as farm sheds and fences (e.g. Building Importance Category 1 structures), are recommended to be built across active faults with average recurrence intervals of surface rupture less than 2000 years. In a "Greenfield" (i.e. undeveloped) setting, more significant structures such as schools, airport terminals, and large hotels (Building Importance Category 3 structures) should not be sited across faults with average recurrence intervals shorter than 10,000 years (i.e. RI Class ≤ IV).

1.3 PREVIOUS FAULT MAPPING

In Hastings District there are many generally NE-striking active fault traces that parallel the plate boundary within the upper (Australian) plate (Cashman and Kelsey, 1990; Cashman et al., 1992). Since 2005, GNS Science has been working with the HBRC to improve data regarding the activity and location of active faults in the region. Active fault mapping projects have been undertaken for all four Territorial Land Authorities (including Napier City) within the region (Langridge and Ries, 2014; Langridge et al., 2006; 2011) including Hastings District (Langridge and Villamor, 2007). These reports typically focused on areas where new detailed land coverage exists from Light Detection and Ranging (LiDAR) surveys and where the district planning needs have been the greatest.

Many active faults in the district have previously been mapped or described in some detail (e.g. *Poukawa Fault Zone* – Kelsey et al. 1998; Begg et al. 1994, 1995). Much of this previous work was improved upon by fault mapping commissioned for Hastings District and undertaken by GNS Science during the last decade (Langridge and Villamor, 2007). The 2007 report was the first GIS-based fault mapping report for the district and focused on mapping faults of the central urban, plains and coastal corridors of Hastings District, due mostly to the availability of LiDAR data across this part of the district. The 2007 report also provided the first example of Fault Avoidance Zones (FAZs) developed for active faults in the district. It has become clear that this approach of fault mapping and surface rupture zonation needs to be extended throughout the district into all areas regardless of the availability of LiDAR.

Therefore, GNS Science undertook a district-wide active fault mapping and Fault Avoidance Zone project for Hastings District. Some of the main reasons for undertaking this review and new work are:

i. the availability of LiDAR surveys in Hastings District since the Langridge and Villamor (2007) report);

ii. the availability of new linework and fault mapping interpretation derived from the QMAP Hawke’s Bay geologic map (Lee et al., 2011);

iii. to provide Hastings District Council with up-to-date geospatial datasets that will be valid for planning purposes.

This report supersedes the earlier report by Langridge and Villamor (2007).

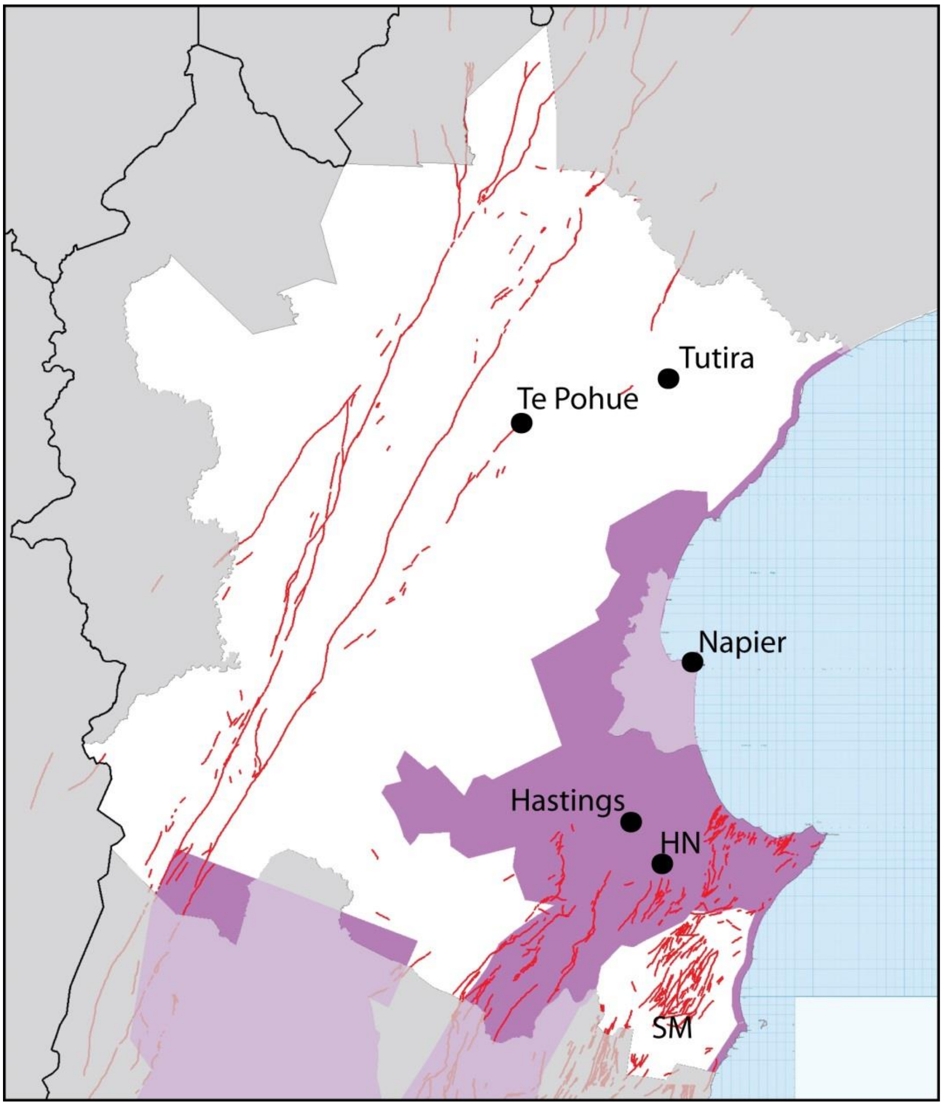

Figure 1.2 Active faults (red lines) mapped within the Hastings District (white polygon) prior to this study (source: New Zealand Active Fault Database). Areas that have airborne LiDAR coverage are shown in purple. Cities and locally important towns within the district are also shown; HN is Havelock North. SM is the southern Maraetotara Plateau area - an area with a high density of mapped fault traces outside the LiDAR coverage.

2.0 WHAT IS AN ACTIVE FAULT?

Active faults are those faults considered capable of generating strong earthquake shaking and ground surface fault rupture, causing significant damage. Ground surface-rupturing earthquakes are typically of magnitude M_w >6.5. An active fault in New Zealand is generally defined as one which has deformed the ground surface within the past 125,000 years (Langridge et al., in press).This is defined in part for practical reasons as those faults which deform marine terraces and alluvial surfaces that formed during the 'Peak Last Interglacial period' or Marine Isotope Stage (MIS) 5e, or younger (MIS 1-4; e.g. Alloway et al., 2007).

The purpose of this chapter is to introduce how active faults express themselves, i.e., their behaviour, styles of deformation, activity and geomorphic expression. Active faults are expressed in the landscape as linear traces displacing surficial geologic features which may include hillslopes, alluvial terraces and fans. The age of these displaced features can be used to define how active a fault is. Typically in New Zealand, alluvial terraces are associated with the contemporary river drainages, and therefore they are typically <30,000 years old. Hillslopes are mainly formed in bedrock and in New Zealand these surfaces have generally been modified by glacial or cold climate processes during the peak of the Last Glacial period (Barrell et al., 2011). This means that well-defined, linear fault traces that cut across bedrock hillslopes are probably also <30,000 years old.

Active faults are often defined by a fault scarp. A fault scarp is formed when a fault displaces or deforms a surface and produces an abrupt linear step, which smooths out with time to form a scarp (Figure 2.1). In some cases, where a fault moves horizontally, only a linear trace or furrow may be observed. Traditionally, faults have been mapped from aerial photographs using stereoscopy, i.e., pairs of overlapping aerial photographs that can be used to visualise the ground surface in 3-D. Airborne LiDAR and detailed Digital Elevation Models (DEM's) have greatly improved the accuracy to which active fault traces can be mapped (Meigs, 2013; Langridge et al., 2014).

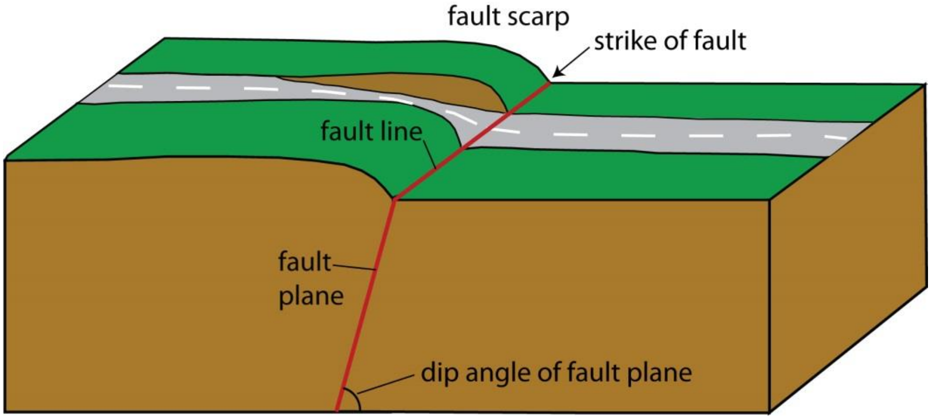

Figure 2.1 Block model of a generic active fault. Fault displacement produces a scarp along the projection of the fault plane at the Earth's surface (fault line or trace).

2.1 STYLES OF FAULT MOVEMENT

Faults can be categorised as: strike-slip faults, where the dominant style (sense) of motion is horizontal (movement in the strike direction of the fault), and dip-slip faults, where the dominant sense of motion is vertical (defined by movement in the dip direction of the fault). Strike-slip faults are defined as either right-lateral (dextral), where the motion on the opposite side of the fault is to the right (Figure 2.2), or, left-lateral (sinistral) where the opposite side of the fault moves to the left.

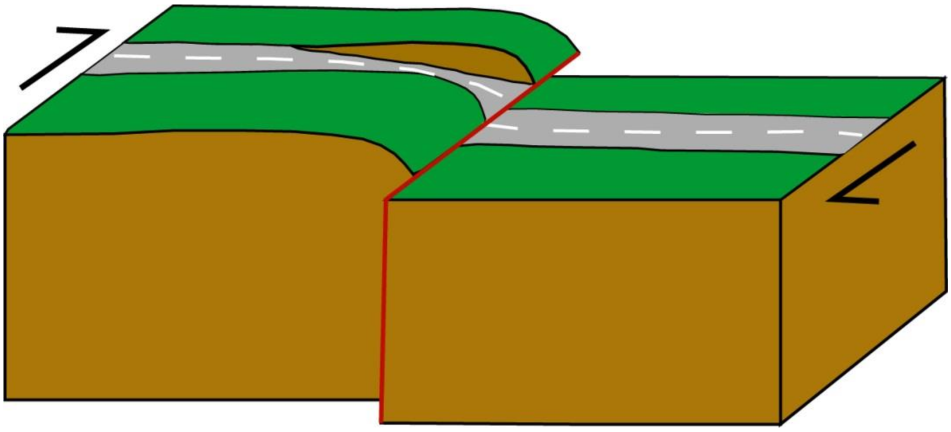

Figure 2.2 Block model of a strike-slip fault (red line). The fault is a right-lateral fault as shown by the black arrows and by the sense of movement across the two blocks and a right separation across the road.

Most strike-slip faults in New Zealand, such as the Alpine, Hope, Wairarapa and Wellington faults, have a mainly right-lateral sense of movement (Beanland and Berryman, 1987; Berryman and Beanland, 1991). Right-lateral strike-slip faults predominate within and on the boundaries of the main Axial Ranges in the western part of Hastings District, and include the Mohaka and Ruahine faults.

Dip-slip faults can be divided into reverse faults, formed mainly under contraction (where the hangingwall block of the fault is pushed up; Figure 2.3) and normal faults, formed under extension (where the hangingwall block of the fault drops down; Figure 2.4).

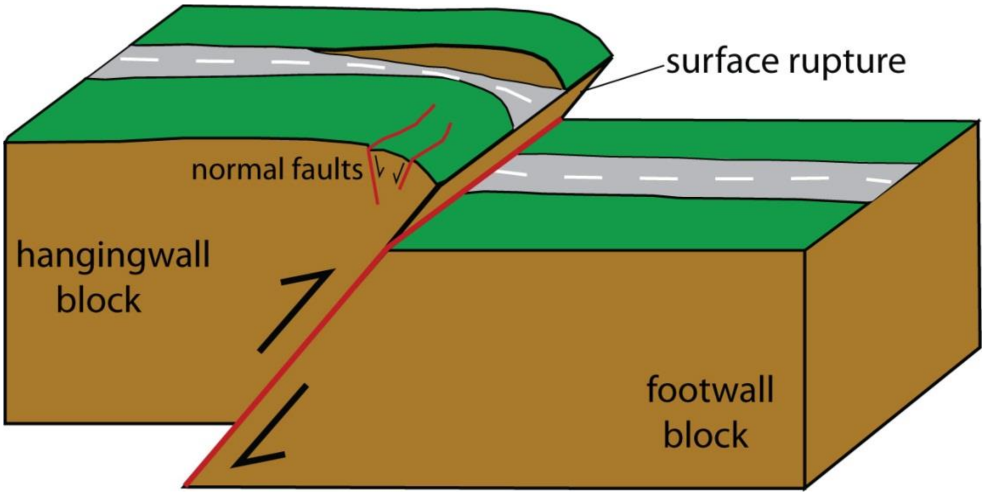

Figure 2.3 Block model of a reverse dip-slip fault that has recently ruptured. Movement of the blocks is vertical and in the dip direction of the fault plane. In this case, the hangingwall block has been pushed up over the footwall block. Folding and normal faulting are common features of deformation in the hangingwall block of reverse faults.

Reverse faults predominate within the central part of Hastings District, and include the Poukawa and Tukituki Fault Zones. Reverse faults have also been mapped off of the east coast of the district by NIWA (e.g. Barnes et al., 2002). A common feature of the tectonics of the Hawkes' Bay region are these sub-parallel, typically east-verging sheets of reverse and thrust[3] faults that occur in the upper crust above the plate boundary, i.e. the thin upper sliver of the Australian plate overlying the Hikurangi subduction zone in the eastern North Island (Cashman et al., 1992; Kelsey et al., 1995).

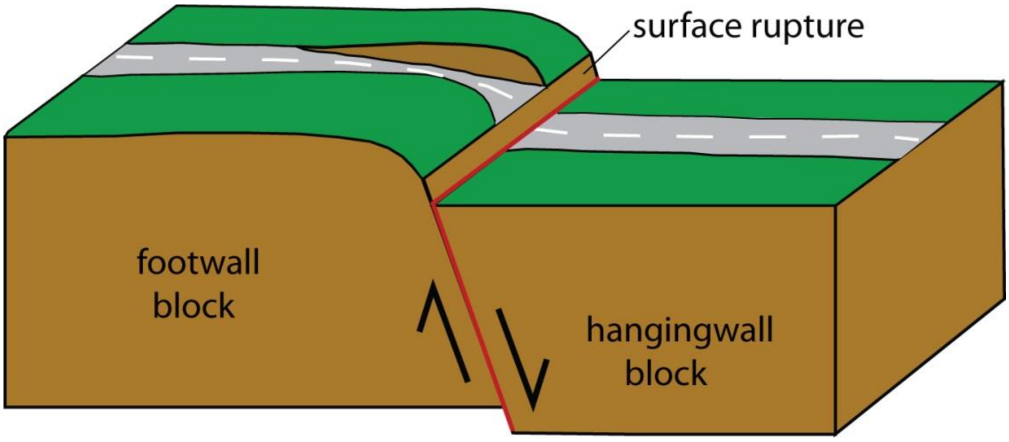

Figure 2.4 Block model of a normal dip-slip fault. The relative movement of the blocks is vertical and in the dip direction of the fault plane. The hangingwall block has dropped down, enhancing the height of the fault scarp.

Despite the predominance of oblique-compressional tectonic activity (i.e. strike-slip and reverse movement) across the plate boundary in Hawke's Bay, normal faults are also present (Cashman and Kelsey, 1990; Cashman et al., 1992). In particular, normal faulting is common within the Coastal Ranges between Cape Kidnappers and Maraetotara (Pettinga, 1980; 2004). The mechanisms for this extension are not well understood; however, the presence of recent normal faulting in this area is not debated and will be expanded upon below.

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[3] A thrust fault is a reverse fault with a low angle of dip, typically ≤40 degrees in the near surface.

2.2 ACTIVE FAULT PARAMETERS: RECURRENCE INTERVAL, SLIP RATE AND SINGLE-EVENT DISPLACEMENT

An important parameter in terms of the hazard posed by an active fault is its recurrence interval. This term refers to the average amount of time between earthquakes large enough to rupture the Earth's surface along the fault. The MfE Guidelines define six recurrence interval classes of active faults based on recurrence times (Table 2.1). Faults with the highest activity fall into RI Class I; these faults have an average recurrence interval of ≤2000 years. In general, the recurrence interval classes match standards correlated against hazard levels and the New Zealand Building Code, such that there are four Recurrence Interval (RI) classes that span the last 10,000 years (RI Classes I, II, III, and IV). The least active class of faults is RI Class VI which includes faults that have an average recurrence interval of 20,000-125,000 yr (Table 2.1). Planning restrictions developed from the MfE Guidelines typically increase with a decrease in the recurrence interval of faulting.

The classes displayed in Table 2.1 provide a context for the discussions that follow concerning individual active faults in Hastings District and the application of Fault Avoidance Zones and their associated planning recommendations.

Table 2.1 Average Recurrence Interval of Surface Rupture, RI Classes and examples of New Zealand faults that fall in each RI Class.

Recurrence Interval Class	Average Recurrence Interval of Surface Rupture	NZ examples (faults); Hastings District examples in bold
I	≤2000 years	Alpine, Hope, Awatere, Wellington, **Mohaka**, **Patoka**
II	>2000 years to ≤3500 years	Ostler FZ, Ohariu, Makuri, Rangipo, **Ruahine**, **Waiohau**
III	>3500 years to ≤5000 years	Dunstan, Lake Heron, Poutu, **Tukituki FZ**, **Poukawa FZ**
IV	>5000 years to ≤10,000 years	Dalgety, Esk, Karioi, **Awanui (1931)**, **Maraetotara FZ**
V	>10,000 years to ≤20,000 years	Pisa, Greendale, Martinborough, **Seafield FZ**
VI	>20,000 years to ≤125,000 years	ND

Notes: Faults with average recurrence intervals >125,000 years are not considered active. FZ = Fault Zone.

When the timing of individual past surface rupturing earthquake events need to be defined, paleoseismic trenches are excavated at sites where the fault and its relationship with recent sediments can be exposed. These sediments offer the opportunity to separate out the evidence for discrete paleoseismic or past surface-rupturing earthquakes.

In the absence of paleoseismic trenching, slip rate and single-event displacement data in combination with geomorphic landscape assessment forms the basis of how faults are defined according to Recurrence Interval for the MfE Guidelines. Careful measurement of well-dated and displaced geomorphic features can be used to calculate a slip rate or displacement rate for a particular fault. A slip rate is the velocity of the fault measured over time, i.e. displacement divided by time. For example, the Mohaka Fault has a moderate slip rate of c. 4 ± 1 mm/yr (or 4 metres per thousand years). In reality, fault displacement occurs in steps during large earthquakes that shift the Earth on either side of the fault by metres at a time (Figure 2.2). Thus, when there is no data available from trenches, the recurrence interval can be defined through the combination of slip rate and single-event displacement data. These latter calculations are often limited by a lack of data and sometimes rely on assuming the age of a faulted surface (e.g. post-glacial; 16,000 ± 2000 years) or the likely amount of displacement in a single event along a fault and hence .the designated recurrence interval is defined as tentative.

3.0 METHODOLGY OF FAULT MAPPING

3.1 FAULT AND FAULT AVOIDANCE ZONE MAPPING

Surface fault traces have been mapped using a combination of LiDAR DEM's and hillshade models, a national scale (10-m) DEM, and by adopting linework from the QMAP geologic mapping program and the NZAFD. There is a large difference between the locational accuracy of mapped fault traces when comparing LiDAR with either the 10-m DEM, QMAP or NZAFD data. The main difference is the scale with which the mapped trace has been digitised, i.e. LiDAR typically 1:5,000, QMAP 1:50,000 (but published at 1:250,000) and the NZAFD typically 1:50,000 scale.

For current land use planning in regard to building on or adjacent to active faults, it is not appropriate to use 1:50,000 scale (or larger) active fault mapping to define the fault location in developed and developing areas (e.g. Begg et al., 1994). Across most of the Axial Ranges zone where no LiDAR coverage exists, the locations of active faults have been assessed using QMAP linework from the Hawke's Bay geologic map (Lee et al., 2011; Figure 4.1). In these areas the QMAP linework has been compared with data already in the NZAFD for presence, accuracy, and continuity of fault trace information. In some cases, data from the NZAFD has taken precedence over QMAP linework. For example, in the southern Maraetotara area within the Coastal Ranges, linework from the NZAFD has been reviewed using the 10-m national scale DEM and a regional scale orthophotograph basemap. In this area the linework has been reviewed in relation to the DEM at a scale of c. 1:20,000.

During the last decade, several campaigns of LiDAR acquisition have been flown across Hastings District and wider region (Figure 1.2). These acquisitions cover the Hawke's Bay coastline, Heretaunga Plains, Pukehou-Poukawa corridor, Cape Kidnappers area and Makaroro area. Data quality and subsequent DEM pixel size has improved from the earlier acquisitions through to the more recent surveys (2010-2011). The raw data from all acquisitions were supplied to GNS by HBRC in New Zealand Map Grid 1949 projection. These data were re-projected into New Zealand Transverse Mercator 2000 projection and DEMs interpolated so that they are now uniformly interpolated to produce 1-m DEM's (see Langridge and Ries, 2014).

3.2 FAULT LOCATION UNCERTAINTY, ATTRIBUTES AND FAULT AVOIDANCE ZONES

For this study, the location and attributes pertaining to active faults have been assembled in a Geographic Information System (GIS) and recorded in a digital geospatial database (provided as supplementary to this report). A detailed description of the attributes assigned to fault locations is contained in Appendix 1.

The digitising of active faults requires expert recognition of fault-influenced geomorphic landforms and an understanding of the local geology. The most obvious landform feature associated with surface fault rupture is a fault scarp (Figure 2.1). Fault scarps are steps in the land surface that coincide with the locations of faults. They can extend for hundreds of metres in length and are often many metres wide. Therefore, representing a scarp as a line within a GIS is problematic. In practice, a line within a GIS database has a width of zero and is meant to represent the location where it is estimated the fault would rupture the ground surface. Active faults are more appropriately defined as zones rather than lines. This is because of the location uncertainty of digitising or surveying a line, the lack of knowledge on the exact location of the fault plane (unless the fault plane is exposed in an excavation), and because the surface area that will be deformed by faulting is likely to be somewhat wider than the main fault plane (fault complexity in Kerr et al., 2003).

The accuracy with which the location of a fault feature can be represented in a GIS is influenced by three types of uncertainty. The first is the uncertainty of the source data relative to a global datum. This uncertainty can be quantified and is differentiated in this study with the attribute in the field **DATA_SOURCE**. The second is resolution of the source data, (i.e. the scale at which a geomorphic landform is able to be resolved from the data). This can be expressed as an average scale at which the fault has been digitised and has been attributed in the field **SCALE**. The third is the uncertainty associated with how accurately the feature can be identified from a geomorphic study and the complexity of the surface deformation associated to a given fault feature. This is also a reflection of the expression of a tectonic (fault-related) feature and is defined as ‘Fault Complexity’ in the MfE Guidelines. Fault complexity is an important component in the definition of planning consent categories. In this study the **ACCURACY** attribute encompasses this expression uncertainty.

These distinctions concerning locational uncertainty are important because of: (i) how they relate to the accuracy of the fault linework; (ii) how we build Fault Avoidance Zones from that linework; (iii) how this fault data is applied by Councils; and, (iv) how the scale and accuracy affect individual land and building owners.

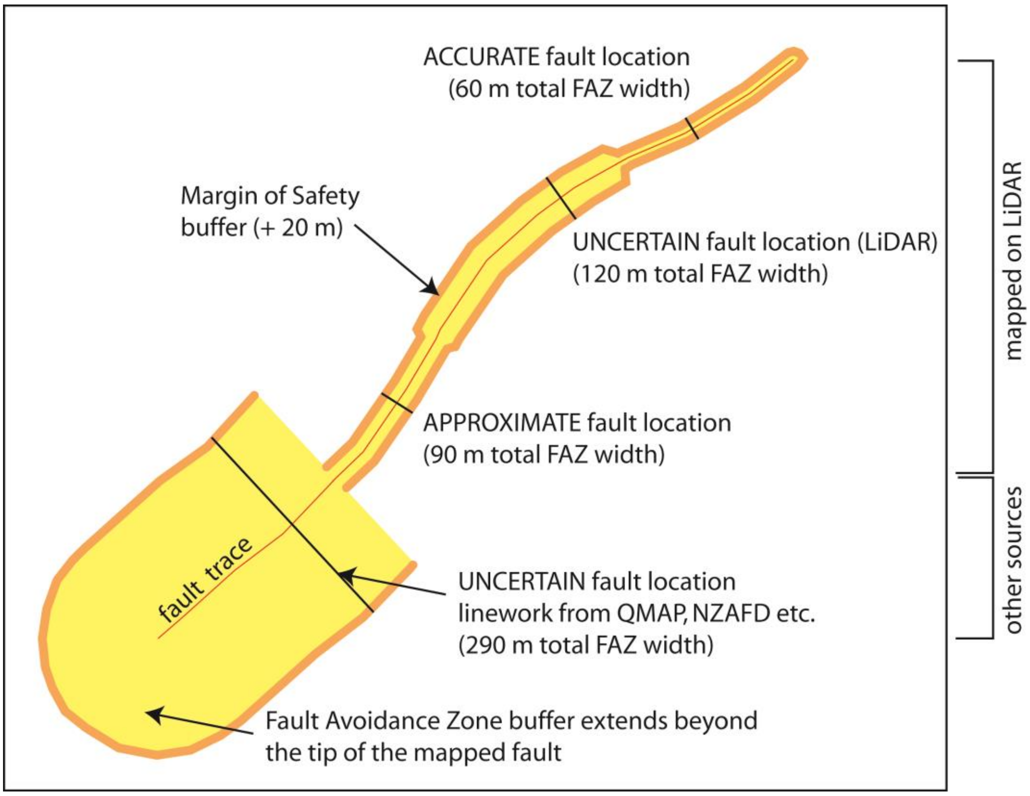


Figure 3.1 Fault Avoidance Zones (sum of yellow and orange) for hypothetical strike-slip or normal faults with varying Fault Location accuracy along strike. The zones at the ends of fault traces are extended and rounded to account for the possibility of deformation extended beyond their tips.

Once a fault trace location has been identified, attributes to describe the fault allow for the calculation of Fault Avoidance Zones (FAZ’s) that reflect the uncertainty regarding the position of surface faulting. The attributes from the fields **DATA_SOURCE, MAP_SCALE** and **ACCURACY**, are used to define the width of one side of FAZs and is assigned a value in metres in the field **BUFFER.** A visual representation of the varying width of a FAZ is presented in Figure 3.1.

The style of faulting (**SLIP_TYPE**) can also influence the width of the zone of surface rupture. For strike-slip and normal faults an equal width either side of the fault is used to develop a FAZ because there is no geological preference toward distributed deformation on one side. However, for reverse faults, it has been demonstrated that the hangingwall block (or uplifted side) of the fault has an increased amount of fault deformation relative to the footwall side. Therefore, the width of the FAZ on the hanging wall side is doubled (Figure 3.2). For example, folding, reverse drag faulting, extension and normal faulting are typical on the upthrown side of historical ruptures of reverse faults and are recognised in trench exposures (see Figure 2.3, Figure 4.7) (Kelsey et al., 1998).

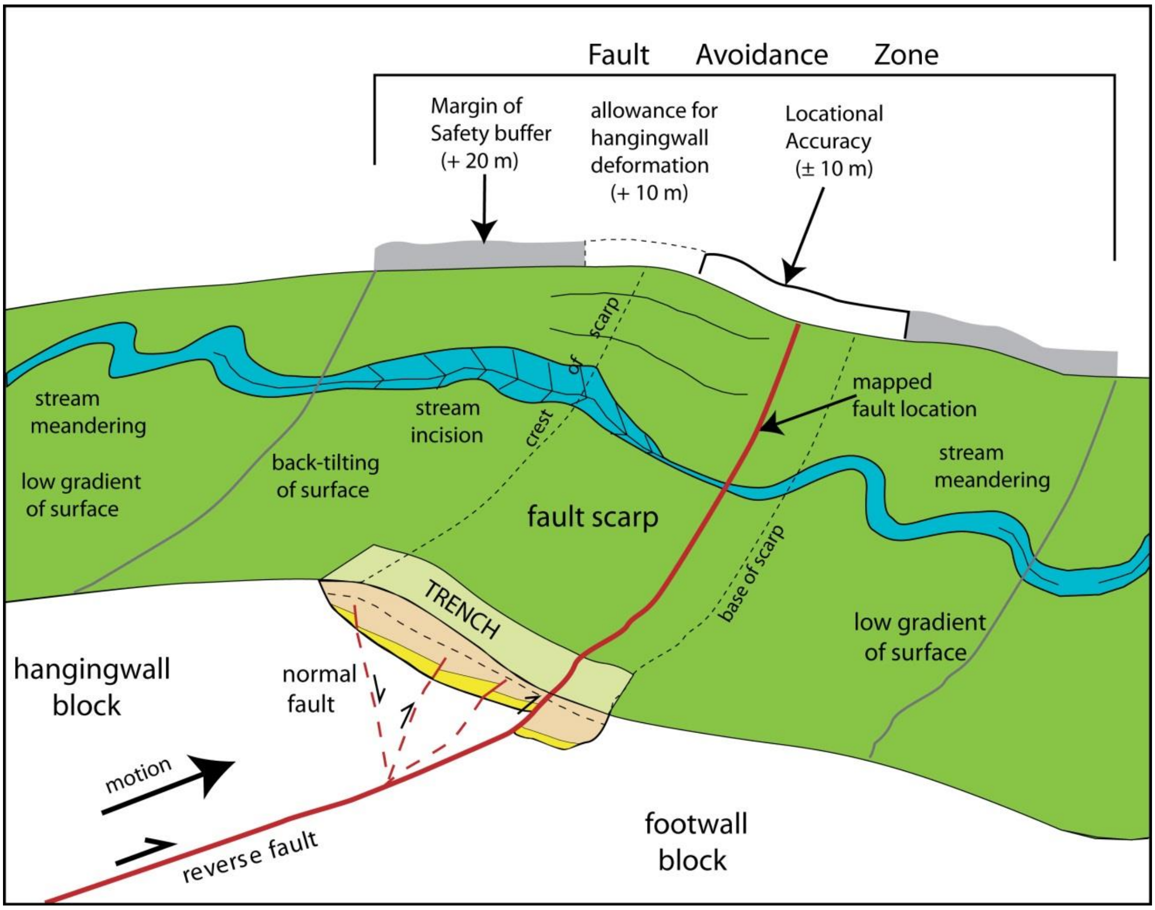


Figure 3.2 Schematic diagram of a dip-slip reverse fault and its scarp. In this case the mapped fault trace (rupture surface; bold red line) is mapped near the base of the scarp. The scarp itself is 'Well-defined', i.e. ±10 m definition on LiDAR. The growth of such scarps affects the long–term morphology of streams that cross the structure. The trench shows the expectation for documenting surface faulting events (e.g. faulted orange layer). The Location Accuracy and Fault Avoidance Zone are shown by the different sized parentheses.

In addition, the MfE Guidelines recommend that a *Margin of Safety Buffer* of +20 m be included as part of the FAZ. This buffer gives some assurance that there is unlikely to be any fault deformation outside the entire width of the Fault Avoidance Zone. The widths of Fault Avoidance Zones for this study are presented in Table 3.1.

In the southern Maraetotara area (Figure 1.2), the linework comes from two main sources: doctoral studies and subsequent papers (Pettinga 1980; 2004), and from a more recent re-assessment of the structure of the area (Cashman et al., 1990; Kelsey et al., 1991) that were digitised for the NZAFD. No aerial photograph review has been undertaken as part of this study. Therefore, although the linework has been reviewed in a GIS at a scale of c. 1:20,000, we have assigned a Location Accuracy of ±125 m, in keeping with the accuracy of QMAP and NZAFD.

Table 3.1 Widths of Fault Avoidance Zones for Hastings District faults.

Slip Type	Data Source	Accuracy	Map Scale	Buffer (m)	Margin of safety buffer (m)	Fault Avoidance Zone width (m)
Strike-slip/ normal	LiDAR	Accurate	1:5,000	±10	±20	**60**
“	“	Approximate	1:5,000	±25	±20	**90**
“	“	Uncertain	1:5,000	±40	±20	**12**
“	QMAP, NZAFD	Uncertain	1:50,000	±125	±20	**290**
“	10-m DTM, orthophoto	Uncertain	1:20,000	±125	±20	**290**
Reverse*/ Thrust*	LiDAR	Accurate	1:5,000	±10 (+ 10*)	±20	**70**
“	“	Approximate	1:5,000	±25 (+ 25*)	±20	**115**
“	“	Uncertain	1:5,000	±40 (+ 40*)	±20	**160**
“	QMAP, NZAFD	Uncertain	1:50,000	±125 (+ 125*)	±20	**415**
“	10-m DTM, orthophoto	Uncertain	1:20,000	±125 (+ 125*)	±20	**415**

* Additional uncertainty added to allow for the deformation on the hangingwall side of reverse and thrust faults.

Where there is more than one fault trace making up a distributed or complex zone of faulting, individual Fault Avoidance Zones may overlap. In this case, a merging function in the GIS amalgamates individual zones together. In Hastings District, this is particularly evident for closely-spaced reverse and normal faults.

In addition, many fault traces terminate in open country without any obvious connection to other faults or to deformed surfaces (see Figure 3.1). In such cases the Fault Avoidance Zone is rounded surrounding the fault tip. This helps account for the uncertainty of where the fault goes or terminates, but recognises that at some distance, it is difficult to identify or map the continuation of a fault.

Fault complexity is defined within the MfE Guidelines by three terms: ‘Well-defined’ (fault location), ‘Distributed’ (deformation) or ‘Uncertain’ (fault location). These three terms are used directly in Resource Consent tables (e.g. Table 5.1). In this study, we refer to Well-Defined fault locations as those that are accurately (±10 m) or approximately (±25 m) located from LiDAR DEMs. Where fault locations are ‘Uncertain’ from the LiDAR (±40 m) we apply the term ‘Distributed’. For fault linework that comes from the 10-m DEM, NZAFD or QMAP (±125 m) we use the term ‘Uncertain’ with respect to its fault complexity.

4.0 ACTIVE FAULTS IN HASTINGS DISTRICT

Within Hastings District four broad morphotectonic zones of active faulting can be identified (Figure 4.1): (i) the Axial Ranges zone in the west, dominated by strike-slip faulting; (ii) the Hawke's Bay Syncline which is characterised by a general paucity of active faulting; (iii) the Poukawa-Heretaunga trough which is characterised by reverse faulting, and (iv) the eastern or Coastal Ranges, which are dominated by normal faulting with a lesser component of reverse faulting. In the following section we describe strike-slip, reverse and normal faults and fault zones from west to east, to give a context for the GIS mapping and Fault Avoidance Zones presented in the following chapters.

4.1 STRIKE-SLIP FAULTING AND THE AXIAL RANGES MORPHOTECTONIC ZONE

Strike-slip faults are prevalent in the west of the district within the Axial Ranges morphotectonic zone (Figure 4.1). Table 4.1 summarises the basic active fault parameters for these strike-slip faults. Two of the most important strike-slip faults in Hastings District are the Mohaka and Ruahine faults (Figure 4.1; Table 2.1). These NNE-striking faults extend for many tens of kilometres within the Axial Ranges and run the entire length of Hastings District and beyond to the north and south of it. The Mohaka and Ruahine faults form part of the western strand of the North Island Dextral Fault Belt, as defined by Beanland (1995). These two faults branch from the Wellington Fault near the Manawatu Gorge (Langridge et al., 2005) and can be clearly mapped in the landscape.

The Mohaka Fault has a long history and offsets bedrock units and some large rivers horizontally by kilometres (Berryman et al., 2002; Langridge et al., 2005) and younger late Quaternary features like spurs and streams by many tens of metres (Figure 4.1, Figure 4.2). Data from trenches indicate that past earthquakes have ruptured the Mohaka Fault on average every c. 1100 years (Langridge et al., 2011). The few observations of single-event displacement (SED) that have been recognised along the fault indicate c. 3-5 m of slip during the last two surface-rupturing earthquakes (Marden, 1984; Raub, 1985). In combination, the observations of slip rate, SED and recurrence interval (the time between earthquakes) are mutually consistent with one another. Because the Mohaka Fault has an average Recurrence Interval of c. 1100 years, it is classified as a RI Class I fault (i.e. RI ≤2000 years) (Table 2.1, Table 4.1). At the northern margin of Hastings District, the Mohaka Fault bifurcates and is renamed as the Whakatane and Waimana faults in the Bay of Plenty region (Figure 4.1; Mouslopoulou, 2006).

The Ruahine Fault (Figure 4.4) is sub-parallel to, and occurs 4-9 km to the west of, the Mohaka Fault (Figure 3.1). The Ruahine Fault is less well studied but existing data indicate that it is somewhat less active than the Mohaka Fault, with a slip rate of 1-2 mm/yr, a single-event displacement of 2-5 m, and a recurrence interval of 1000-5000 years (Beanland and Berryman, 1987; Hanson, 1998). From this data we derive a preliminary mean recurrence interval of c. 3000 years, which defines the Ruahine Fault as a RI Class II fault (i.e. 2000-3500 years). In the northern part of the district, the Ruahine Fault splits and one strand of the fault is thereafter named the Waiohau Fault. The Waiohau Fault becomes an important fault in the Bay of Plenty region and is also considered to be a RI Class II fault (Van Dissen et al., 2003; Mouslopoulou, 2006).

One additional fault within the Axial Ranges morphotectonic zone – the Gwavas Fault – is a normal fault that occurs adjacent to the Mohaka Fault (Figure 4.1; Langridge et al., 2013).

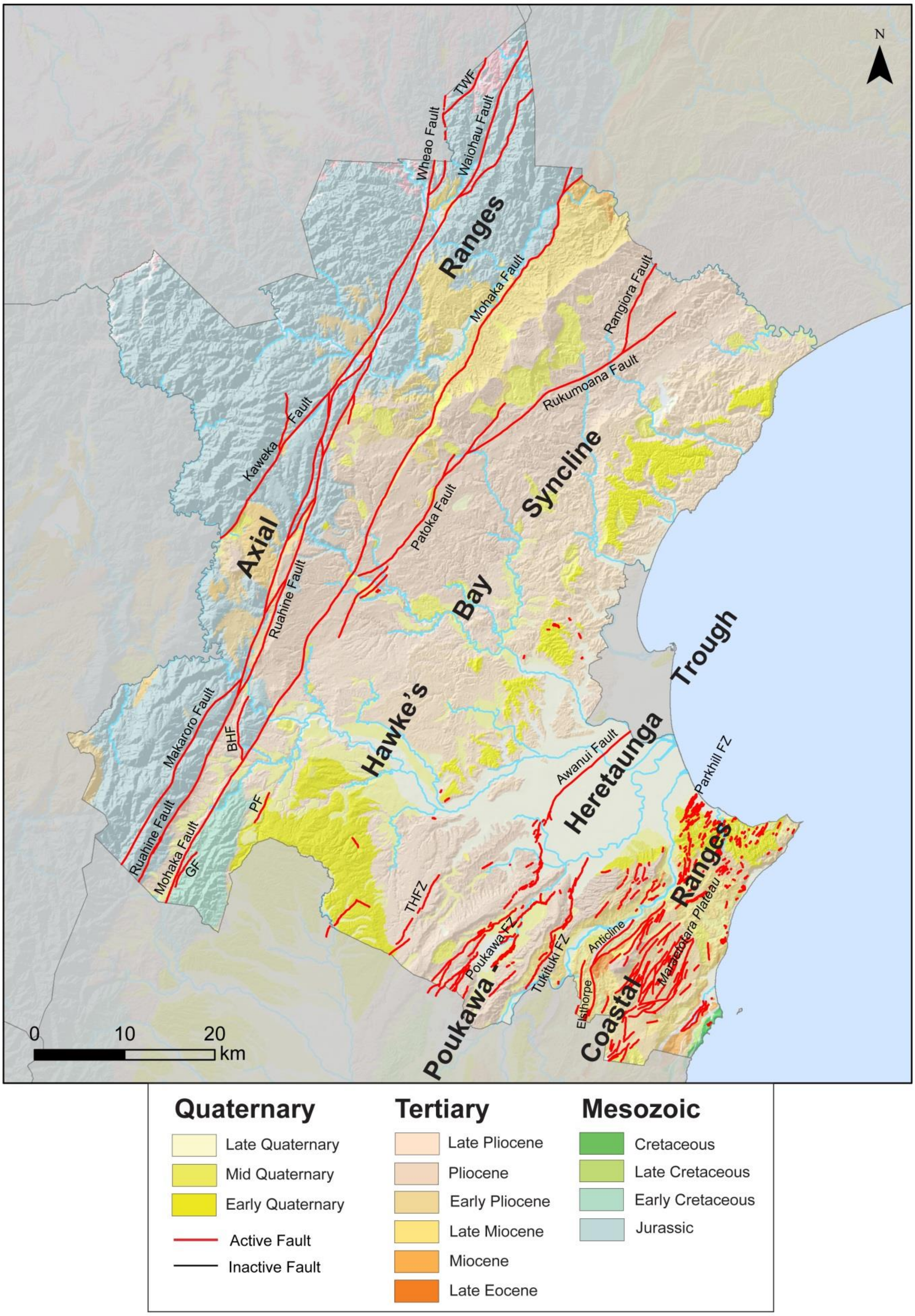


Figure 4.1 Generalised active fault traces (red lines) mapped in Hastings District as part of this study overlain on the bedrock geology (from QMap Hawke's Bay; Lee et al. 2011). Morphotectonic zones, e.g. Coastal Ranges, are highlighted in bold. BHF = Big Hill Fault; THFZ = Te Heka Fault Zone; TWF = Te Whaiti Fault, GF, Gwavas Fault; PF, Poporangi Fault.

Figure 4.2 View to the north along the Mohaka Fault, just to the south of the Ngaruroro River (top right) near Kereru. The active trace of the fault is marked by red arrows, and the sense of movement across the fault is highlighted by white arrows. A pair of offset features (a stream and adjacent ridgeline) are highlighted (dashed lines) to illustrate the right–lateral movement across the fault (Photograph: D.L. Homer, GNS Science).

Figure 4.3 View to the north of the uphill- or range-facing scarp of the Mohaka Fault west of Dannevirke. Person for scale at the base of the scarp. At this locality a ponded basin has been enhanced by a stock dam in the middle distance. An additional scarp of the fault is identified below the farm building.

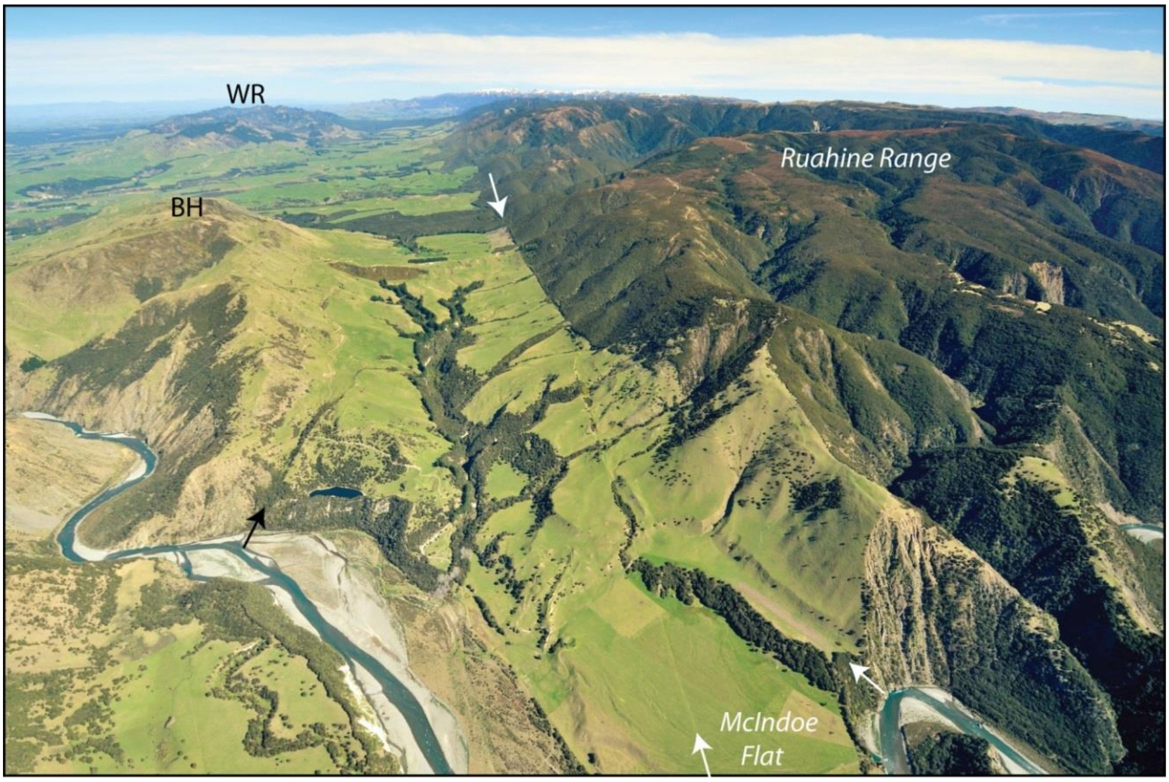


Figure 4.4 View to the south of the Ruahine and Big Hill faults at the Ngaruroro River. An active trace of the Ruahine Fault (white arrows) can be clearly seen crossing M^{c}Indoe Flat in the foreground and running along the rangefront of the Ruahine Range. Black arrow marks a possible trace of the Big Hill Fault. BH = Big Hill; WR = Wakarara Range (Photograph: D. Townsend, GNS Science).

Other strike-slip faults have been identified and mapped in the western part of the Ruahine Ranges sub-parallel to the Ruahine Fault, including the Kaweka Fault (RI class III; Van Dissen et al., 2003). At the northwest border of the district the Kaweka Fault splits, with one strand becoming the Wheao Fault and the other the Te Whaiti Fault. There is little available data for these faults but they are defined as RI Class III, based on their relationship with, or similarity to, the Kaweka Fault. Similarly, although there is no recurrence interval data for the Makaroro Fault, we tentatively assign it to RI Class III, based on its role within the Axial Ranges. The locations of these faults are all derived from the NZAFD and QMAP data. Continuations of these faults into the ‘environs’ of Hastings District (i.e. west and northwest of the district, e.g. Wheao Fault, are also included along with their active fault attribute data.

East of the Mohaka Fault a zone of three important named active faults occurs. The Patoka, Rukumoana and Rangiora faults form a zone of NE-striking active faulting that splays from the Mohaka Fault near Willowford (Figure 4.1). The Patoka Fault strikes to the NE for c. 27 km to Te Pohue on State Highway 5. Paleoseismic studies of the Patoka Fault at Raumati Station reveal that it has produced at least 3 major earthquakes during the last 5000 years (Halliday, 2003; Langridge et al., unpublished data), indicating that it is RI Class I (RI <2000 years) (Figure 4.5). Based on the observation of c. 13 ± 2 m of dextral (right-lateral) offset on an incised stream at Raumati, the Patoka Fault has been assigned a slip rate of 2-3 mm/yr for the late Holocene (Langridge et al., unpublished data).

Farther to the northeast, the Rangiora Fault is named for its proximity to Rangiora Station on Heays Access Road. Paleoseismic studies of the Rangiora Fault near this station reveal that it is also RI Class I (Cutten et al., 1988; Van Dissen et al., 2003). The Rukumoana Fault links the Patoka and Rangiora faults, and has a length of c. 28 km (Lee et al., 2011). It has been designated as RI Class I based on its relationship with the Patoka and Rangiora faults.

Figure 4.5 A paleoseismic trench excavated across the Patoka Fault at Rangiora Station. Layers of peat, soil and volcanic tephra (Waimihia Tephra; bright buff) are folded and faulted. The main fault plane (blue-grey) was exposed in the bottom left of the photo. Three rupture events are recognised during the last 5000 years.

Table 4.1 Summary of major strike-slip faults in Hastings District.

Fault Name	Fault style	Single Event Displacement (m)	Net slip-rate (mm/yr)	Recurrence Interval (yr)†	RI Class	References
Mohaka	dextral	4 ± 1	3-4	<2000	I	Beanland (1995); Raub et al. (1987)
Ruahine	dextral	2 - 5	1-2	2000-3500	II	Beanland and Berryman (1987)
Waiohau	dextral	4 ± 1	1-2	2000-3500	II	Van Dissen et al. (2003)
Makaroro	dextral	ND	ND	3500-5000*	III	*this study
Patoka	dextral	4.3 ± 1	2-3	<2000	I	Halliday (2003); Langridge et al. (unpublished)
Rukumoana	dextral	ND	2-3*	<2000*	I	Lee et al. (2011)
Rangiora	dextral	5 ± 1	4-5	<2000	I	Cutten et al. (1988)
Kaweka	dextral	ND	ND	3500-5000†	III	Van Dissen et al. (2003)
Wheao/ Te Whaiiti	dextral	ND	ND	3500-5000†	III	*this study

Notes

* Preliminary result based on comparing the expression of similar, nearby faults.

† Recurrence interval based on RI Classes of Kerr et al (2003) and Van Dissen et al. (2003).

ND no data.

4.2 THE HAWKE'S BAY SYNCLINE MORPHOTECTONIC ZONE

Active reverse faulting is prevalent in the central, NE-trending corridor of Hastings District, southeast of the Axial Ranges and northwest of the Coastal Ranges (Figure 4.1).The district is traversed by several important zones of reverse faulting that extend north from Central Hawke's Bay District, including the Poukawa and Tukituki Fault Zones. These reverse faults typically extend for many tens of kilometres with a NNE-strike, parallel to the regional structural fabric of the Hikurangi subduction margin (e.g., Kelsey et al., 1995, 1998). Table 4.2 summarises the most important, named reverse fault systems in the district.

The second morphotectonic zone described in this study is called the Hawkes Bay Syncline. This zone is the northern continuation of the Ruataniwha Plains (to the south), however, there is a lack of major through-going active fault zones within it. Its western margin is characterised by the Patoka-Rukumoana-Rangiora fault system, which arguably propagates from the Axial Ranges into the Hawke's Bay Syncline (Figure 4.1).

The westernmost active reverse fault in Hastings District is the Big Hill Fault, which occurs in the Axial Ranges, near Kereru (Lee et al., 2011) (Figure 4.1, Figure 4.4). The c. 8 km long Big Hill Fault is an important splay of the Mohaka Fault. The fault is responsible for uplifting Big Hill (a small block of Mesozoic greywacke), through reverse and/or right-lateral movement, over Pliocene marine rocks (Erdman and Kelsey, 1992). Active traces have been observed along the Big Hill Fault (K. Berryman, personal communication, September 2015). We suggest a tentative recurrence interval of 5000-10,000 years for rupture of the Big Hill Fault (i.e. RI Class IV).

Table 4.2 Summary of the major reverse-slip faults in Hastings District. See Figure 4.1 for locations.

Fault Name	**Fault style**	**Recurrence Interval (yrs)**†	**Recurrence Interval Class (RI Class)**	**Net slip-rate (mm/yr)**	**References**
Big Hill	reverse	5000-10,000	IV	ND	NZAFD‡; Erdman and Kelsey (1992).
Te Heka FZ	reverse	3500-5000*	III	-	Langridge and Ries (2014)
Te Ranga FZ	reverse	3500-5000*	III	-	this study
Poukawa FZ	reverse	3500-5000	III	0.2-1	Kelsey et al. (1998); Langridge (unpublished data)
Awanui (1931)	reverse/ blind fault	5000-10,000	IV	0.2-0.4	Hull (1990); Kelsey et al. (1998)
Tukituki FZ	reverse/ thrust	3500-5000	III	0.2-0.4	Kelsey et al. (1998; unpublished data)
Ryans Ridge FZ	reverse	5000-10,000	IV	>0.1	Langridge and Ries (2014)

Notes

* Preliminary designation based on comparing the expression of similar, nearby faults.

† Recurrence interval based on RI Classes of Kerr et al (2003) and Van Dissen et al. (2003).

‡ NZAFD = New Zealand Active Fault Database.

In the south, two zones of reverse faulting extend into the district from Central Hawke's Bay District. These are called the Te Ranga and Te Heka Fault Zones (Langridge and Ries, 2014). In Hastings District the NNE-striking Te Heka Fault Zone extends for c. 10 km from the southern boundary of the district, west of the Raukawa Range. The recurrence interval class of the THFZ is not known from geological studies. In this case, based on its expression in the landscape and by a comparison to other similar active reverse fault systems in the region, we tentatively assign the THFZ to RI Class III (3500-5000 years). Similarly, the Te Ranga Fault Zone is characterised by only a few short active traces over a distance of c. 2.5 km to the northeast of Gwavas. Based on its expression in the landscape, those characteristics of the THFZ are also applied to the Te Ranga Fault Zone, i.e. active reverse faulting with a tentative classification as RI Class III.

To the west of Napier and within the Hawke's Bay Syncline Zone, a few semi-continuous fault traces have been mapped in the Seafield Road area, and are here named the Seafield Fault Zone (Figure 4.1). These faults are weakly expressed normal faults that cut across late Pliocene and early Quaternary marine rocks (Lee et al., 2011). . As such, we have assigned them a tentative RI Class V (10,000-20,000 years), as it is considered that they have probably moved once or twice since the last cold climate period in New Zealand.

4.3 POUKAWA - HERETAUNGA TROUGH MORPHOTECTONIC ZONE

The next morphotectonic zone to the east is here called the Poukawa-Heretaunga Trough (Figure 4.1; Cashman et al., 1992). This zone is also characterised by reverse faulting typified by the Poukawa and Tukituki Fault Zones (Kelsey et al., 1998; Langridge and Villamor, 2007).

The Poukawa Fault Zone (PFZ) is the northern extension of the reverse-slip Waipukurau-Poukawa Fault Zone which, including the Awanui Fault has a total length of c. 70 km from Hatuma (in Central Hawke's Bay District) to the Hawke Bay coast near Awatoto. The PFZ (as defined here) extends from the Tukituki River north of Waipukurau to the Awanui Fault, north of Poukawa. Within Hastings District the PFZ covers a length of c. 16 km.

The PFZ is characterised by a wide zone of generally west-dipping active reverse faults (typically a 1-2 km wide zone) with multiple, sub-parallel traces (Figure 4.6). The PFZ bounds the east side of the Raukawa Range and the western margin of the Poukawa Basin. Additional active traces are known within, and on the eastern margin of, the Poukawa Basin.

Kelsey et al. (1998) defined the northern, central and southern parts of the Poukawa Fault Zone based on geomorphology, paleoseismic trenching (Figure 4.7) and the occurrence of the M 7.8 February 3, 1931 Hawke's Bay earthquake and its rupture pattern. The northern part of the PFZ corresponds to the Awanui Fault (in this study), which ruptured in the 1931 earthquake (Hull 1990). Based on paleoseismic trenching along the central part of the PFZ, it has been assigned to Recurrence Interval Class III (>3500 to ≤5000 years) (Kelsey et al., 1998; Van Dissen et al., 2003).

The Awanui Fault is part of the main fault that was responsible for the 1931 Hawke's Bay earthquake. The Awanui Fault runs from Awanui Station in the southwest to the north toward Bridge Pa. The fault is not well known between Bridge Pa and Awatoto and is mapped as a concealed (blind) fault with an uncertain location. Re-levelling of the railway line network after the 1931 earthquake showed a northeast–trending line of zero uplift/subsidence which is broadly associated with the location of the Awanui Fault.

Figure 4.6 Geomorphic expression of the Poukawa Fault Zone at the southern edge of Hastings District, in the vicinity of Te Aute College. Three parallel zones of active reverse faulting are indicated by white arrows. State Highway 2 is at right (Photograph: D. Townsend, GNS Science).

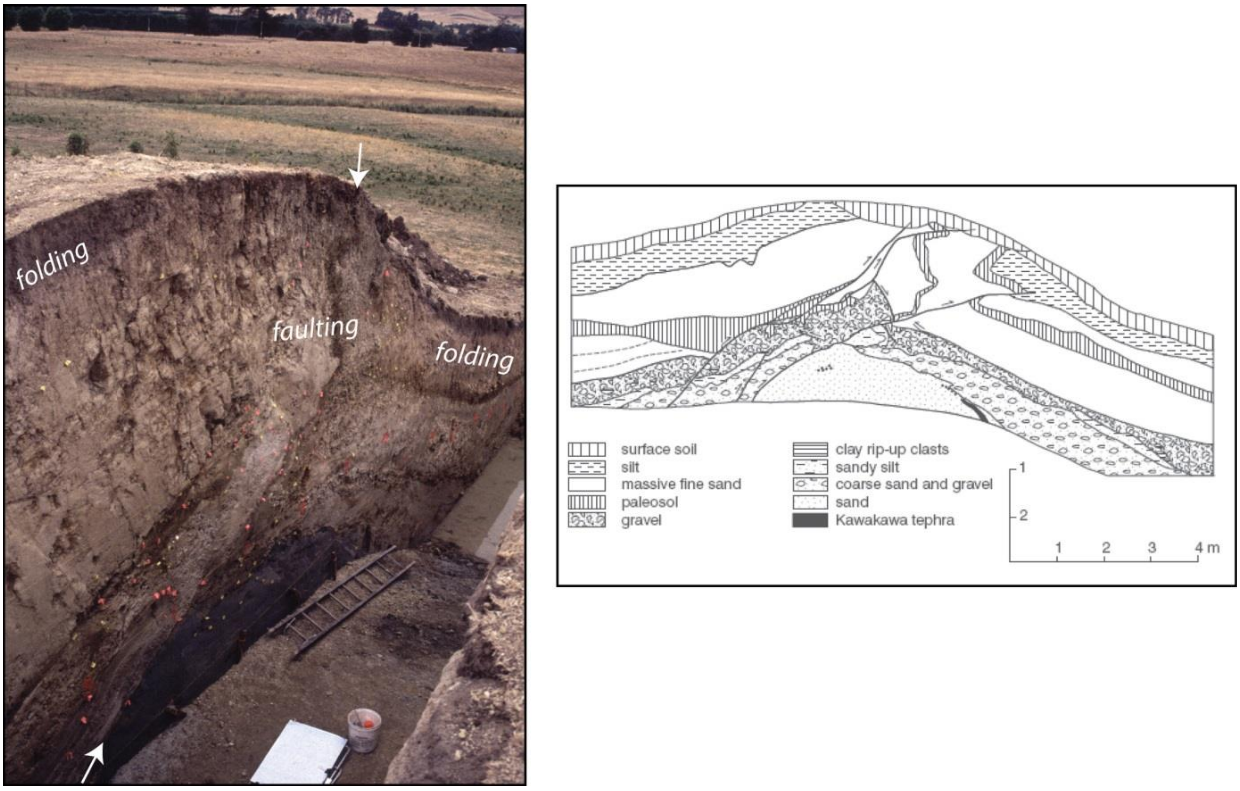


Figure 4.7 A paleoseismic trench excavated across the Poukawa Fault Zone (North wall of Poukawa trench of Kelsey et al. 1998). A. The fault scarp is expressed as a broad fold with a steep forelimb and crest. Ground surface rupture caused by the February 3 1931 Hawke’s Bay earthquake occurred here toward the crest of the scarp (marked by white arrows). B. Geologic log that documents the faulting and folding of units.

The location of this buried trace was re-assessed using a LiDAR DEM and included in the NZAFD (Langridge et al., 2011; in press). In contrast, reverse faults in the northern part of the PFZ near Poukawa and Pakipaki ruptured to the ground surface during the 1931 earthquake (Figure 4.7). These surface ruptures were documented by Hull (1990) and were confirmed in trench excavations across two of those traces (Kelsey et al., 1998). Paleoseismic studies also found that the northern part of the PFZ (Awanui Fault) has a longer recurrence interval - on the order of 7000-12,000 years - compared to the central and southern parts. Based on this data, we have assigned the Awanui Fault to RI Class IV (>5000-≤10,000 years).

The Tukituki Fault Zone (TFZ) occurs to the east of the Poukawa Fault Zone (Figure 4.1). Like the PFZ, the TFZ runs from Central Hawke's Bay District into Hastings District with a total length of c. 36 km. Within Hastings District the fault is first identified at the Tukituki River near Pukekura Station on Middle Road. The TFZ continues north along the eastern side of the Kaokaoroa Range to the Wharehau and Glenrae stations area (Figure 4.8). Here the TFZ comprises two active traces, one at the rangefront and one within the small Middle Road 'valley' (Figure 4.8). North of this valley the TFZ emerges at the southern end of the Heretaunga Plains at Mutiny Road, where it is recognised by a prominent NNE-striking fault scarp across faulted alluvial surfaces. This scarp continues to be mappable on LiDAR as far north as Crystal Road.

A paleoseismic trench excavated across the TFZ in this area (Figure 4.9) confirmed that it is an active zone of reverse faulting with a low slip rate and probable RI Class III (>3500-≤5000 years; Van Dissen et al., 2003).

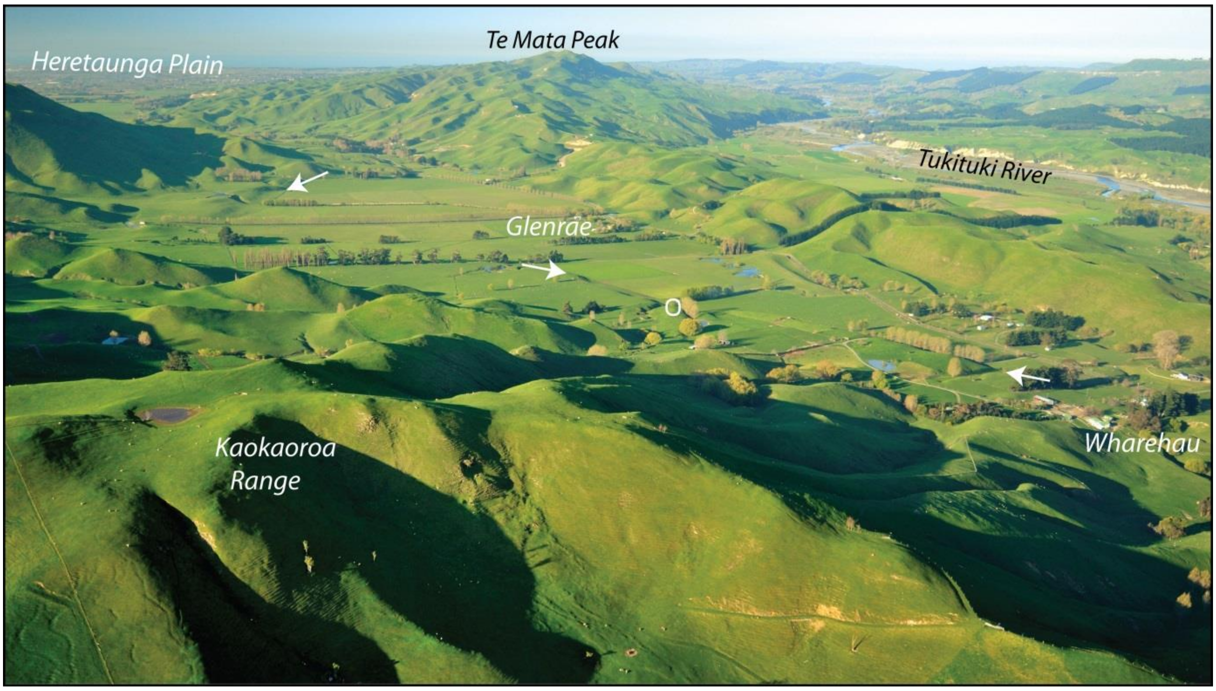


Figure 4.8 View to the north of the Middle Road 'valley' between the Kaokaoroa and Te Mata Peak (Kohinurakau Range), southeast of Hastings. White arrows mark reverse fault scarps of the active Tukituki Fault Zone, which uplifts the Kaokaoroa Range (at left). White circle at middle of photo indicates the trench site highlighted in Figure 4.9. (Photograph: D. Townsend, GNS Science).

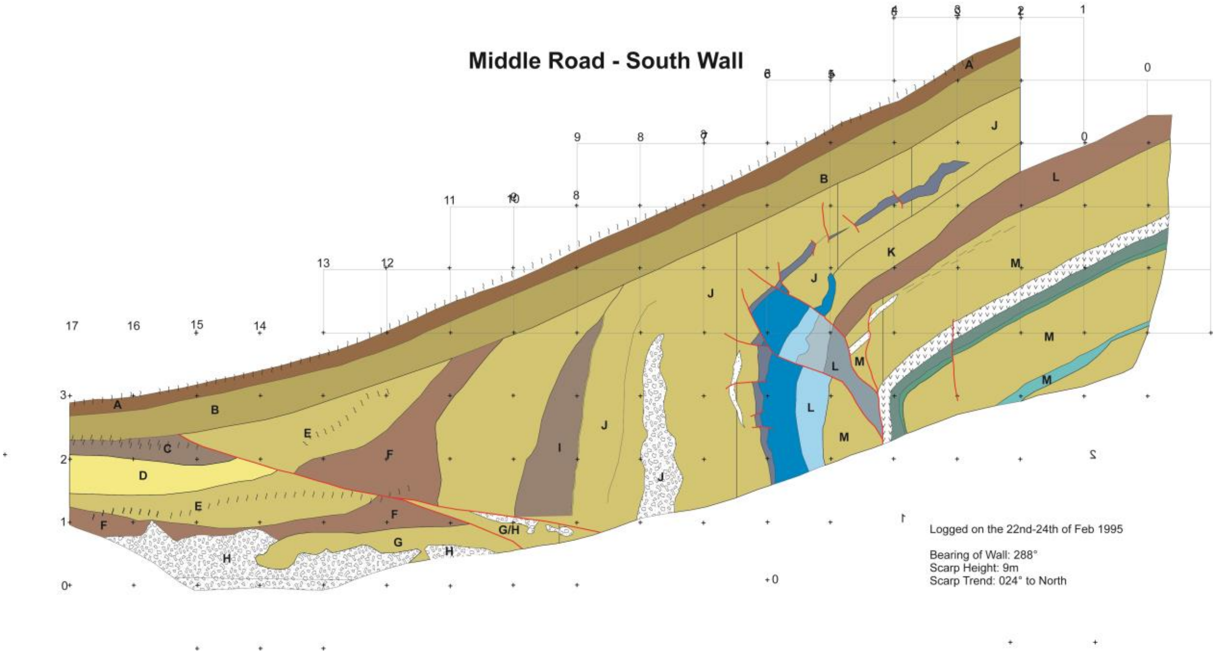


Figure 4.9 Paleoseismic trench log from the Tukituki Fault Zone near Middle Road. The log shows a low-angle thrust fault plane (red line at left) and intense folding and faulting associated with the hangingwall block of the fault (at right). The white unit exposed within the M facies is a prominent volcanic ash unit; the Kawakawa Tephra. Four paleosols (buried soils; brown units) and a modern soil indicate the possible number of faulting events (Source: log from H. Kelsey et al., unpublished data held at GNS Science).

Two short traces that have been associated with the Ryans Ridge Fault Zone have been mapped near the southern boundary of the Hastings District near Somersby Station. The Ryans Ridge Fault Zone is more extensively mapped in Central Hawke's Bay District to the south (Figure 4.1). Based on a comparison to other similar fault zones in Central Hawke's Bay District (described above) the Ryans Ridge Fault Zone is tentatively assigned to RI Class IV (>5000-≤10,000 years).

4.4 NORMAL FAULTING AND THE COASTAL RANGES MORPHOTECTONIC ZONE

Active normal faulting is prevalent in the southeastern part of Hastings District, within the Coastal Ranges morphotectonic zone (Figure 4.1). The Coastal Ranges are traversed by a myriad of short to discontinuous NNE-striking zones of normal faulting that extend north from Central Hawke's Bay District (e.g., Cashman et al., 1995; Kelsey et al., 1995). One additional normal fault of note – the Gwavas Fault – occurs in the west within the Axial Ranges morphotectonic zone (Langridge et al., 2013).

As part of this study, few reverse faults have been positively identified within the Coastal Ranges morphotectonic zone. Some active traces are designated as being associated with the Elsthorpe Anticline and are mapped around the western margin of the Maraetotara Plateau. The linework for the Elsthorpe Anticline is adopted from the QMAP Hawke's Bay geologic sheet and the NZAFD. We suggest a tentative recurrence interval for the Elsthorpe Anticline of 5000-10,000 years (i.e. RI Class IV), based on data sourced from the NZAFD and published papers (Cashman and Kelsey, 1990; Cashman et al., 1992).

The Gwavas Fault is a c. 5 km long active fault mapped adjacent to (east of) the Mohaka Fault in the Gwavas Forest area in the southwest part of the district. The fault can clearly be mapped on LiDAR and has a prominent uphill-facing scarp (Figure 4.10). This mapping also indicates little to no strike-slip displacement on the fault. Field studies identified an east-facing fault scarp in a forest road, which was chosen as a site to excavate a paleoseismic trench (Figure 4.10;

Langridge et al., 2013). The trench exposed a sequence of tephra- or volcanic ash-rich sediments overlying alluvial gravels. These sediments were progressively faulted and indicated up to 7 faulting events during the last 10,000-14,000 years. These results imply a recurrence interval that is c. 2000 years. In this case, we assign the Gwavas Fault to RI Class I (≤2000 years). The documented activity of the Gwavas Fault highlights that splays of the major Axial Ranges faults like the Mohaka Fault, are active and supports the assertion that other splay faults like the reverse-slip Big Hill Fault are also currently active.

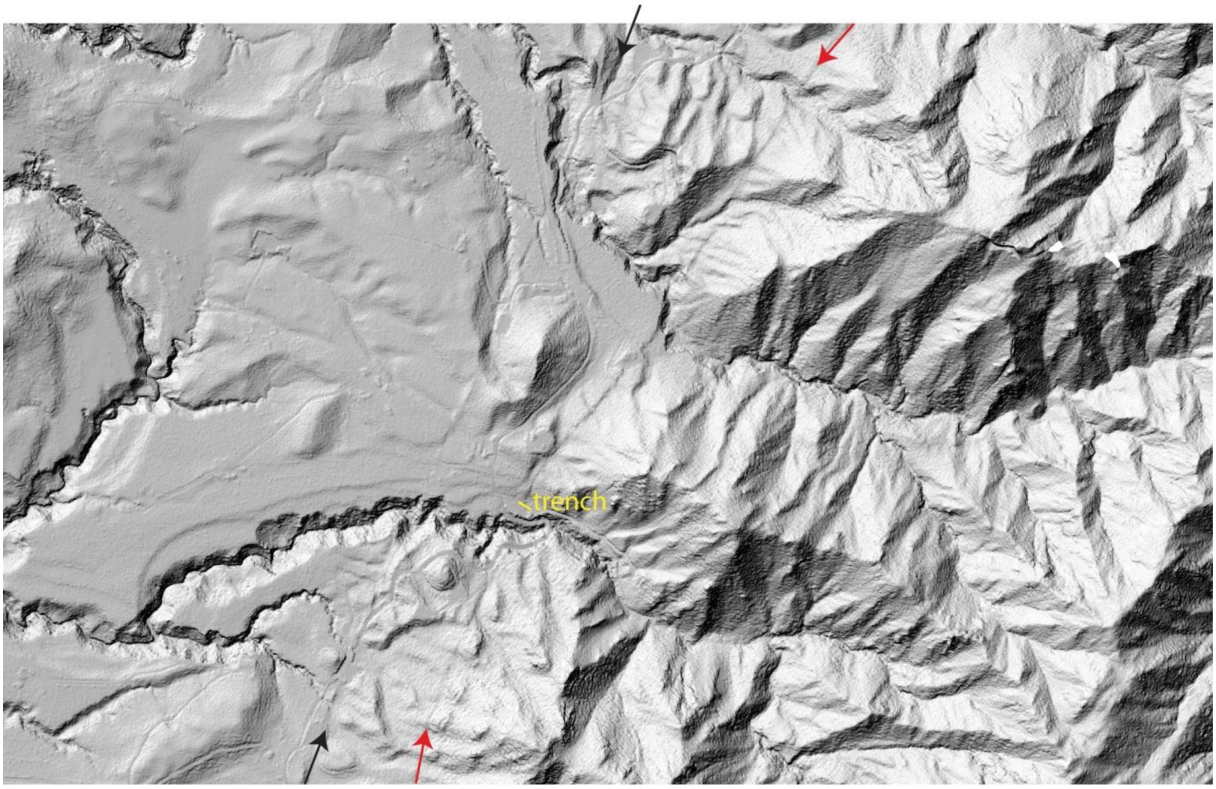


Figure 4.10 LiDAR hillshade image of the Gwavas Fault (red arrows) and Mohaka Fault (black arrows) as seen in the Gwavas Forest. The Gwavas Fault was trenched to determine its earthquake history and recurrence interval.

4.4.1 Mapping normal faults in the Coastal Ranges

One of the goals of this study is to provide better map coverage of the dense array of normal faults in the Coastal Ranges zone. The following section provides background on these normal faults and the rationale behind how we have approached this area.

A characteristic of the high coastal ranges of Hawke's Bay, which are up to 300 m above sea level between Cape Kidnappers and across the Maraetotara Plateau, is a concentration of active, NNE-striking normal faults (Pettinga, 1982; 2004). These were mapped in detail for a doctoral thesis (Pettinga 1980). The area was also investigated and mapped during the 1990's as part of regional tectonic studies (Cashman and Kelsey, 1990; Cashman et al., 1992). These data were uptaken into the NZAFD when it was first assembled in the early 2000's (Figure 4.11).

Prior to this study, in the area of the Coastal Ranges, there was a difference in the portrayal of active normal faults between the NZAFD and the QMAP active fault coverage (Lee et al., 2011) (see Figure 1.1; Figure 4.11). In this study, we recognise many zones of discontinuous active normal faulting. The QMAP Hawke's Bay geologic map (Lee et al., 2011) shows only a few, representative active fault traces in the coastal and northeastern parts of the district while the NZAFD includes many short, parallel normal fault traces mapped by Pettinga (1982).

Figure 4.11 Grouping and naming of active fault traces in the Coastal Ranges morphotectonic zone. All of the mapped zones (except the Elsthorpe Anticline) are related to normal faulting.

Our strategy has been to map the northern and southern parts of the Coastal Ranges in two distinct ways. The northern part of the Coastal Ranges has LiDAR coverage for which a 1-m DEM and hillshade model have been developed. In this area, fault traces have been mapped with some accuracy, where surface traces and/or scarps can be recognised. In contrast, in the southern part of the Coastal Ranges where no LiDAR data exists, we have chosen to review the active fault traces previously shown in the NZAFD with the aid of a national scale 10-m DEM and a georeferenced orthophotograph basemap. In practice, the 10-m DTM and orthophotograph have been used at a scale of c. 1:20,000 onscreen to review pre-existing fault linework. However, this is not meant to imply a high level of precision for the linework and is also reflective of a lack of data concerning the repeated late Quaternary activity of these faults. Because of this, we treat most of the fault traces in the southern Coastal Ranges (southern Maraetotara Plateau) area as ‘Uncertain’ in terms of fault location accuracy.

In future, when better topographic coverage such as LiDAR is available it will be possible to review the southern Coastal Ranges area in order to better locate active faults.

Recent LiDAR acquisitions covering the Hawke’s Bay coastline and the Cape Kidnappers to Maraetotara area have been useful for identifying normal fault traces in these areas. For the northern part of the Coastal Ranges we assigned names for a series of collected normal fault traces in parts of the Coastal Ranges zone. These include the Parkhill (Langridge, 2007), Craggy Range, Maraetuna, Kidnappers, Waiana, Summerlee, Longacre, Te Awanga and Te Mata Fault Zones (Figure 4.11; Table 4.3). In the southern part of the Coastal Ranges, the term ‘Maraetotara Fault Zone’ is applied to most of the normal faults identified in that area.

Mapping of faults suggests a fanning of active fault traces viewed from south to north toward the Hawke Bay coast (Figure 4.11). While zones of faults appear to not be contiguous with one another there are some obvious geographical relationships. For example, the Waiana, Te Awanga and Parkhill Fault Zones (Figure 4.12) span the northwestern side of the Kidnappers area and appear to fan out from the Longacre Fault Zone, while the Summerlee, Craggy Range, Maraetuna and Kidnappers Fault Zones fan away toward the southeast, as linear arrays of NNE-striking normal faults.

Two outcomes of mapping using LiDAR data have been an increase in the accuracy of fault trace mapping (i.e. where faults are clearly mapped) and a decrease in the number, density and continuity of faults compared to previous maps (Pettinga 1982).

Figure 4.12 View to the south across the northern end of the Kidnappers-Te Awanga area. Pairs of arrows highlight active normal fault traces of the Te Awanga (red), Waiana (white), and Summerlee (black) Fault Zones

4.4.2 Recurrence interval of faulting in the Coastal Ranges

Following the work of Cashman and Kelsey (1990), we suggest three possible reasons for the presence of ground surface-rupturing normal faults in the Coastal Ranges area: (i) they are seismogenic normal faults that are cutting and extending the upper crust; (ii) they are normal faults formed in the hangingwall of reverse faults that occur onshore and offshore of the area; or (iii) these faults are related to extension and gravitational collapse of high-standing topography, which is itself driven by rapid anticlinal uplift of the Coastal Ranges (Figure 4.11). Regardless of the mechanism we assert that in all cases, it would be pertinent to consider these faults as ground surface-rupturing faults.

The recurrence intervals for these normal faults are not well known due to a lack of investigation (Table 4.3). Trenching at Parkhill subdivision near Haumoana showed evidence for repeated movements during the last c. 15,000 years (Figure 4.13) with a recurrence interval for surface faulting in the range 5000-10,000 years across the zone of normal faulting there (Langridge, 2007). This is a reasonable basis for considering the activity of normal faults throughout the Coastal Ranges of Hastings District and therefore we assign all of these zones to RI Class IV (>5000-≤10,000 years).

Table 4.3 Summary of the major normal faults and fault zones in Hastings District.

Fault Name	Fault style	Recurrence Interval (yr)	RI Class	References
Gwavas Fault	normal	<2000	I	Langridge et al. (2013)
(northern) Coastal Range faults*	normal	5000-10,000†	IV	Langridge (2007); this study
(southern) Maraetotara Fault Zone	normal	5000-10,000	IV	Langridge and Villamor (2007); this study
Seafield Fault Zone	normal	10,000-20,000	V	this study

Notes

* includes the Silver Range, Parkhill, Craggy Range, Maraetuna, Kidnappers, Waiana, Summerlee, Longacre, Te Awanga and Te Mata Fault Zones.

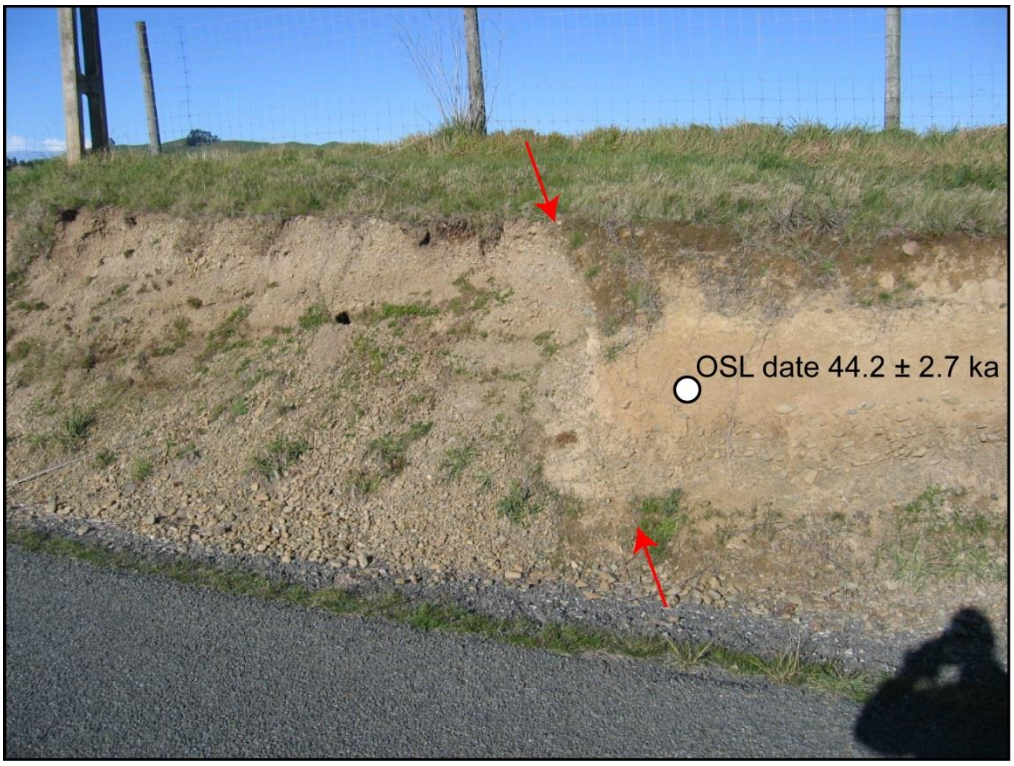


Figure 4.13 An active normal fault exposed in a former roadcut on Parkhill Road, Parkhill Fault Zone. Motion on this fault is down-to-the-northwest juxtaposing silty deposits (at right) against coarse, rounded gravels.

5.0 CASE STUDIES OF USING FAULT AVOIDANCE ZONES FOR PLANNING

Here we provide hypothetical examples of how a council can make sound planning decisions using the Fault Avoidance Zones developed in this study. The purpose of these examples is to show that there is a certain amount of flexibility within the structure of the MfE Guidelines in order to make sensible, informed, risk-based planning decisions. The examples are accompanied by a series of resource consent tables.

5.1 BUILDING IMPORTANCE CLASS

A component of the Resource Consent tables is the Building Importance Category (BIC). The BIC's relate directly to the NZ Building Code and are divided into BIC I (unoccupied structures) through BIC 4 (critical structures) (Table 5.1). BIC 2a and BIC 2b typically distinguish single storey homes from larger normal structures, respectively. A broader description of BIC categories is given by Kerr et al. (2003). Section 5 provides examples of Resource Consent tables for various RI Class faults, Fault Complexity, Building Importance (BIC) and current land use (e.g. developed or Greenfield settings).

Table 5.1 Building Importance Categories and representative examples. For more detail see Kerr et al. (2003), and King et al. (2003).

Building Importance Category	Description	Examples
1	**Temporary structures** with low hazard to life and other property	• Structures with a floor area of $<30m^2$ • Farm buildings, fences • Towers in rural situations
2a	**Timber-framed** residential construction	• Timber framed single-story dwellings
2b	**Normal structures** and structures not in other categories	• Timber framed houses with area $>300\ m^2$ • Houses outside the scope of NZS 3604 "Timber Framed Buildings" • Multi-occupancy residential, commercial, and industrial buildings accommodating <5000 people and $<10{,}000\ m^2$ • Public assembly buildings, theatres and cinemas $<1000\ m^2$ • Car parking buildings
3	**Important structures** that may contain people in crowds or contents of high value to the community or pose risks to people in crowds	• Emergency medical and other emergency facilities not designated as critical post disaster facilities • Airport terminals, principal railway stations, schools • Structures accommodating >5000 people • Public assembly buildings $>1000\ m^2$ • Covered malls $>10{,}000\ m^2$ • Museums and art galleries $>1000\ m^2$ • Municipal buildings • Grandstands >10,000 people • Service stations • Chemical storage facilities $>500m^2$
4	**Critical structures** with special post disaster functions	• Major infrastructure facilities • Air traffic control installations • Designated civilian emergency centres, medical emergency facilities, emergency vehicle garages, fire and police stations

5.2 RI CLASS I FAULT AND FARM RE-DEVELOPMENT

In the first case, a family who own the Hawkston Station on Puketitiri Road wish to improve the already developed dairy milking shed site (double its capacity). The milking shed is within the Fault Avoidance Zone for the Mohaka Fault, the most active onland fault in Hawke's Bay and RI Class I (≤2000 years). However, because the building is a farm shed and not occupied for living the activity is 'Permitted' (Table 5.1). The family also wish to build a new farm workers house (BIC 2a structure) about 400 m SSW of the milking shed. The house site is Greenfield and is also located within the Fault Avoidance Zone for the Mohaka Fault. In this area the fault location is also defined as 'Uncertain', so this activity would be '*Discretionary*' (note the use of *italics*; Table 5.1). In this case a council would have more flexibility around its planning solution. One option for a council would be to ask the family to provide more certainty regarding the location of the fault with respect to the house site by undertaking some surveying or geologic mapping studies, or simply to suggest that the house site be moved outside of the Fault Avoidance Zone.

Table 5.2 Examples, based on the MfE Active Fault Guidelines, of Resource Consent Category for both developed and/or already subdivided sites, and Greenfield sites along RI Class I faults. Categories account for various combinations of Building Importance Category and Fault Complexity.

Example Resource Consent categories for Class I faults (RI ≤2000 years): e.g. Mohaka, Gwavas, Patoka, Rangiora, Rukumoana faults					
Developed and/or Already Subdivided Sites					
Building Importance Category	**1**	**2a**	**2b**	**3**	**4**
Fault Complexity	**Resource Consent Category**				
Well Defined	Permitted	Non-Complying	*Non-Complying*	*Non-Complying*	Non-Complying
Distributed	Permitted	Discretionary	*Non-Complying*	*Non-Complying*	Non-Complying
Uncertain	Permitted	Discretionary	*Non-Complying*	*Non-Complying*	Non-Complying
Greenfield Sites					
Building Importance Category	**1**	**2a**	**2b**	**3**	**4**
Fault Complexity	**Resource Consent Category**				
Well Defined	Permitted	*Non-Complying*	*Non-Complying*	*Non-Complying*	Prohibited
Distributed	Permitted	*Discretionary*	*Non-Complying*	*Non-Complying*	Non-Complying
Uncertain	Permitted	*Discretionary*	*Non-Complying*	*Non-Complying*	Non-Complying

Notes

* Indicates that the Resource Consent Category is permitted, but could be Controlled or Discretionary given that the fault location is well defined.

Italics: The use of italics indicates that the Resource Consent Category – activity status of these categories is more flexible. For example, where Discretionary is indicated, Controlled may be considered more suitable by Council, or vice versa.

5.3 RI CLASS II FAULT AND BIC 2A STRUCTURE

In this case, a farming family that lives at the foot of the Ruahine Range at Matapuna Station wants to build a new hunting hut (BIC 2a structure) within a Fault Avoidance Zone along the Ruahine Fault (a RI Class II fault). At their 'greenfield' hut site in the bush the fault is 'Well-Defined' because of LiDAR coverage and the Resource Consent Category would be '*Non-Complying*' (see Table 5.2). Again, in this case a council would have more flexibility around its planning solution. For example, it could be that such a structure is only occupied on rare occasions so that the likelihood of occupancy during a displacement event is relatively low.

Table 5.3 Examples, based on the MfE Active Fault Guidelines, of Resource Consent Category for both developed and/or already subdivided sites, and Greenfield sites along RI Class II faults. Categories account for various combinations of Building Importance Category and Fault Complexity.

Example Resource Consent categories for Class II faults (RI >2000 to ≤3500 years): e.g., Ruahine and Waiohau faults					
Developed and/or Already Subdivided Sites					
Building Importance Category	**1**	**2a**	**2b**	**3**	**4**
Fault Complexity	**Resource Consent Category**				
Well Defined	Permitted	Permitted*	*Non-Complying*	*Non-Complying*	Non-Complying
Distributed	Permitted	Permitted	*Discretionary*	*Non-Complying*	Non-Complying
Uncertain	Permitted	Permitted	*Discretionary*	*Non-Complying*	Non-Complying
Greenfield Sites					
Building Importance Category	**1**	**2a**	**2b**	**3**	**4**
Fault Complexity	**Resource Consent Category**				
Well Defined	Permitted	*Non-Complying*	*Non-Complying*	*Non-Complying*	Prohibited
Distributed	Permitted	*Discretionary*	*Non-Complying*	*Non-Complying*	Non-Complying
Uncertain	Permitted	*Discretionary*	*Non-Complying*	*Non-Complying*	Non-Complying

Notes

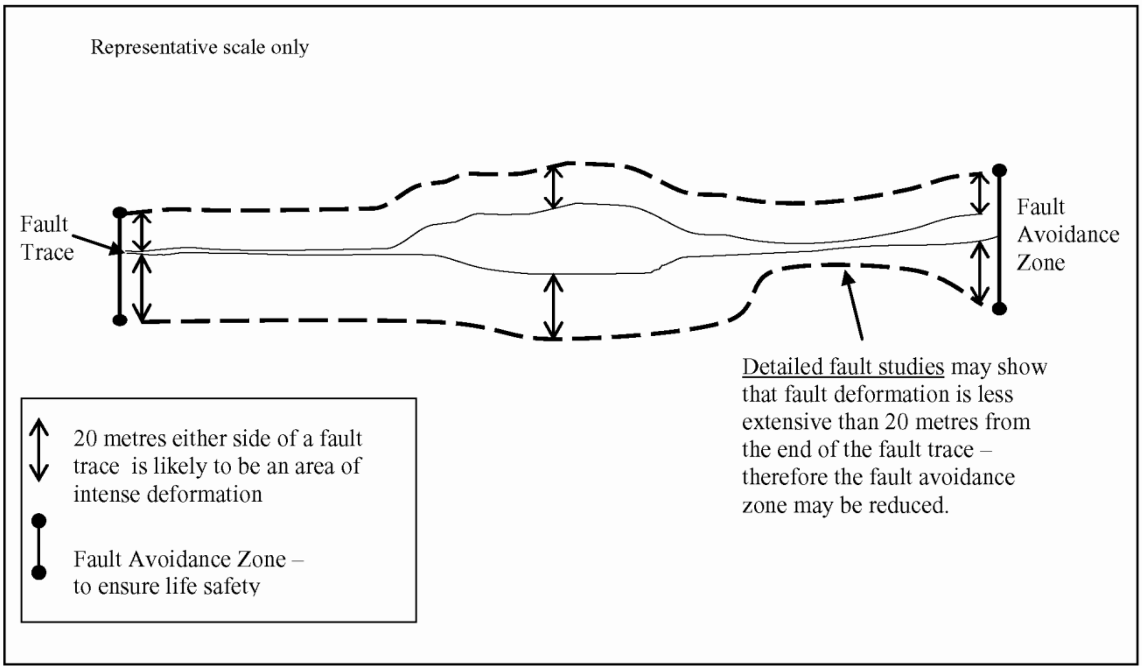
* Indicates that the Resource Consent Category is permitted, but could be Controlled or Discretionary given that the fault location is well defined.

Italics: The use of italics indicates that the Resource Consent Category – activity status of these categories is more flexible. For example, where Discretionary is indicated, Controlled may be considered more suitable by Council, or vice versa.

5.4 RI CLASS III FAULT AND BIC 2B/3 STRUCTURE

As a third example, the community of Te Hauke decide that they want to build a new Community Hall in an area that is within the Fault Avoidance Zone for the Poukawa Fault Zone, a RI Class III fault (Table 5.3). The land is ‘already developed’ or zoned, the fault location is ‘Well-Defined’ because the fault has been mapped on airborne LiDAR in this area. The BIC Category for the hall is either BIC 2b or 3. The Resource Consent Category for such a building would be Permitted* or ‘*Non-Complying’*, respectively. The purpose of the asterisk within the MfE Guidelines table is that a council has the proviso to make an informed decision if the building site is clearly straddling a fault trace or fault scarp. If however, the site was in an area where the fault complexity was defined as Distributed (= uncertain location on LiDAR), then the Resource Consent Category would be ‘Permitted’. Nonetheless, a sensible outcome would be to have the building site set back beyond the Fault Avoidance Zone, where the chances of surface deformation during a fault movement are low. Geologic studies or surveying could be undertaken by the community to consider a reduction in the width of the Fault Avoidance Zone supplied here (Figure 5.1).

The most practical solution would be to build the hall outside of the Fault Avoidance Zone. However, additional geological studies may identify that the new site is in a more distributed zone of deformation, in which case the Activity Status could change to either Permitted or *Discretionary*, respectively. In such cases, the Council can use its discretion considering the occupancy (numbers) or frequency of occupancy of persons in such a building.



Detailed fault studies may show that fault deformation is less extensive than 20 metres from the end of the fault trace – therefore the fault avoidance zone may be reduced.

Figure 5.1 A Fault Avoidance Zone on a district planning map. As noted in the lower right, where detailed fault studies have been undertaken it is possible to reduce the original mapped width of a given Fault Avoidance Zone. From Kerr et al. (2003).

Table 5.4 Examples, based on the MfE Active Fault Guidelines, of Resource Consent Category for both developed and/or already subdivided sites, and Greenfield sites along RI Class III faults. Categories account for various combinations of Building Importance Category and Fault Complexity.

Example Resource Consent categories for Class III faults (>3500 to ≤5000 years) e.g., Kaweka, Wheao, and Te Whaiti faults; Poukawa and Tukituki Fault Zones					
Developed and/or Already Subdivided Sites					
Building Importance Category	**1**	**2a**	**2b**	**3**	**4**
Fault Complexity	**Resource Consent Category**				
Well Defined	Permitted	Permitted*	Permitted*	*Non-Complying*	Non-Complying
Distributed	Permitted	Permitted	Permitted	*Discretionary*	Non-Complying
Uncertain	Permitted	Permitted	Permitted	*Discretionary*	Non-Complying
Greenfield Sites					
Building Importance Category	**1**	**2a**	**2b**	**3**	**4**
Fault Complexity	**Resource Consent Category**				
Well Defined	Permitted	Permitted*	*Non-Complying*	*Non-Complying*	Non-Complying
Distributed	Permitted	Permitted	*Discretionary*	*Discretionary*	Non-Complying
Uncertain	Permitted	Permitted	*Discretionary*	*Discretionary*	Non-Complying

Notes

* Indicates that the Resource Consent Category is permitted, but could be Controlled or Discretionary given that the fault location is well defined.

Italics: The use of italics indicates that the Resource Consent Category – activity status of these categories is more flexible. For example, where Discretionary is indicated, Controlled may be considered more suitable by Council, or vice versa.

Surveying, in conjunction with geology, can provide more certainty about the location of the fault in a cadastral or geodetic framework, thus reducing the width of a Fault Avoidance Zone. A good example of the benefit of surveying is where we have very wide Fault Avoidance Zones derived from the 10-m DEM, NZAFD or QMAP linework, where the uncertainty on fault location is ±125 m. In such a case, accurate mapping or surveying could better define the actual fault location and narrow the Fault Avoidance Zone width.

5.5 RI CLASS IV FAULT AND A HOUSING DEVELOPMENT BIC 2A/2B STRUCTURES

In this case, a developer wants to create a lifestyle housing block near the coast in the hills above Te Awanga (see Langridge, 2007). Some of the Greenfield house sites will have BIC 2a structures and some are planned to have BIC 2b structures. Some of these sites are located within Fault Avoidance Zones for the Te Awanga Fault Zone, which is a RI Class IV fault system (RI >5000-≤10,000 years). All of the mapped traces are 'Well-defined' from LiDAR. For both BIC 2a and 2b house structures near these faults, the Consent Category is Permitted*. Again, the council has some flexibility about how it can define its planning and consent outcomes in such a case.

In a situation where the amount of available land for a building site - before or after a Fault Avoidance Zone has been set - is limited, a developer or homeowner can undertake further geological studies or surveying to better document the location of the fault and therefore the likely zone of fault deformation. These fault studies (see Figure 5.1) could include detailed mapping of fault traces and scarps, trench excavation of the fault to locate deformation (or constrain undeformed ground), and surveying the fault to provide better locational accuracy. In addition, in a case where the recurrence interval is poorly constrained or preliminary, it may be advantageous to undertake paleoseismic studies that can better constrain the timing or regularity of past events. Such studies would require excavation and geologic dating of deposits with a view toward dating earthquakes, or alternatively, using the slip rate to define the recurrence interval. With a better estimate of the recurrence interval, more appropriate decisions regarding the BIC can be made.

Table 5.5 Examples, based on the MfE Active Fault Guidelines, of Resource Consent Category for both developed and/or already subdivided sites, and Greenfield sites along RI Class IV faults. Categories account for various combinations of Building Importance Category and Fault Complexity.

Example Resource Consent categories for Class IV faults (>5000 to ≤10,000 years) **e.g., Awanui Fault; Te Heka and Te Renga Fault Zones; fault zones within the Coastal Ranges**					
Developed and/or Already Subdivided Sites					
Building Importance Category	**1**	**2a**	**2b**	**3**	**4**
Fault Complexity	**Resource Consent Category**				
Well Defined	Permitted	Permitted*	Permitted*	Permitted*	Non-Complying
Distributed	Permitted	Permitted	Permitted	Permitted	Non-Complying
Uncertain	Permitted	Permitted	Permitted	Permitted	Non-Complying
Greenfield Sites					
Building Importance Category	**1**	**2a**	**2b**	**3**	**4**
Fault Complexity	**Resource Consent Category**				
Well Defined	Permitted	Permitted*	Permitted*	*Non-Complying*	Non-Complying
Distributed	Permitted	Permitted	Permitted	*Discretionary*	Non-Complying
Uncertain	Permitted	Permitted	Permitted	*Discretionary*	Non-Complying

Notes

* Indicates that the Resource Consent Category is permitted, but could be Controlled or Discretionary given that the fault location is well defined.

Italics: The use of italics indicates that the Resource Consent Category – activity status of these categories is more flexible. For example, where Discretionary is indicated, Controlled may be considered more suitable by Council, or vice versa.

5.6 RI CLASS V FAULT

In the case of a RI Class V fault (RI >10,000-≤20,000 years, such as those that are part of the Seafield Fault Zone the only activities that are not defined as 'Permitted' or 'Permitted*' are for buildings of BIC Class 4 (Table 5.5). This recognises that the likelihood of a ground-surface rupturing event occurring on a RI Class V fault is very low (though still exists).

Table 5.6 Examples, based on the MfE Active Fault Guidelines, of Resource Consent Category for both developed and/or already subdivided sites, and Greenfield sites along RI Class V faults. Categories account for various combinations of Building Importance Category and Fault Complexity.

Example Resource Consent categories for Seafield Fault Zone: Fault Recurrence Interval Class V (>10,000 to ≤20,000 years)					
Developed and/or Already Subdivided Sites					
Building Importance Category	**1**	**2a**	**2b**	**3**	**4**
Fault Complexity	**Resource Consent Category**				
Well Defined	Permitted	Permitted*	Permitted*	Permitted*	Non-Complying
Distributed	Permitted	Permitted	Permitted	Permitted	Non-Complying
Uncertain	Permitted	Permitted	Permitted	Permitted	Non-Complying
Greenfield Sites					
Building Importance Category	**1**	**2a**	**2b**	**3**	**4**
Fault Complexity	**Resource Consent Category**				
Well Defined	Permitted	Permitted*	Permitted*	Permitted*	Non-Complying
Distributed	Permitted	Permitted	Permitted	Permitted	Non-Complying
Uncertain	Permitted	Permitted	Permitted	Permitted	Non-Complying

Notes

* Indicates that the Resource Consent Category is permitted, but could be Controlled or Discretionary given that the fault location is well defined.

Italics: The use of italics indicates that the Resource Consent Category – activity status of these categories is more flexible. For example, where Discretionary is indicated, Controlled may be considered more suitable by Council, or vice versa.

6.0 SUMMARY

- Active fault traces have been mapped in a GIS database across Hastings District using LiDAR digital hillshade models, a national scale 10-m DEM and orthophotograph basemap, QMAP active fault linework and the NZAFD. This work builds on and supersedes previous fault linework and avoidance zones by Langridge and Villamor (2007). In this report, Fault Avoidance Zones and GIS attributes, including Fault Name, Locational Accuracy, and Recurrence Interval Class are presented along with the active fault linework.
- Fault Avoidance Zones have been defined based on the faults' Location Uncertainty, which depends on the accuracy of mapping, and an additional setback zone in accordance with the MfE Guidelines. Where LiDAR is available, faults have been mapped as either accurate (±10 m), approximate (±25 m), or uncertain (±40 m) in terms of their fault location accuracy. QMAP and NZAFD linework are typically less accurate and have been assigned ±125 m accuracy or uncertainty. A margin of safety (setback) buffer of +20 m is added around each fault location buffer.
- Fault Avoidance Zones range in width from 60 m for accurate (Well-Defined) strike-slip and normal faults, to 290 m for 'Approximately' located QMAP active strike-slip and normal faults using 1:250,000 scale QMAP linework.
- For reverse faults, the fault Location Uncertainty has been doubled on the hangingwall side of the fault to reflect the likelihood of increased/distributed deformation on that side of the fault. Thus for the examples shown in the preceding statement, the minimum and maximum Fault Avoidance Zone widths increase to 70 m and 415 m, respectively.
- Recurrence intervals for surface faulting have been defined for many of the named faults and fault zones with Hastings District. There are several RI Class I faults (e.g. Mohaka, Patoka faults) and RI Class II faults (Ruahine, Waiohau faults) in the district. Faults with RI Class III (>3500 to ≤5000 yr) and RI Class IV (>5000 to ≤10,000 yr) are the most common classes in the district.
- Example Resource Consent Activity tables have been provided with the report to aid councils in the consent process. These tables provide guidance with respect to different land use and building types.

7.0 RECOMMENDATIONS

- We recommend that the fault linework and Fault Avoidance Zones presented as digital geospatial data be adopted by Hastings District Council, and should supersede previous versions of active fault linework, attributes and Fault Avoidance Zones provided by GNS Report 2007-145 (Langridge and Villamor, 2007) and other studies.
- We recommend that the MfE Guidelines regarding active faulting should continue to be used as standard practice for planning and consenting in Hastings District, and as per the ‘Hawke’s Bay Joint Hazard Strategy for Local Authority Land Use Planning’ (Plan #4397) that these fault traces be incorporated within District Plan maps where possible, or within Council GIS databases, in order to set rules for setback distances from active faults, or require proof of consideration of active fault guidelines.
- We also recommend that active fault linework and Fault Avoidance Zones should be updated every decade. Nevertheless it could also be reviewed every 5 years if appropriate new LiDAR coverage becomes available. This is particularly true for areas that are undergoing more rapid land use change, and others such as the southern Maraetotara Plateau area where there are many poorly-defined active fault traces.

8.0 ACKNOWLEDGEMENTS

We wish to thank the Hawke's Bay Regional Council for continuing to acquire high-quality airborne LiDAR and for freely making it available for use for active fault mapping projects. We also wish to thank Jamie Howarth and Nicola Litchfield for their thorough reviews that improved the quality of this report.

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APPENDICES

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A1.0 GIS DATA

This study includes digital data supplied as two ESRI shapefiles, consisting of a polyline shapefile of mapped faults and a polygon shapefile of Fault Avoidance Zones. These data and their attributes are described below. Both the fault linework and Fault Avoidance Zone shapefiles have an identical list of attributes.

File Name: HastingsDC_Faultlines_CR_2015_112
Type: Polyline
Projection: NZGD 2000 New Zealand Transverse Mercator.prj

File Name: HastingsDC_FAZ_CR_2015_112
Type: Polygon
Projection: NZGD 2000 New Zealand Transverse Mercator.prj

Each mapped fault trace is represented as a series of features that have been attributed with the following information:

FAULT_NAME: A fault name is supplied for faults that are long or connected enough to have been given a distinct name in previous studies, i.e. they have an established geological name, e.g. Mohaka Fault or Waipukurau Fault Zone. Many short fault traces or unconnected pieces have yet to be given names.

SECTION: The name given to a fault section. In some cases a fault may be subdivided into distinct sections, where there is a geographical or structural break in the fault. A fault section will typically consist of several to many individual fault traces.

DATA_SOURCE: Refers to the source of the data used to map the fault trace. For this study the data source is limited to:

> *HDC2015_LiDAR*: Mapped from an airborne 1-m LiDAR DEM and hillshade model
>
> *QMAP:* Data from QMAP geologic mapping program of New Zealand
>
> *NZAFD:* Data from New Zealand Active Fault Database (NZAFD), scale c. 1:50,000.
>
> *NZAFD_LiDAR:* Data from New Zealand Active Fault Database (NZAFD) mapped from airborne 1-m LiDAR DEM and hillshade model

SCALE: The scale at which the feature was digitised.

ACCURACY: Refers to the ability to identify and clearly map fault-related features from the available imagery and is limited to three possibilities.

> *Accurate*: Where a fault scarp can be clearly mapped.
>
> *Approximate:* Where the fault/trace is not as clearly expressed but there is clear geomorphic evidence of a surface fault rupture.
>
> *Uncertain:* Where the fault is concealed (buried) or eroded away i.e. where a fault crosses an active river or floodplain.

BUFFER: Is a number value in metres with which we consider to be the maximum mapped location uncertainty for a fault line. These values are used for defining the widths of Fault Avoidance Zones.

For this study the values used are based on the **DATA_SOURCE, SCALE** and **ACCURACY** attributes as explained in the text and in Figure 4.1.

±125 m: All linework from sources mapped at a scale greater than 1:10,000, i.e. QMAP, regional DEM or the NZAFD. A value of ±125 m is used regardless of whether its location is considered accurate, approximate or uncertain[4].

±40 m: Uncertain fault traces mapped from LiDAR hillshade model

±25 m: Approximate fault traces mapped from LiDAR hillshade model

±10 m: Accurate fault traces mapped from LiDAR hillshade model

SLIP_TYPE: Refers to the dominant sense of movement on a fault. These are as described in Chapter 2 and include:

Dextral (right-lateral), *Sinistral* (left-lateral), *Reverse*, *Thrust, and Normal*

The terms *strike-slip*, *dip-slip* and *<Null>* are sometimes used when the style of movement is unclear.

DOWN_QUAD: Refers to the compass quadrant that is downthrown relative to the strike of the fault. They are limited to the following attributes:

N, S, E, W, NW, NE, SW, SE

RI_CLASS: relates to the recurrence interval of faulting. The MfE Guidelines (Kerr et al., 2003) define six recurrence interval classes (RI Classes I-VI) depending on the activity of the fault.

Class I:	≤2000 yr
Class II:	>2000 to ≤3500 yr
Class III:	>3500 to ≤5000 yr
Class IV:	>5000 to ≤10,000 yr
Class V:	>10,000 to ≤20,000 yr
Class VI:	>20,000 to ≤125,000 yr

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[4] We use ±125 m rather than ±250 m, as the latter is an unreasonable assessment of the likely uncertainty on any given piece of data within QMAP. This is in part because QMAP data originated at a scale of 1:50,000.