Active Fault Mapping and Fault Avoidance Zones for Central Hawkes Bay District: 2013 Update

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EXECUTIVE SUMMARY

GNS Science has been tasked with updating active fault linework and Fault Avoidance Zones district-wide for Central Hawke's Bay. Central Hawke's Bay District is traversed by belts of active strike-slip, reverse and normal faults that pose a surface rupture hazard to buildings and infrastructure. With respect to the Ministry for the Environment's guidelines pertaining to active faults, it is important to accurately locate these faults, define their activity in terms of recurrence, and to develop Fault Avoidance Zones that reflect on the quality of fault mapping that is provided.

Active fault trace mapping was undertaken in the district using airborne Light Detection and Ranging (LiDAR) hillshade models and DEMs and from review of active fault linework in Lee et al. (2011; the 'QMap Hawke's Bay') and the GNS Active Faults database. This work builds on previous fault linework and avoidance zone methodology initiated by Langridge et al. (2006). The fault mapping has been done in a GIS at scales of c. 1:10,000 (LiDAR) and at scales of between 1:250,000 and 1:50,000 (QMap, Active Faults database).

Fault location accuracy is arguably the most important factor in defining the geographic position of fault traces and subsequently the dimensions of Fault Avoidance Zones that have been derived. Where LiDAR is available, we have mapped fault traces as either accurate (±10 m), approximate (±25 m), or inferred (±40 m) in terms of their fault Location Accuracy. Where no LiDAR coverage exists we use QMap linework, which is assigned an accuracy of ±125 m due to the scale at which it was mapped. 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 on that side of the fault. Thus for the examples shown in the preceding paragraph, the Fault Avoidance Zone widths are increased to 70 (i.e. ±10 x 3 + 20 x 2 m), 115, 160 and 415 m, respectively.

GIS attributes, including Fault Name, Locational Accuracy, and Recurrence Interval Class, are also presented with the linework. Recurrence intervals for surface rupture (faulting) have been defined for many of the named faults and fault zones with CHB District. There is one Recurrence Interval (RI) Class I (RI <2000 yr) fault (= Mohaka Fault) and one RI Class II (2000-3500 yr) fault (= Ruahine 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.

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. The Ministry for the Environment Guidelines regarding active faulting are risk-based, thus the risk posed by faults of different recurrence interval and also with regards to considering the building type needs to be understood.

We recommend that the fault line and Fault Avoidance Zone data here presented as GIS data be adopted by CHB District Council. 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 few years as more LiDAR coverage 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 and along the coastline and in the northeast of the district, where there is currently relatively poor mapping control of active faults.

1.0 INTRODUCTION

New Zealand lies across the boundary zone between the Australian and Pacific tectonic plates where active faults can 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 is underlain by the subducting Pacific plate and is crossed by a number of significant active faults that can rupture and deform the ground surface, including the Mohaka Fault, Ruahine Fault, Poukawa Fault Zone, and Waipukurau 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 yr), and are capable of generating large earthquakes (M_w >6.5) associated with large (i.e. metre-scale) single event surface rupture displacements (e.g., Langridge et al., 2006, 2011; Kelsey et al., 1998).

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[1]. 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 example of the types of effects, including but not limited to, surface rupture that can occur to man-made built structures from large earthquake 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) has been commissioned by Hawke's Bay Regional Council, to provide an update of mapping of active faults within Central Hawke's Bay (CHB) District.

The main objective for this work is:

To produce high-quality GIS data and maps suitable for planning use across Central Hawke's Bay District at scales that are relevant to the current and expected future land use requirements. CHB District has a high number and density of active faults, which are mostly mapped at a scale >1:10,000 (i.e. QMap 1:250,000 and the GNS Active Faults database (http://data.gns.cri.nz/af/ 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 the CHB District the scope of work is as follows:

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

[1] Later in this report, this type of fault will be defined as a 'seismogenic fault', that is, one which moves during an earthquake, as opposed to a gravitational failure or shallow gravity-driven fault.

- In all other areas of CHB District incorporate new active fault line work and attributes from the recently published QMap Hawke's Bay (Lee et al. 2011) and GNS Active Faults database (1:50,000 to 1:250,000 scale)[2].
- Produce Fault Avoidance Zones based on the fault line data described above.
- Produce a report for HBRC and present results to Central Hawke's Bay District staff.

Chapter 2 of this report provides a background on what active faults are and discusses their styles of movement, while Chapter 3 provides examples of each style of faulting and the recurrence intervals of important faults in Central Hawke's Bay District. Chapter 4 describes the techniques we used to map the faults and how we developed the attributes, uncertainties and Fault Avoidance zones for these fault traces. Chapter 5 provides a summary of the results of this work.

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

The Ministry for the Environment (MfE), has published Guidelines on "Planning for Development of Land on or Close to Active Faults[3] (Kerr at al. 2003, see also King et al. 2003; Van Dissen et al. 2003). 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 (Kerr et al., 2003):

> *"There is no technology to prevent earthquake damage to buildings built across faults."*

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.

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

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2 In this study we have not had the budget to review active fault locations using aerial photographs and rely on previous mapping outside of areas that have LiDAR coverage.

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

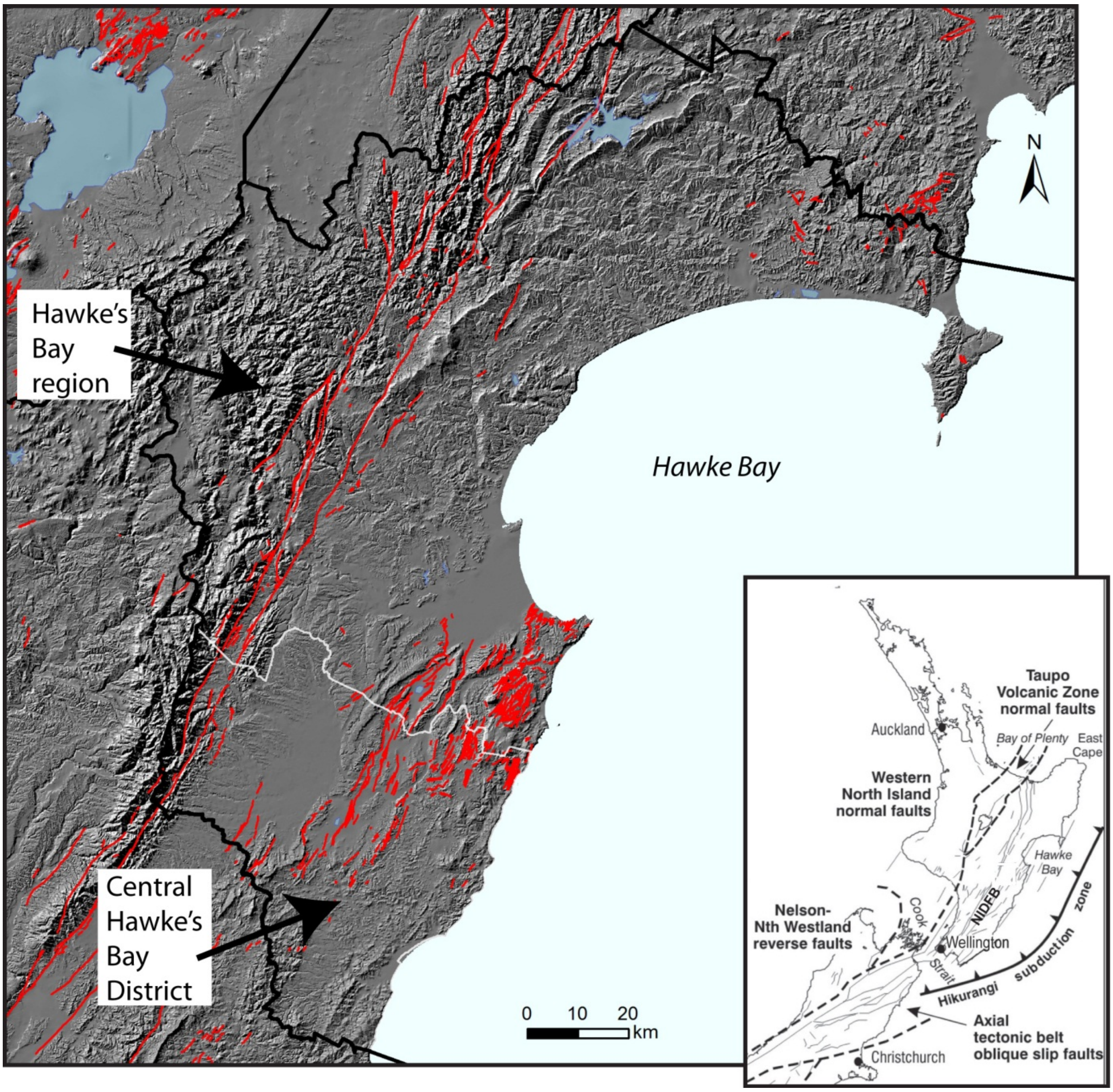

Figure 1.1 Active faults (red) within Hawke's Bay region (within black line), taken from the GNS Science Active Faults database. The study area covering Central Hawke's Bay District occurs to the south of the District Council boundary (white) and within Hawke's Bay region. Inset: Simplified map of North Island plate tectonic boundary.

The MfE Guidelines also advance a hierarchical relationship between fault-avoidance 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 (see Table 4.3, and Appendix 1 for more detail). 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.

1.3 PREVIOUS FAULT MAPPING

In Central Hawke's Bay (CHB) District there are a myriad of typically NE-striking active fault traces that parallel the plate boundary within the upper (Australian) plate. Since 2005, GNS Science has been working with the Hawke's Bay Regional Council to improve data regarding the activity and location of active faults in the region. This has been an important development following the widespread adoption of the MfE Guidelines. Active fault mapping projects have been undertaken for all four Territorial Land Authorities (including Napier City) within the region (Langridge et al., 2007; Langridge and Villamor, 2007; Langridge et al., 2011) including CHB District (Langridge et al. 2006). These recent and detailed studies focused on areas where new detailed land coverage exists in 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. *Waipukurau Fault Zone* – Beanland 1995; Berryman 1983, Begg et al. 1994; *Poukawa Fault Zone* – Kelsey et al. 1995; Begg et al. 1995). Much of this previous work was improved upon by fault mapping commissioned for CHB District and undertaken by GNS Science during the last decade (Langridge et al., 2006). The 2006 report was the first GIS-based fault mapping report in the Hawke's Bay region and focused on mapping faults of the Waipukurau and Poukawa Fault Zones through the urban and peri-urban corridor of CHB District. It also provided the first examples of Fault Avoidance Zones (FAZs) mapped around active faults in Hawke's Bay.

It has become evident that the councils may hold different versions or vintages of fault mapping data, which inevitably will lead to some confusion over which data is most up-to-date or suitable for the purposes of active fault zonation.

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

i. the availability of LiDAR surveys in CHB District since the Langridge et al. (2006) report (=GNS Client Report CR 2006/98);

ii. the availability of mapping for these new areas from Ruataniwha Plains engineering studies and student theses (Klos, 2009; Langridge et al., 2011);

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

iv. to provide CHB District Council with up-to-date GIS datasets are currently valid or most up-to-date for planning purposes. The intent of this report is to update fault data for Central Hawke's Bay District and therefore this report supersedes an earlier fault location report by Langridge et al. (2006).

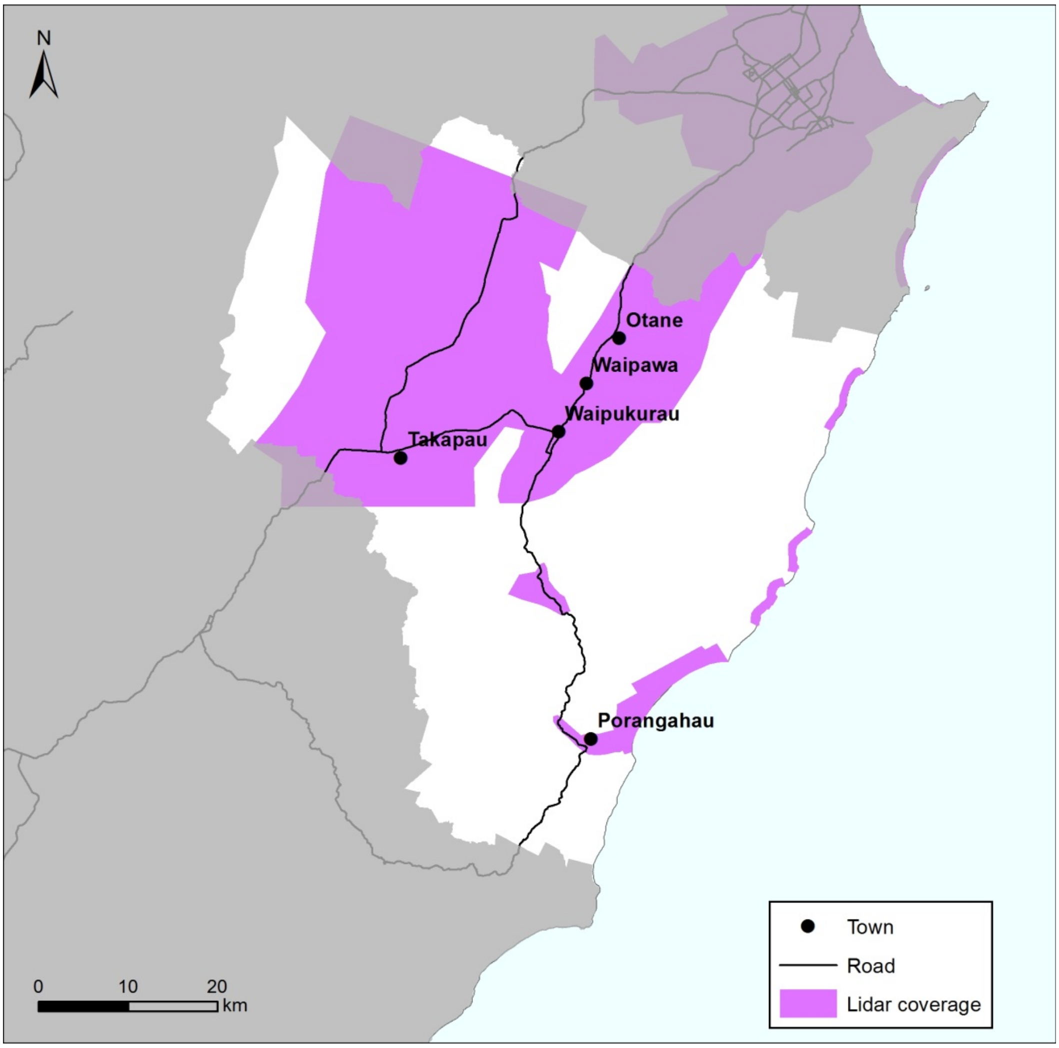

Figure 1.2 Areas within Central Hawke's Bay District where LiDAR DEMs coverage is available. Mapping in other areas is based on QMap, the GNS Active Fault database and aerial photograph interpretation.

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2.0 WHAT IS AN ACTIVE FAULT?

Mappable active faults, or seismogenic faults, are typically capable of generating strong earthquake shaking and surface fault rupture, and are the faults that are most likely to move in the future causing potential damage. Surface-rupturing earthquakes are typically of magnitude M >6.5. The lower limit for surface rupture may be higher, in some areas, e.g. M 6.8 in areas of reverse faulting, and lower in others, e.g. M 6.0, such as in extensional volcanic areas where the crust is thinner, or also if the earthquake is shallow. The typical definition of an active fault in New Zealand is one which has moved in the past 128,000 years. In practice this relates globally to the beginning of the last warm (interglacial) period, i.e. it relates to marine terraces and alluvial surfaces that can be correlated with the 'Last Interglacial period' or Marine Isotope Stage 5 (e.g. Barrell et al., 2011).

The purpose of this chapter is to show how active faults express themselves in the landscape; their behaviour, styles of deformation, activity and geomorphic expression. Active faults express themselves in the landscape as linear traces displacing surficial geologic features which may include hillslopes, alluvial terraces and fans. These displaced features provide an age relationship with which we can define how active a fault is. Typically in New Zealand, alluvial terraces are associated with the contemporary river drainages, and therefore they are often of late Quaternary age (i.e. typically <100,000 yr). Hillslopes are mainly formed in bedrock (Neogene or older rocks) and in New Zealand, these surfaces have typically been modified by glacial or peri-glacial action related to the Last Glacial period (or Last Glacial Maximum; Alloway et al., 2007). This means that well-defined, linear fault traces that cut across bedrock hillslopes are probably also related to active faulting.

Active faults are often defined by a fault scarp. A fault scarp is formed when a fault vertically displaces or deforms a surface and produces a step, which smooth out with time to form a scarp (Figure 2.1). Traditionally, faults were 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. In some cases, where a fault moves horizontally, only a linear trace or furrow may be observed (either on aerial photographs or on the ground). Airborne LiDAR and detailed digital elevation models (DEMs) have greatly improved the accuracy to which active fault traces can be mapped (Meigs, 2013; Langridge et al., 2006).

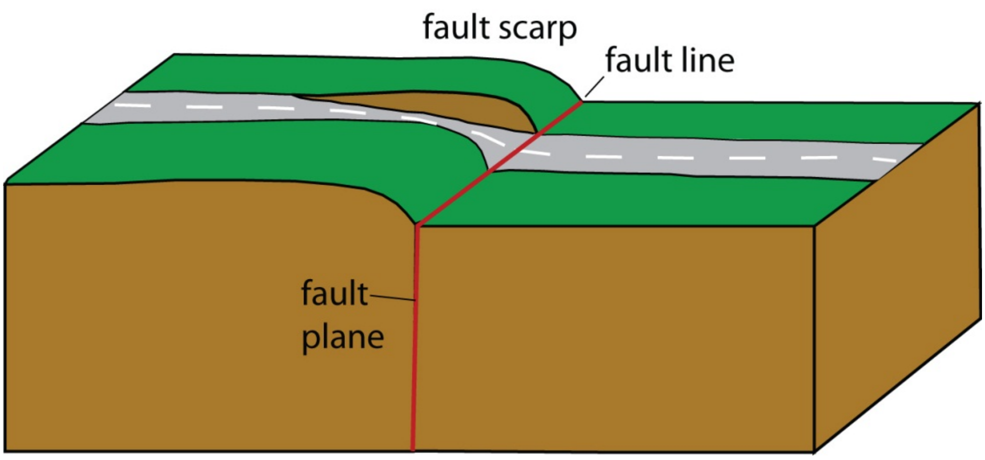

Figure 2.1 Block model of a section through an active fault. Vertical displacement across the fault line (trace) produces a scarp along the projection of the fault plane at the Earth's surface.

2.1 STYLES OF FAULT MOVEMENT

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

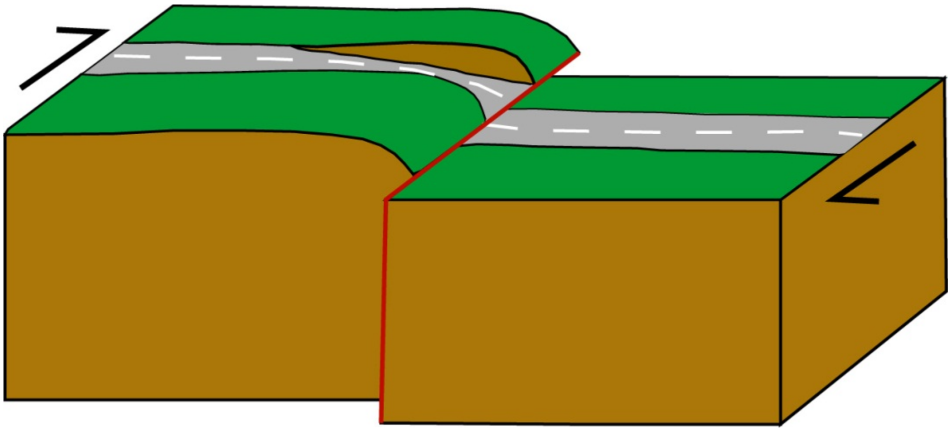

Figure 2.2 Block model of a section through a strike-slip fault (red line) that has recently ruptured. The fault is a right-lateral fault as shown by the black arrows and by the sense of movement across the two blocks and a right separation across the road.

Most strike-slip faults in New Zealand, including the Alpine, Hope, Wairarapa and Wellington faults have a dominant right-lateral style of movement (Beanland and Berryman, 1987, 1991). Strike-slip faults in the western part of Central Hawke's Bay District, including the Mohaka Fault, reside within and on the boundaries of the Axial Ranges.

Dip-slip faults can be divided into normal faults, where extension is prevalent (defined by movement where the hangingwall side of the fault drops down; Figure 2.3), and reverse faults, where contraction is prevalent (defined by movement where the hangingwall side of the fault is pushed up; Figure 2.4). Normal faulting is common in the central North Island (Taupo Volcanic Zone; Figure 1.1) where volcanism and tectonic activity is extending the crust between Ohakune and Whakatane, producing a myriad of active normal faults (e.g. Villamor et al., 2007).

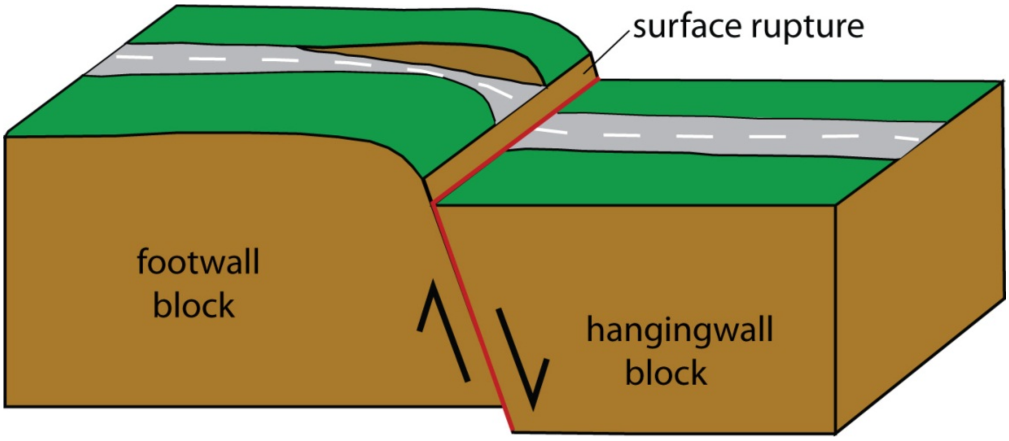

Figure 2.3 Block model of a normal fault (red line) that has recently ruptured. The relative movement of the blocks is vertical and in the dip direction of the fault plane. The hangingwall block has dropped down, enhancing the height of the fault scarp.

Reverse faulting is particularly common within CHB district east of the main Axial Ranges. Several distinct belts of reverse faulting characterise these areas. 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 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). A thrust fault is a reverse fault with a low angle of dip, typically 20-40 degrees in the near surface.

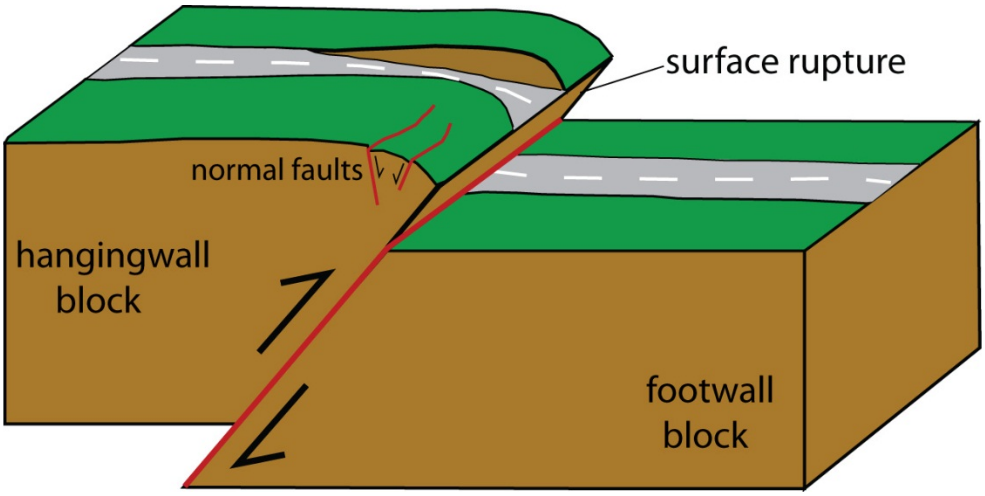

Figure 2.4 Block model of a reverse fault or thrust fault that has recently ruptured. Movement of the blocks is vertical and in the dip direction of the fault plane. In this case, the hangingwall block has moved up, thrusting over the footwall block. This kind of surface rupture is prone to collapse during and following the earthquake due to gravity and erosion acting on the scarp. Folding and normal faulting are common features of deformation in the hangingwall block of reverse faults at scarp, trench or regional scale.

In contrast, normal faulting is not common in Central Hawke's Bay. Nonetheless, there are areas of normal faulting mapped in the coastal ranges south of Maraetotara that may occur as a secondary effect related to reverse faulting (Pettinga, 2004; Figure 2.4). This will be discussed later.

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. This is important when considering the surface rupture hazard posed by such faults. In New Zealand, the MfE guidelines for building on or adjacent to active faults, defined six classes of active faults based on recurrence times (Table 2.1). Active faults are defined as faults that have ruptured during the last 128,000 years. Faults with the highest activity fall into RI Class I; these faults have an average recurrence interval of <2000 yr. 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 Class 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).

The classes displayed in Table 2.1 provide a context for the discussions that follow concerning individual active faults in CHB 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); CHB examples in bold
I	≤2000 years	Alpine, Hope, Awatere, Wellington, **Mohaka**
II	>2000 years to ≤3500 years	Ostler FZ, Ohariu, Makuri, Rangipo, **Ruahine**
III	>3500 years to ≤5000 years	Dunstan, Lake Heron, Poutu, Ngakuru, **Poukawa FZ**
IV	>5000 years to ≤10,000 years	Dalgety, Esk, Karioi, Wheao, **Ruataniwha**
V	>10,000 years to ≤20,000 years	Pisa, Greendale, Martinborough, **Blackburn FZ**
VI	>20,000 years to ≤125,000 years	ND

Notes: Faults with average recurrence intervals >128,000 years are not considered active. FZ = Fault Zone.

In the absence of paleoseismic trenching, slip rate and single-event displacement data 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 meters per thousand years). In reality, this fault movement takes place at once during a large earthquake that shifts the Earth on either side of the fault by metres at a time (Figure 2.2). Figure 3.2 and Figure 3.3 show places where slip rates may be obtained from offset geomorphic features.

When the timing of individual past surface rupturing earthquake events are 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. For example, in Figure 3.3 a possible trench site would be near the lower red arrow, where alluvial and swampy sediments have accumulated adjacent to the fault scarp.

3.0 ACTIVE FAULTS IN CENTRAL HAWKE'S BAY DISTRICT

Within Central Hawke's Bay District four main belts of faulting can be identified: (i) the Axial Ranges zone in the west, characterised by strike-slip faulting with lesser reverse faulting; (ii) the Ruataniwha Plains which is characterised by reverse faulting with lesser strike-slip faulting; (iii) the Central Belt 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.

3.1 STRIKE-SLIP FAULTS IN CENTRAL HAWKE'S BAY

Strike-slip faults occur in the west and the south of the district. Two of the most important strike-slip faults in Central Hawke's Bay District are the Mohaka and Ruahine faults (Figure 3.1; Table 2.1). These NNE-striking faults extend for many tens of kilometres within the Axial Ranges and run the entire length of Central Hawke's Bay 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 (NIDFB), 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.

In particular, the Mohaka Fault offsets bedrock units and some large rivers by kilometres (Berryman et al., 2002; Langridge et al., 2005; 2011) and younger late Quaternary features like spurs and streams by many tens of metres (Figure 3.1, Figure 3.2). Data from trenches indicate that past earthquakes have ruptured the Mohaka Fault on average every c. 1100 years (Langridge et al., 2013). 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 yr, it is classified as a RI Class I fault (i.e. RI <2000 yr) (Table 2.1, Table 3.1).

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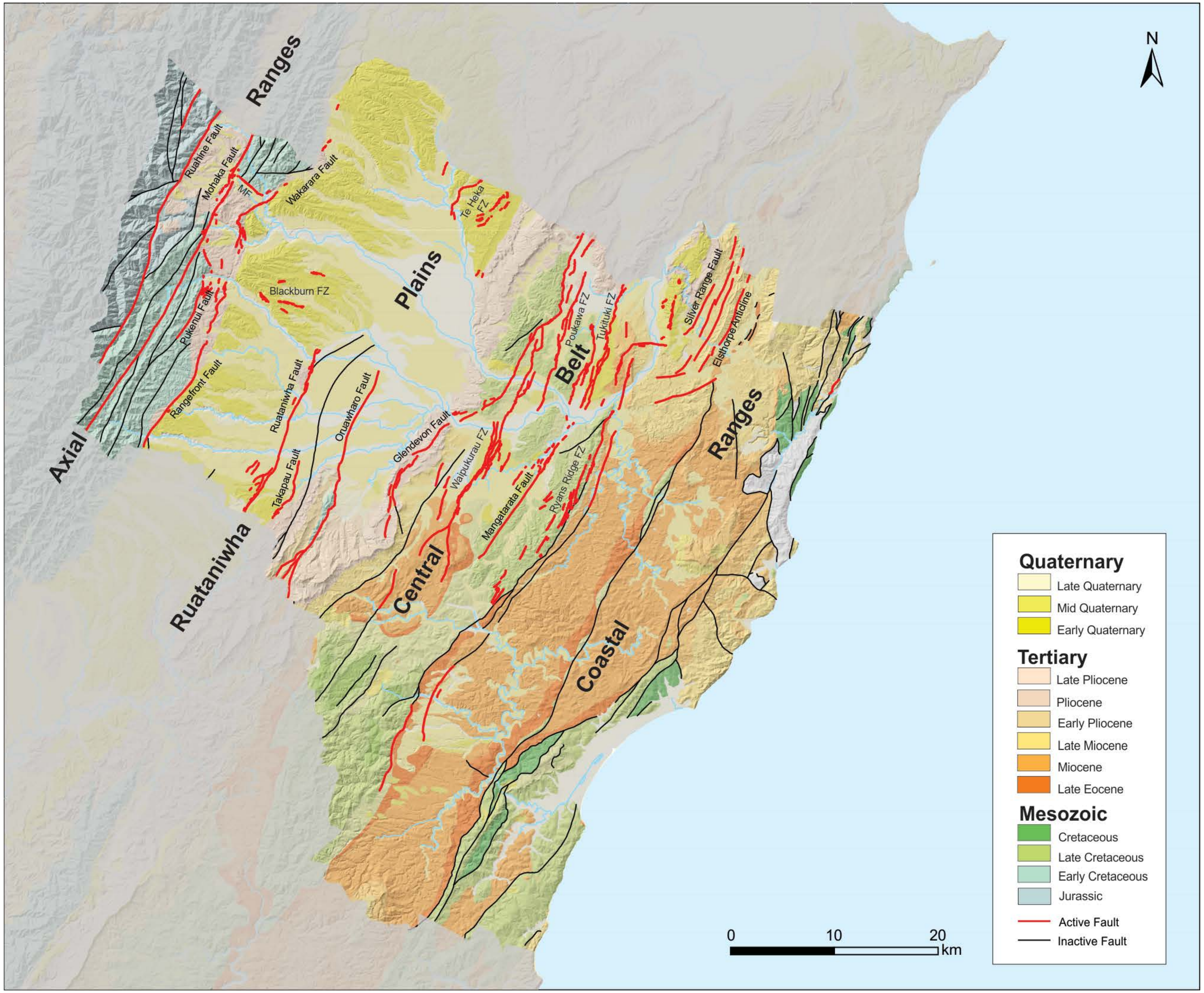

Figure 3.1 Active fault traces (red lines) mapped in Central Hawke's Bay District as part of this study overlain on the bedrock geology (from QMap Hawke's Bay; Lee et al. 2011). Black lines are inactive bedrock faults shown on QMap Hawke's Bay. MF = Mangataura Fault.

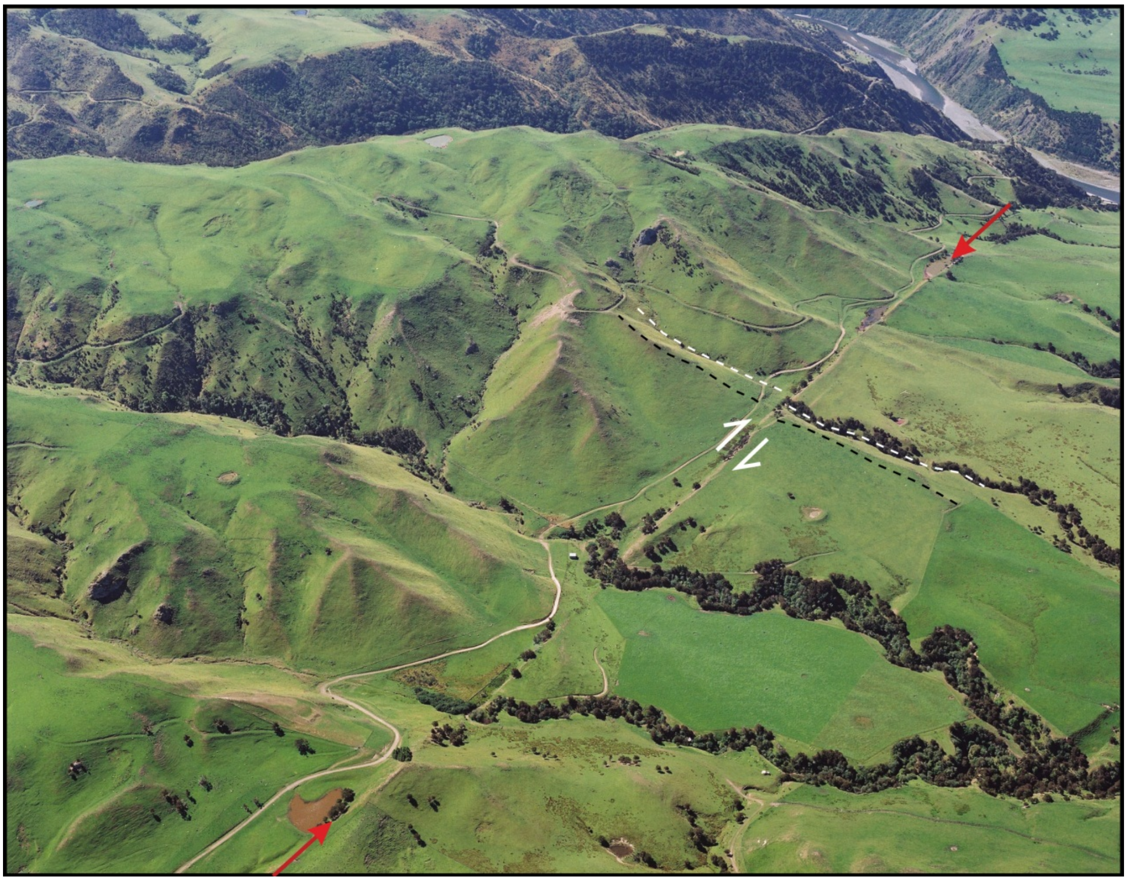

Figure 3.2 View to the north along the Mohaka Fault, just to the south of the Ngaruroro River (pictured) near Kereru. The active trace of the fault is marked by red arrows, and the sense of movement across the fault is highlighted by white arrows. A pair of offset features (a stream and adjacent ridgeline) are highlighted (dashed lines) to illustrate the right–lateral movement across the fault.

Figure 3.3 Uphill-facing scarp of the Mohaka Fault on Rangimarie Station, marked by red arrows. At this locality a ponded basin has formed behind the scarp and the original drainage has been displaced from its source by 27-37 m. The adjacent ridgeline (next to the large tree) is offset from a spur on the displaced shutter ridge (marked by the dog-legged dashed line).

The Ruahine Fault is parallel to and occurs 4 km to the northwest of the Mohaka Fault (Figure 3.4). 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 yr (Beanland and Berryman, 1987; Hanson, 1998). This produces a mean recurrence interval of c. 3000 yr, and defines the Ruahine Fault as a RI Class II fault (i.e. 2000 ≤ RI < 3500 yr).

Figure 3.4 Rangefront of the Ruahine Ranges near Wakarara. The active trace of the Ruahine Fault occurs in the dip in topography in front of the edge of the bush (marked by white arrows).

Other strike-slip faults have been identified and mapped in the Ruahine Ranges parallel to the Ruahine and Mohaka faults. These faults can be confirmed where LiDAR DEMs show linear fault traces cutting across the landscape, for example the Pukenui Fault, shown in the GIS (Figure 3.1). Some NNE-striking faults in this area may be active, e.g. Cullens Fault, but currently we do not have good base maps, such as a DEM derived from LiDAR with which to map fault scarps or to confirm their activity.

During recent fault investigations in the Wakarara area, the presence of an active left-lateral fault in the Mangataura valley was confirmed (Raub, 1985; Langridge et al., 2010; 2011; Lee et al., 2011) (Figure 3.1; Table 3.1). This fault (Mangataura Fault) strikes southeast, perpendicular to the Mohaka Fault, and has a clear fault trace as seen on LiDAR DEMs, aerial photographs and in the field (Figure 3.5). This fault has developed a large, linear fault scarp, indicating that it has probably ruptured more than once during the Holocene, and may indeed rupture sympathetically with the Mohaka Fault or the Rangefront Fault. However, at this time we have no record of the timing or recurrence interval of faulting. Therefore, we assign a preliminary recurrence interval of ≥3500-5000 years (RI Class III) to this fault due to the scale of the fault scarp and its proximity to these other similarly active faults.

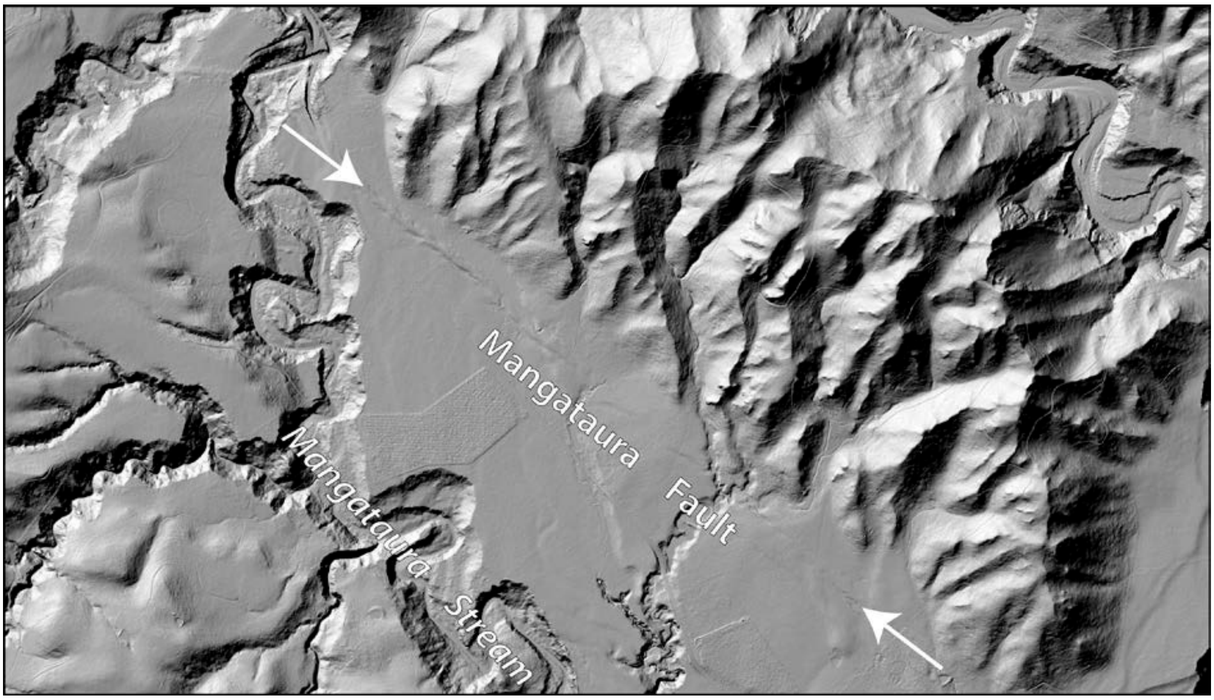

Figure 3.5 LiDAR hillshade model of the mid Mangataura valley. The Mangataura Fault is identified by a series of right-stepping surface traces that create a large 'moletrack' across a late Quaternary alluvial terrace. The fault separates greywacke hills of the Wakarara Block to the NE of it, from Tertiary rocks and alluvial terraces of the Mangataura valley.

The easternmost important strike-slip fault in central Hawke's Bay is the Oruawharo Fault (Figure 3.1). This fault displays the northernmost, well-documented evidence of strike-slip movement on the eastern strand of the NIDFB, i.e. strike-slip faulting related to the Wairarapa Fault (Beanland, 1995). Beanland identified several right-lateral displacements of geomorphic features along the Oruawharo Fault, confirming it has a dominant right-lateral style of movement. Based on these displacements (c. 15 ± 5 m right-lateral; 3 ± 2 m vertical) a preliminary slip rate of c. 1-2 mm/yr (Table 3.1), which is used to define a preliminary recurrence interval of 3500-5000 yr (RI Class III) for the Oruawharo Fault (Van Dissen et al., 2003).

Table 3.1 Summary of major strike-slip faults in Central Hawke's Bay District.

Fault Name	Fault style	Single Event Displacement (m)	Net slip-rate (mm/yr)	Recurrence Interval (yrs)†	RI Class	References
Mohaka	dextral	4 ± 1	3-4	<2000	I	Beanland (1995); Raub et al. (1987)
Ruahine	dextral	4 ± 1	1-2	2000-3500	II	Beanland & Berryman (1987)
Makaroro	dextral	ND	ND	3500-5000*	III	this study
Mangataura	sinistral	ND	ND	3500-5000*	III	Langridge et al. (2011)
Oruawharo	dextral	4 ± 1	1-2	3500-5000	III	Beanland (1995); Van Dissen et al. (2003)

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).

3.2 REVERSE FAULTS IN CENTRAL HAWKE'S BAY

East of the main Axial Ranges, Central Hawke's Bay District is characterised by several important reverse fault zones. These reverse faults typically extend for many tens of kilometres with a NNE-strike, parallel to the regional structural fabric of the East Coast and Hikurangi subduction margin (e.g., Kelsey et al., 1995, 1998). Table 3.2 summarises the most important, named reverse fault systems in the district.

In the vicinity of the Axial Ranges, the important reverse faults are the Wakarara, Rangefront, Hylton and Hinerua (Thrust) faults (Figure 3.1). All of these faults are poorly characterised but are confirmed as being active through fault mapping with LiDAR hillshade models in this study and through field reconnaissance (Raub, 1985; Langridge et al., 2010). The Wakarara and Rangefront faults are along-strike equivalents of the same fault; the change in name occurs where they meet the Mangataura Fault (see Figure 3.1). The Rangefront Fault has a stronger expression in the landscape than the Wakarara Fault, with mappable scarps extending over a distance of 15 km south of the Mangataura valley. Near the western end of Tukituki Road, multiple scarps of the Rangefront Fault cut across alluvial terraces and have a total height of c. 6 to 9 m (Figure 3.6). The terraces are mapped as Q2 alluvial terraces by Lee et al. (2011) and thus they have a probable age of 15,000 ± 3000 years. Based on these measurements, the vertical slip rate across the fault is c. 0.3-0.7 mm/yr at this locality. The dip-slip rate of movement accounts for the vertical component of slip rate along the inclined dip plane of the fault. This value would be higher, possibly approaching 1 mm/yr.

Figure 3.6 A pair of fault scarps related to the active Rangefront Fault across Tukituki Road near the Ruahine Ranges (background). The total scarp height at this location is c. 6 m.

The Wakarara Fault is characterised by a series of discontinuous scarps along the front of the Wakarara Range (Langridge et al., 2010, 2011). For this reason, we consider it to be less active than the Rangefront Fault, and has possibly only ruptured once or twice since the Last Glacial Maximum 15,000-18,000 yr ago.

Farther to the east, near State Highway 2 (SH2) the Ruataniwha and Takapau faults constitute a pair of significant reverse faults located in an area known as the Dannevirke-Ruataniwha Depression, a few km to the NE of the Oruawharo Fault (Figure 3.1; Lee et al., 2011). These faults can clearly be seen on LiDAR hillshade models and aerial photos, cutting across alluvial surfaces. The Ruataniwha Fault, which has the greater expression of these two faults, has a preliminary vertical slip rate of 0.1-0.3 mm/yr and a preliminary recurrence interval of c. 7500 yr (RI Class IV) (Klos, 2009). This data supersedes a preliminary estimate of the recurrence interval of >3500 to ≤5000 yr (RI Class III) in Van Dissen et al. (2003). Another zone of reverse faulting, the Te Heka Fault Zone, occurs in the northern part of the Ruataniwha Depression (Figure 3.1). Based on its similarity to other active fault zones in the area, it has been given a preliminary assignment to Recurrence Interval Class III.

The central corridor of the district is dominated by reverse faults, including from southwest to northeast, the Waipukurau Fault Zone, the Poukawa Fault Zone and the Tukituki Fault Zone (see Langridge et al., 2006; Figure 3.1). These fault zones are characterised by a wide zone of active reverse faults (typically 1-2 km wide) with multiple, sub-parallel traces (Figure 3.7). The Glendevon Fault, located to the west of the Waipukurau Fault Zone (Van Dissen et al., 1989) is probably also a part of this wider zone of reverse faulting (Table 3.2).

Figure 3.7 Oblique aerial photograph of the Waipukurau Fault Zone, south of, and including Waipukurau township, and toward the Tukituki River. The fault zone comprises a series of parallel and stepping anticlinal ridges (scarps) formed on the upthrown side of reverse faults (Photo: Lloyd Homer, GNS Science).

Based on paleoseismic trenching near Waipukurau (Berryman, unpublished data) and along the Poukawa Fault Zone (Kelsey et al., 1998) both the Waipukurau and Poukawa Fault Zones have been assigned to Recurrence Interval Class III (>3500 to ≤5000 yr) (Van Dissen et al., 2003). Similarly, the Glendevon Fault has also been characterised as a RI Class III fault. West of Waipawa, an active reverse fault trenched by Langridge et al. (2006; unpublished data) may constitute the northern continuation of the Glendevon Fault, north of the Tukituki River.

During the M 7.8 February 3, 1931 Hawke's Bay earthquake faults in the northern part of the Poukawa Fault Zone near Pakipaki (Hastings District) ruptured to the surface. These surface ruptures are documented in Hull (1990) and were confirmed in trench excavations across two of those traces (Kelsey et al., 1998). Similarly, another large event, the M 7.5 1863 Waipukurau earthquake is believed to be associated with surface rupture along the southern part of the Poukawa Fault Zone (Gaye Downes, personal comm.) However, with limited historical information and only a few trench exposures (Figure 3.8), it has not been possible to determine which faults among an array of sub-parallel reverse faults, ruptured during that earthquake.

Figure 3.8 An exposure of a thrust fault plane (below thumb of geologist) in a paleoseismic trench, north of Waipawa. Juxtaposed units either side of the low-angle fault (red flags) mark the fault, while green flags mark layers that are folded on the upthrown side of the fault.

The Tukituki Fault Zone occurs to the east of the Poukawa Fault Zone (Figure 3.1). A paleoseismic trench excavated across this zone (in Hastings District) confirmed that it is an active fault zone with a low slip rate and a probable RI Class of III (Figure 3.9). In Central Hawke's Bay District the Tukituki Fault Zone is expressed as a series of faults and folds that occur to the east of Waipawa in a zone marking the "old course of the Waipawa River", an historical description referring to a time when the river flowed in that area following the flooding event of 1867.

Farther to the east, the Ryans Ridge Fault Zone and other reverse faults have been mapped and characterised as active faults (Figure 3.1). Based on a comparison to these other similar fault zones (described above) a preliminary Recurrence Interval Class IV (>5000-10,000 yr) is applied to the Ryans Ridge Fault Zone.

At the northeastern corner of the district a zone of reverse faulting called the Elsthorpe Anticline has been mapped (Pettinga 1982). An anticline usually refers to a zone of folding. In this case, the Elsthorpe Anticline is considered to be a zone of active faulting (e.g. in the GNS Active Faults database) with a low slip rate. The GNS Active Faults database suggests a recurrence interval of 5000-10,000 yr for the Elsthorpe Anticline and we also adopt this as a preliminary recurrence interval range (RI Class IV; Table 3.2).

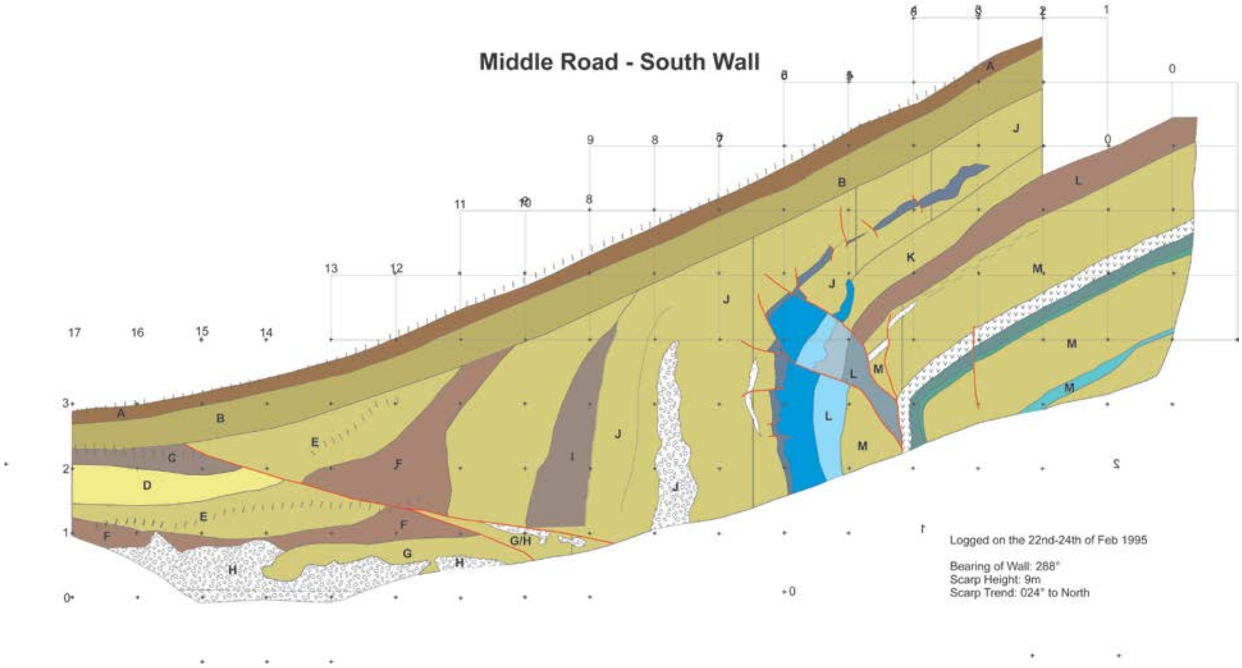

Figure 3.9 Unpublished paleoseismic trench log from the Tukituki Fault Zone near Middle Road. The log shows a thrust fault plane (at left) and intense folding and faulting associated with the hangingwall block of the fault (at right). The white unit exposed within the M facies is a prominent volcanic ash unit; the Kawakawa Tephra.

Table 3.2 Summary of the major reverse-slip faults in Central Hawke's Bay district. See Figure 3.1 for locations.

Fault Name	Fault style	Recurrence Interval (yrs)†	Recurrence Interval Class (RI Class)	Net slip-rate (mm/yr)	References
Rangefront	reverse	3500-5000	III	0.2-0.3	Langridge et al. (2011)
Wakarara	reverse	5000-10,000	IV	>0.1	Beanland (1995); this study
Hinerua/ Pukenui	reverse/thrust	5000-10,000*	IV	nd	Langridge et al. (2011)
Hylton	reverse	3500-5000*	IV	nd	Raub (1985); this study
Ruataniwha	reverse	5000-10,000	IV	c. 0.2	Klos (2010); Van Dissen et al. (2003)
Takapau	reverse	5000-10,000	IV	-	Beanland (1995); Van Dissen et al. (2003)
Te Heka FZ	reverse	3500-5000	III	-	this study
Glendevon	flexural-slip/ reverse	3500-5000	III	-	Van Dissen et al. (2003)
Waipukurau FZ	reverse	3500-5000	III	0.2-0.4	Kelsey et al. (1998); Berryman (unpublished data)
Poukawa FZ	reverse	3500-5000	III	0.2-0.4	Beanland (1995); Raub et al. (1987)
Tukituki FZ	reverse/thrust	3500-5000	III	0.2-0.4	Beanland & Berryman (1987)
Mangatarata	reverse	5000-10,000	IV	>0.1	this study
Ryans Ridge FZ	reverse	5000-10,000	IV	>0.1	Langridge et al. (2011)
Elsthorpe Anticline	reverse/fold	5000-10,000	IV	>0.1	Langridge et al. (2011)

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).

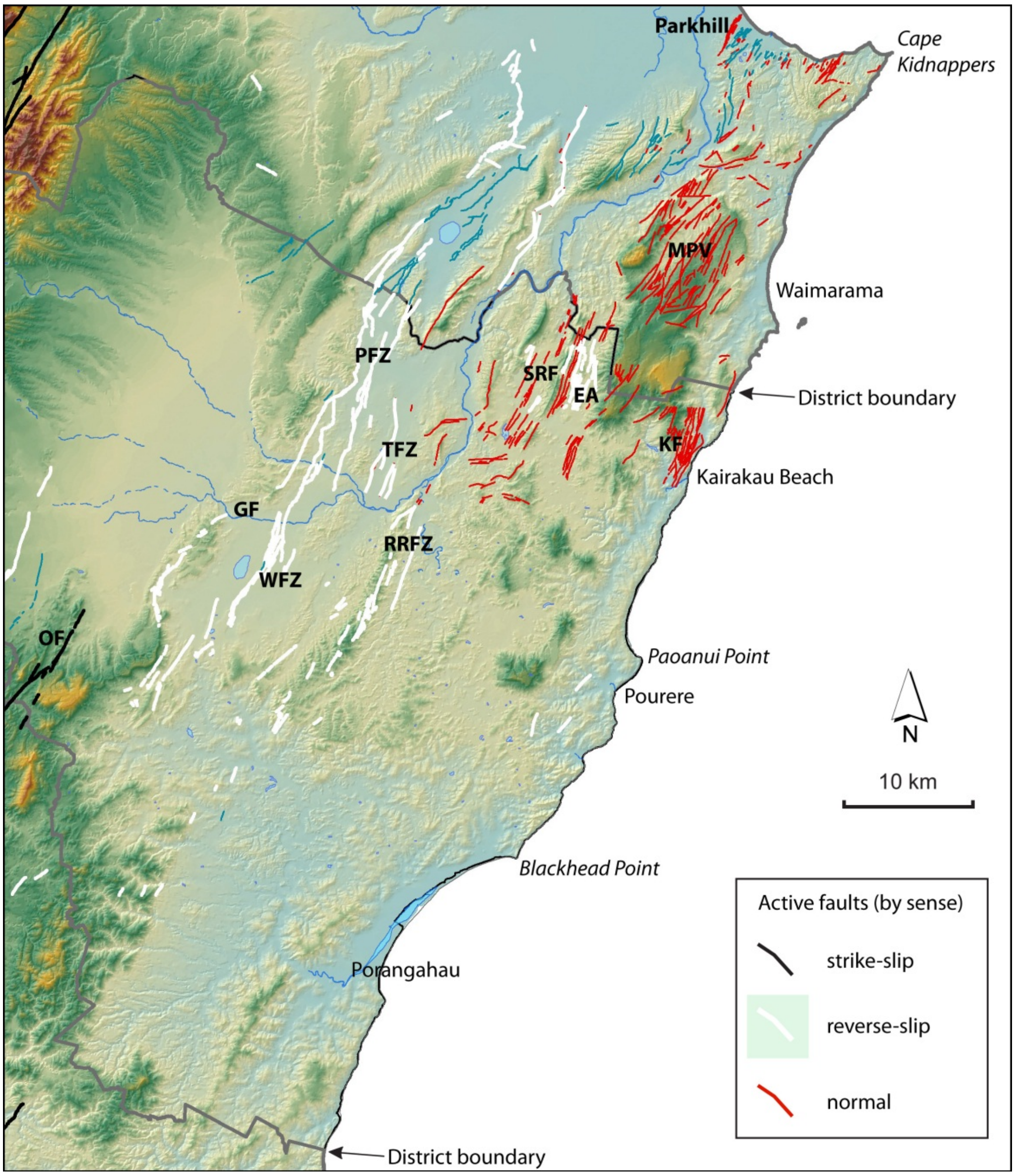

Figure 3.10 Map of coastal Central Hawke's Bay and Hastings districts identifying mapped faults in the GNS Active Faults database. The faults are coloured by their dominant sense of movement (normal faults are white). The northeastern corner of CHB District is characterised by many normal faults, particularly where the coastal ranges topography is greatest. Abbreviations: MPV, Maraetotara Plateau and Valley; KF, Kairakau faults; EA, Elsthorpe Anticline; SRF, Silver Range Fault; RRFZ/TFZ/PFZ/WFZ = Ryans Ridge, Tukituki, Poukawa, Waipukurau fault zones; GF, Glendevon Fault; OF, Oruawharo Fault.

3.3 NORMAL FAULTS IN CENTRAL HAWKE'S BAY

Prior to this study there was a big difference in the portrayal of active faults between the GNS Active Faults database (http://data.gns.cri.nz/af/) and the QMap active fault coverage (Lee et al., 2011) (see Figure 1.1; Figure 3.10). One of the goals of this study is to make decisions about the current status of normal faults in this part of the district. The following paragraphs provide background on these normal faults and the rationale behind how we plan to approach this area. Table 3.3 indicates three of the main areas of normal faulting within the district.

A characteristic of the high coastal ranges of eastern and southern Hawke's Bay that reach 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). Other normal faults have been mapped near the east coast, seaward of the Maraetotara Plateau, between

Waimarama and Paoanui Point (Figure 3.10; Pettinga, 2004). These were mapped in detail for a doctoral thesis (Pettinga 1982) and this data was uploaded to the GNS Science Active faults database when it was first constructed.

The general tectonic model for the East Coast is that it is part of a contractional (reverse) tectonic regime related to the Hikurangi subduction margin. In such a setting the presence of abundant normal faults, rather than reverse faults is anomalous. There are three possible reasons for the presence of surface-rupturing normal faults in this area that we put forward: (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; and (iii) these faults are related to extension and gravitational collapse of high-standing topography near the coast (Figure 3.10). The following paragraphs weigh up arguments for each of these cases.

We assert that in all cases, it would be relevant to consider these features as surface-breaking faults. In fact, the three cases are not exclusive of each other. In cases (i) and (ii), the faults would be treated the same as any other primary or secondary seismogenic fault with the potential to rupture the ground surface, such that planning constraints should be developed for them. In case (iii), it is arguable whether the linear faults are actually landslide scarps, however, as they have probably failed repeatedly, it is pertinent to also treat them as faults.

Can these normal faults be considered as seismogenic faults in their own right? A typical active fault with a length of perhaps 10 km or more would cut the width of the seismogenic part of the crust (typically 10-12 km) and would be capable of generating a large earthquake of M >6.5, for example. The high density (close spacing) of faults shown in the Maraetotara and Kairakau areas suggests that the faults have a shallow root, or that they merge together at a shallow depth, well above the usual depth at which large earthquakes are generated. For example, cross-sections shown by Pettinga (2004) imply that there are shallow, curved (listric) faults that merge into a detachment zone at depths of 100-500 m below sea level.

The recurrence intervals for these normal faults in eastern Hawke’s Bay are not well known as the faults have not been thoroughly investigated (Table 3.3). Trenching at Parkhill subdivision near Haumoana showed evidence for repeated movements during the last c. 15,000 yr with a recurrence interval for surface faulting in the range 5000-10,000 yr 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 (eastern coast) of Hawke’s Bay region.

In the western part of the district, the Blackburn Fault Zone refers to a southeast-striking zone of extension in the Blackburn area near Ongaonga. Several linear zones of extension can be mapped across landforms comprising early Quaternary alluvial surfaces (Lee et al., 2011). Due to their age it is difficult to assess whether they have been active or re-activated during the Holocene or over what time frame. In this case, we suggest a preliminary recurrence interval range of 10,000-20,000 yr to acknowledge this lack of data.

3.4 DECISION ON UPTAKE OF NORMAL FAULTS IN COASTAL BELT

The QMap Hawke's Bay geologic map (Lee et al., 2011) shows only a few active fault traces in the coastal and northeastern parts of the district while the Active Faults database includes many short, parallel normal fault traces mapped by Pettinga (1982).

At this time and for these areas, we have made the decision to only uptake and edit active fault linework from Lee et al. (2011), faults and landslide head-scarps that can be clearly mapped from LiDAR along the coast and linework from named faults within the Active Faults database. In the latter case, this includes the Silver Range Fault (normal) and the Elsthorpe Anticline (reverse). Coastal faults near Kairakau and the Silver Range Fault are listed in Table 3.3.

In future, when better topographic coverage such as LiDAR is available it will be possible to map these coastal and northeastern parts of the district in order to better locate active faults. At this stage, the presence and accuracy of the linework is not good enough to warrant providing approximate fault data and building Fault Avoidance Zones. The reader is referred back to Figure 3.10 which shows the faults mapped within the GNS Active Faults database in this area. In the case that housing or farm developments occur in these areas, and faults are identified by GNS Science or geological consultants, then these faults should be treated (in a preliminary sense) as falling between RI Class III (>3500-≤5000) and RI Class V (>10,000-20,000 yr). This means that for Important and Critical buildings the location and activity of these faults should be of concern.

Table 3.3 Summary of the major normal faults in Central Hawke's Bay district.

Fault Name	Fault style	Recurrence Interval (yr)	RI Class	References
Kairakau faults	normal	5000-10,000	IV	Pettinga (1982; 2004)
Silver Range	normal	3500-5000†	III	Beanland (1995)
Blackburn FZ	normal	10,000-20,000	V	Lee et al. (2011); 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).

4.0 FAULT MAPPING

Surface fault traces have been mapped using a combination of LiDAR hillshade models and by adopting linework from the GNS QMap geologic mapping program and the GNS Active Faults database (AFDB). There is a large difference between the locational accuracy of mapped fault traces when comparing LiDAR with QMap and AFDB data. The main difference between the two discrete datasets is the scale with which the mapped trace has been digitised, i.e. LiDAR 1:10,000, QMap 1:50,000 (presented at 1:250,000) and AFDB 1:50,000. 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 smaller) active fault mapping to define the fault location in developed and developing areas, e.g. Begg et al. (1994). Those parts of the district that are outside of the LiDAR-surveyed areas have been assessed using the QMap linework from the Hawke's Bay geologic map (Lee et al., 2011; Figure 1.2). In these areas the QMap linework has been compared with data already in the GNS Science Active Faults database for presence, accuracy, and continuity of fault trace information. In some cases, data from the Active Faults database has taken precedence over QMap linework.

During the last decade, four main periods of LiDAR acquisition have been flown across Central Hawke's Bay District (Figure 3.1; Table 4.1) The data quality and subsequent DEM pixel size has improved from the original 2003 flights through to the 2010-2011 surveys. The raw data from the 2003, 2006 and 2010 surveys were supplied to GNS by HBRC in New Zealand Map Grid projection. These data were re-projected into NZGD 2000 New Zealand Transverse Mercator projection and DEMs interpolated so that they are uniformly between 1 and 5 m DEM quality.

Table 4.1 Summary of airborne LiDAR areas across CHB District and DEM pixel size used in this study.

LiDAR survey	Year of acquisition	DEM pixel size (m)
Kairakau, Pourerere, Blackhead, Porangahau Beach	2003	5
Wanstead, Porangahau River	2006	1
Central Hawke's Bay	2006	1
Ruataniwha Hills	2010	1
Makaroro	2011	1

4.1 FAULT LOCATION UNCERTAINTY AND ATTRIBUTES

The accuracy with which the location of a fault feature can be digitised into a GIS is influenced by two types of uncertainty. The first is the uncertainty of the location of the digitised line feature, which is sometimes referred to as the *capture uncertainty*. The main influence is the source data and the related scale at which fault data was digitised. This uncertainty can be quantified and is differentiated in this study with the attribute **Data Source**. The second 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. In this study the **Accuracy** attribute encompasses this *expression uncertainty*.

The digitising of active faults requires expert recognition of fault influenced geomorphic landforms and an understanding of the local geologic record. The most obvious landform feature associated with surface fault rupture is a fault scarp (see Figure 2.1). Fault scarps 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 reality, the line within the GIS 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).

Once a fault trace location had been identified, attributes to describe the fault and to allow for the calculation of Fault Avoidance Zones were assigned to each trace. A detailed description of these attributes and how they have been used is outlined in Appendix 1.

From the attributes *Capture* and *Expression uncertainty*, a combined uncertainty can be quantified and in this study it is defined by the attribute **Location Uncertainty**. This is a distance in metres that the fault line could be located within. In reality, the *location uncertainty* is probably a reasonable measure of how wide a fault zone is, and how well-defined the fault location is. That is, we can use a width value (in metres) that reflects the uncertainty regarding the position of surface faulting. Thus, a fault accurately located and mapped on LiDAR has a location uncertainty of ±10 m. This equates to a well-defined fault trace at scale 1:10,000.

The style of faulting can also influence the width of the zone of surface rupture. For strike-slip and normal faults a symmetric Location Uncertainty is used to develop a Fault Avoidance Zone buffer because there is no geological preference toward distributed deformation on one side of the fault or the other.

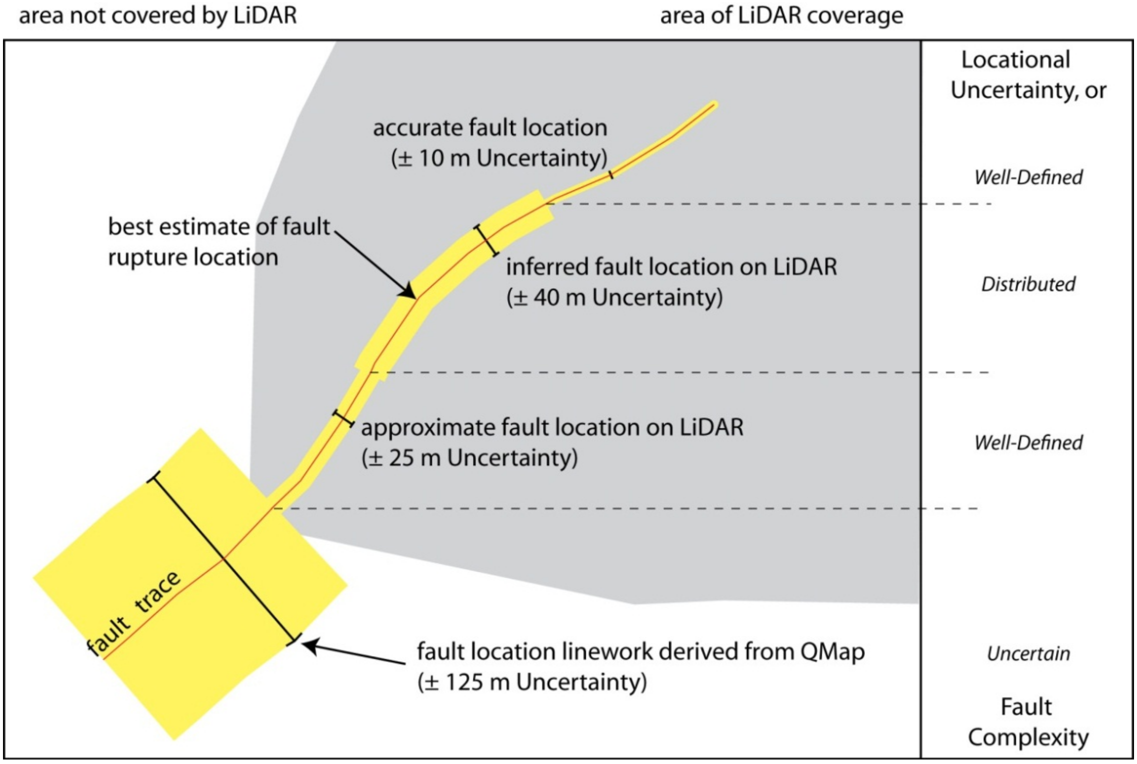

Figure 4.1 Sketch summary of the Uncertainty associated with active fault mapping. A LiDAR DEM is depicted by the grey area. The red line represents the fault trace and yellow bands represent the Location Uncertainty associated with accurate/approximate/inferred linework on LiDAR and the uncertainty for QMap linework.

However, for reverse faults, it has been demonstrated that the hangingwall block side (or uplifted side) of the fault has an increased amount of fault deformation relative to the footwall side. For example, folding, reverse 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 2.4, Figure 4.1) (Kelsey et al., 1998; Langridge, unpublished data). In previous reports for CHB and Hastings districts, the methodology for developing Fault Avoidance Zones for reverse faults was laid out (Langridge and Villamor, 2007; Langridge et al., 2006).

4.2 BUILDING FAULT AVOIDANCE ZONES

Fault Avoidance Zones are constructed from the Location Uncertainty attributes of the fault linework, the style of faulting (particularly important for reverse faults), and a margin of safety (or setback) buffer that is included around these two.

In this study, we construct a buffer equivalent to the Location Uncertainty (±10, ±25, ±40, or ±125 m) around fault linework. Reverse and thrust faults have a further unit of uncertainty (+10, +25, +40, or +125 m) added to the hangingwall sides of the fault scarp. This effectively allows for the additional expected deformation on the hangingwall side (Figure 4.1).

The MfE Guidelines suggest that a *Margin of Safety Buffer* of +20 m be added to the Location Uncertainty. This buffer gives us some assurance that there is unlikely to be any fault deformation within the entire width of the Fault Avoidance Zone. In this example, a strike-slip fault accurately located and mapped using LiDAR will have a total Fault Avoidance Zone width of 60 m, i.e. ±10 m with an additional +20 m margin of safety buffer.

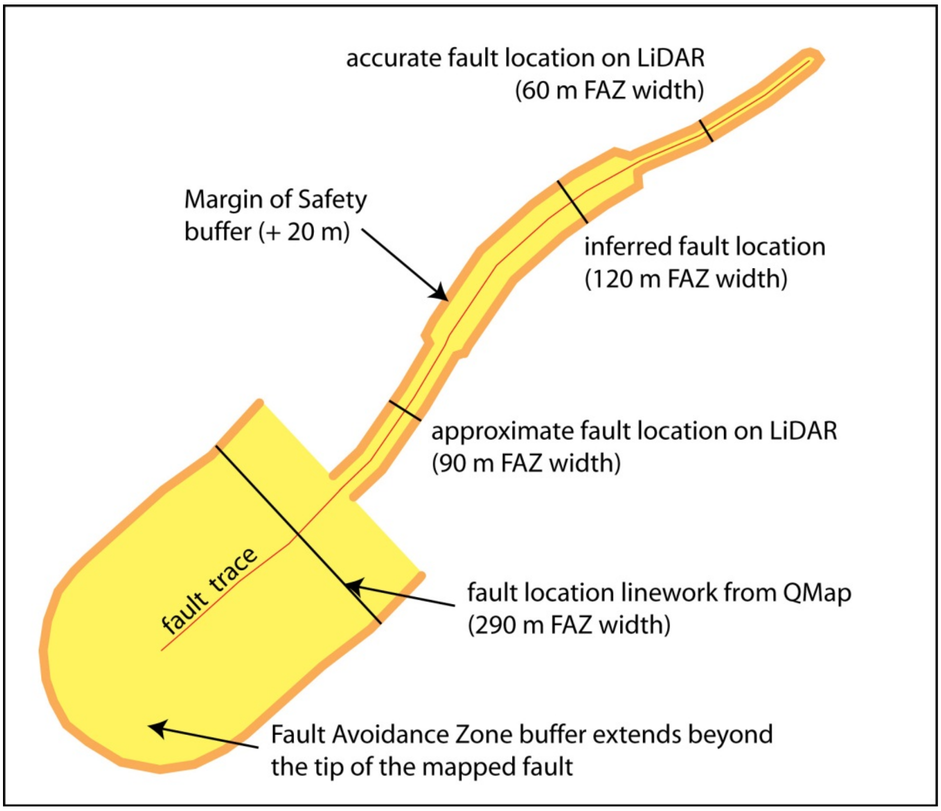

Figure 4.2 Fault Avoidance Zone buffers for hypothetical strike-slip or normal faults, based on the example in Figure 4.1, with varying Fault Location accuracy along strike.

Examples of the width of Fault Avoidance zones for this study are presented in Table 4.2. Note that well-located strike-slip and normal faults have a Fault Avoidance Zone width of 60 m, while reverse faults defined by QMap linework will have a Fault Avoidance Zone width of 415 m. These Fault Avoidance Zone widths reflect the fact that for accurately mapped faults there is a greater confidence that the most intense fault deformation will be within the area that is mapped as well-defined, while for faults that have an uncertain constraint, their location is much less certain.

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 Central Hawke's Bay, this is particularly true 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 4.2). In such cases a rounded buffer end will surround 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.

Table 4.2 Widths of Fault Avoidance Zones for Central Hawke's Bay faults.

Fault Style	Data Source	Location Uncertainty term	Locational Uncertainty (m)	Margin of safety buffer	Fault Avoidance zone width
Strike-slip/ normal	LiDAR	Well-Defined	± 10 m	± 20 m	**60 m**
	"	Distributed	± 25 m	± 20 m	**90 m**
	"	Uncertain	± 40 m	± 20 m	**120 m**
	QMap	Uncertain	± 125 m	± 20 m	**290 m**
Reverse*/ Thrust*	LiDAR	Well-Defined	± 10 m (+ 10 m*)	± 20 m	**70 m**
	"	Distributed	± 25 m (+ 25 m*)	± 20 m	**115 m**
	"	Uncertain	± 40 m (+ 40 m*)	± 20 m	**160 m**
	QMap	Uncertain	± 125 m (+ 125 m*)	± 20 m	**415 m**

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

Fault complexity is dealt with within the MfE Guidelines by considering 'Well-defined' (fault location) versus 'Distributed' (deformation) versus 'Uncertain - constrained' (fault location). These three terms are used directly in Resource Consent tables developed for the MfE Guidelines (e.g. Table 4.3), listed under "Fault Complexity". 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 faults are 'uncertain' or 'inferred' from the LiDAR (± 40 m) we apply the term 'Distributed' and for QMap fault linework (± 125 m) we apply the term 'Uncertain/Unconstrained'.

Thus, in terms of Resource Consent categories, the Fault Avoidance Zones that we have developed can be matched directly against the MfE Guidelines of Kerr et al. (2003).

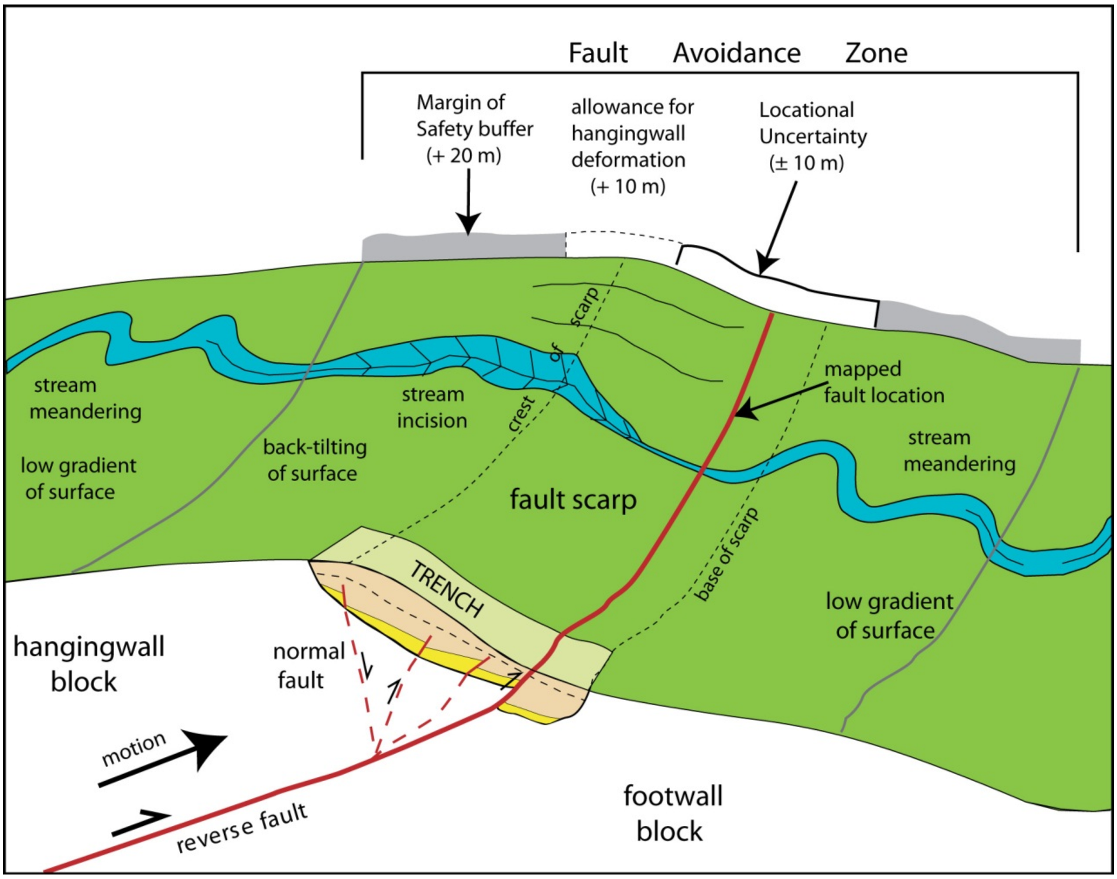

Figure 4.3 Schematic diagram of a dip-slip reverse fault and its scarp. In this case the mapped fault trace (rupture surface; bold red line) is located near the base of the scarp. The scarp itself is well-defined, i.e. ±10 m on LiDAR. The growth of such scarps affects the long–term morphology of streams that cross the structure. The trench shows the expectation for documenting surface faulting events (e.g. faulted orange layer). The concepts of fault Location Accuracy and Fault Avoidance Zone are shown by the different sized parentheses.

4.3 RESOURCE CONSENT CATEGORIES

The final component of the Resource Consent tables is the Building Importance Category (or BIC) level. The BIC categories relate directly to the NZ Building Code and are divided into BIC I (unoccupied structures) through BIC 4 (critical structures). BIC 2a and BIC 2b typically distinguish single storey homes from larger normal structures, respectively. A broader description of BIC categories can be seen in Kerr et al. (2003). Table 4.3 provides an example of a Resource Consent table for RI Class III faults and makes a division between the two types of current land use. Further examples for RI Classes I, II, IV, and V are shown in Appendix 2.

Table 4.3 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 III faults. Categories account for various combinations of Building Importance Category and Fault Complexity.

Resource Consent categories for:
Recurrence Interval Class III (>3500 to ≤5000 years)
e.g., Rangefront, Oruawharo, and Glendevon 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 - constrained	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 - constrained	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.

4.4 EXAMPLES OF USING FAULT AVOIDANCE ZONES FOR PLANNING

Here we provide two hypothetical examples of how the 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.

In the first case, a family wants to build a new, one storey home within a Fault Avoidance Zone along the Tukituki Fault Zone (a RI Class II fault system), east of Waipawa. At their 'greenfield' house site location the fault is 'Well-Defined' and the Resource Consent Category would be 'Permitted*' (see Table 4.3 Notes[4]). The purpose of the asterisk within the MfE table (e.g. Table 4.3) is that the council has the proviso to make an informed decision if the house site is clearly straddling a fault trace or faults scarp. If however, the site was in an area where the fault was mapped as Distributed (= inferred location on LiDAR), then the Resource Consent Category would be 'Permitted'. This process acknowledges that both the risk of a surface faulting event is relatively low, based on the fault recurrence interval, and that the likelihood of the fault being under the foundations of the house are also relatively low, given the uncertainty in the fault location, or the broader distributed pattern of faulting there. Nonetheless, a sensible outcome would be to have the house site set back beyond the Fault Avoidance Zone, where the chances of surface deformation are low. Geologic studies or surveying could be adopted by the family to consider a reduction in the width of the Fault Avoidance Zone supplied here.

As a second example, the community of Otane 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, another RI Class III fault (see Appendix 2). 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 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 would 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.

In a situation where the amount of available land for a house 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 (Figure 3.4) could include detailed mapping of fault traces and scarps, trenching the fault to locate deformation, 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 developing a slip rate approach toward estimating the recurrence interval. With a better handle on the recurrence interval, more appropriate decisions regarding the Building Importance (BIC) can be made.

4 See Appendix 2 for Consent tables of all other Recurrence Interval Classes (RI I, II, IV and V).

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 QMap linework, the uncertainty on fault location is ±125 m. In such a case, accurate mapping or surveying could better define the actual fault location and a define a more practical Fault Avoidance Zone width .

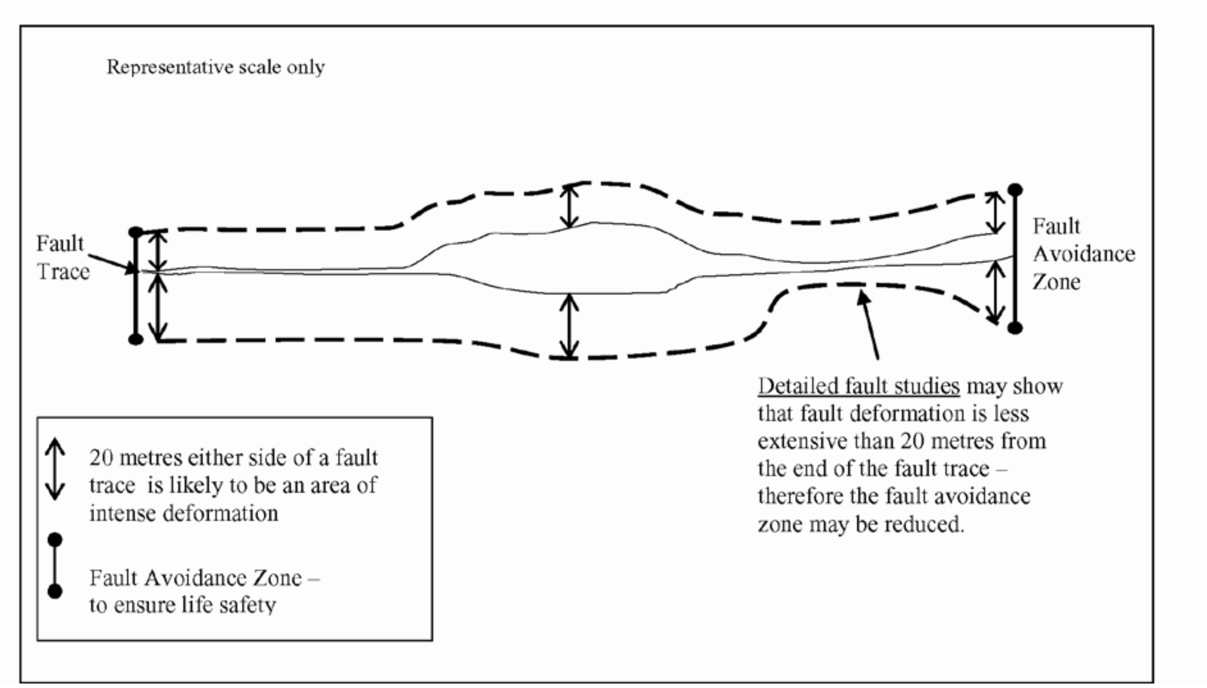

Figure 4.4 Original caption from Kerr et al. (2003) – 'A fault avoidance zone on a district planning map'. As noted in the lower right, where detailed fault studies have been undertaken it is possible to reduce the original mapped width of a given Fault Avoidance Zone.

5.0 SUMMARY

- Active fault traces have been mapped in Central Hawke's Bay (CHB) District using airborne Light Detection and Ranging (LiDAR) digital hillshade models, QMap active fault linework and the GNS Active Faults database. This work builds on previous fault linework and avoidance zone methodology initiated by Langridge et al (2006). Fault Avoidance Zones, GIS attributes, including Fault Name, Locational Accuracy, and Recurrence Interval Class are also presented with the 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 Ministry for the Environment Guidelines (regarding building on or adjacent to active faults). Where LiDAR is available, faults have been mapped as either accurate (±10 m), approximate (±25 m), or inferred (±40 m) in terms of their fault location accuracy. QMap linework is typically less accurate and has 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 Accuracy 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 CHB District. There is one RI Class I fault (Mohaka Fault) and one RI Class II fault (Ruahine Fault) 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.
- 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.

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6.0 RECOMMENDATIONS

- We recommend that the fault line and Fault Avoidance Zones presented as GIS data be adopted by Central Hawke's Bay District Council, i.e. taken up as part of the District Plan. These should supersede previous versions of active fault linework, attributes and Fault Avoidance Zones provided by GNS Report 2006-98 (Langridge et al., 2006) and other studies.
- We recommend that the Ministry for the Environment's guidelines regarding active faulting should be adopted as standard practice for planning and consenting in Central Hawke's Bay District.
- We also recommend that active fault linework and Fault Avoidance Zones should be updated every few years as more LiDAR coverage becomes available. This is particularly true for areas that are undergoing more rapid land use change, such as along the coast and in the northeast of the district where active faults are poorly constrained, in terms of their location and recurrence interval.

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APPENDICES

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APPENDIX 1: 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 supplementary data and the attributes associated to these data are described below. They have an identical list of attributes.

Shapefile Name: CHB_Faultlines_CR_2013_151.shp

Shapefile type: Polyline

Projection: NZGD 2000 New Zealand Transverse Mercator.prj

Shapefile Name: CHB_FAZ_CR_2013_151.shp

Shapefile type: Polygon

Projection: NZGD 2000 New Zealand Transverse Mercator.prj

Each mapped fault trace is represented as a series of line segments 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.

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

LiDAR: Mapped from an airborne LiDAR hillshade model

QMap: Data from QMap geologic mapping program of New Zealand

AFDB: Data from GNS Active Fault Database

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.

Inferred/Uncertain: Where the fault is concealed (buried) or eroded away i.e. where a fault crosses an active river or floodplain.

Location Uncertainty: Is a number value in metres with which we consider to be the maximum mapped location uncertainty for a line segment. These values are used for defining the widths of Fault Avoidance Zones. These distinctions concerning locational uncertainty are important because of: (i) how they relate to the accuracy of the fault linework; (ii) how we build FAZs 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.

For this study the values used are based on the **Data Source** and **Accuracy** attributes as explained in the text and in Figure 4.1.

±*125m*: All Linework from sources mapped at a scale greater than 1:10,000 i.e. QMap or AFDB. A value of ±125 m is used regardless of whether its location is considered accurate, approximate or inferred[5].

±*40 m:* Inferred 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

Dom Sense: 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 Ministry for Environment guidelines (Kerr et al., 2003) defines six recurrence interval classes (RI Classes I-VI) depending on the activity of the fault. The six recurrence interval classes from Kerr et al. (2003) are shown in Table 4.1.

[5] 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.

APPENDIX 2: RESOURCE CONSENT CATEGORY TABLES

Examples, based on the MfE Active Fault Guidelines, of Resource Consent Category for both developed and/or already subdivided sites, and Greenfield sites.

Resource Consent categories for the Mohaka Fault: Fault Recurrence Interval Class I (≤2000 years)					
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 - constrained	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 - constrained	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.

Resource Consent categories for the Ruahine Fault: Fault Recurrence Interval Class II (>2000 to ≤3500 years years)					
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 - constrained	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 - constrained	Permitted	*Discretionary*	*Non-Complying*	*Non-Complying*	Non-Complying
Notes: see previous table.					

Resource Consent categories for: Fault Recurrence Interval Class IV (>5000 to ≤10,000 years) e.g., Wakarara, Ruataniwha, Ryans Ridge FZ					
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 - constrained	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 - constrained	Permitted	Permitted	Permitted	*Discretionary*	Non-Complying
Notes: see first table above.					

Resource Consent categories for Blackburn 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 - constrained	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 - constrained	Permitted	Permitted	Permitted	Permitted	Non-Complying
Notes: see first table above.					