Active Fault Mapping for Western Bay of Plenty Growth Areas

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GNS Science Consultancy Report 2017/97
July 2017

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Clark KJ, Villamor P, Ries WF. 2017. Active Fault Mapping for Western Bay of Plenty Growth Areas. Lower Hutt (NZ): GNS Science. 19 p + CD. (GNS Science consultancy report; 2017/97).

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EXECUTIVE SUMMARY

Active faults represent a source for strong earthquakes and when they rupture to the ground surface, they also represent a ground deformation hazard. This report details GNS Science's commissioned investigation into the identification and mapping of active faults within the Te Tumu and Tauriko West development areas, near Tauranga. We have reviewed active fault studies in the region and analysed geological and topographic data (LiDAR) to identify active faults, and possible active faults, within the development areas. The following is a summary of our results:

- A topographic lineation has been identified in the Tauriko West area as a possible active fault, although other (non-tectonic) origins are also possible.
- Geological evidence suggests that, if the lineation is an active fault, then it has a very low slip rate of 0.017 – 0.04 mm/yr and a recurrence interval of >10,000 years (Recurrence Interval (RI) Class V).
- According to the Ministry for the Environment (MfE) Active Fault Guidelines, residential development (Building Importance category 2a and 2b) may be permitted across the possible active fault at Tauroko West because there is a low likelihood of fault rupture and a commensurate low hazard. Building Importance category 3 structures are also allowable on RI Class V faults, but Building Importance category 4 structures (structures with special post disaster functions) should not be allowable.
- Further investigation regarding fault location and activity would be required prior to issuing building consent for high Building Importance structures, such as emergency service and medical emergency facilities, on, or near, the possible RI Class V fault scarp.
- No evidence of active faults was found in the Te Tumu area.

1.0 INTRODUCTION

The Bay of Plenty Regional Council (BOPRC) is assisting Tauranga City Council to identify development constraints for structure planning purposes, by understanding the nature of active faults within two growth areas in the Western Bay of Plenty, Te Tumu and Tauriko West development areas (Figure 1.1). The Ministry for the Environment (MfE) has developed a set of guidelines to provide direction on land use planning approaches for land on or close to active faults (Kerr et al. 2003); these guidelines are hereafter referred to as the “MfE Active Fault Guidelines”. The objective of this project is to identify and map active faults in areas proposed for urban growth, prior to development, so the active fault hazard can be managed in a way that reduces risk.

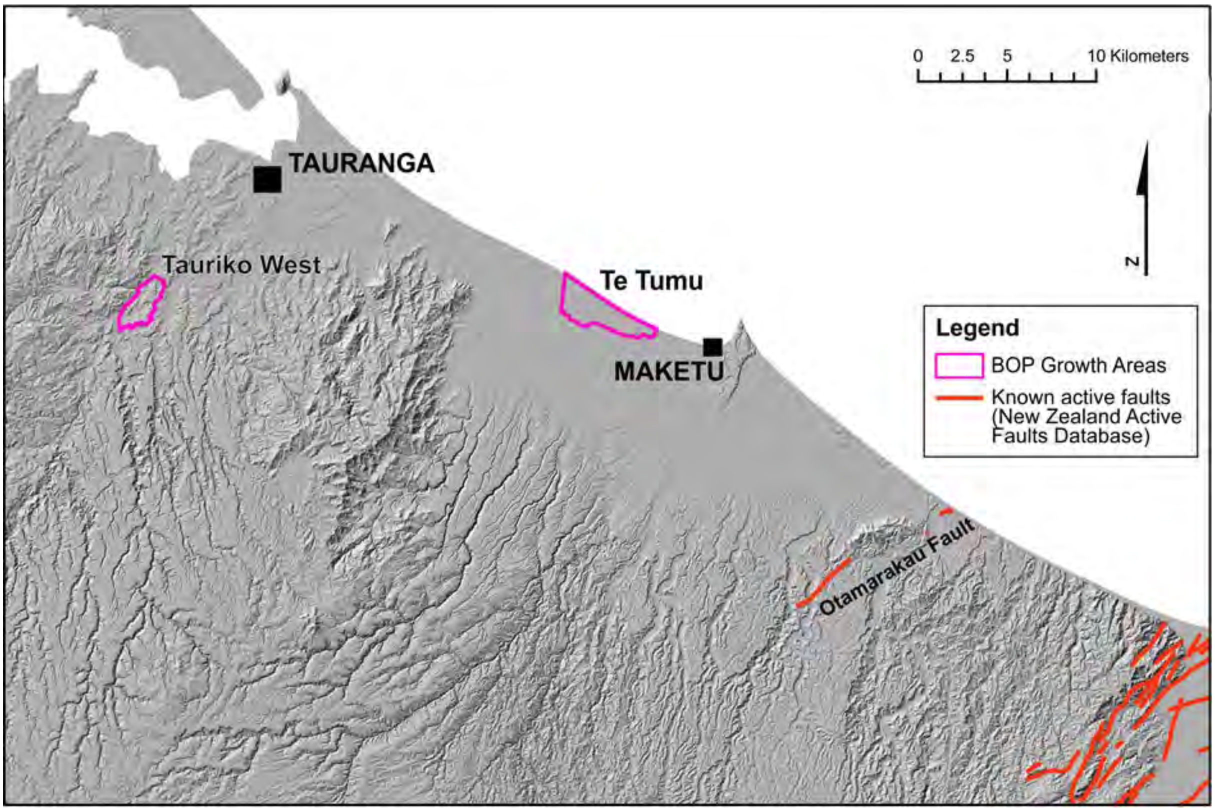


Figure 1.1 The Tauriko West and Te Tumu growth areas in the Bay of Plenty, shown on a hillshade LiDAR digital elevation model with the location of previously identified nearby active faults (Langridge et al. 2016).

1.1 METHODS

Active faults, in the context used in this report, are faults that rupture the Earth's crust all the way to the ground surface, are capable of producing large earthquakes (usually ≥M_w6), and that are currently defined as active. New Zealand Active fault database defines a fault as active if it has ruptured within the last 125,000 years, and for the Taupo Volcanic Zone (TVZ), if it has ruptured within the last 25,000 years (Langridge et al 2016). This latter definition is related to the fast evolution of faults in the TVZ. The area of study is within the older part of the TVZ, an area where scientists have interpreted that volcanism (Wilson et al 1995) and faulting (Villamor and Berryman 2006; and Villamor et al in prep) have ceased as the active rift has migrated southwards. However, because studies of active faults with LIDAR data (see below) are bringing new insights into fault activity we will use the broader age threshold of 125,000 years for this study.

Active faults are typically identified by a landscape feature of a fault scarp (elongated bump, step or groove in the ground); the scarps tend to be relatively linear and usually cut across other landforms, such as river terraces (terrace surfaces or risers), hill slopes, river beds, etc. Often it's possible to know the age of the main geomorphic features (landforms) in the landscape; therefore, the history of fault activity can be deduced from the age of the displaced features.

In this study, we follow the MfE Active Fault Guidelines (Kerr et al., 2003) to assess the areas of land development that may need special considerations for building with respect to active fault lines, and the ground deformation hazard they pose. The main considerations are: the location where an active fault plane will rupture the ground; and the level of activity of the fault (measured by the recurrence interval, further explained below), which dictates what type of buildings may, or may, not be permitted on, or near, that fault (Table A1.1).

Following the MfE Active Fault Guidelines, we map active or potentially active faults in the areas of interest, and examine the relationship between fault scarps and the age of the geomorphic surfaces to assess the activity of the fault. In the TVZ, faults have a normal sense of movement, and they typically form clear fault scarps with the land on one side of the fault higher that the other side, resulting from vertical displacement across the fault during rupture (Figure A1.1). Therefore, faults are typically identified as sublinear features that cross geomorphic surfaces and display clear differences in height of the land across it. Fault scarps may cut across surfaces of different ages or only be present on certain age surfaces. They may also be at the boundary between two different geological units (rock types).

To identify faults scarps it is best to use the highest resolution topographic models available, and for this project we have used LiDAR data collected in 2014 and provided by BOPRC. For regional-scale analysis, 2 m gridded bare earth LiDAR data was used and we combined hillshade and digital elevation models (DEMs) to identify regional-scale landscape features. For more detailed local-scale analysis in the areas of interest we used 0.5 m and 0.2 m gridded bare earth LiDAR data and used combinations of hillshade, DEM and slope maps to identify local-scale landscape features such as scarps, river terraces and terrace risers.

In addition to the high-resolution topographic models we have also used geological data that has a bearing on active faults; namely the New Zealand Active Faults Database (Langridge et al. 2016), geological mapping in QMAP (Leonard et al. 2010), and some unpublished data on active fault locations west of Maketu from P. Villamor of GNS Science. Where the scarp of an active fault has been identified, it has been mapped in a GIS using the most recent set of active fault trace GIS attributes used by GNS Science. In accordance with the MfE Active Fault

Guidelines, we place a fault rupture hazard zone around the fault trace and an additional setback buffer of 20 m width in order to construct what is defined in the MfE Active Fault Guidelines as a Fault Avoidance Zone (FAZ).

The MfE Active Fault Guidelines require the assessment of the recurrence interval (RI) of the fault as the parameter to evaluate fault activity. The RI is the time between large, ground-surface rupturing earthquakes on a particular fault. This parameter is best evaluated where the fault plane can be exposed (for example, by trenching across a fault scarp). However, excavation and analysis of exploratory trenches is beyond the scope of this study, so we have alternatively assessed the fault slip rate from analysing the height of any fault scarps and an estimate of the landscape age. The slip rate is another measure for fault activity and it represents its “velocity”. It is usually expressed in mm/yr but in reality the fault moves in jumps of several cm to several meters per rupture (single event displacement, SED). If we can calculate the slip rate and assume a reasonable SED, we can derive a preliminary RI. The MfE Active Fault Guidelines categorise ranges of RIs into RI Classes. In the MfE Active Fault Guidelines these RI Classes are in turn tabulated to show which types of buildings (as defined by Building Importance Class) are permitted for each RI Class (Table A1.1 and Table A1.2; Kerr et al 2003).

2.0 RESULTS: TAURIKO WEST

The geomorphology of the Tauriko West area consists of elevated, near-flat terrace surfaces, steep terrace risers, and a low, flat area of infilled floodplain deposits (Figure 2.1 and Figure 2.2). The landscape features at Tauriko West were formed at different times. The main terrace surface (T1) is formed of ignimbrite (Chimp Formation, 0.3 million years old: (Leonard et al. 2010), a massive and thick volcanic deposit that usually covers and fills the whole landscape as it flows, during eruption, along the river network. It is expressed in the landscape as an extensive geomorphic surface, and forms the broad plateau that dominates the region from Mamaku to the Bay of Plenty coastline. The study area of Tauriko West is located at the distal edge of this plateau. The ignimbrite surface has been incised by the Wairoa River to create a sequence of lower river terraces at 35-40 m (T2), and 15 m (T3) elevation above sea level. The risers separating these terraces are typically very steep (15 - 20°). The lower terraces and risers are <0.3 Ma in age. The lowest elevation river terrace surface (Fluvial 1), at ~5 m above sea level is formed of Holocene (<12,000 years) fluvial deposits (Figure 2.1b).

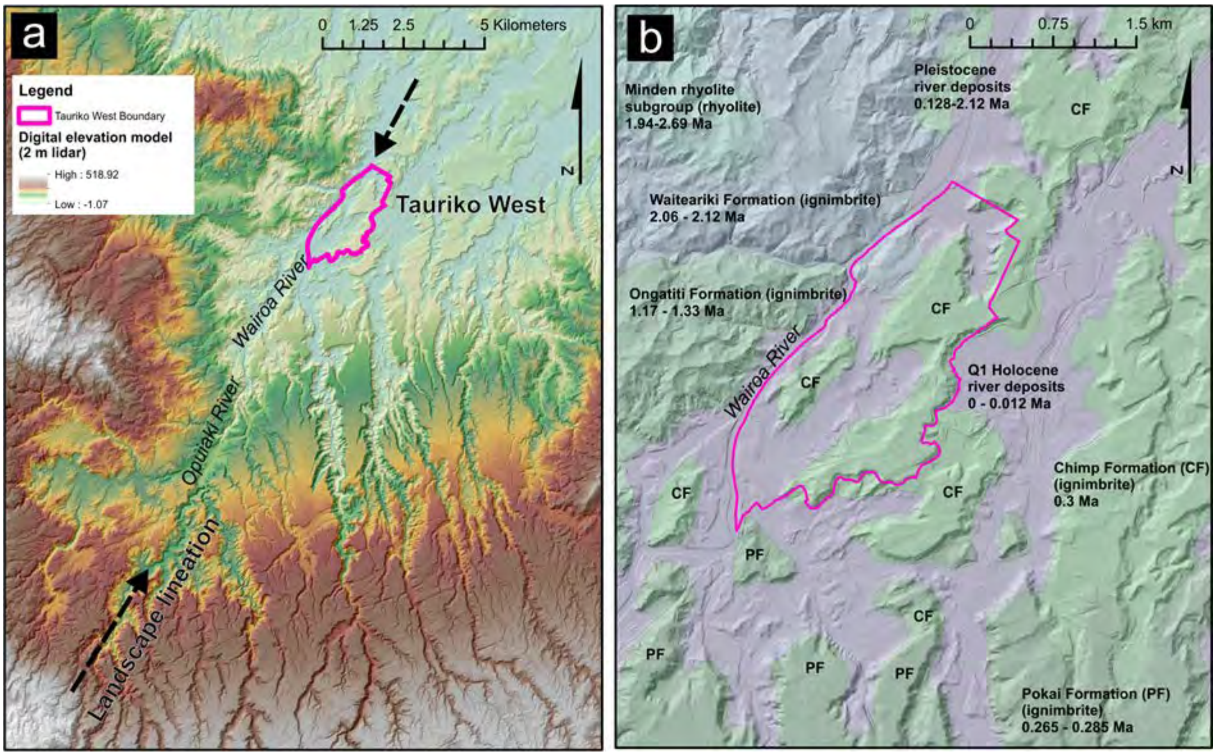


Figure 2.1 (a) A digital elevation and hillshade LiDAR DEM of the topography of the region surrounding the Tauriko West area. The black arrows point out the large-scale landscape lineation that may represent a fault line. (b) The geology and landform ages of the Tauriko West area, from Leonard et al. (2010).

One topographic lineation, that may represent an active fault, has been identified in the Tauriko West area (Figure 2.2). The southwest-northeast trending topographic lineation may be a possible active fault for two reasons: (1) it aligns with a regional-scale landscape lineation that suggests the presence of a basement fault; and (2) the morphology of the topographic scarp, in terms of linearity and slope, is anomalous compared with nearby river-cut terrace risers. We expand on each of these points below.

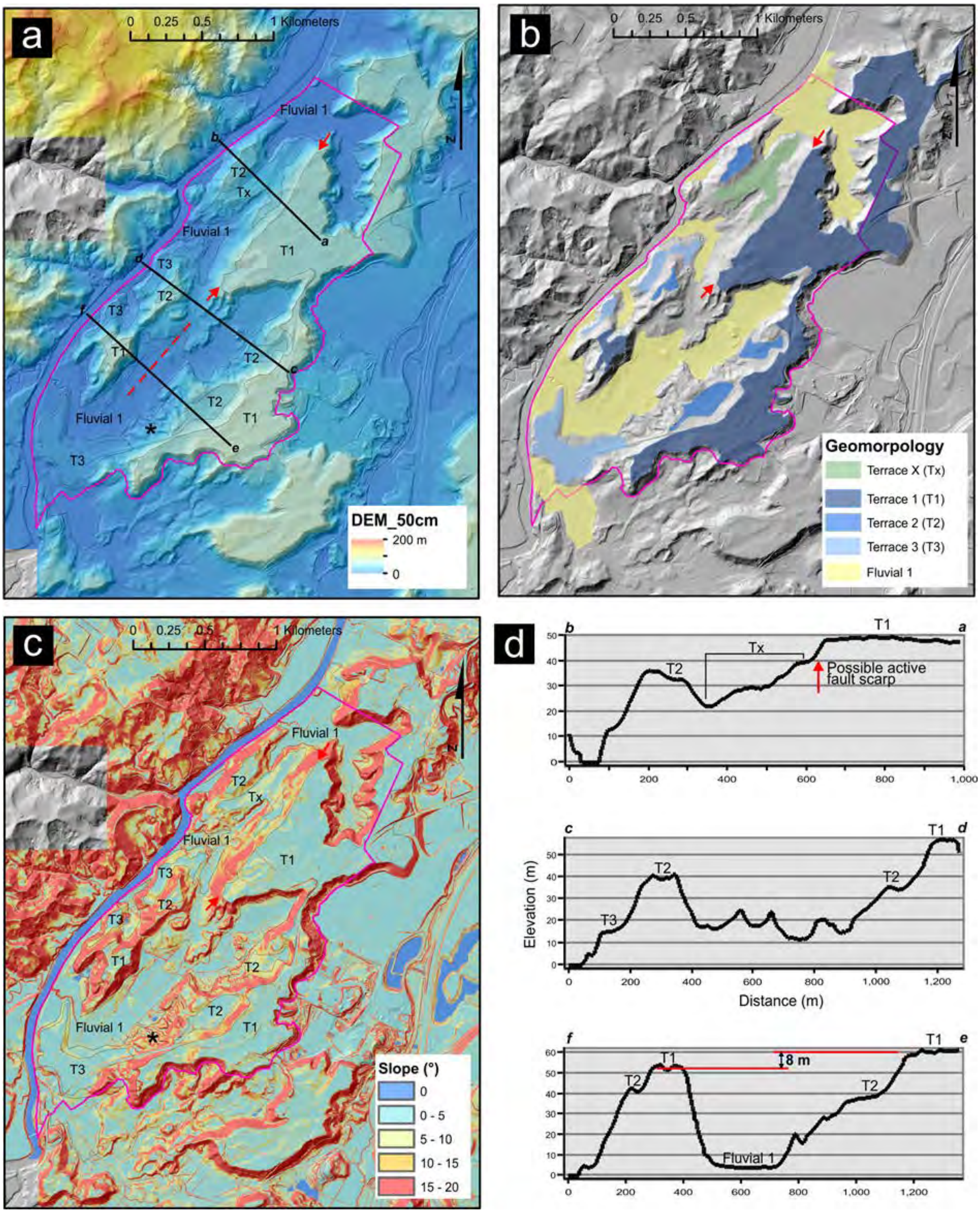


Figure 2.2 (a) Digital elevation and hillshade LiDAR DEM of the Tauriko West area. The location of the topographic lineation is shown by the red arrows. Red dashed line shows the along-strike projection of the lineation, * shows the location of landslide debris at the base of terrace risers and the black lines show the locations of the topographic profiles of figure (d). (b) Geomorphic map of the terrace surfaces of the Tauriko West area showing, mainly, the distribution of various terraces (both volcanic and fluvial) in the area. (c) Slope DEM of the Tauriko West area. The river terrace risers, which are typically irregular and steep (15 – 20°) are shown well by this imagery. (d) Topographic profiles from across the possible active fault scarp and its along-strike projection. We show the possible faulted offset of surface T1 in profile e-f.

2.1 REGIONAL-SCALE LANDSCAPE LINEATION

The Wairoa/Opuiaki Rivers flow along a SW-NE trending valley (Figure 2.1a); the straightness of these river valleys is somewhat anomalous for the region and one possible explanation for this "straightness" is that the rivers follow a fault line. Such a fault line does not necessarily have to be active (i.e., to have ruptured in the past 125,000 years); the river may just be exploiting a line of weakness in the basement rocks created by an old fault. Indeed, the location and strike of this possible fault, well to the northwest of the currently active faults of the Taupo Volcanic Zone (TVZ), suggests it could be one of the faults that bounded the old Taupo Rift, which was active between 2 and 0.35 million years ago (Villamor and Berryman 2006; Villamor et al. in prep). A fault at that location could have created a large fault scarp in the landscape in the past that could have been a barrier for the deposition the Chimp Formation Ignimbrite at 0.3 million years ago. The ignimbrite is not present on the west side of the lineament, suggesting that this could be the case. The juxtaposition of different rock formations of either side of the fault could have promoted river diversion along the fault, thus creating a lineament in the landscape that is controlled by old, inactive geological structures.

2.2 ANOMALOUS SCARP MORPHOLOGY

We have undertaken geomorphic mapping of the Tauriko West area in order to identify the different terrace levels and the morphology of the terrace risers (Figure 2.2a-c). Most terraces are separated by risers that are relatively steep (15 - 20°) and have an irregular, sometimes scalloped-shape, morphology. These terrace risers are typical of fluvial systems where the terraces are cut by meandering fluvial channels. The topographic lineation that we discuss as a possible active fault is different from a typical terrace riser in two ways:

- The slope is less (10 - 15°) than typical for terrace risers (Figure 2.2c).
- It follows a more or less straight line for ~1 km, whereas most terrace risers have a more irregular shape (Figure 2.2a).

2.3 OFFSET ACROSS THE POSSIBLE ACTIVE FAULT

If the topographic lineation is an active fault, then the difference in height across the scarp can be interpreted as the cumulative earthquake displacement from several surface ruptures, (i.e. accumulation of several SEDs) after the formation of the geomorphic surface. To estimate a slip rate of the fault, one needs to know the scarp height and the approximate age of the faulted surface. The topographic lineation at Tauriko West appears to offset the highest terrace surface (the T1 surface of the Chimp Formation, 0.3 million years old; Figure 2.1b), but the terrace on the downthrown side (Tx) does not seem to be the same terrace, based on its geomorphic character. Topographic profiles show that T1 is very flat, while the ground-surface on the downthrown side of the topographic lineation (Tx) has undulating topography and only a few flat portions that could be terrace surfaces (Figure 2.2a, Figure 2.2d). Without field work to investigate the underlying geological units, it is difficult to ascertain if Tx is indeed a terrace surface, and whether it is equivalent in age to T1.

Rather than determining an offset directly at the topographic lineation we can speculatively estimate an offset of the T1 terrace across the along-strike extension of the topographic lineation. On profile e-f (Figure 2.2d), the T1 surface occurs at different elevations in the east (60 m above sea level) and west (52 m above sea level) across the along-strike extension of the topographic lineation (which presumably has no expression where it is covered by young Holocene fluvial sediments in the valley floor). The ~8 m offset in the T1 surface across the topographic lineation extension may represent a faulted offset. Given the age of the T1 surface of 0.3 million years, this 8 m vertical offset yields a slip rate of 0.027 mm/yr. Assuming age uncertainties of ± 0.05 million years and offset uncertainties of ± 2 m; this gives a slip rate range of 0.017 mm/yr – 0.04 mm/yr. This is a very low slip rate compared to the slip rates of active faults in the modern TVZ of 0.2 to 2 mm/yr (Stirling et al. 2012; Villamor et al. 2001).

The timing of past earthquakes on the possible active fault at Tauriko West can be roughly constrained by the offsets of different aged surfaces. The T1 surface (0.3 million years) may be offset by 8 ± 2 m. Such a large displacement is likely to represent several earthquakes (TVZ faults tend to have a maximum of 2 m SED; Stirling et al 2012). However, the next youngest terrace (T2) does not appear to have any vertical offset across the along-strike extension of the topographic lineation on profiles c-d and e-f (Figure 2.2d); in fact, in both profiles it appears that T2 is slightly higher on the western side of the topographic lineation which is of opposite sense to the scarp displacement. There is no displacement on the valley flats (Fluvial 1 surface, <12,000 years). That the topographic lineation appears to offset the 0.3 million year old surface but not younger surfaces could yield information about the timing of the last fault rupture, except that we have no data on the age of the non-offset T2 surface. If the identified topographic lineation is an active fault, we can only confirm that the last event occurred between the Holocene period (<12,000 years) and 0.3 million years ago.

The very low slip rate and evidence that the possible fault has not been active in the Holocene imply the possible active fault has a very long recurrence interval. Typical SED displacements in TVZ faults range between 0.5 and 2 m (depending on the earthquake magnitude) (Villamor et al 2001; Stirling et al 2012). If we use those values together with slip rate, we calculate RIs ranging from 12,500 to 100,000 years. The RI is therefore highly likely to be >10,000 years, which places this fault in RI Class V or higher, according to the classification of the MfE Active Fault Guidelines. According to the MfE Active Fault Guidelines, residential development (Building Importance category 2a and 2b) and structures of Building Importance category 3 may be permitted across the fault scarp because there is a low fault rupture hazard (Appendix 1).

2.4 ALTERNATIVE EXPLANATIONS FOR THE ANOMALOUS SCARP

The topographic lineation could be an active fault scarp but there are other alternative, non-tectonic, processes that could have formed the lineation. The most logical alternative explanation is that the lineation is a river terrace riser; we explain this below.

- The lesser slope of the scarp of the topographic lineation, compared to nearby terrace risers, could be due to slope movement or slumping of the riser. Indeed, evidence of past landslides at the base of terrace risers can be seen in other areas of Tauriko West (see * in Figure 2.2a and Figure 2.2c).
- The straightness of the topographic lineation could be due to the river being pinned in this area in a relatively narrow valley, and therefore having little room to meander; much like the straight river channel seen in the present day at this location. This narrow valley can be a consequence of the river exploiting the contact between the two different rock formations on both sides of the river.
- The apparent ~8 m offset of the T1 surface across the along-strike extension of the topographic lineation could simply be due to erosion of the T1 river terrace and formation of a lower terrace surface on the western side of the valley where it is closer to the modern river course.

Further aspects of the topographic lineation that suggest it does not have a tectonic origin include:

- There is an absence of terrace surface tilt away from the topographic lineation. If the topographic lineation on T1 were an active fault, we would expect that the surface of T1 would have been progressively back tilted by surface rupture of the fault. There is no evidence of tilt on T1 (Figure 2.2a, d).
- The sense of throw on the fault is the opposite to what would be expected given the regional tectonics. Faults on the northwestern side of the TVZ are typically downthrown to the southeast, whereas the topographic lineation that we identify at Tauriko West is downthrown to the northwest. This opposite sense of throw on the scarp is supporting (but not diagnostic) evidence that it is not an active fault scarp.

In summary, all of the characteristics of the topographic lineation that suggest it may be an active fault, could also be explained by non-tectonic processes. Resolving the origin of the scarp is not possible without field investigations.

2.5 SCARP LOCATION, FAULT AVOIDANCE ZONE AND BUFFER ZONE

If we assume that the topographic lineation described above as a “possible fault” is, in fact, an active fault, then we have mapped the Fault Avoidance Zone (FAZ) for this feature in a GIS (Figure 2.3). The location has been defined as the lower edge of the topographic scarp, which is the typical location of a normal fault with respect to the scarp. The fault rupture hazard zone is ± 50 m wide either side of the fault (yellow area, Figure 2.3). This area comprises the uncertainly in the exact location where the fault plane would cut the surface (as it can be anywhere within the fault scarp, although observations of active fault ruptures suggest that it has a higher likelihood to be located at the base of the scarp) and also other secondary deformation that can occur in close proximity to the main fault trace.

The possible fault location has also been mapped across the low elevation floodplain to the northeast and southwest of the fault scrap; we infer that if the feature is, in fact, an active fault (with a very low rate of activity) then it is located within this zone, but is concealed by recent floodplain sediments. There is a wider fault rupture hazard zone around the possible fault trace across the floodplain to reflect the locational uncertainty. In addition to the fault uncertainty zone, the MfE Guidelines recommend an additional 20 m wide buffer zone (orange area, Figure 2.3). Together these zones form the FAZ (Figure 2.3). The GIS file of the possible FAS is provided as a digital appendix to this report.

According to the MfE Guidelines, residential development (Building Importance category 2a and 2b) may be permitted across the possible active fault scarp identified at Tauriko West because it poses a very low fault rupture hazard. Building Importance category 3 structures are also allowable on RI Class V faults, but Building Importance category 4 structures (structures with special post disaster functions) should not be allowable. Further investigation regarding fault location and activity would be required prior to issuing building consent for high Building Importance structures, such as emergency service and medical emergency facilities, on, or near, the possible RI Class V fault scarp.

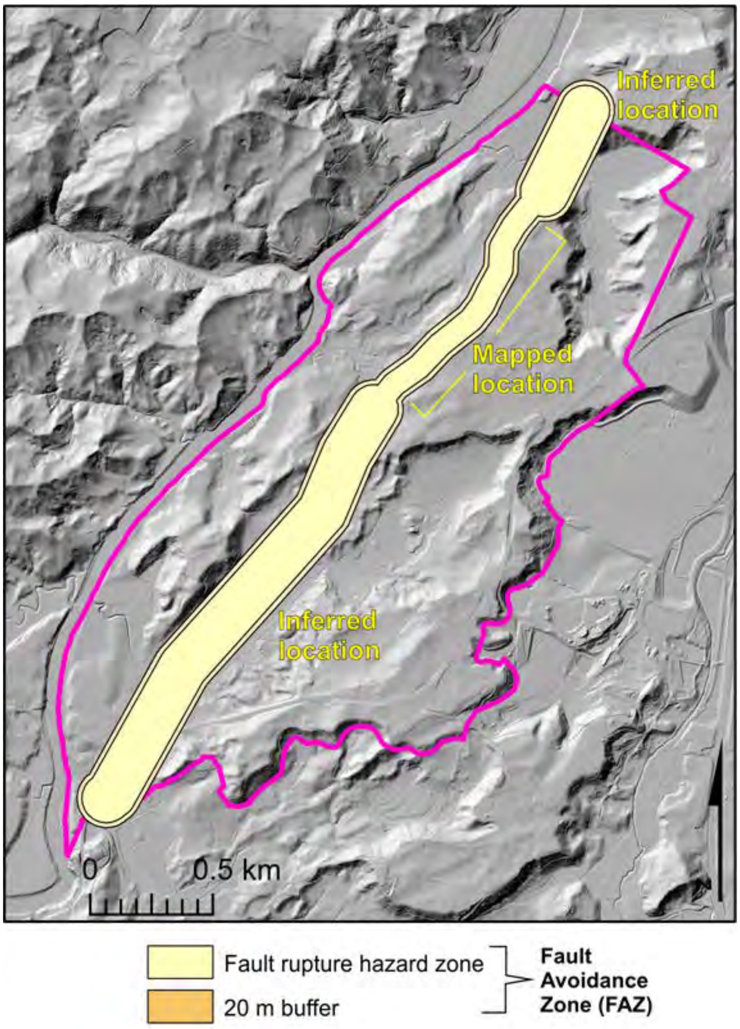


Figure 2.3 The FAZ for the possible active fault scarp in the Tauriko West area. Note that we can only map the possible fault scarp location across the higher T1 terrace; we infer the fault location across the low elevation floodplain and in this area there is a much higher locational uncertainty as the possible fault is concealed, resulting in a wider FAZ.

3.0 RESULTS: TE TUMU

No active fault traces have been identified in the Te Tumu growth area from the examination of LiDAR and geological data: however, the area is covered by relatively young sediment that could obscure an active fault that has simply not ruptured in the past ~7,000 years (Figure 3.1). The Te Tumu area is located entirely on Holocene beach deposits that are defined as <12,000 years old, but in reality are much more likely to be <7,000 years old, as they have probably accumulated since the time of Holocene sea level stabilisation at ~7,000 years before present (BP).

A detailed examination of the topography and slope DEMs of the Te Tumu area was undertaken and no evidence of active faulting was seen (Figure 3.2). The geomorphology of the area is dominated by a sequence of shore-parallel low dune ridges (up to 15 m elevation above sea level) and inter-dune swales (1 – 2 m elevation above sea level). One lineation was seen near the middle of the Te Tumu area where two sharp changes in the location of the dune crests are seen (blue arrows, Figure 3.2a). However, not only are the coastal and inland dune crests offset in opposite directions (inconsistent with faulting which would offset features in the same direction) but the dune ridges in between show no evidence of an offset (circled area, Figure 3.2a). We conclude these sharp offsets in the dune crests are natural features that coincidentally occur in a lineation.

Further inland and further offshore of the Te Tumu area, no active faults have been identified, and this supports the conclusion that no active faults underlie the Te Tumu area (Figure 3.1). Most active faults of the region near the TVZ trend southwest to northeast, so should an active fault underlie the Te Tumu area it is likely the fault would be present on older surfaces to the northeast or southwest of Te Tumu. Southwest of Te Tumu are Quaternary alluvial sediments (<12,000 years old), late Quaternary alluvial sediments (<128,000 years old) and Quaternary ignimbrite surfaces of the Mangaone subgroup (229,000 – 251,000 years old; Figure 3.1b). None of these surfaces show topographic scarps indicative of active fault offsets.

Several inactive faults have been mapped by Leonard et al. (2010) in the area near Te Tumu (yellow lines, Figure 3.1) and there are observations of Quaternary fault offsets in the coastal cliffs around Maketu. Unpublished data by P Villamor shows that ~322,000-240,000 year old formations exposed in the coastal cliffs around Maketu are offset by several normal faults, but overlying 240,000 year old ignimbrites and the last Interglacial (~125,000 years old) paleosol are not displaced, indicating that faulting had ceased before 240,000 years ago. For the purposes of this report, these are considered inactive faults.

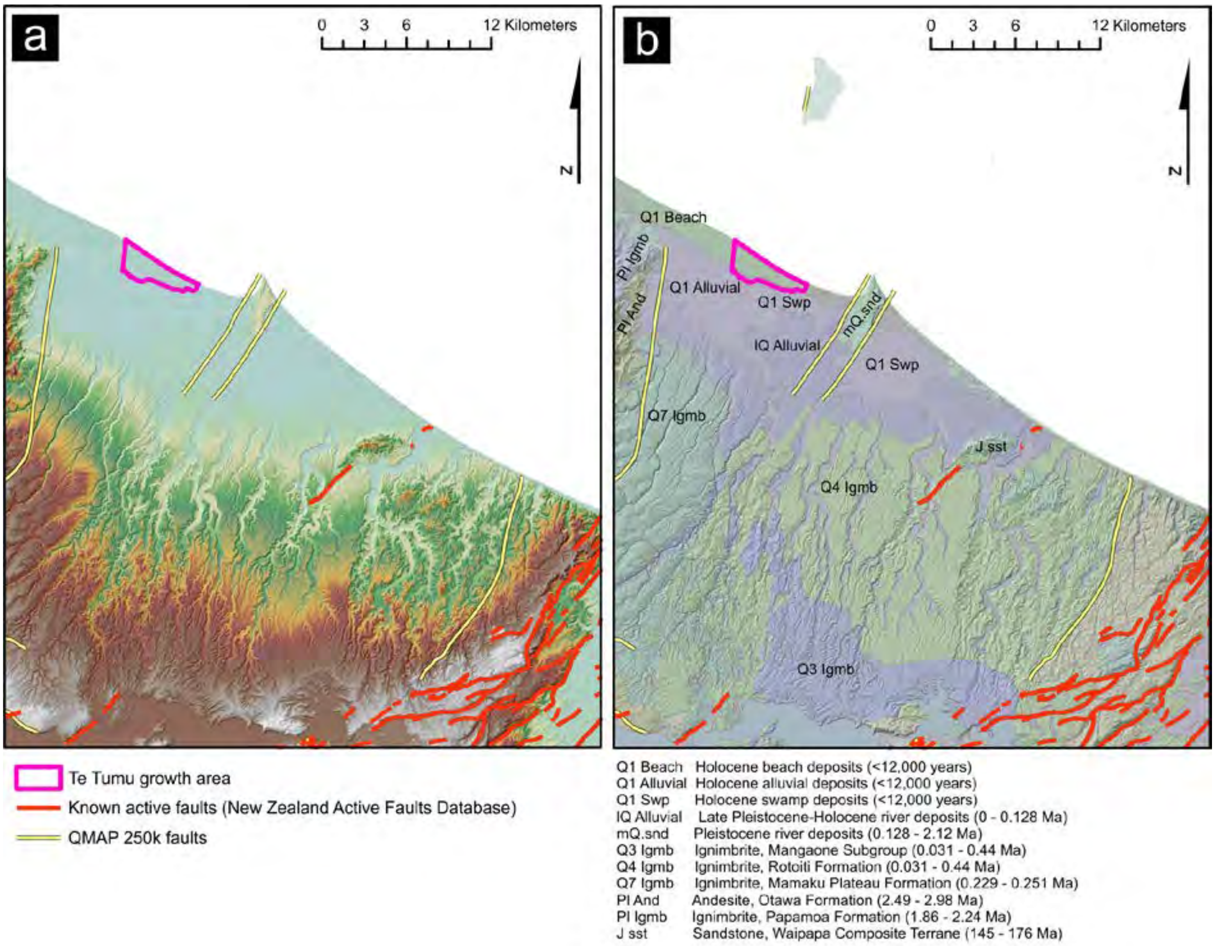
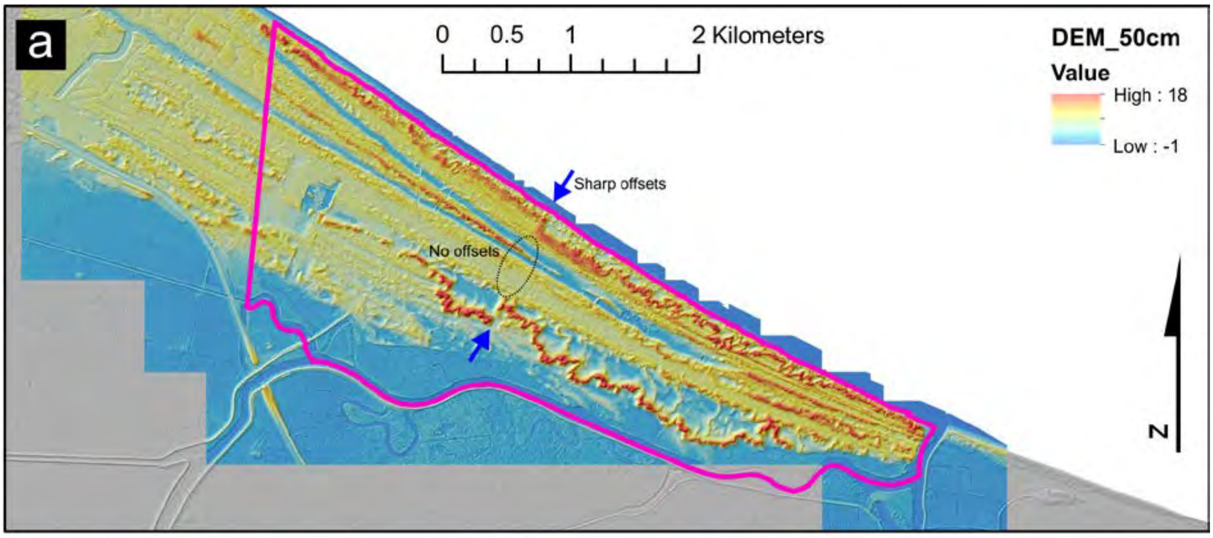


Figure 3.1 (a) A digital elevation and hillshade LiDAR DEM of the topography of the region surrounding Te Tumu. Onshore active faults from the NZ Active Faults database (Langridge et al. 2016), inactive faults from Leonard et al. (2010). (b) The geology and surface ages of the Te Tumu area, geological mapping from Leonard et al. (2010).



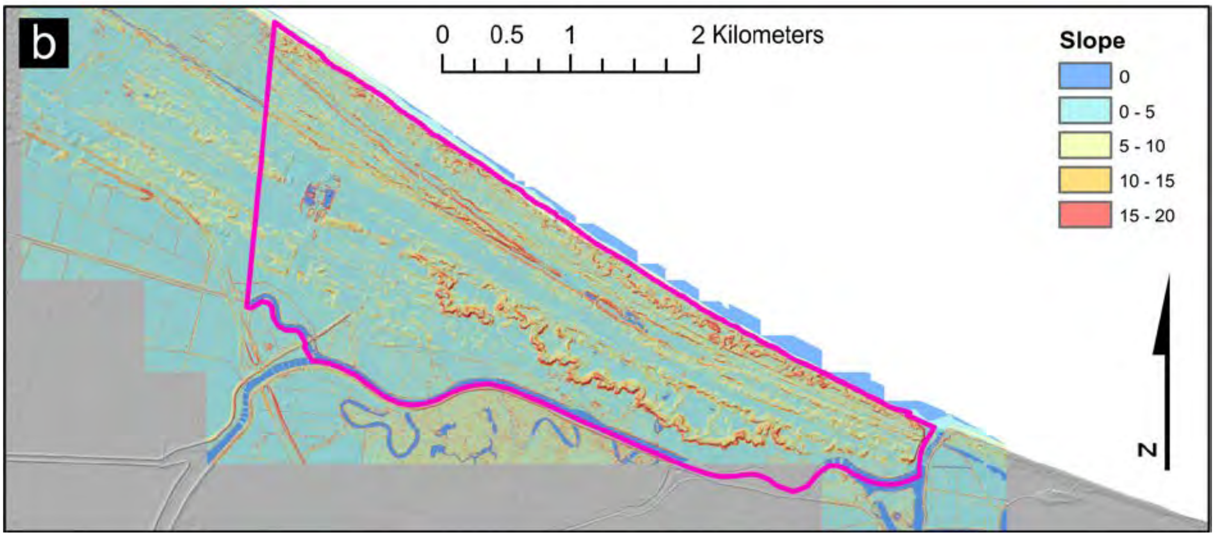


Figure 3.2 (a) Digital elevation and hillshade topographic LiDAR DEM of the Te Tumu area. The location of a lineation is shown by the blue arrows. (b) Slope DEM of the Te Tumu area. No scarp features compatible with active faults are seen.

4.0 SUMMARY AND RECOMMENDATIONS

A topographic lineation has been identified in the Tauriko West area. The lineation could represent a possible active fault, however, there is not strong evidence for a tectonic origin for this scarp, and it could have formed by non-tectonic processes. If the anomalous scarp is an active fault, currently available geological data suggests it has a very low slip rate of 0.017 – 0.04 mm/yr and a RI of >10,000 years (RI Class V).

No evidence of active faults was found in the Te Tumu area. The sediments of the Te Tumu area are very young (<7,000 years old) therefore could conceal an active fault that has not ruptured in the past 7,000 years but there is also no expression of active faulting inland of Te Tumu on older surfaces.

In the case of planning for the location of future critical facilities (e.g. structures with special post disaster functions such as emergency service and medical emergency facilities) in the Tauriko West area, field investigations would need to be undertaken to determine if the topographic lineation is, in fact, an active fault and to determine the slip rate and recurrence interval. Alternatively, the footprint of the building, where it crosses the possible fault scarp, could be trenched to determine if it does cross an active fault. GNS Science can provide recommendations for future field work studies if this possible fault scarp requires further investigation.

5.0 ACKNOWLEDGEMENTS

We would like to thank Russ Van Dissen and Sally Dellow for providing peer reviews of this report. We also thank Dave Heron for assistance with the LiDAR processing.

6.0 REFERENCES

Kerr J, Nathan S, Van Dissen RJ, Webb P, Brunsdon D, King AB. 2003. Planning for development of land on or close to active faults: A guideline to assist resource management planners in New Zealand. Wellington (NZ): Ministry for the Environment. 68 p. http://www.mfe.govt.nz/publications/rma/planning-development-active-faults-dec04/planning-development-active-faults-dec04.pdf.

Langridge RM, Ries WF, Litchfield NJ, Villamor P, Van Dissen RJ, Barrell DJA, Rattenbury MS, Heron DW, Haubrock S, Townsend DB, et al. 2016. The New Zealand Active Faults Database. *New Zealand Journal of Geology and Geophysics*. 59(1):86-96. doi:10.1080/00288306.2015.1112818.

Leonard GS, Begg JG, Wilson CJ. 2010. Geology of the Rotorua area [map]. Lower Hutt (NZ): Institute of Geological and Nuclear Sciences. 1 sheet + 99 p., scale 1:250 000. (Institute of Geological and Nuclear Sciences 1:250 000 geological map; 5).

Stirling MW, McVerry GH, Gerstenberger MC, Litchfield NJ, Van Dissen RJ, Berryman KR, Barnes P, Wallace LM, Bradley B, Villamor P, et al. 2012. National Seismic Hazard Model for New Zealand: 2010 Update. *Bulletin of Seismological Society of America*. 102(4):1514-1542; doi: 1510.1785/0120110170.

Villamor P, Berryman KR. 2006. Evolution of the southern termination of the Taupo Rift, New Zealand. *New Zealand Journal of Geology and Geophysics*. 49(1):23-37.

Villamor P, Berryman KR, Ellis SM, Schreurs G, Wallace LM, Leonard GS, Langridge RJ, Nairn IA, Ries WF. in prep. Rapid evolution of an intra-arc rift: The role of voluminous rhyolite volcanism, Taupo Rift, New Zealand. *Tectonics*.

Villamor P, Berryman KR, Webb TH, Stirling MW, McGinty PJ, Downes GL, Harris JS, Litchfield NJ. 2001. Waikato seismic loads - Task 2.1 Revision of seismic source characterisation. Lower Hutt (NZ): Institute of Geological & Nuclear Sciences. 109 p. (Institute of Geological & Nuclear Sciences client report; 2001/59).

APPENDICES

A1.0 APPENDIX 1

Table A1.1 Relationship between fault RI and Building Importance Category (source: Kerr et al., 2003). Note: Faults with average recurrence intervals >125,000 years are not considered active.

Recurrence Interval Class	Fault Recurrence Interval	Building Importance Category (BIC) Limitations* (allowable buildings)	
		Previously Subdivided or Developed Sites	"Greenfield" Sites
I	≤2000 years	BIC 1	BIC 1
II	>2000 years to ≤3500 years	BIC 1 and 2a	
III	>3500 years to ≤5000 years	BIC 1, 2a and 2b	BIC 1 and 2a
IV	>5000 years to ≤10,000 years	BIC 1, 2a, 2b and 3	BIC 1, 2a and 2b
V	>10,000 years to ≤20,000 years		BIC 1, 2a, 2b and 3
VI	>20,000 years to ≤125,000 years	BI Category 1, 2a, 2b, 3 and 4	

Table A1.2 Building Importance Categories and representative examples. For more detail see Kerr 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

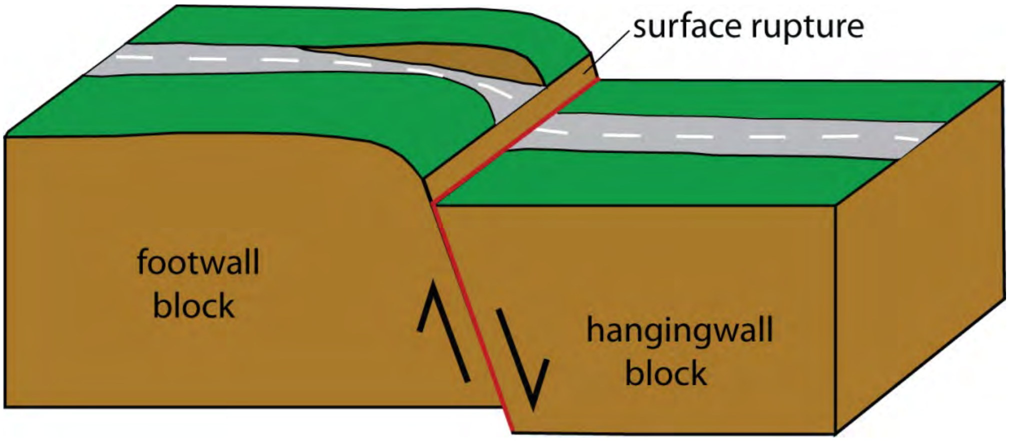


Figure A1.1 Block model of a normal dip-slip fault, typical of the TVZ faults. The relative movement of the blocks is vertical and in the dip direction of the fault plane. The hanging-wall block has dropped down, enhancing the height of the fault scarp.

A2.0 DIGITAL APPENDIX

FAZ for the topographic lineation identified at Tauriko West.

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