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8 March 2021

Policy Advisor
Taupō District Council
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Attention: Aidan Smith

Dear Aidan,

Active fault mapping in the south western bays (Pukawa, Omori, Kuratau) of Lake Taupō: Response to requests

1.0 BACKGROUND AND PURPOSE

GNS Science was commissioned in 2019 by Taupō District Council to provide advice and updated active fault information for planning purposes. This information was supplied in a report (Litchfield et al. 2020) accompanied by GIS data of active faults (lines or traces), Fault Avoidance Zones and Fault Awareness Areas.

As part of that study, three ‘possible’ active fault traces were mapped in the south western bays (Pukawa, Omori, Kuratau – hereafter referred to as the SW Bays), and the community would like more information on how these have been identified and what is known/unknown about them. This report provides that additional information.

2.0 ADDITIONAL INFORMATION ON THE FAULT LINE MAPPING

Prior to the study of Litchfield et al. (2020), no active faults had been mapped in the SW Bays. Taupō District Council requested GNS Science to look closely at parts of the SW Bays that have been identified for future development (blue areas in Figure 2.1).

The SW Bays are also now covered by Light Detection and Ranging (LiDAR) data collected in 2006 and 2009 (grey-shaded areas in Figure 2.1). LiDAR data is collected from light in the form of a pulsed laser to measure ranges (variable distances to the Earth). The LiDAR data used in the SW Bays was collected from a fixed wing aircraft and processed to create a 1 m resolution 3D digital topographic map of the ground surface. LiDAR is able to penetrate through vegetation, and the resulting 3D map represents the ground surface with vegetation, built structures and other above ground features removed. Prior to the existence of this type

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of high-resolution topographic map, fault mapping studies relied exclusively on aerial photography and lower-resolution maps, which, in some locations, have not been useful to identify all active faults present.

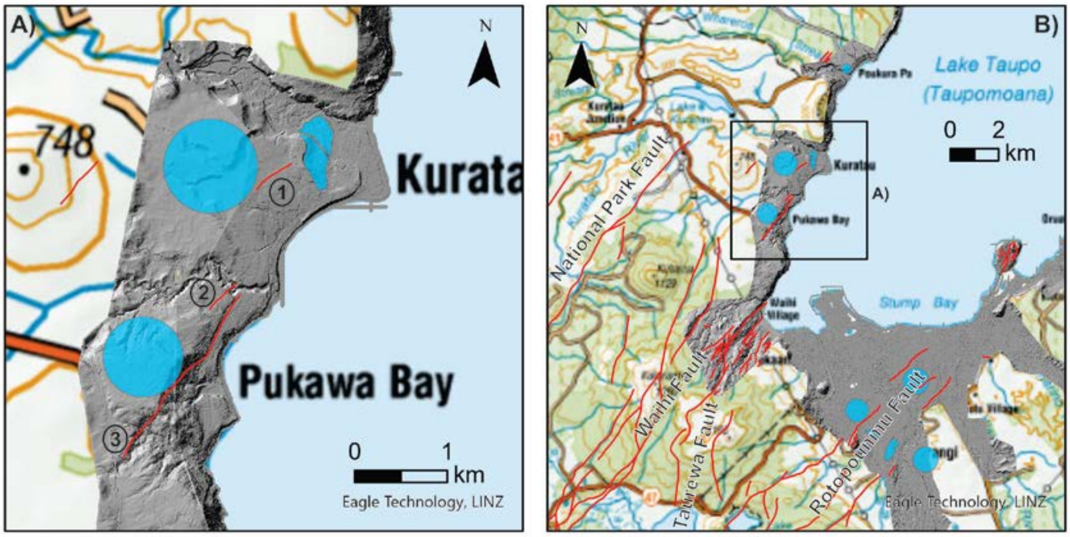

Figure 2.1 Active faults (red lines) mapped in the SW Bays by Litchfield et al. (2020). Blue areas are the priority areas for future development and grey-shaded areas show the LiDAR data coverage. (A) Close-up of the SW Bays; (B) regional map showing active faults mapped in the wider area.

The active fault mapping in the SW Bays was undertaken using LiDAR maps illuminated from different directions (northeast and northwest) so that we could map features of different orientations. The mapping was undertaken by the authors of this report, who have >20 years combined experience mapping faults using LiDAR data in the Taupō Rift and other areas of New Zealand. The mapping and classifications were reviewed by the reviewer of this report.

Fault traces were identified in the LiDAR data as typically sharp, relatively straight, steps that cut across other natural topographic features, such as lake shorelines or riverbanks/terraces. Topographic profiles were also sometimes drawn across features to check whether there are changes in ground elevation or river erosion as a result of tectonic deformation. Mapping was undertaken at a variety of scales, taking account of previous mapping using other types of data (e.g. aerial photographs) and the wider tectonic setting. Most of the active faults identified in the SW Bays are oriented northeast-southwest, which is sub-parallel to both the lake shore and other faults in the area, so the cutting across other features is a key method to distinguish them from lake shorelines.

Three active fault traces were mapped in the SW Bays, numbered 1 to 3 from north to south on Figure 2.1A. These were assigned to the Waihi fault, which is the closest fault along-trend to the south (Figure 2.1B). However, it is also possible that they belong to another fault, including possible unmapped faults beneath Lake Taupō where there is currently no active fault information, as the method used for this LiDAR capture cannot penetrate through water. The three traces were assigned to Recurrence Interval Class I (<2000 years), along with all the other faults in the Taupō Rift. If they are part of the Waihi fault, then there is paleoseismic evidence for this classification from the southern part of the Waihi fault (Tongariro National Park), where paleoearthquakes compiled from multiple natural exposures show it to be one of the most active faults in the Taupō Rift, with a recurrence interval of 570 ± 100 years (Gómez-Vasconcelos et al. 2017).

The tectonic origin of these three fault traces were classified as ‘possible’ because: (1) they all have similar trends to other active faults in the area, which creates suspicion of tectonic origin; (2) there is no prior information about these faults, particularly paleoseismic information such as trenching to expose the fault, that clearly demonstrates they are faults; and (3) a non-tectonic origin for these faults cannot be ruled out.

Possible non-tectonic origins in the SW Bays include: (1) lake shorelines, (2) riverbanks/ terraces and (3) gravitational processes (landslides). These are discussed below for each fault in turn, along with the evidence for mapping and uncertainties.

2.1 Active Fault Trace 1 (West Side of Kuratau)

Trace 1 was identified in the LiDAR data as a relatively straight up-to-3-m-high topographic step that is down-to-the-northwest (Figure 2.2). This step is broader than, and in the opposite direction to, lake shoreline steps clearly visible to the south (Figure 2.2). We are therefore confident that trace 1 is not a lake shoreline feature, but other origins, such as stream erosion, currently cannot be ruled out.

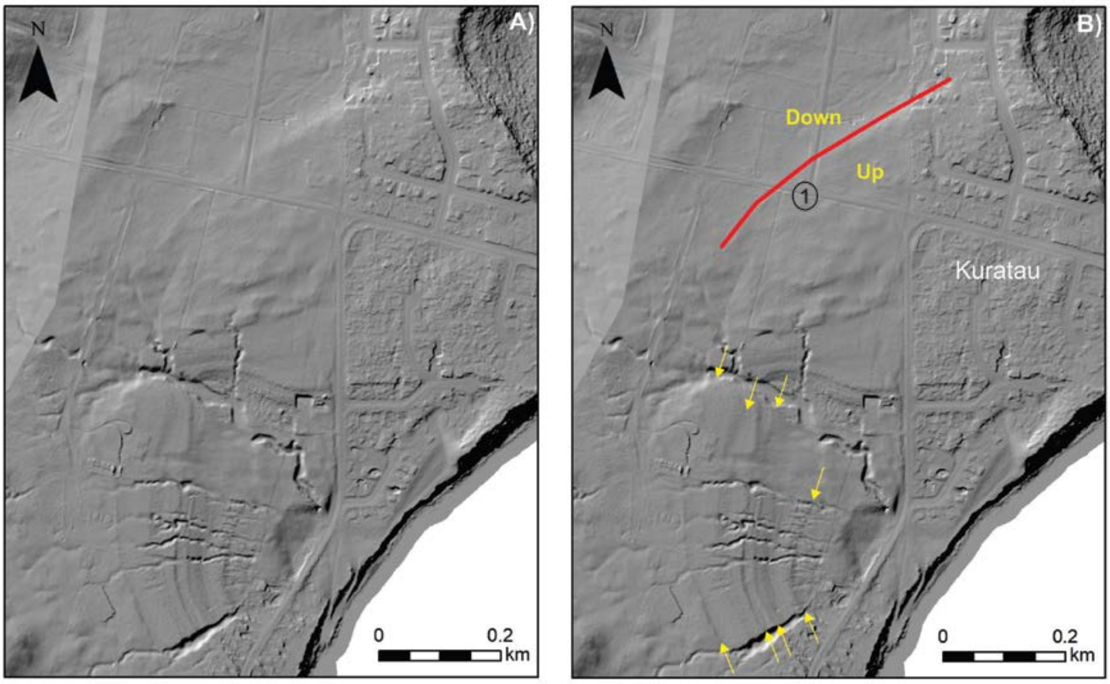

Figure 2.2 Active fault trace 1. (A) Bare LiDAR hillshade map, illuminated from the northwest. (B) The same map as (A), showing the mapped active fault (red line) and former lake shorelines (between the yellow arrows).

2.2 Active Fault Trace 2 (Northern Omori)

Trace 2 was identified in the LiDAR data as a relatively straight up-to-8-m-high topographic step that is down-to-the-northwest (Figure 2.3). The southwest part (red line) is the most distinct, although there has been some modification by the development of the properties built on top of it. The central part (orange line) is less distinct and has also been modified by development. There is no sign of a fault northeast of Omori Stream gully, and there is no clear scarp within the gully, but it is reasonable to infer that trace 2 does not just stop where it has been eroded. It has therefore been extended as an inferred fault along a relatively straight stretch (blue line).

Like trace 1, the trace 2 topographic step is on a similar trend to other active faults in the area and is broader than, and steps down in the opposite direction to, lake shorelines, so it is unlikely to be a lake shoreline feature. However, other non-tectonic origins, such as stream erosion, currently cannot be ruled out.

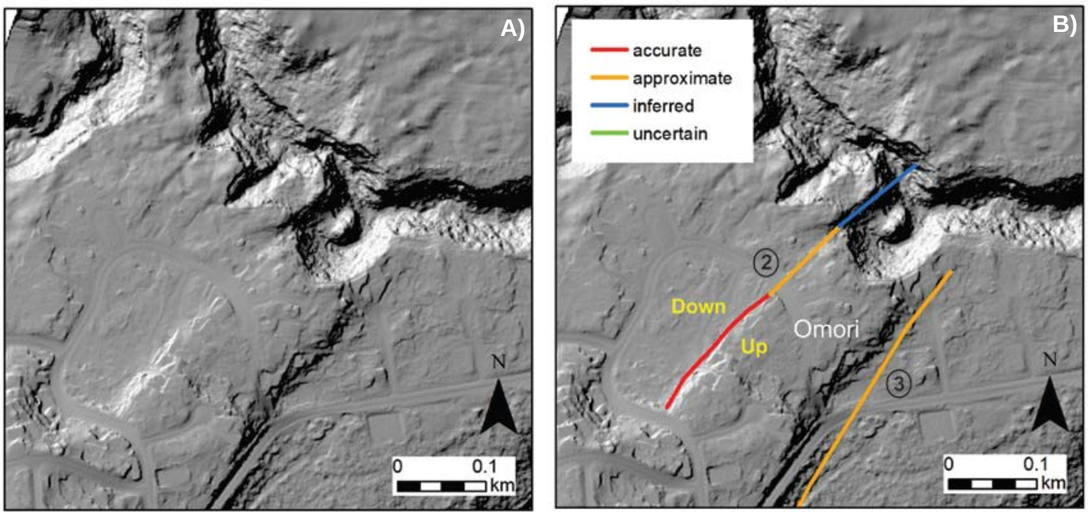

Figure 2.3 Active fault trace 2 (and part of 3). (A) Bare LiDAR hillshade map, illuminated from the northwest. (B) The same map as (A), showing the mapped active fault classified by accuracy of the location at the ground surface. Note that there are no ‘uncertain’ (green) faults in this area.

2.3 Active Fault Trace 3 (Eastern Omori and West of Pukawa)

Trace 3 was identified using LiDAR data as a down-to-the-southeast topographic step that is more distinct in the north (orange line in Figure 2.4) than in the south (green line). The northern part has been modified by the building of the road and some of the properties above it, however.

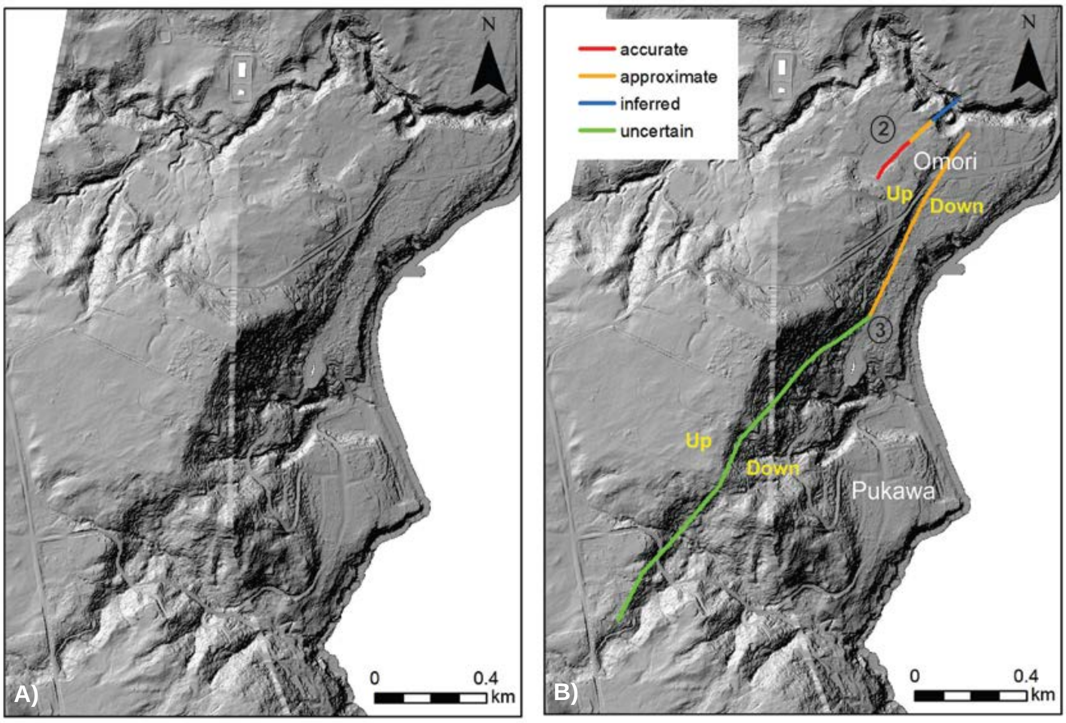

Figure 2.4 Active fault trace 3 (and 2). (A) Bare LiDAR hillshade map, illuminated from the northwest. (B) The same map as (A), showing the mapped active fault classified by accuracy of the location at the ground surface.

The large topographic step, which increases in height southwards (up to 200 m), is in the same direction as the lake shorelines but it is broader than the shorelines to the northeast. Therefore, the possibility that it is an older lake shoreline currently cannot be ruled out. The southern part may also have been affected by stream erosion or gravitational processes (landsliding) and so could have been formed or modified by multiple tectonic and non-tectonic processes.

3.0 WHAT THE FAULTS MIGHT LOOK LIKE TODAY AND AFTER AN EARTHQUAKE RUPTURE

GNS Science has not visited the SW Bays active fault traces 1–3 in person but, based upon our experience and interpretations of the LiDAR data, aerial photographs and Google Street view, we can make some comments about what the traces look like today and what they will likely look like in a future rupture.

3.1 Active Fault Traces Today

The SW Bay traces are generally broad, or gentle, relatively smooth rises of the ground surface, with higher ground on one side of the trace than the other. They trend northeast-southwest and, as mentioned in Section 2, are straighter than and cut across, or up to, other topographic features such as streams and lake shorelines.

Figure 3.1 shows an example of similar topographic steps in an undeveloped area in the northern Taupō Rift. These faults were initially mapped using aerial photographs and LiDAR data like those in the SW Bays but were then proven to be active faults by paleoseismic trenching (Figure 3.2A) and Ground Penetrating Radar (GPR) analysis (see description below).

Figure 3.1 Example of active fault traces in the northern Taupō Rift (Manawahe fault south of Matata). Red arrows point to three parallel traces of different heights. These were confirmed as active faults by trenching (Figure 3.2A) and GPR analysis. Photograph by Nicola Litchfield.

If people have previously undertaken excavation works on their properties, it is possible that they may have exposed a fault plane, but it may not have been clear, especially if the excavation was 1.5 m deep or less. To clearly see a fault plane, the trench walls need to be carefully cleaned to identify lines separating soils or volcanic ash units that may be slightly different on either side and/or step down across the fault. Even then, an expert eye may be required to identify faults from other features, such as cracks or landslide slide planes. Some ideal examples are shown in Figure 3.2.

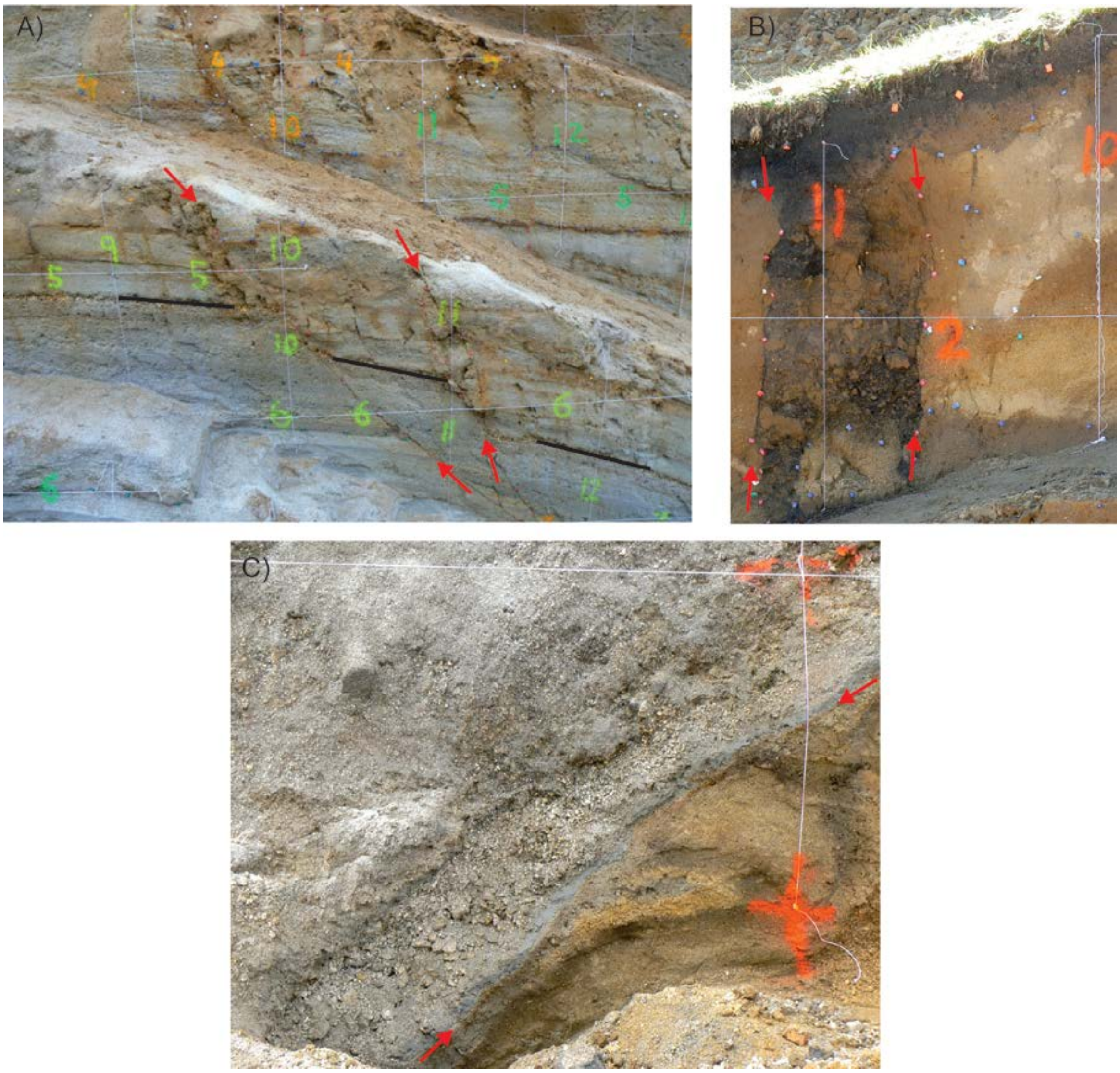

Figure 3.2 Ideal examples of Taupō Rift fault planes in excavations. Red arrows point to faults. (A) Manawahe fault; black lines highlight a layer displaced by the faults. Photograph by Nicola Litchfield. (B) Tumunui-Highlands Road fault. The fault terminates at the top in a fissure that is filled with broken black soil. Photograph by Nicola Litchfield. (C) Te Mihi fault. The buff to grey layers on the left, about 1700 years old, were dropped down during the earthquake along the fault (red arrows) and are currently juxtaposed against soils that are older than 10,000 years (light brown colours). Photograph by Pilar Villamor.

Another challenge to seeing faults in shallow (<1.5 m) excavations in the Lake Taupō area is that the uppermost layers are often thick and can bury faults. These include volcanic ash from the last Taupō Volcano eruption around 1700 years ago and can also be eroded and re-deposited by stream or landslide deposits, which can be locally thick. This is one of the reasons why GPR is sometimes recommended over, or prior to, excavations, as discussed further in Section 4.

3.2 Active Faults in Future Ruptures

Active faults in the Taupō Rift are normal faults formed by extension, or pulling apart, of the ground, and we expect the SW Bays faults to be the same. The pulling apart will likely cause opening up of cracks, and the earthquakes will also force one side of the fault upwards and the other side downwards. We expect the up and down direction to be the same as past ruptures, so traces 1 and 2 to rupture down-to-the-northwest and trace 3 to rupture down-to-the-southeast. The vertical displacement is likely to vary from a few centimetres to possibly as much as 4 m (more typically 0.5–3 m).

Earthquakes typically start deep (several kilometres) within the crust and rupture upwards toward the ground surface, during which they are influenced by the local rocks and soils. The layered, soft soils in the Taupō Rift are likely to cause the rupture to break up into multiple small ruptures rather than being a single clean break. We anticipate that ruptures on the SW Bay faults will likely be similar to the examples shown in Figure 3.3.

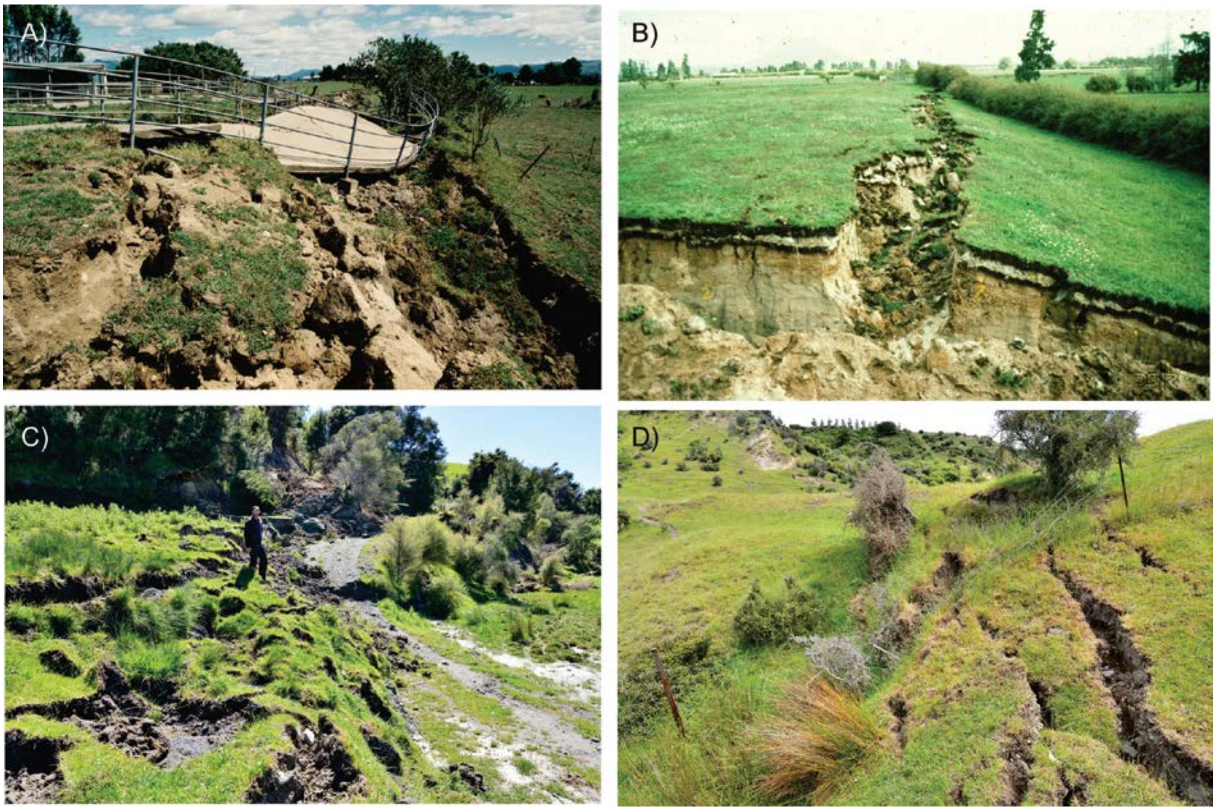

Figure 3.3 Examples of ruptures that we consider to be similar to future ruptures on the SW Bay faults. (A) Edgecumbe fault in the 1987 Edgecumbe Earthquake. CN 4053; Lloyd Homer. (B) Edgecumbe fault in the 1987 Edgecumbe Earthquake. CN 140634; Lloyd Homer. (C) Kekerengu fault in the 2016 Kaikōura Earthquake. CN 209793; Dougal Townsend. (D) Leader fault in the 2016 Kaikōura Earthquake. CN 210128; Dougal Townsend.

4.0 FAULT AVOIDANCE ZONES

4.1 Methodology and Classifications

The active fault line mapping described in Section 2 is the starting point for the construction of the Fault Avoidance Zones (FAZs). The methodology for the construction of FAZs is described in the Litchfield et al. (2020) report, but, briefly, it is constructed from buffers around the fault lines incorporating the: (1) deformation width (variable), (2) capture uncertainty (±3 m) and (3) setback zone (±20 m).

The deformation width is where fault rupture is most likely to occur and, in practise, is defined from the horizontal width of the topographic step and/or the maximum width of where the deformation could be located. So, in the SW Bays, the deformation widths are narrowest (10–20 m) for the low, distinct, traces (red lines in Figures 2.2–2.4) and are widest (80 m) for the high, indistinct, part of southern trace 3 (green line in Figure 2.4).

The FAZ fault complexity follows the definitions in the Ministry for the Environment Active Fault Guidelines (Kerr et al. 2003), and, in the SW Bays, most of the faults are single topographic steps of metres to tens of metres wide, clearly visible in the LiDAR data. They have therefore been assigned a fault complexity of ‘well-defined’ for consistency with mapping in other areas. The exception is the inferred northern end of trace 2 in the Omori Stream gully, which is classified as ‘uncertain-constrained’, as it is an inferred trace as mentioned above.

4.2 Potential for Refining Fault Avoidance Zones

FAZ widths can sometimes be reduced (or even entirely removed) by further investigations to more accurately locate the fault(s), and here we make some comments about the potential in the SW Bays. As noted in Section 3, we have not visited the SW Bays in person, so the below recommendations are based upon the most recent available LiDAR, aerial photo and land parcel data, as well as our experience elsewhere.

As discussed in Section 3.1.1, excavations in the Lake Taupō area are likely to be challenging because they would likely need to be deep (>3 m) to uncover the faults. Excavations will also be challenging in developed areas, across high (>4 m) scarps and in vegetated areas. We therefore recommend that the most prospective method is GPR in selected locations (Figure 4.1).

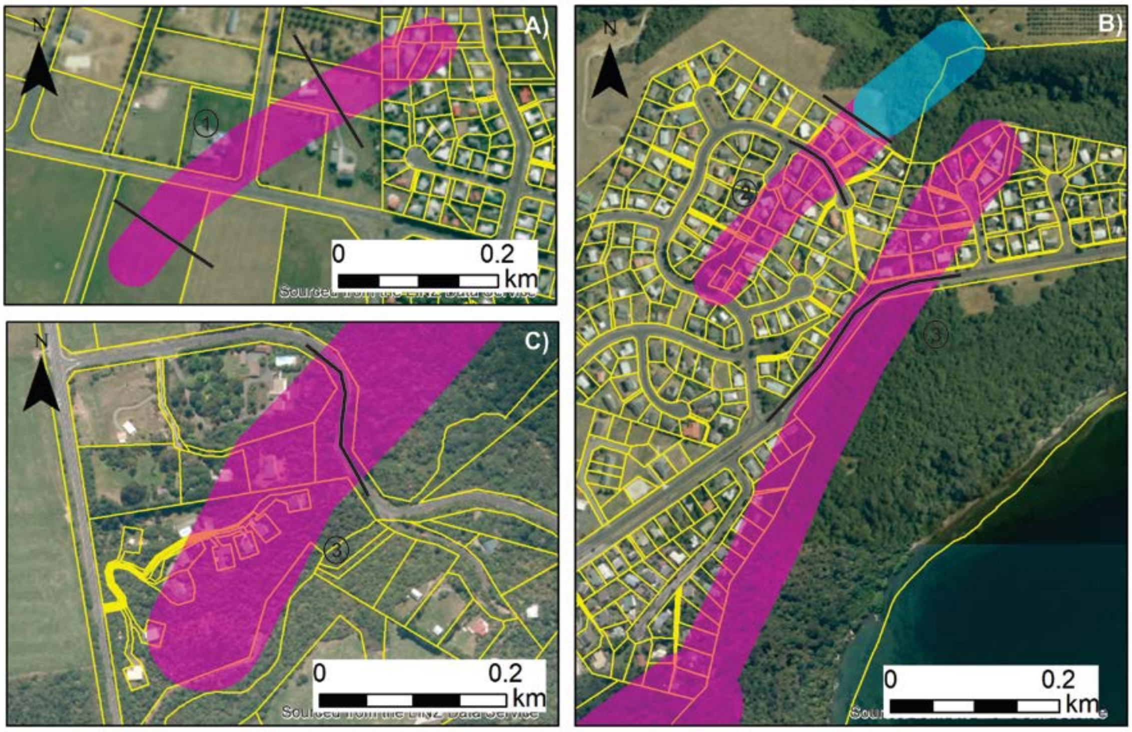

Figure 4.1 FAZs for traces 1–3 in developed areas. Black lines are potential GPR profile locations. (A) Trace 1 in Kuratau. (B) Trace 2 and the northern end of trace 3 in Omori. (C) The southern end of trace 3 in Pukawa.

GPR is a non-destructive geophysical method that uses radar pulses to image layers in the subsurface. Radar waves are sent into the ground and bounce back at sharp contrasts between soil layers, producing an image similar to an Xray. GPR has proven to be very successful at imaging faults and the volcanic ash and soil layers in the Taupō Rift. The data s generally collected by carrying or towing equipment along lines that are ideally straight, at high angles to the fault, and are at least as long as the width of the FAZ (ideally longer). The resolution of the GPR data can be varied, using different equipment, and can reach up to 15 m depth, although there is a trade-off between resolution and depth (i.e. the deeper you go the less detail you can image).

The most prospective place for undertaking GPR is across the relatively low step of trace 1, which is on a relatively low surface that is likely to have contrasting layers that can be imaged. In Figure 4.1A, we show two potential GPR profile locations, with a preference toward the eastern one as it is closer to the centre of the trace.

Trace 2 is more challenging because of the greater density of development. In Figure 4.1B, we show two potential GPR profile locations, one north of the developed area and the other along Kaimanawa Street. The northern one may be more prospective because the land is undisturbed.

Trace 3 is the most challenging because of the steep topography, vegetation and, in places, development. The only possible places to undertake GPR profiles appear to be along Omori Road (Figure 4.1B, C), but we would recommend obtaining further expert advice as to whether it is likely to work there or not.

If the GPR data showed no evidence for faults, then it is possible that the FAZs could be removed in many of these locations. If the GPR data did show evidence for faults, then the tectonic origin would be changed from ‘possible’ to ‘definite’ and the FAZ reviewed. If the total fault width is narrower than the deformation width constructed using the LiDAR data, then it is likely that the FAZs could be narrowed. Alternatively, if the total fault width observed from the GPR data is wider than the deformation width constructed using the LiDAR data, then the FAZs would need to be widened.

GNS Science does not have GPR equipment but can provide contact details of some providers that have undertaken work in the Taupō Rift. Costs and availability for this work should be obtained from these providers, but, depending on the amount of analysis required, our experience is that ballpark costs are in the range of $10k–$25k. GNS Science could review GPR study reports and/or be involved in some aspects of the siting and analysis; ballpark costs for this are in the range of $10k–$50k.

If the GPR data showed clear evidence for faults at shallow depths (<3 m), then it may be possible to undertake localised excavations to further refine the FAZs. Indicative ballpark costs for trench excavations led by GNS Science are $35–$150k, depending on the number and depths of trenches and the analysis required.

5.0 SUMMARY AND CONCLUSIONS

- Additional information is provided about the mapping of three ‘possible’ active fault lines (traces) in the SW Bays and their uncertainties.
- GNS Science has not visited the SW Bays active fault traces 1–3 in person but, based upon our experience, available information and surface ruptures in recent earthquakes on similar faults, information is provided about what the fault traces look like today and what they may look like in future ruptures.
- Additional information is provided about the SW Bay FAZs and the potential to refine these through GPR investigations, with indicative ballpark costs.

Yours sincerely,

N J Litchfield

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