Rotorua District Council Hazard Studies: Distribution and identification of soft soils

G.D. Dellow

GNS Science Consultancy Report 2010/81
October 2010

GNS SCIENCE
TE PŪ AO

DISCLAIMER

BIBLIOGRAPHIC REFERENCE

Dellow, G.D., 2010. Distribution and engineering properties of young lake sediments in Rotorua District, *GNS Science Consultancy Report* 2010/81. 13p.

CONTENTS

EXECUTIVE SUMMARY ..... **II**
1.0 INTRODUCTION **1**
2.0 GEOLOGICAL DATA **1**
3.0 GEOTECHNICAL DATA **4**
4.0 DISCUSSION **4**
5.0 CONCLUSIONS **7**
6.0 RECOMMENDATIONS **8**
7.0 ACKNOWLEDGEMENTS **8**
8.0 REFERENCES **8**
9.0 GLOSSARY **10**
9.1 Abbreviations 10
9.2 Technical terms 10

FIGURES

Figure 1 Distribution of soft to very soft ground within Rotorua District. 5

EXECUTIVE SUMMARY

The Rotorua District Council (RDC) has commissioned GNS Science to undertake a study describing the distribution and engineering properties of soft to very soft sediments in the Rotorua District. The RDC has identified soft and very soft sediments as a potential geological hazard in the district because when additional loads are applied (e.g. by fill placement or building construction) they can produce differential settlements. This has damaged and has the potential to damage buildings and other infrastructure founded on these materials.

Soft and very soft sediments are usually formed when fine grained materials (fine sands and silts) are deposited in a low energy environment (e.g. settle out of suspension in a standing water body such as a lake or swamp). As these sediments age, they settle and consolidate (become stronger).

The locations of very soft to soft sediments in the Rotorua District is largely confined to swamp deposits, stream and river deltas marginal to lakes in the district and young lacustrine (lake) sediments deposited around Lake Rotorua between the 9000 year-old and current shorelines and which may now be overlain by younger alluvium and fan deposits.

The identification of soft to very soft sediments can be made using standard investigation techniques commonly used in the geotechnical community. In this instance the scala penetrometer test has been selected as one test method because it is already in widespread use as a hand-tool to measure ground strength at the individual residential lot scale. In areas where soft to very soft sediments are likely to be located deeper than two metres a cone penetrometer test (CPT) should be carried out with a rig capable of reaching depths of twenty metres.

The scala penetrometer test, if evaluated using the criteria set out in NZS 3604 (draft DZ3604), can identify areas of soft to very soft sediments (sites that fail to meet the criteria of good ground). However, because the scala penetrometer test is commonly not taken deeper than two metres, it is most useful where soft to very soft sediments are present in the surficial layer. Areas where rocks and soils derived from volcanic processes and sediments older than 10,000 years are mapped will likely have soft or very soft soil units present as thin, young surficial deposits on top of the older surfaces. The scala penetrometer test is suitable for identifying soft or very soft ground in these areas.

In areas where the soft to very soft sediments might be buried by a younger deposit, either Holocene alluvium or recent fill (made ground) then the scala penetrometer test may lack sufficient penetration to reach the soft to very soft materials. In this instance a CPT test to a depth of at least 10 m and preferably 20 m is required to establish the presence (or absence) of soft or very soft sediments (q_c < 0.3 MPa). The areas where the cone penetrometer test is required to definitively confirm the presence or absence of soft to very soft soil units are swamp deposits and stream and river deltas of Holocene age (0 to 10,000 years old) marginal to lakes in the district and young lacustrine (lake) sediments deposited around Lake Rotorua between the 9000 year-old and current shorelines and which may now be overlain by younger alluvium and fan deposits.

1.0 INTRODUCTION

The Rotorua District Council (RDC) has commissioned GNS Science to undertake a study describing the distribution and engineering properties of soft to very soft sediments in the Rotorua District. The RDC has identified soft and very soft sediments as a potential geological hazard in the district because when additional loads are applied (e.g. by fill placement or building construction) they can produce differential settlements. This has the potential to damage buildings and other infrastructure founded on these materials.

The scope of work involved in the report is to:

- Review existing published and unpublished geological maps to ascertain the distribution of soft to very soft sediments within the boundaries of the Rotorua District. The age of the soft to very soft sediment deposits will be determined as geologic age is likely a key indicator of the level of hazard (i.e. the younger the sediments the more hazardous they potentially are). A map identifying the areas of soft to very soft sediments in the Rotorua District will be provided.

- Review geotechnical data for soils in the Rotorua District. The review of geotechnical information will allow the identification of appropriate investigation tools and methods for proving/disproving the presence of very soft to soft soils. As part of this the parameter values for diagnosing the presence of soft to very soft soils will be provided.

- Prepare a report describing the work carried out above. The information provided in the report will enable the Rotorua District Council to formulate suitable policies and rules for identifying and mitigating this hazard in the context of the District Plan.

2.0 GEOLOGICAL DATA

The formation of very soft to soft sediments usually requires a specific set of environmental conditions. These environmental conditions can be characterised as the deposition of fine grained sediments in a low energy environment. An example is the deposition of fine sands and silts carried in water-born suspension in a lake delta. Only fine-grained sediments (fine sands, silts and clays) can be deposited using low-energy processes (insufficient energy is available to move larger particle sizes). The settling out of fine-grained materials carried in suspension results in the formation of sediments with open, loosely packed structures. It is this open, loosely packed structure that allows settlement to occur when additional loads are applied at the ground surface (e.g. by the placement of fill or construction of a building). These sediments settle and consolidate with time through compaction (including compaction induced by liquefaction during strong earthquake shaking), burial and weathering. Therefore to identify the areas in Rotorua District where very soft to soft sediments might be present it is necessary to locate the sites of young, fine-grained sediments deposited in a slack water environment.

A map of the geology of the Rotorua District was compiled using the best available data. The composite geological map used three data sources. These are:

1. The 1:50,000 scale unpublished geological map of the Upper Kaituna Catchment prepared by William Esler. Although unpublished this map has been used as source data for the new 1:250,000 scale geological map of the Rotorua area. The Esler map is used because of the fine detail of the mapping around the margins of Lake Rotorua. Esler states in his notes accompanying the map that one of his intents was to map the distribution of soft to very soft soils that cause problems for civil engineering works.

2. The 1:50,000 Okataina map by Ian Nairn. The scale of the map allows for a better resolution of geological information around most of the lakes in the Rotorua District; and

3. The new 1:250,000 geological map of the Rotorua area (Leonard *et al*, in prep). This map was used to provide geological information in the areas of the district not covered by the two maps listed above.

The geology of Rotorua District is dominated by the calderas of the Taupo Volcanic Zone (TVZ) and their products (ignimbrites). In the Rotorua District four calderas or rhyolitic volcanic centres are identified, namely the Okataina, Rotorua, Kapenga and Reporoa calderas (Nairn, 2002). Holocene eruptive activity has been recorded in the Okataina Volcanic centre but not in the others in the Rotorua District. Surrounding the calderas to the north, west and east are extensive ignimbrite sheets formed by older eruptions from the calderas (e.g. Mamaku Ignimbrite, Kaingaroa Ignimbrite, Rotoiti Breccia).

The ignimbrite sheets of the Rotorua District (e.g. Mamaku Ignimbrite, Kaingaroa Ignimbrite, Rotoiti Breccia) do not provide conditions suitable for the formation of very weak (soft) sediments because no large standing water bodies are present or have been present in the past in these areas at the current ground surface (upper surface of thick ignimbrite sheets). The upper surfaces of the ignimbrites are usually covered in younger ash and the unwelded portion of the ignimbrite sheets. These materials are usually highly porous and easily eroded by water which precludes the formation of long-lived bodies of standing water such as lakes (and swamps).

This leaves the calderas (large basins of volcanic origin) and their infill lakes within the Taupo Volcanic Zone as potential sites of very soft to soft sediments. Volcanic rocks and associated deposits (e.g. lavas, pyroclastic falls and flows, domes) can be eliminated because these units were deposited by high-energy processes and are therefore usually dense soils and/or rock. This leaves areas mapped as sedimentary rocks. The sedimentary rocks in the Rotorua District belong to one of five distinct units:

1. Huka Group sediments ranging in age between >220 ka and 22 ka. These are usually mapped in three distinct groups (Nairn, 2002):

    a. The oldest Huka Group sediments (u_1) pre-date the Mamaku Ignimbrite. These are of sufficient age that any fine-grained materials deposited in a low-energy environment will be well consolidated by now. These sediments are primarily located within the Kapenga Caldera to the southwest of Rotorua, although isolated outcrops are found further to the east.

b. Sediments deposited after emplacement of the 220 ka Mamaku Ignimbrite but before emplacement of the 65 ka Earthquake Flat Pyroclastics (u_2). These sediments are predominantly located within the Kapenga Caldera southwest of Rotorua.

c. Huka Group sediments aged between 65 ka and 22 ka deposited in the Rotorua caldera during the lake high-stand (u_3) and now exposed (or buried by younger deposits) between the former high-water mark and the current lake margin. Minor deposits have also been identified along the course of the Tarawera River.

2. The Hinuera Formation (20 ka). The Hinuera Formation (hn) consists of Rhyolitic sands and gravels forming fluviatile terrace and fan deposits (Nairn, 2002). Most of these sediments were deposited at the peak of the last glaciation about 20 ka. They are predominantly mapped in the Reporoa caldera to the south-west of Rotorua although small areas are also mapped within the Kapenga caldera.

3. Holocene sediments (<20 ka) (fa, fs, ff, ft etc) are identified as the most likely source of soft or very soft soils. More recent sediments are highly variable and have been deposited by different processes in a range of environments. These sediments are present in small pockets throughout the district. By taking into account the dominant grain-size in the various units (i.e. coarse sands and gravels versus fine sands, silts and clays) and the relative energy available in the depositional environment (i.e. rapid high-energy water flows versus low-energy lake environments) areas where very soft to soft sediments may be present can be identified.

All five units can potentially contain fine-grained sediments deposited in a low energy environment. The sediments of the Huka Group are lake-derived in places. However, they are of sufficient age that the lake sediments have likely consolidated over time (through a combination of settlement, burial, weathering and liquefaction) and probably now have sufficient strength to meet the criteria of being 'good ground' as per the draft New Zealand Standard for timber framed buildings (DZ3604). The u_3 sediments are the youngest of the Huka Group (65-22 ka) and were deposited in a low-energy environment (proto-Lake Rotorua during the 65-22 ka high-stand). The extent of the u_3 unit is confined within the boundaries of the Rotorua caldera. Since deposition some localities where this unit is known have been overlain by younger alluvium (fa) or fan deposits (ff). Again these sediments are of sufficient age that they have probably consolidated enough to meet the criteria of 'good ground'.

There was little potential for the development of extensive thicknesses of very soft to soft sediments in the Hinuera Formation because it was deposited over a relatively short period (22-18 ka; Nairn, 2002) by relatively high-energy processes reworking coarser materials (pumiceous sands and gravels).

In the Holocene three environments in the Rotorua District stand out as providing the necessary low-energy conditions which are a prerequisite to forming the open, loosely packed structure typical of very soft to soft sediments. These are swamps (fs), lake deltas and the lakes themselves. Extensive areas of very soft to soft sediments in the Rotorua District are largely limited to swamp deposits, stream and river deltas marginal to the lakes in the district and young (<9,000 years old) lake sediments deposited around Lake Rotorua between the nine thousand year old and current lake-shores which may now be overlain by younger alluvium and fan deposits.

3.0 GEOTECHNICAL DATA

The Rotorua District Council has provided several reports containing geotechnical information relating to very soft to soft sediments present in the district (e.g. Cowbourne, 2010; Phillips, 2009). In these reports geotechnical data is provided for soft to very soft sediments from the results of scala penetrometer tests (most reports) and cone penetrometer tests (CPT).

In the draft New Zealand Standard for timber framed buildings (DZ3604) 'good ground' (i.e. ground that requires no engineering modification or special design provisions for building construction) can be identified using the scala penetrometer. If the criteria for establishing the presence of good ground were used against the provided scala penetrometer test results then sites at Ohinemutu (Cowborne, 2010), Lynmore (Robinson, 2004) and Te Akau Rd, Lake Rotoiti (Fitchett, 2007) fail to meet the criteria. The site at Ngongotaha presents a mixed bag with respect to the scala penetrometer results. Some tests results indicate good ground is present as per the criteria proposed for the draft NZS 3604, while other test results show that good ground is not present using the criteria.

Additional testing using CPT's was undertaken at Ngongotaha (Phillips, 2009) and at Koutu (Cowbourne, 2009). These tests (and subsequent geotechnical tests) established that for 8-12 metres below the ground surface significant intervals (up to 10 metres) of soft to very soft sediments were present. Based on the results of the CPT tests, the soft to very soft sediments were defined as intervals were the cone resistance (q_c) was less than 0.3 MPa.

In summary, where soft to very soft sediments are the surficial deposit then the criteria for interpreting the results of a scala penetrometer test as set out in the draft NZS 3604 is adequate for identifying the presence (or absence) of soft or very soft sediments within two metres of the ground surface. Where the soft to very soft sediments may be buried or overlain by younger sediments, then a CPT to a depth of at least 10 m and preferably 20 m is required to establish if substantial (i.e. greater than 1 m thick) thicknesses of soft to very soft sediments are present.

4.0 DISCUSSION

A map of the location of soft ground in the Rotorua District is provided as Figure 1. The map displays areas where soft ground is present as well as areas where soft ground may have been present in the past. Four zones are mapped:

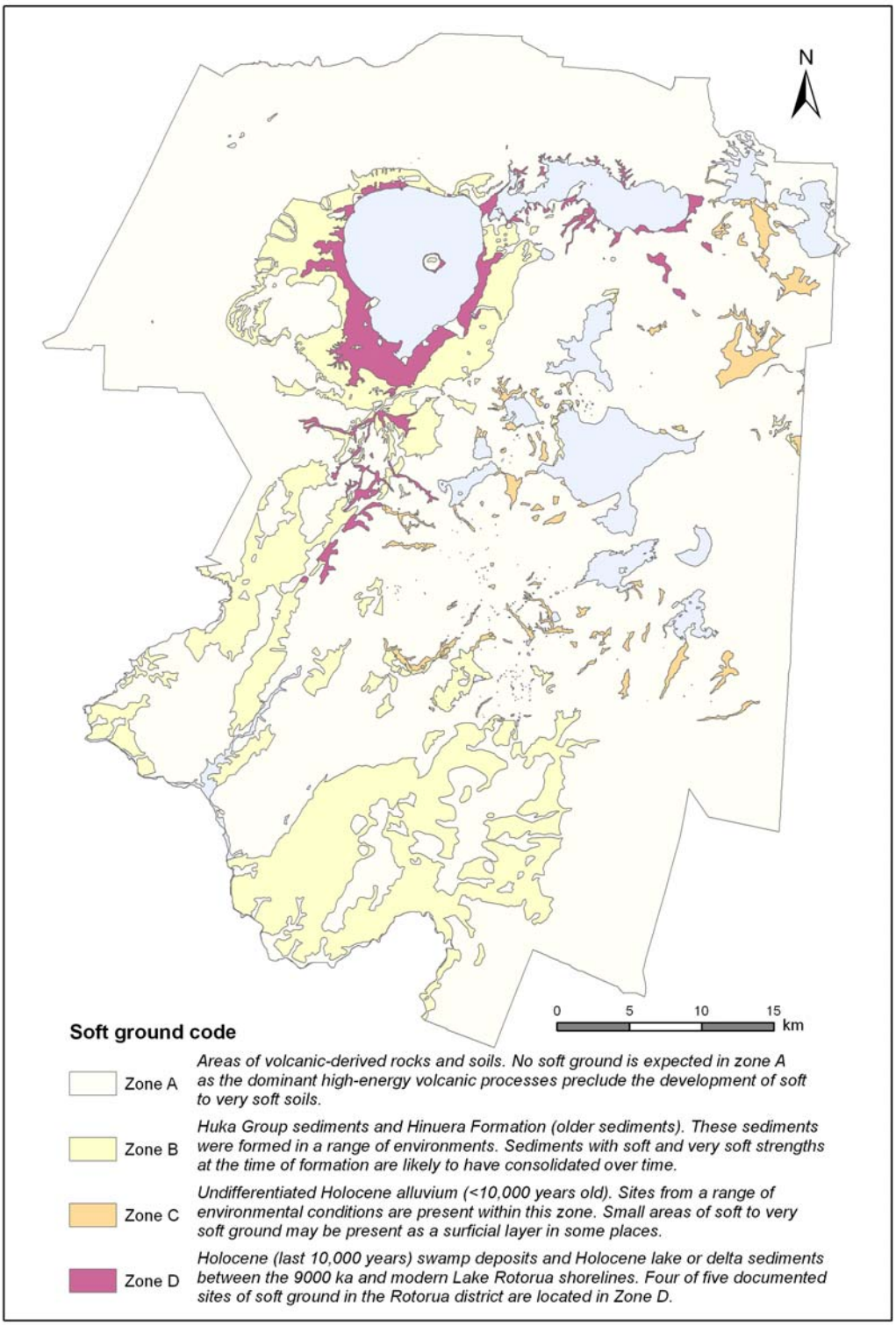

Figure 1 Distribution of soft to very soft ground within Rotorua District.

Zone A: Areas of volcanic-derived rocks and soils. Volcanic processes by their very nature are high-energy. No soft ground is expected in zone A as the dominant processes preclude the conditions necessary for its development.

Zone B: Huka Group sediments and Hinuera Formation. These sediments were formed in a range of environments. Sediments with soft and very soft strengths at the time of formation have consolidated over time and are now likely to meet the requirements for being defined as good ground as per the draft New Zealand Standard for timber framed buildings (DZ3604).

Zone C: Undifferentiated Holocene alluvium. Sites from a range of environmental conditions are present within this zone. Small areas of soft to very soft ground may be present as a surficial layer in some places.

Zone D: Sites of Holocene (last 10,000 years) swamp deposits and Holocene lake or delta sediments between the 9000 ka and modern shorelines. Four of the five documented sites of soft ground (Fitchett, 2007; Phillips, 2009; and Cowbourne 2009, 2010) are located at sites mapped as Zone D.

Zones A, B and C only have a little soft or very soft ground or none at all. A scala penetrometer used to depths of at least 2 m in these areas should confirm the presence or otherwise of 'good ground' as per the draft New Zealand Standard for timber framed buildings (DZ3604). Any soft ground will be small in extent and at the surface if present. RDC provided a number of geotechnical reports for various localities in the district. Only one of these reports identified soft ground outside of Zone D. This was a site at Lynmore (Robinson, 2004) where the soft ground was picked up using a scala penetrometer. The site is also only between 100 and 500 metres from an area mapped as Zone D.

Zone D contains extensive areas of soft ground, but probably also contains areas of better ground. The soft ground site described in Phillips (2009) at Ngongotaha is located on a valley floor containing a meandering stream. The Ohinemutu site described in Cowbourne (2010) is located on the lake delta of the Ohinemutu Stream, another small meandering stream. Several other small meandering streams are present on the western and south-western shores of Lake Rotorua. On the eastern and south-eastern shores of Lake Rotorua the small streams have straighter alignments, which if natural, indicate steeper stream gradients and hence a slightly higher energy environment and thus sediment with higher strengths.

Additional sites of soft to very soft ground were identified at Koutu (Cowbourne, 2009) using CPT and Te Akau Rd on the shores of Lake Rotoiti (Fitchett, 2007) using a scala penetrometer. The CPT results at Koutu cannot be compared with scala penetrometer results but do indicate that the upper two metres of had q_c values between 1-2 MPa.

The site at Ngongotaha has had an influx of fine to coarse sand deposited by alluvial processes over the top of lake sediments. This probably explains the slightly better scala penetrometer results for the Ngongotaha site compared to the Ohinemutu site. However, the burial by slightly stronger sediments means that a scala penetrometer lacked the depth penetration to reach the soft sediments. In Zone D a scala penetrometer can only confirm the absence of 'good ground' as per the draft New Zealand Standard for timber framed buildings (DZ3604). A deeper test is therefore required to establish the presence of 'good ground'. As demonstrated at Ngongotaha and Koutu a cone penetrometer probe to at least 20 m depth

(or refusal) is adequate for this task. Soft to very soft sediments can be defined as intervals where the measured cone resistance (q_c) is less than 0.3 MPa.

Further refinement of Zone D to reduce the area of potentially soft ground is possible. Primarily this requires more extensive geotechnical information (scala, cone or standard penetrometer test results) that can be compared with the fine-scale geomorphology around the terrestrial margins of Lake Rotorua. These results could be used to further refine the mapping of soft and very soft soils in the Rotorua District.

5.0 CONCLUSIONS

Soft and very soft sediments are usually formed when fine grained materials (fine sands and silts) are deposited in a low energy environment (e.g. settle out of suspension in a standing water body such as a lake or swamp). Younger sediments are weaker than older sediments because as sediments age, they settle and consolidate (become stronger).

Young, soft to very soft sediments are present at various localities within the Rotorua District. Three distinct environmental settings within the district are conducive to the formation of layers or beds of soft to very soft sediments. These areas are:

1. Current or historical swamps;

2. Stream and river deltas marginal to existing lakes; and

3. Young lake sediments deposited around Lake Rotorua between the 9000 year-old and current shorelines and which may now be overlain by younger alluvium, fan deposits or even fill.

The identification of soft to very soft sediments can be made using standard investigation techniques commonly used in the geotechnical community.

The scala penetrometer test, if evaluated using the criteria set out in NZS 3604 (draft DZ3604), can identify areas of soft to very soft sediments (sites that fail to meet the criteria of good ground). However, because the scala penetrometer test is commonly not taken deeper than two metres it is most useful where soft to very soft sediments are present in the surficial layer. Areas where rocks and soils derived from volcanic processes and sediments older than 10,000 years are mapped will likely have soft or very soft soil units present as thin, young surficial deposits on top of the older surfaces. The scala penetrometer test is suitable/adequate for identifying soft or very soft ground in these areas (Zones A, B and C on Figure 1).

In areas where the soft to very soft sediments might be buried by a younger deposit, either Holocene alluvium or recent fill (made ground) then the scala penetrometer test make lack sufficient penetration to reach the soft to very soft materials. In this instance a CPT test to a depth of at least 10 m and preferably 20 m is required to establish the presence (or absence) of soft or very soft sediments (q_c < 0.3 MPa). The area where the cone penetrometer test is required to definitively confirm the absence of soft to very soft soil units is shown as Zone D on Figure 1.

6.0 RECOMMENDATIONS

The following recommendations are made with respect to soft to very soft sediments in Rotorua District:

It is recommended that the RDC develop a policy in relation to the district plan requiring mitigation of the hazard from soft or very soft ground. Examples of mitigation options available to parties required to operate under this policy include, for example, ground remediation, special foundation design provisions or avoidance.

It is recommended that use of the scala penetrometer test (as per NZ3604; Draft DZ3604) be required to identify soft or very soft ground in Zones A, B and C (Figure 1). If the test results do not show good ground as per the method in NZS 3604, then soft or very soft soils are present. If soft or very soft ground is determined by this method then the hazard from soft to very soft ground needs to be mitigated as per RDC policy.

In Zone D (Figure 1) it is recommended that the cone penetrometer test be used to identify soft or very soft ground. If the cone resistance (q_c) is less than 0.3 MPa then soft or very soft ground is present. If soft or very soft ground is determined by this method then the hazard from soft to very soft ground needs to be mitigated as per RDC policy.

7.0 ACKNOWLEDGEMENTS

Graham Leonard and Will Estler and thanked for their input into mapping the distribution of Quaternary sediments in the Rotorua area. Biljana Lukovic prepared the maps. Rob Langridge and Dick Beetham are thanked for their timely reviews.

8.0 REFERENCES

Cowbourne, A.J., 2009: Residential Subdivision, Ian Street, Koutu, Rotorua – Geotechnical Assessment Report. Unpublished report by Terrane Consultants Limited, Tauranga; dated 12/1/2009; 16 pages.

Cowbourne, T., 2010: Proposed building extension, Tipu Ora Medical Centre, Ohinemutu; Preliminary Report. Unpublished report by Terrane Consultants Limited, Tauranga; dated 25/3/2010; 6 pages.

Esler, W., 2005. Upper Kaituna Geology. Unpublished geology map 1:50 000, Rotorua; dated 2/8/2005.

Fitchett, P.F.R., 2007: Edgewater Trust – Application for subdivision consent of 130 Te Akau Road, Lake Rotoiti. Unpublished report by Sigma Consultants Limited, Rotorua; dated 31/1/2007; 4 pages.

Leonard, G.S., Begg, J.G., Wilson, C.J.N., (compilers) (in prep): Geology of the Rotorua area. Institute of Geological & Nuclear Sciences 1:250 000 geological map 5. 1 Sheet. Lower Hutt, New Zealand: Institute of Geological & Nuclear Sciences Limited.

Nairn, I.A., 2002: Geology of the Okataina Volcanic Centre, scale 1:50,000. Institute of Geological and Nuclear Sciences geological map 25. 1 sheet = 156 p. Lower Hutt, New Zealand: Institute of Geological and Nuclear Sciences.

NZS 3604, 2010: Timber framed buildings (draft [DZ3604] for public comment). New Zealand Standards, Wellington, New Zealand.

Phillips, R., 2009: Western Road, Ngongotaha: Geotechnical assessment report prepared for Pioneer Property Trust. Unpublished report by Tonkin and Taylor Ltd; dated March 2009; 377 pages (Volume 1 of 2).

Robinson, A.J., 2004: G Spence – Proposed rezoning, Iles Rd, Rotorua. Unpublished report by Martin, McCauley Morton Limited, Rotorua; dated 24/6/2004; 34 pages.

9.0 GLOSSARY

9.1 Abbreviations

CPT Cone penetrometer test

ka Thousand years

m metres

MPa Mega-pascals (units for measuring soil strength)

q_c Cone resistance (soil parameter measured during cone penetration testing)

TVZ Taupo Volcanic Zone

9.2 Technical terms

Cone penetrometer test – a test for measuring ground strength using a truck or rig mounted probe. Used for depths below 2-3 metres. Can reach depths greater than 20 metres in suitable conditions.

Fine-grained sediments – sands, silts and clays.

Good ground – ground suitable for timber framed structures without ground modification of special foundation design provision. Defined using strength as measured by scala penetrometer test and the cone penetrometer test

Lacustrine - of or relating to a body of fresh water.

Low-energy processes – processes where the energy input into the system is very small. For example sediment, such as fine sands and silts, settling out of suspension is a low-energy process compared to sediment being moved as bed-load transport, which requires high velocity flows and is a high-energy process.

Scala penetrometer test – a test for measuring ground strength using a hand-held ground probe. Used for depths of 2-3 metres usually but can reach to five metres in some circumstances.

Soft to very soft sediments - -ground not suitable for timber framed structures without ground modification of special foundation design provision. Defined using strength measured by the scala penetrometer test and the cone penetrometer test.

www.gns.cri.nz

Principal Location

1 Fairway Drive
Avalon
PO Box 30368
Lower Hutt
New Zealand
T +64-4-570 1444
F +64-4-570 4600

Other Locations

Dunedin Research Centre
764 Cumberland Street
Private Bag 1930
Dunedin
New Zealand
T +64-3-477 4050
F +64-3-477 5232

Wairakei Research Centre
114 Karetoto Road
Wairakei
Private Bag 2000, Taupo
New Zealand
T +64-7-374 8211
F +64-7-374 8199

National Isotope Centre
30 Gracefield Road
PO Box 31312
Lower Hutt
New Zealand
T +64-4-570 1444
F +64-4-570 4657