Geology, Natural Resources and Hazards of the Maniapoto Rohe

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EXECUTIVE SUMMARY

GNS Science was contracted to compile geology, natural resources and hazards data it holds as part of a Maniapoto Māori Trust Board project to consider options for landuse, development, and optimising economic potential and employment within the Maniapoto rohe. This report accompanies a geodatabase of geological information on the rohe and is split into three separate parts. This executive summary lists some important potential resources and hazards. A second part provides more detailed information on specific resources and hazards, and a third part provides a general geological outline of the rohe and more detailed discussion of the geology, resources and hazards.

Resources

- Significant coal resources underlie parts of the rohe. In most fields, coal quality is poor. In most, the resource is available only, or mainly, using expensive and hazardous underground mining methods.
- The best and most accessible coal is in the Mokau Coalfield, where 37 million tonnes is realistically available using opencast techniques.
- Limitations on use of this resource include remote location, high sulphur, thin, multiple seams, low current prices, cost of consent application and potential waste and water management issues.
- Limestone resource is widely distributed and high quality in places. It is suitable for horticultural, agricultural and some industrial purposes.
- Limitations on exploiting limestone resource include local overburden, capital investment and competition from other producers.
- A significant coastal ironsand resource is present at Taharoa, but is currently in production for internal and export supply.
- The rohe has a number of aggregate reserves, some of moderate and some high quality.
- Limitations include the small size of the high quality resource, although lower quality material for road construction and maintenance is locally plentiful. Transport to place of sale may cut competitiveness and resource consent costs and water quality management may be issues.
- Groundwater is an important resource, but currently limited information is available.

Hazards

- Landslides and volcanic ashfall are the major hazards within the rohe.
- Landslides are widespread in weak, fine grained rocks. These materials may fail on slopes, particularly when saturated by heavy or persistent rainfall.
- Landslide mitigation is often possible through drainage and tree planting. Geotechnical investigation should be undertaken for new significant structures to be built on susceptible ground.
- Volcanic ashfall presents a potential hazard to water and electrical supply systems, may disrupt transport and may result in animal and human health issues.

Special geomorphic and geological features

- Aligned volcanic cones
- Limestone formations
- Coastal cliffs and scenery
- Triassic and Jurassic rocks of the Kawhia to Awakino area
- Holocene dunefields
- Miocene coastal section

KEYWORDS

Maniapoto Māori Trust Board, rohe, geology, resources, hazards

INTRODUCTION

Maniapoto Māori Trust Board approached GNS Science and other Crown Research Institutes to provide them with digital scientific data, and a brief explanatory report, relevant to their consideration of options for future landuse and development for optimising economic potential within the rohe. To fulfil this need, GNS Science has pulled together available earth science information that will provide an earth science background for the Trust Board in considering options.

This report is deliberately split into three main sections. The first section provides an executive summary that highlights specific information that may of interest to Maniapoto for this project. The second section summarises known information within the rohe that is more spatially defined in the accompanying digital data (geodatabase). The third part is a broader geological background that will provide a useful resource for any individual more interested and knowledgeable in geology and interested in the geological features and geological history of the rohe. Some of the language in this second part of the report is necessarily technical.

Neither section is accompanied by references to make reading easier, but documentation describing derivation of the information presented will be available from GNS Science on request.

The digital data that accompanies this report is suitable for use at a regional scale and for alerting Maniapoto users to the likely geology, resources and hazards at a regional scale rather than a block by block basis. The geological units data is derived from the GNS Science QMAP 1:250 000 scale Geological Map of the Waikato Area (Map 4; Edbrooke 2005) and Geological Map of the Rotorua Area (Map 5; Leonard et al., 2010) information. While the data for this map was compiled at a scale of 1:50 000 scale, the linework was simplified to 1:250 000 scale for map publication. Thus in places, smoothed linework may be several hundred metres from boundaries on the ground surface. While this simplification phase makes the dataset of limited use when applied to specific land blocks, it does provide a geological context for each specific land block.

The geodatabase that accompanies the report contains shapefiles, projected to NZTM2000, derived from appropriate national and regional datasets held by GNS Science.

Table 1 List of data in the Maniapoto geodatabase.

Maniapoto_rohe_TM	polygon	Rohe extent
Maniapoto_geotherm	point	Known geothermal location
Maniapoto_landslides	polygon	Known landslides
eq_MM_500yr	polyline	MM ground shaking intensity 500 year return period
Taupo_ignimb	polyline	extent of AD233 ignimbrite
Ash_m_1Myr	polyline	Probable thickness (m) of ashfall in 1 million years
Ash_mm_10kyr	polyline	Probable ash thickness (mm) in 10 000 years
Ash_mm_500yr	polyline	Probable ash thickness (mm) in 500 years
Maniapoto_pet_lab_view	point	PETLAB analytical
Maniapoto_germ_site_view	point	GERM minerals
Maniapoto_germ_materials_pt	point	GERM materials
Maniapoto_ironsand_dep	polygon	Ironsand field
Maniapoto_mineral_coal_drillhole	point	coal exploration drillholes
Maniapoto_mineral_coalfields	polygon	coalfields
Maniapoto_lmst	polyline	limestone horizons
Maniapoto_limestone	polygon	rocks units with significant limestone component
Maniapoto_wells	point	petroleum and exploration drillholes
Maniapoto_recent_wells	point	recent drillhole
Maniapoto_seismic_2D_NZBO2014	polyline	petroleum seismic reflection lines
Maniapoto_3d_seismic	polygon	petroleum 3D seismic reflection line data
Maniapoto_blocks_offer_2013	polygon	2013 petroleum lease blocks
Maniapoto_oil_gas_fields	polygon	petroleum fields
Maniapoto_petroleum_nz_license	polygon	petroleum permits
QMAP_horizons	polyline	QMAP horizons
QMAP_geol_units_TM	polyline	QMAP geological units
Maniapoto_geology_250k	image	QMAP image, Maniapoto rohe
Waikato_geology_250k	image	QMAP Waikato image, Edbrooke 2005
QMAP_Rotorua_r	image	QMAP Rotorua image, Leonard, Begg & Wilson 2010
ALLOC_IRIS_AQUIFER_DETAILED_Maniapoto	polygon	Waipa aquifer
WRC_AUTHORISATION_IRIS_gw	Point	Consented groundwater sites
WRC_AUTHORISATION_IRIS_sw	Point	Consented surface water sites
WRC_APPLICATION_IRIS_maniapoto	point	Consent applications

1.0 PART 1: SUMMARY OF GEOLOGICAL RESOURCES AND HAZARDS

The purpose of this section is to provide a quick and easily accessible summary of geology, resources and hazards within the rohe.

1.1 PAPATUANUKU

1.1.1 Coal: Coalfields occur in a number of areas within the rohe. They are listed below with comments on the quality and quantity of each resource and potential limits on their value, and potential hazards associated with their exploitation.

Uses and potential uses: Domestic and industrial fuel; power station fuel; steel manufacture; potential source of coal bed methane; potential for foreign export.

Limitations: Greenhouse gas emissions; currently considered environmentally unfriendly; likely resource consent requirements; high capital investment; underground mining expensive and hazardous; high sulphur and ash contents of most rohe coals; toxic waste; land remediation after mining and water management issues during and after mining.

Table 2 Rohe Coal Resource Assets:

Coalfield	Coal-in-ground resource in millions of tonnes (Mt)	Recoverable coal resource in millions of tonnes (Mt)
South Waikato		
Kawhia	182	56
Tihiroa	180	49
Te Kuiti	38	11
Mangapehi	58	10
Total South Waikato	**458**	**126**
King Country		
Mokau	166	108
Aria	2	-
Waitewhena	90	30
Ohura-Tangarakau	110	33

1.1.1.1 South Waikato Coalfields:

Kawhia Coalfield:

Location: North and south of Kawhia Road.

Characteristics: Estimated 182 Mt coal-in-ground; about 56 Mt recoverable; Coal seams up to 10 m thick, but typically 3–5 m thick. Most coal lies at depths between 100 m and 500 m below the ground surface.

Limiting factors: Poor quality, with medium to high ash content and high sulphur; therefore limited demand; small opencast potential; expensive and potentially difficult resource consent process; currently low international price.

Potential hazards: Toxic waste and water management issues; costs and hazards associated with underground mining methods.

Tihiroa Coalfield

Location: North and south of Kawhia Road, east of Kawhia Coalfield.

Characteristics: Entirely subsurface, so poorly known; most coal is at depths greater than 200 m below the ground surface; up to three seams present; medium ash content and medium sulphur content.

Limiting factors: Proving the resource requires significant investment; underground mining required; no opencast mining potential.

Potential hazards: Costs and hazards associated with underground mining methods.

Te Kuiti Coalfield

Location: NE of Te Kuiti.

Characteristics: Poor quality, high-ash, high sulphur coal; total in-ground resource c. 38 Mt, but only c. 11 Mt recoverable.

Limiting factors: Poor coal quality; most resource at 200–400 m below the ground surface; small recoverable resource; very limited demand for coal of this type.

Potential hazards: Costs and hazards associated with underground mining methods.

Mangapehi Coalfield

Location: Immediately NE of Benneydale.

Characteristics: Better quality than most other south Waikato coalfields; lower ash and sulphur contents and higher energy value; current in-ground estimate 58 Mt, c. 10 Mt recoverable.

Limiting factors: Relatively poorly explored; most coal >200 m below the ground surface; distance from potential markets.

Potential hazards: Costs and hazards associated with underground mining methods; flooding of underground workings from water-filled old workings.

1.1.1.2 *King Country Coalfields*: Mokau, Waitewhena, Ohura-Tangarakau and Aria fields.

Mokau Coalfield

Location: about 20 km inland, between the Mokau and Awakino rivers.

Characteristics: Distribution has been well investigated; subbituminous coal rank; medium to high sulphur (1–4%); low to medium ash content; thin seams (up to 3 m thick) with uniform thickness over wide areas; potential for opencast mining; potential in-ground resource 46 Mt, realistically 37 Mt from opencast mining; underground resource c. 120 Mt, of which c. 71 Mt is likely to be recoverable.

Limiting factors: Relatively remote, hilly, bush-covered site; high sulphur coal; multiple thin seams; potential waste and water management issues.

Potential hazards: Costs and hazards associated with underground mining methods.

Waitewhena Coalfield

Location: Waitewhena Valley, c. 15 km NW from Matiere.

Characteristics: Seams up to 3.5 m thick; medium to high ash and sulphur contents; 78 Mt estimated in-ground coal, 22 Mt potentially recoverable, and 8 Mt potentially recoverable using opencast mining.

Limiting factors: Remote area; poor quality coal; many geological faults in the area.

Potential hazards: Difficult underground mining conditions due to faulting and thin seams.

Aria Coalfield

Location: South of Aria.

Characteristics: Narrow fault-bounded sliver of coal-bearing rocks; remaining in-ground resource c. 2 Mt.

Limiting factors: Coal is deep and the area is complex structurally; no economically viable recoverable resource remains.

Ohura-Tangarakau Coalfield

Location: W and NW of Ohura.

Characteristics: Not well explored; underlies a large area of rugged hill country; in-ground coal estimated at 110 Mt, with 33 Mt recoverable.

Limiting factors: Remote and rugged location; Mostly suitable only for underground working.

Potential hazards: Costs and hazards associated with underground mining methods; difficult underground mining conditions in thin, faulted seams.

1.1.2 Limestone

Location: Widely distributed, particularly in a wide, central N-S belt of the rohe from Te Kauri Reserve to Ohura.

Characteristics: Often well-exposed and easily accessible. High quality for agricultural and industrial use (up to 98% calcium carbonate, $CaCO_3$).

Uses and potential uses: Include horticultural and agricultural lime, cement-making, iron and steel making, paper manufacturing, glass making, sugar industry, filler in the plastics industry, road metal, building stone. Large processing plants already exist at Te Kuiti and Otorohanga; existing quarries near Te Kuiti, Wairere and Otorohanga. Limestone also produces revenue as a tourist attraction (Waitomo Caves with potential in other cave systems). Limestone is also one of the rohe's special landscape features.

Limiting factors: Mudstone overburden; requires large capital investment; resource consent costs; competition from other limestone producing areas (e.g., Northland and Hawke's Bay)

1.1.3 Iron Sand

Location: A coastal resource occurring onshore in dune and beach sands along the open coast and offshore. Largest resource at Taharoa; other locations at Kawhia North Head, Harihari, Marokopa, Awakino and Mokau are probably not currently economic. A very large iron sand resource is present locally offshore in waters 20 to 40 m deep.

Characteristics: Kawhia North Head concentrated resource estimated at 50 Mt, Harihari 1 Mt, Marokopa 25 Mt, Awakino 6 Mt and Mokau 4 Mt. The very large resource at Taharoa is estimated to contain 360 Mt of magnetite concentrate.

Uses and potential uses: Source for titanomagnetite; titanomagnetite is used to produce steel, and is also a source of vanadium, used in rust-resistant steel and steel for high speed tools. Used in New Zealand (Glenbrook, supplied by slurry pipeline from Waikato North Head) and exported through an offshore facility at Taharoa to Japan, South Korea and China.

Limiting factors: Titanomagnetite concentration in sand; capital investment in plant; resource consent process (particularly for offshore mining; note resource consent decline for offshore Taranaki application).

1.1.4 Aggregate

Location: N-S belts of basement rocks in the west and the east provide most aggregate; some from streams in catchments supplied from the Ruapehu area; some from Pirongia and Te Kawa Hill; some from limestone deposits

Characteristics: Quality of aggregate varies across the area: sandstones from the western belt of Murihiku rocks: moderate quality; sandstone from the eastern belt of Manaia Hill Group: high quality; basalt and andesite from the base of Pirongia and Te Kawa Hill: high quality; river gravels derived from Ruapehu andesites: high quality; Te Kuiti Group limestone: poor quality.

Uses and potential uses: Aggregate is used for road construction and maintenance, landscaping and in concrete.

Limiting factors: The best aggregate quality is from volcanic rocks at Pirongia and from streams carrying Ruapehu-derived rocks, and these are well-suited to use in concrete, but supply is limited. Manaia Hill Group sandstone in the east includes the mineral prehnite which can contribute to breakdown of the gravel through time, although quality is generally better than for Murihiku rocks in the west. The presence of the mineral zeolite in Murihiku rocks results in frittering through exposure to weather and reduces its quality. Limestone is soft and weathers more rapidly than the other sources, and is only satisfactory for use on low usage roads.

While high quality aggregate is a valuable resource, proximity to well-formed roads for transport, and to place of use or sale, is a key element in commercial exploitation. Other potential issues are resource consent and water quality management and competition with other producers.

1.1.5 Serpentinite

Location: Wairere, 9 km south of Piopio.

Characteristics: A small linear area of fault-bounded and sheared serpentinite.

Uses and potential uses: Additive for superphosphate.

Limiting factors: Limited resource volume; resource only present at one isolated location.

1.1.6 Onshore/Offshore Petroleum Resources

Location: The greatest petroleum prospect area is offshore; minor occurrence of gas onshore is the result of gas generation from buried peat deposits. The offshore area of the rohe has been explored for over 20 years with no commercial finds. There is currently only minor exploration activity – Kea Petroleum drilled the Mauku-1 well onshore north of Awakino in 2013.

Coal seam gas is potentially prospective onshore, but recent testing needs to be reviewed prior to further investigation.

Characteristics: Hydrocarbon traces have been found in some offshore exploration drillholes, but no major discoveries have been made to date.

Coal seam gas is an environmentally clean product, and easier to transport and use than coal. In addition, it can potentially exploit coal resources otherwise unmineable due to depth of burial, and without the problems associated with high sulphur and ash content

Uses and potential uses: Oil and gas have many uses and a highly developed international market.

Limiting factors: Exploration is high risk and very costly. Gas is a clean-burning energy source, but oil is less so. A significant offshore oil find would require heavy investment in infrastructure prior to production, and offshore production comes with potential environmental problems that require careful and expensive contingency plans.

1.2 TANGAROA

1.2.1 Groundwater

Location: Governing bodies: Waikato Regional Council ("WRC", dominant), Horizons Regional Council ("Horizons"), Taranaki Regional Council ("TRC").

Consents for takes: Required for daily takes of greater than 15 m^3 (WRC) or greater than 50 m^3 (Horizons and TRC).

Location: Coastal and WRC West Coast Catchment

Characteristics: Holocene river deposits and mobile dunes are likely to provide groundwater resources within primary porosity. Water is also provided from springs sourced from fractures in older geological units (Tertiary and basement rock).

Quality: Generally good, some high dissolved iron levels near the coast.

Current uses: Iron sand mining, domestic and municipal supply.

Limiting factors: Very little information currently available. The dominant geological units make groundwater exploration difficult and limit expected well yields; useful groundwater volumes are expected to be small and localised.

Location: Inland and WRC Waipa Catchment

Characteristics: Tauranga Group geology supplies a significant water resource. Additional important water sources occur within fractured basalt and basaltic andesite of the Alexandra Volcanic Group and both primary porosity and fractured and jointed rock of the Pakaumanu Group and Whakamaru Group ignimbrites. A set of these geological units have been roughly mapped and named the 'Waipa aquifer' for WRC allocation purposes. Small, localised volumes of water are also sourced from fractures in Tertiary and Basement rock.

Quality: Generally good, two groundwater monitoring sites show nitrogen impacts, likely from land use activities.

Current uses: Irrigation, municipal supply, domestic supply, quarrying and dairy farming.

Limiting factors: Groundwater and surface water are strongly linked and allocations must be managed as one system. There is significant existing use of the Waipa aquifer, as well as applications for further consented uses. Current knowledge is limited though work is currently underway to remedy this.

1.3 RUAUMOKO

1.3.1 Geothermal

Location: The only well documented geothermal spring within the rohe is at Te Puia hot springs in western Kawhia.

Characteristics: Te Puia springs are warm and rich in chloride and HCO_3; associated gases are nitrogen and methane. Here cold seawater mixes with warm water derived from rainfall. Te Puia represents a low enthalpy geothermal resource. No high temperature geothermal systems are known within the rohe.

Uses and potential uses: Insufficient information available about the resource.

Limiting factors: Relatively low temperature (58°C) and low flow.

1.4 HAZARDS

1.4.1 Volcanic Hazard

Hazard source: Mount Taranaki, Ruapehu, Ngauruhoe, Tongariro; Central North Island rhyolitic volcanoes.

Characteristics: Ashfall is the principal volcanic hazard in the rohe. Taranaki is expected to be the source of most of the ashfall from these andesitic volcanoes.

The Central North Island rhyolitic volcanoes erupt less frequently, but can generate huge volumes of ashfall and ignimbrites may reach the eastern part of the rohe.

Hazards: Modelling suggests cumulative ashfall depth of 5 to < 1 mm over any 500 year period, thicker to the south and east of the rohe.

Less than 1 mm may result in lung and eye irritation, closure of airports, minor abrasive damage to vehicles, houses and equipment, contamination of water supplies, particularly in roof-fed rainwater supplies. 1–5 mm of ash will include these and other impacts such as crop damage, ill-health in livestock, electricity supply loss, water supply failures, water contamination and storm-water and sewerage system blockages.

Of the central North Island rhyolitic volcanoes, Okataina and Taupo are the most hazardous. Ignimbrite from Taupo Moana in AD 233 destroyed trees and other vegetation and river drainage systems were obliterated. Loose pumice ash choked downstream drainages, causing blockages and breakout floods.

Hazard mitigation: Little can be done to mitigate the effects of these ashfall and ignimbrite hazards. Warnings of impending eruptions can be brief or non-existent, although warning signs of larger eruptions are expected to be detectable.

1.4.2 Earthquake Hazard

Hazard source: Sources for strong ground shaking are almost all outside the rohe. Potential sources include the Taupo Fault Belt, the North Island Fault System, the Kerepehi Fault, the offshore Turi Fault, and rupture of the subducting slab at depth beneath the rohe.

Seismicity and expected seismicity: In historical times, low to moderate seismicity compared with other areas of New Zealand. This may have been the case in the recent geological past. The offshore Turi Fault is known to be active, but its earthquake-generating characteristics are unknown. Taupo Fault Belt earthquakes are unlikely to exceed M 7 and strong ground motion is unlikely to create widespread damage because of distance from source (>50 km). Some hazard is associated with faults of the North Island Fault System because, while more distant (>100 km), earthquakes are expected to be significantly larger (up to M 7.6).

In the future, the Maniapoto rohe can expect similar levels of seismicity to that experienced in the last 150 years. Ground shaking intensities of between MM7 and MM8 are modelled to occur every 500 years. This may be expected to result in general alarm, serious damage to old masonry buildings and topple chimneys, and result in some landslides on over-steepened slopes.

1.4.3 Landslide Hazard

Distribution: Landslides are common within the rohe. They occur widely in sloping areas underlain by geologically young mudstones. Landslides in susceptible sediments may undermine stronger overlying rocks resulting in block failures. When saturated, weathered bedrock, uncompacted sand, and pumiceous soil deposits are also vulnerable to slumping on slopes; the latter may even fail on gentle slopes.

Characteristics: Most landslides within the rohe are earthflows in saturated mudstones; these may de-stabilise overlying rocks causing block failures, e.g., blockfalls from Te Kuiti Group limestone scarps resulting from undermining by slumping of underlying units. Landslides are often associated with extreme and/or localised rainfall events.

Mitigating measures: Care should be made not to load existing landslides with new materials, and care should be taken before siting new structures close to steep escarpments. Drainage, where possible, and planting with fast growing, deep rooted trees will help mitigate some landslide problems. Geotechnical investigations should be carried out before any significant structures are built on landslide prone soils.

1.4.4 Tsunami Hazard

Distribution: Low-lying coastal areas and the lower reaches of rivers in the rohe are vulnerable to tsunami.

Potential sources: The most likely potential source of tsunami in the area is from large regional earthquakes, which may be located outside the New Zealand region, or from local submarine or coastal landslides.

Mitigating measures: Strong earthquake shaking is a warning to leave quickly low-lying coastal areas. Unusual changes in sea behaviour accompanied by a roaring noise are also warning signs to seek higher ground.

1.4.5 Special Geomorphic and Geological Features

Features: Aligned volcanic cones (Pirongia, Kakepuku, Te Kawa and Tokanui).

Ignimbrite sheets; Particularly in the southeast.

Limestone formations (bluffs and escarpments, karst features, caves systems, sinkholes).

Coastal scenery (including Kawhia Harbour).

Fossiliferous Triassic and Jurassic rocks (Kawhia and south to Awakino).

Holocene dunefields (Taharoa).

The Miocene coastal section (cliffs south from Tirua Point to Tongaporutu).

2.0 PART 2: GENERAL DESCRIPTION OF MANIAPOTO ROHE

The aim of this part of the report is to provide a general background to the information provided above, and to help readers understand the geology of the Maniapoto rohe. Note that the language is a little more technical than in the proceeding parts.

2.1 THE GEOLOGY OF THE MANIAPOTO ROHE

The rocks of the Maniapoto rohe comprise four major rock groups, basement, Tertiary, volcanics and Quaternary cover deposits. These four groups represent significant periods New Zealand geological history.

2.1.1 Basement

The oldest rocks in the rohe are Permian in age, but are restricted at the surface to a tiny block about one kilometre long crossing Kohua Road near Aria. These are serpentinised gabbroic rocks of the Dun Mountain Ophiolite Group, directly correlative with the serpentinites quarried near Piopio. This thin belt of rocks extends semi-continuously along the length of the country, sometimes faulted out and sometimes buried beneath younger rocks, between the southeastern Otago coast and Northland. They were deposited as part of the sea floor east of the supercontinent Gondwana about 290 million years ago.

The next oldest rocks are Triassic and Jurassic mostly marine deposits of the Murihiku Supergroup, also belong to the group of rocks known as “basement”. They are exposed in a folded, south-north oriented belt between the Awakino River and Moerangi, and are also well-exposed along the coast between Tapirimoko Point to Te Maika and along the south Kawhia Harbour shore to Waipuna. These consist mostly of sandstone, siltstone, mudstone, conglomerate and volcanic ash deposited mostly on the sea floor east of the Gondwana supercontinent’s coastline between 225 and 145 million years ago.

A further belt of basement rocks, the Manaia Hill Group (also known as Waipapa terrane), are patchily exposed along the eastern margin of the rohe between Meringa and Te Awamutu. These consist largely of complexly deformed interbedded sandstone and mudstone rocks of Jurassic age (200–145 million years), deposited offshore from eastern Gondwana, but further offshore than Murihiku Supergroup rocks.

2.1.2 Tertiary

Tertiary sedimentary rocks form much of the central and southern parts of the rohe. They date from about 34 to 2 million years and cover the Oligocene, Miocene and Pliocene geological periods. They unconformably overlie much older, more indurated basement rocks, the unconformity representing a long period of non-deposition, weathering and erosion of the basement rocks before deposition of the Tertiary rocks began. Most of the Tertiary rocks were deposited in marine environments, ranging from shallow water continental shelf to deep water conditions, although two coal measure units were deposited on land. The rocks deposited during each epoch have particular characteristics reflecting the geological setting of the time and the following discussion will deal in turn with the Oligocene rocks represented by the Te Kuiti Group, the Miocene rocks represented by the Mahoenui, Mokau, Wai-iti and Whangamomona groups, and the Pliocene Awhitu Group.

Oligocene Epoch (34–23 million years):

The Oligocene was generally a tectonically quiet period in New Zealand's geological history and in the Waikato area there was widespread regional subsidence, deposition beginning with non-marine coal measures (terrestrial) and grading through marginal marine to outer shelf (as deep as 200 m water depth) of a predominantly transgressive sequence changing from basal, non-marine coal measures through marginal marine to outer shelf calcareous mudstone, sandstone and limestone with time. This sequence of rocks, known as the Te Kuiti Group, occurs widely throughout the rohe, overlies basement rocks, and is best exposed in the north, between Kawhia Harbour and Piopio, and around Te Kuiti. The basal coal measures are exposed only at Benneydale and east of Kawhia Harbour, near Te Rauamoa. Subbituminous coal seams have been mined at both locations, but none is currently being extracted. As well as coal seams, the coal measures comprise carbonaceous mudstone, muddy sandstone and rare conglomerate. Marine sedimentary rocks overlying the coal measures include calcareous mudstone and sandstone, commonly with bioclastic limestones up to 70 m thick at the top of the sequence. Sandstones commonly contain the mineral glauconite. Limestones are characteristic of the Te Kuiti Group and they crop out widely in the northern part of the rohe, commonly forming steep cliffs and bluffs and characteristic karst (or tomo) landscapes, particularly around Waitomo and Te Kuiti. The well-known Waitomo Caves are formed within Te Kuiti Group limestone and the rock is an important source for the production of agricultural and industrial lime.

Te Kuiti Group rocks are little deformed, typically having low dip angles where they have been tilted by later earth movements.

Miocene Epoch (23–5 million years):

Earliest Miocene time saw a change in tectonic activity as the convergent Australian-Pacific plate boundary propagated through northern New Zealand, beginning a period of active tectonism that persists to the present day. This change ended carbonate-dominated deposition of the Te Kuiti Group and initiated terrigenous-dominated sedimentation in rapidly subsiding basins.

Early Miocene, mudstone-dominated marine sedimentary rocks, locally over 1000 m thick, overlie Te Kuiti Group south of Otorohanga, but are thickest in the southeast near Taumarunui. These rocks, known as the Mahoenui Group, crop out widely in the southeast of the rohe and comprise massive to weakly bedded, calcareous mudstone to fine sandy mudstone with rare bioclastic limestone beds. Some well bedded, alternating sandstone and mudstone occurs in the area between Mangapehi and Taumarunui. Mahoenui Group mudstones are susceptible to instability in road cuts and on natural slopes, and landslides and active earth flows are common in this material.

Later in the Miocene, much of the King Country area was uplifted and parts of the Mahoenui Group were eroded, but this was soon followed by deposition of shallow marine sandstone and mudstone with interbedded paralic (shoreline) deposits, including coal measures. This group of rocks is known as the Mokau Group and it occurs mainly in the southwest of the rohe, south of Mahoenui, but is also present around Te Kuiti. Coal measures of the Mokau Group are only present in the south. They comprise carbonaceous sandstone, mudstone and shale with multiple, thin, laterally persistent subbituminous coal seams. Coal seams crop out and have been mined in the Mokau, Aria, Waitewhena, Ohura and Tangarakau coalfields in the King Country, but none is currently being extracted.

Renewed deepening of the Waikato and King Country area in the Middle Miocene led to the deposition of mainly deep water sandstone, siltstone and mudstone of the Whangamomona Group, over Mokau or Mahoenui group; deposition continued into the Late Miocene. Wai-iti and Whangamomona group rocks are present mainly in the south of the rohe, cropping out along the coast south of Tirua Point to Tongaporutu and inland to Taumarunui. Bedding is relatively undeformed, but relatively small scale faults displacing and tilting beds are common.

Pliocene Epoch (5–2 million years):

By Pliocene time, marine sedimentation had ended in the Waikato area and the only rocks preserved are those deposited on land. The only Pliocene sedimentary rocks within the rohe are old dune sands covering a small area between Kawhia and Aotea. They comprise moderately to poorly consolidated, weakly cemented, dune-bedded sandstone with minor interbedded carbonaceous siltstone.

2.1.3 Volcanics

The remnants of volcanic activity are scattered across the rohe and are significant features of the landscape in the north and east. Three types of volcanic rocks occur within the area and while they are all relatively young geologically, there are no centres of active volcanism within the rohe. However, many of the deposits in the east were erupted from the Taupo Volcanic Zone, east of the rohe, which remains an area of active volcanism. In addition, volcanic material was also sourced from the Taranaki volcanoes and left deposits in the southwest portion of the rohe.

The oldest rocks are the subvolcanic remnants of Pliocene (3–4 million years) volcanoes that once existed near the coast, south of Kawhia Harbour. These volcanoes have now been completely eroded and only deeply weathered, near surface intrusive rocks are preserved at three centres between Kawhia Harbour and Waikawau. The Otauanui centre covers about 4 km^2 west of Kawhia Harbour, the Pehimatea centre comprises two intrusions near Kiritehere, and the Whareorino centre is about 4 km south of Moeatoa. The rocks represent the near surface “plumbing” of the now-eroded volcanoes and consist of feeder dikes, sills, volcanic necks and plutons (high-level magma reservoirs) that are now exposed within the uplifted Murihiku basement rocks. Compositionally the rocks are andesites and dacites, similar to those of Mount Taranaki. The approximate north-south alignment of the centres suggests that major faults in the basement rocks may have controlled their distribution.

Slightly younger, Pliocene to Early Quaternary (1.6–3.0 Ma), volcanoes of basaltic to andesitic composition are aligned across the northern part of the rohe. These aligned volcanoes are known collectively as the Alexandra Volcanic Group. They comprise the large stratovolcanoes of Mount Karioi (outside the rohe boundary) and Mount Pirongia in the west, and the smaller volcanoes Kakepuku, Te Kawa and Tokanui to the east. Pirongia is a 959 m high composite volcano with an andesitic cone surmounting a basaltic shield volcano. The cone is constructed from a succession of lava flows, volcanic breccia, ash and debris flows, and was originally 100–150 m higher than it is today. The smaller volcanoes are constructed mainly of basalt lava flows with minor scoria and tuff.

The remaining volcanic rock type, ignimbrite, is the most widespread within the rohe. Ignimbrites are sheet-like deposits formed from ground-hugging flows of hot ash and pumice produced by very large, explosive rhyolitic eruptions. They may be loose, non-welded deposits through to hard, dense, welded rocks. Eruptions of this type have occurred intermittently in the Taupo Volcanic Zone over the last 1.6 million years and deposited ignimbrites across the central North Island. Older, landscape-forming, variably welded ignimbrites (Early Quaternary, 1.0–1.6 million years) cover large areas in the east of the rohe, almost completely burying the underlying sedimentary rocks east of Te Kuiti and Mangapehi. Scattered ignimbrite remnants persist as far west as Piopio. These rocks are thought to have been erupted from a large vent in the vicinity of Mangakino. Younger, Middle and Late Quaternary ignimbrite deposits, erupted from centres further east, are much less widely distributed within the rohe. They tend to be preserved in valleys cut in the older ignimbrite sheets, mainly southeast of Mangapehi.

Practically all of the volcanic rocks present were generated by subduction of the Pacific Plate beneath the North Island, with a minor component of intraplate volcanism contained within the Alexandra Volcanic Group.

2.1.4 Quaternary Period (2.58 million years to the present)

While Quaternary-aged sediments within the rohe are all of Late Quaternary age, deposited over the last 130,000 years. Quaternary sedimentary rocks are predominantly non-marine as the area was land throughout the period. They are subdivided into those deposited near the coast, on beaches and by wind, and those deposited mainly further inland by rivers and streams, and in lakes and swamps.

The coastal deposits include uplifted marine terrace cover deposits that are present along the coast from Awakino to the southern boundary, south of Pukearuhe. The well preserved terrace extends up to 2 km inland. The covering deposits are up to 30 m thick and typically comprise a basal conglomerate overlain by sands and mud with interbedded thin woody lignite beds and old soil horizons. These beds accumulated in a range of marginal marine environments, but mainly on beaches between 70,000–130,000 years ago. Other coastal deposits include dunes on the north side of Kawhia Harbour, south of Paparoa Point and elsewhere along the rohe coast. They include soils and fossil forest deposits near north Taranaki river mouths (e.g., Tongaporutu and Mohakatino river mouths), both fixed and mobile dunes, with the older, sparsely vegetated fixed dunes commonly overtopped by mobile, unvegetated dunes. Horizons of titanomagnetite-rich sand are included in these dune complexes and the deposits at Taharoa have been mined for ironsand since 1972.

Inland deposits comprise mainly pumice-rich, valley-confined alluvium overlying Tertiary and older rocks. They include unconsolidated gravel and sand, and soft silt, mud and peat deposited by rivers and in lakes and swamps. Some deposits include ash from the most recent ignimbrite eruptions. Redeposited volcanic materials including pumiceous and rhyolitic gravel sand and silt cover much of the lowland area south of Hamilton. Thickness of Quaternary alluvial deposits is highly variable but is typically in the range 5–30 m. The deposits occur throughout the rohe, covering relatively small areas within the valleys of major rivers and streams.

2.2 SPECIAL GEOMORPHIC AND GEOLOGICAL FEATURES

There are several landscape features within the rohe that give the area its distinctive character. These features reflect the underlying geology and were formed by major geological events, such as volcanic activity, regional subsidence and uplift, faulting, and prolonged weathering and erosion.

Perhaps the most significant and characteristic landscape feature is the presence of extensive limestone formations in the central part, mainly between Otorohanga and Mahoenui, and in the vicinity of Te Kuiti. Steep slopes and bluffs are common where limestones crop out and distinctive karst landscapes, characterised by sinkholes, disappearing streams, caves, natural arches and fluted rock outcrops, are formed in limestone areas. Karst features are produced by chemical solution of the limestone by natural waters, including rain. A particularly well developed karst landscape is formed on Te Kuiti Group limestone around and west of Waitomo Caves. The surface is characterised by numerous sinkholes surrounded by irregular limestone ridges. Rainwater and surface streams enter the underground cave system through the surface sinkholes. Spectacular formations in the cave system at Waitomo draw many visiting speleologists and tourists to the area, and the caves are an internationally known tourist attraction. Te Kuiti Group limestone is also an important resource, quarried and processed for a range of industrial and agricultural uses.

Amongst the generally subdued topography of low hills and ranges, the aligned volcanic cones in the north are particularly distinct landscape features. The radially dissected, 959 m high, composite cone of Pirongia dominates the northern part of the area and ranks amongst the most prominent features of the Waikato region. East of Pirongia, its smaller relation Kakepuku is a symmetrical volcanic cone rising to a height of 450 m from the plain between the Waipa and Punui rivers. Further east the smaller semi-circular cone of Te Kawa and the small lava mound at Tokanui complete the line of basaltic and andesitic volcanoes that erupted between 2.8 and 1.6 million years ago.

Later volcanic activity in the Taupo Volcanic Zone produced the landscape-forming ignimbrite sheets that form the western fringe of the volcanic plateau and dominate the eastern part of the rohe. The ignimbrite sheets are present as extensive hill and ridge top caps above Tertiary sedimentary rocks and largely bury the older basement rock ranges further east. The now eroded ignimbrite surface forms rounded and flat-topped hills, between 250 m and 1000 m high, with characteristic eroding bluffs along the margins. Ridge-capping escarpments of welded ignimbrite are a characteristic feature of the east and southeast of the rohe. These early and middle Quaternary volcanic rocks, mostly derived from an old volcanic centre in the Mangakino area, are particularly conspicuous along State Highway 4, and in the Whakamaru area.

The rohe also has a spectacular coast with some special geomorphic features. In the north, Kawhia Harbour was formed by drowning of the landscape during Holocene sea-level rise. Its southern shore, out to Albatross Point, is a nationally important geological location, where a section through New Zealand’s Triassic – Jurassic rocks is exposed. Many key fossil localities that have contributed to understanding the stratigraphy of Jurassic rocks are found within this section. Large, Holocene dune fields have accumulated at the north head of Kawhia Harbour and south of Albatross Point, at Taharoa. They contain a significant ironsand resource. From Tirua Point south, the coast consists of a stretch of cliffs, typically up to 40 m high, cut by small streams, and in which from Mokau to Pukearuhe, are exposed an exceptionally continuous sequence of gently dipping strata. In a special section between Waikiekie Stream and Pukearuhe, known as Whitecliffs, the near-vertical cliffs are up to 200 m high and are a very prominent coastal feature in this area.

Coal seams, although almost always concealed beneath younger rocks, are a geological feature of the area. A significant part of the North Island coal resource is present within the rohe, contained within Oligocene (33 Ma) seams that underlie parts of the area between Kawhia and Benneydale, and Miocene (17 Ma) seams in the King Country area, mainly inland from Mokau.

2.3 RESOURCES

2.3.1 Oil and gas

Indications of petroleum onshore are rare and exploration drilling in the rohe has been unsuccessful to date. Some shallow holes drilled for water around and north of Te Awamutu have encountered small quantities of gas, almost certainly derived from buried peat beds. A very small flow of oil and gas was obtained from a shallow water bore at Mokauiti, the hydrocarbons probably flowing from fault fractures. Pukearuhe-1 well, drilled at Pariokariwa Point, was dry but found traces of oil. The most recent well drilled in the area was Mauku-1 was drilled in 2013 north of Awakino by Kea Petroleum, but did not encounter hydrocarbons.

The offshore area of the rohe is at the eastern margin of the northern part of the Taranaki Basin and is prospective for oil and gas. Several offshore wells have been drilled with hydrocarbon shows occurring in some, but no discoveries have been made to date. Coal seam gas in the Maryville Coal Measures has been investigated and tested, but no development has occurred.

Oil and gas exploration typically has high financial cost and risk, and prospects within the rohe are poor so no exploration can be recommended. Coal seam gas prospects within the Maryville Coal Measures are more promising, but the results from Solid Energy's recent exploration and testing in Ohura-Tangarakau Coalfield would need to be reviewed before any further investigation was undertaken. The typically thin Maryville coal seams are not ideal for coal seam gas extraction, but a significant resource may be present. Coal seam gas developments have the advantage of extracting a resource form deep coal seams that are otherwise unmineable. The predominantly methane gas extracted is a clean fuel that does not have the problematic sulphur content of the source coal seams. Gas is also a more readily transportable and usable fuel than coal, although infrastructural investment is high if not already available locally.

2.3.2 Coal

There is a significant coal resource within the rohe, lying within two coal measures formations. In the north, between Kawhia and Benneydale, Waikato Coal Measures lie at the base of the Oligocene Te Kuiti Group, resting on much older basement rocks. The coal measures are largely concealed by younger rocks, but do crop out in the Kawhia area, northeast of Te Kuiti and at Benneydale, and coal mines have operated in each of these areas. Four coalfields with potentially mineable resources are recognised; they are Kawhia, Tihiroa, Te Kuiti and Mangapehi coalfields and are collectively referred to as the South Waikato Coalfields. Coal seams in the south are included in the younger, Miocene age Maryville Coal Measures that lie within the otherwise predominantly marine Mokau Group. The Maryville Coal Measures are present over a wide area in the south of the rohe, and are subdivided into Mokau, Aria, Waitewhena and Ohura-Tangarakau coalfields; collectively they are the called King Country Coalfields.

2.3.2.1 South Waikato Coalfields

Waikato Coal Measures contain four coal seams in the south Waikato area. Pirongia Seam lies near the base of locally thick coal measures in Tihiroa Coalfield. It is up to 14 m thick, but typically is less than 7 m and has never been mined. Waipa Seam overlies Pirongia Seam and is also restricted to Tihiroa Coalfield; it is a thin ‘dirty’ seam, typically less than 4 m thick. Okoko Seam is the most widespread seam, occurring near the top of the coal measures in all south Waikato coalfields except Mangapehi. Okoko Seam is typically less than 4 m thick but may reach 10 m locally. It has been mined in Kawhia and Te Kuiti coalfields. Mangapehi Seam is restricted to, and is the only seam in Mangapehi Coalfield. It is up to 14 m thick and lies within the lower half of the coal measures; it has been worked at Benneydale. South Waikato coals are of subbituminous rank, typically with medium to high ash contents and medium to high sulphur.

Kawhia Coalfield has the largest coal resource, estimated at 182 million tonnes (Mt) coal-in-ground with about 56 Mt of that likely to be recoverable by opencast and underground mining methods. Mines in Kawhia Coalfield have produced a total of about 1.5 Mt since 1930, with the majority of this coming from Glencoal Energy’s Pirongia Opencast Mine (1.3 Mt). The mine worked Okoko Seam, producing a poor quality coal with a medium to high ash content and high sulphur. Pirongia Mine closed in 1999 and there are no mines currently operating in the coalfield. Only a small amount of opencast coal remains in southern Kawhia Coalfield, but a significant resource of deeper coal is present to the north and west. Although coal outcrops up to 2.6 m thick occur in the area south of Kawhia Coalfield, drilling found only seams less than 2 m thick and no mineable resource is present.

Tihiroa Coalfield, northwest of Otorohanga and immediately west of the Waipa River, is a completely concealed coalfield with no coal outcrops. It was discovered in 1979 by scout drilling east of the known Kawhia Coalfield. There has been no mining in Tihiroa Coalfield and a coal-in-ground resource of 180 Mt is estimated, of which 49 Mt is considered recoverable. However, the coalfield is unlikely to be mined economically as most of the resource is at depths of between 200 and 400 m and could only be mined by underground methods.

Te Kuiti Coalfield, about 10 km northeast of Te Kuiti, was worked by several small-scale opencast and underground mines between 1921 and 1973, producing a total of about 35 000 tonnes of generally poor quality coal. The remaining in-ground coal resource is estimated to be 38 Mt, of which 11 Mt is considered recoverable, mainly by underground methods, but there is some opencast potential in the southeast. Okoko Seam in Te Kuiti Coalfield is characterised by common mudstone partings which contributes to the high ash content of the coal. The high ash, together with high sulphur content, means that any coal worked from this area is likely to be of very poor quality.

Mangapehi Coalfield is about 30 km southeast of Te Kuiti and 8 km east of Mangapehi. Underground mining began at Benneydale in the early 1930s with the opening of Mangapehi Mine and mining continued until 1962. In 1978 a new underground mine, Benneydale Mine, opened and produced about 10 000 t annually until its closure in 1998. The two mines produced a total of just over 1 Mt between 1933 and 1998. Mangapehi Coalfield is not well explored and the remaining resource is uncertain. Current estimates put the in-ground resource at 58 Mt and the recoverable resource at about 10 Mt. Most coal is deeper than 200 m and is only recoverable by underground mining. Mangapehi coal is of better quality than that from other south Waikato coalfields, generally having lower ash and sulphur contents and a higher energy value.

2.3.2.2 King Country Coalfields

The King Country coalfields include Mokau, Aria, Waitewhena and Ohura-Tangarakau coalfields. The geological setting of the King Country coals is unusual as they lie within the predominantly marine Mokau Group. The Maryville Coal Measures are underlain and overlain by shallow marine, Mokau Group sandstones. This geological setting, largely free from the effects of basement topography, has led to the development of typically thin seams of very uniform thickness, persisting over relatively large areas. Maryville Coal Measures are up to 100 m thick and contain at least 11 coal seams up to 3 m thick, but no more than 5 seams occur at any one location. The area of thickest coal formation migrated northward with time, producing a south to north pattern of lower seams pinching out and being replaced by new upper seams.

All King Country coals are of subbituminous rank and the majority have medium to high (1–4%) sulphur contents, but they range from 0.9% (low) to 5.7% (very high). The relatively high sulphur content is due to the significant marine influence on the Maryville Coal Measures. Most seams have low to medium ash contents. When King Country coals were mined, they supplied local and provincial household and industrial markets.

Mokau Coalfield is about 20 km inland from the coast and the exposed part covers an area of about 100 km^2 between the Mokau and Awakino rivers. It contains the largest resource and is the most thoroughly investigated of the King Country coalfields. The coalfield contains clearly distinguishable opencast and underground mining prospects. In some parts of the area, the overlying marine sandstone has been removed by erosion, exposing a dipslope surface cut into the Maryville Coal Measures. The uppermost seam is commonly eroded, but the lower seams are potentially suitable for opencast mining. Eroded bluffs rise behind the dipslopes, forming the limit to potential opencast working. As many as twelve dipslope opencast areas have been identified, containing an in-ground resource of about 46 Mt. With opencast recovery estimated conservatively at about 80%, some 37 Mt is likely to be recoverable. The remainder of the coalfield has potential for underground working where seams are more than 1.2 m thick, but resource quantities are influenced by the choice of minimum seam thickness and maximum ash parting. The potential underground resource is estimated to be 120 Mt of which about 71 Mt is considered recoverable. In summary, the total Mokau resource is estimated at 166 Mt in-ground and 108 Mt recoverable.

There has been a long history of predominantly small-scale underground and opencast mining in Mokau Coalfield, beginning in 1884. Twelve mines have operated, producing a total of 240 000 t, with the most recent mine closing in 1987. Mokau Coalfield was examined in detail in the 1980s, as a potential source of coal for a proposed 1000 MW thermal power station to be built in the south Waikato-King Country area. The investigations included geotechnical, preliminary mining feasibility, environmental constraints and coal utilisation studies. Annual production of 2.64 Mt was envisaged, from an opencast mine and three underground mines. However, plans to build the power station did not proceed and the coalfield development did not occur.

Aria Coalfield, about 32 km south of Te Kuiti is a narrow, fault-bounded, northern extension of Waitewhena Coalfield. Four small underground mines produced a total of 53 000 t from the area between 1917 and 1961, and the coalfield has a remaining in-ground resource of about 2 Mt. The depth of the coal and structural complexity of the area suggest that there is no economically recoverable resource present.

Waitewhena Coalfield is centred on the Waitewhena Valley, north of Ohura and is separated from Ohura-Tangarakau Coalfield to the south by an area of thin, high ash coal. Mining in Waitewhena Coalfield began in 1935 and since then 29 underground and opencast mines have produced a total of about 2 Mt. The most recent mine, and the last to operate in the King Country area, closed in 1993. Dipslopes, similar to those in Mokau Coalfield, provide opencast prospects estimated at about 12 Mt in-ground, of which 8 Mt is potentially recoverable. The estimate of coal suitable for underground mining is about 78 Mt in-ground, with 22 Mt potentially recoverable. In summary, the total Waitewhena resource is estimated to be 90 Mt in-ground and 30 Mt recoverable.

Ohura-Tangarakau Coalfield extends from northwest of Ohura to south of the rohe boundary; it adjoins the southern parts of Mokau and Waitewhena coalfields. The coalfield is generally rugged and access is difficult, though Maryville Coal Measures crop out widely across the area. Mining in Ohura-Tangarakau Coalfield began in 1927 with several small opencast and underground mines near Ohura, but the only mine with significant production was Tatu State underground mine, south of Ohura, which produced just over 1 Mt between 1940 and 1971. Total production from Ohura-Tangarakau Coalfield has been about 1.4 Mt. Although a few small areas underlying dipslopes may offer opportunities for opencast working, the coalfield is predominantly accessible by underground mining. The coalfield is not well explored and resource estimates are uncertain; current estimates put the in-ground resource at 110 Mt and the recoverable resource at about 33 Mt.

Table 3 Summary of coal resource estimates.

Coalfield	Coal-in-ground resource in millions of tonnes (Mt)	Recoverable coal resource in millions of tonnes (Mt)
South Waikato		
Kawhia	182	56
Tihiroa	180	49
Te Kuiti	38	11
Mangapehi	58	10
Total South Waikato	**458**	**126**
King Country		
Mokau	166	108
Aria	2	-
Waitewhena	90	30
Ohura-Tangarakau	110	33
Total King Country	**368**	**171**

2.3.2.3 Coal Drillholes

A database of coal exploration drillholes was created during the 1980s as part of the New Zealand Coal Resources Survey. The database holds information from holes drilled during the exploration of the coalfields discussed above, as well as a number of scout holes drilled outside of the coalfields, mainly between Tihiroa and Te Kuiti coalfields. Information available includes drillhole identification and location, stratigraphy, coal thickness, geophysical log data if recorded and coal quality data from coal analyses, if they were undertaken. Because outcrops of the Waikato Coal Measures are so rare in the rohe, the information from drillholes has been the primary source of data for estimating coal resources and assessing coal quality. While the Maryville Coal Measures of the King Country coalfields are better exposed, drillholes still provided essential information for the assessment of these coalfields. The drillhole data is public information available on request from New Zealand Petroleum & Minerals (MBIE) or GNS Science.

2.3.3 Aggregate

Large quantities of rock, sand and gravel aggregate are extracted from the Waikato area and used for roading, building construction, reclamation, shore protection and general fill. Within the rohe, the rock types used for aggregate include basement greywacke (hard sandstone), argillite (hard mudstone) and conglomerate (naturally cemented gravel), Alexandra Volcanic Group andesite and basalt, Te Kuiti Group limestone, and river sand and gravel.

Greywacke is the main rock quarried for aggregate, sourced from both the Murihiku Supergroup and Manaia Hill Group. Although unweathered greywacke is hard, the Murihiku rocks commonly contain the soft mineral zeolite which is inclined to break down with repeated wetting and drying. The finer grained rock type argillite usually provides a poor quality aggregate. The Manaia Hill Group rocks generally provide a better quality aggregate, although the presence of the mineral prehnite and associated zeolites can promote breakdown of the rock. Hard sandstones and conglomerates provide the best aggregate and are the main rock types quarried. Many quarries, of varying scale, produce aggregate from the basement rocks that crop out in the rohe.

Basalt and andesite of the Alexandra Volcanic Group have been extracted from stream beds and quarries around the base of Pirongia, and from Te Kawa Hill south of Te Awamutu. The crushed unweathered andesite and basalt provides a high quality aggregate.

A small quantity of Te Kuiti Group limestone is used on secondary roads and for road maintenance in the vicinity of Te Kuiti, but it is not generally considered sufficiently hard wearing for this purpose. River gravels are extracted in several areas as a source of good quality aggregate. In the Taumarunui area, andesite gravels derived from Mount Ruapehu are extracted from the Whanganui River and used locally for roading and building aggregate. Mokau Group conglomerates in the Ohura area have been quarried intermittently for use on local roads.

New Zealand Petroleum & Minerals production statistics are only available for the whole Waikato region; they show that recent production of rock, sand and gravel aggregate has been around 5.3 Mt annually. Of this, 35 000 t was used for reclamation and protection, 1.1 Mt for building, 3.5 Mt for roading and 0.7 Mt for general fill.

2.3.4 Limestone

Limestone is a common rock type within the rohe and much of it is of good quality for agricultural and industrial uses because of its high calcium carbonate ($CaCO_3$) content. Unweathered limestone is dense and crystalline with a blue-grey colour and is typically closely jointed and flaggy. Early stage weathering removes iron oxides and stains the rock brown or cream. Later in the weathering process, the pure white residue becomes enriched with redeposited calcite to give purities as high as 98% calcium carbonate. The zone of enrichment can extend to depths of 30 m.

Limestone with $CaCO_3$ exceeding 80%, has been quarried in the south Waikato for over a century with most recent production coming from large quarries in the Te Kuiti area and smaller quarries at Wairere and west of Otorohanga. Large limestone processing plants are located at Te Kuiti and Otorohanga. Substantial quantities of limestone have been quarried and processed into lime for agricultural and horticultural uses, and recent annual production has averaged around 37 000 tonnes. Several quarries produce high quality limestone for industrial uses that require high purity calcium carbonate. These include iron and steel making, the paper industry, glass making, the sugar industry and as a filler in some plastics. In the past, limestone was also used in the manufacture of cement at Te Kuiti. Recent production of industrial lime has averaged about 80 000 tonnes annually. Small amounts of limestone are used for road metal and selected limestone flags have been used as a building stone.

Limestones in the vicinity of Te Kuiti are relatively pure, well exposed and easily accessible. A quarry at Te Kumi, a few kilometres north of Te Kuiti, produces limestone with an average calcium carbonate content of 98%, making it one of the best quality limestones in New Zealand. East and south of Te Kuiti, limestones range from 87–96% calcium carbonate. While the limestone resource in the rohe is very large, the mineable resource is limited by increasing thicknesses of the overlying mudstone.

The limestone is well known for the hundreds of caves within it, but only a few at Waitomo have been developed as tourist attractions. Several others have good tourist potential with easy access, stalagmites, stalactites and glow worms.

2.3.5 Serpentinite

A fault-bounded linear mass of sheared serpentinite is present at Wairere, 9 km south of Piopio. The deposit has been quarried since 1945 and has produced more than 2 Mt; current production is about 35 000 t annually. More than half of New Zealand’s total serpentinite production has come from this source. It has been used as an additive to superphosphate fertiliser to supply magnesium and improve its free-flowing characteristics for aerial spreading. Smaller lenses occur elsewhere in the same general area, but none have been quarried.

2.3.6 Ironsand

Large deposits of iron ore, in the form of titanomagnetite, are present within the Quaternary “blacksand” beach and dune sands that occur along the coast of the rohe. Extensive marine deposits are also present offshore, on the inner continental shelf. The titanomagnetite is derived principally from erosion of Quaternary age andesite volcanoes of the Taranaki region, with minor contributions from other central and western North Island volcanic centres. A small contribution also comes from the erosion of volcanic-rich sedimentary rocks that crop out along the coast between Tirua Point and Mokau. Titanomagnetite has been transported northwards along the west coast by longshore currents and subsequently concentrated by wave and wind action into beach and dune lag deposits, varying in thickness from a few metres to over one hundred metres. The titanomagnetite content of the ironsand deposits ranges from 10% to 70%, but is mostly between 20% and 40%. Magnetic concentration during the mining process raises the iron content to about 56%. The west coast ironsand deposits have been investigated since 1949 and resource estimates determined for several sites, including Kawhia North Head, Taharoa, Harihari, Marokopa, Awakino and Mokau. Only the Taharoa deposit has been mined.

The richest deposit is at Taharoa where an extensive dunefield contains the largest onshore ironsand deposit on the west coast of the North Island. It occupies a coastal depression 8 km in length and extends inland for about 2 km. The deposit has an average titanomagnetite content of about 40% but it is as high as 70% in some horizons. An economic resource of 360 million tonnes of magnetic concentrate is estimated from drilling and geophysical exploration. The Taharoa deposit has been mined since 1972 using a cutter suction dredge and floating concentrator to extract and process the sand. The concentrate is pumped as slurry through a pipeline to ore-carrying ships anchored at an offshore loading buoy. Recently, up to 2 Mt of concentrate has been exported annually to Japan and South Korea, and more than 50 Mt has been exported since operations began.

The large dune field between Aotea and Kawhia harbours is estimated to contain about 500 Mt of sand with a grade of 10% magnetics, representing a 50 Mt resource of ironsand concentrate. At Harihari, just south of the Taharoa deposit, a high level, 30 m thick weathered dune remnant rests on basement rock. The small deposit is estimated to contain about 1 Mt of ironsand concentrate. Dunes at the mouth of the Marokopa River have an average grade of 45% magnetics and contain a resource estimated at 25 Mt of concentrate. Smaller resources have been identified at the mouths of the Awakino and Mokau rivers, comprising 6 Mt and 4 Mt of concentrate, respectively, at grades ranging from 37% to 63% magnetics.

Recent magnetic surveys and seabed coring off the west coast has identified an offshore resource of about 1200 Mt of concentrate at about 60% iron content. The ironsand covers the seabed and typically extends to depths of 60 m below the seabed. The resource is located in shallow water, between 20 m and 40 m deep. Part of this very large marine resource lies within the offshore part of the rohe.

2.3.7 Geothermal

The west Kawhia (Te Puia) thermal springs are the only geothermal springs documented within the rohe. The measured temperature of these springs is 58°C but their geothermal potential is poorly known. They are a low enthalpy resource, probably unsuited to power generation, but potentially useful for supplementary heating through heat exchange. The springs are Na-Cl rich and associated gases include N_2 and CH_4. They are considered to be intra-formational waters that have been diluted with rainwater and seawater, and their estimated highest temperature is 159–199°C.

2.3.8 Groundwater

The Maniapoto rohe falls into three different regional council's domains: Waikato Regional Council (WRC), Horizons Regional Council (Horizons) and Taranaki Regional Council (TRC). The majority of the groundwater resources lie within the Waikato Region. Within the WRC domain, the Maniapoto rohe falls into two main catchment management zones: the Waipa Catchment and the West Coast catchment. The only delineated aquifer used for allocation limits is the Waipa aquifer (*ALLOC_IRIS_AQUIFER_DETAILED_Maniapoto*). Groundwater quality monitoring and reporting is undertaken periodically. Within the Horizons domain, the rohe falls within the Whanganui catchment management zone and there are no delineated aquifers in the area. Within the TRC domain, the rohe falls mainly within the Tongaporutu River catchment and there are no delineated aquifers in the area. Since there is minimal utilisation of groundwater within the TRC and Horizons domains (9 registered wells in total), these areas are no longer individually discussed.

Within TDC and Horizons, groundwater takes less than 50 m^3/day do not require consent. Within WRC, groundwater takes of less than 15 m^3 per day do not require consent and takes of more than 50 m^3 per day are required to have a flow meter installed to measure water usage. Currently there is a total of 22 800 m^3/day consented groundwater takes at 49 sites (*WRC_AUTHORISATION_IRIS_gw*) and 162 000 m^3/day consented surface water takes at 55 sites (*WRC_AUTHORISATION_IRIS_sw*) in the Maniapoto rohe WRC domain. There are also 516 existing consent applications for both groundwater and surface water takes (*WRC_APPLICATION_IRIS_maniapoto*), summing to a total of 62 700 m^3/day (34% of the existing total take).

In general, the rohe area has not had previous significant groundwater investigations carried out and there are currently no groundwater models (neither conceptual or flow) for the area. A portion of the Waipa Catchment is located within the Hamilton Basin, whose hydrogeology has previously been reported in a thorough technical study. Additionally, there is a WRC funded GNS Science project currently underway for the Waipa Catchment. This project is aimed at reviewing the existing data and information and creating a workplan for additional data collection for the future creation of a conceptual hydrogeological model that will be a useful basis for groundwater flow modelling. These models will assist to inform sustainable water management of the catchment and related requirements under the Vision and Strategy for the Waikato River (Te Ture Whaimana o Te Awa o Waikato) and the National Policy Statement. It is particularly relevant to the Healthy Rivers Project. The description presented below contains excerpts from this project report.

Within the West Coast catchment, the demand for groundwater is presently low in the Kawhia and Aotea harbour catchments. Iron levels in shallow groundwater near Kawhia township are relatively high, but otherwise groundwater quality is currently considered good. The only reticulated water service in these catchments is within Kawhia township. This service is managed by the Otorohanga District Council, and water is sourced from both a spring and a 30 m deep bore. The current average demand is 300 m^3/day, and the supply has been estimated to have a long term supply capacity of 500 m^3/day. During peak summer periods, demand exceeds this capacity and water restrictions are put in place. Otorohanga District Council has investigated extending the extent of this reticulated supply, but due to costs and environmental issues this is unlikely to occur. Taharoa township also has a consented take from two bores for up to 79 m^3/day and Benneydale has a consented take of 180 m^3/day from a single bore (*WRC_AUTHORISATION_IRIS_gw*). Other large consented takes in the catchment are associated with iron sand mining. Holocene river deposits and mobile dunes provide the majority of existing groundwater resources within primary porosity.

Within the Waipa catchment, significant consented takes are associated with irrigation, municipal supply, domestic supply, quarrying and dairy farming purposes (*WRC_AUTHORISATION_IRIS_gw*). The most significant groundwater resources in the Maniapoto rohe lie within the Hamilton Basin; within the Quaternary alluvium and underlying volcanics. Within the Waipa catchment, groundwater and surface water are strongly linked, and as such WRC policy requires that the two systems be managed and allocated as a joint system. Groundwater quality is generally good, although two monitoring sites are over halfway towards not meetings the nitrogen drinking water guideline.

Basement

Within basement rocks, jointing and shearing provide discrete locations of high secondary permeability, with associated water storage capacities. The typically limited extents and discrete nature of these resources, however, result in restricted productive groundwater storage volumes. Typical well yields of 0.3–0.4 litre/s have been reported, and up to 2.15 litre/s.

Tertiary

Within Tertiary rocks, the Te Kuiti Group has three formations with aquifer potential: Pukemiro Sandstone, Elgood Limestone and Glen Massey Sandstone. The Pukemiro Sandstone has seeps and springs associated with outcrops. The Elgood Limestone has water source potential where solution cavities are located. The Glen Massey Sandstone has crevices and minor solution cavities associated with calcareous deposits. An artesian flow of >55 litre/s has been obtained from the Elgood Limestone.

Volcanics

The Alexandra Volcanic Group are likely to be a significant aquifer due to the lava flows being well-jointed, and the fact that Mount Pirongia (the main locus of Alexandra Volcanic Group) is likely a location of significant rainfall recharge as it has a high annual rainfall and a large areal extent. This is apparent from the number of wells located on the geologically mapped group (*Wells_Waipa*) and an allocated high consent volume. The Pakaumanu Group ignimbrites also form a significant aquifer unit. Within the Pakaumanu Group ignimbrites, typically an upper porous layer overlies a welded and fractured zone. A few wells are drilled into the Whakamaru Group ignimbrites. Although limited in their extent in the Maniapoto rohe, this group forms good water-bearing layers outside of this area and ignimbrite lithologies form the dominant Taupo Volcanic Zone aquifer units.

Quaternary

The majority of wells are located on Tauranga Group geology, and the Quaternary pumiceous sands and gravels of this group form the main Waipa aquifer, with large consented takes from the group. The Walton Subgroup typically provides large volumes of good quality water, whilst the Piako Subgroup provides water of variable quality and yields. Bores in these groups may yields greater than 28 litre/s. At the regional scale and over long time periods, the Tauranga Group can be considered one hydrogeological unit. However, at smaller scales the heterogeneity of the group becomes both important and difficult to map. The unit is essentially a series of small distinct leaky aquifers, and for wells to achieve a useful yield they are often constructed with lengthy screens that intercept a number of small aquifers rather than a single one. The fine silty sediments at the base of the Tauranga Group form a discontinuous aquitard. Holocene river deposits may also form productive aquifers. As with the Tauranga Group sediments, there are likely to be a number of small permeable layers interfingered with finer sediments that form aquitards. The distribution of wells avoids peat-rich areas and large areas of clay.

Aquifer transmissivities estimated from the Tauranga Group supplies in the Hamilton Basin range from 6 m^2/d to 950 m^2/d, but are usually less than 100 m^2/d. The sediments of the Tauranga Group are typically poorly sorted, and this poor sorting typically results in hydraulic conductivity values lower than expected based on grain size and type. Estimates of aquifer storage varied from $\approx 4x10^{-3}$ for deep, confined, or semi-confined aquifers to 0.1 for shallow, unconfined aquifers. Most bores in the Tauranga Group intercept confined or semi-confined aquifers.

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2.4 HAZARDS

2.4.1 Volcanic hazard

Mounts Taranaki, Ruapehu, Ngauruhoe, Tongariro and the Central North Island rhyolitic volcanoes represent a hazard to the Maniapoto rohe. This hazard can be separated into two distinct parts by the nature of the volcanism. The Taranaki, Ruapehu, Ngauruhoe and Tongariro volcanoes are of andesitic and basaltic composition and generally erupt in relatively frequent events that generate small to moderate amounts of ashfall across the rohe.

In contrast, the Central North Island rhyolitic volcanoes, mostly expressed in the landscape as features of low relief (e.g., Taupo Moana), erupt less frequently, but very violently, sometimes producing huge volumes of pumiceous ash. In a number of instances in the past, these eruptions have resulted in ignimbrite, superheated fluids of pumice ash, blocks and volcanic gases, sweeping across the landscape, eroding the ground surface, depositing thick pumiceous material and killing almost all in their path.

Ashfall is the principal volcanic hazard in the rohe. The andesitic/basaltic volcanoes of Taranaki, Ruapehu, Ngauruhoe and Tongariro have erupted frequently during the last several thousand years and are the source of ashfall. Taranaki is expected to be the source of most of the ashfall from these andesitic volcanoes.

The Central North Island rhyolitic volcanoes are completely different. They erupt less frequently, but when they do, they generate huge volumes of ashfall and ignimbrites (super-heated ground-hugging ashflows) that can flow at 600–900 km/hour and may reach the eastern part of the rohe.

Probablistic ashfall modelling suggests a cumulative ashfall depth of 5 to < 1 mm over a period of 500 years, mainly the result of Taranaki, Ruapehu, Ngauruhoe and Tongariro eruptions. Thicker ashfall thicknesses are modelled to the south and east of the rohe.

Less than 1 mm may result in lung and eye irritation, closure of airports, minor abrasive damage to vehicles, houses and equipment, contamination of water supplies, particularly in roof-fed rainwater supplies. 1–5 mm of ash will include these and other impacts such as crop damage, ill-health in livestock, electricity supply loss, water supply failures, water contamination and storm-water and sewerage system blockages.

The less frequent large central North Island rhyolitic eruptions are far more hazardous. The two most hazardous centres are the Okataina and Taupo Volcanic Centres. Okataina is further away and thus represents a lesser hazard. Ignimbrite erupted from the current site of Taupo Moana was deposited across the western part of the rohe from Wharepuhunga to Benneydale to Taumarunui during the AD 233 eruption within the space of 10 minutes. Trees and other vegetation were mostly destroyed by the superheated pumice fragments and gases, and river drainage systems were obliterated. Loose pumice ash choked downstream drainages, causing blockages and breakout floods.

Little can be done to mitigate the effects of these ashfall and ignimbrite hazards. Warnings of impending eruptions can be brief or non-existent, although warning signs of larger eruptions are expected to be detectable.

2.4.2 Earthquake hazard

Potential sources of strong ground shaking include the faults of the Taupo Fault Belt, the North Island Fault System, the Kerepehi Fault, and earthquakes at depth from rupture of the subducting slab.

In historical times, the area has experienced low to moderate seismicity compared with other areas of New Zealand and the absence of active faults onshore within the rohe suggest that this also may have been the case in the recent geological past. The offshore Turi Fault is known to be active, but its earthquake-generating characteristics are unknown.

Fault rupture of Taupo Fault Belt faults are unlikely to exceed M 7 and strong ground motion is unlikely to create widespread damage across the rohe because of their distance from it (>50 km). Some hazard is associated with faults of the North Island Fault System as, while more distant (>100 km), earthquakes may be significantly larger (up to M 7.6).

In the future, the Maniapoto rohe can expect similar levels of seismicity to that experienced in the last 150 years. Modelling suggests that ground shaking intensities of between MM7 and MM8 occur every 500 years. This may be expected to result in serious damage to old masonry buildings and topple chimneys, and result in some landslides on over-steepened slopes.

2.4.3 Landslide hazard

Landslides are common within the rohe. They occur widely in sloping areas underlain by geologically young mudstones. Landslides in susceptible sediments may undermine stronger overlying rocks resulting in block failures. When saturated, weathered bedrock, uncompacted sand and pumiceous soil deposits are also vulnerable to slumping on slopes, although the latter may even fail on gentle slopes. Mudstone and siltstone of the Mahoenui Group and Maryville Coal Measures, and to a lesser degree, the Whangamomona Group is particularly prone to landslides.

The majority of landslides within the area are earthflows in saturated mudstones; these may de-stabilise overlying rocks causing block failures. Destabilisation of Te Kuiti Group limestone by downslope slumping of underlying units leads to blockfall. Landslides are often associated with extreme and/or localised rainfall events.

Care should be made not to load existing landslides with new materials, and care should be taken before siting new structures close to steep escarpments. Drainage, where possible, and planting with fast growing, deep rooted trees will help mitigate some landslide problems. Geotechnical investigations should be carried out before any significant structures are built on landslide prone soils.

2.4.4 Tsunami hazard

Low-lying coastal areas and the lower reaches of rivers in the rohe are vulnerable to tsunami.

The most likely potential source of tsunami in the area is from large regional earthquakes, which may be located outside the New Zealand region, or from local submarine or coastal landslides.

Strong earthquake shaking is a warning to leave quickly low-lying coastal areas. Unusual changes in sea behaviour accompanied by a roaring noise are also warning signs to seek higher ground.

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