

Mineral resource assessment of the
Northland Region, New Zealand

A B Christie
R G Barker

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A B Christie, GNS Science, PO Box 30-368, Lower Hutt
R G Barker, Consulting Geologist, PO Box 54-094, Bucklands Beach, Auckland

CONTENTS

| | |
|---|------------|
| ABSTRACT | vii |
| KEYWORDS | vii |
| 1.0 INTRODUCTION | 1 |
| 2.0 MINERAL RESOURCE ASSESSMENT FACTORS AND LIMITATIONS | 7 |
| 3.0 PREVIOUS WORK | 9 |
| 4.0 METHODS | 11 |
| 5.0 DATA | 11 |
| 6.0 RESOURCE MAPS | 13 |
| 7.0 SETTING | 15 |
| 7.1. Population and infrastructure | 15 |
| 7.2. Geomorphology | 15 |
| 8.0 GEOLOGY | 15 |
| 8.1 Previous work | 15 |
| 8.2 Greywacke basement..... | 19 |
| 8.3 Cretaceous – Cenozoic pre-allochthon sedimentary rocks..... | 19 |
| 8.4 Northland Allochthon | 19 |
| 8.5 Post allochthon rocks | 23 |
| 8.6 Structure | 23 |
| 9.0 BULK COMMODITIES: ROCK AGGREGATE, SAND, BUILDING STONE AND LIMESTONE | 27 |
| 9.1 Rock Aggregate..... | 27 |
| 9.1.1 Northland deposits | 28 |
| 9.1.2 Future potential | 34 |
| 9.2 Sand | 34 |
| 9.2.1 Northland deposits | 34 |
| 9.2.2 Future potential | 35 |
| 9.3 Building and dimension stone | 37 |
| 9.3.1 Northland deposits | 37 |
| 9.3.2 Future potential | 37 |
| 9.4 Limestone | 39 |
| 9.4.1 Northland deposits | 39 |
| 9.4.2 Future potential | 43 |
| 10.0 COAL AND PEAT | 45 |
| 10.1 Sub-bituminous – bituminous coal | 45 |
| 10.1.1 Northland deposits | 45 |
| 10.1.2 Post-1980 exploration (Isaac 1985) | 45 |
| 10.1.3 Future potential | 46 |
| 10.2 Lignite | 48 |
| 10.2.1 Northland deposits | 48 |
| 10.2.2 Future potential | 48 |
| 10.3 Peat | 48 |
| 10.3.1 Northland deposits)..... | 48 |
| 10.3.2 Future potential | 48 |
| 11.0 MINERAL RESOURCE ASSESSMENT OF METALLIC AND INDUSTRIAL MINERALS | 51 |
| 11.1 Assessment method | 51 |
| 11.2 Mineral deposit models | 51 |
| 12.0 METALLIC MINERAL DEPOSITS | 53 |
| 12.1 Aluminium..... | 53 |
| 12.1.1 Laterite bauxite type aluminium deposits..... | 53 |
| 12.2 Antimony..... | 55 |

| | | |
|-------------|--|------------|
| 12.2.1 | Hot spring Sb-As type antimony deposits..... | 55 |
| 12.3 | Chromium..... | 57 |
| 12.3.1 | Podiform chromite type chromium deposits..... | 57 |
| 12.4 | Copper..... | 59 |
| 12.4.1 | Cyprus VMS Cu type copper deposits..... | 59 |
| 12.4.2 | Besshi VMS Cu type copper deposits..... | 61 |
| 12.4.3 | Porphyry Cu type copper deposits..... | 62 |
| 12.5 | Gold-Silver..... | 66 |
| 12.5.1 | Hot spring Au-Ag type gold-silver deposits..... | 66 |
| 12.5.2 | Low sulphidation epithermal Au-Ag type gold-silver deposits..... | 74 |
| 12.5.3 | Sediment hosted Au type gold-silver deposits..... | 77 |
| 12.5.4 | Au skarn type gold-silver deposits..... | 79 |
| 12.6 | Iron..... | 82 |
| 12.6.1 | Bog iron)..... | 82 |
| 12.7 | Manganese..... | 82 |
| 12.7.1 | Volcanogenic Mn type manganese deposits..... | 82 |
| 12.8 | Mercury..... | 87 |
| 12.8.1 | Hot spring Hg type mercury deposits..... | 87 |
| 12.9 | Nickel..... | 90 |
| 12.9.1 | Lateritic Ni deposits..... | 90 |
| 12.9.2 | Gabbroid-associated Ni-Cu type nickel deposits..... | 90 |
| 12.10 | Zinc and Lead..... | 92 |
| 12.10.1 | Zn-Pb polymetallic vein type zinc and lead deposits..... | 92 |
| 12.10.2 | Zn-Pb skarn type zinc and lead deposits..... | 94 |
| 13.0 | NON-METALLIC MINERALS AND ROCKS | 97 |
| 13.1 | Asbestos..... | 97 |
| 13.2 | Barite..... | 97 |
| 13.3 | Clays..... | 97 |
| 13.3.1 | Rhyolite-hosted halloysite clay..... | 97 |
| 13.3.2 | Volcanic-related kaolin clay..... | 102 |
| 13.3.3 | Sedimentary kaolinite clay..... | 104 |
| 13.3.4 | Coal measure clays..... | 106 |
| 13.3.5 | Bentonite..... | 108 |
| 13.4 | Diatomite..... | 110 |
| 13.4.1 | Lacustrine diatomite..... | 110 |
| 13.4.2 | Marine diatomite..... | 112 |
| 13.5 | Feldspar..... | 112 |
| 13.5.1 | Feldspar sand..... | 112 |
| 13.6 | Kauri Gum..... | 115 |
| 13.7 | Phosphate..... | 117 |
| 13.7.1 | Upwelling type phosphate deposits..... | 117 |
| 13.8 | Serpentinite..... | 118 |
| 13.8.1 | Serpentine in gabbro-peridotite complexes..... | 118 |
| 13.8.2 | Diapiric serpentinite..... | 120 |
| 13.9 | Silica Sand..... | 123 |
| 13.9.1 | Model..... | 123 |
| 13.9.2 | Known deposits..... | 123 |
| 13.9.3 | Potential..... | 124 |
| 13.10 | Sulphur..... | 124 |
| 13.11 | Zeolite..... | 124 |
| 13.11.1 | Open system zeolites..... | 124 |
| 14.0 | VALUE OF MINERAL RESOURCES | 129 |
| 14.1 | Production Scenario..... | 133 |
| 14.1.1 | Methods..... | 133 |
| 14.1.2 | Synthesis..... | 138 |
| 15.0 | CONCLUSIONS..... | 139 |
| 16.0 | FUTURE WORK..... | 139 |
| 17.0 | ACKNOWLEDGEMENTS..... | 141 |

| | |
|--|------------|
| 18.0 REFERENCES AND SELECTED BIBLIOGRAPHY | 141 |
| APPENDIX 1 - DIGITAL DATA SETS | 167 |

FIGURES

| | | |
|------------------|--|----|
| Figure 1 | Location map and division of Northland into regional authorities. | 2 |
| Figure 2 | Topographic map of Northland reproduced from the LINZ 1:2,000,000 map..... | 3 |
| Figure 3 | Areas of land administered by the Department of Conservation (DoC) | 4 |
| Figure 4 | Current mineral production in Northland consists of high quality halloysite china clay for export, limestone for cement, agriculture, industry and roading, sand for building and industry, and aggregate for roading, building, and protection. Photos: 1. Matauri Bay clay pit and inset of high quality china product; 2. Golden Bay Cement plant at Portland; 3. aggregate stockpile; 4. spreading aggregate for unsealed road maintenance; and 5. spreading lime on pasture for fertiliser..... | 5 |
| Figure 5 | USGS 3-step process of mineral resource assessment..... | 13 |
| Figure 6 | Māori population and Māori land in Northland..... | 16 |
| Figure 7 | Hill shaded digital elevation model illustrating topographic relief and photos of some landforms. Photos by Lloyd Homer..... | 17 |
| Figure 8 | Geology map of Northland from the GNS Science 1:1,000,000 digital geological map. | 18 |
| Figure 9 | Stratigraphy of Cretaceous – Cenozoic autochthonous rocks of Northland (after Fig. 1.4 of Isaac et al. 1994). | 20 |
| Figure 10 | Original stratigraphy of the allochthonous rocks of the Northland Allochthon (after Fig. 1.4 of Isaac et al. 1994). See Figure 9 for legend..... | 21 |
| Figure 11 | Terranes and metamorphic mineral zones in the greywacke basement rocks (modified after Fig. 1 of Black 1989)..... | 22 |
| Figure 12 | The Northland Allochthon extends west of Northland and as far south as Auckland. The East Coast Allochthon is a correlative. Much of the Northland Allochthon has been eroded. The major Tangihua Complex massifs are numbered and named (after Fig. 4.1 of Isaac et al. 1994). | 24 |
| Figure 13 | Schematic cross-section of Northland showing mineralisation types in relation to stratigraphy (after Figure 14 of Brathwaite & Pirajno 1993). | 25 |
| Figure 14 | Miocene to Quaternary volcanic zones and centres and associated mineralisation in northern New Zealand (after Fig. 24 of Brathwaite & Pirajno 1993)..... | 26 |
| Figure 15 | Location of aggregate quarries and sites from the GERM database. Inset graphs show the 2005 aggregate production and end use for the three districts. The inset map shows road and sea distances from the Auckland Harbour bridge..... | 29 |
| Figure 16 | Areas of the major stratigraphic units and rock types utilised for aggregate | 30 |
| Figure 17 | Larmers Rd quarry south of Kaitaia. The quarry is operated by Bellingham Quarries Ltd and produces basalt aggregate. Photo: Tony Christie. | 30 |
| Figure 18 | Puketona quarry northwest of Paihia. The quarry is operated by McBreen Jenkins Construction Ltd and produces both greywacke and basalt aggregate. Photo: Tony Christie. | 31 |
| Figure 19 | Vertical aerial photo of Puketona quarry. Photo: Courtesy McBreen Jenkins Construction Ltd. | 31 |
| Figure 20 | Vertical aerial photo of Turiwiri quarry, Dargaville. Photo: Courtesy McBreen Jenkins Construction Ltd. | 32 |
| Figure 21 | Panorama view of Jensel Holdings shale quarry located between Awanui and Mangonui. Photo: Courtesy Brian Bellingham. | 33 |

| | | |
|------------------|---|----|
| Figure 22 | Location of sand sites from the GERM database and proportions of quartz and feldspar in coastal sand (after Schofield 1970). | 36 |
| Figure 23 | Location of building and dimension stone sites from the GERM database. | 38 |
| Figure 24 | Location of limestone sites from the GERM database and areas of limestone from Turnbull & Smith Lyttle (1999). Inset graphs show the 2005 limestone production and end use for the three districts. The inset map shows the limestone types (after Turnbull & Smith Lyttle 1999). | 40 |
| Figure 25 | Golden Bay Cement's limestone quarry and plant at Portland, 8 km south of Whangarei. The plant has an annual production capacity of 600,000 t. Cement is shipped to eight distribution centres throughout New Zealand and approximately 20% is exported to Tahiti and other Pacific Island countries. Photo: Lloyd Homer CN26655/12..... | 41 |
| Figure 26 | Portland limestone quarry (foreground) and plant (distance), with Whangarei Harbour in the background. Photo: Lloyd Homer CN26630/19. | 42 |
| Figure 27 | Rarewa Lime plant operated by Avoca Lime. Photo: Tony Christie. | 43 |
| Figure 28 | Rarewa Lime quarry operated by Avoca Lime. Photo: Tony Christie. | 43 |
| Figure 29 | Location of Sub-bituminous – bituminous coal sites from the GERM database and areas of coal bearing formations..... | 47 |
| Figure 30 | Location of lignite sites from the GERM database and areas of lignite bearing formations. | 49 |
| Figure 31 | Location of peat sites from the GERM database and areas of peat bearing formations.... | 50 |
| Figure 32 | Areas of basalt that may be prospective host rocks for laterite bauxite deposits. The bauxite deposits are mostly found in the triangular area between Kaeo, Kaikohe and Kerikeri. | 54 |
| Figure 33 | Location of antimony sites from the GERM database and areas of greywacke and volcanic rocks prospective for hot spring Sb-As deposits. | 56 |
| Figure 34 | Location of chromium sites from the GERM database and areas of mafic intrusive rocks prospective for podiform chromite deposits. | 58 |
| Figure 35 | Location of Cyprus volcanogenic massive sulphide Cu sites from the GERM database and areas of Tangihua Complex rocks that are prospective host rocks..... | 60 |
| Figure 36 | Location of Besshi volcanogenic massive sulphide Cu sites from the GERM database and areas of greywacke that are prospective host rocks..... | 63 |
| Figure 37 | Location of porphyry Cu sites from the GERM database and areas of greywacke and intrusive rocks that are prospective host rocks..... | 65 |
| Figure 38 | Location of gold prospects from the GERM database and areas of greywacke and volcanic rocks prospective for hot spring Au-Ag deposits. | 68 |
| Figure 39 | Structural and geological maps of the Puhipuhi prospect (after Grieve et al. 1997). | 69 |
| Figure 40 | Bedded silica sinter sheet exposed in a former quarry at Mt Mitchell, Puhipuhi. The sinter contains antimony and mercury. Photo: Tony Christie. | 70 |
| Figure 41 | A. Plum Duff breccia mound at Puhipuhi, representing the collapse of a silica sinter sheet. B. A boulder of breccia containing sinter sheet clasts. Photos: Tony Christie. | 70 |
| Figure 42 | Geologist examining a lag deposit of pyrite crystals in the stream bed of Pyrite Creek, Maungaparerua. Photo: Tony Christie..... | 71 |
| Figure 43 | A. Aurora Minerals Hazelbrook and Lanigans epithermal gold-silver project areas. B. Backyard prospect in the Hazelbrook project area. C. Huia trend within the Hazelbrook project area. Maps courtesy of Aurora Minerals. | 73 |
| Figure 44 | Drilling on Aurora Minerals Hazelbrook epithermal gold-silver project area. A. RAB (rotary air boring) drilling soil samples. B. Reverse circulation drilling with cyclone separator (white) near centre and bagged samples in the foreground. C. Diamond drilling - core drilling with a diamond bit. Photos: courtesy of Aurora Minerals..... | 75 |

| | | |
|------------------|--|-----|
| Figure 45 | Prospectivity map for epithermal gold-silver deposits in Northland (after Rattenbury & Partington 2003). The colour ramp from pale green, through, darker green, pale yellow, yellow, mauve, purple and red denotes increasing prospectivity. | 76 |
| Figure 46 | Location of gold prospects from the GERM database and areas of greywacke and volcanic rocks prospective for low sulphidation epithermal Au-Ag deposits. | 78 |
| Figure 47 | Areas of sedimentary rocks prospective for sediment hosted Au deposits. | 80 |
| Figure 48 | Areas of calcareous and intrusive rocks prospective for Au skarn deposits. | 81 |
| Figure 49 | Locations of bog iron deposits from the GERM database. | 83 |
| Figure 50 | Locations of volcanogenic Mn deposits from the GERM database and areas of greywacke that are prospective host rocks. | 84 |
| Figure 51 | Manganese minerals (black) in bedded red and pale brown argillite, Manganese Point, Whangarei. Photo: Bob Brathwaite. | 86 |
| Figure 52 | Location of mercury prospects from the GERM database and areas of greywacke and volcanic rocks prospective for hot spring Hg deposits. | 88 |
| Figure 53 | Location of nickel sites from the GERM database and areas of mafic intrusive rocks prospective for lateritic Ni deposits. | 91 |
| Figure 54 | Location of nickel sites from the GERM database and areas of mafic intrusive rocks prospective for gabbroid associated Ni-Cu deposits. | 93 |
| Figure 55 | Location of Zn-Pb polymetallic vein deposits from the GERM database and areas of greywacke and volcanic rocks that are prospective host rocks. | 95 |
| Figure 56 | Location of the Motukokako (Piercy Island) Zn-Pb skarn deposit and areas of limestone and intrusive rocks prospective for Zn-Pb skarn deposits. | 96 |
| Figure 57 | Location of rhyolite-hosted halloysite clay deposits from the GERM database and areas of rhyolite. | 99 |
| Figure 58 | Location of Putahi Rhyolite domes and associated halloysite deposits in the Kaikohe - Bay of Islands area (after Figure 2 of Townsend et al. 2006). | 100 |
| Figure 59 | Matauri Bay (foreground) and Mahimahi (distant) halloysite clay pits. Photo: Imerys Tableware Ltd. | 101 |
| Figure 60 | Halloysite clay processing plant (centre) and Matauri Bay clay pit (bottom). Photo: Imerys Tableware Ltd. | 101 |
| Figure 61 | Location of volcanic related kaolin clay deposits from the GERM database and prospective areas of volcanic rocks. | 103 |
| Figure 62 | Location of residual and sedimentary clay deposits from the GERM database and prospective areas of volcanic and sedimentary rocks. | 105 |
| Figure 63 | Location of coal measure clay deposits from the GERM database and areas of sedimentary rocks prospective for coal measures. | 107 |
| Figure 64 | Location of bentonite deposits from the GERM database and areas of sedimentary rocks prospective for bentonite. | 109 |
| Figure 65 | Location of lacustrine diatomite deposits from the GERM database. | 111 |
| Figure 66 | Location of the Kaiwaka marine diatomite deposit and areas of prospective calcareous rocks. | 113 |
| Figure 67 | Location of feldspar sand deposits from the GERM database and band of coast with feldspar-rich sand. | 114 |
| Figure 68 | Location of kauri gum deposits from the GERM database and areas of swamp and peat prospective for kauri gum. | 116 |
| Figure 69 | View east over Kaimaumau swamp. Photo: Lloyd Homer CN9056/22. | 117 |
| Figure 70 | Location of phosphate occurrences from the GERM database. | 119 |

| | | |
|------------------|---|-----|
| Figure 71 | Location of serpentine in gabbro-peridotite complexes and area of prospective mafic intrusive rocks. | 121 |
| Figure 72 | Location of diapiric serpentinite deposits from the GERM database and areas of prospective rocks. | 122 |
| Figure 73 | Location of silica sand deposits from the GERM database, areas of coastal sand and band of coast with quartz-rich sand. | 125 |
| Figure 74 | View west of white silica sand of Kokota Spit, Parengarenga Harbour. Photo: Lloyd Homer CN352/15. | 126 |
| Figure 75 | SeaTow barge mining silica sand off Kokota Spit, Parengarenga Harbour. Photo: Colin Douch. | 126 |
| Figure 76 | Location of zeolite deposits from the GERM database and areas of calcareous sediments that are prospective for open-system zeolite deposits. | 128 |
| Figure 77 | Possible types and potential prospective areas for new mining operations in the hypothetical scenario 15 years in the future, following extensive exploration. Inset graphs show the value of the new production and total production (including all commodities) in the scenario, portioned to the three districts. | 137 |

TABLES

| | | |
|----------------|--|-----|
| Table 1 | Northland mineral production in 2005 by district and total. All values in tonnes except for the dollar values in the last row. Source: Crown Minerals unpublished data | 1 |
| Table 2 | Mineral prices. | 129 |
| Table 3 | Summary of in-ground sub-bituminous – bituminous coal, lignite and peat resources and value by district. | 130 |
| Table 4 | Potential resources of metals by mineral deposit type. | 131 |
| Table 5 | Potential resources of non-metallic minerals and rocks (excluding limestone, aggregate, and sand and building stone for construction) | 132 |
| Table 6 | Annual production statistics and derived maximum values for Northland. | 134 |
| Table 7 | Annual production scenario of new mining operations and split between districts. ... | 136 |
| Table 8 | Annual production scenario by district including new mining operations. | 138 |

ABSTRACT

The Northland region contains a wide variety of mineral commodities and currently produces high quality ceramic clays, limestone for cement and agriculture, and rock and sand aggregates. Antimony, coal, copper, diatomite, kaolinite clay, kauri gum, manganese, mercury, peat, serpentine, silica sand and silver have been mined in the past and there are prospects for aluminium, bentonite, chrome, feldspar sand, gold, lead, nickel, phosphate, zeolite and zinc.

Resources of rock aggregate, sand and limestone have not been quantified, but are estimated to be large and sufficient to meet foreseeable local demand. Previous estimates have been used for sub-bituminous and bituminous coal (23 Mt valued at \$1,150 M), lignite (31 Mt valued at \$620 M) and peat (300 Mt valued at \$12,000 M). Other potential mineral resources have been estimated using a three step process involving mineral deposit models, a geographic information system (GIS) of spatial data sets, and a counting method of assessment. Estimates of value for 16 metallic mineral deposit types total NZ\$5,235 million, and for 14 non-metallic mineral deposit types they total NZ\$28,019 million.

A scenario is proposed whereby the value of Northland's mineral production could increase from the current NZ\$58 million to more than NZ\$354 million annually by:

- An increase in production of aggregate and limestone to past maximum annual levels;
- Development of a gold-silver mine;
- Development of a second metalliferous mine (e.g. aluminium, copper or gold-silver);
- Development of a second halloysite clay mine
- Reintroduction of silica sand mining; and
- Small mining operations in one or more commodities such as bentonite, coal, feldspar, kaolinite clay, kauri gum, peat and zeolite.

This scenario would be possible over a 15 year time-frame, provided that 1. there is a sufficient level of exploration to define the new resources and 2. new discoveries can be developed.

Although the assessed potential value of non-metal resources is about 5 times higher than the value of metals, it is the metals that contribute most to the potential increase in the value of production. Markets for the metals are highly developed and are not a barrier to new production. The development of non-metals is constrained by the size of the market within the region (and New Zealand). Developing markets for high value, specialised industrial minerals such as halloysite clay requires substantial investment and a long term commitment.

Attracting explorers to work in the region will require marketing Northland's mineral potential to the international exploration community along with identifying and overcoming barriers to exploration and mineral development.

KEYWORDS

Mineral resource assessment; Northland; GIS; geology; mineral deposits; aggregate; aluminium; antimony; bentonite, clay; coal; chrome; copper; diatomite; dimension stone; feldspar sand; gold; halloysite; kaolinite; kauri gum; lead; lignite; limestone; limonite; manganese; mercury; nickel, peat; phosphate; silica sand; serpentine; silver; zeolite; zinc.

1.0 INTRODUCTION

This report describes a mineral resource assessment of the mainland area of the Northland region, with a southern boundary through the Kaipara Harbour, and comprising a land area of approximately 12,600 km² (Figs 1 and 2), which amounts to about 4.7% of the land area of New Zealand. The land is administered by the Northland Regional Council, and Far North, Kaipara and Whangarei district councils (Fig. 1). Approximately 2000 km² is land under stewardship of the Department of Conservation (Fig. 3).

The aim of this report is to provide mineral resource quantity and value data for use in an economic study by the New Zealand Institute of Economic Research (Walton 2007) that examines the potential economic impacts of increased utilisation of mineral resources, similar to the study by Walton et al. (2002). The two studies are part of a wider project to provide information to local and central Government that will lead to a better understanding of mineral resources and their potential economic benefits (Barker et al. 2006a, 2006b). The Far North and Whangarei district councils wanted the economic study on a district basis and therefore this has also required that the results of the mineral resource assessment be reported on a district basis.

The Northland region contains a wide variety of mineral commodities and currently produces high quality ceramic clays, limestone for cement and agriculture, and rock and sand aggregates (Table 1; Fig. 4). Antimony, coal, copper, diatomite, kaolinite clay, kauri gum, manganese, mercury, peat, serpentine, silica sand and silver have been mined in the past and there are prospects for aluminium, bentonite, chrome, feldspar sand, gold, lead, nickel, phosphate, zeolite and zinc.

The minerals industry forms an essential part of the Northland economy. Aggregate production underpins infrastructure and building development. Limestone used as fertiliser supports the agricultural industry. Although specific statistics are not available, in terms of end value, cement manufacture is one of the most important industries in Northland, worth more than \$100 M per year. High value china clay is a significant export commodity.

Table 1. Northland mineral production in 2005 by district and total. All values in tonnes except for the dollar values in the last row. Source: Crown Minerals unpublished data.

| Mineral Commodity | Far North | Kaipara | Whangarei | Northland |
|-------------------------------------|---------------------|---------------------|---------------------|---------------------|
| Building and Dimension stone | - | - | 1200 | 1,200 |
| Clay for brick, tiles etc | - | - | - | 0 |
| Clay for pottery and ceramics | 15,370 | | | 15,370 |
| Decorative pebbles including scoria | | | 45,000 | 45,000 |
| Limestone and marl for cement | | | 990,880 | 990,880 |
| Limestone for agriculture | 80,540 | 178,339 | 33,804 | 292,683 |
| Limestone for industry & roading | 41,107 | 51,903 | - | 93,010 |
| Rock for reclamation & protection | 11,021 | - | 8,797 | 19,818 |
| Rock, sand and gravel for building | 8,703 | 276,020 | 356,939 | 641,662 |
| Rock, sand and gravel for roading | 533,149 | 652,411 | 590,188 | 1,775,748 |
| Rock, sand, gravel & clay for fill | 55,557 | 27,000 | 338,031 | 420,588 |
| Sand for industry | 2,204 | 108,000 | 1,942 | 112,146 |
| Total tonnes | 747,651 | 1,293,673 | 2,366,781 | 4,408,105 |
| Total \$ value | \$19,984,119 | \$13,530,085 | \$22,090,134 | \$55,604,338 |

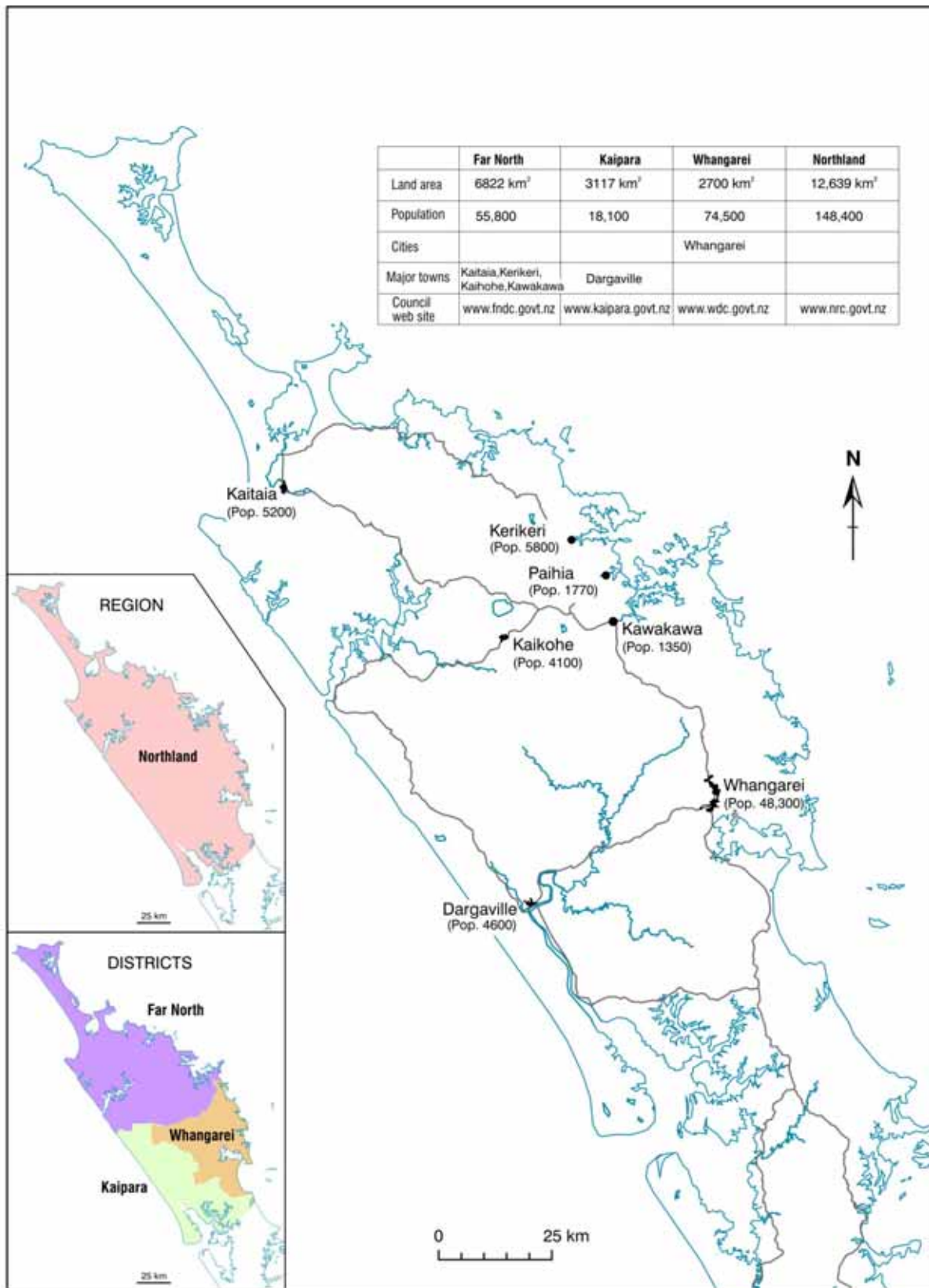


Figure 1. Location map and division of Northland into regional authorities.



Figure 2. Topographic map of Northland reproduced from the LINZ 1:2,000,000 map.

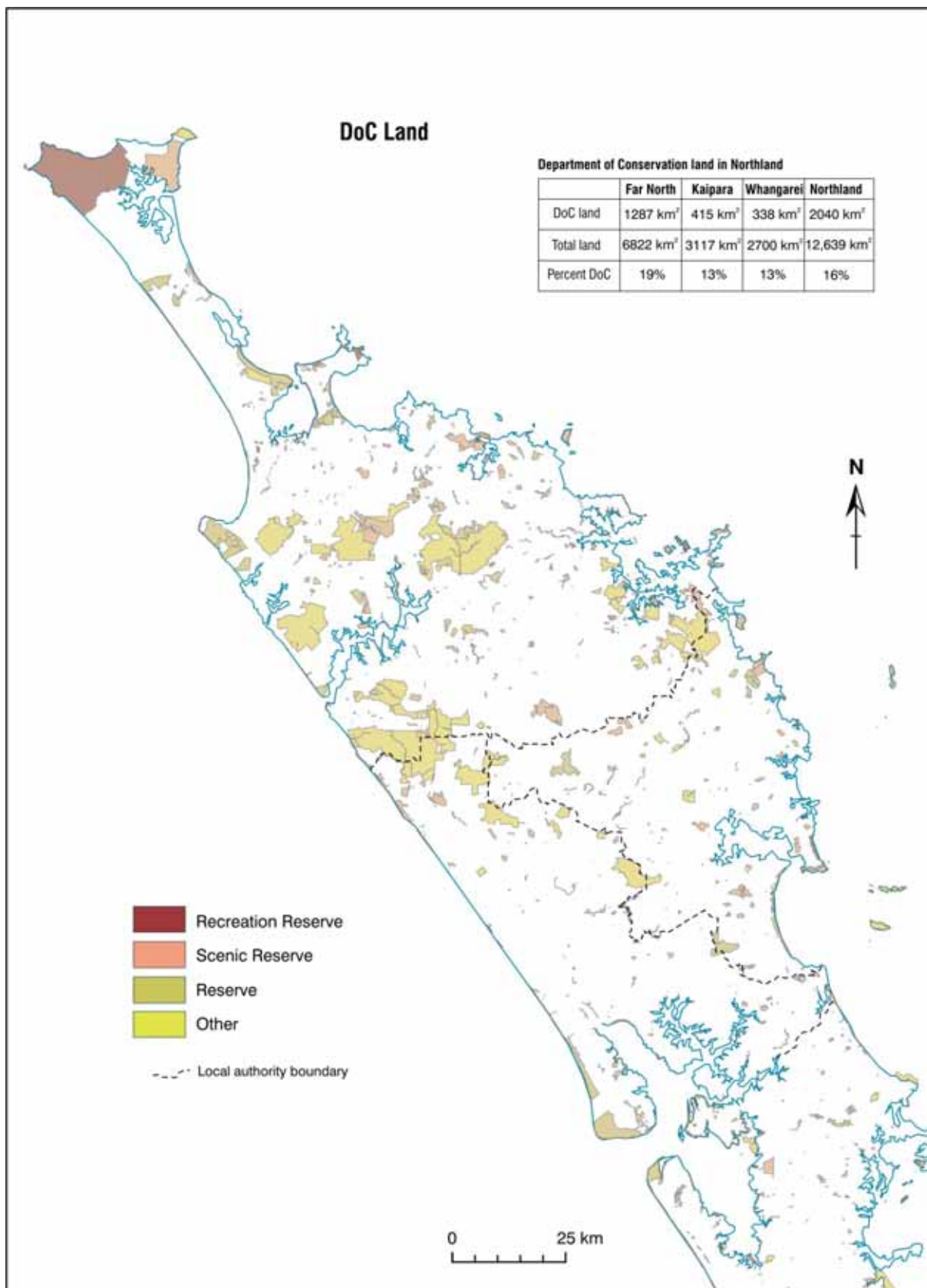


Figure 3. Areas of land administered by the Department of Conservation (DoC).

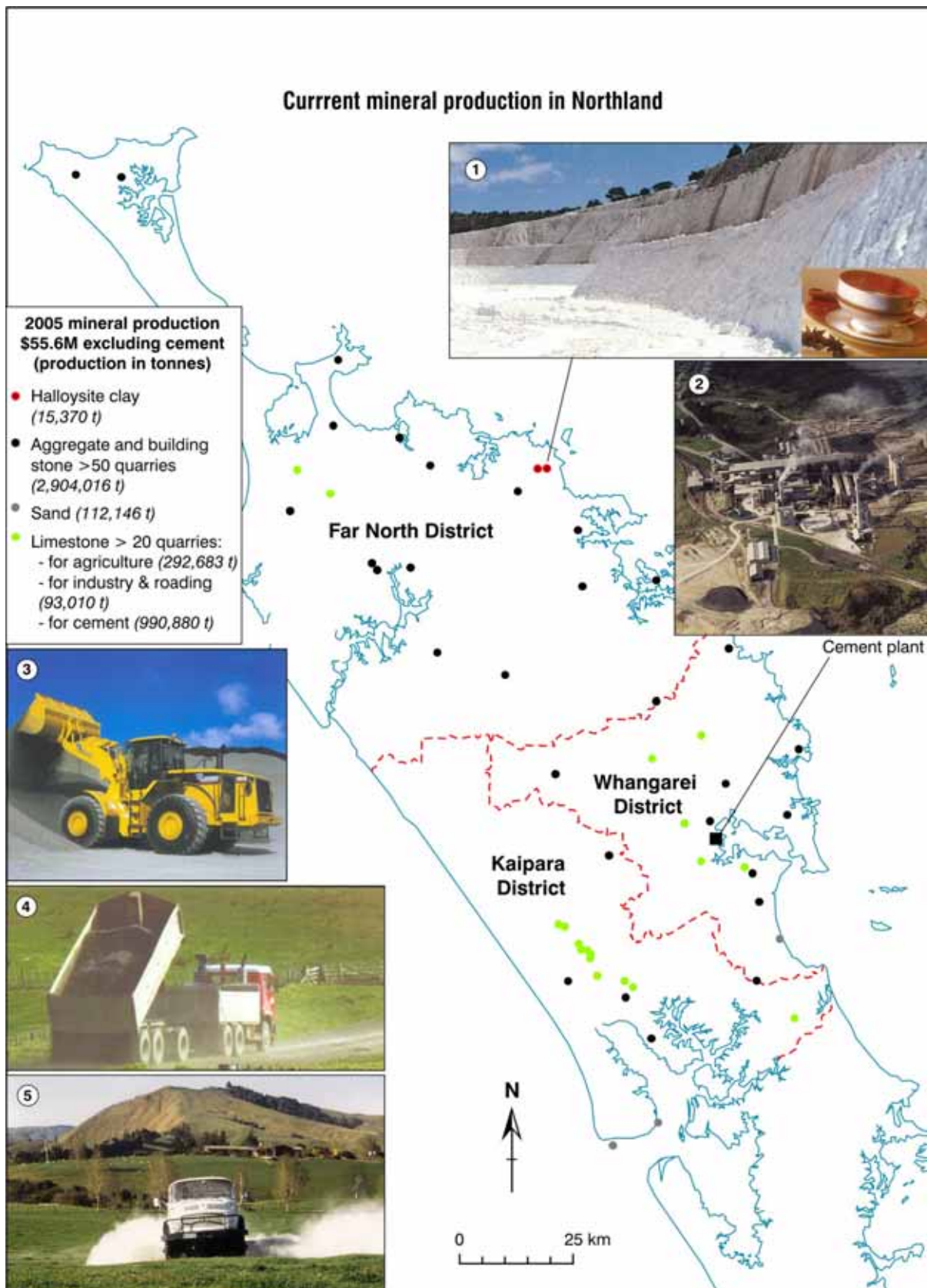


Figure 4. Current mineral production in Northland consists of high quality halloysite china clay for export, limestone for cement, agriculture, industry and roading, sand for building and industry, and aggregate for roading, building, and protection. Photos: 1. Matauri Bay clay pit and inset of high quality china product; 2. Golden Bay Cement plant at Portland; 3. aggregate stockpile; 4. spreading aggregate for unsealed road maintenance; and 5. spreading lime on pasture for fertiliser.

2.0 MINERAL RESOURCE ASSESSMENT FACTORS AND LIMITATIONS

This mineral resource assessment has been carried out with existing information and therefore the results must be considered in the light of the following factors:

Desk top study

This project is a desk top study that reviews available literature and data. There has been no field checking or new work on the geology of the deposits for this project.

In-ground resources

Mineral resource estimates are for “in ground” resources. They do not imply that they are recoverable, or that they can be mined at a profit.

Value

Gross values have been calculated from the market price or sale price of the commodity and to realise this value, there will be costs in exploration, mining and processing that are not considered in this assessment.

Constraints not considered

The mineral resource estimates have been made ignoring physical, topographical, political, environmental and other non-geological constraints, and are based solely on the probability of each environment containing a deposit of the specified type.

Undiscovered deposits

The estimates of undiscovered deposits are the probability of a deposit being present, rather than of being found. Also, the estimation process treats a prospective area as a single homogeneous unit. Estimated undiscovered deposits have no fixed position within the area, but also cannot be assumed to be evenly distributed throughout the area.

Changing technology

Advances in exploration, mining and processing technology may allow lower grade, smaller and or deeper deposits to be discovered and mined in the future.

Changing economics

Commodity prices fluctuate with time and market conditions.

New mineral deposit types

The future discovery of new mineral deposit types internationally and locally may greatly increase the prospectivity of some geological units and may make some of the estimates gross underestimates, particularly when relying on past history of production.

For example, several commodities such as aluminium and manganese may not be considered worth exploring under current prices and with existing technology, however changes in these in the future may make them worth investigating, and therefore they are included here as they represent resources that may have value in the future.

Studies of mineral potential based on existing data are inherently conservative because it is not possible to predict economic changes and technical advances. For example, in 1974 Gordon Williams, economic geologist and Dean of the Faculty of Technology at Otago University wrote (Williams 1974): “In the general area of the former Hauraki Goldfields, it is not likely that mines will be re-opened for their gold content, or that new vein deposits will be found.” Few would have disagreed with him at the time. Since then, the Martha mine at Waihi has been reopened for its gold content and new vein deposits have been discovered in the district at Golden Cross and Favona, containing a total of several million ounces of gold. These have resulted from the development of new technology, changes in the economics of mining, and continuing exploration.

3.0 PREVIOUS WORK

The Northland resource assessment project follows similar previous projects for the whole of New Zealand (Christie & Brathwaite 1999) and the Coromandel region (Christie et al. 2001a).

The geological resources of Northland were described in the New Zealand Geological Survey bulletins by Bell & Clarke (1909), Ferrar (1925, 1934) and Hay (1960). More recently they were compiled on 1:100,000 geological maps by Kermode (1981a, 1981b, 1982), Markham (1981, 1982), Markham & Crippen (1981, 1982) and Petty (1981, 1982a, 1982b). A computerised national datafile of mineral occurrences, the Geological Resource Map (GERM), was compiled and used to produce a series of 1:250,000 maps (Petty 1987; Wyss et al. 1990; Brathwaite et al. 1991; Kermode et al. 1992). This data has recently been made available on the GNS Science web site (www.gns.cri.nz) via the MinMap interface. Northland mineral resources are included in national reviews by Williams (1974), MacFarlan & Barry (1991) and Brathwaite & Pirajno (1993). Jennings (1992) reviewed the mineral resources of Northland as a response to a national park proposal, and Brown (1989) reviewed potential mineral developments of Northland. National reviews of individual mineral commodities that describe mineral resources in Northland, include: building stones (Marshall 1926; Hayward 1987), clay (Schofield 1977), diatomite (Ritchie 1962b), limestone (Morgan 1919), manganese (Reed 1960; Roser et al. 1980) and serpentine (Coleman 1966), and a series of mineral commodity reports published in *New Zealand Mining* (e.g. Christie et al. 2000 (clay), 2001b (limestone), 2001c (aggregate)). The prospectivity for epithermal gold was given by Rattenbury & Partington (2003) and Anon (2003), which included a compilation of geological and geochemical data in digital form.

The results of mineral exploration since the late 1960s are described in reports submitted by explorers to Government as part of the condition of their permits and licences. These reports are held by Crown Minerals, Ministry of Economic Development, with many available for downloading from www.crownminerals.govt.nz. The reports record two main phases of exploration, the first during the late 1960s to 1970s and the second during the 1980s to 1990s. Reports for a third phase of exploration, from 2002, are currently mostly held on closed file, but some information has been released on company web sites and in the news media.

Exploration in Northland for metals in the first phase was carried out by a number of companies, notably: Asarco (Nielsen 1967), CRA Exploration Pty Ltd (Adamson 1968, 1969), Kaiser Mining & Developments Ltd (Lalor & Purvis 1971; Lalor & Reynolds 1971b) and Strategic Exploration Ltd (Bell 1977) for copper; Adaras Developments Ltd (Corcoran 1972; Bell 1973a-c) and Pacminex Pty Ltd (Neuss 1972a-f; Neuss & MacNamara 1972; MacNamara 1972a, 1972b) for gold, copper, lead, zinc and nickel; Pacminex for phosphate (Neuss 1972a, 1972b); Western Mining Corporation Ltd for mercury (Shugg 1973); Consolidated Silver Company of New Zealand Ltd for antimony (Alexander 1971); Winstone Minerals Ltd for manganese (Carlson 1974a, 1974b); and Consolidated Zinc (Consolidated Zinc 1961; Warren 1961; Evans 1963, 1966) and Magellan Minerals (Manix 1971; Rolston 1971a, 1971b; Pearson 1973) for aluminium (bauxite).

During the second phase, exploration focussed on epithermal style Hg-Sb-As-Ag-Au mineralisation and hydrothermal alteration mostly in eastern Northland (Brown 1987b, 1989) and involved companies including ACM NZ Ltd (Anon 1989b; Drummond 1989); Austrasian Marine Resources Pty Ltd (Brown & Wilson 1982; Brown 1987a; Brown & Evans 1987, 1988); BHP Gold Mines (NZ) Ltd (Moore et al. 1984; Maxwell 1985a, 1985b; BHP Gold 1987,

1988; Gregory et al. 1988; Cameron 1989a, 1989b, 1989c); BP Oil NZ Ltd (Maxwell 1984, 1985c, 1988; McDonald 1984; White 1985a, 1985b); Canyon Resources Pty Ltd (Bell 1982a, 1982b, 1983; Corner 1983; Waterman 1986); CRA Exploration Co Ltd (Kelley 1984; Rutherford 1984; McOnie 1985); Homestake NZ Exploration Ltd (Hill & Cranny 1982; Cranney 1984, 1985); Kiwi International Resources Ltd (Murfitt 1987, 1994, 1999; Tulloch 1987; Anon 1991; Murfitt & Licence 1995); Lachlan Resources NL (Jones 1990a, 1990b); Macraes Mining Co Ltd (Grieve 1995; Reynolds 2003); and Newmont (McDonald 1983).

Crown Lynn Potteries Ltd and New Zealand China Clays Ltd carried out major exploration and drilling projects for clay in the 1960s and 1970s (Gallot 1967a, 1967b, 1971a, 1971b, 1972a, 1972b; Harvey 1968, 1975, 1980).

Exploration for coal resources in Northland was carried out in the early 1980s as part of the Government-funded National Coal Resources Survey, described by Isaac (1982, 1985). The coal resources were also summarised by Barry et al. (1994), and in the geological resource maps by Petty (1987) and Brathwaite et al. (1991).

The Ministry of Economic Development has been compiling and publishing exploration spending data since 2001. Exploration spending in New Zealand has risen from \$1.3 million in 2001 to \$25 million in 2006 (www.crownminerals.govt.nz), but only 4.5% of the 2006 total was spent in the Northland region.

4.0 METHODS

The mineral commodities are examined in three groups because of the different level and type of information available:

Aggregate, sand and limestone

Resources of aggregate and limestone are large and poorly known, because they occur over large areas and their low value relative to many other mineral commodities precludes regional exploration and resource definition. Resources are usually investigated only in the vicinity of local markets, because transport over long distances is generally precluded by the low dollar value per tonne for these commodities. Past production has fluctuated in relation to the state of the local and national economies, and with infrastructure development. Therefore, our assessment of these commodities is based on their annual production, specifically their maximum annual production in the years 2000-2005.

Coal and peat

Nationally, resources of coal are generally better known than most other mineral commodities, because of the government funded National Coal Resources Survey exploration programme during the 1980s and earlier surveys. Therefore, for this study, data is taken directly from the National Coal Resources Survey. Resources of peat were taken from company assessments.

Metallic minerals and industrial minerals

These mineral commodities generally have a high value and there is potential for export out of the region (and New Zealand). In the case of most of the metals, there are large international markets, and any quantity of the metal that can be produced in Northland could be readily sold. For most industrial minerals, markets must be sought and may be a limitation to the potential quantity of production. Exploration has helped to broadly define resources of some specific metallic mineral and industrial mineral deposits reported in the literature, and we have additionally used a process of mineral resource assessment to estimate undiscovered resources (Fig. 5; see section MINERAL RESOURCE ASSESSMENT OF METALLIC AND INDUSTRIAL MINERALS, p. 46).

5.0 DATA

Fundamental to the mineral resource assessment process is the collation of available information in a suitable form for analysis. Various spatial data sets have been assembled in a geographic information system (GIS) using ArcGIS software, enabling layered organisation, analysis and presentation of the spatial information. This digital data is included on the enclosed CD-ROM and described in Appendix 1. Mineral occurrences in the GERM database are referenced by e-number, e.g. Puketona Quarry is P05/e34, where P05 is the LINZ Infomap 260 map sheet number and e34 is the unique number within that sheet. The GERM database was mostly compiled prior to 1994, with production figures to 1993, the last year the Ministry of Energy (now Crown Minerals of Ministry of Economic Development) published annual production statistics for individual operations. Since then, production statistics have been amalgamated on a regional basis and figures for individual operations are not publicly available. Therefore, the post-1993 operational and production status of many of the mining operations (e.g. aggregate quarry and river gravel operations) may have changed and some new operations may have commenced. Few operations new since 1994 are included in the GERM database.

6.0 RESOURCE MAPS

The results of our analysis are presented as a series of maps for specific mineral commodities or mineral deposit types that generally include one or more of the following:

- Locations of mineral occurrences from the GERM database for the specific deposit type;
- Geological units prospective for the mineral deposit type;
- A table describing the mineral deposit type (top right, if present);
- A table of past estimates of resources (lower left, if present); and
- A table of our estimates of resources based on known deposits and potential undiscovered deposits (lowest left, if present).

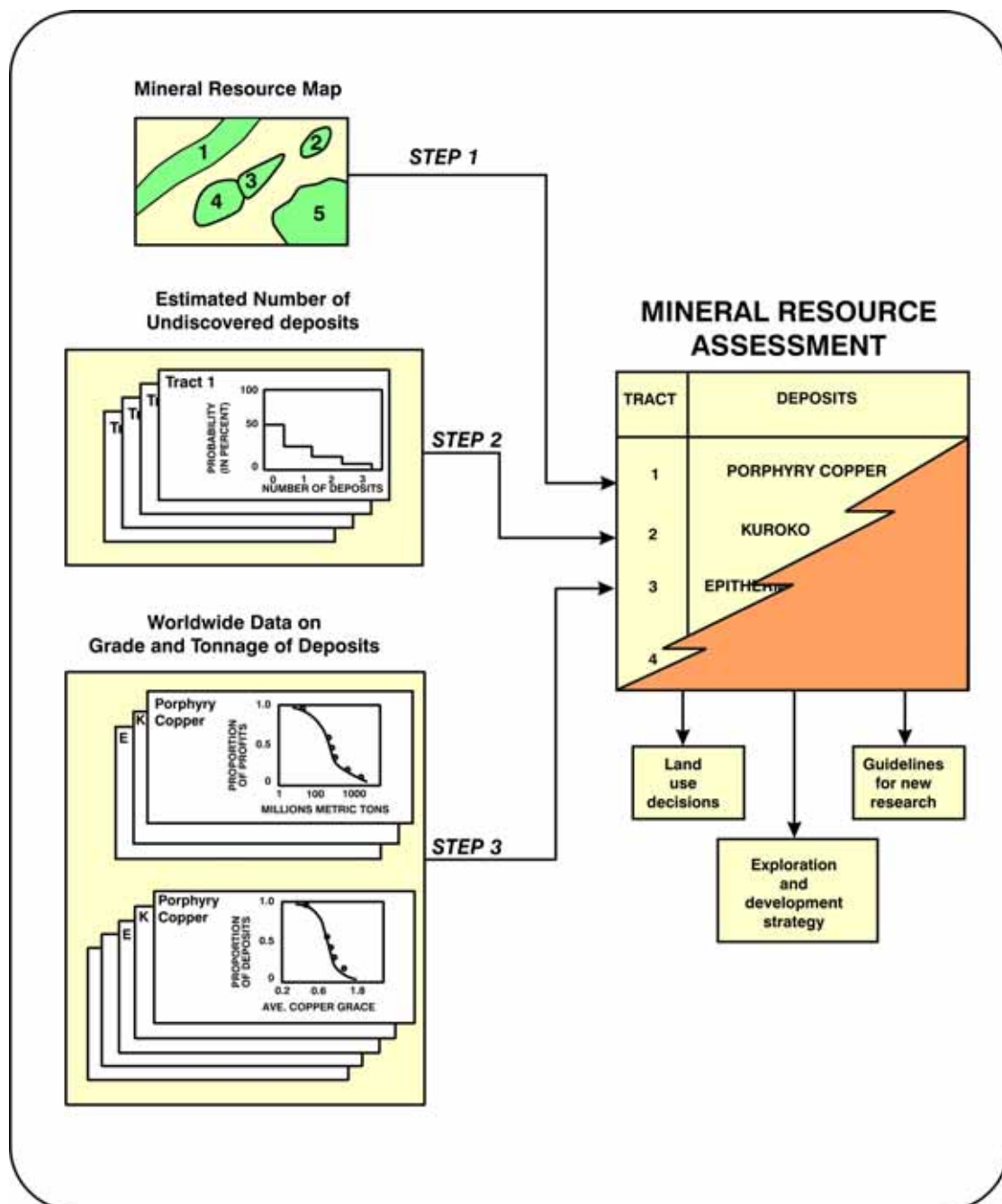


Figure 5. USGS 3-step process of mineral resource assessment.

7.0 SETTING

7.1. POPULATION AND INFRASTRUCTURE

Northland has a total population of about 148,400 (Fig. 1) including 43,500 Māori (29%; Fig. 6). The main centre of population and industry in Northland is the city and harbour of Whangarei (population 48,300) with its nearby cement and fertiliser works, and an oil refinery at Marsden Point. Other population centres include the towns of Kaitaia, Kerikeri, Kaikohe, Kawakawa and Dargaville (Fig. 1). The major commercial activities in the region are exotic forestry, farming, horticulture, tourism, fishing, aquaculture and industrial mineral mining and processing.

7.2 GEOMORPHOLOGY

The topographic relief of Northland is illustrated in Figure 7. Much of the region consists of low-lying, gently dissected terrain underlain by Cretaceous and Tertiary sediments. Rising to higher altitudes are ranges of basaltic volcanics of the Tangihua Complex and the Tutamoe Plateau (about 600 m asl) in the west, consisting of Miocene basalt flows. To the east a series of north-tilted blocks of Permian-Jurassic greywacke have been uplifted and eroded.

The east coast consists of irregular, steeply cliffed stretches of coastline linked by arcuate bays, which are commonly breached by swampy flats behind coastal dunes. Two sand and alluvial tombolos connect 'islands' of Mesozoic and Cenozoic rock to the main land mass of Northland. The largest 'island', the Cape Reinga-North Cape area, is a moderately rugged block of land connected by the Aupouri Peninsula tombolo. The other 'island', southwards from Cape Karikari, is connected by its own smaller Karikari Peninsula tombolo. The hilly areas have associated harbours; Parengarenga Harbour near North Cape, and Rangaunu Harbour separating Karikari Peninsula from the lower Aupouri Peninsula.

Sandy beaches dominate the west coast, backed by Pliocene-Pleistocene dune deposits covered by partly remobilised Holocene dunes. Kaipara Harbour breaks the coastline at the southwestern part of the region as a large estuarine drowned valley system.

8.0 GEOLOGY

The geology of the Northland region is illustrated in Figures 8 – 12, a cross section of Northland illustrating the setting of different mineralisation types is shown in Figure 13, and a map of volcanic centres and associated mineralisation is shown in Figure 14.

8.1 PREVIOUS WORK

The geology of the Northland region was mapped at 1:63,360 for the New Zealand Geological Survey bulletins by Bell & Clarke (1909), Ferrar (1925, 1934) and Hay (1960), and for the first edition of the 1:250,000 geological map series by Thompson (1960, 1961), and Kear & Hay (1961). The 1:250,000 map series was revised as the QMap project (Nathan 1994, 1998; Rattenbury & Heron 1997) and includes new map sheets by Isaac (1996), Edbrooke (2001) and Edbrooke & Brook (in prep.). Parts of Northland have been mapped at 1:25,000 by Brook et al. (1988), 1:50,000 by Evans (1993a, 1993b, 1993c), 1:63,360 by Hay (1975, 1981, 1983) and Brook (1989), and 1:100,000 by Brook & Hayward (1989). The Whangarei urban area was mapped at 1:25,000 by White & Perrin (2003). The Cretaceous and Paleogene stratigraphy, structure and paleogeography of Northland has been summarised by

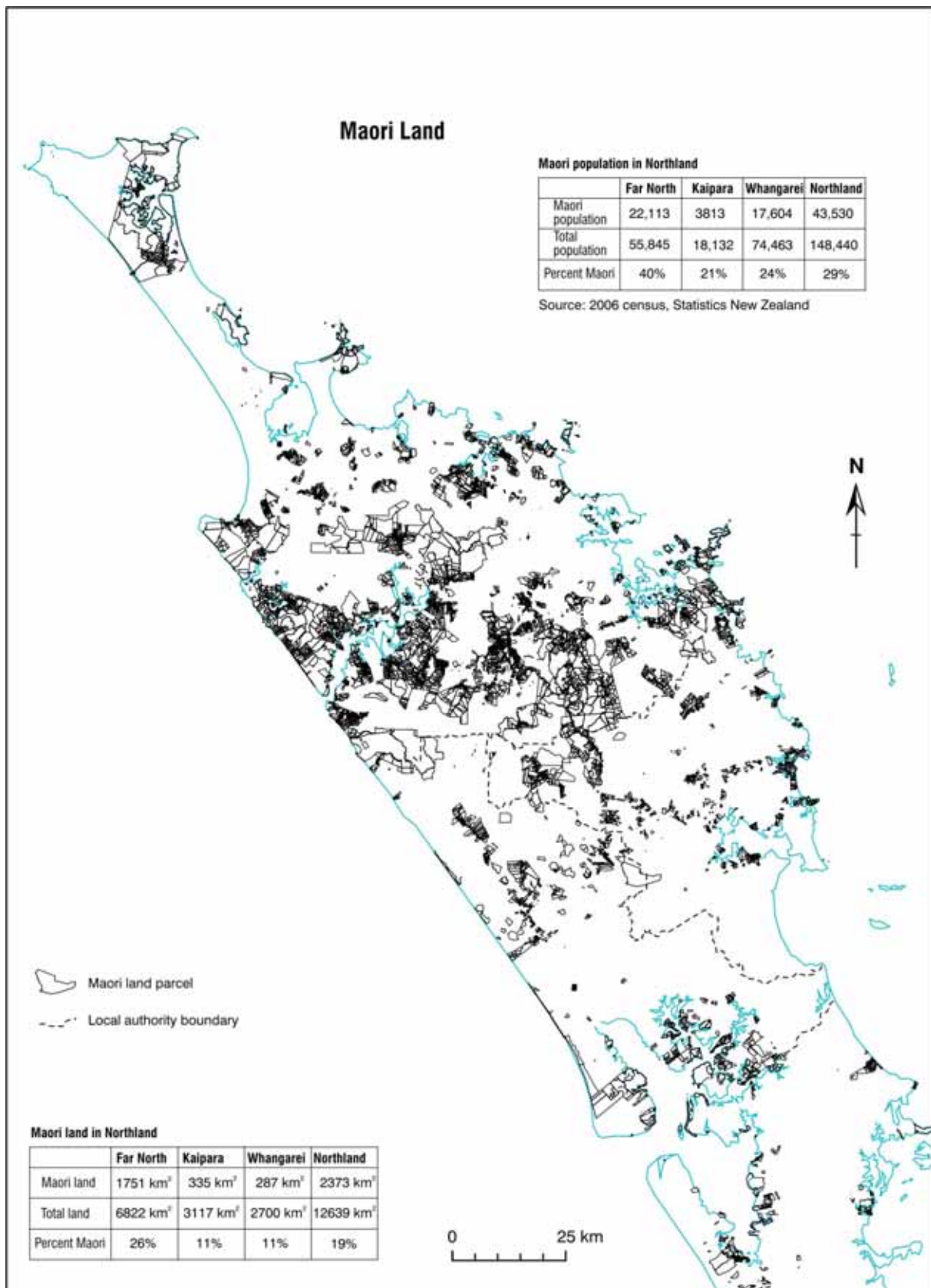


Figure 6. Māori population and Māori land in Northland.

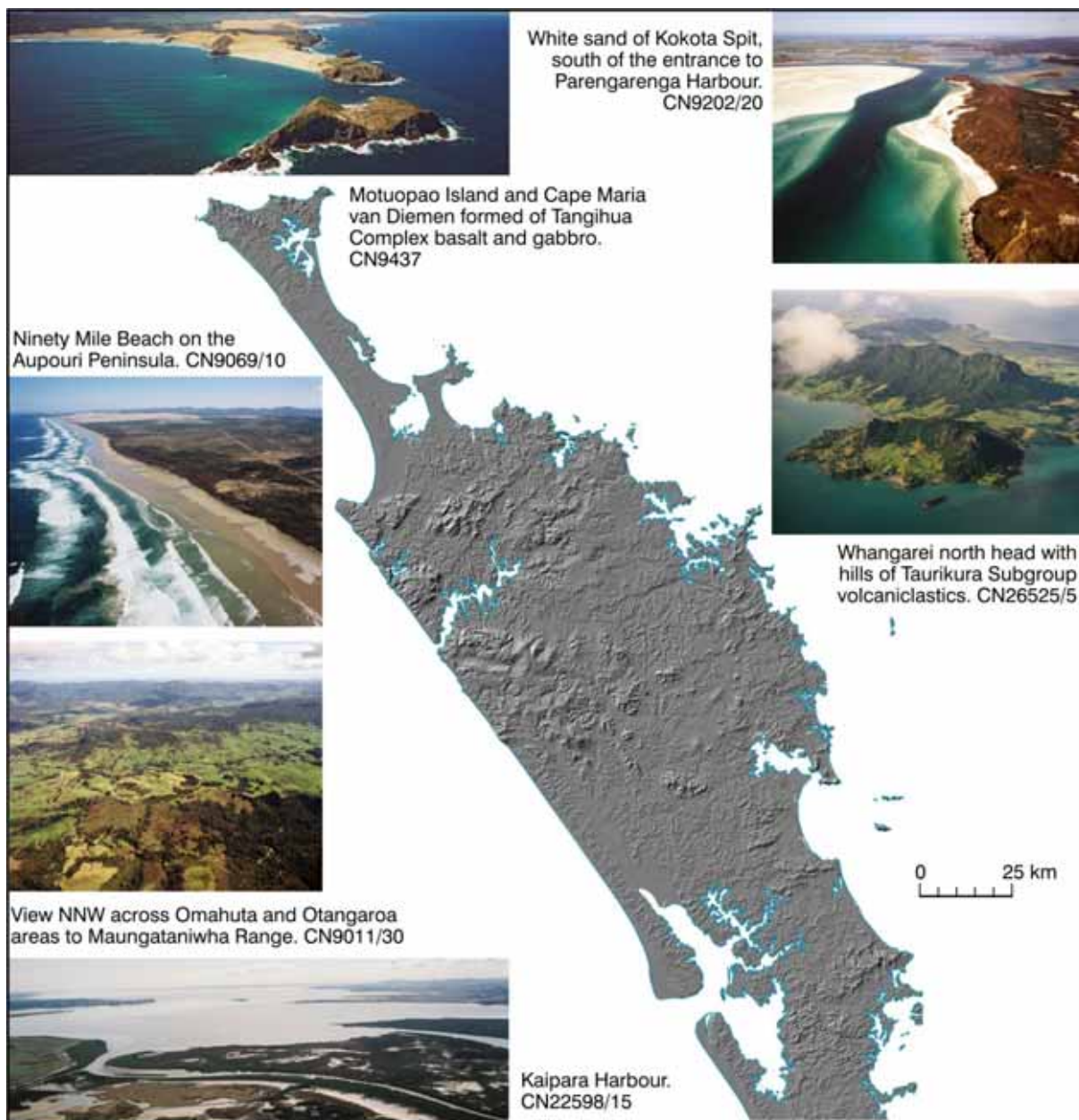


Figure 7. Hill shaded digital elevation model illustrating topographic relief and photos of some landforms. Photos by Lloyd Homer.

Hayward et al. (1989), and Isaac et al. (1994) provided a detailed description of Northland geology as part of the GNS Cretaceous Cenozoic project. A collection of 23 papers on Northland geology were published in The Royal Society of New Zealand bulletin 26 (Spörli & Kear 1989).

8.2 GREYWACKE BASEMENT

The oldest rocks in the Northland region are Permian-Jurassic indurated sedimentary rocks comprising greywacke (indurated sandstone) and argillite (indurated mudstone), and minor basaltic volcanic rocks, chert and quartzite. The rocks are extensively deformed with areas of broken formation and melange. They were accreted onto the Gondwana continental margin during the Mesozoic. The upper surface of the basement is tilted to the west so that the basement greywacke rocks crop out in east Northland. Two terranes of greywacke rocks are identified (Fig. 11). The greywacke rocks in eastern Northland belong to the Waipapa terrane, whereas the greywacke block of the Puketi and Omahuta forest parks and nearby smaller slices belong to the Caples terrane. Waipapa terrane greywackes, specifically the Hunua facies in Northland, dominantly contain andesitic volcanic rock fragments and pyroxene and hornblende crystals derived from them, whereas Caples terrane greywackes are predominantly composed of basaltic and basic andesite debris.

Minor areas of intercalated basalt and basaltic andesite lava, rhyolitic tuff, conglomerate, sandstone and mudstone in northern Northland are considered to belong to a separate, Mount Camel terrane. These Early Cretaceous basement rocks are lithologically and structurally distinct from Caples and Waipapa basement.

8.3 CRETACEOUS – CENOZOIC PRE-ALLOCHTHON SEDIMENTARY ROCKS

Unconformably overlying the basement greywacke is the mid Eocene-Oligocene Te Kuiti Group of terrestrial and mainly shallow marine sediments. The Te Kuiti Group consists of: Kamo Coal Measures (at the base), Ruatangata Sandstone (quartzose glauconitic sandstone), Mangapa Mudstone (calcareous mudstone, with abundant glauconite in the lower part of the formation), Whangarei Limestone (bioclastic crystalline limestone) and Onemama Formation (glauconitic calcareous sandstone and sandy limestone).

8.4 NORTHLAND ALLOCHTHON

During the Early Miocene, the Waipapa and Te Kuiti group rocks were overridden by thrust sheets of Early Cretaceous to Late Oligocene sedimentary and volcanic rocks of the Northland Allochthon (Fig. 12; Ballance & Spörli 1979; Brook et al. 1988; Brook & Hayward 1989; Hayward et al. 1989). The allochthonous masses were emplaced by gravity sliding from the north and northeast, in a series of nappes that slid into a rapidly subsiding basin which propagated southwards through Northland. The allochthon is 2.86 km thick in the Waimamaku No 2 well (Hornibrook et al. 1976), but may be thicker in the Hokianga area (cf. Woodward 1970), and thins eastward due to erosion of the upper part. It has a total extent of over 370 km north to south, and over 60 km west to east.

The Northland Allochthon rocks are subdivided into the Tupou, Tangihua, Mangakahia, and Motatau complexes (Brook et al. 1988; Brook & Hayward 1989).

The Tupou Complex (Early Cretaceous) is restricted to the Whangaroa area and comprises strongly indurated, poorly stratified conglomerate, sandstone and argillite. These rocks are probably displaced, distal equivalents of the Mount Camel terrane (Isaac et al. 1994).

The Tangihua Complex (Cretaceous to Eocene) consists of submarine basalt, gabbro, dolerite and related sediments. They form isolated, thin slabs less than 1 km thick and up to 40 km in diameter (Cassidy & Locke 1987). These slabs are composed of incomplete ophiolite sequences of pillow basalt, with intercalated siliceous mudstone, and dolerite and gabbro sills and dikes (e.g. Brook & Hayward 1989). Ultramafic members are absent, except at North Cape where an ultramafic-mafic complex is composed of serpentinised harzburgite and lherzolite (Surville Serpentinite) of probable cumulus origin, overlain by layered olivine- and orthopyroxene-gabbro cumulates (Murimotu Intrusives), that are intruded by a sheeted dike swarm of dominantly quartz microdiorite (Bennett 1976; Brook 1989). The complex is in fault contact with tholeiitic submarine basalts. The Tangihua Complex volcanic rocks are mainly tholeiitic in composition, although they include some alkaline rocks (Brothers & DeLaloye 1982; Malpas et al. 1992).

The Mangakahia Complex (Late Cretaceous to Early Eocene) comprises siliceous mudstone (Whangai Formation), terrigenous sandstone, conglomerate, muddy limestone and non-calcareous mudstone. The Motatau Complex (Early Eocene to Oligocene) consists of calcareous mudstone (Taipa mudstone), glauconitic sandstone (greensand; Omahuta sandstone), and limestone (Mahurangi limestone).

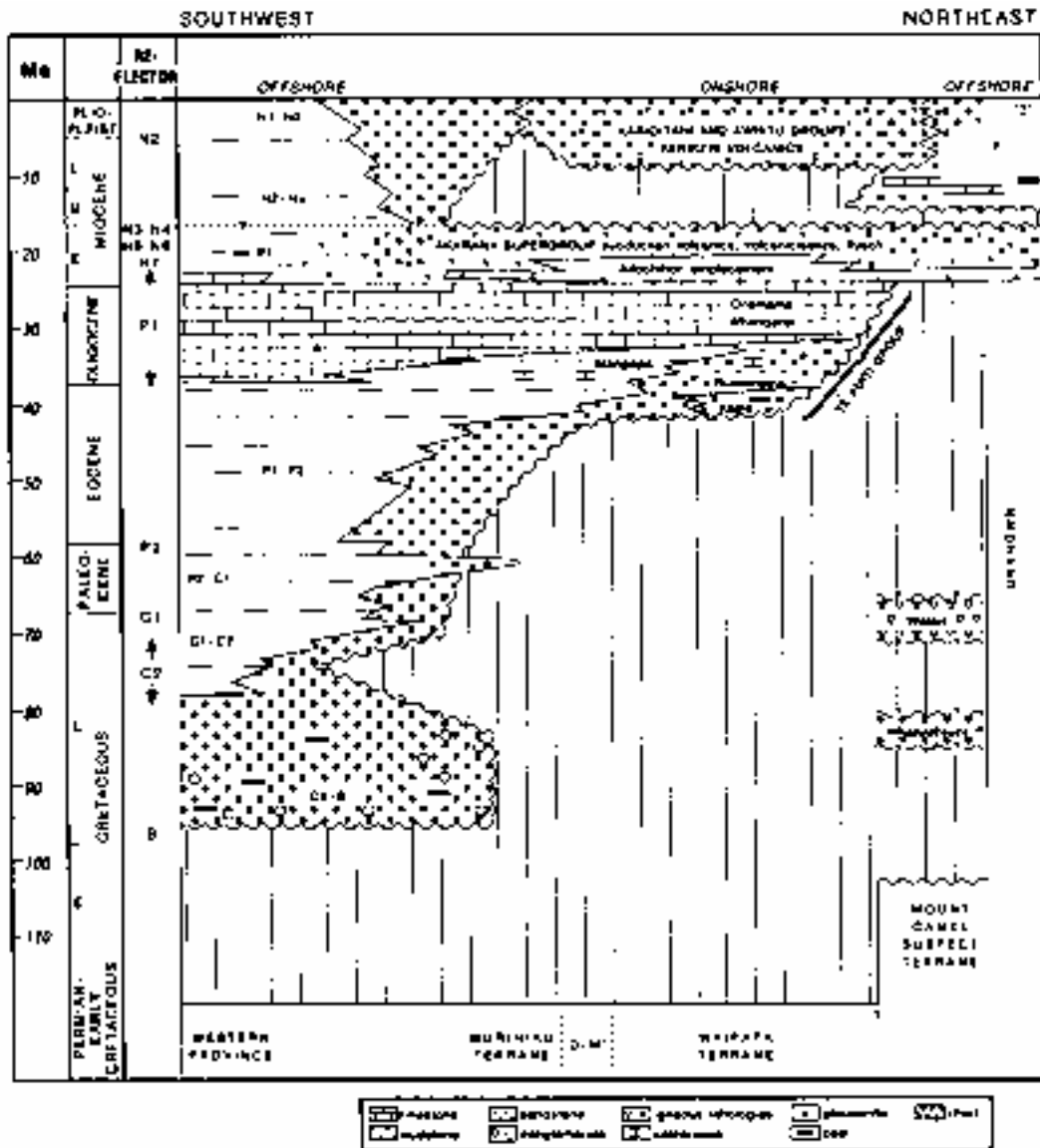


Figure 9. Stratigraphy of Cretaceous – Cenozoic autochthonous rocks of Northland (after Fig. 1.4 of Isaac et al. 1994).

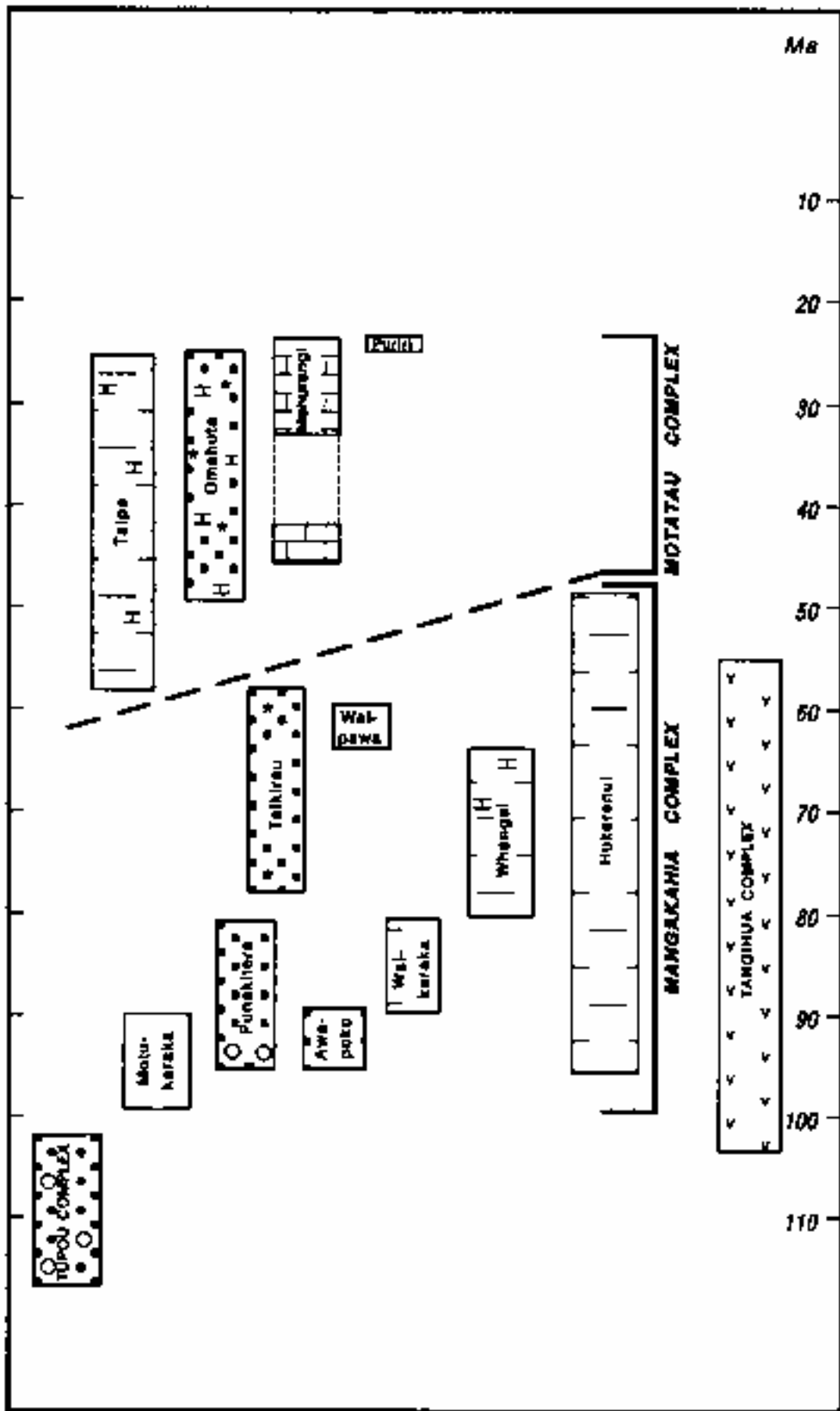


Figure 10. Original stratigraphy of the allochthonous rocks of the Northland Allochthon (after Fig. 1.4 of Isaac et al. 1994). See Figure 9 for legend.

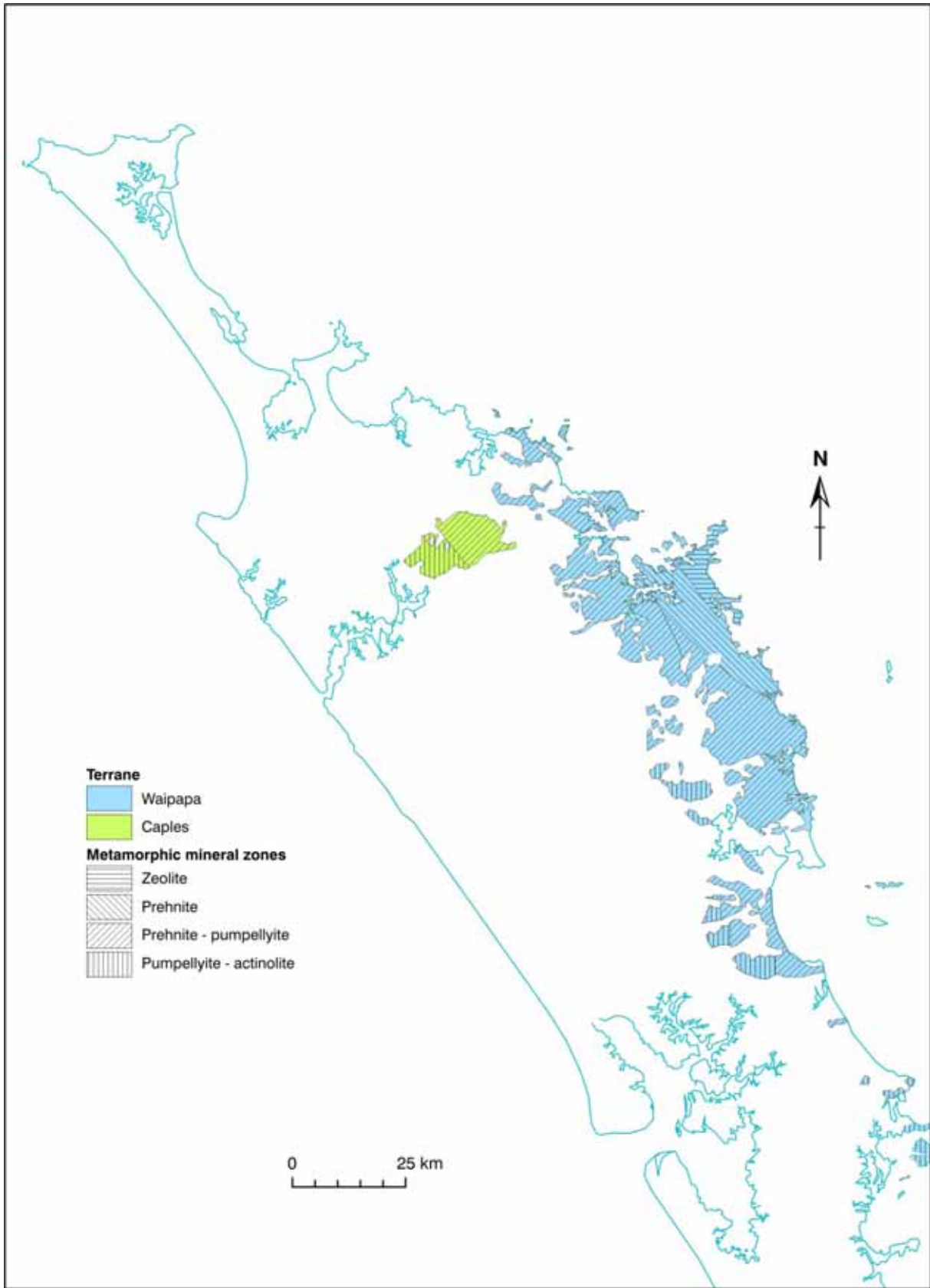


Figure 11. Terranes and metamorphic mineral zones in the greywacke basement rocks (modified after Fig. 1 of Black 1989).

8.5 POST ALLOCHTHON ROCKS

Post allochthonous sedimentary rocks include the Early Miocene Waitemata Group of volcanoclastic flysch and shelf sediments, the Mangonui Formation, and Pliocene-Holocene dune sands and alluvium. The Waitemata Group flysch incorporates olistostromes, made up of blocks of allochthon lithologies that have been mapped as Onerahi Formation or Onerahi Chaos Breccia (Hayward et al. 1989).

The earliest (23-15 Ma) episode of volcanic activity was subduction related. It is recorded by calc-alkaline and high-K volcanic/plutonic centres along two distinct NNW trending belts, 15 to 40 km apart along the Northland Peninsula (Ballance 1976; Smith et al. 1986; Smith et al. 1989), as shown on Figure 14. The western belt (Waitakere Arc of Ballance 1976) is made up of the Waipoua, Tokatoka, Hukatere, Kaipara and Waitakere volcanic centres. These consist mainly of high-Al basalt and pyroxene andesite with minor dacite and rhyolite, intruded by dikes and small plugs of similar composition (Wright & Black 1981). They are medium- to high-K calc-alkaline in character (Smith et al. 1989).

In the Kaipara and Waitakere centres, volcanism was largely submarine and the products comprise lavas, breccias and volcanoclastic sedimentary rocks (Hayward 1979). Terrestrial lavas and pyroclastic rocks were erupted at the Waipoua centre and during the later phases of eruption at the Hukatere and Waitakere centres. Only subvolcanic intrusions are preserved at the Tokatoka centre.

The eastern belt of Northland (Coromandel arc) extends south to the Hauraki Volcanic Region. Volcanism was active from about 23 to 15 Ma in Northland (Brothers 1984; Skinner 1986; Ballance 1988), erupting hornblende andesites (Whangaroa and Taurikura volcanics) and dacites (Parahaki Volcanics). The volcanic rocks and basement greywacke are intruded by andesite and dacite dikes, and by small stocks of diorite and granodiorite of Early to mid Miocene age.

A second phase of volcanism began in the Late Miocene and continued into the Late Quaternary (9-0.06 Ma), producing the extensive basalt flows and scoria cones of the Kerikeri Volcanics. The northern Kaikohe-Bay of Islands Volcanic Field includes several alkaline and peralkaline rhyolite domes including those at Putahi, Maungaparerua, Pungaere, Te Mata, Te Mahimahi and Te Pene. These rocks are commonly altered to white halloysitic clays. The southern Puhipuhi-Whangarei Volcanic Field includes the dacite domes of Parakiore (previously known as Maungarei), Hikurangi and Opuawhanga.

With the exception of the most recent rocks, almost all of the rocks in the area have been affected by subtropical weathering, which has produced large areas of surficial clay and altered rock.

8.6 STRUCTURE

The dominant structural element is the thinning of the post-basement sedimentary sequence eastwards, resulting in the convergence of beds up dip onto the basement high. This rise relates to diachronism, as well as structural uplift on the eastern side of Northland. A series of major block faults occur trending both across and parallel to the axis of the Northland Peninsula.



Figure 12. The Northland Allochthon extends west of Northland and as far south as Auckland. The East Coast Allochthon is a correlative. Much of the Northland Allochthon has been eroded. The major Tangihua Complex massifs are numbered and named (after Fig. 4.1 of Isaac et al. 1994).

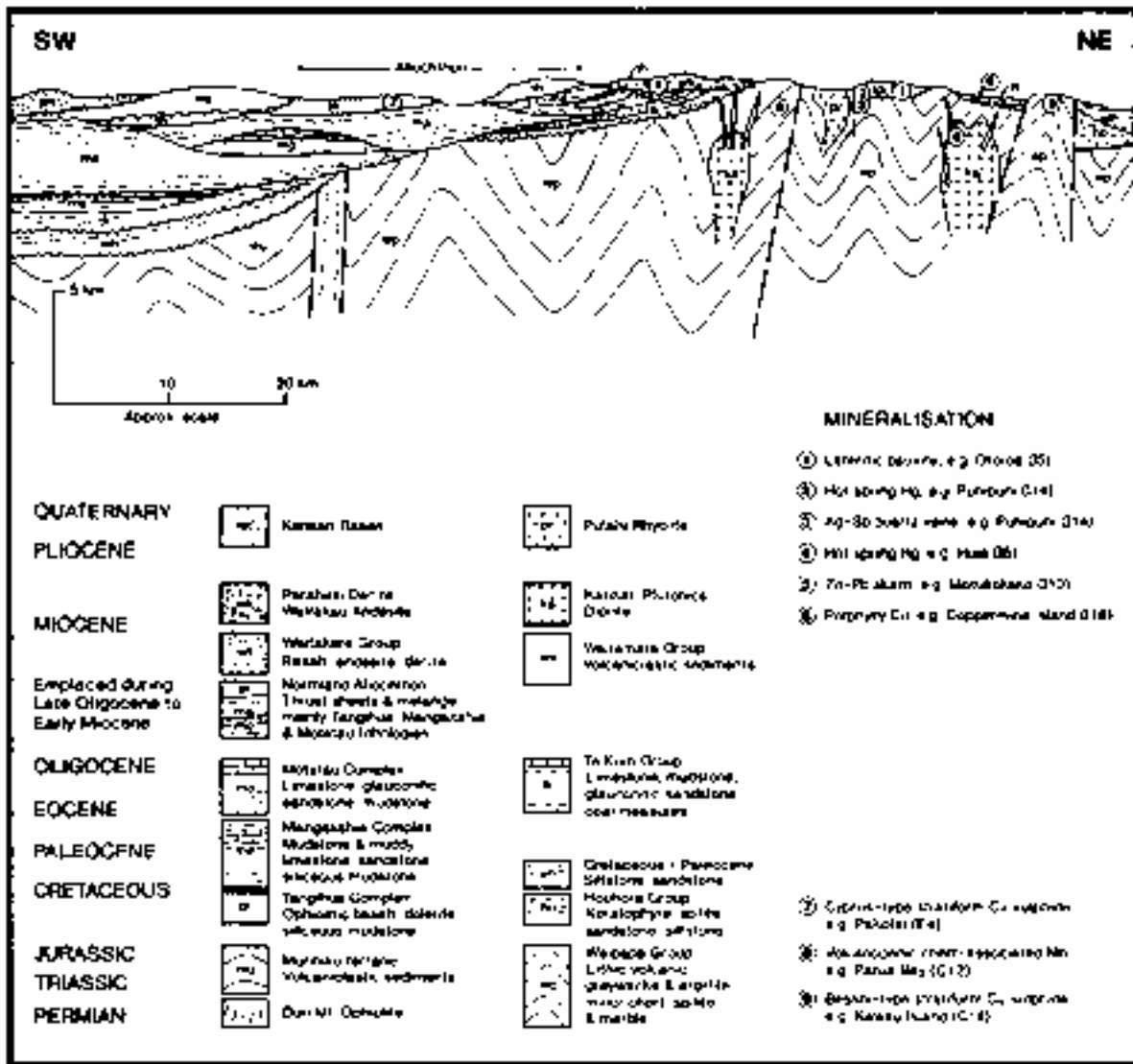


Figure 13. Schematic cross-section of Northland showing mineralisation types in relation to stratigraphy (after Figure 14 of Brathwaite & Pirajno 1993).

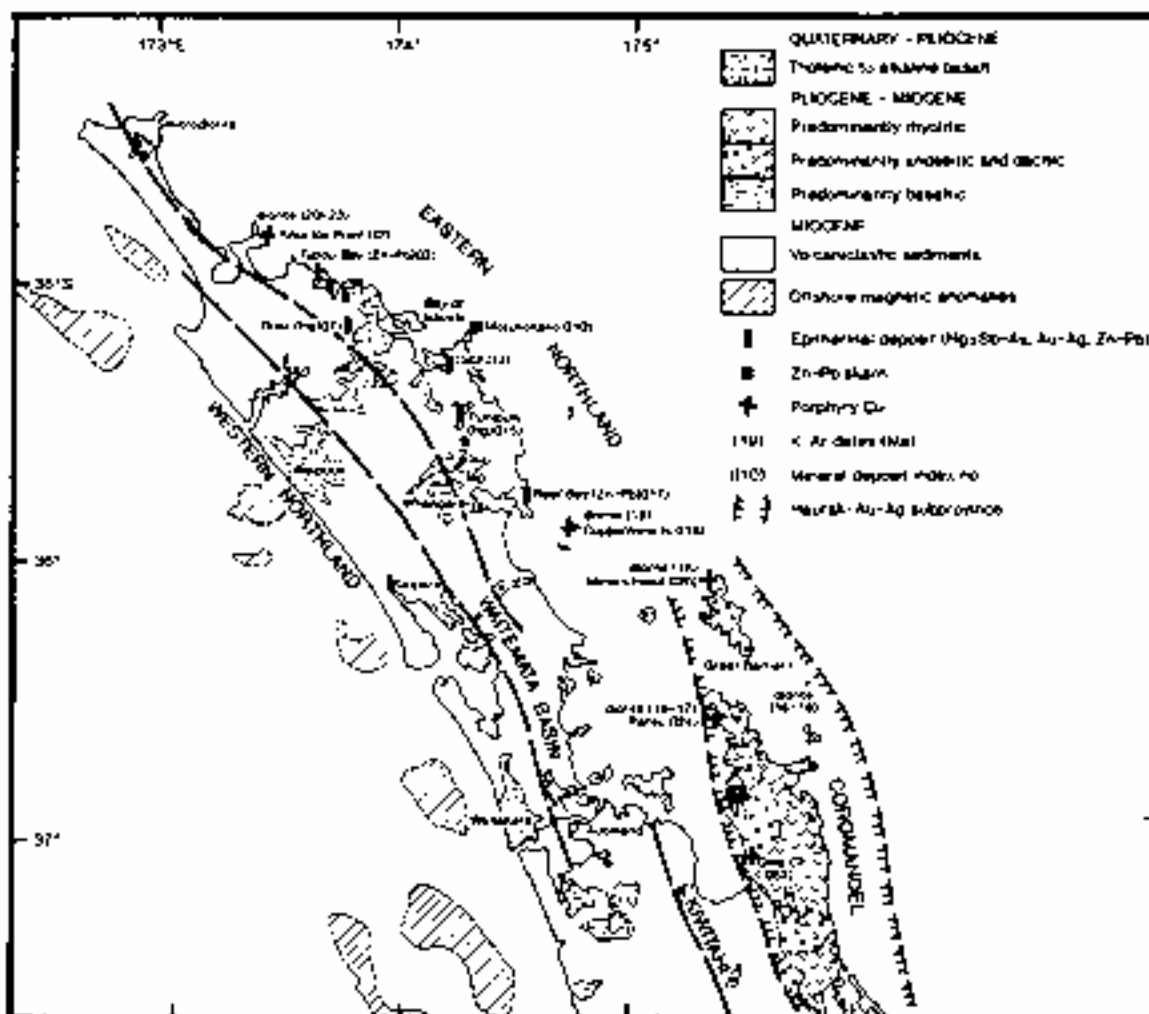


Figure 14. Miocene to Quaternary volcanic zones and centres and associated mineralisation in northern New Zealand (after Fig. 24 of Brathwaite & Pirajno 1993).

9.0 BULK COMMODITIES: ROCK AGGREGATE, SAND, BUILDING STONE AND LIMESTONE

9.1 ROCK AGGREGATE

The locations of the main aggregate quarries are illustrated in Figure 15 and the areas of the main rock types of potential use for aggregate are shown in Figure 16. Rock aggregate is supplied mainly from quarries in greywacke and volcanic rocks, although a wide variety of other rock types are also used, including limestone, where other rock types are locally unavailable. Gravel extraction is uncommon. High quality aggregate, for use in concrete aggregate or as roading sealing chip (Transit New Zealand M06 specification; <http://www.transit.govt.nz/technical/specifications.jsp>), is usually available only from the larger, long-operating quarries that have mined below the weathered zone. Most of the smaller quarries struggle to provide aggregate of suitable quality to meet the Transit New Zealand M04 Basecourse specification. Aggregate stabilisation, by the addition of lime, cement or proprietary products, is commonly used during road construction in Northland to improve the engineering properties of the poorer quality road aggregate. Limestones, shales and other sedimentary products when used for a sub base or pavements on unsealed roads tend to compact easily so have the advantage of “locking up” the top layer of the pavement. However, if the road is to be tar sealed, an intermediate layer of quality basalt type aggregate is needed between the bitumen coat and the sub base.

The main companies producing aggregate in Northland are:

| | |
|----------------------------------|---|
| Atlas Quarries Ltd | (www.atlasconcrete.co.nz) |
| McBreen Jenkins Construction Ltd | (http://www.mcbreens.co.nz/quarries/) |
| Bellingham Quarries Ltd | |
| Fulton Hogan Ltd | (http://www.fultonhogan.co.nz/) |
| United Carriers Ltd | (http://www.unitedcarriers.co.nz/) |
| Winstone Aggregates | (http://www.winstoneaggregates.co.nz/) |

Otaika and Maungatauroto (Brynderwyn; includes Piro and Stanaways) are the only quarries in Northland that produce more than 500,000 t per year, although several other large quarries produce between 100,000 and 500,000 tonnes annually, namely Larmers Road (Fig. 17), Pukepoto (Masters), Puketona (Figs 18 and 19), Loop Road, Turiwiri (Fig 20), Mountfield, and Hukatere (includes Webers). Northland has a large number of small quarries (<50,000 t per year), many of which are worked intermittently, spread over the area to utilise local deposits and minimise cartage costs. This is particularly relevant to the construction and maintenance of Northland’s many unsealed roads.

Larmers Road (Bellingham’s), Pukepoto (Master’s), Puketona (McBreen Jenkins), Otaika (Winstone Aggregates) and Maungatauroto (Atlas) are the only quarries that are currently producing sealing chip, concrete aggregate and other high quality products. This small number reflects the high cost of operating the relevant crushing equipment and the limitations in obtaining high quality aggregate in Northland. Their location is generally dictated by market requirements, and provides a distribution network that minimises trucking distance in supplying the major sealed roads and other markets.

There is currently a shortage of good quality aggregate in the north Hokianga area (GHD Ltd 2003, 2004) requiring trucking of aggregate into the area. This is particularly critical because the roads in the north Hokianga area are expected to become increasingly heavily trafficked over the next few years as a number of commercial forests reach maturity and logging truck activity increases.

Northland has vast sand resources in coastal dunes and beaches, as well as offshore sands, both of which are utilised in producing sand for aggregate and industrial uses. Small quantities of sand are also produced as a by-product of crushing aggregate at some quarries (e.g. Otaika) and in processing of china clay at Matauri Bay.

9.1.1 Northland deposits (Figs 15 and 16)

9.1.1.1 Sedimentary rocks

Waipapa Group

Waipapa Group greywacke (Permian to Jurassic) crops out mostly on the eastern part of Northland. Deep weathering results in high overburden stripping costs to access fresh rock (MacFarlan & Barry 1991). Much of the greywacke is sheared, veined and altered, and therefore only a few quarries can supply a sealing chip to state highway standard. The main quarries in greywacke include Puketona (Figs 18 and 19; P05/e34), Russell, Dicksons (Glenbervie, Q06/331116), Otaika (Q07/e10), and Western Hills. Greywacke is most accessible on the scarp slopes of the faulted blocks, but most of these have been left in bush and have become landscape features. Proposals for new quarries will compete with proposals to protect the prominent bush-covered slopes.

Te Kuiti Group

Sandstone of the Te Kuiti Group has been quarried in the Whangarei area, e.g. the former Harbour Board sandstone quarry (Q07/e15). Many smaller quarries are worked from greywacke, sandstone, mudstone and shale throughout the area.

Mangakahia and Motatau complexes

Rocks of both complexes are generally low grade, having low crushing strength so that plastic fines are quickly produced. The aggregate is most often used on unsealed roads, and is commonly quarried from private pits. The Motatau Complex is worked at Dangen's quarry (O04/e11) and Paranui shale pit (O04/e18).

9.1.1.2 Igneous rocks

Igneous rocks including basalt, andesite, rhyolite and dolerite, are worked from the Tangihua Complex, Waipoua Basalt, Waitakere Group, and the Kerikeri Volcanic Group. Black (2005) discussed the deleterious properties of alteration minerals in andesites.

Mount Camel terrane

Cretaceous basalt, dolerite, diorite and rhyolitic tuff in the Mt Camel and Karikari areas have been the main source of local road rock and some building aggregate.

Tangihua Complex

Constituent rock types include basalt, dolerite, gabbro and breccia. Generally these rocks are deeply weathered, and may be highly sheared, zeolitised or hydrothermally altered, with the joints filled with chlorite. Aggregate from the Tangihua Complex is generally of poorer quality than the best of the greywacke, so it is generally used as low-grade basecourse or sub-basecourse, or as high-grade fill material. The main quarries include Larmers Road (Fig. 17; O04/e27), Masters (N04/e4), Hicks (O05/e8; now closed), Dark Creek (O05/e15; now closed) and Turiwiri (Fig. 20; P07/e22).

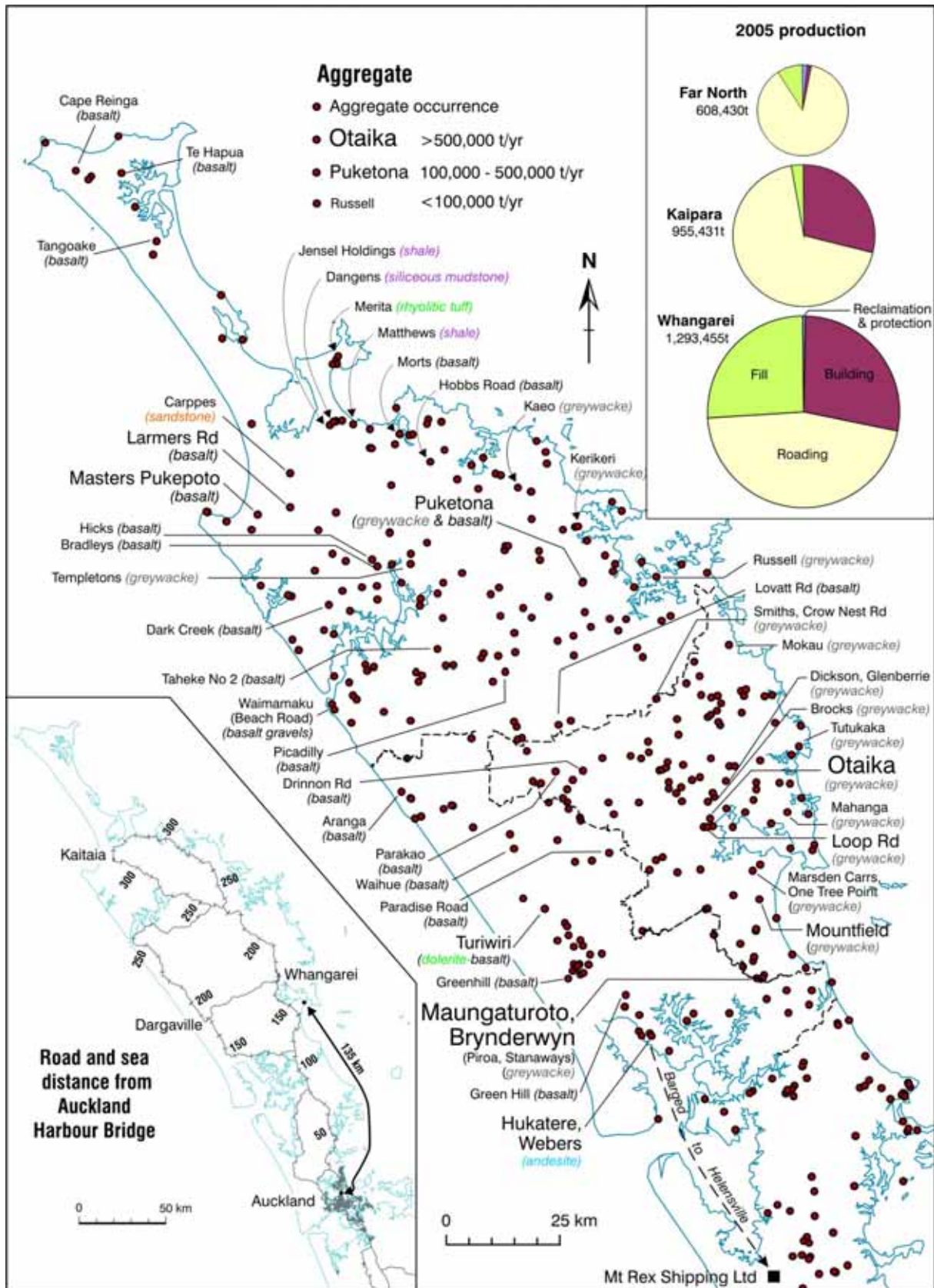


Figure 15. Location of aggregate quarries and sites from the GERM database. Inset graphs show the 2005 aggregate production and end use for the three districts. The inset map shows road and sea distances from the Auckland Harbour bridge.

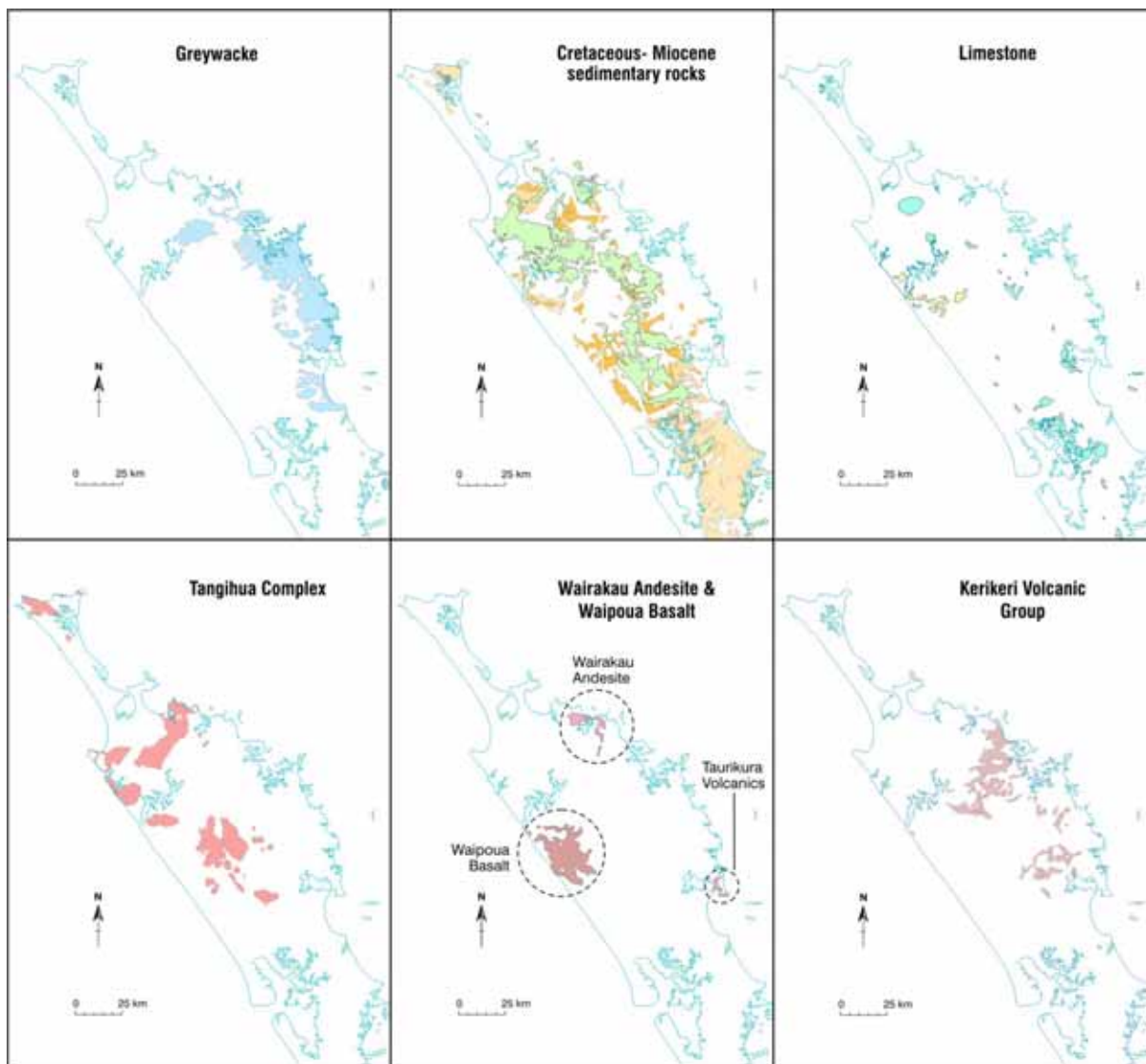


Figure 16. Areas of the major stratigraphic units and rock types utilised for aggregate.



Figure 17. Larmers Rd quarry south of Kaitiāia. The quarry is operated by Bellingham Quarries Ltd and produces basalt aggregate. Photo: Tony Christie.



Figure 18. Puketona quarry northwest of Paihia. The quarry is operated by McBreen Jenkins Construction Ltd and produces both greywacke and basalt aggregate. Photo: Tony Christie.



Figure 19. Vertical aerial photo of Puketona quarry. Photo: Courtesy McBreen Jenkins Construction Ltd.



Figure 20. Vertical aerial photo of Turiwiri quarry, Dargaville. Photo: Courtesy McBreen Jenkins Construction Ltd.



Figure 21. Panorama view of Jensel Holdings shale quarry located between Awanui and Mangonui. Photo: Courtesy Brian Bellingham.

Waitakere Group

Waitakere Group (Early Miocene) is a source of basalt and andesite. Basalt from the Waipoua Plateau (Waipoua Subgroup) is hard and durable, although the chlorite content, which is concentrated along the joints, tends to be high, and the rock may be weathered to kaolinite. Nevertheless, the rock is of good quality and potential for further development of quarries in the basalt is good. Overburden thickness is variable, but not generally high. Quarries include Tattersals (O07/e2) and Clements (P07/e13), north of Dargaville. In southern Northland, andesite has been extracted from Hukatere or Weber's quarry (Q08/e27).

Kerikeri Volcanic Group

Kerikeri Volcanic Group basalt (Late Miocene – Late Pleistocene), where unweathered, provides good quality aggregate. The weathered zone, particularly in the older basalts, may be more than 30 m thick, which is greater than the thickness of many basalt flows. Quarries include Blackbridge, Taheke, Piccadilly Road, Puketona (P05/e34), Kerikeri Irrigation (P05/e3, e4) and previously at Titoki.

Large basalt boulders have been used for riprap in rock walls protecting Marsden Point Port and also in retaining wall material for slip repair and bank stabilisation, and protecting riverbanks from erosion. The boulders were collected from fields at Puhipuhi, Glenbervie, Poroti-Maungatapere, Okaihau and Kerikeri. United Carriers has a stockpile of basalt boulders collected as farms and horticultural blocks are cleared of surface rock.

9.1.1.3 Alluvial (river and stream) gravel

Gravel was commonly used for local roading in the past (e.g. in the late 1960s and early 1970s), but extraction at present is limited to only a few operations (e.g. Puhipuhi Plateau). Greywacke gravels have been extracted from rivers such as the Waipu, Waiarohia-Whangarei, Peach Orchard-Kaimamaku, and smaller Whangarei East Coast rivers and streams such as Punaruku, Mokau, Helena Bay, Whananaki, and Ngunguru, the Tirohanga near Kawakawa, Oromahoe and Waitangi, Kaeo, and Waipapa River at Rahiri Settlement. Gravels of Tangihua basalt have been taken from the Mangamuka, Waima, Whirinaki, Waimamaku, Kaihu, Mangakahia, Kaikou (Pipiwai), Moengawahine, Victoria and Takahue (Awanui) rivers. These were small deposits that were either extracted and used as is, or at Kaihu, Mangakahia, Waima and Waimamaku, the rock was crushed.

Some western rivers have been investigated recently for supply of aggregate in the Hokianga area (GHD Ltd 2003). However, the investigation concluded that because of their low quality, the river gravels would be better suited for use as drainage gravels rather than road sub-base materials.

9.1.2 Future potential

Aggregate demand will increase as a result of increased infrastructure development and building in Northland, related to increasing population and wealth. Sterilisation of Auckland's aggregate resources by housing has resulted in an increased demand for aggregate from sources outside of Auckland, generally to the south. There is potential to supply aggregate to Auckland from Northland as prices for aggregate in Auckland increase, initially by trucking to markets in the northern part of the city or if prices rise substantially, by barging. Currently aggregate is trucked from some south Northland quarries (e.g. Maungatauroto) into North Auckland. Aggregate from the Hukatere quarry is barged over the Kaipara Harbour to Helensville and from there trucked to concrete plants in North Auckland. However, exporting aggregate from further north in Northland would involve large distances for transport. For example, using aggregate from say the Otaika quarry in Whangarei would involve trucking approximately 150 km to service the northern part of Auckland city or alternatively barging approximately 135 km from Whangarei to Auckland (Fig. 15). Barging over this distance is not unrealistic, as demonstrated by the current operation barging aggregate to Auckland from H.G. Leach & Co Ltd's Tirohia quarry south of Thames. At \$0.18 per tonne per km, trucking 150 km would cost \$27 per tonne. A critical factor may be finding material to back-load from Auckland to Northland to avoid trucks making the return journey empty.

Aggregate supply is increasingly coming under threat from urbanisation and local opposition to quarry operations. Many of the small intermittently operated quarries and pits have closed and there is increasing reliance on fewer larger quarries, also partly because of increasing resource consent application and compliance costs. Notable recent closures in the Far North District are Hicks quarry and Dark Creek quarry (GHD Ltd 2004), closed partly because of opposition from local Iwi.

9.2 SAND

9.2.1 Northland deposits (Fig. 22)

The coastal areas of Northland contain very large onshore and offshore sand deposits of Pliocene-Holocene age. Sands of the west coast generally have approximately equal quantities of quartz and feldspar (Fig. 22; Schofield 1970; Schofield & Woolhouse 1969; Applied Geology Associates 1982). An exception is the silica sands of Hokianga North Head (O06/e19; see section 13.9.2.3 Silica sand).

At Kaipara Harbour, sand has previously been extracted by Mt Rex Shipping Ltd using a suction dredge, from offshore near Pouto, at the harbour entrance and barged to Auckland, but this extraction has ceased at present. Sand is extracted from Millers Bank (Lady Franklin Bank) north of Pouto by Kaipara Water Transport (consented 25,000m³). It is screened to remove shell and oversize material, and barged to Dargaville. South, across the boundary between Northland and North Auckland, sand is extracted offshore from Taporapora Bank by Winstone Aggregate Ltd and Mt Rex Shipping Ltd, and barged to Helensville to supply the Auckland market for building and industrial sand. McCullum Brothers Ltd are investigating

mining sand from the Kaipara delta off the mouth of the Kaipara Harbour, partly within Northland and partly within North Auckland regions. The sand will be shipped to Onehunga for the Auckland market.

The extensive sand dunes of the west coast (e.g. North Kaipara Barrier) may have potential as a source of silica, feldspar and specialist sands such as for foundry use, but exploration is needed to delineate areas for detailed sampling to determine the quality and the quantities involved.

Sands on the northern part of the east coast are silica sands with mostly quartz and minor feldspar (e.g. Parengarenga). Some of New Zealand's largest sand deposits occur on the east coast, within the Aupouri Peninsula, between Cape Karikari and North Cape. The Kokoto Sandspit, which forms the south head of Parengarenga Harbour, is a large deposit of very pure quartz sand, which until recently was dredged mainly for glass manufacture. Ngakengo Beach, just north of Parengarenga Harbour entrance, is a similar quartz sand deposit, although it has a higher shell content.

Further south, feldspar generally dominates, particularly at Ruakaka. Extensive feldspathic sand deposits with 50-75% Na-Ca feldspar are present along the east coast, both onshore and offshore, from Ocean Beach to Te Arai (Schofield & Woolhouse 1969; Schofield 1970; Gillie & Kirk 1980; Hilton 1989). Semenoff Sand Supplies Ltd onshore operation at Waipu supplies building sand to the Whangarei market. Sand for construction was extracted from a sand bar deposit at Waipu River mouth, and nearshore deposits at Ocean Beach and in Bream Bay have been dredged in the past (Hilton 1989). Offshore at Mangawhai, suction dredging has extracted sand from a long-shore bar about 200 m offshore, in water depths of 4-8 m. This fine, well-sorted sand has been used for building aggregate (Hilton 1989). Sand extraction at Mangawhai has ceased after resource consents were declined by the Northland Regional Council, however sand extraction offshore of Pakiri (North Auckland region) still continues and sand is barged to Auckland mainly for use in the building industry. Several other potential offshore sand resources have been investigated by Gillie (1979a), Landsea Minerals Ltd (Gillie 1979b; Gillie & Kirk 1980) and Applied Geology Associates (1982).

Small quantities of silica sand are produced as a by-product of halloysite clay mining at Matauri Bay and used in the local market for clean fill and as a component of builders mix.

9.2.2 Future potential

Demand for sand will increase as a result of increased infrastructure development and building in Northland and Auckland, related to increasing population and wealth. Marine extraction of sand on the east coast is discouraged because of public concern over coastal erosion (which may be unconnected to sand extraction), and therefore there will be an increase in extraction from onshore sites. On the west coast, increased production from Kaipara Harbour is likely, because of the large resources in the Kaipara delta that are replenished by longshore drift from the south.

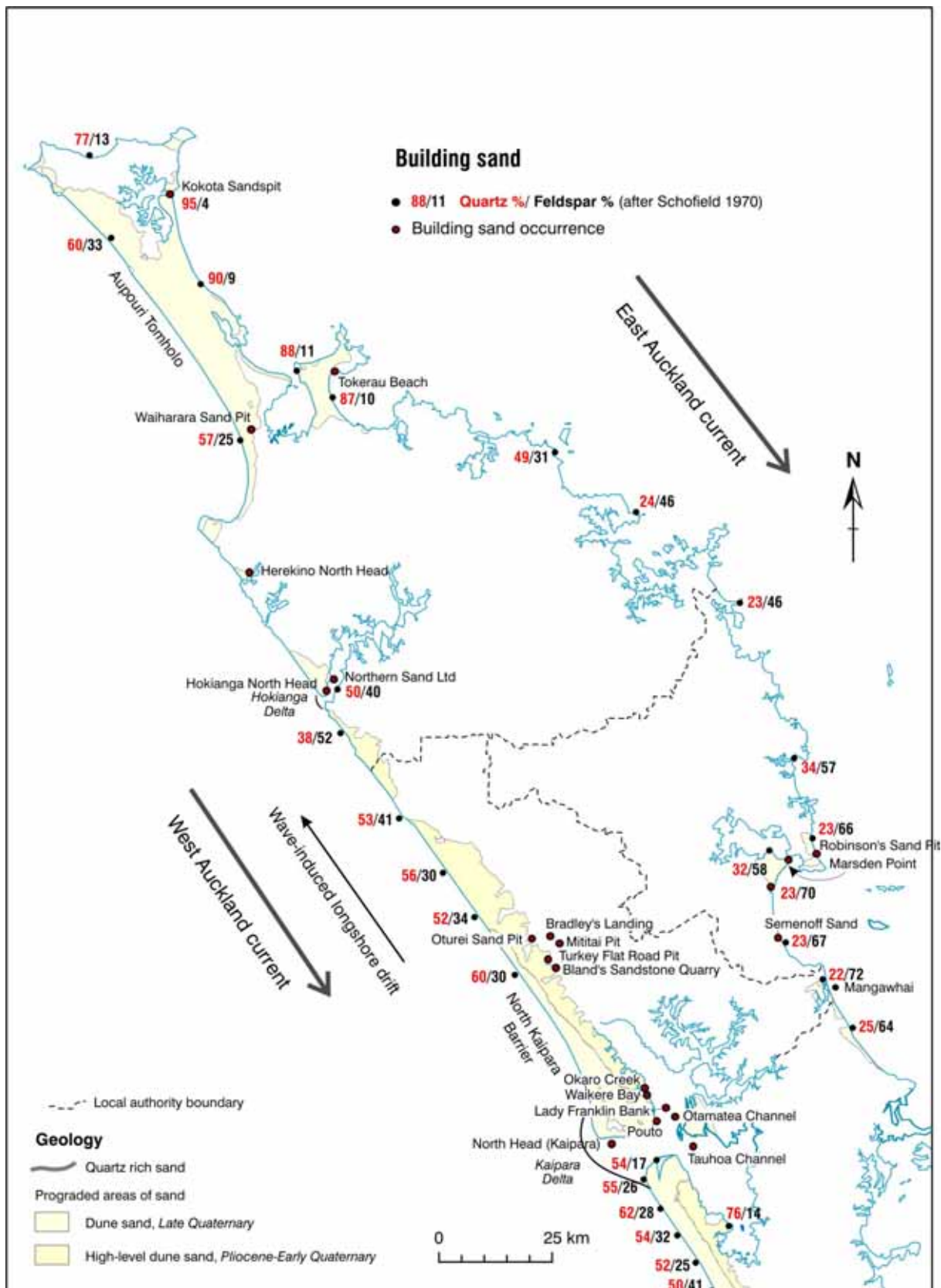


Figure 22. Location of sand sites from the GERM database and proportions of quartz and feldspar in coastal sand (after Schofield 1970).

9.3 BUILDING AND DIMENSION STONE

9.3.1 Northland deposits (Fig. 23)

The thick zone of weathering and the degree of fracturing and alteration has rendered many of the hard rocks unsuitable as building and dimension stone. However, basaltic lava and scoria (Kerikeri Volcanics), shale (Mangakahia Complex), greywacke (Waipapa Group), crystalline limestone (Te Kuiti Group) and red chert (Tangihua Complex) have been quarried for use as dimension stone. Some rocks to be considered include serpentine, the various ultramafic rocks (e.g. gabbro), dacite (e.g. Bald Rock, Kaiwaka), and the attractive green and red shales and cherts within the Tangihua Complex. Some of the Mount Camel terrane silicic volcanic rocks could also be used if selectively quarried.

9.3.1.1 Basalt

Young (less than 2 million years old) basalt occurs in two main areas: Bay of Islands – Kaikohe and Whangarei. These generally consist of a number of small spatter cones built of red and black scoria, that are surrounded by extensive fields of dark grey lava flows. When the prehistoric Māori and later European settlers, farmed these lava fields, they collected up all the loose surface stones and piled them, into heaps or used them to build dry stone walls. Fresh basalt from the lava flows was used locally for building in the 19th century (e.g. Kerikeri Stone store built 1832-1836) and to a lesser extent in the 20th century (e.g. St Pauls Church, Paihia, 1925). Scoria is still extracted from some sites, e.g. Kamo scoria quarry on the west side of Hurupaki cone.

9.3.1.2 Limestone

Whangarei 'Marble', a shelly, dull yellow, cream or pink-tinted limestone (Whangarei Limestone) has been extracted commercially since the 1920s. A quarry beside Waro railway Station, Hikurangi and others around Whangarei supplied ornamental polished panels for a number of buildings throughout New Zealand in the 1920s to 1950s (e.g. T. and G. Life Insurance, Auckland; Napier Post Office; Wellington central Library; Lower Hutt Library; Dunedin Post Office).

Another locality, northwest of Whangarei was the source of polished facing panels (called Ruawai Stone) for several Wellington buildings in the 1980s (e.g. Court of Appeal, National provident Fund Building). Small quantities of flagstones (Onemama Formation) from Paradise quarry have been extracted for ornamental use since the 1970s. Similar stone has been obtained further south to build the local Waipu Memorial Museum (1953) and a motel at Waipu Cove (1985).

9.3.2 Future potential

There is potential for increased extraction of rocks for building and dimension stone, but in terms of value, and in comparison to other commodities, any new operations are likely to make only a very small contribution to Northland's mineral production.

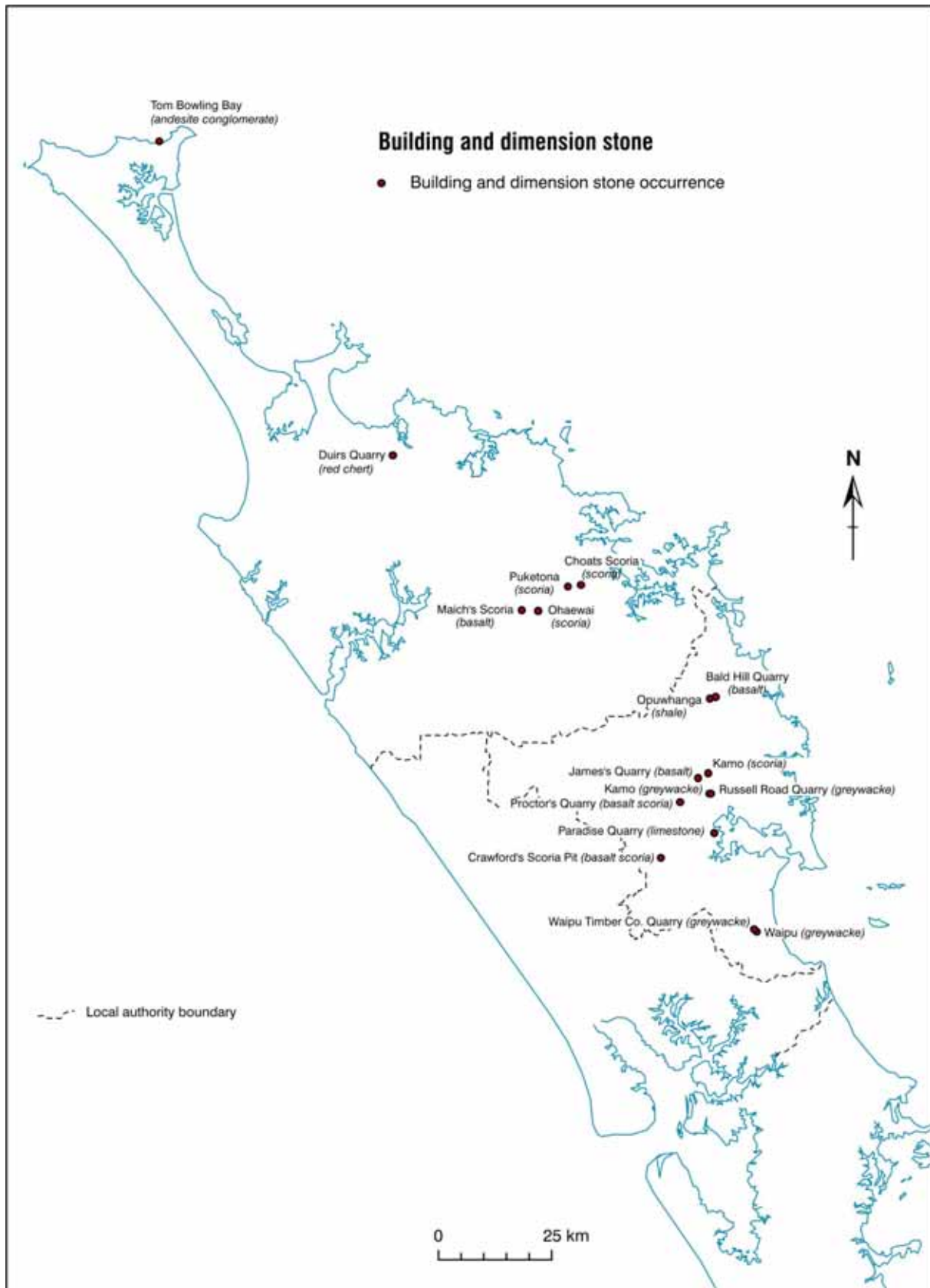


Figure 23. Location of building and dimension stone sites from the GERM database.

9.4 LIMESTONE

9.4.1 Northland deposits (Fig. 24)

There are two major and distinctive limestone units present in Northland, namely the crystalline Whangarei Limestone and the argillaceous Mahurangi Limestone. The Whangarei Limestone is Oligocene to Early Miocene in age and lies along the eastern side of Northland from the Bay of Islands to south of Whangarei. It is of shallow water origin, consisting mainly of bryozoan, echinoid and foraminiferal debris. The CaCO_3 content ranges from 75% to 95%. In general, it lies either directly on basement rocks or on the nearby coal measures. At Wilsonville quarry the deposit is gently dipping and up to 113 m thick.

The argillaceous micritic Mahurangi Limestone, of Eocene to Early Miocene age, lies within the Northland Allochthon and is widespread throughout Northland. It consists mainly of coccoliths and foraminifera of bathyal origin, and contains a significant clay fraction. The CaCO_3 content varies between 40% and 76%. Mahurangi Limestone deposits tend to occur as fault bounded blocks of varying size. The Portland deposit is one of the largest known, with at least two sheets juxtaposed by thrust faulting.

Limestone production in Northland is dominated, both in terms of quantity and value, by its use in the manufacture of cement at Golden Bay Cement Ltd's plant at Portland (Figs 24, 25 and 26; www.goldenbay.co.nz). Both Mahurangi and Whangarei limestones are used in the manufacture of cement and for agricultural fertiliser (Figs 4, 27 and 28). Mahurangi Limestone is quarried at Tikorangi Hill, Portland (Q07/e36; 70-80% CaCO_3) and supplies approximately 75% of the cement kiln raw feed. Whangarei Limestone is quarried at Wilsonville (Q06/e41; 90-95% CaCO_3), 20 km north of Whangarei, and is trucked to Portland. Mahurangi Limestone is also used as a road aggregate, especially in areas where other aggregate materials of better quality are scarce. Lime is used for binding in unsealed roads and in stabilisation of road aggregate. Argillaceous limestone is ideal for farm tracks, being less abrasive on the animals' hooves than most other hard rock aggregates. There are no burnt lime works in Northland, and all of the limestone produced and used for fertiliser is applied as crushed limestone, in some instances with other fertiliser additives.

The locations of the main limestone quarries are shown in Figure 24. Prominent quarry operations in argillaceous limestone, providing lime for agricultural use and for roading, include: Fairburn Lime (O04/e28), Paranui Lime (O04/e32), Oue Lime (O06/e1), Pokapu Lime (P05/e32), Wairoa Lime (P07/e25), Mata Lime (Q07/e41, also for industrial use), and Papanui Lime (Q08/e30). Other quarries include Borrow's Lime, Redvale Lime, and Te Hana Lime. Avoca Lime is the largest limestone producer in Northland, with three quarries averaging about 85,000 t per year. Ravensdown Fertiliser Co-op Ltd in Dargaville is the second largest producer, probably at about 40,000 t per year. Other producers include Bellingham Lime (Fairburn Lime and Otangaroa), and Collings (Paranui Lime).

Crushed shell from beaches has also been used for agricultural lime. Crushed shell deposits range from limited extent beach concentrations (O03/e3) to extensive inner harbour shell banks. Both Parengarenga (N02/e10) and Rangaunu Harbours have moderately extensive shell banks. Within the latter, the banks have a CaCO_3 content of up to 93% (Hay 1975; Petty 1982a). Shell beds within the dunes of Tokerau Beach (O03/e2) have been quarried, crushed and calcined to produce shell lime for direct application onto farmland.

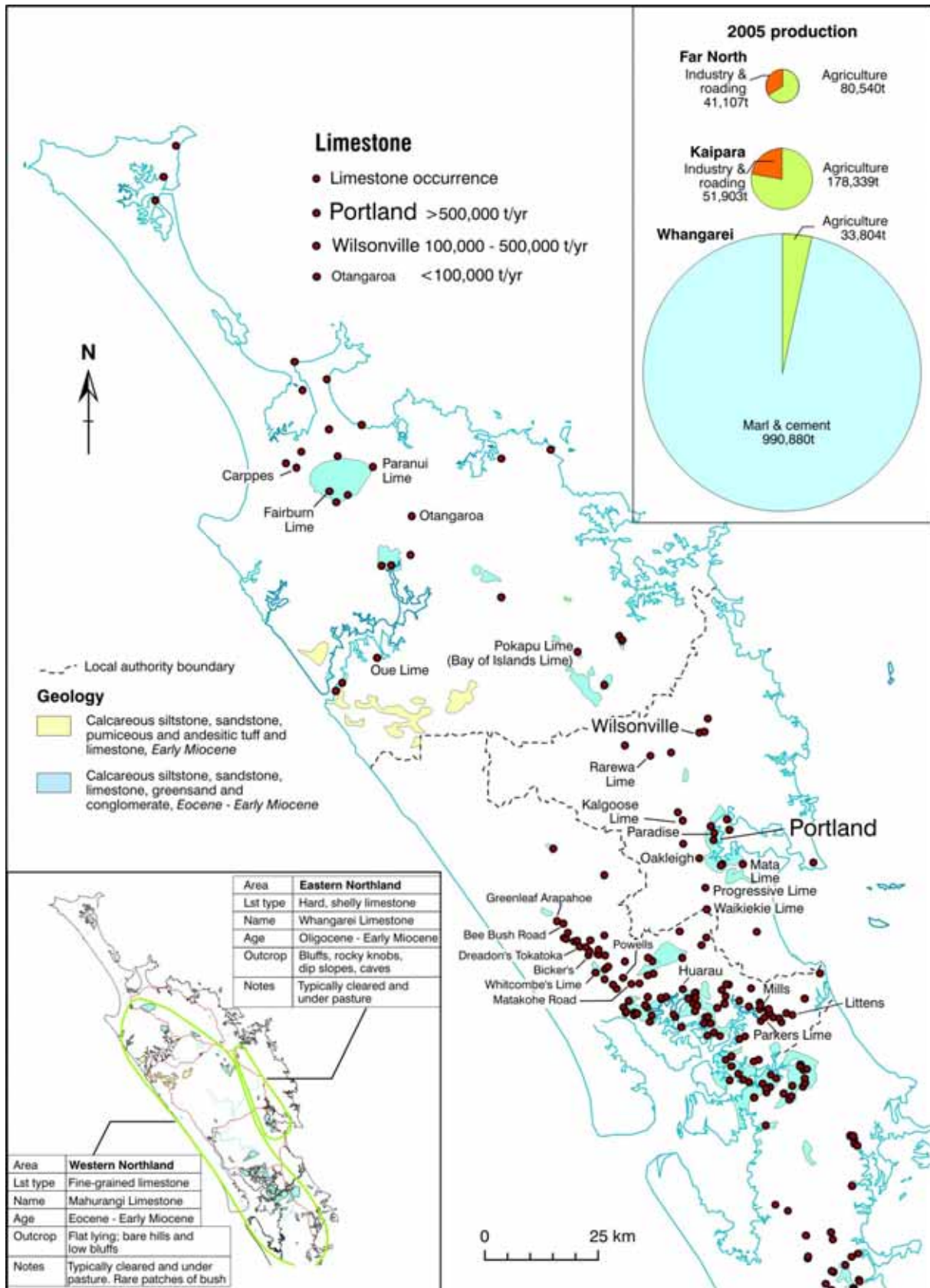


Figure 24. Location of limestone sites from the GERM database and areas of limestone from Turnbull & Smith Lyttle (1999). Inset graphs show the 2005 limestone production and end use for the three districts. The inset map shows the limestone types (after Turnbull & Smith Lyttle 1999).



Figure 25. Golden Bay Cement's limestone quarry and plant at Portland, 8 km south of Whangarei. The plant has an annual production capacity of 600,000 t. Cement is shipped to eight distribution centres throughout New Zealand and approximately 20% is exported to Tahiti and other Pacific Island countries. Photo: Lloyd Homer CN26655/12.



Figure 26. Portland limestone quarry (foreground) and plant (distance), with Whangarei Harbour in the background. Photo: Lloyd Homer CN26630/19.



Figure 27. Rarewa Lime plant operated by Avoca Lime. Photo: Tony Christie.

9.4.2 Future potential

Limestone demand will increase for use in cement manufacture, agriculture and roading. An increase in the demand for cement is expected because of increased infrastructure development and building in Northland, Auckland and other cement markets, related to increasing population and wealth. The current rate of application of lime as fertiliser on farms is considered well below optimum for pasture nutrition. There is considerable potential to increase this quantity, partly offset by the future decrease in the area of land under pasture because of housing developments. Increasing traffic movements on roads will require increased maintenance and demand for limestone where other suitable aggregate is unavailable. Similarly, there will be increased use of lime in stabilisation of road aggregate and to bind aggregate in unsealed roads.



Figure 28. Rarewa Lime quarry operated by Avoca Lime. Photo: Tony Christie.

10.0 COAL AND PEAT

10.1 SUB-BITUMINOUS – BITUMINOUS COAL

10.1.1 Northland deposits (Fig. 29)

In Northland, five small coalfields have produced about 7.3 million tonnes of coal between 1865 and 1982 (Fig. 29). There are no currently active mines. Exploration carried out by the New Zealand Coal Resources Survey (NZCRS) during 1982 and 1983 (Isaac 1985; Ankorn et al. 1988; Barry et al. 1994), included some drilling, resulted in the coal-in-ground resource estimates listed in Figure 29.

In the eastern coalfields, the coal occurs within the Eocene Kamo Coal Measures, which lie immediately west of, or in fault angle depressions within the basement Waipapa Group greywacke in a belt between Kawakawa and Waipu. The coal measures are absent from many areas, either because of non-deposition due to basement paleorelief, or erosion prior to deposition of the overlying Ruatangata Sandstone (Isaac 1985).

The Kamo Coal Measures range from 5 to 100 m in thickness and contain mudstone, fireclay, minor sandstone, and one or more coal seams up to 5 m in thickness. The coals are sub-bituminous to marginally bituminous, and analyses indicate that they are low in moisture and high in sulphur.

The Avoca Coalfield is an isolated, displaced block incorporated within the Northland Allochthon, and is older, with coal of lower rank than the coals of eastern Northland (Hayward et al. 1989). The coal is of sub-bituminous C rank, with a low ash and medium sulphur content.

10.1.2 Post-1980 exploration (Isaac 1985)

Kawakawa Coalfield

The NZCRS drilled one hole north of the Kawakawa Fault (d79) and two holes (d78, d81) south of the fault to try to determine if the Kawakawa Coalfield extends to the west. No coal measures were encountered in the drillhole north of the fault. South of the fault, coal measures were encountered (10.2 m thick), but did not contain coal. The conclusion was that there is little prospect of discovering a deposit of one million tonnes or more of coal either west or north of the old field (Isaac 1985).

Hikurangi Coalfield

Exploration by the NZCRS involved drilling northwest of Hikurangi township. A hole drilled on the margin of the Hikurangi swamp (d74) encountered two discrete intervals of coal measures separated by the Ruatangata Sandstone. The coal measures contain thin coal seams and coaly shale, but no workable coal. Hole d82, drilled to determine if the coal measures persist beneath the northern part of the swamp, did not intersect coal measures. Three holes drilled in the southern Hikurangi Swamp (d73, d75, d80) reached basement, but the coal measures were not present.

The most recent investigations were carried out for Golden Bay Cement by Applied Geology Associates Ltd (Miller 1988; Anon 1989a). A review of existing data, geological mapping, and a six-hole drilling programme were conducted. Two areas containing potentially opencastable coal in and adjacent to old underground workings were defined, with 50,000 to 0,000 t in an area adjacent to the railway and 0.5 to 0.8 Mt under the Hikurangi golf course,

which is located in the eastern part of the coalfield. In both areas, overburden is 5 to 20 m thick, and the coal seam up to 3.6 m thick.

Barry et al. (1994) noted that a previously unmined area to the northeast of the old workings, could contain 3.3 Mt (hypothetical), in a seam up to 3.5 m thick and at depths of 5 to 50 m. Isaac (1982) inferred that a further area between Waro coal mines and the basement outcrop could contain 0.4 Mt of coal.

The high sulphur content (3-6%) made Hikurangi coal unacceptable for use at the Portland cement factory.

Kamo Coalfield

Kear (1959a) estimated that 1 Mt of coal remains in the pillars of old mines, and 0.7 Mt remains in the flooded New Kamo No. 3 mine.

The NZCRS hole d72 was drilled approximately midway between the small workings at Ketenikau and Hakanoa. It found 1.2 m of coal in 3 m of coal measures beneath 67 m of water-bearing basalt. It is probable that the coal measures lie at depth beneath Whangarei City to the south of the Kamo area.

Kiripaka Coalfield (including Whareroa)

NZCRS hole d71 was drilled in the northwest of the Whareroa depression. The only coal measures located were several metres of carbonaceous sandstone. Some subsequent drilling has been carried out (Anon 1981; Costello 1989). Substantial amounts of coal were reported in and around the old workings, but no estimates of quantities are available.

Avoca Coalfield (P07/e31)

The Avoca coalfield represents a small, structurally complex remnant of coal overlain by limestone, within the Northland Allochthon. It is older, with coal of lower rank than the coals of eastern Northland (Raine 1982; Hayward et al 1989). A single near-vertical, discontinuous seam 2 to 9 m thick was worked. The coal is of sub-bituminous C rank, with a low ash and medium sulphur content. The extent of the coal is unknown, but probably small (Kear 1959; Schofield 1974; Isaac 1982).

Other Areas

Coal seams less than 12 cm thick occur within an overall 35 m thick rhythmically bedded Early Miocene sequence on the northern shore of the Parengarenga Harbour entrance (N02/e16). At present only some of the carbonaceous mudstones can be seen in the bank above the beach. The rest of the outcrop is covered by beach sand.

Small discontinuous patches of coal measures occur up to 40 km south of Whangarei City and a small quantity of coal was mined near Waipu. Prospects are poor (Isaac 1985).

10.1.3 Future potential

Resources and values listed in Figure 29 total 23 Mt of sub-bituminous – bituminous coal valued at \$1,150 million using the maximum estimates from Barry et al. (1994). Given the large resources of coal in the Waikato it is unlikely that Northland coals will be utilised on a significant scale in the near future. However, establishment of a new local industry that could utilise coal may provide the impetus to develop one or more of Northland's coalfields, although the high sulphur content will always be a problem for utilisation.

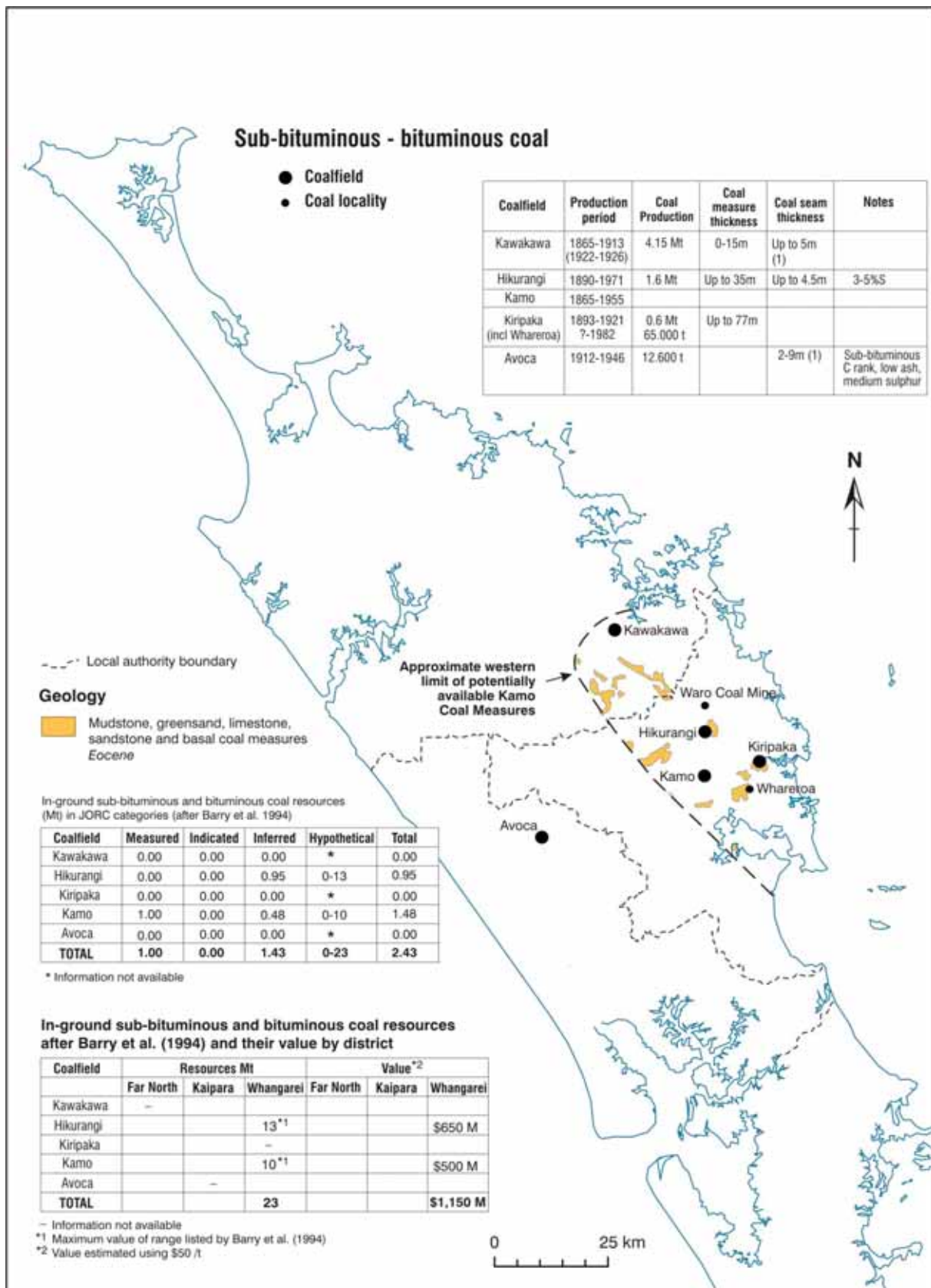


Figure 29. Location of Sub-bituminous – bituminous coal sites from the GERM database and areas of coal bearing formations.

10.2 LIGNITE

10.2.1 Northland deposits (Fig. 30)

Lignite (brown coal) occurs as seams interbedded with the Pliocene and Pleistocene sand-dominated beds of the Aupouri Peninsula and North Kaipara Barrier (Hay 1981, 1983; Edbrooke 1995a; Isaac 1996). The deposits are lenticular and mostly less than 3 m thick, although lignite up to 8 m thick has been encountered in water bores drilled in the Sweetwater area, southern Aupouri Peninsula (Isaac 1996). The lignite seams probably originated as river valley peat swamps parallel and behind the dune belt, and as dune-dammed lakes (Sherwood & Schofield 1985) and interdune lakes. Estimates of coal-in-ground by Sherwood & Schofield (1985) were 12 Mt of lignite in the Aupouri Peninsula and 19.2 Mt for the coastal section including North Kaipara Barrier (Fig. 30). The deposits are covered with a soft sand or clayey sand overburden with high overburden:lignite ratios of up to 25:1. The lignites are little altered from the original peats. They are of low rank and have a high moisture content, in excess of 63%. However, deposits with low overburden ratios could be used locally as a source of fuel.

Northpower Ltd drilled 10 holes in the Sweetwater lignite prospect and estimated a total resource of 16.9 Mt of lignite within the prospect, but only 6.9 Mt of this is in a seam greater than 2 m thick, with a cover to lignite ration of less than 10:1 (Edbrooke 1997). The lignite is a high moisture coal of ASTM Lignite B rank, with a low to moderate ash content and low to medium sulphur content.

10.2.2 Future potential

Resources and values listed in Figure 30 total 31 Mt of lignite valued at \$620 million using the maximum estimates from Barry et al. (1994).

10.3 PEAT

10.3.1 Northland deposits (Fig 31)

Large areas of surface peat are present on the Aupouri Tombolo, near the west coast between Sweetwater and Ahipara, and on the east coast between Motutangi and Kaimaumau.

Surface peat south of Sweetwater (O04/e34) covers some 56 km² between the coastal sand dunes of Ninety Mile Beach and Kaitaia in the east (Edbrooke 1997). The peat is up to 10 m thick and averages about 5 m thick. It is classified as mesotrophic with some oligotrophic characteristics. Davoren (1978) estimated a resource of 285 M m³ of peat.

The Motutangi-Kaimaumau deposit covers an area of about 30 km² and is up to 6 m thick. In 1974, Kauri Deposit Surveys Ltd was formed to extract resins and waxes from the peat (see Kauri gum section). A resources of about 15 M m³ of peat was estimated.

Four small deposits (less than 5 m thick) of peat occur in the Hikurangi area (P07/e31) and peat also occurs in the old Ngawha Lake beds (P05/e55) extending over 5.3 hectares and averaging 4 m in thickness (Bell & Clarke 1909). It is possible that more peat deposits could be found within areas of alluvium.

10.3.2 Future potential

Resources and values listed in Figure 31 total 300 Mm³ of peat valued at \$12,000 million. No estimate is made for the Ngawha and Hikurangi deposits.

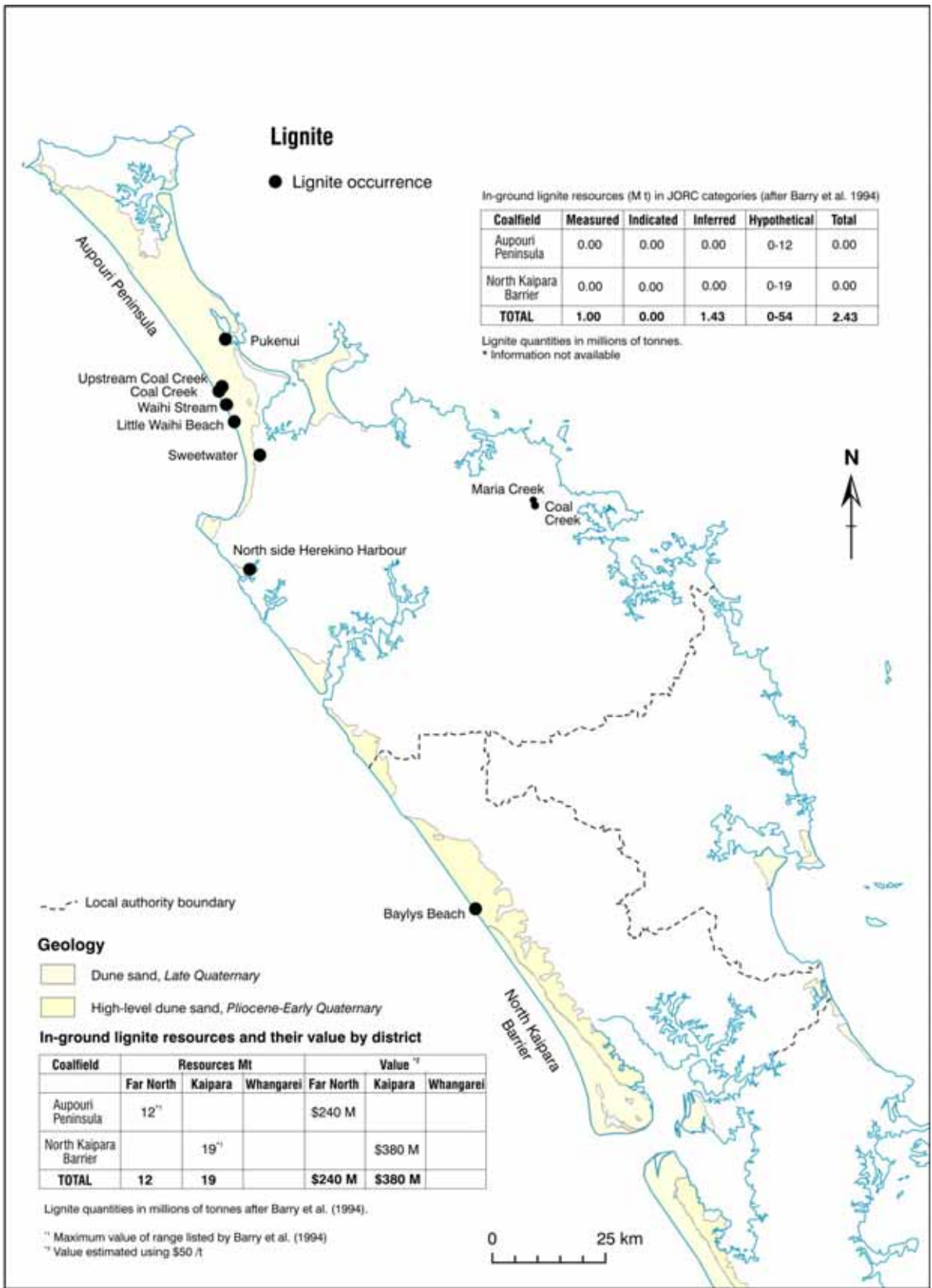


Figure 30. Location of lignite sites from the GERM database and areas of lignite bearing formations.

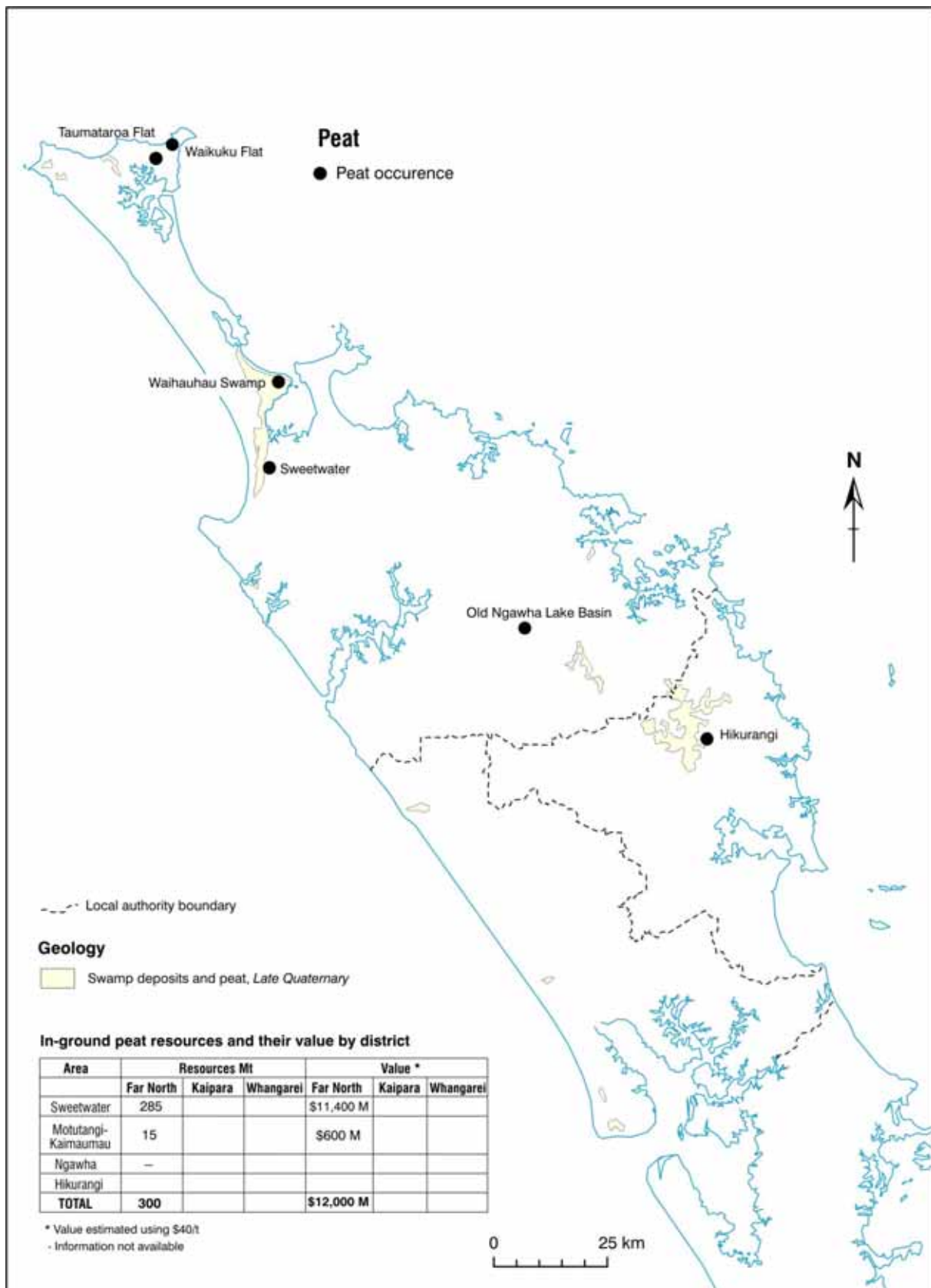


Figure 31. Location of peat sites from the GERM database and areas of peat bearing formations.

11.0 MINERAL RESOURCE ASSESSMENT OF METALLIC AND INDUSTRIAL MINERALS

11.1 ASSESSMENT METHOD

For metallic and industrial minerals, mineral resource assessment has been carried out using a three step process (Fig. 5) established by the US Geological Survey (USGS) that is based on the principle of conceptual models of selected mineral deposit types (Singer & Mosier 1981; Sangster 1983; Cox 1993; Singer 1993; Grunsky et al. 1994). In this method, descriptive and genetic models are assembled for each mineral deposit type (see below). In the second step, the models are then compared with the geology of the area being assessed and estimates of resources are made. In the third step, the amount of metal and some characteristics of ore are estimated by means of grade-tonnage models.

Two methods have been used for the estimates in Step 2. The first method is an estimate on the probability of economic resources in individual known prospects, the "counting method" of Cox (1993) and Singer (1993). This is accomplished by making a percentage estimate of the probability that a specific deposit contains the average tonnage and grade for the relevant mineral deposit model. The second method is an estimate of the percentage probability of the occurrence of an as yet undiscovered economic deposit of a specific type, given knowledge of the local geology, local past production from this type of deposit, mineral exploration data and mineral deposit models. The percentages from the two parts are summed and used as a multiplying factor for the tonnage of an average deposit of this type, using both local (where available) and world mineral deposit grade and tonnage models. The resulting figures are then translated to the weight of contained metal or processed mineral and assigned a dollar value based on published commodity prices.

11.2 MINERAL DEPOSIT MODELS

Mineral deposit models (e.g. Cox & Singer 1986; Kirkam et al. 1993; Eckstrand et al. 1995; Lefebure & Ray 1995; Lefebure & Höy 1996) describe the essential geological and geochemical attributes that are common to a number of similar mineral deposits that are presumed to have been formed by the same genetic process. The main attributes used in classifying a mineral deposit type are: tectonic setting, structural controls, host rock lithology, form of the deposit, main economic elements or minerals, mineralogy of ore and host rocks, and geochemical and geophysical characteristics. We have used mainly the USGS and British Columbia Geological Survey (BCGS) mineral deposit models as sources of information for our international models.

Deposit models are linked to grade-tonnage models, which show the range of grade and tonnage of different deposits of a specific type and derive statistical parameters such as the average grade and tonnage (Cox & Singer 1986). Grade-tonnage models are compiled from pre-mining resource estimates or from production figures for mined-out deposits. These figures vary according to mining conditions (e.g. mining method used) and economic factors (e.g. metal prices), but the conditions and factors are reasonably consistent for production figures from the same district or region over specific periods of mining activity.

12.0 METALLIC MINERAL DEPOSITS

12.1 ALUMINIUM

12.1.1 Laterite bauxite type aluminium deposits (Fig. 32)

12.1.1.1 *International model*

Reference

USGS model 38b Laterite type bauxite (Cox & Singer 1986)

Description

Bauxite is residual material in subsoil formed by weathering of aluminous silicate rocks under tropical or semitropical conditions. It consists mainly of gibbsite or a mixture of gibbsite and boehmite in a gangue mineral assemblage of hematite, goethite, anatase, and locally quartz. Ore textures are pisolitic, massive, earthy and nodular. A typical bauxite contains 35-65% Al_2O_3 , 2-10% SiO_2 , 2-10% Fe_2O_3 , 1-3% TiO_2 , and 10-30% combined water. For aluminium ore, bauxite should contain preferably at least 35% Al_2O_3 and less than 5% SiO_2 , 6% Fe_2O_3 , and 3% TiO_2 .

International examples

Jamaica; Surinam; Weipa, Jarrahdale, Coore and Mitchell Plateau in Australia; Georgia-Alabama, USA

Grade-tonnage data

USGS model 38b 50th percentile = 25 Mt at 45% Al_2O_3 (Cox & Singer 1986, pp. 255-257).

12.1.1.2 *Northland deposits*

Bauxite deposits are found in Northland, within a triangular area between Kerikeri, Kaikohe, and Kaeo (Fig. 32; P04/e18, 19, 26, 41, 42, 43). Late Miocene to Early Pleistocene Kerikeri Basalt has been extensively altered to halloysite and where rainfall and leaching has been sufficient, gibbsite (bauxite) has been produced from the halloysite (Carr et al. 1980). At Otoroa (Matauri Bay area), where the largest resources are known, the average thickness of the gibbsite-rich profiles is between 3 m and 4.6 m, and the maximum thickness is 12 m.

Prospecting and research by DSIR (Kear 1959, 1960; Swindale 1959a, 1959b; Kear et al. 1960a, 1960b; Waterhouse 1960) resulted in a resource estimate for the Otoroa area of 20 Mt of bauxite typically grading 37.4 % Al_2O_3 (equivalent to 30.6% extractable alumina), 5.5% SiO_2 , 23.3% Fe_2O_3 , 2.3% FeO , and 6.4% TiO_2 (Kear et al. 1960b). Additional auger drilling by Comalco/Consolidated Zinc (Warren 1961; Berkman 1961, 1962; Consolidated Zinc 1961; Evans 1963), and later Magellan (Manix 1971; Rolston 1971a, 1971b; Pearson 1973), confirmed the DSIR resource estimate of the Otoroa deposit and identified another 15 small deposits nearby, collectively containing about 9.25 Mt of bauxite with 30% alumina or better. The largest of these deposits contained about 2.4 Mt.

12.1.1.3 *Potential*

Previously estimated resources for the Kerikeri-Kaikohe-Kaeo area are 30 Mt of bauxite at 30 % Al_2O_3 (alumina). Beneficiation tests showed that the Otoroa bauxite could be upgraded from 30% extractable alumina to approximately 44% by wet screening, but this increase in grade was coupled with a more than 40% reduction in the tonnage of the alumina resource, to about 8 Mt Al_2O_3 (Fig. 32). The area of this resource is only a very small part of the total area of young basalt (Fig. 32) and therefore there is likely to be some additional potential, but this is not quantified here.

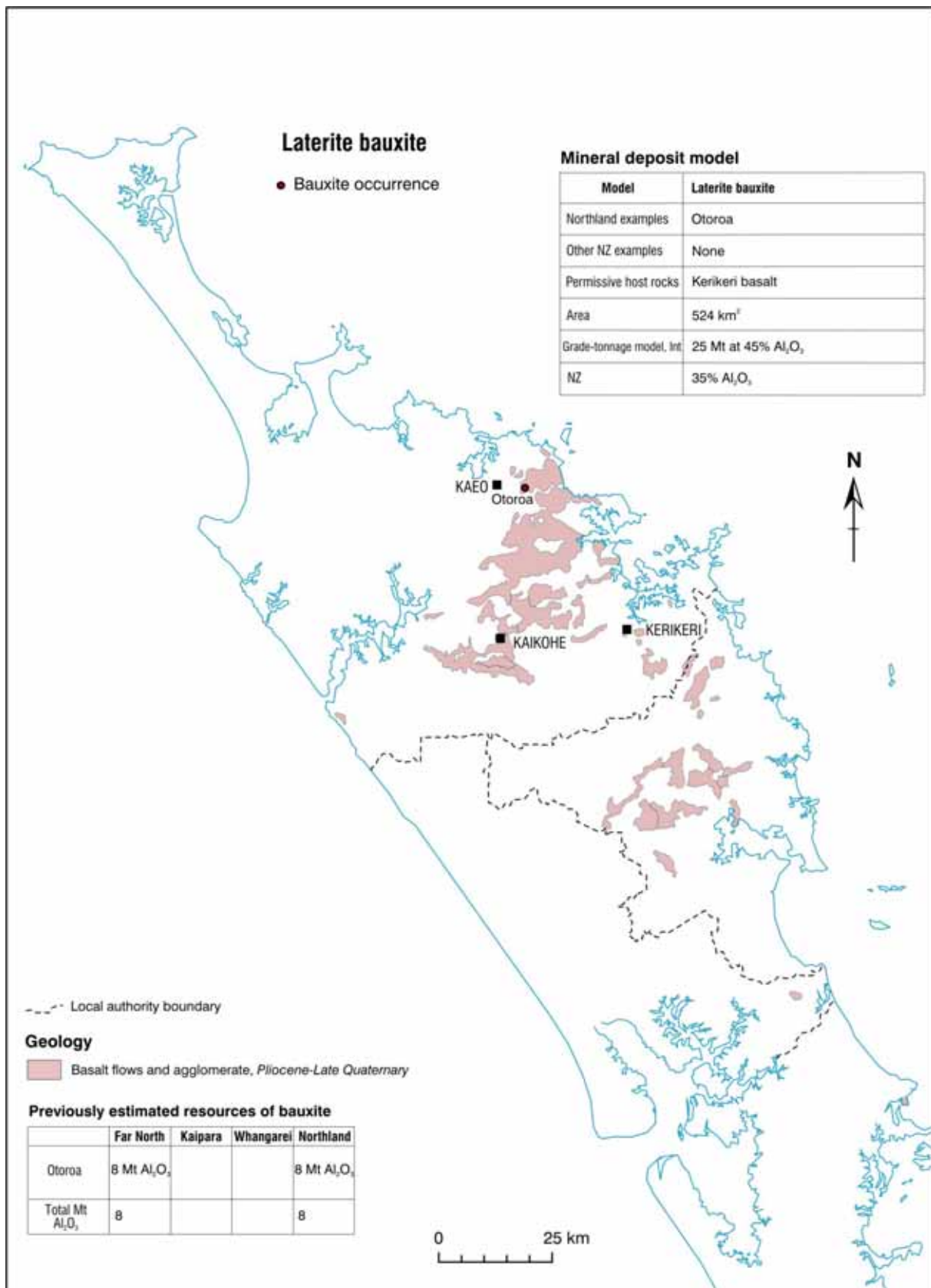


Figure 32. Areas of basalt that may be prospective host rocks for laterite bauxite deposits. The bauxite deposits are mostly found in the triangular area between Kaeo, Kaikohe and Kerikeri.

12.2 ANTIMONY

12.2.1 Hot spring Sb-As type antimony deposits (Fig. 33)

12.2.1.1 Model

Description

Quartz veins and sinters formed at the surface and in the near surface environments of epithermal systems. They are hosted in volcanic and sedimentary rocks and contain stibnite, pyrite and cinnabar.

Grade-tonnage data

There is no well-documented international model so we have assigned a tonnage of 4000 t contained Sb.

12.2.1.2 Northland deposits

At Rangitaroe Hill (Lanigan's Mine; Q05/e13; Fig. 33), 10 km southeast of Russell, stibnite is found within a 3 m wide silicified crush zone, dipping 80° SW, in Waipapa Group greywacke (Ferrar 1925). The deposit was first mined in 1907 and 115 t of ore, at an average grade of 50-60% Sb, was extracted and exported. Fricker (1970) reported analyses of up to 40% Sb and 0.51% Hg in samples taken from the lode.

At Puhipuhi (Q06/e70), radiating aggregates of acicular stibnite occur in sinter and silicified greywacke associated with mercury deposits (see description of Puhipuhi in the section on Mercury). At Ngawha (P05/e56), minor stibnite is associated with mercury in Pleistocene lake sediments and is related to the active Ngawha geothermal system.

Exploration has found hydrothermal breccia dikes and quartz veins with geochemically anomalous As, Sb, Au (up to 1.35 ppm), and Ag (up to 16 ppm) in the Waikare River area, 7-10 km north of Puhipuhi (Bell 1983; Corner 1983; McDonald 1984). This mineralisation is also hosted in greywacke, and it is probably broadly contemporaneous with the mineralisation at Puhipuhi.

Stibnite and cinnabar have been reported at Takahue Prospect (O05), and exploration by Pacminex (Neuss 1972a) located disseminated stockwork pyrite, and defined a Cu geochemical anomaly.

12.2.1.3 Potential

Given past mining of antimony in Northland, several known occurrences and a relatively large area of potential host rocks, we consider there is good potential for the presence of a deposit of the model size and have divided this equally between Far North and Whangarei districts (Fig. 33). We consider that the known deposits have a 5% probability of containing the model's quantity of antimony.

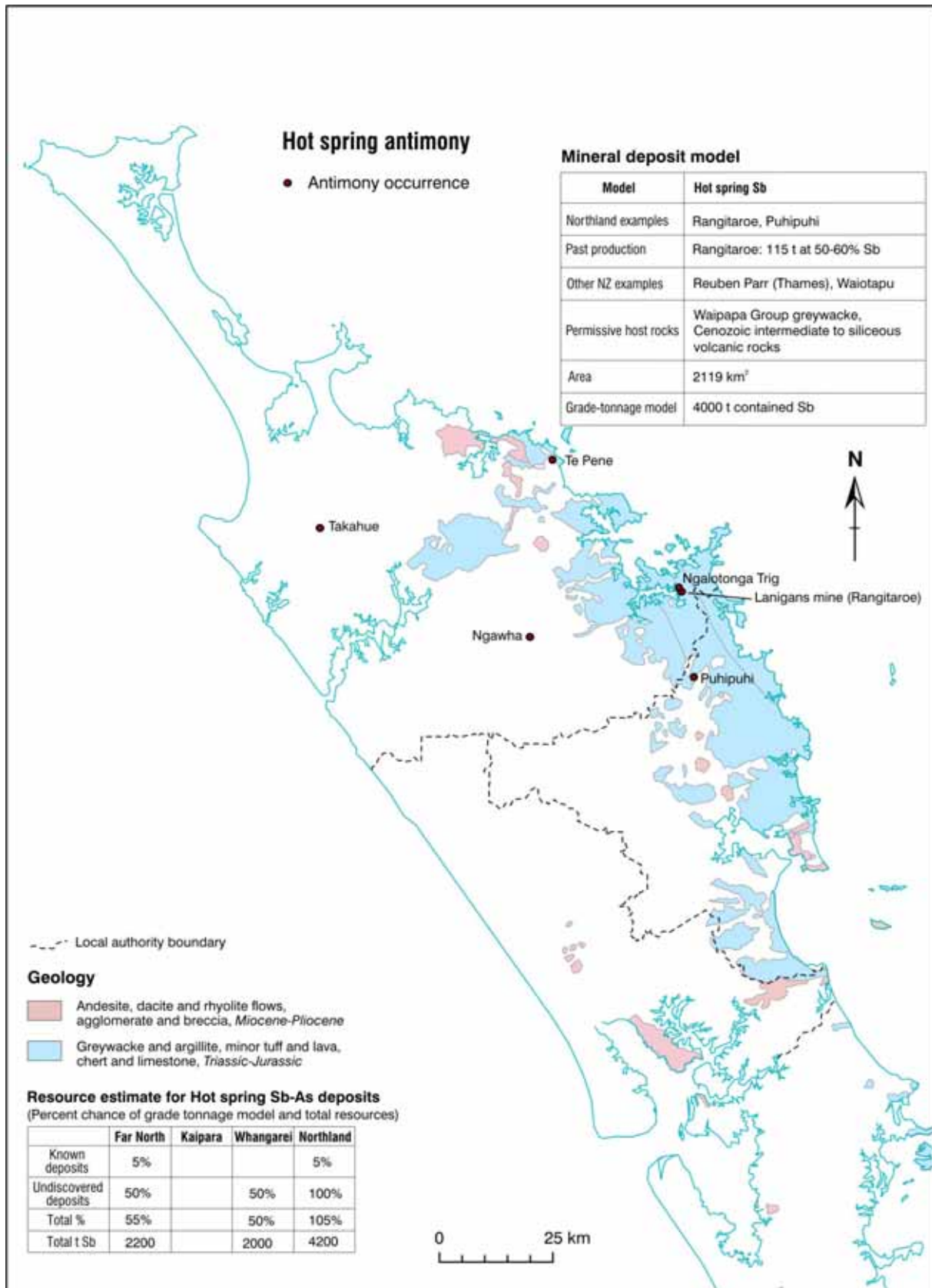


Figure 33. Location of antimony sites from the GERM database and areas of greywacke and volcanic rocks prospective for hot spring Sb-As deposits.

12.3 CHROMIUM

12.3.1 Podiform chromite type chromium deposits (Fig. 34)

12.3.1.1 *International model*

References

USGS model 8a Podiform chromite (Cox & Singer 1986) and BCGS model M03 Podiform chromite (Lefebure & Höy 1996)

Description

Deposits of massive chromitite occur as pods, tabular lenses or layers within ophiolitic ultramafic rocks. The deposits are formed as a primary magmatic differentiate during early olivine and chrome-spinel crystal fractionation of basaltic liquid at an oceanic spreading centre. The host rocks represent obducted fragments of oceanic, lower crustal and upper mantle ultramafic rocks within accreted oceanic terranes.

International examples

Guleman ore field, Turkey; Kalimash - Kukes-Tropoje district, Bulquize and Todo Manco - Bater-Martanesh district (Mirdita ophiolite), Albania; Tiébaghi ophiolite and Massif du Sud, New Caledonia; Acoje and Masinloc-Coto (Zambales range/ophiolite), Luzon, Phillipines; Batamshinsk, Stepninsk, Tagashaisai and Main SE ore fields (Kempirsai massif), Southern Urals, Russia; Xeraivado and Skoumtsa mines (Vourinos ophiolite), Greece; Semail ophiolite, Oman; Luobusa, Donqiao, Sartohay, Yushi, Solun, Wudu and Hegenshan deposits, China.

Grade and tonnage

Grades range from 20 to 60% Cr₂O₃ and tonnages range from several thousand tonnes to several million tonnes. USGS model 8a 50th percentile = 20,000 t at 46% Cr₂O₃ (Cox & Singer 1986, pp. 43).

12.3.1.2 *Northland deposits*

Minor disseminated chromite is found in serpentinite at Surville Cliffs (N02/e18; Fig. 34) and detrital chromite occurs in the Waikuku Flat alluvial deposits (N02/e19). Bennett (1976) noted that the cumulate harzburgite-lherzolite zone of the Murimotu Intrusives contains disseminated chromite and a possible underlying tectonite harzburgite zone with podiform chromite could lie offshore.

12.3.1.3 *Potential*

We consider that there is a small probability (0.5%) of a deposit onshore at Surville Cliffs (Fig. 34). We have also assigned an 0.5% probability of the model size for undiscovered deposits in the Far North district, the low probability reflecting the apparent scarcity of suitable intrusive host rocks.

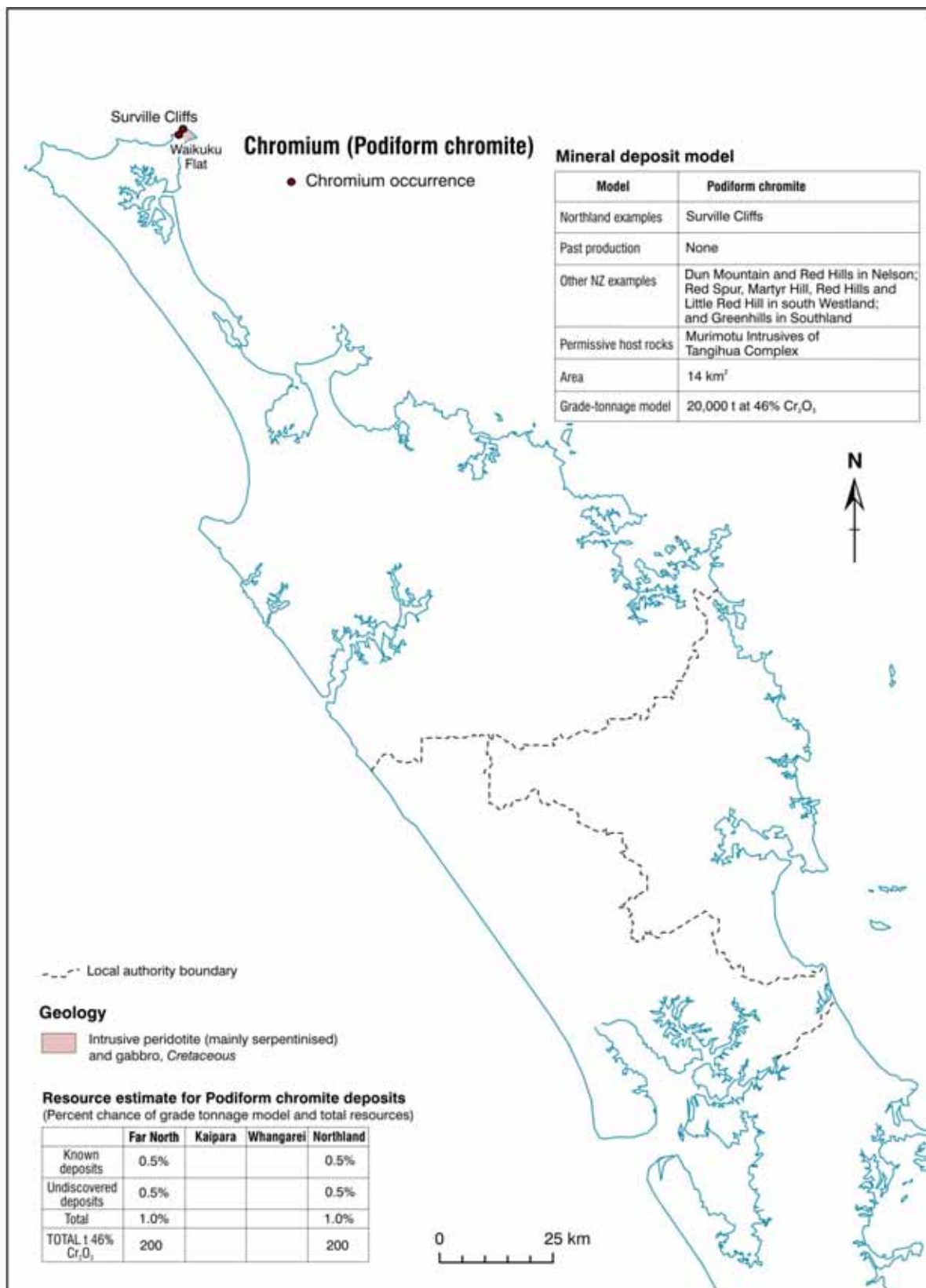


Figure 34. Location of chromium sites from the GERM database and areas of mafic intrusive rocks prospective for podiform chromite deposits.

12.4 COPPER

12.4.1 Cyprus VMS Cu type copper deposits (Fig. 35)

12.4.1.1 *International model*

References

USGS model 24a Cyprus massive sulphide (Cox & Singer 1986) and BCGS model G05 Cyprus massive sulphide Cu (Zn) (Lefebure & Ray 1995).

Description

Sea-floor deposition of sulphide mounds contemporaneous with mafic volcanism, such as spreading ridges and back-arc basins. Deposits typically comprise one or more lenses of massive pyrite and chalcopyrite hosted by mafic volcanic rocks and underlain by a well developed pipe-shaped stockwork zone. Lenses commonly are in tholeiitic or calcalkaline marine basalts, commonly pillowed, near a transition with overlying argillaceous sediments. Many lenses appear to be structurally controlled, aligned near steep normal faults. The main minerals are pyrite, chalcopyrite, magnetite and sphalerite, with lesser marcasite, galena, pyrrotite, cubanite, stannite-besterite and hematite, in a gangue mineral assemblage of talc, chert, magnetite and chlorite.

International examples

Cyprus; York Harbour and Betts Cove, Newfoundland, Canada; Turner-Albright, USA; Lokken, Norway.

Grade-tonnage data

USGS model 24a 50th percentile = 1.6 Mt at 1.7% Cu, possible byproduct Ag, Au, Pb and/or Zn (0-33 g/t Ag; 0-1.9 g/t Au, 0-2.1 % Zn) (Cox & Singer 1986, pp. 131-135). See also Lefebure & Höy (1996, pp. 130-131) for BCGS model G05.

12.4.1.2 *Northland deposits*

Copper occurs in volcanogenic massive sulphide deposits hosted in the Cretaceous Tangihua Complex (basalt, dolerite and gabbro) (Fig. 35). The mineralisation occurs as stratiform lenses of pyrite, chalcopyrite and sphalerite at the contact of, or within, mudstone and claystone interbedded with, or in close proximity to, the volcanic rocks (Mason 1973; Mason & Kobe 1989).

Pupuke (P04/e30)

The Pupuke deposit consists of small, irregular, tectonically disturbed lensoidal bodies of cupriferous sulphide, enclosed in soft claystone and sandstone in close proximity to dolerite and basalt. Copper was first discovered in the area in 1892 and prospecting continued until 1910. The deposit was worked by the Hare-Ratjen Company, producing 133 tonnes of ore from which 12 tonnes of concentrate were shipped to Sydney. Some prospecting and mining of small quantities of ore was carried out by Hazelbrook Mines from 1964-1968 with assistance from DSIR (Bowen 1963a, 1965b). Licence (1989) reported up to 0.9 g/t Au in grab samples of massive sulphide ore.

Pakotai Deposit (P06/e23, e24, e25)

The Pakotai deposit is hosted in mudstone in fault contact with volcanic rocks. It was discovered in 1944 and has produced a total of 1,381 tonnes of copper ore. Assays of the ore shipped overseas averaged 12.7% Cu, 57 g/t Ag and 5.8 g/t Au (Hay 1960). Geological,

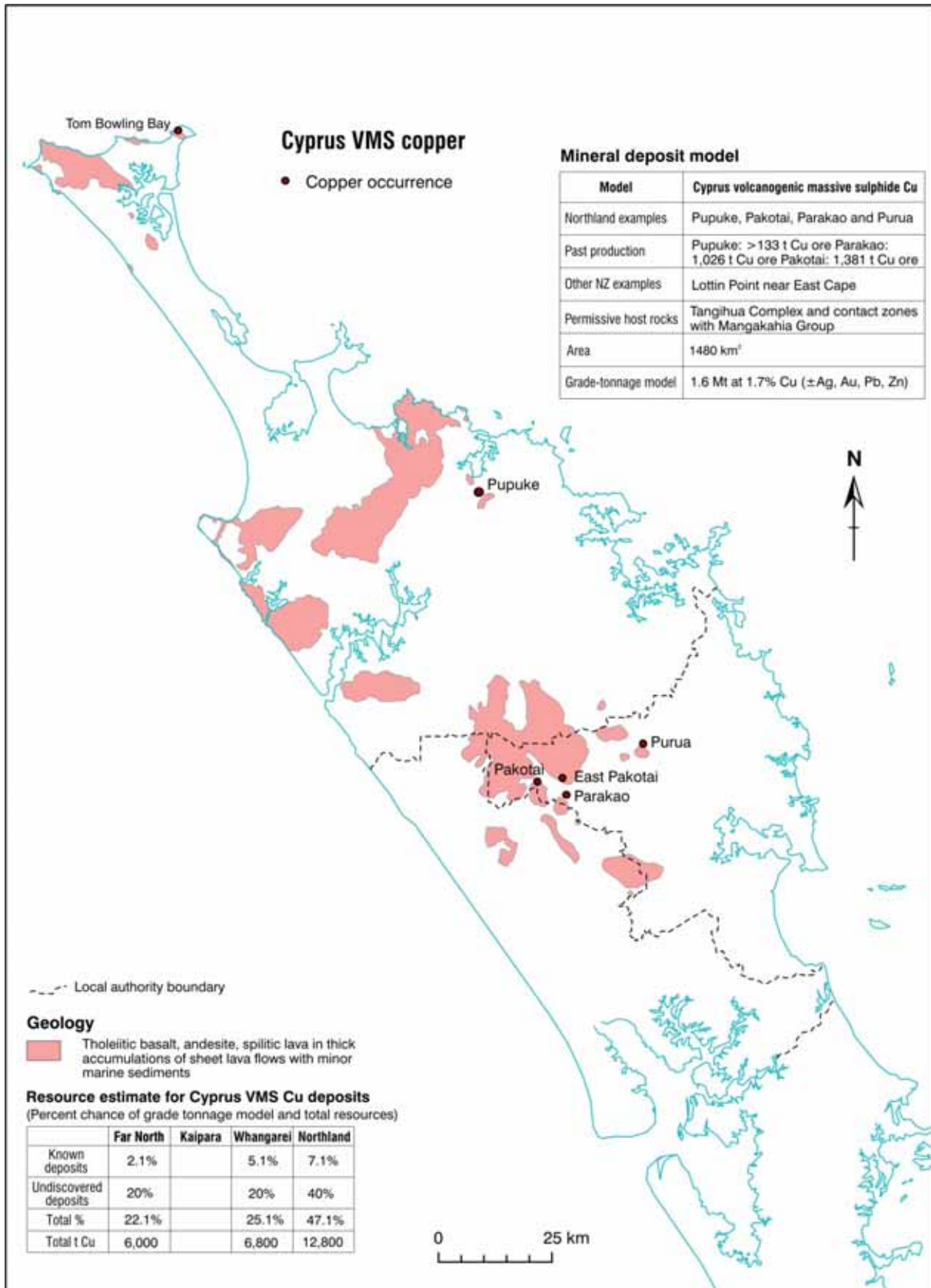


Figure 35. Location of Cyprus volcanogenic massive sulphide Cu sites from the GERM database and areas of Tangihua Complex rocks that are prospective host rocks.

geophysical and geochemical surveys followed by trenching and shallow diamond drilling showed that the sulphide bodies are discontinuous lenses (Landreth et al. 1947; Robertson 1948; Clifton 1972; Pirajno 1979). Licence (1989) reported assays up to 21.5 g/t Au in grab samples of massive sulphide.

Parakao deposit (P07/e20, Copper Queen mine)

The Parakao deposit was worked in 1962-63 from the zone of oxidation and secondary enrichment, and produced 1026 tonnes of copper ore (Rowe 1963). The orebody has a lenticular shape and extends to only shallow depth. Licence (1989) reported assays of 5.1-19.5 g/t Au for three grab samples of massive sulphide.

Purua (Q06/e117)

The Purua prospect was discovered by Adaras Developments Ltd in 1971 with a soil geochemical survey, following up a weak stream sediment anomaly. Additional soil surveys, geophysical surveys, trenching and drilling of five diamond holes totalling 125 m were carried out by Adaras Developments Ltd (Bell 1971a, 1972, 1973b, 1974) and Strategic Exploration Ltd (Bell 1978, 1979). Oxidised copper mineralisation occurs as disseminations and stringers in a 5 m thick porphyritic pyroxene basalt band within a sequence of basalt flows. It consists of malachite, azurite, chalcopyrite, various copper oxides and magnetite. The drill core assayed up to 2.1% Cu (Bell 1974), whereas channel samples of trenches collected by Strategic Exploration Ltd returned assays up to 3.5% Cu (Bell 1978).

Others

Geochemical sampling by Magellan (Bailey 1971) revealed a Ni-Cu geochemical anomaly in an extensively altered and faulted area at Tangihua (O04). Further geochemical sampling was recommended. Layton and Associates (1971a, 1971b) outlined areas considered to be geologically favourable for copper mineralisation at Herekino (NO5, O05), and in the Mangamuka Range (O05), but no geochemical sampling was undertaken. Rock and stream sediment sampling by Pacminex (Pty) Limited (Neuss 1972c, 1972d) revealed several Cu-Pb-Zn geochemical anomalies and one Ni anomaly at Reef Point (NO4, NO5, O04, O05). Further sampling by Pacminex (McNamara 1972) identified malachite, pyrite and chalcopyrite in quartz veins in the Whirinaki-Waima State Forest (O06).

12.4.1.3 Potential

Past mining of copper from these types of deposits and a fairly large area of prospective host rocks in Northland suggests that there is a good chance of additional discoveries, mainly in the Far North and Whangarei districts. However, the known deposits are very small and hence the conservative estimates in Figure 35 in expressing the potential in terms of the model size. The main exploration interest is in their gold content, which has not been quantified.

12.4.2 Besshi VMS Cu type copper deposits (Fig. 36)

12.4.2.1 International model

References

USGS model 24a Besshi massive sulphide (Cox & Singer 1986) and BCGS model G04 Besshi massive sulphide Zn-Cu-Pb (Lefebure & Ray 1995).

Description

Thin, sheet like bodies of massive to well-laminated pyrite, pyrrhotite, and chalcopyrite within thinly laminated clastic sediments and marine volcanic rocks; basaltic tuffs and flows, shale and siltstone, commonly calcareous; less commonly chert and iron formations. The deposits represent seafloor deposition of sulphide mounds in back-arc basins, or several other tectonic settings, contemporaneous with volcanism.

International examples

Besshi and Motoyasu, Japan; Greens Creek, Alaska, USA; Kieslager, Austria; Raul, Peru.

Grade-tonnage data

USGS model 24a 50th percentile = 0.22 Mt at 1.5% Cu, possible byproduct Ag, Au and/or Zn (2-9 g/t Ag, and 0.4-2% Zn) (Cox & Singer 1986, pp. 136-138). See also Lefebure & Höy (1996, pp. 128-129) for BCGS model G04.

12.4.2.2 Northland deposits

There are no known examples in Northland, However, Volcanogenic massive sulphide deposits associated with volcanic rocks in the basement greywacke are found in several locations elsewhere in New Zealand, including Kawau Island in the North Auckland region (Fig. 36).

12.4.2.1 Potential

We consider that undiscovered Besshi type volcanogenic massive sulphide deposits are present in Northland and have assigned a 10% probability of the model size, split equally between the Far North and Whangarei districts, based on their similar area of potential host rocks (Fig. 36).

12.4.3 Porphyry Cu type copper deposits (Fig. 37)

12.4.3.1 International model

References

USGS model 17 Porphyry copper (Cox & Singer 1986) and BCGS model L04 Porphyry Cu±Mo±Au (Lefebure & Ray 1995).

Description

Quartz vein stockwork and disseminated Cu±Au±Mo mineralisation in potassic altered dacitic or quartz diorite porphyry intrusive into andesite-dacite lavas and breccias, and greywacke basement rocks. The main metallic minerals are chalcopyrite and pyrite, with local bornite and magnetite.

International examples

Ray, Kalamazoo and Santa Rita (Arizona), Bingham (Utah), Chuquicamata, La Escondida, El Salvador (Chile), and Panguna (Bougainville, PNG)

Grade-tonnage data - international

USGS model 17 50th percentile = 140 Mt at 0.54% Cu, possible byproduct Ag, Au and/or Mo (Cox & Singer 1986, pp. 77-81). See also Lefebure & Höy (1996, p. 143) for BCGS model L04.

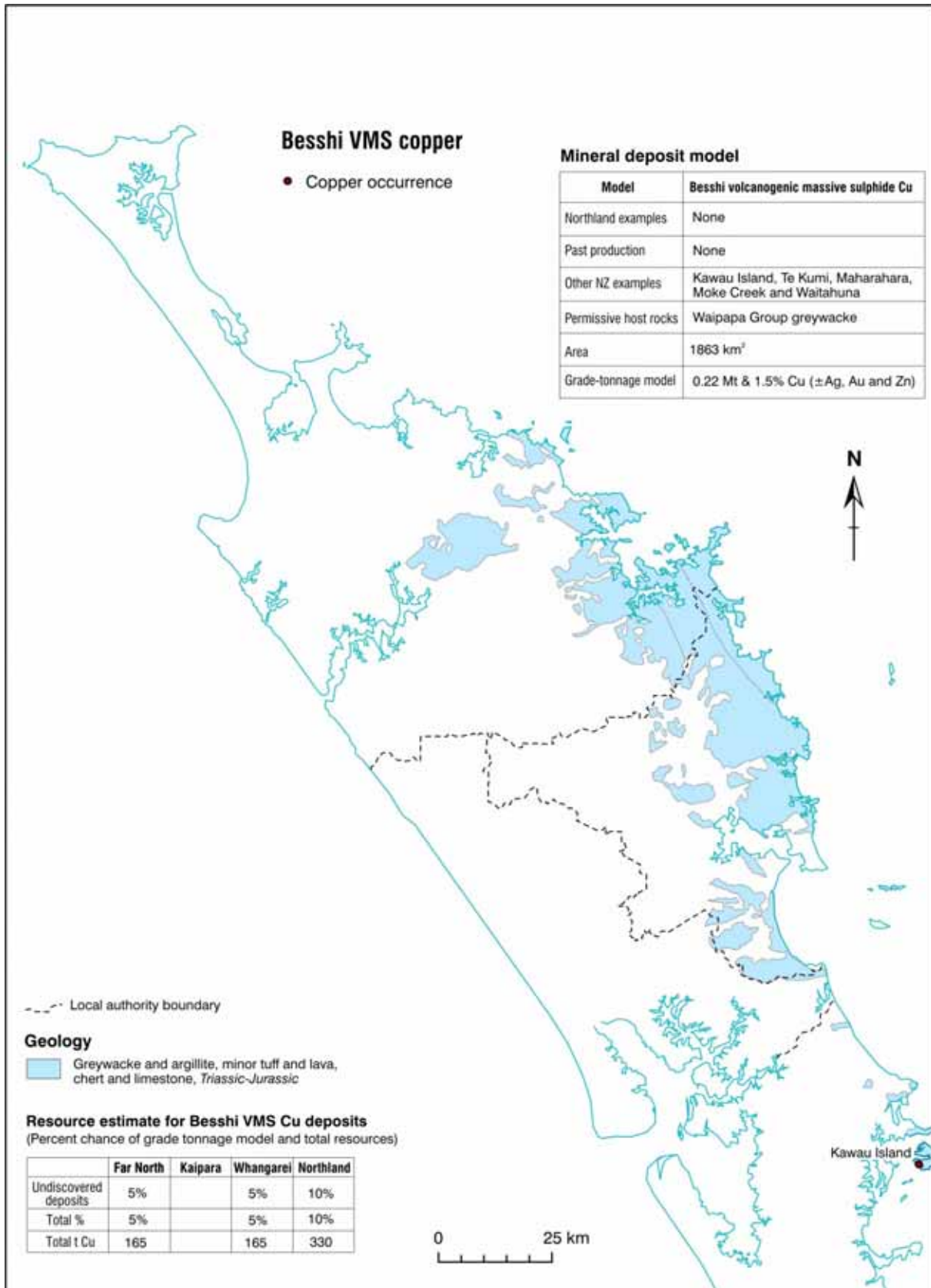


Figure 36. Location of Besshi volcanogenic massive sulphide Cu sites from the GERM database and areas of greywacke that are prospective host rocks.

12.4.3.2 Northland deposits

At Knuckle Point (O03/e7), the eastern tip of Karikari Peninsula, disseminated chalcopyrite, pyrite and native copper occur in the carbonate cement of a breccia containing fragments of diorite wall rock, tonalite, silicic volcanoclastics and basalt (Hay 1966a, 1967). The mineralisation crops out over an area of 75 m x 75 m and was prospected as Bodies Copper Mine during 1847, 1849, and 1857. Two analyses quoted by Hay (1967) had up to 0.1% Cu, 2.1 g/t Au and 60 g/t Ag.

Similar breccias, some of which are mineralised, occur intermittently along the coast as far south as Taupo Bay and Stephenson Island (Hay 1966b), and to the north, in an embayment just south of Pihakoa Point (O03/e8), a 3 m wide mineralised zone contains pyrite and chalcopyrite (Hay 1975).

On Coppermine Island, the most easterly island of the Hen and Chicken Group, copper mineralisation is associated with dioritic intrusive rocks (Miocene) in Waipapa Group greywacke basement (Wodzicki & Thompson 1970). Sulphide mineralisation, mainly pyrrhotite, pyrite, and chalcopyrite, occupies joints in altered diorite and interstices between fragments in dacite breccia. A four-hole diamond drilling programme by CRA Exploration Pty Ltd (Johnston 1969) indicated that grades were 0.03-0.11% Cu, and that grade generally decreases with depth.

Other areas of mineralisation occur, especially within the older volcanic rocks where pyrite and chalcopyrite are present disseminated within quartz veins, for example in the Tangihua Complex at Kerr Point (N02/e17). Selected vein samples have analysed as high as 18% Cu (New Zealand Geological Survey 1966; Bowen 1970a, 1970b), but the wall rocks (e.g. green chert clasts within volcanic conglomerate at Tom Bowling Bay) have low values of Cu (0.04-0.06% Cu).

Discovery of minor alluvial gold at Whangarei Heads in 1887 led to the driving of a number of adits in zones of silicification in the greywacke rocks of the Waipapa Group. Minor pyrolusite was found to accompany silicification. Limonite and malachite-bearing quartz veins were encountered, and copper was reported to run up to 720 ppm (Bell 1976). At nearby Kauri Mountain, a small hornblende andesite porphyry stock is hydrothermally altered, and adjacent stream sediments yield copper geochemical anomalies (Bell 1976).

12.4.3.4 Potential

The occurrence of several porphyry style copper deposits in Northland indicates good potential for additional discoveries. These are likely to occur along the eastern edge of Northland where erosion is deepest. The model deposit size is very large and as a result we have given low percentage estimates for known (0.6%) and undiscovered deposits (7%) listed in Figure 37. These are split between Far North and Whangarei districts.

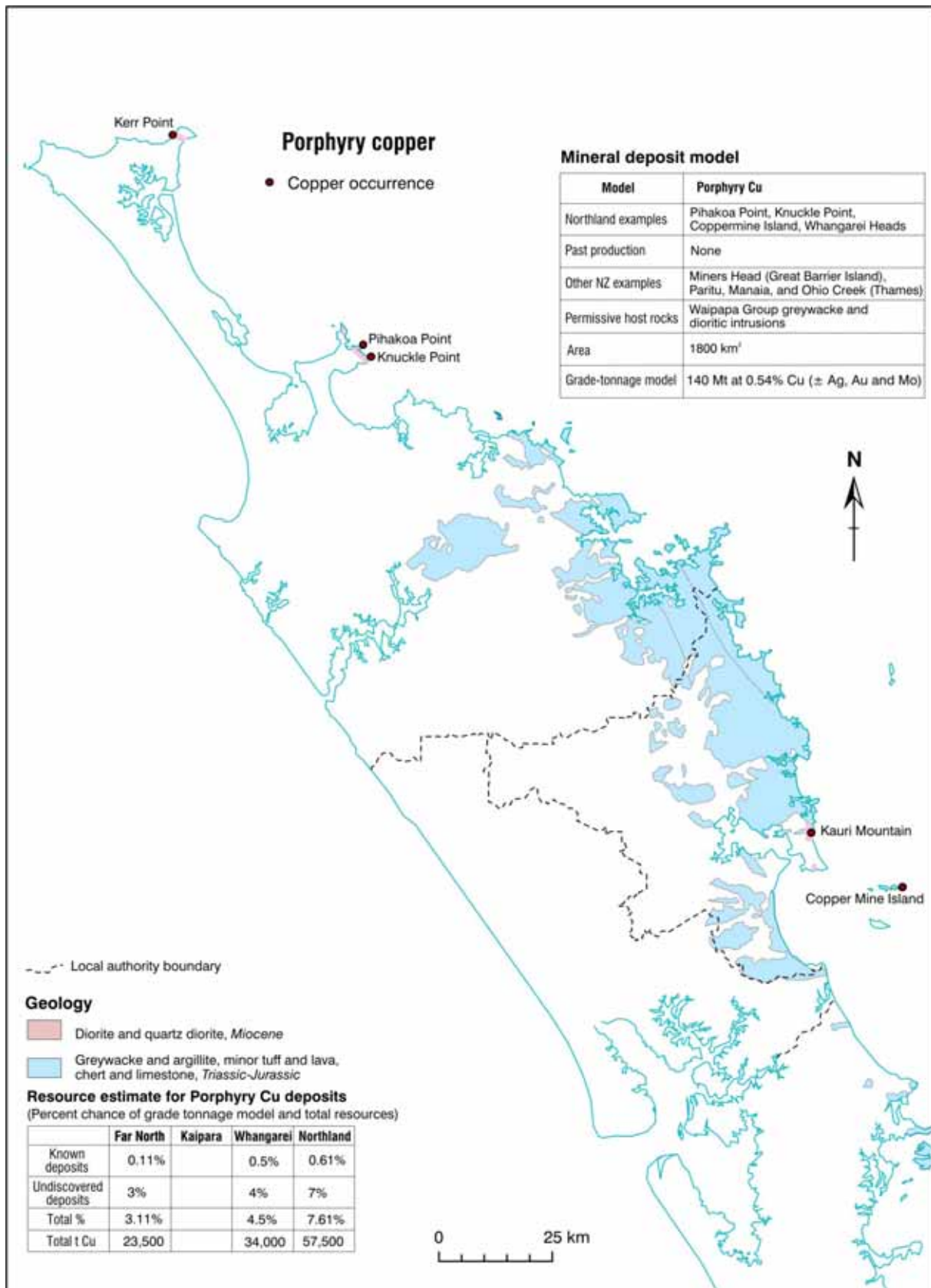


Figure 37. Location of porphyry Cu sites from the GERM database and areas of greywacke and intrusive rocks that are prospective host rocks.

12.5 GOLD-SILVER

12.5.1 Hot spring Au-Ag type gold-silver deposits (Fig. 38)

12.5.1.1 *International model*

References

USGS model 25a Hot-spring Au-Ag (Cox & Singer 1986) and BCGS model H03 Hot-spring Au-Ag (Lefebure & Höy 1996).

Description

Auriferous chalcedonic or opaline silica and fine-grained quartz form veins, stockworks and matrix filling in breccias hosted by volcanic and, less commonly, sedimentary rocks. These are the uppermost parts of epithermal systems that develop mineralised siliceous caps a few metres to hundreds of metres below surface with subaerial siliceous sinter deposits at the water table and explosion breccias above.

The deposits occur in subaerial volcanic centres including flow-dome or caldera complexes and related radial and ring fracture systems. Host rocks are intermediate or bimodal basaltic-rhyolitic volcanics including volcanic flows, flow domes, tuffs and breccias; hydrothermal breccias and siliceous sinters.

Pyrite, marcasite, electrum (gold-silver alloy), stibnite, sulphosalt minerals, realgar and cinnabar occur in a gangue mineral assemblage of quartz and chalcedony, and less common opal, calcite, dolomite and barite.

International examples

McLaughlin, California, USA; Round Mountain, Nevada, USA; Delamar, Idaho, USA.

Grade and tonnage data

Mineralization tends to be low grade. Economically attractive bulk-mineable deposits contain >10 Mt of 1 to 2 g/t Au, or greater. High-grade veins and stockworks within the larger mineralized zones can be exploited by underground methods. The McLaughlin deposit, a superior discovery, contained initial reserves of 17.5 Mt with 5.2 g/t Au and about 16 g/t Ag, including a sheeted vein zone with 2.45 Mt at 9.15 g/t Au. A value of 1 M oz Au and 2 M oz Ag, based on 10 Mt at 3.1 g/t Au and 6.2 g/t Ag, is assigned for our grade tonnage model.

12.5.1.2 *Northland deposits*

Quartz veins with traces of gold were prospected in several areas of Northland (e.g. Ferrar 1925), but there has been no historic gold production. However, the recognition in the early 1980s that many features of Northland geology and mineralisation matched models of epithermal gold environments, resulted in considerable exploration activity (e.g. Maxwell 1985a, 1985b, 1985c, 1988; White 1985a, 1985b; BHP Gold 1988; Brown 1989; Cameron 1989) and the identification of several prospects (Fig. 38) based on the occurrence of siliceous sinter, silicified breccias, quartz veins, hydrothermal clay alteration zones and mercury, antimony and arsenic mineralisation.

Puhipuhi (Q06/e73)

In the Puhipuhi field (Figs 38 and 39), a group of cinnabar deposits (Mt Mitchell, Puhipuhi and Rising Sun) define a northerly trend over a distance of 6.4 km (Ferrar 1925; White 1983, 1986; Cranney 1984, 1985). The stratigraphy consists of greywacke basement

unconformably overlain by Pliocene lake sediments and basalt flows. At Mt Mitchell, a sheet of siliceous sinter contains cinnabar (Fig. 40), as well as stibnite, marcasite and pyrite. Nearby, a collapsed sinter sheet is represented at Plum Duff (Fig. 41). At the Puhupuhi Mine, mercury was mined from silicified breccia (White 1983). The orebody at the Rising Sun Mine consisted of a thin layer of shattered, silicified greywacke carrying cinnabar as 'paint' on joints. Some alluvial cinnabar was also worked, both from present-day streams and from gravels underlying the basalt.

Silver-bearing quartz veins in the basement greywacke, 2 km to the northwest and 100 m below the level of the cinnabar deposits, probably represent a deeper level exposure of the Puhupuhi hydrothermal system. The silver mineralisation is in quartz veins and ill-defined fissure zones of silicified greywacke (0.3-2.6 m in width), which were prospected over a vertical range of 90 m (Ferrar 1925). Recorded production amounts to only 42 kg of silver, and payable ore was confined to the upper or oxidised portion of the veins. The silver minerals are argentian tetrahedrite, pyrargyrite and acanthite, and they are associated with marcasite, pyrite and chalcopyrite (White 1986).

Recent exploration of the Puhupuhi field for epithermal gold (Cranney 1985; BHP Gold 1988, Gregory et al. 1988; Brown 1989; Grieve et al. 1997, 2006) has outlined a zone 4.5 km long by 1.0 km wide of geochemically anomalous Au, Ag, Sb, As, Hg and Ba contents in soil samples. BHP Gold (1988) reported that significant results of reconnaissance drilling directed at fossil hydrothermal fluid feeder zones included intersections of 5.3 g/t Au and 18.5 g/t Ag over 10 m in a chalcedonic quartz vein cutting an eruption breccia, and 0.3 g/t Au and 10.4 g/t Ag over 24 m in altered rocks below sinter.

Ngawha (P05/e92)

The presence of mercury and sulphur deposits, and assays of trace Au and Ag in drill holes indicate that the Ngawha geothermal system may be prospective for gold and silver.

Topps Prospect

An uplifted block of basement greywacke is capped by remnants of greensand which host patches of pyritic and quartz stockwork mineralisation. Stream sediments are anomalous in arsenic, but to date no significant gold or silver has been detected in geochemical sampling of the area.

Te Mata (P04/e53)

Arsenic sulphide mineralisation and colloform banded quartz veins occur in argillically altered lake sediments and greywacke (Maxwell 1985b; Cameron 1986; Anon 1991). The Te Mata rhyolite dome is bounded by the Te Mata Fault, which cuts through an associated area of siliceous sinters, mineralised lake sediments, explosion breccias, argillic alteration and quartz veining. Native arsenic, realgar, orpiment and arsenopyrite occur in association with pyrite, marcasite and cinnabar. The rare ammonium feldspar, buddingtonite, was recorded by Cameron (1986). The maximum gold assay of rocks was 3.5 ppm Au from a sulphidic clay derived from Waipapa Group basement rocks.

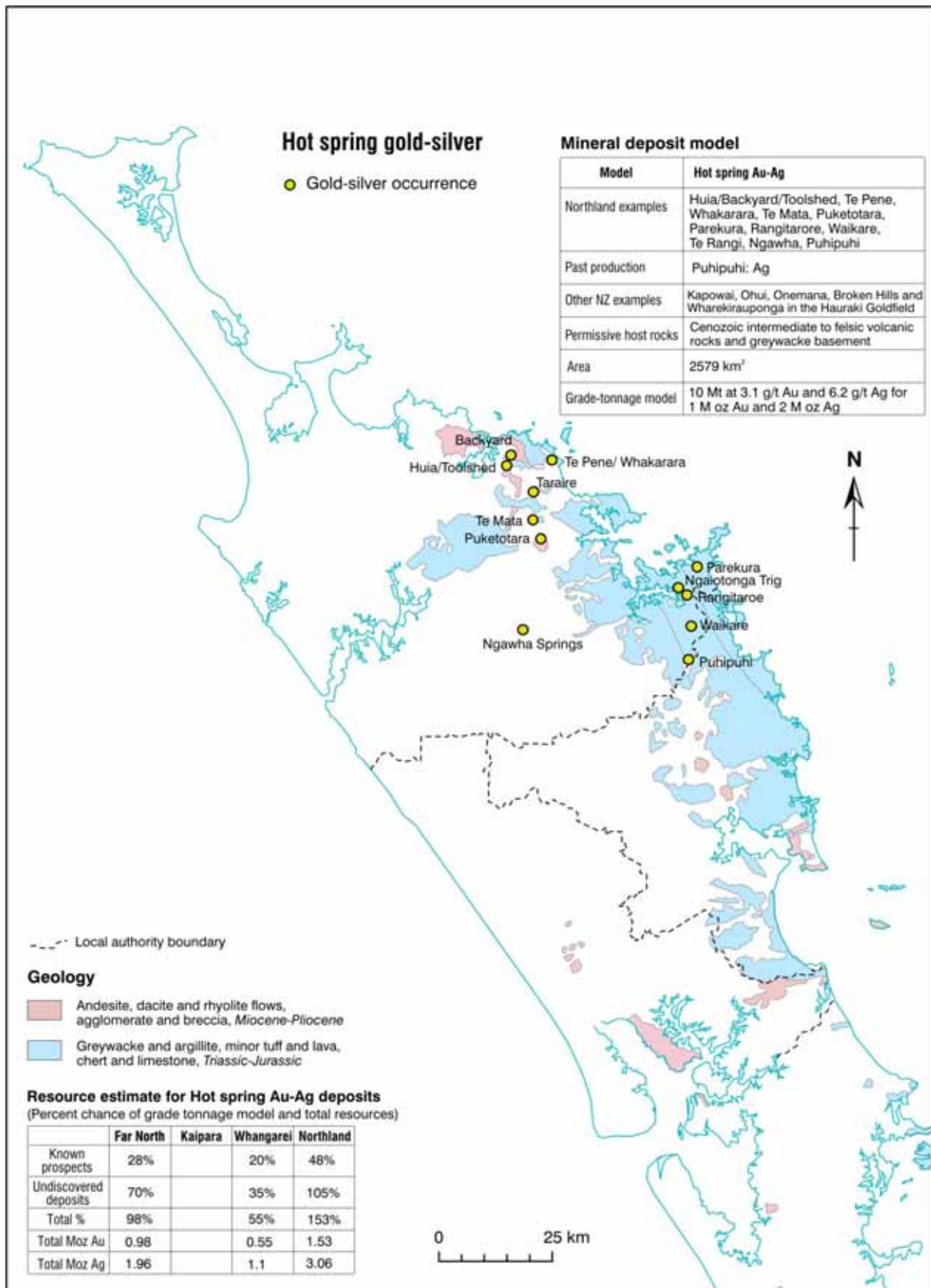


Figure 38. Location of gold prospects from the GERM database and areas of greywacke and volcanic rocks prospective for hot spring Au-Ag deposits.

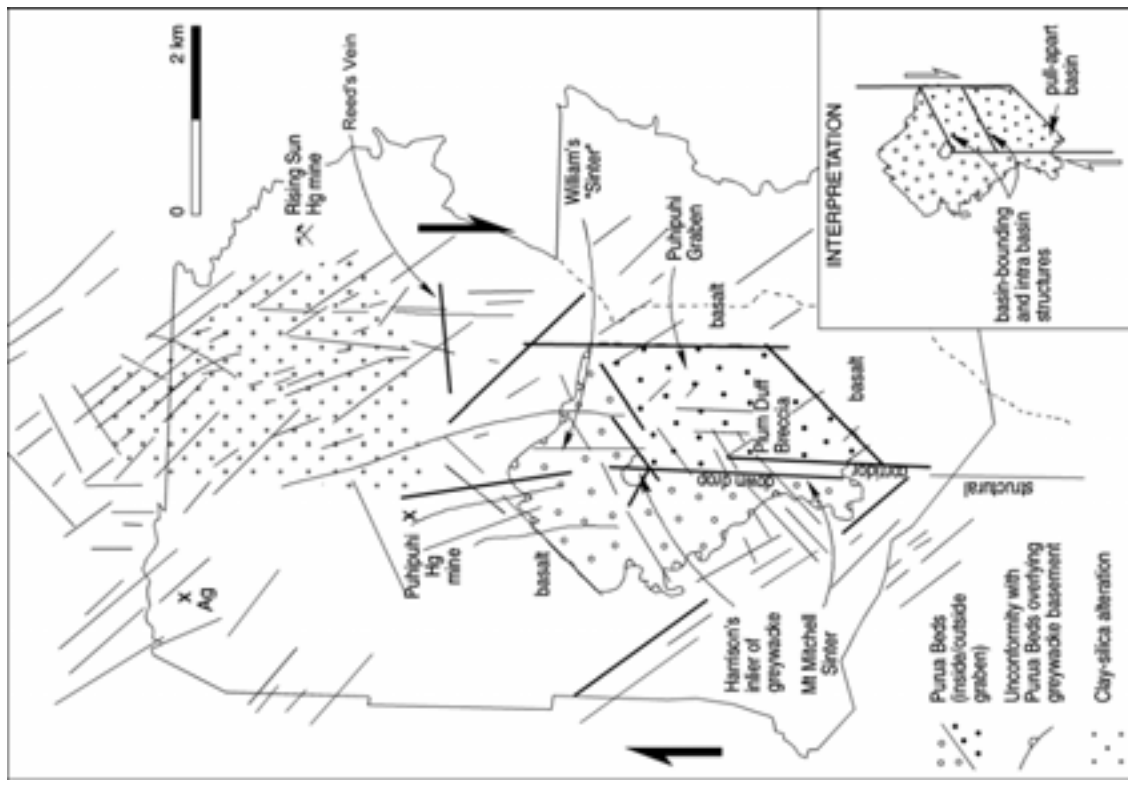
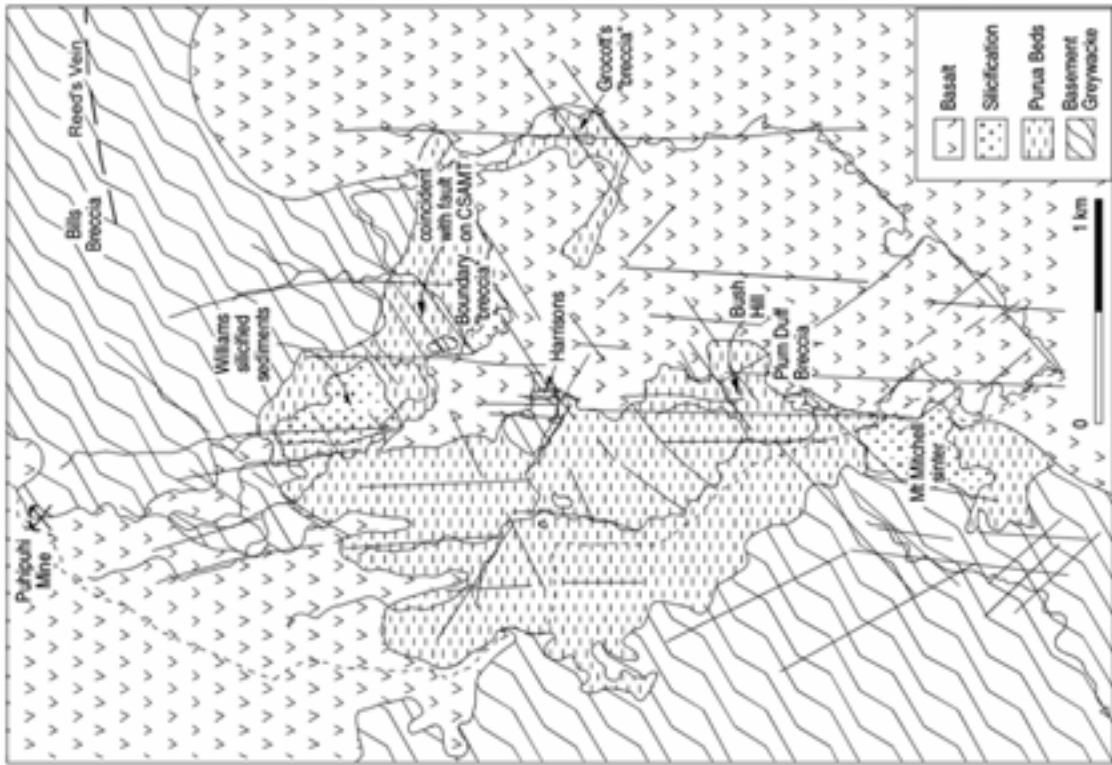


Figure 39. Structural and geological maps of the Pupihupi prospect (after Grieve et al. 1997).



Figure 40. Bedded silica sinter sheet exposed in a former quarry at Mt Mitchell, Puhipuhi. The sinter contains antimony and mercury. Photo: Tony Christie.

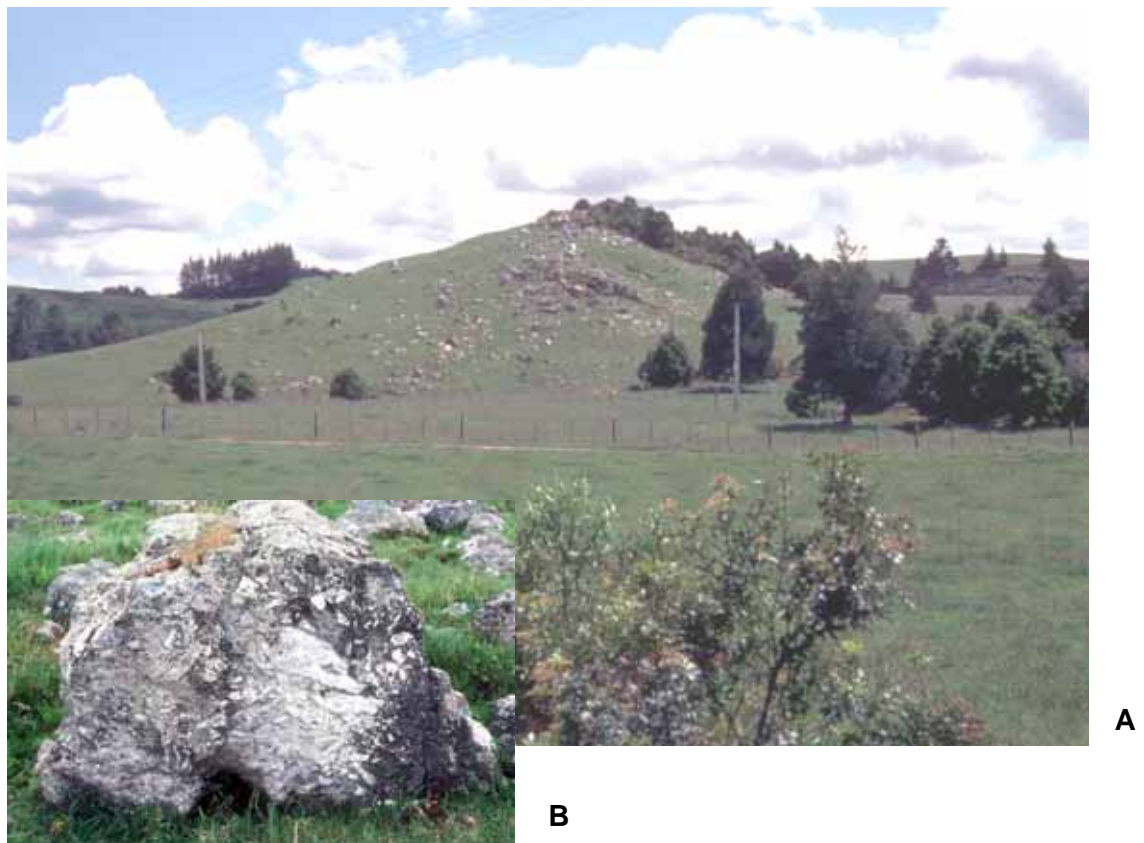


Figure 41. **A.** Plum Duff breccia mound at Puhipuhi, representing the collapse of a silica sinter sheet. **B.** A boulder of breccia containing sinter sheet clasts. Photos: Tony Christie.

Puketotara (P05/e110)

A 3 km² zone of argillic alteration lies adjacent to the major Maungaparerua rhyolite dome, and straddles the Pirau Fault. This alteration carries disseminated and vein cinnabar and pyrite-marcasite (Fig. 42) with traces of sphalerite, and chalcopyrite in hydrothermally altered basalt and rhyolite (Wodzicki & Weissberg 1982).

New Zealand China Clays Limited drilled about 150 holes in the Maungaparerua prospect between 1965 and 1970 to determine the clay resources. During this programme, sulphide mineralisation was discovered and a further drilling programme totalling 2600 m in 39 holes was completed. Deepest drilling went to 245 m and 348 samples were assayed by Johnson Matthey in London, of which 347 returned some precious metal results. Investigations by DSIR indicated that high platinum values reported from this deposit in 1970 by Consolidated Brick and Pipe Investments Ltd were due to "contamination" (Wodzicki & Weissberg 1982). Subsequent exploration by BP, including one diamond drill hole to a depth of 172 m in 1984, has shown weak Au (0.02-0.25 ppm), Ag, Zn and Cu geochemical anomalies associated with thin quartz veins and weakly silicified fault zones enclosed by a broad zone of argillic alteration in Pliocene lake sediments and basalt flows (White 1985a). Six shallow holes totalling 188 m were drilled by Kiwi Gold in late 1987 to test possible anomalous surface mineralisation, but assays of the drill core yielded low gold values with a maximum of 0.028 ppm Au (Murfitt 1987; Tulloch 1987). They suggested that any likely gold zone would be at greater depths (>200 m).



Figure 42. Geologist examining a lag deposit of pyrite crystals in the stream bed of Pyrite Creek, Maungaparerua. Photo: Tony Christie.

Huia (including Toolshed and Backyard)

Cinnabar float and small quartz veins were recorded from streams draining the Huia area by Bell & Clarke (1909). Reconnaissance soil sampling and stream sediment surveys by Adaras Mining and WMC in the early 1970's revealed areas of alteration at Taraire and Huia, and WMC drilled three small cinnabar orebodies at Huia, containing values of up to several percent Hg. Strategic Minerals and Canyon Resources also drilled for mercury nearby, but did not intersect economic grades. CRA recognised As, Sb and Hg anomalies near Huia, associated with hydrothermal alteration and widespread silicification (McOnie 1985).

From 2004, exploration by Aurora Minerals identified the Backyard and Toolshed prospects (Fig. 43). At Backyard, gold values of up to 6.9 g/t were recorded in outcropping quartz veins. Sixteen RC drill holes totalling 1600 m and 4 diamond drill holes totalling 1600 m intersected quartz veins and brecciation, but assays returned only trace gold (Fig. 44). At Toolshed, soil sampling returned up to 52 ppb Au and samples of thin quartz veins in surface float contained up to 300 ppb Au. The Eastern Anomaly area, about 5 km east of the Backyard prospect and north of the Mahimahi clay pit, was defined by soil anomalies of up to 355 ppb Au and rock chip samples with up to 3.4 g/t Au. These prospects define the Huia Trend hosted in Waipapa greywacke, Eocene greensand, and Wairakau Andesite.

Te Pene (P04/e52)

Hydrothermal breccias outcropping in Waipapa greywacke basement rocks were discovered by BP during regional exploration in 1983 (Maxwell 1985b; Brown 1989). The breccias consist of altered greywacke and siliceous clasts, and are associated with silicification and veining. The area is anomalous in Sb (up to 5000 ppm) and As (up to 1000 ppm), and rock chip assays returned up to 0.8 ppm Au and 25 ppm Ag. GEONZ Associates Ltd (Jones 1990a, 1990b) carried out soil sampling, a ground magnetic survey and drilling of two diamond drill holes of 50 m and 80 m lengths. Hole DDH-1 returned anomalous values up to 1600 ppm As, 2660 ppm Sb, 0.55 g/t Au and 1.7 g/t Ag between downhole depths of 40 m and 50 m, in brecciated silicified sedimentary rocks.

Whakarara

Hydrothermal alteration, two quartz veins and hydrothermal breccias, possibly representing five epithermal vents, are present on the southeast and western flanks of Whakarara Hill, north of Te Pene (Murfitt 1994). The mineralisation is hosted in Waipapa greywacke, but may be genetically related to the nearby rhyolite at Te Pene. Samples of quartz veins assayed up to 5.86 g/t Au and 28.0 g/t Ag.

Waikaire

Rock chip samples containing >0.1 g/t Au occur in an area of approximately 7 km², within a 30 km² area containing rock chip samples with >85 ppm As (Corcocran 1972; Bell 1983; Corner 1983; McDonald 1984). Two hydrothermal breccia dikes have been traced over 500 m of strike length and are up to 3 m wide. Samples of the dikes contain up to 0.9 g/t Au and 22 g/t Ag.

Others

Bell & Clarke (1909) reported traces of gold and silver in rusty quartz veins within the Tangihua Complex near Kerr Point (same locality as N02/e17).

Quartz veins with traces of gold in Waipapa greywacke have been reported from Whangarei Heads (Kauri Mountain, R07/e9) (Bell 1976), Ngaiotonga (Q05/e17), Parekura Bay

(Q05/e18) and Waihaha (Cape Brett, Q05/e2). The mineralisation is found as narrow, discontinuous quartz stringers and veinlets, and as silicified zones, particularly along faults.

12.5.1.3 Potential

Although there has been no mining of gold from Northland, a large number of hot spring Au-Ag prospects are known and exploration to date has been only of a reconnaissance nature. Northland was included in the epithermal gold data package prepared by GNS Science and Crown Minerals (Anon 2003). This study identified moderately and highly prospective areas in Northland that corresponded to the known prospects (Fig. 45), but the lack of regional exploration data prevented the application of the prospectivity modelling method to the whole of the potentially prospective area in the region.

Similarities with the Hauraki Goldfield suggest a high potential for the presence of deposits meeting the model size, which we have quantified as 48% for known prospects and 105% for undiscovered prospects, split between the Far North and Whangarei districts (Fig. 38).

12.5.2 Low sulphidation epithermal Au-Ag type gold-silver deposits (Fig. 46)

12.5.2.1 International model

References

USGS model 25c Comstock epithermal veins (Cox & Singer 1986) and BCGS model H05 Epithermal Au-Ag: low sulphidation (Lefebure & Höy 1996).

Description

Au+Ag±Zn±Pb±Cu bearing quartz veins, quartz vein stockworks and hydrothermal breccias hosted in andesitic and dacitic lavas, breccias and tuffs, and adjacent basement greywacke. The main ore minerals are electrum and acanthite with ubiquitous pyrite, and some deposits contain significant sphalerite, galena and chalcopyrite at depth. Quartz and calcite are the main gangue minerals, with Mn-carbonate, adularia and inesite present in some deposits. Bladed quartz and quartz pseudomorphous after calcite are common textures in some veins.

International examples

Comstock, Nevada; Guanajuato (low Au:Ag ratio), Mexico; Hishikari, Japan.

Grade-tonnage data

See Lefebure & Höy et al. (1996, p. 133) for BCGS model H05. Mosier & Menzie (1986) noted that the median size of 41 low sulphidation deposits was 0.77 Mt at 7.5 g/t Au and 110 g/t Ag (186,000 oz Au and 2,723,000 oz Ag). These figures are compiled from historic mining of small high grade deposits. For a more realistic model we have taken 5 Mt at 3 g/t Au and 12 g/t Ag for 500,000 oz of Au and 2 M oz Ag.

12.5.2.2 Northland deposits

None, but deeper levels of some hot-spring Au-Ag, hot-spring Sb, and hot spring Hg deposits may grade into low sulphidation epithermal Au-Ag similar to these types of deposits in the Hauraki Goldfield (e.g. Martha, Waihi).



A



B



C

Figure 44. Drilling on Aurora Minerals Hazelbrook epithermal gold-silver project area. **A.** RAB (rotary air boring) drilling soil samples. **B.** Reverse circulation drilling with cyclone separator (white) near centre and bagged samples in the foreground. **C.** Diamond drilling - core drilling with a diamond bit. Photos: courtesy of Aurora Minerals.

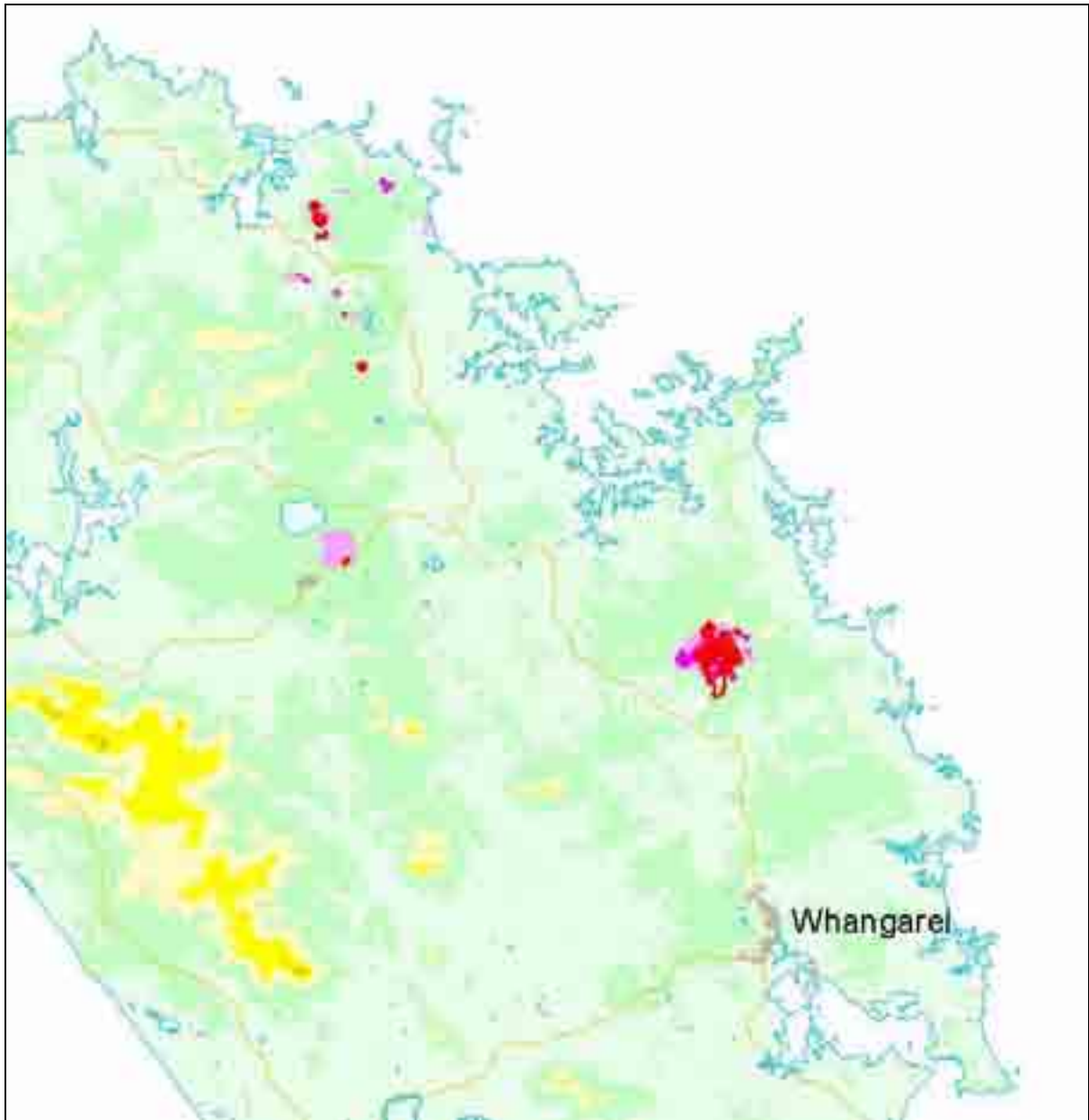


Figure 45. Prospectivity map for epithermal gold-silver deposits in Northland (after Rattenbury & Partington 2003). The colour ramp from pale green, through, darker green, pale yellow, yellow, mauve, purple and red denotes increasing prospectivity.

12.5.2.3 Potential

There is a 30% probability that undiscovered low sulphidation epithermal Au-Ag deposits meet the model size, and this is split evenly between the Far North and Whangarei districts (Fig. 46).

12.5.3 Sediment hosted Au type gold-silver deposits (Fig. 47)

12.5.3.1 International model

References

USGS model 26a Carbonate-hosted gold-silver (Cox & Singer 1986) and BCGS model E03 Carbonate-hosted disseminated Au-Ag (Lefebure & Höy 1996).

Description

Very fine-grained gold and sulphides disseminated in zones of decarbonated calcareous rocks and associated jasperoids. Gold occurs evenly distributed throughout the host rocks in stratabound concordant zones and in discordant breccias. The host rocks are thin-bedded carbonaceous shales, and silty or argillaceous carbonaceous limestone or dolomite, mostly of Cambrian to Devonian age. Cretaceous and Cenozoic age felsic intrusive rocks are found in, or nearby, many deposits.

The deposits are generally tabular, stratabound bodies localised at contacts between contrasting lithologies. Bodies are irregular in shape, but commonly straddle lithological contacts which, in some cases, are thrust faults. Felsic plutons and dikes are also mineralised at some deposits.

Silica replacement of carbonate is accompanied by volume loss so that brecciation of host rocks is common. Tectonic brecciation adjacent to steep normal faults is also common. Generally less than 1% fine grained sulphides are disseminated throughout the host rock. Native gold (micron-sized), pyrite, realgar, orpiment, plus local arsenopyrite, cinnabar, fluorite, barite, and stibnite occur in a gangue mineral assemblage of quartz, calcite, barite and carbonaceous matter.

International examples

Carlin, Post, Gold Quarry, Getchell, Cortez, Gold Acres, Jerrit Canyon in Nevada, USA; Mercur in Utah, USA.

Grade-tonnage data

USGS model 26a 50th percentile = 5.1 Mt and 2.5 g/t Au (410,000 oz Au), possible byproduct Ag (Cox & Singer 1986, pp. 175-177). Mosier et al. (1992) reported the median size of 39 US deposits as 6.6 Mt grading 2.3 g/t Au (488,000 oz Au), with most deposits in the range between 1 and 50 Mt with grades from 1.0 to 6 g/t. However, two zones of the Carlin trend are significantly larger, Gold Quarry-Deep West-Maggie Creek with 464 Mt at 1.32 g/t Au, and Goldstrike-Post-Blue Star-Genesis-Bobcat-North Star with 307 Mt at 2.89 g/t Au. We assign a value of 0.5 M oz Au for our model.

12.5.3.2 Northland deposits

Sediment hosted deposits are an important gold deposit type in Nevada and some other overseas locations, but have so far not been discovered in New Zealand. Reconnaissance exploration has been carried out in Northland for this type of deposit with no success to date.

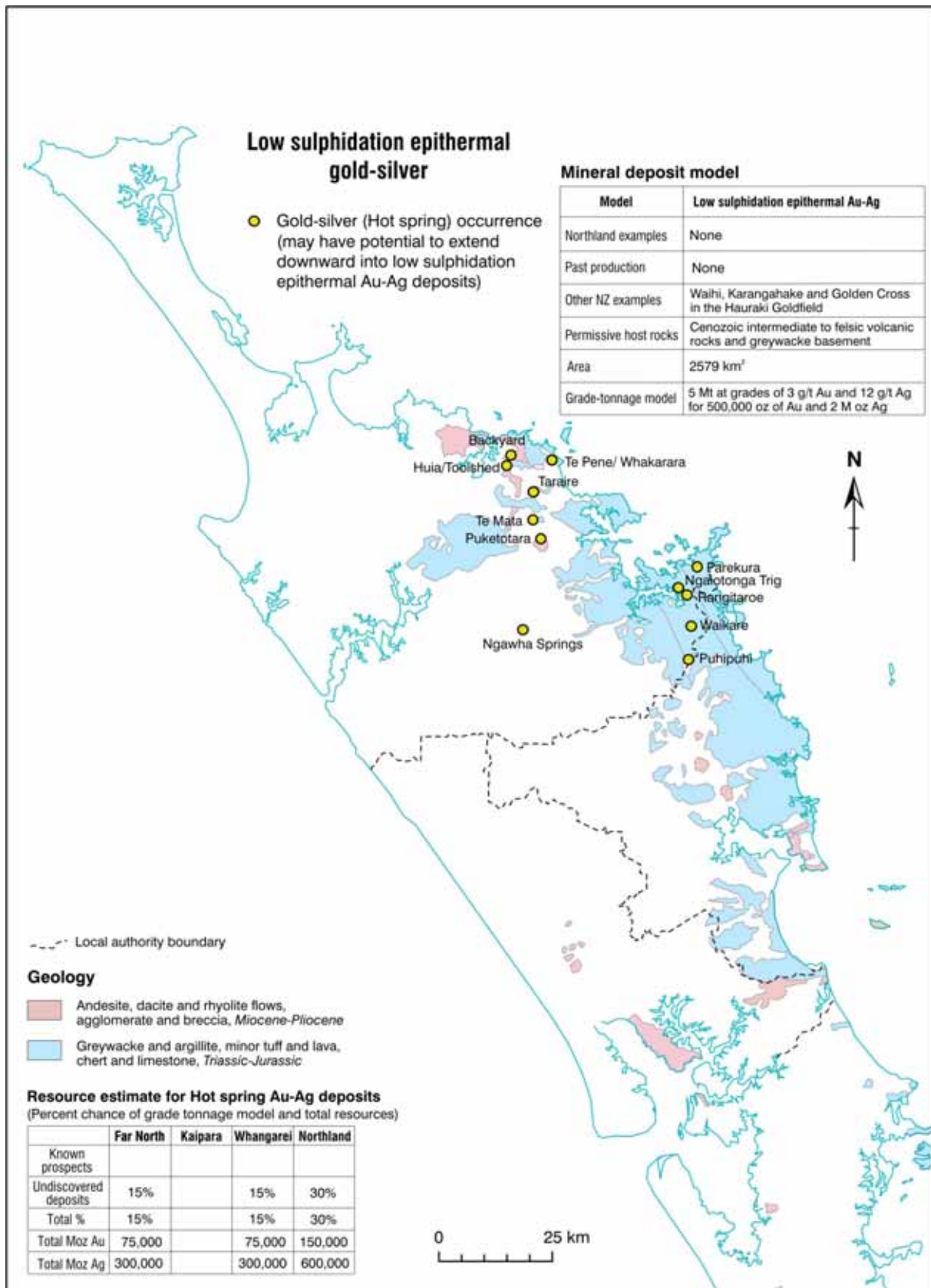


Figure 46. Location of gold prospects from the GERM database and areas of greywacke and volcanic rocks prospective for low sulphidation epithermal Au-Ag deposits.

12.5.3.3 Potential

There is a 5% probability of the presence of 1 medium sized sediment-hosted gold deposit in Northland representing 30,000 oz of gold (Fig. 47).

12.5.4 Au skarn type gold-silver deposits (Fig. 48)

12.5.4.1 International model

Reference

BCGS model K04 Au-skarns (Lefebure & Ray 1995).

Description

Gold-dominant mineralisation associated with skarns developed by metasomatic and hydrothermal processes where plutons intrude carbonate-bearing rocks. Gold skarns are hosted by sedimentary carbonates, calcareous clastics, volcanoclastics or (rarely) volcanic flows. They are commonly related to high to intermediate level stocks, sills and dikes of gabbro, diorite, quartz diorite or granodiorite composition. There is a worldwide spatial, temporal and genetic association between porphyry Cu provinces and calcic Au skarns.

Gold skarns vary in form from irregular lenses and veins to tabular or stratiform orebodies with lengths ranging up to many hundreds of metres. Rare examples occur as vertical pipe-like bodies along permeable structures. Orebodies form veins or stratiform tabular lenses containing ore mineral assemblages of native gold, chalcopyrite, pyrrhotite, arsenopyrite and tellurides. The skarn gangue consists of Ca-Fe-Mg silicate minerals, such as clinopyroxene, garnet and epidote.

International examples

Nickel Plate, British Columbia, Canada; Fortitude, McCoy and Tomboy-Minnie, Nevada, USA; Buckhorn Mountain, Washington, USA; Diamond Hill, New World district and Butte Highlands, Montana, USA; Nixon Fork, Alaska, USA; Thanksgiving, Philippines; Browns Creek and Junction Reefs-Sheahan-Grants, New South Wales, Australia; Mount Biggenden, Queensland, Australia; Savage Lode, Coogee, Western Australia; Nambija, Ecuador; Wabu, Irian Jaya, Indonesia.

Grade-tonnage data

Skarn deposits range from 0.4 to 10 Mt and grade from 2 to 15 g/t Au. Nickel Plate in British Columbia, Canada, has produced over 8 Mt grading 7.4 g/t Au (Ray 1995). We suggest 5 Mt at 8 g/t Au as a representative model.

12.5.4.2 Northland deposits

This deposit type has not been discovered in New Zealand to date.

12.5.4.3 Potential

There is a 1% probability of the presence of 1 medium sized Au skarn deposit in Northland representing 12,860 oz of gold (Fig. 48); this is split evenly between the Far North and Whangarei districts. Gold skarn type deposits are most likely to occur in the eastern part of Northland where erosion is deepest.

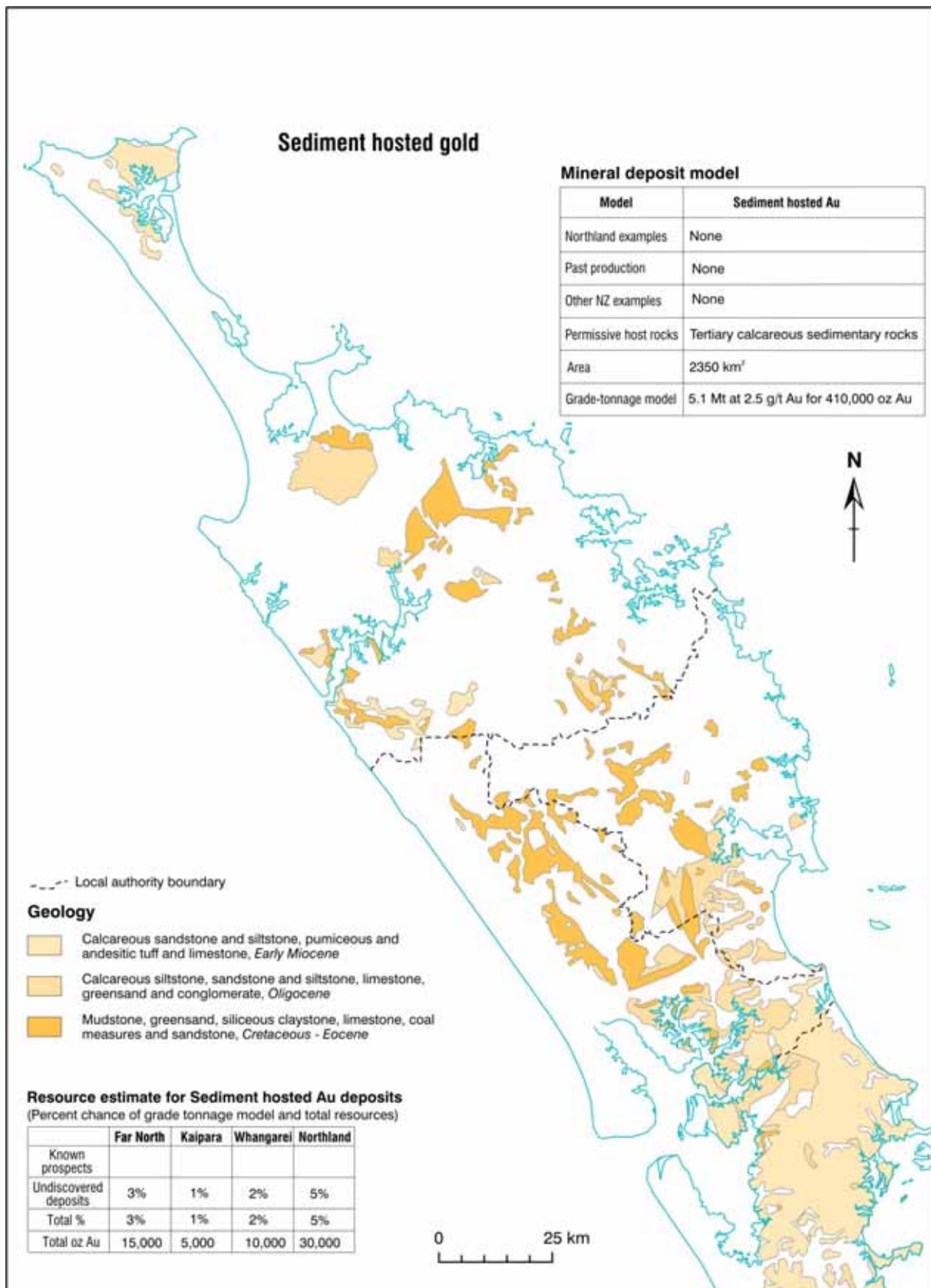


Figure 47. Areas of sedimentary rocks prospective for sediment hosted Au deposits.

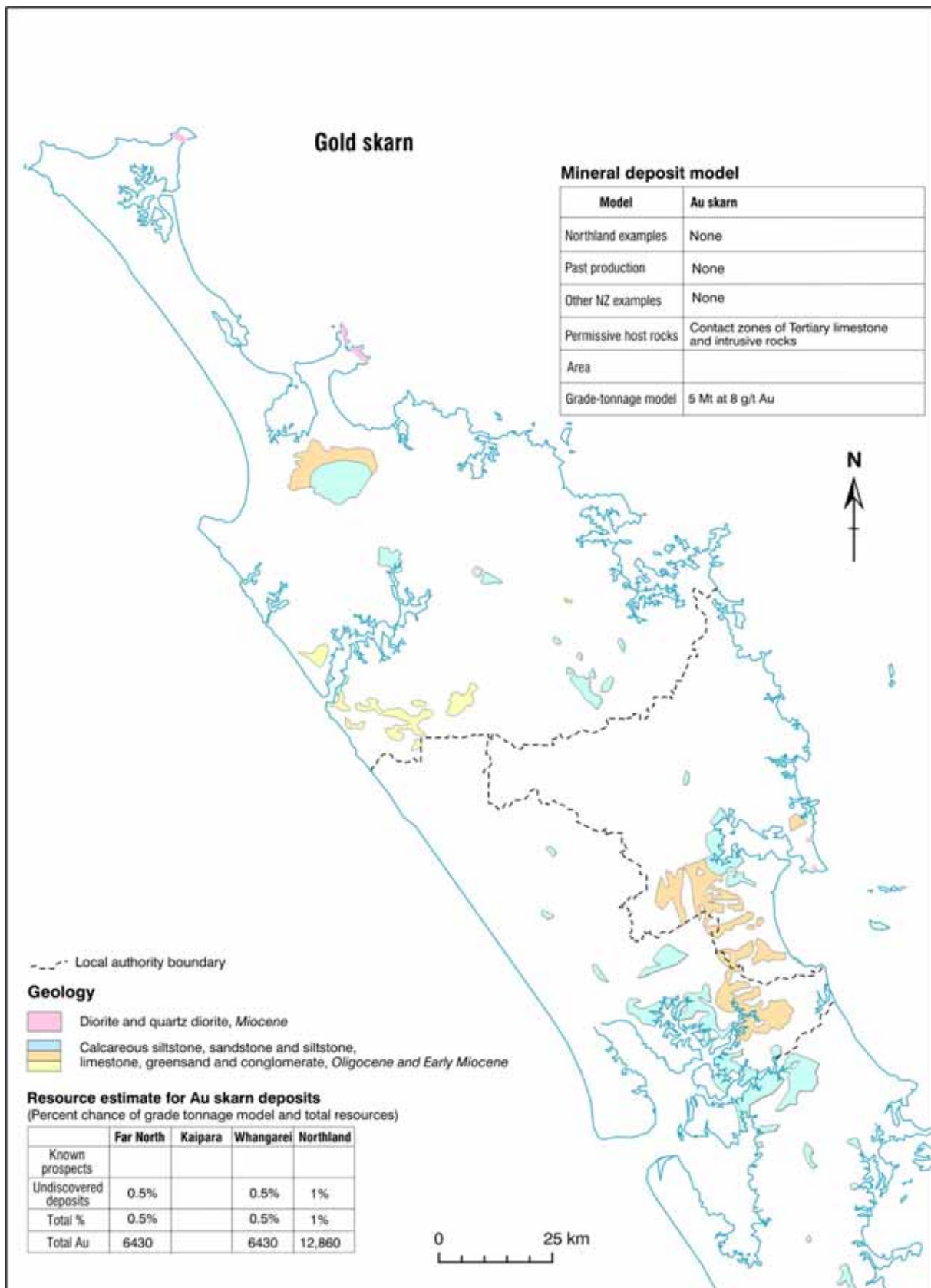


Figure 48. Areas of calcareous and intrusive rocks prospective for Au skarn deposits.

12.6 IRON

12.6.1 Bog iron (Fig. 49)

12.6.1.1 Model

Description

Limonitic bog iron formed from leaching of iron-bearing rocks such as basalt by carbonated surface and ground waters with subsequent deposition at the surface as ferric hydroxides.

Grade-tonnage data

Model = 100,000 t Fe

12.6.1.2 Northland deposits

Small limonitic bog iron deposits occur near Kaeo, Okaihau, Kerikeri and Kamo (Fig. 49). They have been formed from leaching of iron from Kerikeri Basalt. The deposit near Okaihau (P05/e67) has been intermittently worked, producing a combined total of 39,111 t up until 1961. The material was used as an agricultural stock lick to relieve 'bush sickness', as an absorbent in the purification of coal gas, as a colouring agent in bricks, and as road metal. The deposit is less than 1 m thick and some 60,000 t containing 60% Fe₂O₃ remain. The deposit near Kamo (Q06/e40) has been intermittently worked, producing 26,165 t of ore up until 1961. The deposit near Kaeo (P04/e54) contains between 10 and 36% Fe₂O₃ and may be an exhumed fossil laterite. Similar buried deposits could be discovered elsewhere in the region (Williams 1974).

12.6.1.3 Potential

There is a 360% probability of medium sized bog iron deposits in Northland representing 360,000 t of iron, mainly from undiscovered deposits (Fig. 49). This potential is mainly in the Far North district with lesser potential in the Whangarei district.

12.7 MANGANESE

12.7.1 Volcanogenic Mn type manganese deposits (Fig. 50)

12.7.1.1 International model

Reference

USGS model 24c Volcanogenic Mn (Cox & Singer 1986)

Description

Lenses and stratiform bodies of manganese oxide, carbonate and silicate in chert associated with sedimentary and mafic volcanic rocks. Their genesis is related to volcanogenic processes. Host rocks include chert, shale, sandstone, greywacke, jasper, basaltic lava and tuff, and serpentinite.

The ore minerals occur in fine-grained massive crystalline aggregates, or botryoidal, colloform and lensoid masses, veinlets and disseminations. The main ore minerals are psilomelane, pyrolusite, rhodochrosite, hausmannite, braunite, and neotocite.

International examples

Olympic Peninsula, Washington, USA; Franciscan Type, California, USA.

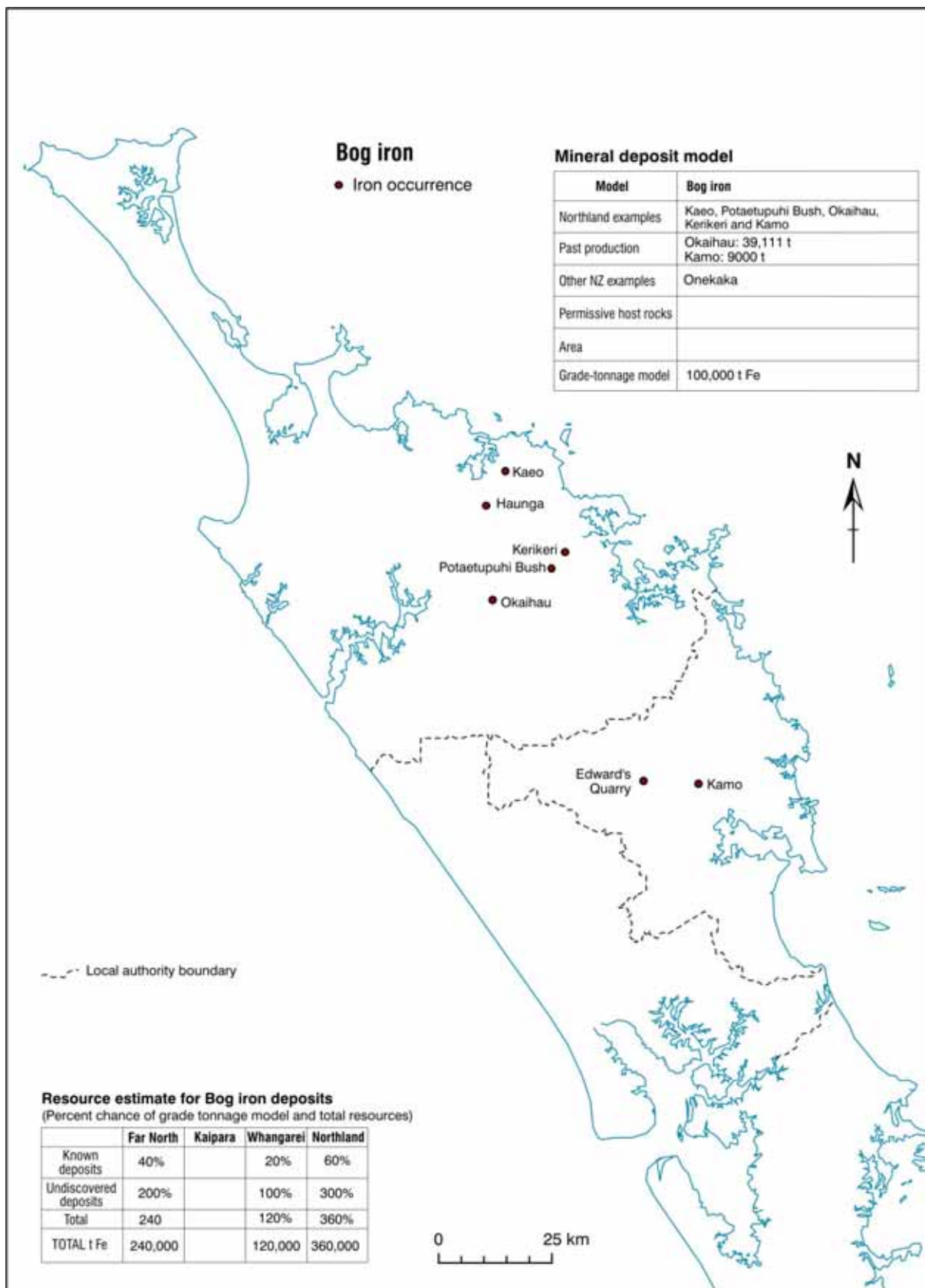


Figure 49. Locations of bog iron deposits from the GERM database.

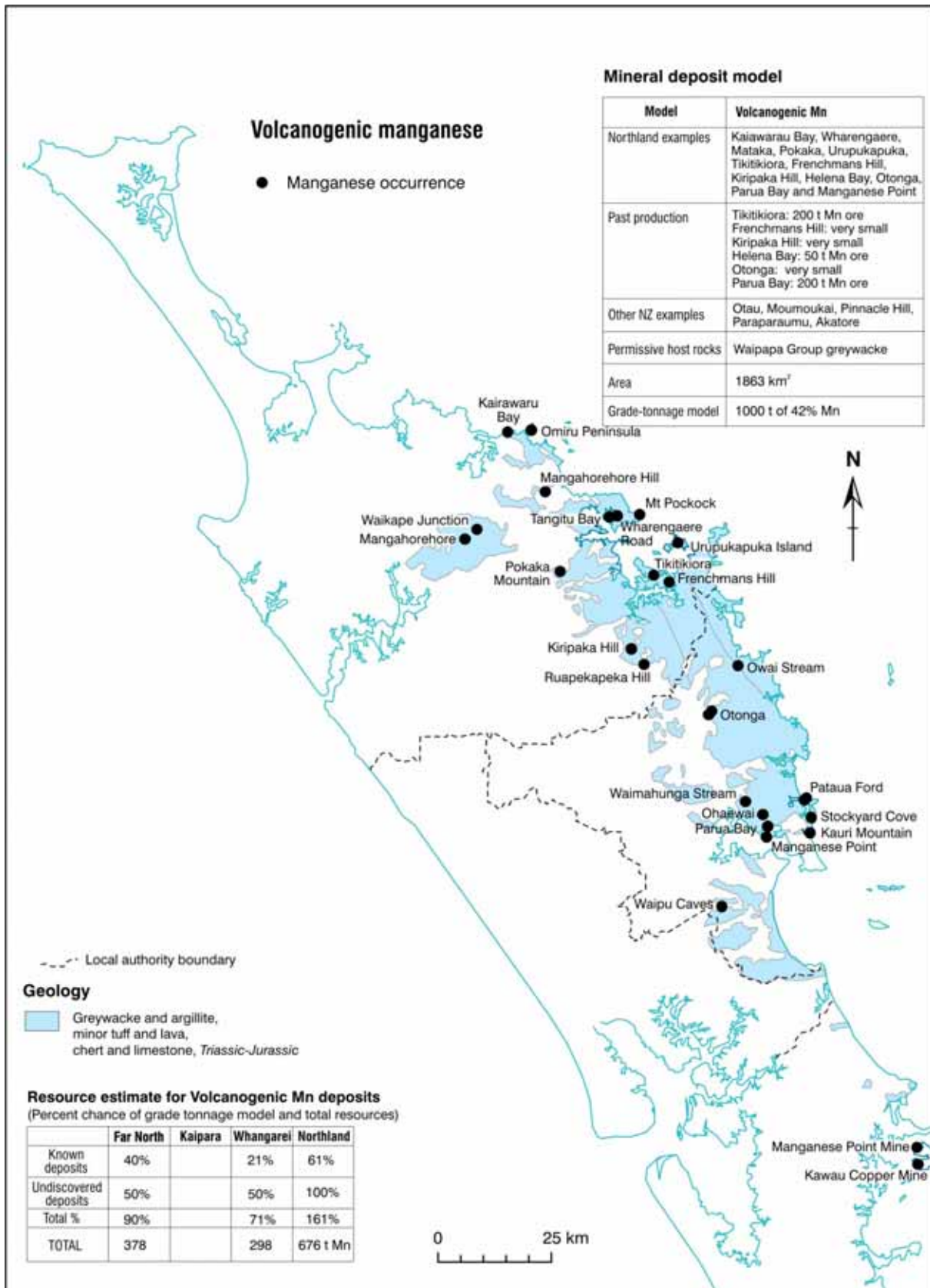


Figure 50. Locations of volcanogenic Mn deposits from the GERM database and areas of greywacke that are prospective host rocks.

Grade and tonnage

USGS model 24c 50th percentile = 47,000 t at 42% Mn (Cox & Singer 1986, pp. 139-141). See also BCGS model K02 (Lefebure & Höy 1996, p. 139). However, previous production from New Zealand deposits has been small and therefore the international model is heavily discounted to a value of 1000 t of 42% Mn.

12.7.1.2 Northland deposits

Small manganese oxide deposits occur as stratabound lenses, lenticular laminae, nodules, disseminations and rhythmic layers associated with mafic lava, chert and volcanic argillite of the Permian-Jurassic Waipapa Group greywacke (Figs 50 and 51; Stanaway et al. 1978). The belt of Waipapa Group rocks containing the chert and manganese deposits extends along strike southeast from Whangaroa Bay to Whangarei Harbour. Total manganese production between 1878 and 1911 from the most significant deposits (Tikitikiora and Purerua Peninsula in the Bay of Islands, and Whangarei Harbour) was 19,364 tonnes (New Zealand Geological Survey 1970). Mineralogical and geochemical data on the deposits are given by Stanaway et al. (1978) and Roser (1983).

Bay of Islands

At Tikitikiore (Tikiora Hill; Q05/e15), stratabound lenticular lenses of manganese mineralisation, 1-10 m long and less than 1 m thick, are present in argillite, and pink and white chert within the greywacke-argillite rocks of the Waipapa Group (Sekula 1972; Roser 1983). The mineralisation consists of braunite, cryptomelane, nsutite (bementite), psilomelane, pyrolusite and lithiophorite. Between 1864 and 1885, several hundred tonnes of ore were mined from small pockets in 'quartzose or jasperoid greywacke'. Exploration by Winstone Mineral Exploration Ltd (Carlson 1974b) recorded manganese values of 50.8% and 28.2% (with low Fe) on selected samples.

At Frenchman's Hill (Q05/e16), small quantities of ore were recovered in the 1800s from numerous quarries and trenches. The manganese was associated with a bedded chert in Waipapa Group greywacke.

A number of other small deposits are present in the northeast Northland area and many were worked in the 1800s. They include deposits at: Kaiwauwaru Bay, Puketi, Purerua Peninsula (Mt Pocock; Q04/e1), Kiripaka Hill (Q05/e11), Manganese Hill, Hukerenui, Ruapekapeka (Q06/e64), and Otonga (Q06/e94 and Q06/e103) (Bell & Clark 1909; Ferrar 1925; Bell 1971b; Sekula 1972; Carlson 1974a, 1974b; Stanaway et al. 1978). Analyses for single samples have been reported for material at Kiripaka - 49.4% Mn (Ferrar 1925), Otonga - 63.4% (Ferrar 1925) and Mt Pocock - 50.0% Mn (Carlson 1974a). Bell (1976) reported that the deposit at Hukerenui (between Kawakawa and Whangarei) contains about 150,000 t of mineralised rock with assays up to 79% MnO₂.

Whangarei Harbour

At Parua Bay (Q07/e67), manganese is present in a thin sequence of red argillite, chert, and red and green basalts (Roser 1983). Over 2000 t of ore containing jacobsite and psilomelane was extracted between 1884 and 1894. Ferrar (1925) reported a single analysis of 41.16% Mn.

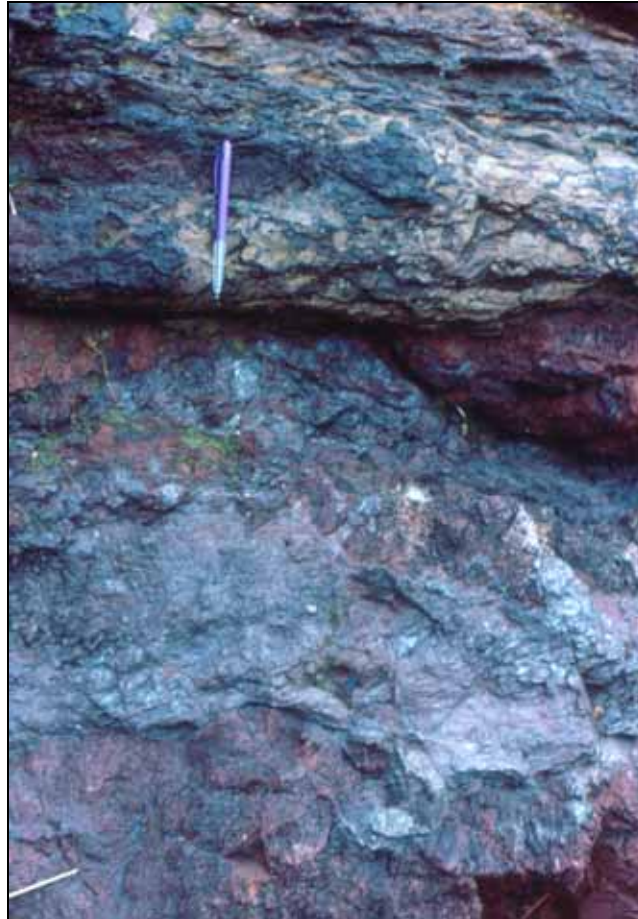


Figure 51. Manganese minerals (black) in bedded red and pale brown argillite, Manganese Point, Whangarei. Photo: Bob Brathwaite.

At Manganese Point (Q07/e66), a complex sequence of interbedded basalt, cherts, and argillites are intercalated in the Waipapa Group greywacke-argillite. Stratabound pods less than 30 cm in length and conformable lamellae less than 5 cm thick are present in red and pink cherts and red argillites, and contain cryptomelane, psilomelane, minor pyrolusite and braunite (Roser 1983).

At Stockyard Cove (R07/e8), a sequence of basalt, argillite and chert is terminated by a fault and overlain by sandstone and manganese-bearing bedded chert (Roser 1983). Psilomelane and pyrolusite are present as one cm-wide secondary joint fillings in cream and red cherts. The deposit was prospected by several adits but no production was recorded.

12.7.1.3 Potential

We consider that there is a 161% probability of the presence of manganese resources corresponding to the model size in Northland, representing 676 t of manganese, in known and undiscovered deposits (Fig. 50). The larger number of known deposits in the Far North district results in a larger estimate than the Whangarei district.

12.8 MERCURY

12.8.1 Hot spring Hg type mercury deposits (Fig. 52)

12.8.1.1 *International model*

References

USGS model 27a Hot-spring mercury (Cox & Singer 1986) and BCGS model H02 Hot-spring Hg (Lefebure & Höy 1996).

Description

Cinnabar is found disseminated in siliceous sinters, hydrothermal breccias and lacustrine sediments overlying or adjacent to greywacke, and andesite and rhyolite lavas, breccias and tuffs. The ore consists of cinnabar, pyrite and marcasite disseminated in laminated chalcedonic quartz. Stibnite and electrum may also be present.

International examples

Sulphur Bank and Knoxville District, California; McDermitt and Steamboat Springs, Nevada; Abuta mine, Japan.

Grade and tonnage

USGS model 27a 50th percentile = 9500 t and 0.35% Hg, equivalent to 33 t Hg (Cox & Singer 1986, pp. 178-179). This seems low in comparison with the known resources in Northland deposits such as Puhipuhi, Huia and Puketū (85 t, 230 t and 87 t respectively) and therefore a value of 100 t is selected for our model.

12.8.1.2 *Northland deposits*

Major occurrences of mercury are related to fossil Plio-Pleistocene hydrothermal activity at Puhipuhi Plateau, and the active geothermal system at Ngawha (Fig. 52). In the late 1980s, Vulcan Mines Limited planned to mine mercury at Huia and Puketū, but these plans were abandoned following administrative delays and a fall in the price of mercury (Brown 1989).

Puhipuhi (Q06/e73)

Alluvial cinnabar was found at Puhipuhi in 1892, and in 1907 cinnabar was discovered in siliceous sinter. Four areas of mineralised rock were eventually found along a northerly trend over a distance of 6.5 km: Rising Sun, Puhipuhi, Plum Duff and Mount Mitchell (Henderson 1944; Williams 1974; Cranny & Hill 1983; White 1983, 1986). Surface and underground mining of the deposits between 1917 and 1945 produced a total of 31.1 t of mercury at grades of 0.25 to 1% Hg (Williams 1974). Much of this mining was subsidised to meet wartime strategic requirements, and was probably uneconomic (Williams 1974).

The deposits consist of mineralised siliceous sinter, silicified breccias, and hydrothermally altered Waipapa Group greywacke country rock. The greywacke is unconformably overlain by erosional remnants of Plio-Pleistocene lake beds and Kerikeri Basalt, both of which are hydrothermally altered to varying degrees.

At the Rising Sun mine, cinnabar is present as 'paint' coating joints in a thin layer of shattered, silicified greywacke. At the Puhipuhi mine, mercury was mined from silicified breccia, which White (1983) interpreted as a fossil scree. The breccia is cemented by chalcedonic quartz with vugs and partings coated by cinnabar and marcasite. Plum Duff consists of a collapsed sinter sheet containing brecciated and silicified blocks of sinter. At Mt

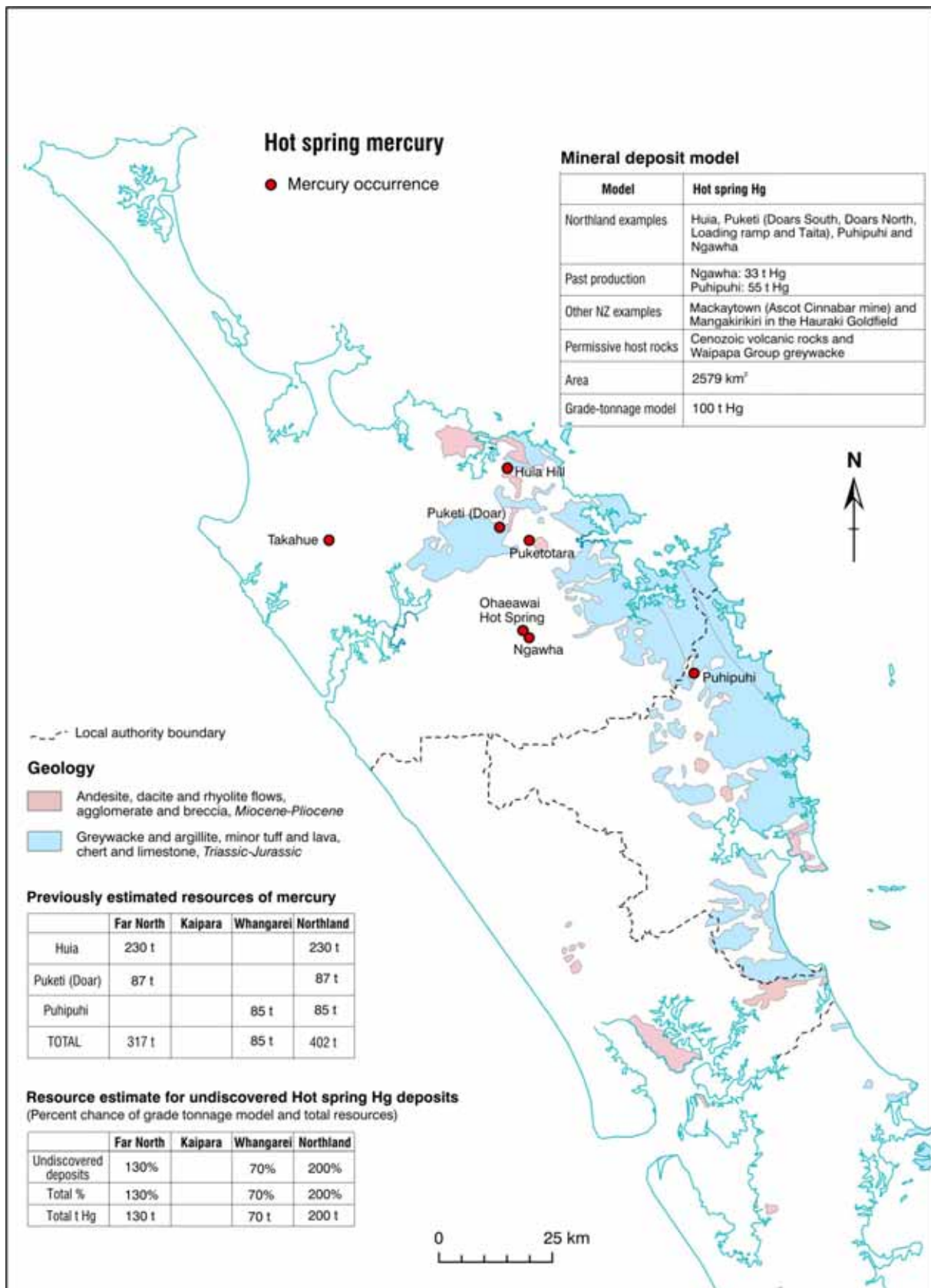


Figure 52. Location of mercury prospects from the GERM database and areas of greywacke and volcanic rocks prospective for hot spring Hg deposits.

Mitchell, a sheet of siliceous sinter contains cinnabar, stibnite, marcasite and pyrite. Silver-bearing quartz veins in the basement greywacke, 2 km to the northwest and probably 100 m below the level of the cinnabar deposits, represent a deeper level exposure of the Puhipuhi epithermal system.

Lime & Marble Ltd carried out drilling in the Mt Mitchell area (Braithwaite & Ball 1969), and IMC Corporation explored the Puhipuhi mine area, defining an inferred resource of 85 t of mercury (Carlson & Main 1971). However, previous mining ventures were not significantly profitable, and the high overburden ratio of about 35:1, coupled with the low grade of the mineralisation, indicated that the deposit was subeconomic. Exploration of the Puhipuhi field since 1980 has targeted gold mineralisation (Cranney 1985; BHP Gold 1988; Brown 1989).

Ngawha (P05/e60)

Mercury deposits at Ngawha are related to active hot springs, vapour emanations, and mud pools in the Ohaeawai area (Bell & Clarke 1909; Henderson 1944; Williams 1974; Davey & van Moort 1986). The mercury, as cinnabar and native mercury, is associated with one or more of marcasite, stibnite, realgar, hydrocarbons, and bituminous matter. Assays of thin sinters, intercalated with lake muds and sands, showed only traces of gold and silver (Bell & Clarke 1909). The ore-bearing rock is Late Pleistocene lacustrine mudstone and sandstone, deposited in a valley formed as a result of damming by lava flows. The deposits were worked in the 1890's and also from 1927-1934 and 1941-1945, for a total yield of about 33 tonnes of mercury at an average grade of 0.2% Hg. Drillholes for site investigation at the newly constructed prison intersected fossil lake sediments with significant mercury mineralisation.

Huia Hill prospect (P04/e33)

Prospecting, including shallow auger drilling by Western Mining Corporation in the early 1970s, defined four lenses of cinnabar mineralisation in hydrothermally altered, bedded andesitic tuffs (Wairakau Andesite) at Huia Hill, near Kaeo (Anon 1972c; Shugg 1972b, 1973; Bell 1982a; McOnie 1985; Brown 1987b, 1989). The lenses are 1-5 m thick and up to 25 m in length, with average grades of 0.47-1.3% Hg (Shugg 1973). Within the lenses, the cinnabar occurs in veins and veinlets. At Tairaire, 2 km southeast of Huia, diamond drilling outlined small lenses of low grade (<1.0% Hg) cinnabar mineralisation in argillically altered andesitic breccias and tuffs (Bell 1982a; Canyon Resources 1986).

Doar prospect, Puketi (P04/e51)

Flat-lying lenses of fracture-fill cinnabar and disseminated pyrite mineralisation, grading 0.18-0.49% Hg, occur in the lower 3 m of a 9 m thick Eocene greensand bed (probably Ruatangata Sandstone of Te Kuiti Group), which is overlain and underlain by mudstone (Shugg 1973; Brown 1987b, 1989). White (1983) noted that the mercury is associated with pyritic clay-silica alteration in the adjacent greywacke basement, and is related to a regional fault zone. Proposals to develop these deposits have, so far, not come to fruition (Brown 1989).

Takahue Prospect (O05)

Stibnite and cinnabar have been reported at Takahue and exploration by Pacminex (Neuss 1972e) located disseminated stockwork pyrite, and defined a Cu geochemical anomaly.

12.8.1.3 Potential

In addition to defined inferred resources of 402 t of mercury (Fig. 52), we consider that there is a 240% probability of the presence of 1 medium sized hot spring Hg deposit in Northland, representing 240 t of mercury (Fig. 52), making a total of 642 t.

12.9 NICKEL

12.9.1 Lateritic Ni deposits (Fig. 53)

12.9.1.1 International model

Reference

USGS model 38a Lateritic Ni (Cox & Singer 1986).

Description

Nickel-rich *in situ* lateritic weathering products developed from ultramafic rocks, particularly peridotite, dunite and serpentinitised peridotite. Nickel-rich iron oxides are most common. Some deposits are predominantly nickel silicates.

International examples

Poru, New Caledonia; Cerro Matosa, Columbia; Nickel Mountain, Oregon, USA; Greenvale, Queensland, Australia.

Grade and tonnage

USGS model 38a 50th percentile = 44 Mt at 1.4% Ni (Cox & Singer 1986, pp. 252-254).

12.9.1.2 Northland deposits

Traces of nickel have been found in the laterite developed on the serpentinite and gabbro at Surville Cliffs, North Cape (Fig. 53; Bell & Clarke 1909).

12.9.1.3 Potential

There is a 0.01% probability of the Surville Cliffs area hosting a medium sized Lateritic Ni deposit, representing 6160 t Ni. The low probability reflects the large size of the international model and the small potential area or outcropping rocks at Surville Cliffs (Fig. 53). No estimate is made for undiscovered deposits, because of the scarcity of suitable outcropping ultramafic plutonic rocks elsewhere in Northland.

12.9.2 Gabbroid-associated Ni-Cu type nickel deposits (Fig. 54)

12.9.2.1 International model

Reference

USGS model 7a Synorogenic-synvolcanic Ni-Cu (Cox & Singer 1986).

Description

Massive lenses, matrix and disseminated sulphide in small to medium sized gabbroic intrusions in greenstone belts. The sulphides are commonly in the more ultramafic parts of the complex and near the basal contacts of the intrusion. Host rocks are norite, gabbro-norite, pyroxenite, peridotite, troctolite, and anorthosite, forming layered or composite igneous complexes. The main ore minerals are pyrrhotite, pentlandite, chalcopyrite, plus local pyrite, Ti-magnetite, Cr-magnetite, graphite, byproduct Co and PGE.

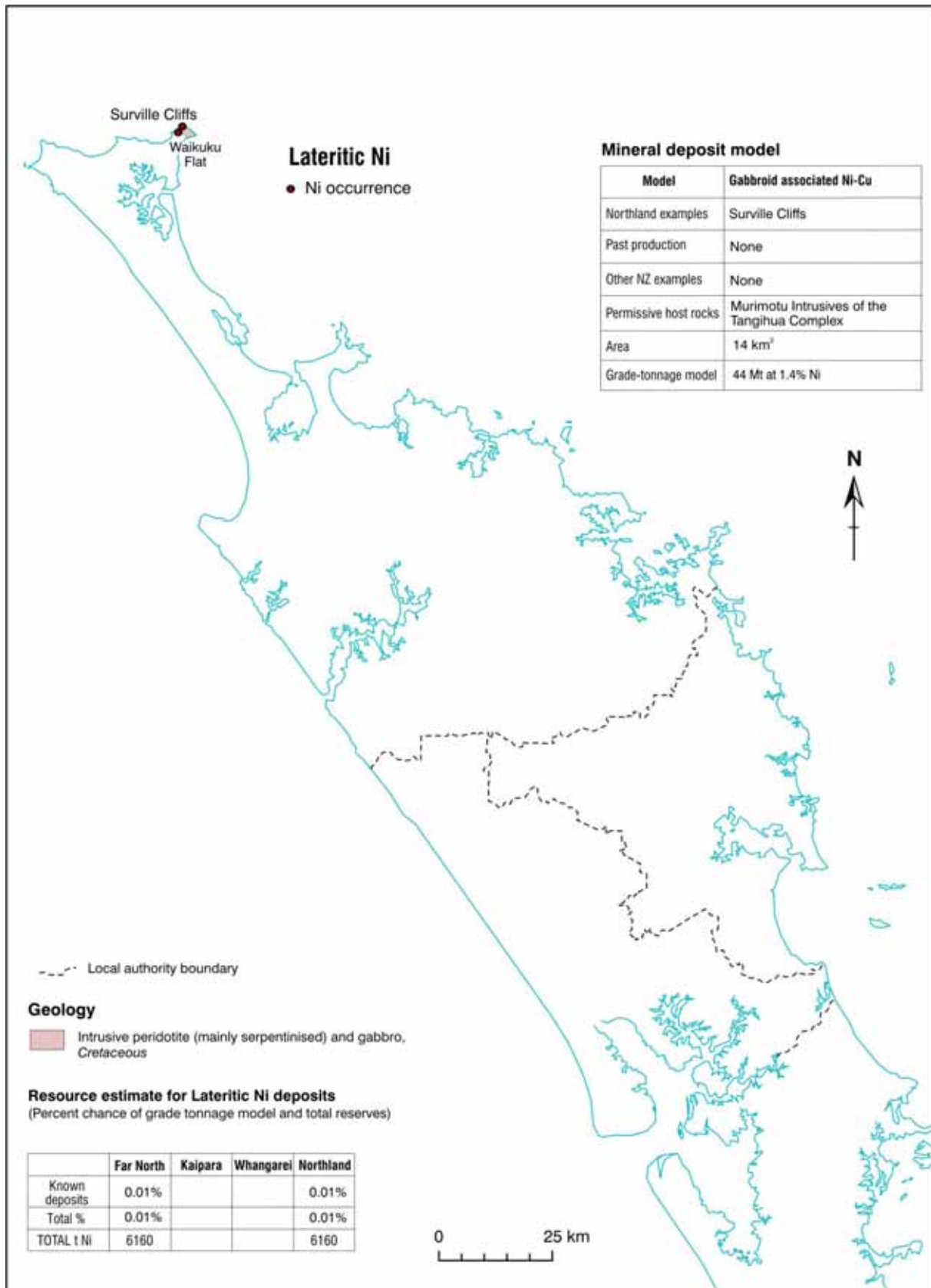


Figure 53. Location of nickel sites from the GERM database and areas of mafic intrusive rocks prospective for lateritic Ni deposits.

International examples

Sally Malay, Western Australia; Rana, Norway; Moxie pluton, Massachusetts, USA.

Grade and tonnage

USGS model 7a 50th percentile = 2.1 Mt at 0.77% Ni and 0.47% Cu (Cox & Singer 1986, pp. 28-31).

12.9.2.2 Northland deposits

Traces of nickel have been found in the laterite developed on the serpentinite and gabbro at Surville Cliffs, North Cape (Fig. 54; Bell & Clarke 1909).

12.9.2.3 Potential

There is a 0.5% probability of the Surville Cliffs area hosting a medium sized Gabbroid-associated Ni-Cu deposit. A 0.5% probability of the model is also assigned for undiscovered deposits in the Far North district, the low probability reflecting the apparent scarcity of suitable intrusive host rocks. The total 1% represents 162 t Ni and 99 t of copper (Fig. 54).

12.10 ZINC AND LEAD

12.10.1 Zn-Pb polymetallic vein type zinc and lead deposits (Fig. 55)

12.10.1.1 International model

References

USGS model 22c Polymetallic veins and USGS model 25b Creede epithermal veins (Cox & Singer 1986), and BCGS model I05 Polymetallic veins Ag-Pb-Zn±Au (Lefebure & Höy 1996).

Description

Sulphide-rich veins containing sphalerite, galena, silver and sulphosalt minerals in a carbonate and quartz gangue. These veins can be subdivided into those hosted by metasediments and another group hosted by volcanic or intrusive rocks. The latter type of mineralization is typically contemporaneous with emplacement of a nearby intrusion. The veins are typically steeply dipping, narrow, tabular or splayed. They commonly occur as sets of parallel and offset veins. Individual veins vary from centimetres up to more than 3 m wide and can be followed from a few hundred to more than 1000 m in length and depth. Veins may grade into broad zones of stockwork or breccia.

International examples

- Metasediment host: Coeur d'Alene district, Idaho, USA; Harz Mountains and Freiberg district, Germany; Příbram district, Czechoslovakia.
- Igneous host: Sunnyside and Idorado, Silverton district and Creede, Colorado, USA; Pachuca, Mexico.

Grade-tonnage data

Individual vein systems range from several hundred to several million tonnes grading from 5 to 1500 g/t Ag, 0.5 to 20% Pb and 0.5 to 8% Zn. The 50th percentile for polymetallic veins given by Cox in Cox & Singer (1986) is 7600 t at 820 g/t Ag, 0.13 g/t Au, 9% Pb and 2.1% Zn.

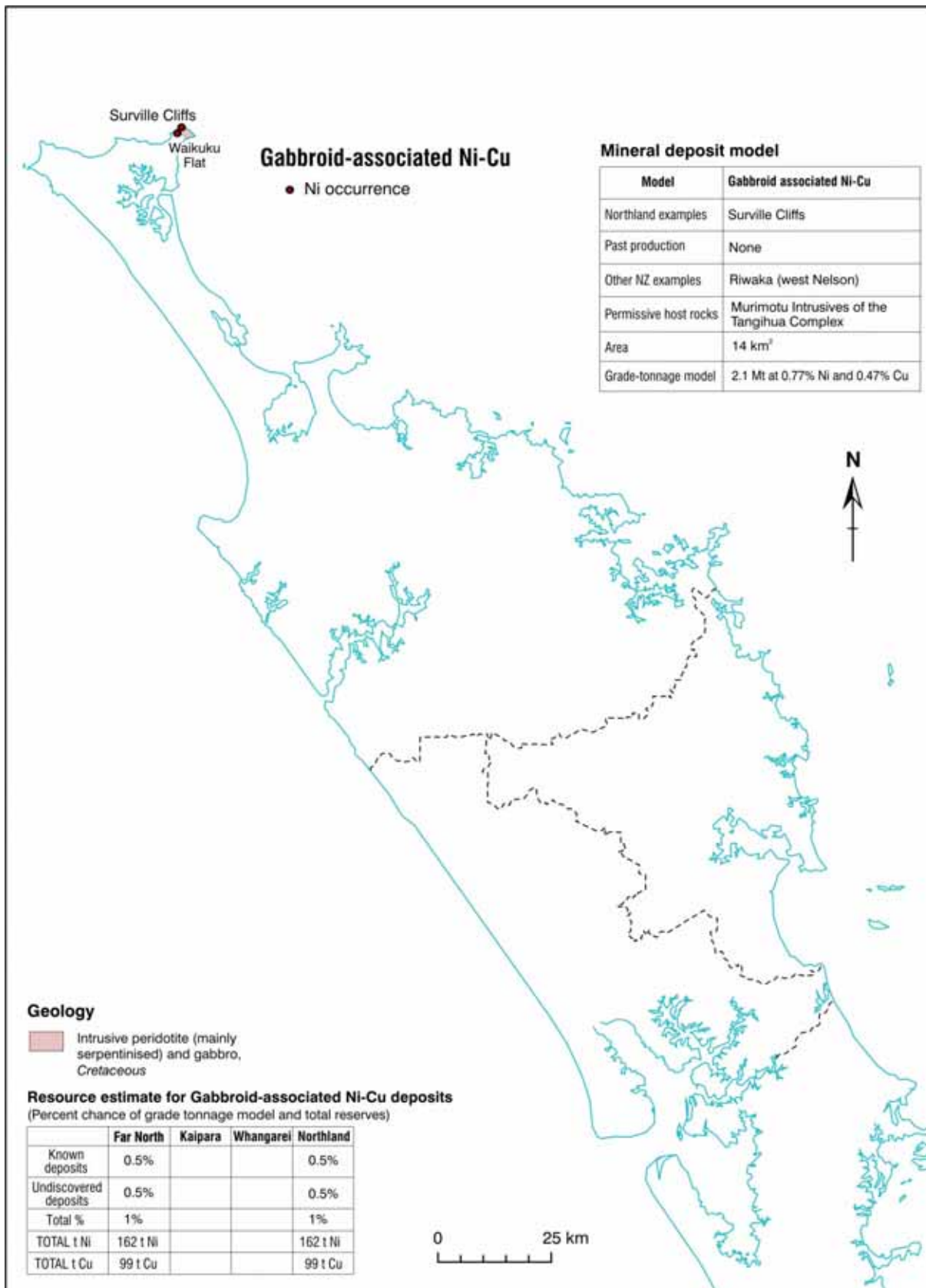


Figure 54. Location of nickel sites from the GERM database and areas of mafic intrusive rocks prospective for gabbroid associated Ni-Cu deposits.

12.10.1.2 Northland deposits

Kauri Mountain

A 1.2 m wide vein of mixed sulphides, mainly sphalerite and pyrite, with chalcopyrite and galena, occurs in greywacke on the shoreline (Reef Bay) near Kauri Mountain (R07/e9; Fig. 55), and may be associated with nearby andesite porphyry stock that intrudes Oligocene-Miocene siltstone and limestone (Ferrar 1925; Bell 1976).

12.10.1.3 Potential

There is a 10% probability of known deposits and a 20% probability of undiscovered deposits containing resources equivalent to the model, split evenly between Far North and Whangarei districts (Fig. 55).

12.10.2 Zn-Pb skarn type zinc and lead deposits (Fig. 56)

12.10.2.1 International model

References

USGS model 18c Zinc-lead skarn (Cox & Singer 1986) and BCGS model K02 Zn-Pb skarns (Lefebure & Ray 1995).

Description

Deposits consist of Zn-Pb-Ag sulphide minerals as replacement bodies in limestone proximal or distal to quartz diorite stocks. They contain disseminated sphalerite, galena and pyrite.

International examples

San Antonio and Santa Eulalia, Mexico; Yeonhua, Korea; Ban Ban, Australia; El Sapo, Columbia.

Grade-tonnage data - international

USGS model 18c 50th percentile = 1.4 Mt, and 5.9% Zn and 2.8% Pb, possible byproduct Ag, Au and/or Cu (Cox & Singer 1986, pp. 90-93). See also Lefebure & Höy (1996, p. 139) BCGS model K02. Worldwide, skarn deposits range from <1 to 30 Mt and grade 10-20% Zn + Pb and 30-300 g/t Ag.

12.10.2.2 Northland deposits

Motukokako

During the 1980s, zinc-lead skarn mineralisation was discovered in Oligocene Whangarei Limestone at Motukokako (Piercy Island; Q05/825; Fig. 56), Cape Brett (Brathwaite et al. 1990). The skarn is composed of the calc-silicate minerals hedenbergite, garnet, epidote, axinite, ilvaite and babingtonite, which are enriched to varying degrees in manganese and iron. Sphalerite and galena are disseminated in the skarn, in adjacent recrystallised limestone, and in quartz veins that cut the limestone and the unconformably underlying greywacke. The grade of the skarn mineralisation is of the order of 1-6 % Zn and 0.2-1 % Pb, with up to 100 ppm Ag (Brathwaite et al. 1990), which is significantly lower than average grades of 9 % Zn and 6 % Pb from economic Zn-Pb skarn deposits (Einaudi & Burt 1982). There are no igneous rocks exposed and the skarn is distal, in the sense that the most likely igneous source, a quartz-diorite stock, may lie several kilometres below or lateral to the skarn.

12.10.2.3 Potential

The permissive host rocks are contact zones between intrusive rocks and limestones and other calcareous rocks, however the geological mapping is insufficiently detailed to show these on Figure 56. We suggest that there is a 65% probability of known (5%) and undiscovered (60%) deposits containing resources equivalent to the model, mostly in the Far North district (Fig. 56). This equates to total resources of 53,690 t Zn and 25,480 t Pb for Northland.

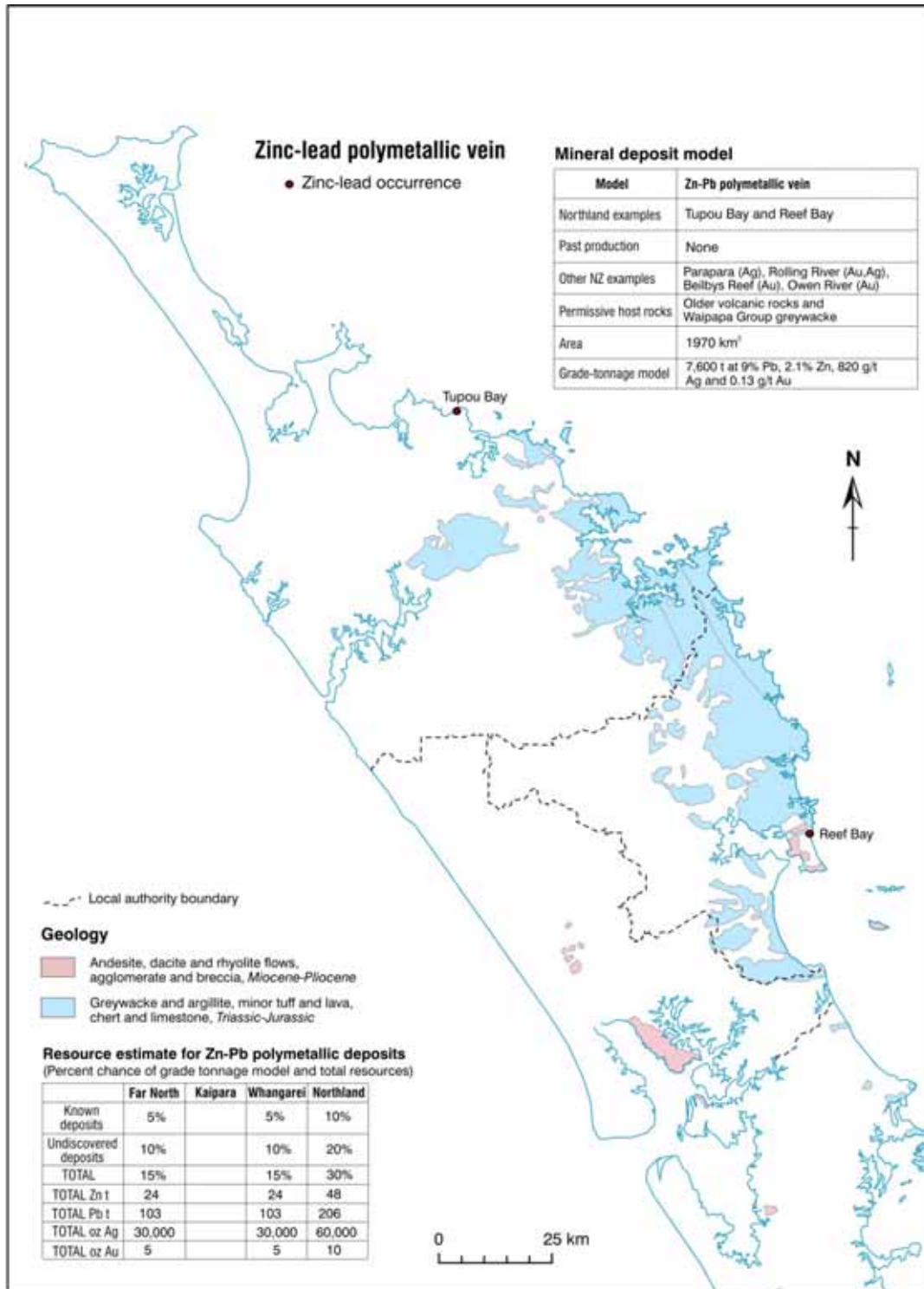


Figure 55. Location of Zn-Pb polymetallic vein deposits from the GERM database and areas of greywacke and volcanic rocks that are prospective host rocks.

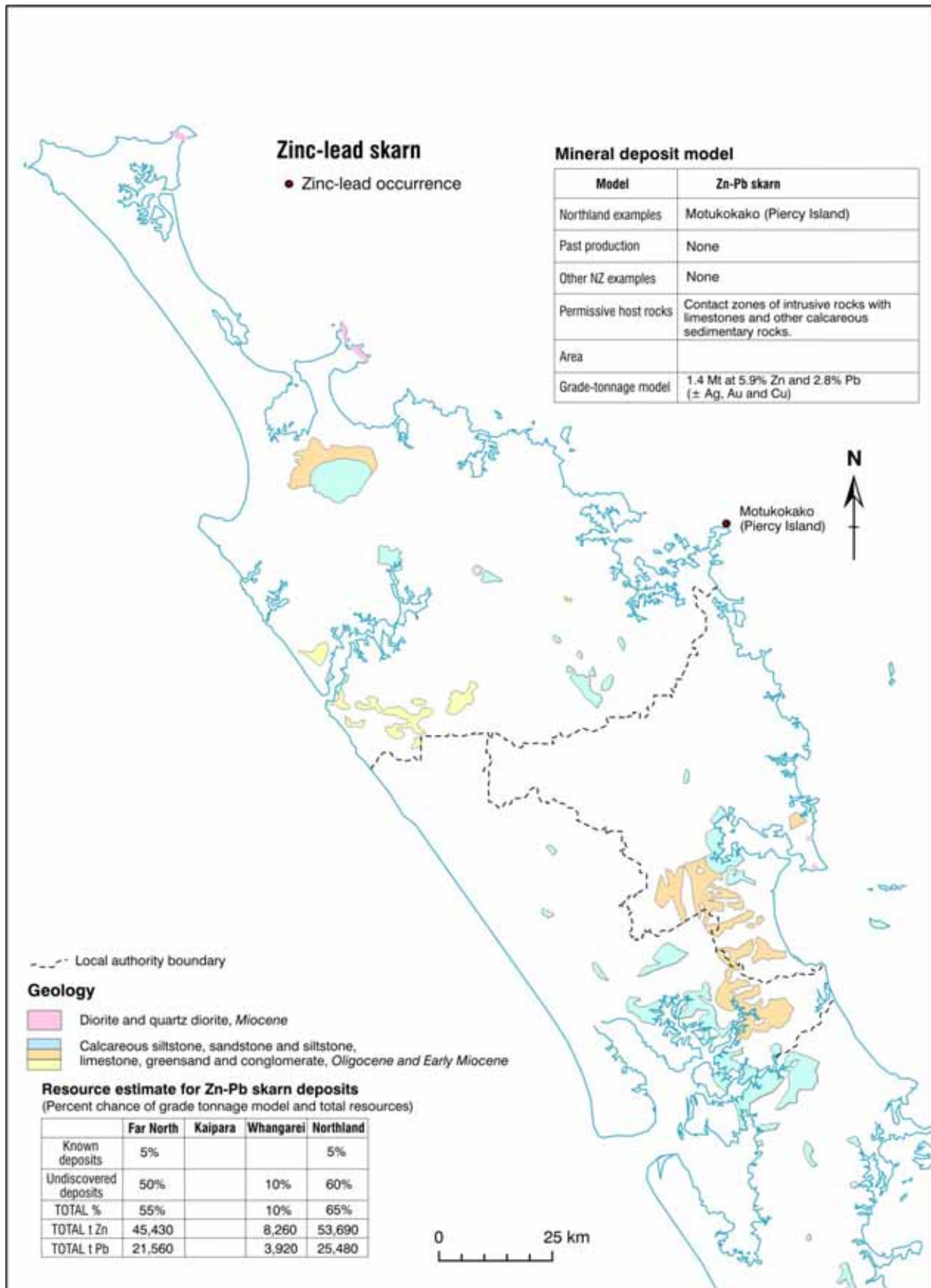


Figure 56. Location of the Motukokako (Piercy Island) Zn-Pb skarn deposit and areas of limestone and intrusive rocks prospective for Zn-Pb skarn deposits.

13.0 NON-METALLIC MINERALS AND ROCKS

13.1 ASBESTOS

Asbestos, as chrysotile in veins, is associated with the serpentinite at Surville Cliffs (N02/e20). This occurrence is considered a curiosity and the potential for an economic deposit of asbestos in Northland has not been quantified in this study.

13.2 BARITE

Barite concretions from mudstones within the Whangakea Volcanics occur at Herangi Hill (M02/e3). The quantity is small and therefore the potential for barite in Northland has not been quantified in this study.

13.3 CLAYS

Almost all of the rocks of Northland have been affected by subtropical weathering. This has resulted in extensive areas of clay with a wide variety of colour and texture. Five geologically distinct genetic types are found in Northland: (a) rhyolite-hosted halloysite clay; (b) volcanic-related kaolinite clay (transitional with (a)), (c) sedimentary kaolinite clay, including primary, *in situ* or transported clays, (d) fireclays associated with coal measures, and (e) bentonite (Quennell 1964; Bowen 1966a, 1974; Gallot, 1967a, 1967b, 1972a, 1972b; Harvey 1968, 1975; Townsend 1989; Townsend et al. 2006).

13.3.1 Rhyolite-hosted halloysite clay (Fig. 57)

13.3.1.1 Model

Description

Halloysite clay deposits formed from hydrothermal alteration and weathering of rhyolite domes.

Grade-tonnage data

We suggest 2 Mt at about 50% halloysite for a Northland model.

13.3.1.2 Northland deposits

Northland contains many deposits of halloysitic clays produced by hydrothermal alteration and weathering of volcanic rocks. Many of these deposits also have significant quantities of kaolinite and are therefore also included in the Volcanic-related kaolin clay model section following.

Matauri Bay (P04/e17)

Halloysite clay, reputed to be 'the world's whitest clay', is produced from mines at Matauri Bay and nearby Mahimahi, by Imerys Tableware NZ Ltd, formerly NZ China Clays Limited (Townsend 1989; Harvey et al. 1990; Harvey & Murray 1993; Luke 1997; Townsend et al. 2006; Figures 58, 59 and 60). The clay is formed by hydrothermal alteration and subtropical weathering of Pliocene to Pleistocene rhyolite domes (Putahi Rhyolite) to material comprising approximately 50% clay and 50% quartz, cristobalite and minor feldspar.

The Matauri Bay rhyolite dome is about 29 ha in area, of low relief and completely surrounded and partly overlapped by thick (up to 60 m) flows of basalt. The Mahimahi deposit consists of a rhyolite dome similar to that at Matauri Bay, but emplaced through glauconitic sandstone (MacFarlan & Barry 1991).

The high purity halloysite product from Matauri Bay possesses exceptional whiteness and brightness, an overall fine particle size, coupled with low iron (0.28%) and titania levels (0.08%). It is exported to more than 20 countries for the manufacture of high-quality ceramics, principally porcelain, but also fine bone china and technical ceramics. There are two main applications in the technical ceramics industry. The main market is in synthetic zeolite-based molecular sieves, whereas the other is in the manufacture of honeycomb catalyst supports. A coarser by-product is sold on the local market as filler clay. A silica sand by-product is used in the local building industry and for golf course bunkers.

The Northland halloysite deposits have been worked since 1969. About 80,000 tpa of raw clay is mined from the Matauri Bay and Mahimahi deposits with 50% of plant feed from each. Plant capacity is about 25,000 tpa of processed halloysite.

Shepherds Hill

Shepherds Hill rhyolite dome lies along the same east-west alignment as the Matauri Bay and Mahimahi deposits.

Te Pene (P04/e11)

More than 50 holes were drilled at Te Pene by Clay Enterprises Ltd resulting in a resource estimate of 5.39 M m³ of clay, with an additional 1.61 M m³ of discoloured clay (Quennell 1963, 1964a, 1964b). The halloysite and cristobalite deposit extends over an area of approximately 24 hectares, to a maximum depth of 52 m.

Maungaparerua (P05/e5)

Maungaparerua is the largest of the Northland rhyolite domes (Bowen 1969a, 1996b). It is semicircular in plan and 142 ha in area. A hard siliceous clay formed by hydrothermal alteration has been further altered by intense surficial weathering to produce relatively soft clay in an upper 8-30 m (averaging 15 m) thick zone, 600 to 700 m in diameter (Murray et al. 1976). On the western side of the dome, a zone of locally intense hydrothermal alteration in adjacent basalt consists of kaolinitic clays with siliceous sinters and disseminated metallic sulphides (Wodzicki & Weissberg 1982; MacFarlan 1992). Various drilling programmes (Gallot 1967a, 1967b; 1971a, 1971b; Poynter 1967; Harvey 1968) resulted in a resource estimate of 8 Mt of clay that could yield 2.25 Mt of premier product (Harvey 1975).

Ocean Beach, Whangarei Heads (R07/e5)

Seven holes were drilled at Ocean Beach by Mineral Holdings Ltd to a maximum depth of 23.4 m into white halloysitic clays formed from Pukekaroro Rhyodacites of Miocene-Pliocene age (Fergusson 1970, 1971a, 1971b). The clay is discoloured from iron staining, being white-yellow, pink, and brown in colour. The deposits of prime white clay are small and dispersed. Near two of the drillholes there is an indicated 50,000 t of clay, and smaller resources north and northeast of a clay pit at R07/517943. There are substantial quantities of impure clay present, but these are unsuitable as a filler because of colour and the presence of quartz and iron.

Pukekaroro Hills, Kaiwaka (Q08/e8)

At Pukekaroro Hills, hand augering to depths of 6 m on the lower slopes consisting of Pukekaroro Rhyodacite, showed that good quality clay is common, although the colour is variable (Bell, in Robinson et al. 1971, for Adaras). One locality contains 100,000 t of grey-white clay with a composition indicated by XRD analysis of 70% halloysite and 30% SiO₂.

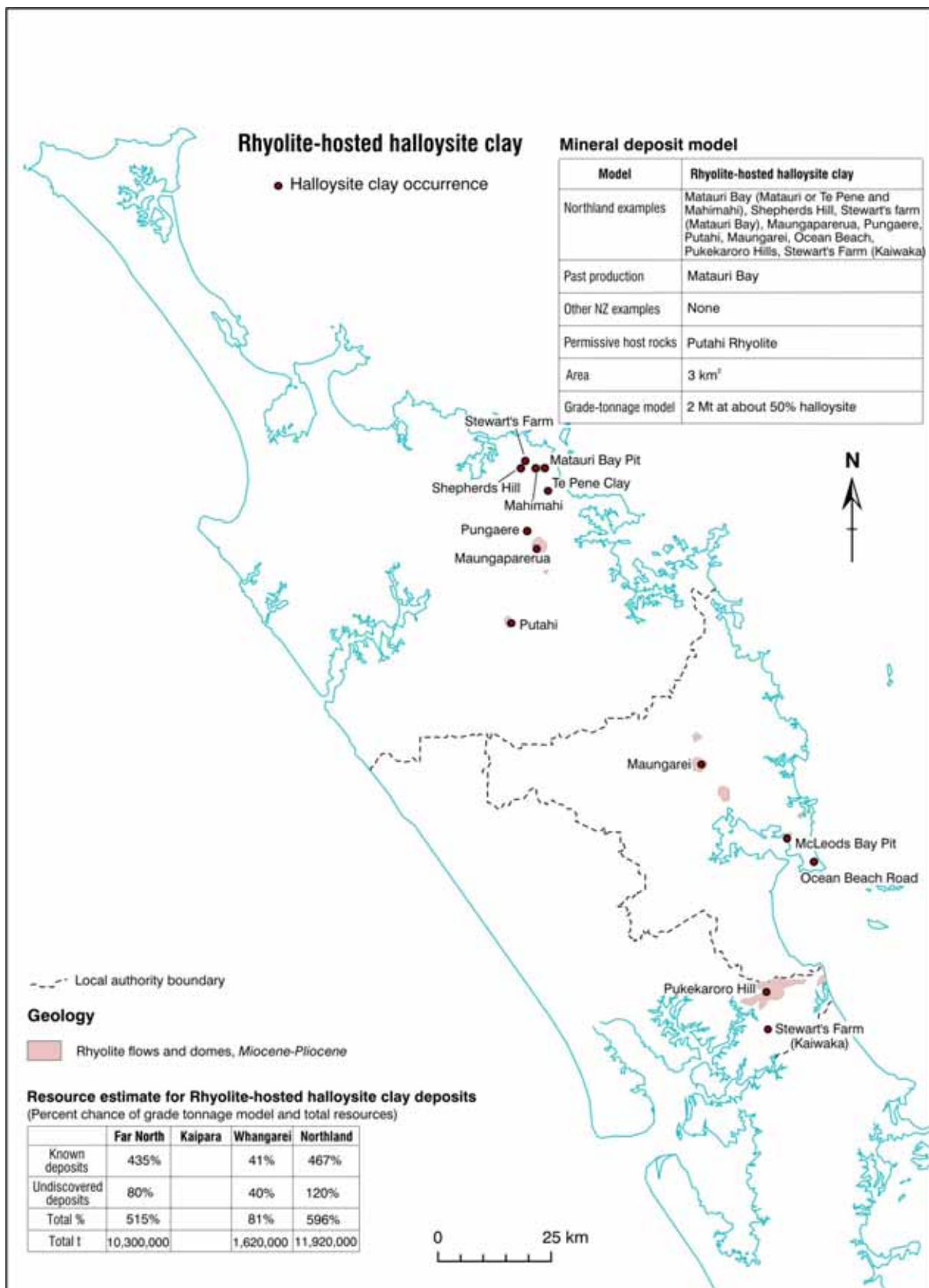


Figure 57. Location of rhyolite-hosted halloysite clay deposits from the GERM database and areas of rhyolite.

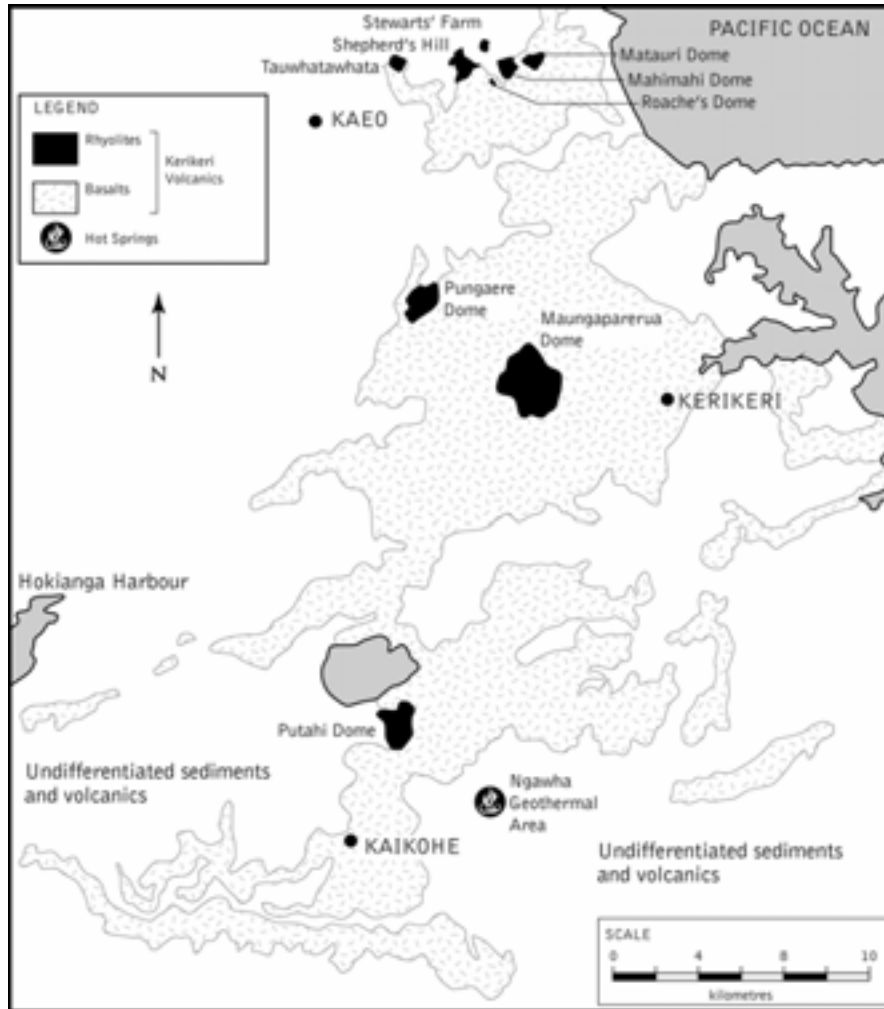


Figure 58. Location of Putahi Rhyolite domes and associated halloysite deposits in the Kaikohe - Bay of Islands area (after Figure 2 of Townsend et al. 2006).



Figure 59. Matauri Bay (foreground) and Mahimahi (distant) halloysite clay pits. Photo: Imerys Tableware Ltd.



Figure 60. Halloysite clay processing plant (centre) and Matauri Bay clay pit (bottom). Photo: Imerys Tableware Ltd.

Stewarts farm, Kaiwaka

At Stewart's farm, hand augering to depths of 6 m indicated a resource of 48,600 m³ of clay, of which 6100 m³ is of good quality and white in colour (Robinson et al. 1971). XRD analysis of a sample indicated a composition of 70% hydrated halloysite and 30% quartz. Additional drilling was carried out in 1972. This investigation showed that the clay deposits on the hill slopes were, in general less thick, more variable in texture and colour, and coarser in grade than that on the terraces.

13.3.1.3 Potential

Sufficient proven reserves of high quality clay exist at the Matauri Bay and nearby Mahimahi deposits to sustain production for over 12 years at current production rates and product types. If markets can be obtained in areas where the current very tight product parameters can be relaxed, the mine life projections will be extended to 50 years or greater. Research into these new markets is ongoing. Potential resources are present in other deposits at Shepherds Hill, Maungaparerua, and to a lesser extent several other known deposits, although quality may be an issue. There is also some potential for undiscovered deposits. Therefore, we have estimated 596% probability of clay resources present in known (467%) and undiscovered (120%) deposits equivalent to the model (Fig. 57).

13.3.2 Volcanic-related kaolin clay (Fig. 61)

13.3.2.1 Model

Description

Kaolinite clay deposits formed from hydrothermal alteration of rhyolite, dacite and andesite. The main minerals are kaolinite, smectite, cristobalite, tridymite and quartz, with halloysite, pyrophyllite, diaspore, dickite and alunite locally present. Deleterious pyrite and marcasite may be present.

Grade-tonnage data

We suggest 0.5 Mt at 50% kaolinite for a Northland model.

13.3.2.2 Northland deposits

Kaolin deposits formed by alteration and weathering of volcanic rocks are widespread in Northland, but are generally of small extent. They include deposits of weathered and altered Pukekaroro Rhyodacite, Maungarei Dacite and Putahi Rhyolite (Fig. 61). Some have significant halloysite and are also included in the preceding Rhyolite-hosted halloysite clay model. Kaolin deposits.

have been recorded from Maungaparerua (P05/e5), Waikaraumu (P05/e65, 66), Paramata (Q05/e20), Hikurangi (Q06/e97), Kauri (Q06/e87), Maungarei (Q06/e88), Ocean Beach Road (R07/e5), McLeods Bay (Q07/e54) and Pukekaroro Hills (Q08/e8). All are white clays of low plasticity and contain kaolinite and halloysite. Some are of excellent quality, having low iron and alkali (Na₂O + K₂O) content and have been used in the manufacture of china ware or porcelain ware, and in the case of Kauri pit, for the manufacture of refractory bricks (Kamo Green Refractories). Bowen (1966a, 1974) gave resource estimates for some of these deposits, based on geological mapping and limited drilling, e.g. Maungarei 240,000 t and Munro Bay 50,000 t. At Puhipuhi, potters clay or potters earth has been recorded from Mount Mitchell, and elsewhere, drilling by BHP during gold exploration intersected kaolinite beneath basalt.

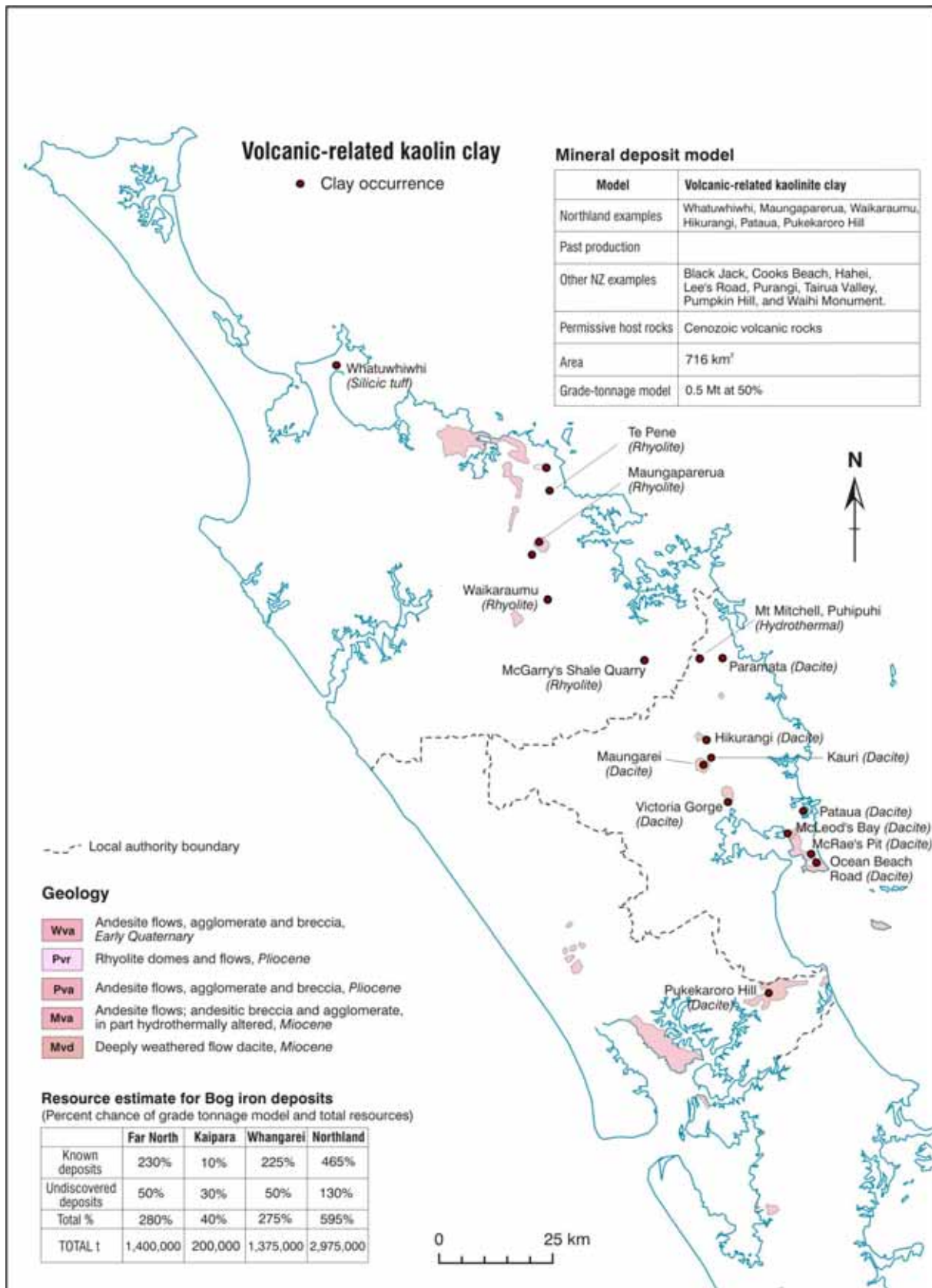


Figure 61. Location of volcanic related kaolin clay deposits from the GERM database and prospective areas of volcanic rocks.

13.3.2.3 Potential

There is a 595% probability of clay resources present in known (465%) and undiscovered (130%) deposits equivalent to the model (Fig. 61). These resources are likely to be mostly in the Far North and Whangarei districts.

13.3.3 Sedimentary kaolinite clay (Fig. 62)

13.3.3.1 Model

Reference

BCGS model E07 Sedimentary kaolin (Hora 1999).

Description

Kaolinitic clays formed by weathering of feldspathic rocks are eroded and transported to estuaries, lagoons, oxbow lakes and ponds forming beds, lenses and saucer-shaped bodies of clay. These are hosted by clastic sedimentary rocks, with or without coaly layers or coal seams. Diatomite deposits may also be present. Kaolinite is the main mineral, and halloysite, quartz, dickite, nacrite, diaspore, boehmite, gibbsite may be present. Post-depositional leaching, oxidation, and diagenesis can significantly modify the original clay mineralogy with improvement of kaolin quality.

The clay beds exhibit variable thickness, usually a few metres; sometimes multiple beds have an aggregate thickness of approximately 20 m. Deposits commonly extend over areas of at least several square kilometers.

International examples

Cypress Hills, Alberta, Canada; Eastend, Wood Mountain, Ravenscrag, Saskatchewan, Canada; Moose River Basin, Ontario, Canada; Shubenacadie Valley, Nova Scotia, Canada; Aiken, South Carolina, USA; Wrens, Sandersville, Macon-Gordon, Andersonville, Georgia, USA; Eufaula, Alabama, USA; Weipa, Queensland, Australia; Jari, Capim, Brazil.

Grade and tonnage data

Published data on individual deposits are very scarce. Deposits in Georgia, USA contain 90 to 95% kaolinite. Individual Cretaceous beds are reported to be up to 12 m thick and extend more than 2 km while those in the Tertiary sequence are 10 to 25 m thick and up to 18 km along strike. The Weipa deposit in Australia is 8 to 12 m thick and contains 40 to 70% kaolinite. In Brazil, the Jari deposit contains more than 250 Mt of commercial grade kaolin, and the Capim deposit contains greater than 200 Mt of kaolin. Ball clay deposits in Tennessee and Kentucky consist of kaolin with from 5 to 30% silica; individual deposits may be more than 9 m thick and extend over areas from 100 to 800 m long and up to 300 m wide. We suggest 0.5 Mt at 50% kaolinite for a Northland model.

13.3.3.2 Northland deposits

Northland has many deposits of primary, *in situ* or transported, most commonly bedded clays derived from the weathering of older volcanic, sedimentary and meta-sedimentary rock (Fig. 62). Sedimentary clays are common in both marine and non-marine beds and have been used in the past for making bricks and pipes. For example, Figure 20-4 of Fieldes et al. (1974) lists clay from claystones and mudstones at Whangarei and Dargaville.

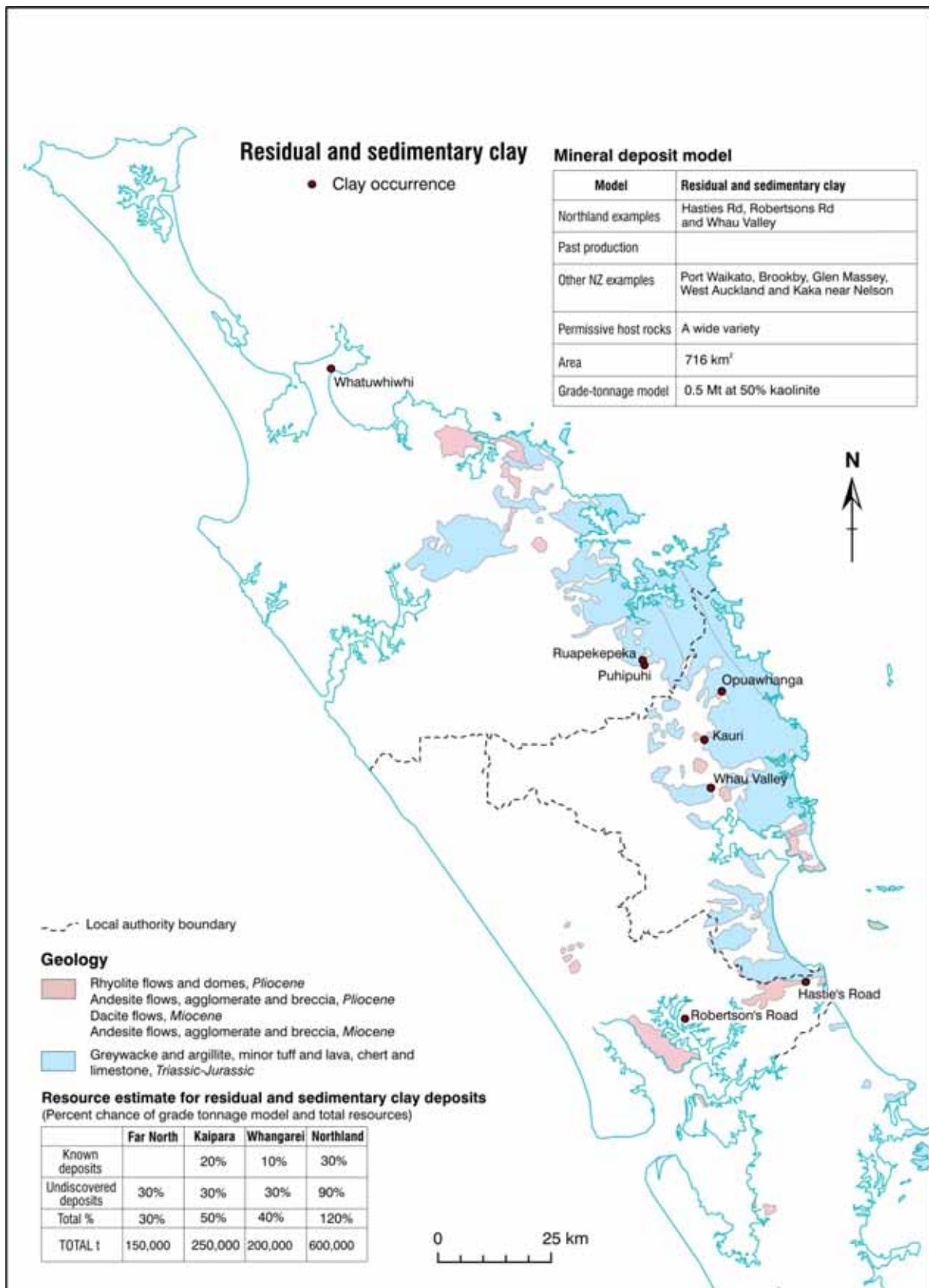


Figure 62. Location of residual and sedimentary clay deposits from the GERM database and prospective areas of volcanic and sedimentary rocks.

Fullers earth (fine grained naturally occurring clay or clay like material possessing a high adsorptive capacity) usually forms as a residual deposit by decomposition of a body of rocks, for example by devitrification of volcanic glass. It has been reported from Opuwhanga (Q06/e104) and Mount Parahaki (Q07/e61).

At Whatuwhiwhi two quarries (O03/e6) in weathered volcanics, and, another in alluvial clay (O03/e4), have produced clay for base course and fill.

13.3.3.3 Potential

There is a 120% probability of clay resources equivalent to the model present in known (30%) and undiscovered (90%) deposits, equating to 600,000 t of clay, with the largest potential in Kaipara district (Fig. 62).

13.3.4 Coal measure clays (Fig. 63)

13.3.4.1 Model

Description

Clay deposits associated with coal measures originate as primary sedimentary deposits or as deposits of mudstone that have been acid leached to produce fire clays. The fireclays are usually plastic, refractory and burn to pale colours. The kaolinite bearing beds are associated with coal (sub-bituminous and lignite), mudstone, siltstone, sandstone and conglomerate. The beds exhibit variable thickness, usually a few metres; sometimes multiple beds have an aggregate thickness of approximately 20 m. Deposits commonly extend over areas of at least several square kilometres. The kaolinite may be associated with quartz, and minor limonite, goethite, feldspar, mica, siderite, pyrite, ilmenite, leucoxene and anatase may be present.

Grade and tonnage data

We suggest 0.5 Mt at 40% kaolinite for a Northland model.

13.3.4.2 Known deposits

Clay from coal measures at Kamo (Q06/e74), north of Whangarei, was used in the past by Kamo Green Refractories Limited to produce industrial refractory products such as crucibles and fire brick (MacFarlan & Barry 1991) (high-alumina clays from Waikato Coal Measures and white, leached chert from the Waipapa Group metasediments were also used). Other Northland occurrences of fireclay include Mt. Hikurangi (Q06/e97), Mt. Parahaki (Q07/e61) and Hihi Valley (Whangarei). The composition of the clays approaches kaolinite, the better grades containing at least 35% Al₂O₃. Potters clay occurs at Kawakawa (P05/e42), underlying a small outcrop of coal in the Waiomio Stream. Low iron and alkali contents make the clay suitable for the manufacture of fire bricks and high grade pottery.

13.3.4.3 Potential

There is a 280% probability of clay resources equivalent to the model present in known (160%) and undiscovered (120%) deposits, equating to 1.4 Mt of clay, with the largest potential in Whangarei district (Fig. 63).

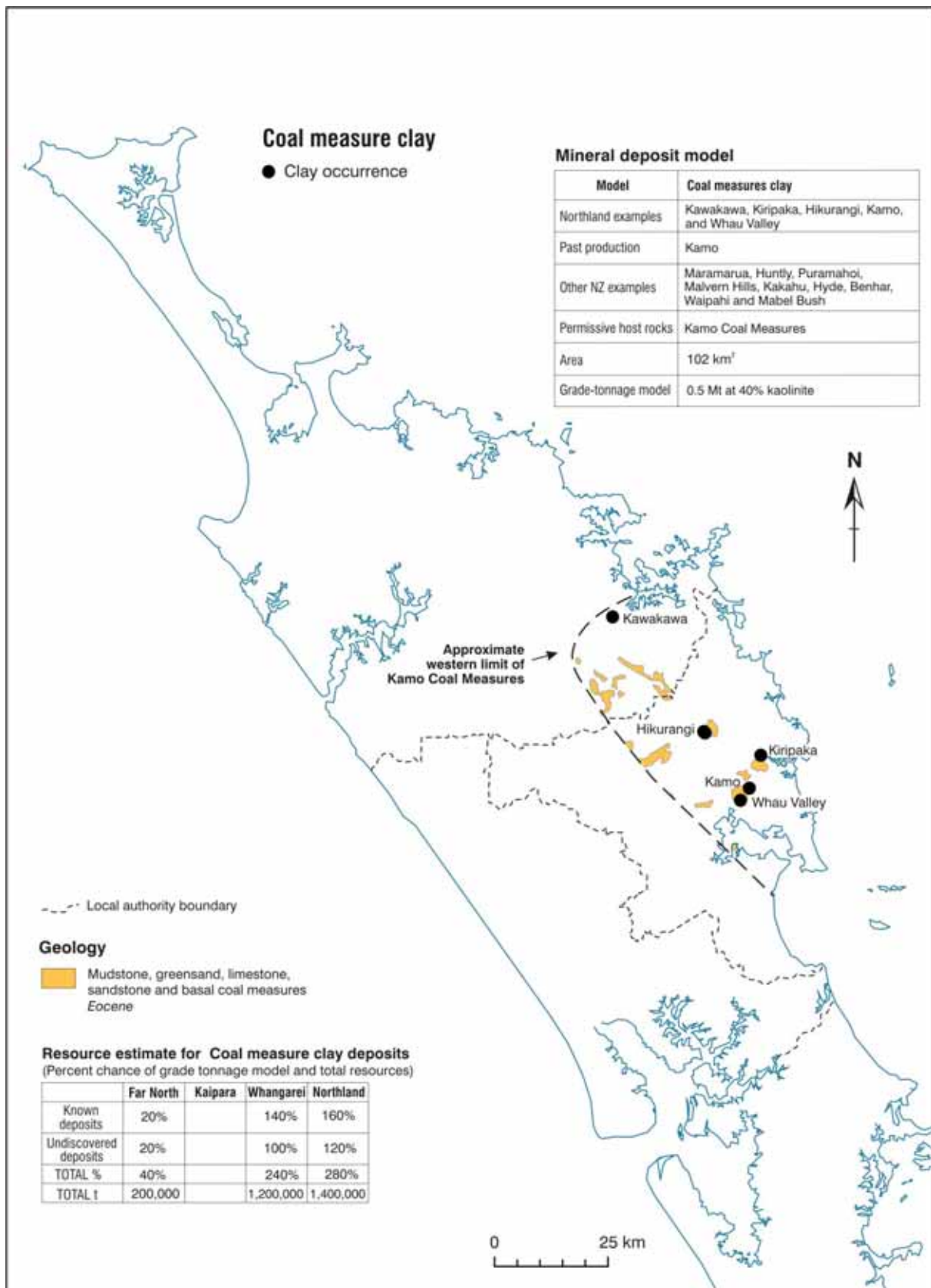


Figure 63. Location of coal measure clay deposits from the GERM database and areas of sedimentary rocks prospective for coal measures.

13.3.5 Bentonite (Fig. 64)

13.3.5.1 International and New Zealand model

Description

Bentonite clay is found interstratified with sedimentary rocks and was formed by the alteration of volcanic ash by seawater, freshwater or hydrothermal alteration. The bentonite beds are typically interbedded with siltstone, mudstone and sandstone.

Bentonite is a clay consisting predominantly of smectite (montmorillonite) minerals. It is characterised by exchangeable Na^+ , Ca^{2+} or Mg^{2+} cations which greatly influence the properties of the clay (and therefore its commercial applications). There are two types of naturally occurring bentonite: a swelling bentonite which has a high sodium-to-calcium ratio (sodium bentonite or Wyoming bentonite) and is typically associated with marine sediments, and a non-swelling bentonite with a low sodium to calcium ratio (calcium bentonite) that is typically associated with freshwater sediments. The swelling variety has the ability to absorb water and swell many times its original volume to form gel-like masses. Calcium bentonite can be converted to a sodium-type (termed sodium exchange bentonite) by treatment with soda ash to improve swelling capacity. It can also be used to produce acid-activated bentonite by treatment with inorganic acids to replace divalent calcium ions with monovalent hydrogen ions and to leach out ferric, ferrous, aluminium and magnesium ions, thus altering the crystal structure, and increasing the specific surface area and porosity.

International examples

Swelling (Na-smectite) in Wyoming and Montana, and low swelling (Ca-bentonite) in Mississippi, Texas, California, Colorado and Arizona, USA; Milos Island, Greece; Bavaria, Germany; Ankara region of Turkey; Honshu, Japan; and Sardinia, Italy.

Grade and tonnage – New Zealand

At Stoddart's Farm, Porangahau, there is a resource of about 1 Mt, but selective mining is necessary to produce to specification. At Coalgate, measured resources total about 11 Mt of fairly pure, non-swelling bentonite. A value of 1 Mt of contained bentonite is selected as a resource model.

13.3.5.2 Known deposits in Northland

Ritchie (1962a) listed samples of bentonite from three localities in Northland: Kaeo, Motatu (P06/e29) and Puhipuhi (Q06/e77) (Fig. 64). The Puhipuhi locality was described as decomposed lower part of basalt overlying mercury ore.

13.3.5.3 Potential

There is a 86% probability of bentonite resources equivalent to the model present in known (11%) and undiscovered (75%) deposits, equating to 860,000 t of bentonite, with the largest potential in the Far North district (Fig. 64).

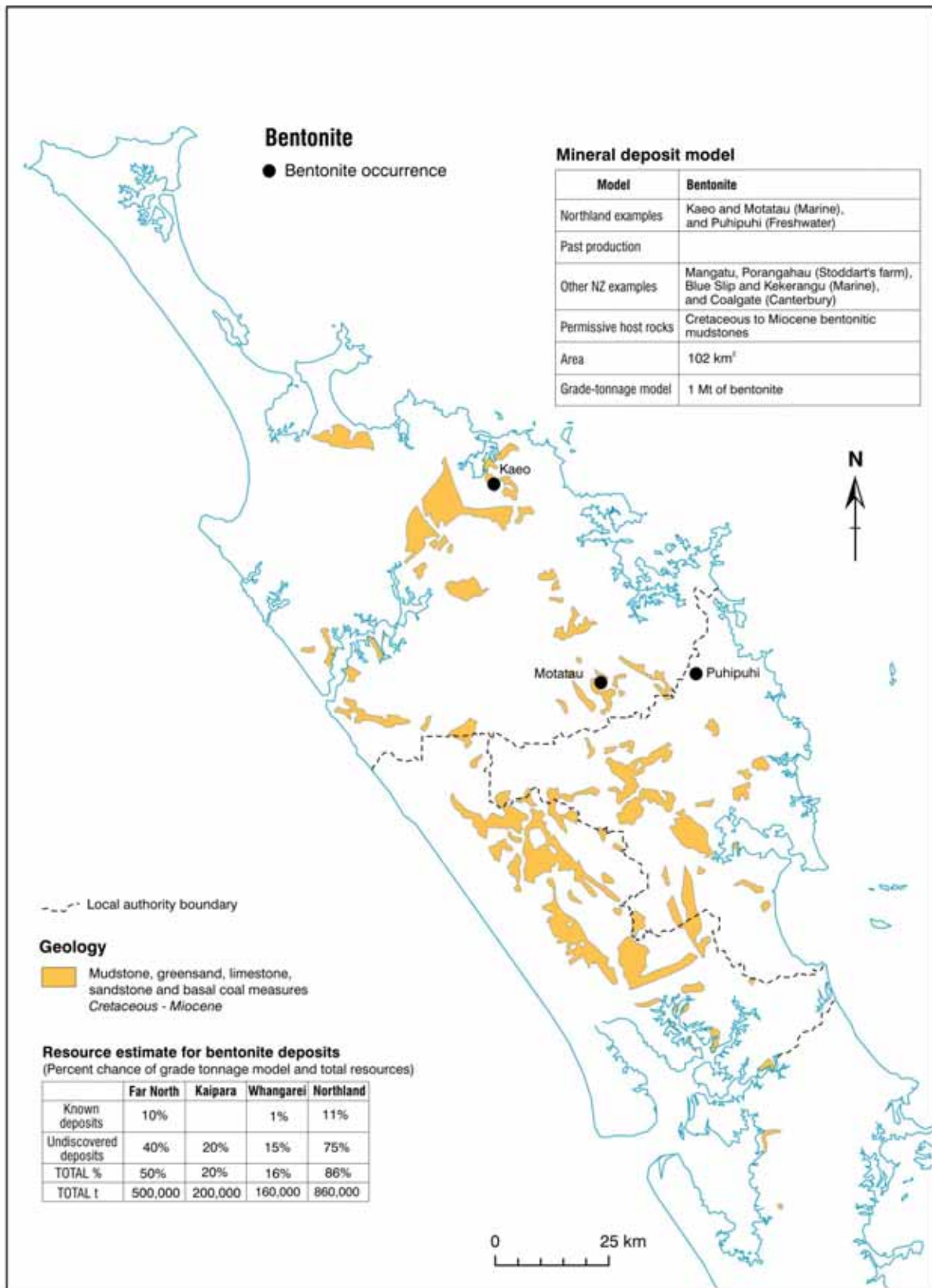


Figure 64. Location of bentonite deposits from the GERM database and areas of sedimentary rocks prospective for bentonite.

13.4 DIATOMITE

13.4.1 Lacustrine diatomite (Fig. 65)

13.4.1.1 *International and New Zealand model*

Reference

USGS model 31s Lacustrine diatomite (Shenk in Orris & Bliss 1991).

Description

Lacustrine diatomite deposits are typically associated with volcanism. Weathering and deposition of silica rich volcanic rocks is believed to provide the large quantities of silica necessary for thick accumulations of diatoms. The released silica is subsequently transported to the lake through runoff, groundwater, and hot or cold springs.

Diatomaceous lake sediments are typically hosted in: 1. volcanic rocks (craters, maars), 2. volcanic and sedimentary rocks (interbedded volcanic flows or tuffs and fluvial or alluvial sediments) or 3. sedimentary rocks. Deposits commonly extend over areas 2.5 to 65 km² and attain thicknesses of 3 m to >60 m. Deposits covering <2.5 km² and < 3 m thick are generally uneconomic. The main minerals are diatomaceous silica and opal-cristobalite. Contaminants consist of siliciclastics (various clays, quartz and feldspar grains, and volcanic glass), calcite, organic matter, ± Fe- and Mn-oxides, ± gypsum, ± halite.

International examples

Juntura and Otis basins, Oregon, USA; Kariandus, Kenya; Lake Myvatn, Iceland; Riom-les-Montagnes, France; Luneburger-Heide, Germany.

Grade and tonnage – New Zealand

Resources are about 5 Mt at Middlemarch, 2 Mt at Whirinaki and 200,000 t at Lower Kaimai. A resource of 1 Mt of diatomite is selected for the model.

13.4.1.2 *Known deposits*

A deposit at Lake Owhareiti (P05/e83; Fig. 65) is not pure, containing soil and vegetation. However, a pond 1 km south of Pakaraka contains a pure diatomite deposit at least 2 m in thickness. Small deposits also occur around Kamo, notably near Ruatangata railway station (Q06/e91) where 800 t of diatomite was extracted (1941-1975) from a deposit 9 ha in area, and ranging from 2 to 11 m in thickness. The dried material is light sepia to dark brown in colour, but some of the colour is lost during calcination. It is composed of the cylindrical form *Melosira* (Grange, 1930), though Ritchie (1962) noted that *Cyclotella* is very common in a sample from this general area.

Two deposits at Springs Flat, Kamo (Q06/e98) produced 1000 t between 1938-1952 (Petty 1978).

13.4.1.3 *Potential*

There is a 48% probability of diatomite resources present in known (18%) and undiscovered (30%) deposits equivalent to the model (Fig. 65). These resources are distributed in all three districts.

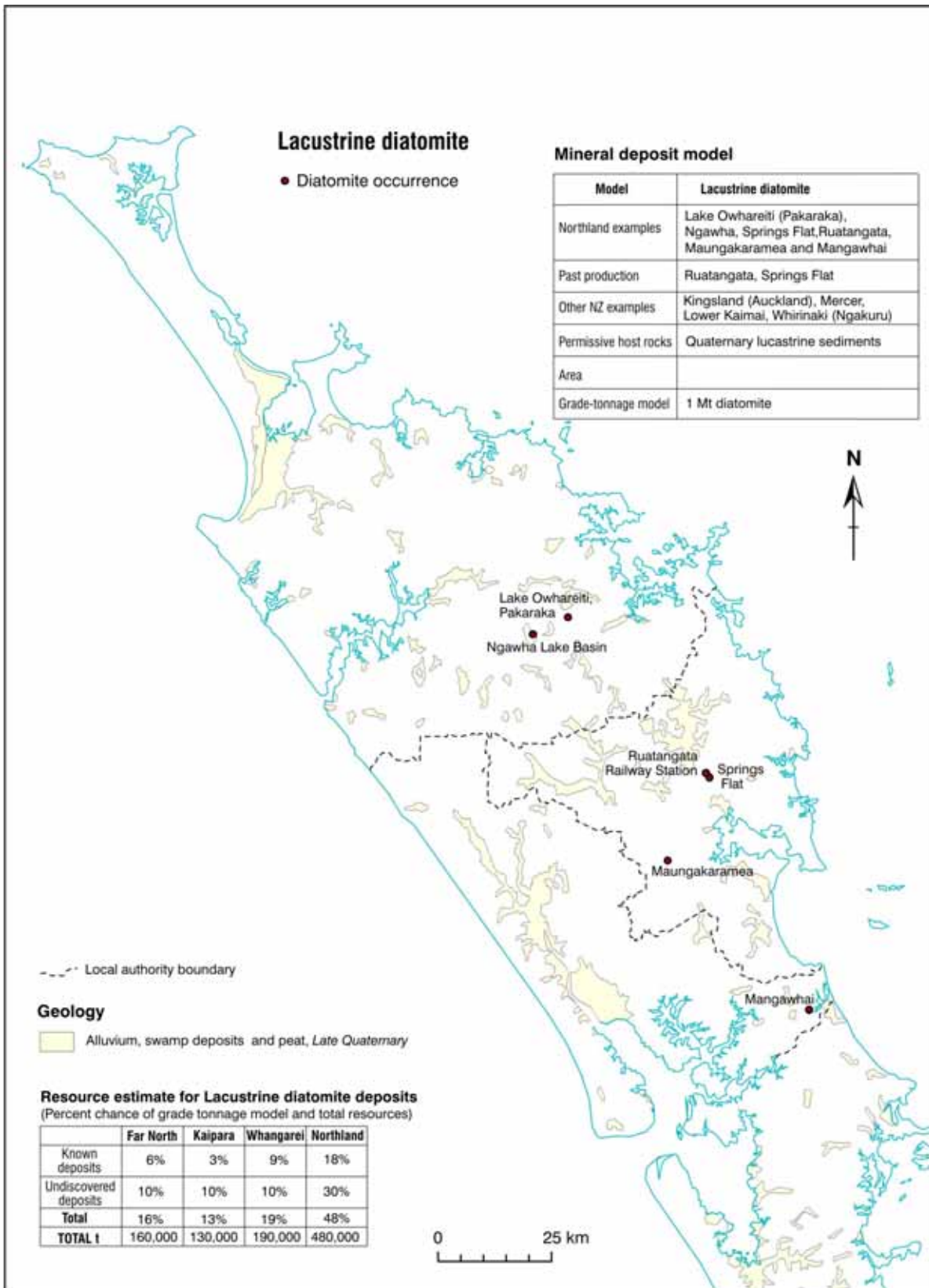


Figure 65. Location of lacustrine diatomite deposits from the GERM database.

13.4.2 Marine diatomite (Fig. 66)

13.4.2.1 Model

Description

Diatomite associated with limestone.

Grade and tonnage – New Zealand

Resources at Oamaru are large, probably on the order of several million tonnes. Therefore a resource model of 2 Mt is selected.

13.4.2.2 Known deposits

At Kaiwaka, diatomaceous and radiolarian ooze is associated with Oligocene argillaceous limestone (Marshall 1916). It mainly contains Globigerina, but some radiolaria and sponge spicules are also present.

13.4.2.3 Potential

There is only one known occurrence in Northland for which is assigned a 5% probability of it containing resources equivalent to the model. There is a large area of potential host rocks and therefore we have assigned a 35% probability of undiscovered deposits hosting resources equivalent to the model.

13.5 FELDSPAR

13.5.1 Feldspar sand (Fig. 67)

13.5.1.1 Model

Description

Feldspar in dune, beach and marine sands of Quaternary age.

Grade tonnage data

100 Mt at 70% feldspar.

13.5.1.2 Known deposits and exploration

In the past, sand from offshore Pouto (Kaipara Harbour) has been used as a source of feldspar in glass manufacture.

Quaternary beach and dune sands on the coast between Whangarei Heads and Warkworth contain 50 to 75% plagioclase feldspar (Fig. 67). Drilling in the Ruakaka Flats area (Gallot 1970; Crown Lynn Potteries 1972; Lawless 1972) indicated that the top 1.5 to 2.44 m consists of dry, loose or poorly compacted, wind blown sand overlying medium grain-sized sand to a depth of at least 9.81 m in some holes. Below the base of the sand lie dense to very dense shell beds. Peat is present in almost equal quantities with dune sand, mainly in the upper levels of the consolidated dune sand.

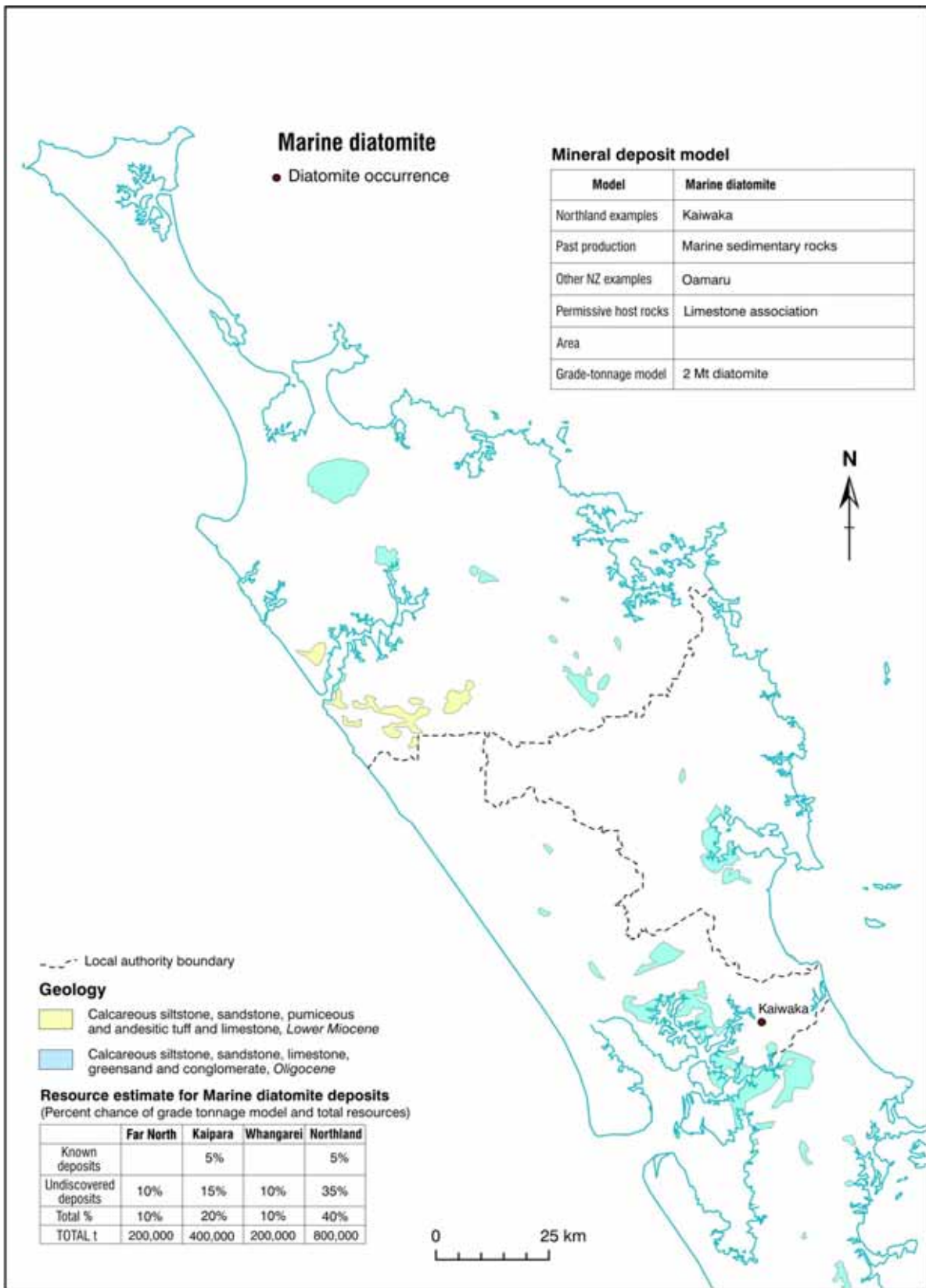


Figure 66. Location of the Kaiwaka marine diatomite deposit and areas of prospective calcareous rocks.

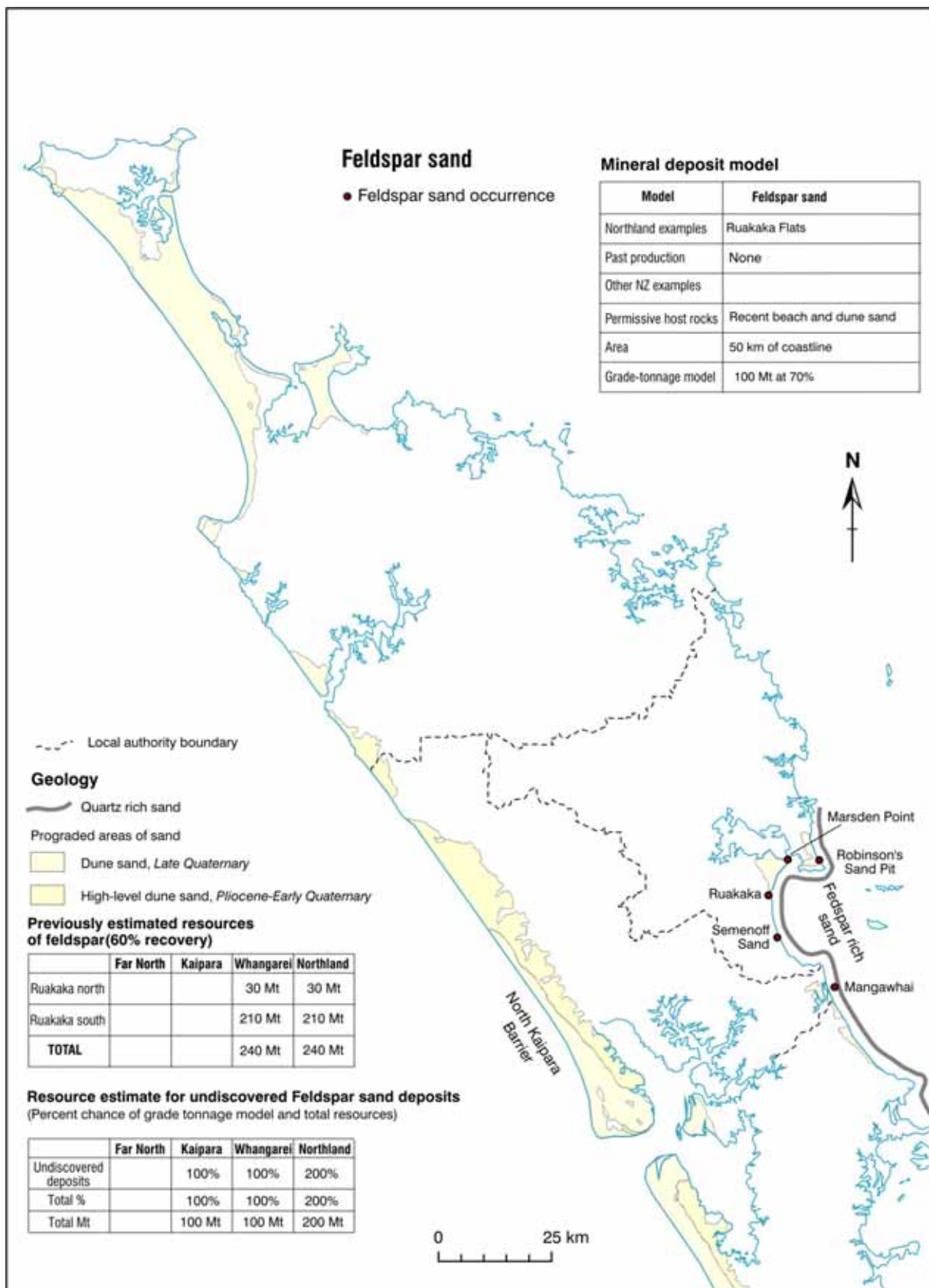


Figure 67. Location of feldspar sand deposits from the GERM database and band of coast with feldspar-rich sand.

The sand near Ruakaka consists of feldspar (65-70%), quartz (25%), rock fragments (1-4%), heavy minerals (1-4%), shell (1-2%), and a variable amount of organic material. Chemical analyses indicate 0.7-6.0% total iron oxide, with a mean Fe₂O₃ content of 2%. The feldspar/quartz ratio is slightly higher at the southern end of Ruakaka Flats, where the sand is coarser. At the northern end (Marsden Point) of the Ruakaka Flats, a strip 240 m wide, 7 m deep, and 12 km in length is estimated to contain 50 Mt of sand and would yield, at 60% recovery, 30 Mt of saleable minerals. At the southern end of the Ruakaka Flats, where the sand dunes are more than 12.2 m high, and 30.5-45.7 m deep, the total quantity of sand present is assumed to exceed 350 Mt.

13.5.1.3 Potential

The east coast feldspar sand deposits contain large resources of glass grade alumina (with the required addition of an alkali) suitable for beneficiation. Laboratory scale beneficiation processes have produced low iron content sand, and bulk trials suggest that an acceptable iron content can probably be achieved. The subsurface peat and heavy minerals can be removed by beneficiation. There is sufficient tonnage present to establish a major plant. Inferred resources of 240 Mt of sand have been estimated at Ruakaka (Fig. 67). There is probably undefined resources equivalent to the model in both Whangarei and Kaipara districts totalling 200 Mt of feldspar sand.

13.6 KAURI GUM

Almost every swampy area in Northland has at sometime been dug over for kauri gum during the 90-year life (1865-1955) of the kauri gum industry. A historical account of the gumdigging by Hayward (1982) noted that the best known gumfields in New Zealand were on the Aupouri Tombolo (e.g. Kaimaumau, Waipapakauri, Sweetwater, and Awanui; Figs 68 and 69), where production peaked between 1890 and 1935. One of the last major gumfields to be worked was on the hills above Ahipara, 15 km southwest of Kaitaia. Other gumdigging localities in Northland included Waikuku (N02/e21), Taumatara Flat (N02/e22) and Kaimaumau (O03/e10; Fig. 69), Ohia, Mangonui, Kaitaia, Kaeo (P04/e32), Whangape, Lake Omapere, Kawakawa, Hukerenui, Hikurangi, Ruakaka, Mangawhai, Mangakahia, Dargaville, Aratapu, and Ruawai (Hayward 1982). At Waihuahua Swamp (O03/e9 and e10), gum was produced as a byproduct of peat mining.

An area of 1.2 km² of peatland near Kaimaumau, set aside under the Kauri Gum Industry Amendment Act 1915, was taken up by the New Zealand Peat Oils Company in 1917. A retorting plant was set up as a result (O04/e33), but the venture proved to be uneconomic. In 1974, Kauri Deposit Surveys Ltd was formed to extract resins and waxes from the peat (Anon 1979a, 1979b). About 15 M m³ of peat was estimated in the Motutangi-Kaimaumau deposit. In 1985 a successor company, Kaurex Corporation Limited, was formed to finance and build a production plant. The Kaurex project was designed to recover resins and waxes by the solvent extraction of peat, at about 5000-15,000 t per year. A plant and mine were established (O03/e9), but largely due to technical problems the plant did not achieve the expected recoveries of resins and waxes, and the company was put into receivership in 1987.

13.6.1.1 Potential

The 1985 Kaurex Corporation Limited prospectus suggested resources in the Kaimaumau peat deposit of 600,000 t of resins and waxes based on a level of 8.5% extractable resins and waxes from dried peat. This was valued in the prospectus at \$1200 million in 1985.

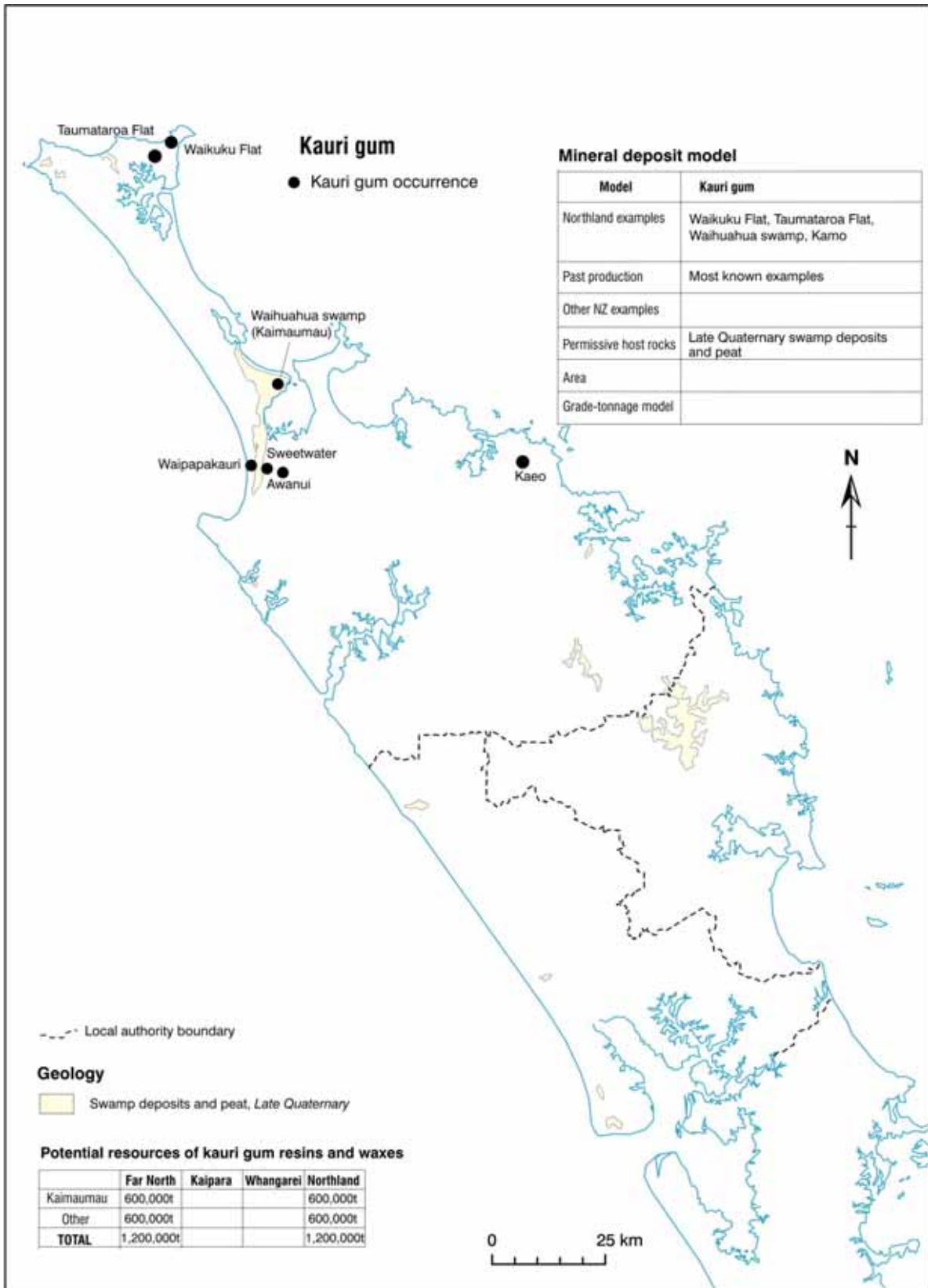


Figure 68. Location of kauri gum deposits from the GERM database and areas of swamp and peat prospective for kauri gum.

Resources of other kauri gum deposits are unknown, but collectively could potentially be equivalent to the Kaimaumu resources and therefore the total gum resource is c. 1.2 Mt, all of which is located in the Far North District.

13.7 PHOSPHATE

13.7.1 Upwelling type phosphate deposits (Fig. 70)

13.7.1.1 *International model*

References

USGS model 34c Upwelling type phosphate deposits (Cox & Singer 1986) and USGS model 34d Warm-current type phosphate deposits (Cox & Singer 1986).

Description

Phosphorite sediments form a major stratigraphic unit within a sequence of marine sediments in upwelling areas in basins with good connection to the open sea. The host rocks are phosphorite, marl, shale, chert, limestone, dolomite, and volcanic materials. Individual beds may be a metre thick or more and may extend over hundreds of square kilometres. The phosphorite occurs as pellets, nodules, phosphatised shell and bone material. The main minerals are apatite and fluorapatite, dolomite, calcite, quartz, clays (smectite or illite), plus local halite, gypsum, iron oxides, siderite, pyrite and carnotite.



Figure 69. View east over Kaimaumu swamp. Photo: Lloyd Homer CN9056/22.

Grade and tonnage - international

The 50th percentile of USGS model 34c is 330 Mt at 25% P₂O₅.

Grade-tonnage model – New Zealand

Clarendon has resources of about 5 Mt at 11 % P₂O₅, but production was mostly at a grade of 25% P₂O₅. This is more than two orders of magnitude lower than the international model size. Therefore we have selected a resource model of 5 Mt at 25% P₂O₅ = 1.8 Mt at 68% P₂O₅ has been selected.

13.7.1.2 Northland deposits

The phosphate content of glauconitic rocks in the Cretaceous sequences of Northland was investigated in the early 1970s. The argillite at Motukahakaha Bay contains concretionary nodules in some horizons, and the phosphorus content of 22 samples collected for analysis ranged between 0.06% and 0.12% P (Quennell 1970). Reconnaissance prospecting in the Cape Horn area of Whangaroa Harbour (Neuss 1972a) and at Houhora (Neuss 1972b) was unsuccessful.

Offshore phosphate deposits are present at water depths of 500-600 m on the steep southern flank of the Hokianga Terrace (Phillip & Gregory 1986; N07/el). The two dominant phosphatic lithologies recovered in a dredge haul were phosphatic nodules and slabby chunks of intraformational ferruginous/phosphatic conglomerate. The phosphatic nodules have an average diameter of 3-4 cm, are irregularly rounded and bored, were originally micritic, and have a glauconite coating. The conglomerate consists of phosphate nodule clasts and internal clasts of bivalves and brachiopods, set in a phosphatised micritic and glauconitic matrix. The dominant mineral phase is carbonate-apatite.

Phillip & Gregory (1986) considered that the deposits were Late Oligocene to Early Miocene in age and formed where phosphorus was supplied by upwelling onto a sediment-starved, sub-tropical continental shelf. Reworking and concentration of phosphatic nodules probably accompanied the glacially induced sea-level changes in the Plio-Pleistocene. Phillip & Gregory (1986) suggested that similar phosphate deposits are likely to occur on other submarine topographic prominences of the outer shelf and slope of the west coast region (e.g. Herekino Bank M05/610630 and Whangape Bank M05/650410) but that they are unlikely to prove as economically prospective as those on the Chatham Rise.

13.7.1.3 Potential

Exploration for phosphatic sedimentary rocks in Northland has so far not been fruitful although examples are present. There is a 15% potential of resources equivalent to the model in undiscovered deposits distributed equally among the three districts (Fig. 70).

13.8 SERPENTINITE

13.8.1 Serpentine in gabbro-peridotite complexes (Fig. 71)

13.8.1.1 Model

Description

Serpentinisation of magnesium-bearing minerals in gabbro-peridotite complexes occurs by processes of hydration and oxidation.

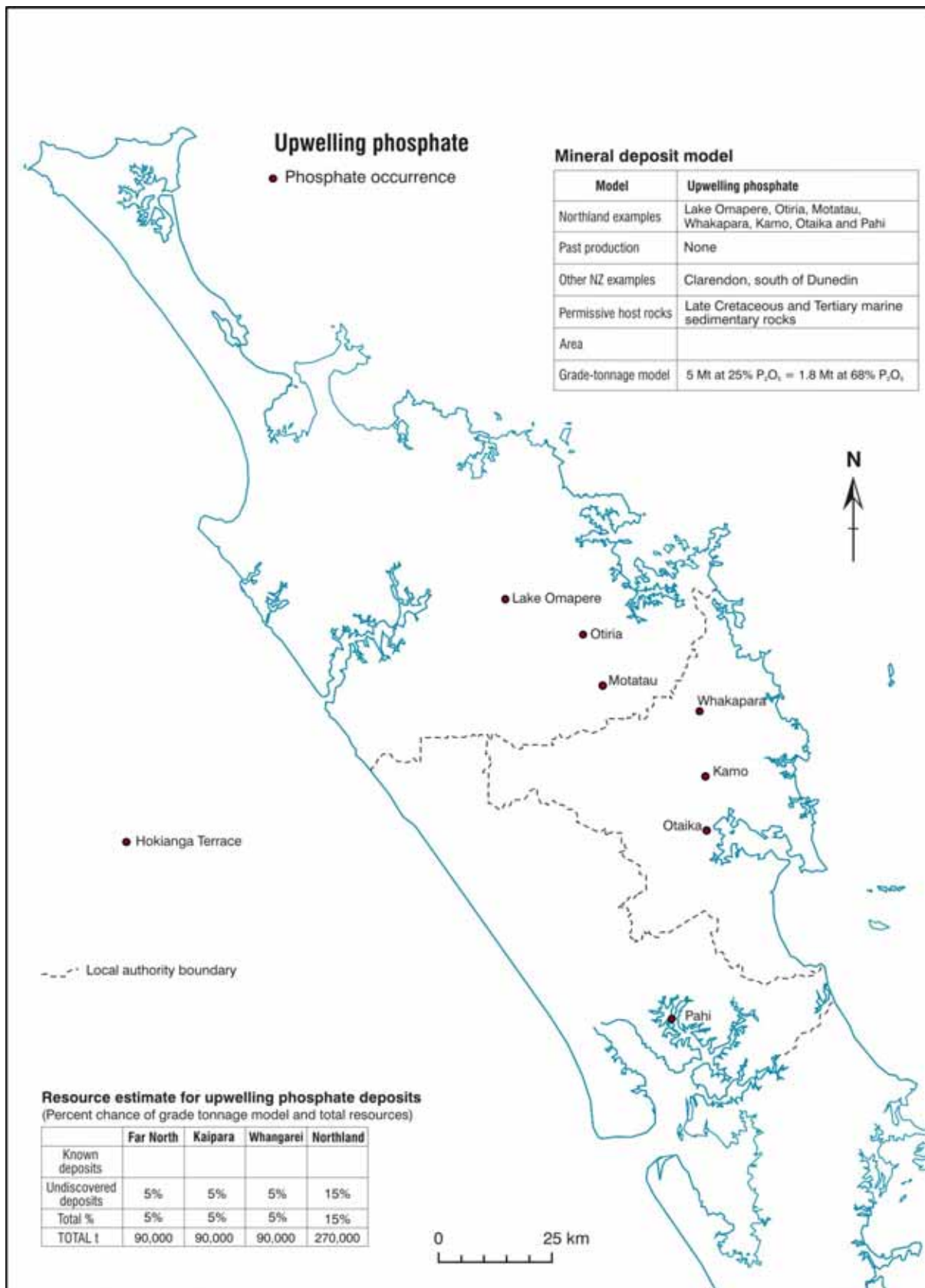


Figure 70. Location of phosphate occurrences from the GERM database.

Grade and tonnage data

1 Mt of serpentine is assigned for the Northland model.

13.8.1.2 Northland deposits

In the Surville Cliffs-North Cape area (Fig. 71), the western contact of the ultramafic complex and the volcanic rocks is marked by a zone of highly sheared serpentinised harzburgite and lherzolite approximately 9 m wide. The surface of the ultramafics is covered by laterite up to 1.5 m thick and the ultramafics below the laterite weathers as a blocky serpentinite. The serpentine resource has been estimated in the millions of tonnes range and was quarried (N02/e3) intermittently from 1964 to 1984 for use as a fertiliser additive and for local roading. To the west of Te Kao, Karena's Quarry (N03/e1; Fig. 71) has produced road aggregate from partly serpentinised peridotite (wehrlite).

13.8.1.3 Potential

Resources equivalent to the model are assigned for the North Cape deposit, although they could be larger than the 1 Mt of the model (Fig. 71). There is probably some potential for undiscovered deposits associated with other mafic complexes currently not mapped.

13.8.2 Diapiric serpentinite (Fig. 72)

13.8.2.1 Northland model

Description

Rootless discrete bodies of serpentinite tectonically emplaced in Late Cretaceous and Early Tertiary sedimentary rocks of the Northland Allochthon. Their association with faults and their shape imply a diapiric origin. The serpentine bodies are up to 1 km in length and 60 m in width, with volumes of 350 m³ to 24,000 m³ (O'Brien & Rogers 1973). The serpentinite bodies consist mainly of dunitic and harzburgitic serpentine with a predominance of the latter. Feldspathic varieties also occur and at some localities pockets are composed entirely of bastite pseudomorphs, of serpentine after pyroxene. The serpentinite is fractured or sheared and often weathered near the contact with the surrounding sediments. Carbonate and secondary chrysotile serpentine are common throughout.

A wide variety of rock types have been found as inclusions within the serpentinites. Inclusions which Bartrum (1948) believed to be almost certainly related to the serpentine include anorthosite, pyroxenite, troctolite, gabbro, olivine gabbro, norite, dolerite, and variolite. More acidic intrusive rocks, sediments, lavas, and a variety of schists and gneisses have also been found within the serpentinite.

The main minerals are clinochrysotile, orthochrysotile and lizardite (Coleman 1966).

Grade and tonnage – New Zealand

Individual serpentinite bodies have a size of about 50,000 t.

13.8.2.2 Northland deposits

Several diapiric serpentinite deposits in Northland were listed O'Brien & Rogers (1973). They consist of lenses of serpentinite in shear contact with enclosing sedimentary rocks of the Northland Allochthon. Many have been quarried in the past for fertilizer (e.g. Kaipara Forest

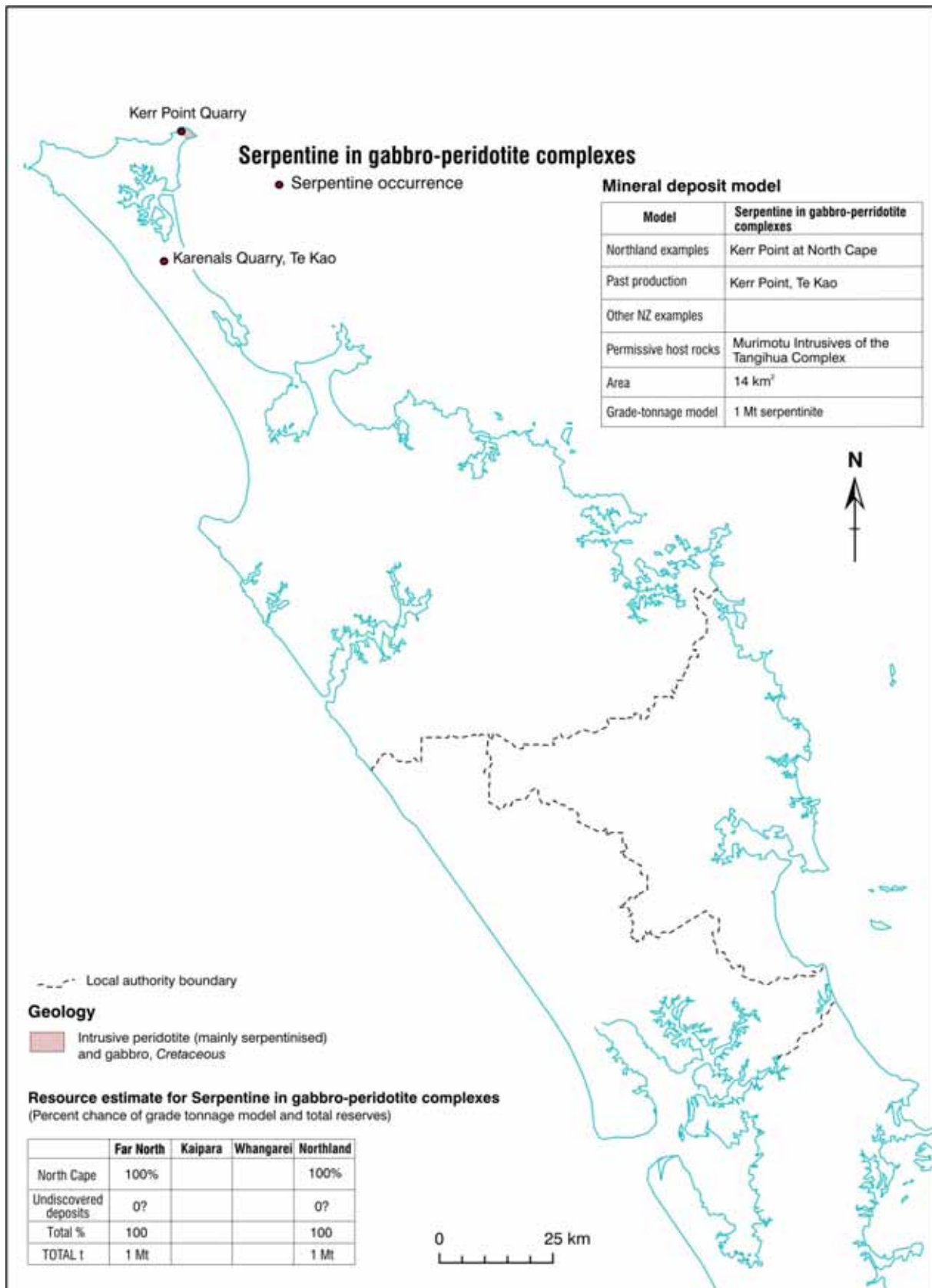


Figure 71. Location of serpentine in gabbro-peridotite complexes and area of prospective mafic intrusive rocks.

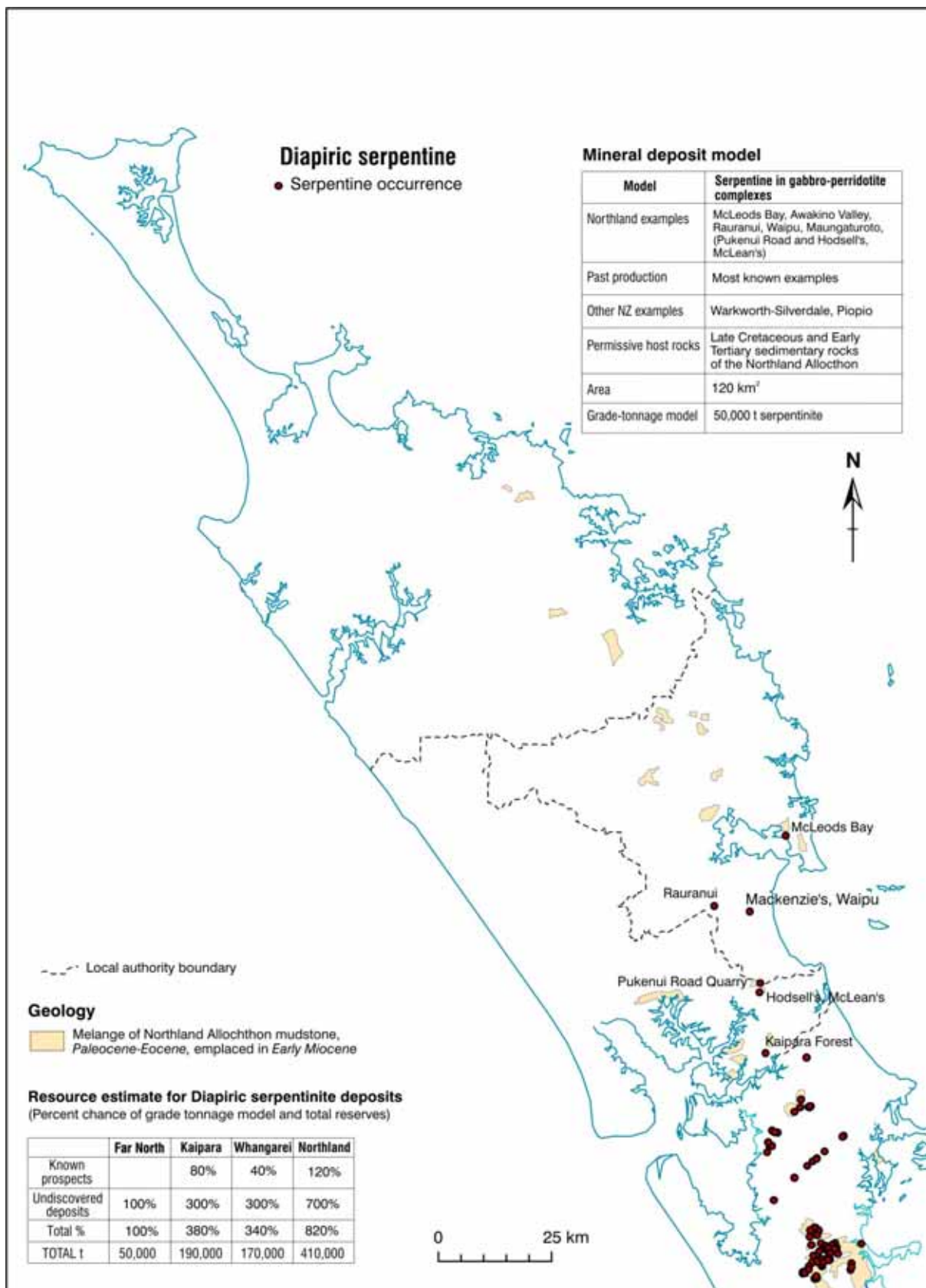


Figure 72. Location of diapiropic serpentinite deposits from the GERM database and areas of prospective rocks.

Q08/e103). Recent exploration at McKenzie's, Waipu, including a ground magnetic survey (Vidanovich 2001) and trenching (Hawthorn & Carryer 2002), indicated that additional deposits are present, but covered by at least 5 m of overburden.

13.8.2.3 Potential

The main known deposits are regarded as mostly worked out, however there is potential for undiscovered deposits (e.g. MacKenzies). There is an 820% probability of serpentinite resources present in known (120%) and undiscovered (700%) deposits equivalent to the model (Fig. 72). These resources are distributed in all three districts, although most are in Kaipara and Whangarei districts.

13.9 SILICA SAND

13.9.1 Model

Description

Dune, beach and shallow offshore marine sand along the present day coastline.

13.9.2 Known deposits

Silica sand occurs on the northern part of the east coast and in terrace deposits by Kaipara Harbour (Fig. 73).

13.9.2.1 Parengarenga

The Kokota Sandspit (Figs 74 and 75), which forms the south head of Parengarenga Harbour on the east coast, has been estimated to have resources from at least 30 M m³ up to 80 M m³ of high quality silica glass sand (N02/e6). The sand is mainly fine grained (0.15-0.22mm), loose, well sorted, angular to semi rounded, with 95-98% SiO₂, 0.05-0.42% Fe₂O₃ and 0.004-0.0013% chromic oxide (Schofield 1968, 1970; Schofield & Woolhouse 1969). The highest quality silica sand with the lowest iron content is found at the mouth of the Parengarenga Harbour, where it was dredged and then barged to the plate-glass works in Whangarei (until closure in 1991) and container glass works in Auckland (Fig. 75). The dredging operation ceased in 1997.

High-quality quartz sand also occurs at Ngakengo Beach, just to the north of Parengarenga Harbour entrance, although it has high shell content, and on the east coast of the Aupouri peninsula south of Parengarenga Harbour, and inland on parts of the peninsula itself.

13.9.2.2 Tokerau Beach, Karikari Peninsula

A 6.6 ha triangular block west of Inland Road is covered by longitudinal sand dunes of Holocene age lying 8-9 m above the swamp floor. These dunes were sampled by 42 auger holes (Fergusson, 1979, for Clays and Minerals Ltd.). The first 26 holes were for reconnaissance purposes, the remaining 16 determined the quantity of sand in one area of 2 dunes. The general downward sequence is root-stained sand, then pure white silica sand, black peaty sand 5-10 cm thick, resting on firm yellow-brown sand. The northern dune contains pure white sand with a minimum thickness of 30 cm, an average thickness of 70 cm and provided a volume of approximately 7000 m³. The minimum thickness of pure white sand in the southern dune is less than 30 cm, and the total quantity is approximately 6500 m³. As the area investigated forms a very small part of the foredune sands mapped by Hay (1975), sampling the remaining area may prove significant quantities of silica sand.

13.9.2.3 Hokianga North Head (O06/e19)

These sands have been investigated for use in glass making. Although their size grading is suitable, iron contamination is too high for commercial production and only small-scale local workings have been carried out.

13.9.2.4 Kaipara Harbour

High level Early Quaternary coastal sands from the eastern shores of the Kaipara Harbour are worked to provide industrial sand for the Auckland market (e.g. wallboard, cement making and foundry sand). The sand occurs beneath an oxidised, weathered surface zone, and is up to 6 m thick. The best is glass-grade silica sand, which with processing, produces a higher quality sand than Parengarenga sand. Several pits have been worked in the past, but current production comes from Glorit, north of Helensville in North Auckland. Resources are large, but poorly defined.

13.9.2.4 Matauri Bay

Small quantities of silica sand are produced as a by-product of halloysite clay mining at Matauri Bay. About 3000 t per annum are produced and used in the local market for clean fill and as a component of builders mix. The sand contains about 90% SiO₂ and would require further processing for use in glass making and some other industrial applications of silica sand.

13.9.3 Potential

At Parengarenga Harbour, there is about 120 Mt on the northern part of Kokota Spit and a regional resource of about 1,500 Mt (Williams 1974). There is possibly 10 Mt in the Kaipara Harbour area (but partly in North Auckland).

Currently, silica sand is imported from Stradbroke Island in Queensland for use in glass manufacture by ACI Operations NZ Ltd, Auckland. Parengarenga silica sand was previously used in glass manufacture and could substitute for the imported sand.

13.10 SULPHUR

The most significant occurrence of sulphur is at the Waiparaheka Pond, Ngawha geothermal field (P05/e52, e53), where mud surrounding the pool contains up to 66.6% sulphur. Water from this pond is milky due to the abundance of elemental sulphur.

No potentially economic sulphur resources are known in Northland.

13.11 ZEOLITE

13.11.1 Open system zeolites (Fig. 76)

13.11.1.1 International and New Zealand model

Reference

USGS model 25o Sedimentary zeolites (Sheppard in Orris & Bliss 1991), zeolites in lacustrine tuffs (e.g. Brathwaite et al. 2006).

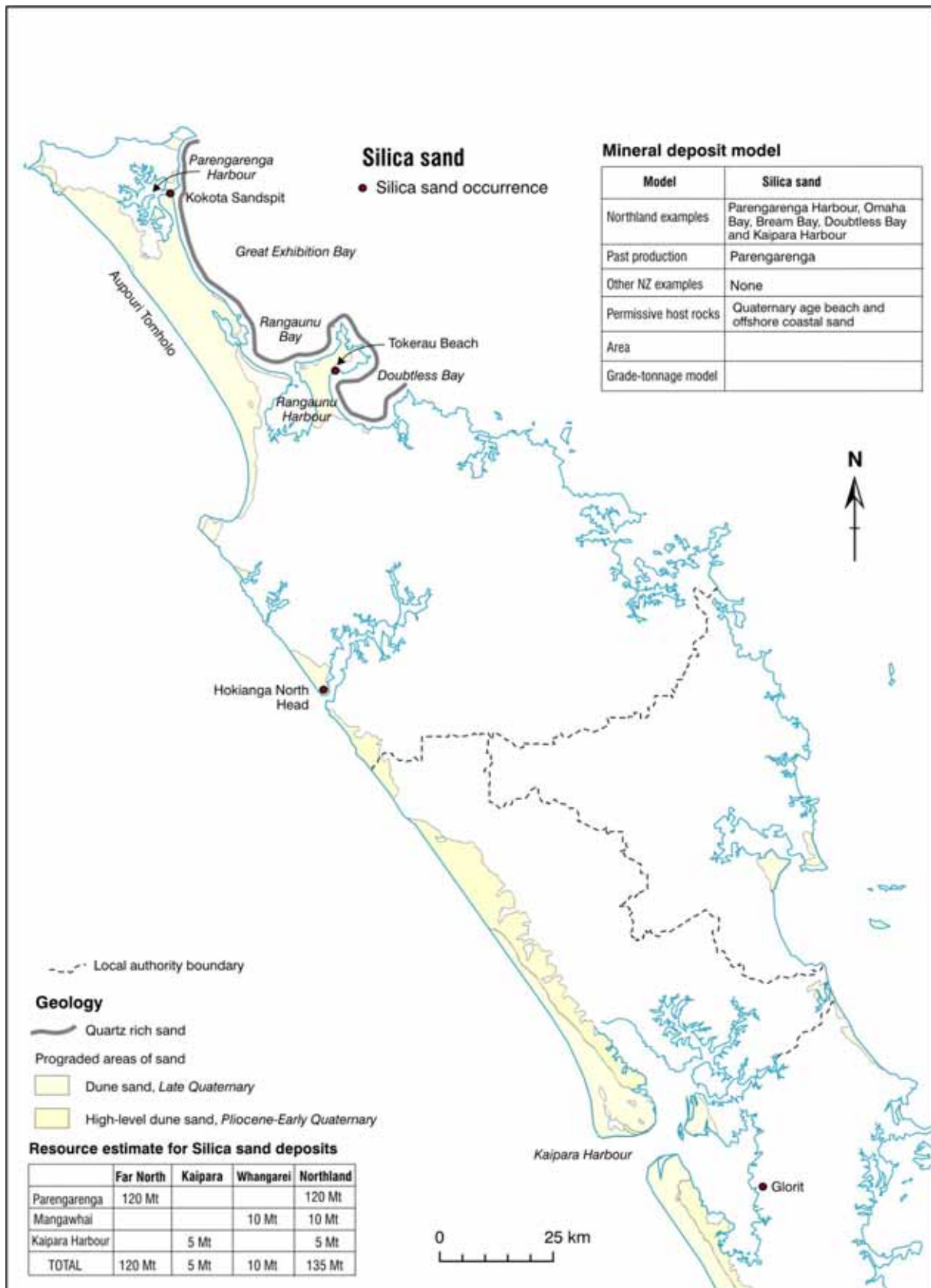


Figure 73. Location of silica sand deposits from the GERM database, areas of coastal sand and band of coast with quartz-rich sand.



Figure 74. View west of white silica sand of Kokota Spit, Parengarenga Harbour. Photo: Lloyd Homer CN352/15.



Figure 75. SeaTow barge mining silica sand off Kokota Spit, Parengarenga Harbour. Photo: Colin Douch.

Description

Zeolites are typically formed by low-temperature hydrothermal (<200° C) alteration and metamorphism in tuffs and volcanic sandstones, and volcanic-rich lake and marine sediments. Zeolite formation is linked to syn- and post-depositional reaction of volcanic glass with relatively alkaline solutions. Zeolitization temperatures are believed to be less than 100°C, but higher temperatures are estimated for some of the deposits. In many cases, there is debate as to whether the fluids are low temperature hydrothermal solutions, diagenetic fluids or heated meteoric waters.

The zeolite-bearing rocks are hosted by volcanic ash and tuff beds with minor intercalated flows. Silicic tuffs commonly were deposited as non-welded ignimbrites. Other rock types include fluvial mudstone, sandstone, conglomerate and diatomite. The thickness of the zeolite tuffs commonly ranges from 100s to 1000s m. The areal extent is commonly 100s to 1000s km². Clinoptilolite, chabazite, mordenite and phillipsite are the main minerals and occur in a gangue of authigenic smectite, mixed layer illite-smectite, opal, quartz, plagioclase, microcline, sanidine, biotite, muscovite, and calcite.

International examples

- Clinoptilolite: John Day Formation, Oregon, USA; Death Valley Junction, California, USA.
- Clinoptilolite and mordenite: Miocene Paintbrush Tuff, Calico Hills and Crater Flat Tuffs, Nye County, Nevada, USA.
- Phillipsite and chabazite: Yellow tuffs near Naples, Italy.

Grade and tonnage data

500,000 t of 50% zeolite is assigned for the zeolite model.

13.11.1.2 Northland deposits

Veins of zeolite occur throughout the Tangihua Complex volcanic rocks and associated sediments at North Cape (Fig. 76) and elsewhere.

Zeolite occurs in Miocene marine tuffs formed by the alteration of volcanic glass (Sameshima 1979). At Whareana Bay (N02/e9), near North Cape, Tom Bowling Bay Formation contains clinoptilolite, which was formed in a lacustrine, sedimentary environment. White tuff beds, 10-40 cm thick, consist of almost wholly zeolite, with minor chlorite. Interbedded with these are darker coloured sandy tuffs, which contain up to 70% clinoptilolite (Sameshima 1978).

At Paradise Quarry, Paradise Creek, southeast of Whangarei, a 5 m thick, hard, altered, siliceous tuff (Paradise Tuff Member) consisting of mordenite and lesser amounts of quartz and chlorite is interbedded with limestone of Onemama Formation. At Puketotara Peninsula, in the Kaipara Harbour, tuff beds in the deep, marine Timber Bay Formation contain erionite and lesser amounts of chabazite and clinoptilolite.

13.11.1.3 Potential

There is a 140% probability of zeolite resources present in known (20%) and undiscovered (120%) deposits equivalent to the model (Fig. 76). These resources are distributed in all three districts.

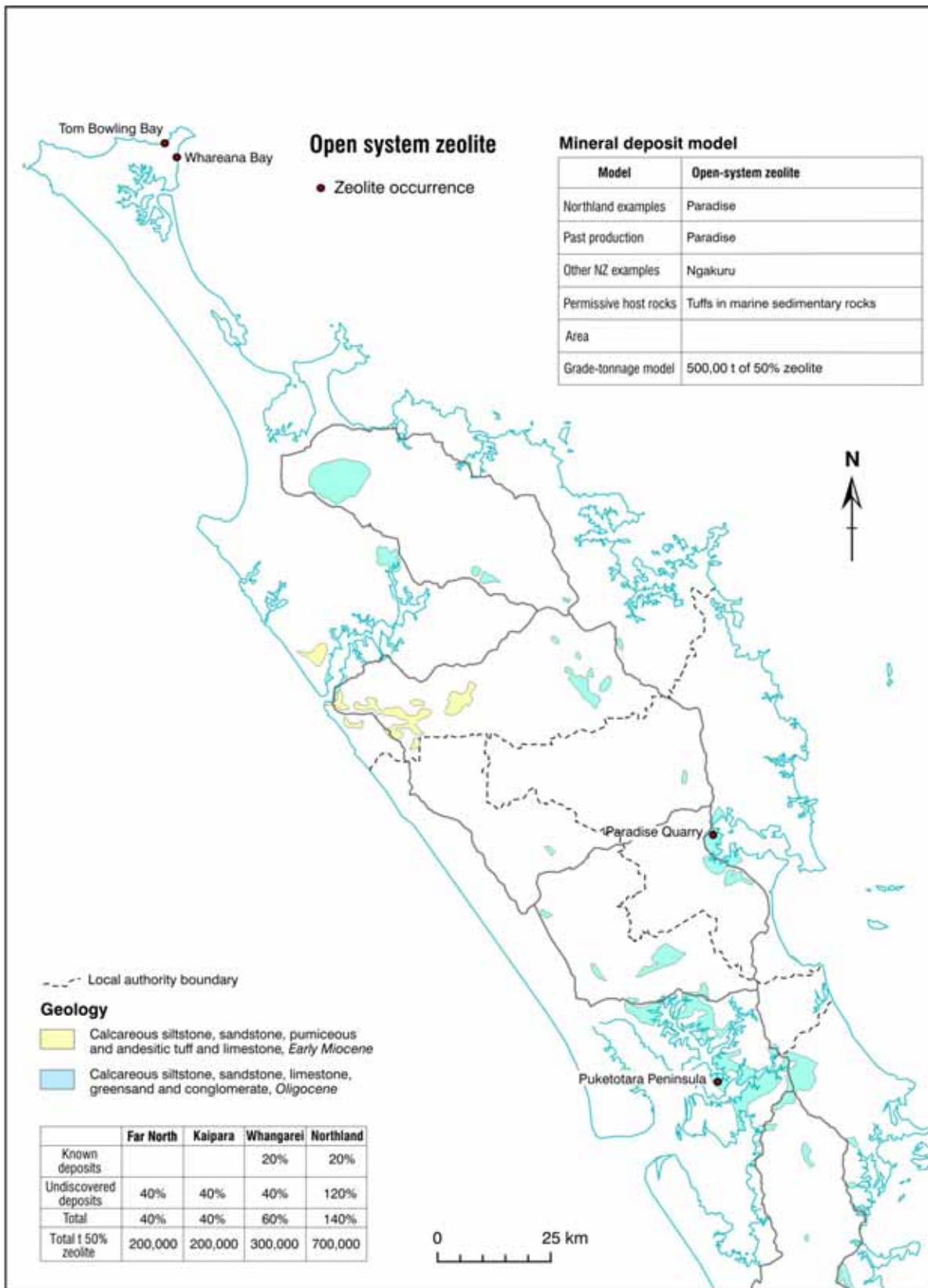


Figure 76. Location of zeolite deposits from the GERM database and areas of calcareous sediments that are prospective for open-system zeolite deposits.

14.0 VALUE OF MINERAL RESOURCES

Northland has potential for a wide range of metallic and non-metallic minerals, though past production has generally been small. Resource potential for 16 types of metallic mineral deposit and 14 non-metallic mineral deposit types have been outlined in the previous sections of this report and are shown on the maps.

Estimates of potential value have been calculated for each of these commodities using 2006 commodity prices (Table 2). Commodity prices vary over time and have risen strongly over the past 5 years. In spite of some spectacular metal price increases over this period (about 5-fold for copper), inflation adjusted metal prices are still well below past peak values (www.imf.org/Pubs/FT/weo/2006/02/chp5data/Fig5_2.csv), with the possible exception of nickel, a commodity that is not significant for this study.

Table 2. Mineral prices.

| Mineral commodity | Source | Price Quoted Overseas | Price NZ \$ |
|--|------------------------------------|---|-------------|
| Bauxite | IM June 2006 | US\$ 130 / t | 208 / t |
| Antimony | MJ 18 Aug 06 | US\$ 5250 / t | 8400 / t |
| Bentonite | IM June 06 | US\$ 40 | 64 / t |
| Building/dimension stone | CM 2005 | | 147 / t |
| Chrome | | US\$ 11,020 / t | 20,000 / t |
| Clay for bricks, tiles | CM 2005 | | 9 / t |
| Clay for ceramics | CM 2005 | | 20 / t |
| Clay – halloysite for export | Townsend (Imerys) pers comm.. 2006 | | 700 / t |
| Clay – fireclay 45% Al ₂ O ₃ | IM June 06 | US\$ 80 / t | 130 / t |
| Coal | Barker et al. (2006) for 2004 | | 50 / t |
| Copper | MJ Jul 06 av | US\$ 7710 / t | 12330 / t |
| Decorative stone incl scoria | CM 2005 | | 21 / t |
| Diatomite | IM June 06 | £400 / t | 1125 / t |
| Feldspar | IM June 06 | US\$ 50 / t | 80 / t |
| Feldspar sand | | | 15 / t |
| Gold | Aug 06 | US\$ 630 / oz | 1000 / oz |
| Iron | | | 76 / t |
| Lead | MJ Jul 06 av | US\$ 1051 / t | 1680 / t |
| Lead concentrate | MJ 18 Aug 06 | US\$ 800 / t | 1280 / t |
| Lignite | Barker et al. (2006) for 2004 | | 20 / t |
| Limestone for roading | CM 2005 | | 14 / t |
| Limestone for agriculture | CM 2005 | | 16 / t |
| Limestone for industry | | | 55 / t |
| Limestone for marl and cement | | | 4 / t |
| Manganese metal (99.7%) | MJ 18 Aug 06 | US\$ 1,350 | 2160 / t |
| Mercury (99.9%) | MJ 18 Aug 06 | US\$ 500 / flask (34.5 kg) US\$ 14,490 / t | 23,180 / t |
| Nickel | MJ Jul 06 av | US\$ 26,568 / t | 42,510 / t |
| Peat | | | 40 / t |

Table 2. Continued.

| Mineral commodity | Source | Price Quoted Overseas | Price NZ \$ |
|--------------------------------------|--------------|-----------------------|-------------|
| Phosphate 65-68% BPI | IM June 06 | US\$ 30 / t | 48 / t |
| Rock for reclamation and protection | CM 2005 | | 11 / t |
| Rock, sand, and gravel for building | CM 2005 | | 13 / t |
| Rock, sand, and gravel for roading | CM 2005 | | 10 / t |
| Rock, sand, gravel and clay for fill | CM 2005 | | 6 / t |
| Sand for industry | CM 2005 | | 13 / t |
| Serpentinite | | | 23 / t |
| Silica sand | CM 2005 | | 66 / t |
| Silica sand | IM June 06 | US\$ 14-25 / t | |
| Silver | Aug 06 | US\$ 12 / oz | 19 / oz |
| Zeolite | | | 100 / t |
| Zinc | MJ Jul 06 av | US\$ 3338 / t | 5340 / t |
| Zinc concentrate | MJ 18 Aug 06 | US\$ 1400 / t | 2240 / t |

CM 2005 = Crown Minerals annual production statistics for 2005 released in 2006 (values are averages for New Zealand's total production of the specified commodity)

IM = Industrial Minerals

MJ = Mining Journal

Totals for resource estimates of coal, including lignite, and peat are listed in Table 3, along with derived prices giving a Northland total of \$13,770 million. Peat accounts for nearly 90% of this total value.

The potential resource estimates for the metals and non-metals from the previous sections are listed in Tables 4 and 5 along with NZ\$ values derived using the prices listed in Table 2. This assessment gives a gross value of the potential resources of the Northland region as \$5235 million for metals and \$28,019 million for non-metallic industrial minerals.

Table 3. Summary of in-ground sub-bituminous – bituminous coal, lignite and peat resources and value by district.

| | Resources Mt | | | | Value | | | |
|----------------------------------|--------------|---------|-----------|-----------|------------|---------|-----------|------------|
| | Far North | Kaipara | Whangarei | Northland | Far North | Kaipara | Whangarei | Northland |
| Sub-bituminous – bituminous coal | | | 23 | 23 | | | \$1150 M | \$1150 M |
| Lignite | 12 | 19 | | 31 | \$240 M | \$380 M | | \$620 M |
| Peat | 300 | | | 300 | \$12,000 M | | | \$12,000 M |
| Total | | | | | \$12,240 M | \$380 M | \$1150 M | \$13,770 M |

Table 4. Potential resources of metals by mineral deposit type.

| Metal | Deposit type | Potential resources | | | | Value, \$ million | | | |
|--------------|---|-------------------------------|------------|-------------------------------|--------------------------------|-------------------|----------|-------------|-------------|
| | | Far North | Kaipara | Whangarei | Northland | Far North | Kaipara | Whangarei | Northland |
| Aluminium | Laterite bauxite t Al ₂ O ₃ | 8,000,000 t | | | 8,000,000 t | 1664 | | | 1664 |
| Antimony | Hot spring Sb-As t Sb | 2200 t | | 2000 t | 4200 t | 18 | | 17 | 35 |
| Chromium | Podiform chromite, t 46% Cr ₂ O ₃ | 100 t | | | 100 t | 1 | | | 1 |
| Copper | Cyprus VMS Cu t Cu | 6000 t | | 6800 t | 12,800 t | 74 | | 84 | 158 |
| | Besshi VMS Cu t Cu | 165 t | | 165 t | 330 t | 2 | | 2 | 4 |
| | Porphyry Cu, t Cu | 23,500 t | | 34,000 t | 57,500 t | 290 | | 419 | 709 |
| Gold-silver | Hot spring Au-Ag | 980,000 oz Au | | 550,000 oz Au | 1,530,000 oz Au | 980 | | 550 | 1530 |
| | | 1,960,000 oz Ag | | 1,100,000 oz Ag | 3,060,000 oz Ag | 37 | | 21 | 58 |
| | Low sulphidation epithermal Au-Ag | 75,000 oz Au 300,000 oz Ag | | 75,000 oz Au 300,000 oz Ag | 150,000 oz Au 600,000 oz Ag | 75 6 | | 75 6 | 150 12 |
| | Sediment hosted Au | 15,000 oz Au | 5000 oz Au | 10,000 oz Au | 30,000 oz Au | 15 | 5 | 10 | 30 |
| | Au skarn oz Au | 6,430 oz Au | | 6,430 oz Au | 12,860 oz Au | 6 | | 6 | 12 |
| Iron | Bog iron t Fe | 240,000 t | | 120,000 | 360,000 | 18 | | 9 | 27 |
| Manganese | Volcanogenic Mn | 378 t Mn | | 298 t Mn | 676 t Mn | 1 | | 1 | 2 |
| Mercury | Hot spring Hg | 447 t Hg | | 155 t Hg | 602 t Hg | 10 | | 4 | 14 |
| Nickel | Lateritic Ni | 6160 t Ni | | | 6160 t Ni | 262 | | | 262 |
| | Gabbroid-associated Ni-Cu | 162 t Ni 99 t Cu | | | 162 t Ni 99 t Cu | 7 1 | | | 7 1 |
| Lead-zinc | Zn-Pb polymetallic vein | 5 oz Au | | 5 oz Au | 10 oz Au | 0.5 | | 0.5 | 1 |
| | | 30,000 oz Ag | | 30,000 oz Ag | 60,000 oz Ag | 0.2 | | 0.2 | 0.4 |
| | | 103 t Pb 24 t Zn | | 103 t Pb 24 t Zn | 203 t Pb 48 T Zn | 0.1 | | 0.1 | 0.2 |
| | Zn-Pb skarn | 49,600 t Zn 23,500 t Pb | | 41,300 t Zn 19,600 t Pb | 90,860 t Zn 43,120 t Pb | 265 39 | | 220 33 | 485 72 |
| TOTAL | | | | | | 3772 | 5 | 1458 | 5235 |

Table 5. Potential resources of non-metallic minerals and rocks (excluding limestone, aggregate, and sand and building stone for construction)

| Mineral | Deposit type | Potential resources, tonnes | | | | Value, \$ million | | | |
|--------------------------|---|-----------------------------|-------------|-------------|-------------|-------------------|-------------|-------------|---------------|
| | | Far North | Kaipara | Whangarei | Northland | Far North | Kaipara | Whangarei | Northland |
| Clay | Rhyolite-hosted halloysite | 10,300,000 | | 1,620,000 | 11,920,000 | 7210 | | 1134 | 8344 |
| | Volcanic-related kaolinite | 1,400,000 | 200,000 | 1,375,000 | 2,975,000 | 28 | 4 | 28 | 60 |
| | Kaolinitic clay from weathering 50% kaolinite | 150,000 | 250,000 | 200,000 | 600,000 | 3 | 5 | 4 | 12 |
| | Coal measure clay 40% kaolinite | 200,000 | | 1,200,000 | 1,400,000 | 12 | | 72 | 84 |
| | Bentonite clay | 500,000 | 200,000 | 160,000 | 860,000 | 32 | 13 | 10 | 55 |
| Diatomite | Lacustrine diatomite | 160,000 | 130,000 | 190,000 | 480,000 | 180 | 146 | 214 | 540 |
| | Marine diatomite | 200,000 | 400,000 | 200,000 | 800,000 | 225 | 450 | 225 | 900 |
| Feldspar | Feldspar sand | | 100,000,000 | 340,000,000 | 440,000,000 | | 1500 | 5100 | 6600 |
| Kauri gum (resins & wax) | | 1,200,000 t | | | | 2,400 | | | 2400 |
| Phosphate | Upwelling phosphate t 68% P ₂ O ₅ | 90,000 | 90,000 | 90,000 | 270,000 | 4 | 4 | 4 | 13 |
| Serpentinite | Serpentine in gabbro-peridotite complexes | 1,000,000 | | | 1,000,000 | 23 | | | 23 |
| | Diapiric serpentinite | 50,000 | 190,000 | 170,000 | 410,000 | 1 | 4 | 4 | 9 |
| Silica | Silica sand | 100,000,000 | 5,000,000 | 10,000,000 | 115,000,000 | 7,920 | 330 | 660 | 8910 |
| Zeolite | Zeolite 50% t | 200,000 | 200,000 | 300,000 | 700,000 | 20 | 20 | 30 | 70 |
| TOTAL | | | | | | 18,058 | 2476 | 7485 | 28,019 |

14.1 PRODUCTION SCENARIO

The previous sections have established that Northland has potential for a variety of mineral resources capable of sustaining substantial mineral production with a more diversified range of commodities than at present. This section of the report proposes a possible future mineral production scenario for economic modelling in the subsequent study by the New Zealand Institute of Economic Research (Walton 2007). We suggest that this scenario would be possible in 15 years, provided that

1. There is a sufficient level of exploration to define the new resources and
2. The resources, if discovered, can be developed.

Exploration spending is reported to the Ministry of Economic Development by the holders of prospecting and exploration permits, and the results are compiled and published by region (www.crownminerals.govt.nz/minerals/index.asp). Total, reported annual exploration spending in New Zealand (excluding consent and access costs) has increased from \$1.3 million in 2001 to \$25 million in 2006, but Northland accounted for less than 5% of total exploration spending in 2006. A substantial increase in exploration activity in Northland is required for the scenario to be achieved.

14.1.1 Methods

Two methods have been used to calculate the future mineral production scenario: 1. assignment of past maximum annual production values to the commodities currently in production, and 2. proposal of several hypothetical new mining operations based on the propectivity of specific commodities.

14.1.1.1 Past maximum production

Table 6 lists Northland annual mineral production for 2000 – 2005, with additional columns for a maximum production (based on highest annual 2000 – 2005 figure) and value (based on National 2005 values) for each commodity. Pre 2000 figures are not available separately for the Northland region. The 2005 statistics in Table 1 for the individual districts were specifically assembled for this project by Crown Minerals and are available only for 2005. During the compilation of the district figures, Crown Minerals discovered that the Northland statistics included some operations from the north of the Auckland Region and hence the discrepancy between Tables 1 and 6 for total Northland production. Nevertheless for consistency in comparison with past years, we have had to use the uncorrected figures for 2005.

Table 6. Annual production statistics and derived maximum values for Northland

| | Annual production | | | | | | Maximum production | | |
|-------------------------------------|-------------------|---------------------|---------------------|-----------------------|---------------------|---------------------|---------------------|---------------------------|---------------------|
| | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | t | 2005 \$ / t ^{*2} | Total value \$ |
| Building and Dimension stone | 1410 | 1520 | 1100 | 1560 | 1300 | 1200 | 1560 | 147.01 | 229,336 |
| Clay for brick, tiles etc | 4800 | 0 | 0 | 340 | 130 | 0 | 4,800 | 8.86 | 42,528 |
| Clay for pottery and ceramics | 15,570 | 14,050 | 15,850 | 14,000 | 14,950 | 15,370 | 15,850 | 640.70 | 10,155,000 |
| Decorative pebbles including scoria | 13,580 | 6800 | 8050 | 12,000 | 15,000 | 45,000 | 45,000 | 20.90 | 940,000 |
| Limestone and marl for cement | 895,490 | 844,350 | 946,550 | 880,000 | 875,320 | 990,880 | 990,880 | 17.17 ^{*3} | 17,101,656 |
| Limestone for agriculture | 300,670 | 337,650 | 564,200 | 371,190 | 375,800 | 355,500 | 564,200 | 16.30 | 9,196,460 |
| Limestone for industry & roading | 28,030 | 56,750 | 46,950 | 112,550 ^{*1} | 107,520 | 93,000 | 107,520 | 13.90 | 1,494,528 |
| Rock for reclamation & protection | 97,020 | 7600 | 6650 | 6940 | 16,720 | 19,810 | 97,020 | 11.33 | 1,099,237 |
| Rock, sand & gravel for building | 500,440 | 490,750 | 566,200 | 324,560 | 735,170 | 767,120 | 767,120 | 13.01 | 9,980,230 |
| Rock, sand & gravel for roading | 1,696,780 | 1,764,750 | 1,830,650 | 1,965,420 | 2,029,650 | 1,926,860 | 2,029,650 | 9.87 | 20,032,644 |
| Rock, sand, gravel & clay for fill | 202,950 | 371,800 | 247,150 | 375,500 | 354,730 | 420,890 | 420,890 | 5.62 | 2,365,402 |
| Sand for industry | 105,690 | 141,000 | 95,850 | 205,950 | 122,300 | 129,140 | 205,950 | 12.79 | 2,634,101 |
| Total | 3,862,430 | 4,037,020 | 4,329,200 | 4,270,000 | 4,648,990 | 4,764,770 | 5,285,140 | | |
| Value | 52,783,140 | \$48,870,434 | \$47,474,274 | \$55,925,195 | \$55,764,797 | \$59,849,389 | \$67,995,549 | | \$75,271,122 |

Source Crown Minerals (www.crownminerals.govt.nz).
Total value information only is provided for the regions.

*1 The 2004 value for Limestone for industry & roading was used as the maximum production value, but the 2003 figures for Limestone for agriculture and Limestone for industry & roading were changed by Crown Minerals just before the printing of this report making the 2003 slightly higher than the 2004 figure.

*2 2005 \$/t is the average value for total production for the commodity in New Zealand in 2005, but excludes cement (withheld).

*3 2005 \$/t for Limestone and marl for cement was back-calculated by assigning the national value figures to Northland 2005 commodities (\$42,831,733) and subtracting from the published \$ total (\$59,849,389) to solve for the one unknown ($\$17,017,656 / 990,880 = \$17.17 / t$).

14.1.1.2 New mining operations

Based on the mineral resource assessment, we think that there is potential for several new mining operations in Northland. A prerequisite is that there must be sufficient mineral exploration to locate and define these resources. For the purposes of this scenario we envisage four specific new mining operations: a gold-silver mine, a second metalliferous mine, a halloysite clay mine (additional to the existing Matauri Bay mines), and a silica sand mine (Table 7 and Figure 77). Additionally, we think there is potential for development of some other commodities which we have grouped in a category of 'Non specific new mining operations'.

Gold-silver mine

There is potential for a mine with a similar output to the Martha mine at Waihi. It could be an open pit mine producing 1.2 Mt/yr at 3 g/t Au and 3 g/t Ag, or an underground mine producing 0.4 Mt/yr at 9 g/t Au and 9 g/t Ag, for an annual yield of 120,000 oz Au (\$120 M) and 120,000 oz Ag (\$2.3 M), with a total gross value of \$122 M/yr. The type of deposit is unspecified and the value of production is spread between the Far North and Whangarei districts (65% Far North; 35% Whangarei) to broadly reflect the likely prospects for gold deposits in Northland (Figs 38, 46, 47 and 48).

Second metalliferous mine

Potential candidates are a second gold mine, a bauxite (aluminium) mine or a copper mine with an annual value of \$125 M spread between Far North (68%) and Whangarei (32%) districts (although a bauxite mine would be in the Far North) where known resources are located.

Second gold-silver mine:

This could have similar parameters to the gold-silver mine described above, with a total value of \$125 M/yr, spread between Far North (65%) and Whangarei (35%) districts.

Bauxite mine:

Open pit mining of bauxite at a rate of 1 Mt/yr of 37% alumina (equivalent to 30% extractable alumina) is envisaged. To allow for the extra processing cost of the low grade bauxite, the international price is discounted by one third (from NZ\$208 to NZ\$138) to give an annual value of \$138 M/yr. Mining of bauxite is mostly likely to occur in the Far North District (Fig. 32).

Copper mine:

A small open pit copper mine producing 1 Mt/yr at 1.0% Cu and 0.5 g/t Au for an annual yield of 10,000 t Cu and 16,000 oz Au is envisaged. The copper ore would be concentrated on site and then shipped overseas for smelting. Discounting the copper price by 10% to account for the cost of transport, smelting and refining, results in values of \$110 M for copper and \$16 M for gold, totalling \$126 M/yr. The type of deposit is unspecified and the value of production is spread between Far North and Whangarei districts (Far North 40%; Whangarei 60%) to broadly reflect the likely prospects for copper deposits in Northland (Figs 35, 36 and 37).

Halloysite clay mine

Provided a market can be secured, a second mining operation with equivalent production of halloysite (15,000 t/yr) worth \$10.5 M is possible. The value of production is spread between Far North and Whangarei districts (66% Far North; 34% Whangarei) to broadly reflect the likely prospects for halloysite clay deposits in Northland (Fig. 57).

Silica sand mine

Sea-Tow Ltd, on behalf of ACI, produced more than 50,000 tpa (e.g. 62,603 t in 1990) from Parengarenga for many years, for use in glass manufacture. Sand for this use is now imported from Australia, however there is potential to return to local production from the Far North deposit. An annual production of 70,000 t for a value of \$4.6 M is possible.

Non specific new mining operations

There is potential for production of additional commodities such as bentonite, coal, feldspar, kaolinite clay, kauri gum, peat, and zeolite and an annual production value of \$15 M is assigned, divided equally between the three districts, without specifying the individual commodities.

Table 7. Annual production scenario of new mining operations and split between districts.

| Commodity (FND/KD/WD) | Production rate | Grade | Component | Value component | Northland | Far North | Kaipara | Whangarei |
|---|-----------------|----------|---------------------|-----------------|-----------|-----------|---------|-----------|
| Gold-silver (65%/0%/35%) | 1.2 Mt/yr | 3 g/t Au | 120,000 oz Au | \$120 M | \$122 M | \$79.3 M | | \$42.7 M |
| | | 3 g/t Ag | 120,000 oz Ag | \$2 M | | | | |
| 2 nd metallic: Au-Ag, Al or Cu-Au (68%/0%/32%) | | | | \$125 M | \$125 M | \$85 M | | \$40 M |
| Halloysite (66%/0%/34%) | 45,000 t/yr | 33% | 15,000 t halloysite | \$10.5 M | \$10.5 M | \$6.93 M | | \$3.57 M |
| Silica sand (100%/0%/0%) | 70,000 t/yr | | | \$4.6 M | \$4.6 M | \$4.6 M | | |
| Other | | | | \$15 M | \$15 M | \$5 M | \$5 M | \$5 M |
| TOTAL (rounded) | | | | | \$277 M | \$181 M | \$5 M | \$91 M |

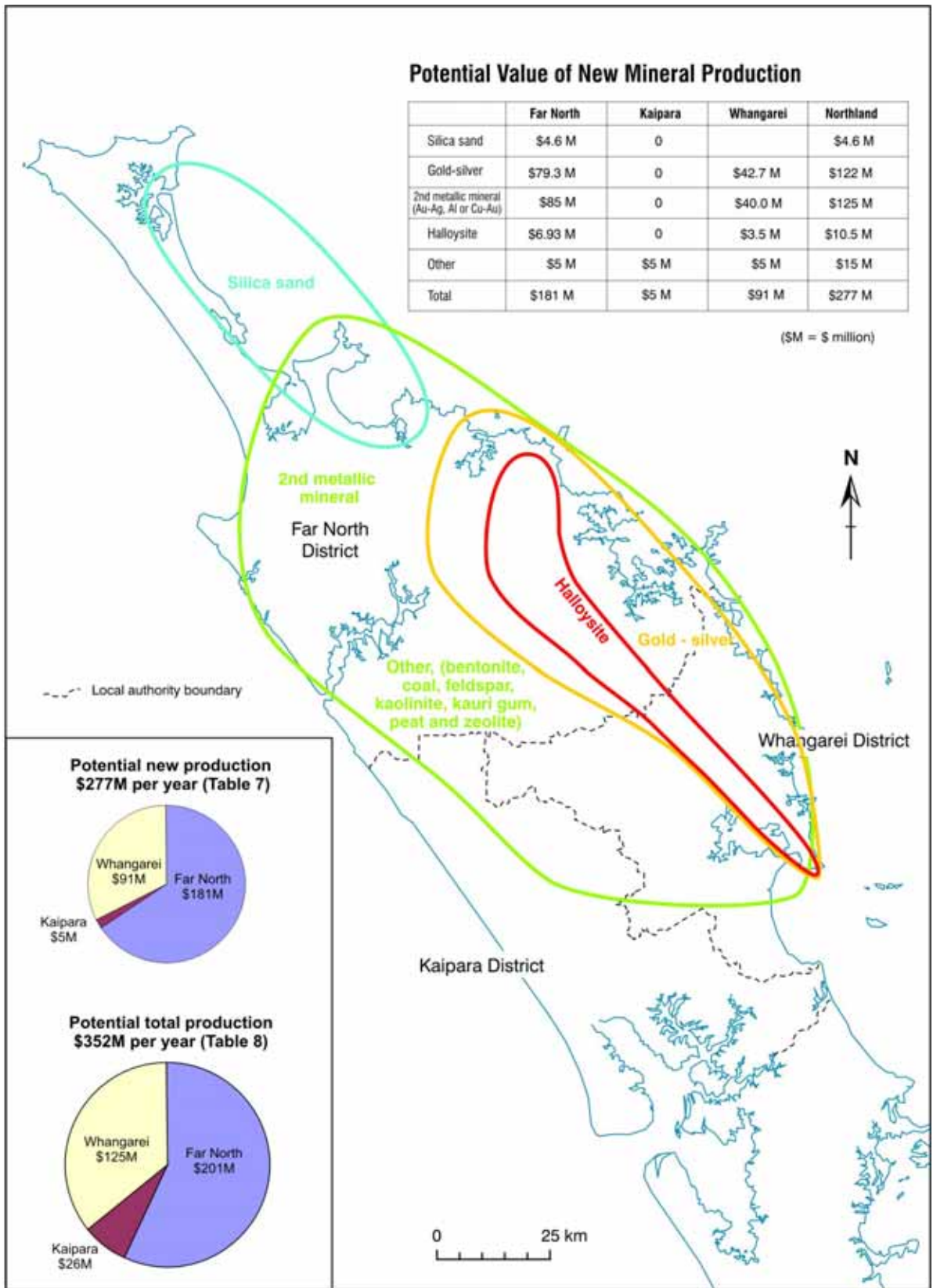


Figure 77. Possible types and potential prospective areas for new mining operations in the hypothetical scenario 15 years in the future, following extensive exploration. Inset graphs show the value of the new production and total production (including all commodities) in the scenario, portioned to the three districts.

14.1.2 Synthesis

Table 8 combines the data from the various methods to provide the full list of values for future mineral production. It shows substantial increases from 2005 values amounting to increases of 1007% for Far North district, 190% for Kaipara district, 567% for Whangarei district, and 634% for the Northland region overall. Changing commodities of the new mines varies the mix between districts. For example, envisaging a new coal mine instead of a new halloysite mine could increase the production value of Whangarei and possibly Kaipara at the expense of Far North.

Table 8. Annual production scenario by district including new mining operations.

| | Far North | Kaipara | Whangarei | Northland |
|--|----------------------|---------------------|----------------------|----------------------|
| Expanded existing production | | | | |
| Building & dimension stone | | | \$229,336 | \$229,336 |
| Clay for bricks, tiles, etc | | | \$42,528 | \$42,528 |
| Clay for pottery and ceramics (Matauri Bay halloysite mine) | \$10,155,000 | | | \$10,155,000 |
| Decorative pebbles including scoria | | | \$940,000 | \$940,000 |
| Limestone & marl for cement | | | \$17,101,656 | \$17,101,656 |
| Limestone for agriculture | \$2,529,027 | \$5,600,644 | \$1,066,789 | \$9,196,460 |
| Limestone for industry & roading | \$660,581 | \$833,947 | | \$1,494,528 |
| Rock for reclamation & protection | \$611,176 | | \$488,061 | \$1,099,237 |
| Rock, sand and gravel for building | \$139,723 | \$4,291,499 | \$5,549,008 | \$9,980,230 |
| Rock, sand and gravel for roading | \$6,009,793 | \$7,351,981 | \$6,670,870 | \$20,032,644 |
| Rock, sand, gravel and clay for fill | \$312,233 | \$151,386 | \$1,901,783 | \$2,365,402 |
| Sand for industry | \$52,682 | \$2,536,639 | \$44,780 | \$2,634,101 |
| Sub-total | \$20,470,215 | \$20,766,096 | \$34,034,811 | \$75,271,122 |
| New operations | | | | |
| Gold-silver mine – new (65%/0%/35%) | \$79,300,000 | | \$42,700,000 | \$122,000,000 |
| 2 nd metalliferous mine – new (68%/0%/32%) | \$85,000,000 | | \$40,000,000 | \$125,000,000 |
| Halloysite mine – new (66%/0%/34%) | \$6,930,000 | | \$3,570,000 | \$10,500,000 |
| Silica sand – new (100%/0%/0%) | \$4,600,000 | | | \$4,600,000 |
| Other – new | \$5,000,000 | \$5,000,000 | \$5,000,000 | \$15,000,000 |
| Sub-total | \$180,830,000 | \$5,000,000 | \$91,270,000 | \$277,100,000 |
| TOTAL | \$201,300,215 | \$25,766,096 | \$125,304,811 | \$352,371,122 |
| 2005 | \$19,984,119 | \$13,530,085 | \$22,090,134 | \$55,604,339 |
| \$ increase from 2005 | \$181,316,096 | \$12,236,011 | \$103,214,677 | \$296,766,783 |
| % increase from 2005 | 907% | 90% | 467% | 534% |

15.0 CONCLUSIONS

1. Production of aggregate and limestone is likely to increase provided the Northland economy and population continue to grow. There is potential to expand the market for aggregate by exporting to Auckland. Risks include sterilisation of aggregate resources by urban development and possible site-specific constraints on quarry development.
2. Some of the previously estimated resources of sub-bituminous and bituminous coal (23 Mt, here valued at \$1150 M), lignite (31 Mt, here valued at \$620 M) and peat (300 Mt, here valued at \$12,000 M) could be utilised if markets could be developed.
3. Resources of metallic minerals modelled in 16 different mineral deposit types are valued at \$5,235 million.
4. Resources of non-metallic minerals modelled in 14 different mineral deposit types are valued at \$28,019 million.
5. The best potential for exploration and development is for commodities such as gold and silver, clay and silica sand, with good potential also for aluminium, bentonite, copper, feldspar, kaolinite clay, kauri gum, peat and zeolite.
6. Other commodities present with lesser potential include antimony, chromium, diatomite, iron, manganese, mercury, nickel, phosphate, serpentinite and zinc-lead.
7. An increased level of mineral exploration is required to locate and define the mineral resources in order to expand the contribution of the minerals industry to the Northland economy. While an analysis of the factors impeding exploration in Northland is outside the scope of this study, attracting explorers to work in the region will require marketing Northland's mineral potential to the national and international exploration community along with overcoming barriers to exploration and mineral development.

16.0 FUTURE WORK

This study has shown that Northland has potential for a wide range of minerals, both metallic and non-metallic. Walton (2007) has quantified the economic significance of this potential by applying the scenario described here to a regional economic model. To realise the potential for high value minerals (metals and non-metallic minerals) a substantial, sustained increase in exploration activity is needed. While an investigation of the factors that are impeding exploration here is outside the scope of this study, they could include a lack of accessible data on the resource potential of the region, negative perceptions about the mineral potential of the district and the effects of Government policies that apply throughout the region to exploration and mining.

For aggregates, where production close to the market significantly reduces transport costs and the impact of transport, a more detail investigation of potential sources of supply and future demand would allow planning to better provide for the production of these materials in the future.

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APPENDIX 1 - DIGITAL DATA SETS

The accompanying CD-ROM contains a GIS with layers or themes for the following:

Minerals

Metals

- Aluminium
- Antimony
- Chromium
- Copper
- Gold and silver
- Iron
- Lead and zinc
- Manganese
- Mercury

Non metals

- Aggregate
- Bentonite
- Clay
- Diatomite
- Dimension stone
- Limestone
- Phosphate
- Sulphur
- Sand
- Serpentinite
- Silica

Coal

- Coalfields
- Coal sites

Māori land

Authority boundaries

- Districts
- Regions

Map indices

- 1:50K
- 1:250K

Topography and culture

- Roads
- Coastline
- Rivers
- Lakes
- Urban areas

Limestone

Geological maps

- QMAP Kaitaia
- QMAP Auckland
- Geology 1M
- Shaded DEM

MINERAL DEPOSITS

Mineral deposit locations and summary information have been taken from the GERM (GEological Resource Map) mineral deposit inventory database (Petty 1987; Wyss et al. 1990; Brathwaite et al. 1991; Kermode et al. 1992). For each entry, the GERM database contains summary information on the commodities, location, type of site, operator, production, prospecting activity, geology, and references. The data are presented as different layers/themes for different commodities: metals, non metals and coal.

The data were compiled between 1986 and 1993. There has been no systematic update of the data since 1993, and therefore the status of some mining and quarrying operations may have changed. Few new operations since 1994 are included in the GERM database.

MĀORI LAND – LINZ DATABASE

Digitised polygons of Māori land were obtained from LINZ and are presented in the GIS as a separate layer. They represent land parcels of Māori owned land in the LINZ cadastral database as supplied to GNS in 2006 and retrieved by searches of two fields: parcel Type = Māori and Name = Māori. These parcels are described by lines with attributed land ownership information. The Māori land parcels probably represent a minimum of Māori land holdings.

AUTHORITY BOUNDARIES

Boundaries for Regional and District councils are presented as separate layers.

MAP INDICES

Sheet boundaries for the Infomap 260 1:50,000 map series and the 1:250,000 map series are represented as separate layers.

GEOGRAPHIC LAYERS

Individual layers for the roads, coastline, rivers, lakes, and urban areas were obtained from the 1:250,000 data set of Land Information New Zealand (LINZ).

LIMESTONE

A map of areas of limestone was compiled by Turnbull & Smith Lyttle (1999). It represents the extent of formations in the QMAP database mapped as limestone or calcareous rich sedimentary rocks, and therefore may over-represent the areas of limestone where shown. There are several small areas of limestone that have not been captured. The data are classified according to the age of the rocks.

GEOLOGY: 1:250 K QMAP KAITAIA AND AUCKLAND

The digital 1:250,000 maps for the Kaitaia (Isaac 1996) and Auckland (Edbrooke 2001) QMAP sheets are from the QMAP database. Data for QMAP were assembled at a scale of 1:50,000 and simplified for the published 1:250,000 map sheets. The data represent a synthesis of previous 1:63,360, 1:50,000 and 1:250,000 scale mapping, and new unpublished infill mapping.

GEOLOGY: 1:1 M MAP

The digital 1:1 million map is a modified version of the published 1:1,000,000 maps, that were enlarged to 1:250,000 for digitising. The GIS map database includes geology, lithology and age attributes for individual polygons.

SHADED DEM

The hill shaded relief Digital Elevation Model (DEM) was constructed with topographic data obtained in digital form from LINZ. Twenty metre contour interval data was converted to a DEM using the Triangular Irregular Network (TIN) modelling technique. The DEM was used to make hill-shaded relief models by illuminating the elevation model with an artificial sun at a specified elevation angle and orientation. The relief model used a sun elevation angle of 30°, directed from the northeast.



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