The mineral potential of New Zealand – Part 1: Overview of New Zealand's mineral deposits and their resources

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Past and Current Exploration in New Zealand

New Zealand's major mineral products are gold and ironsands, with coal production declining over recent years. Gold production is dominated by mines at Macraes in Otago and Waihi in the Coromandel Peninsula (Waikato). Some silver is mined as a co-product of gold mining, largely at Waihi. Heavy-mineral sands are mined from the west coast of both main islands: titanomagnetite with by-product vanadium in the North Island and ilmenite with by-product garnet, zircon and monazite from the South Island. Coal is mined dominantly from Waikato (industrial and power generation), the west coast of the South Island (export) and Otago/Southland (local industry). Non-metallic mineral mining is dominated by aggregate and sand.

Onshore exploration since the 1980s has focused on hard-rock and placer gold, as well as placer ironsands. Brownfields exploration near existing deposits or mines has been most successful over the past 50 years, and greenfields exploration has also made new discoveries. Offshore exploration has included placer ironsand, placer gold, hydrothermal massive sulfide deposits and phosphorite nodules. Scientific and industry cruises have highlighted the mineral potential of Kermadec Arc seafloor massive sulfides, Campbell Plateau ferromanganese nodules and Chatham Rise phosphorite nodules.

Geological Setting of New Zealand's Mineral Potential

Geologically, New Zealand is relatively young and tectonically active, sitting astride the Australian/Pacific plate boundary. New Zealand's mineral potential is determined by its geological history and current tectonics. Two prolonged periods of mountain building separated by a period with very little tectonic activity provide the context for a variety of mineral deposits described in this report.

Marine sedimentary rocks present in the South Island formed along the edge of a subduction zone on the margin of the supercontinent Gondwana between ~500 and 360 Ma (million years ago). Similar rocks are also found in southeast Australia. They host similar mineral deposits, for example, the Reefton (New Zealand) and Victoria (Australia) goldfields. Magmatic intrusions into these rocks have associate tin, tungsten and molybdenum deposits. Sedimentary rocks that formed from ~200 to 100 Ma in both the North and South Islands host manganese and copper deposits. Parts were deeply buried and metamorphosed to schist that hosts gold ± tungsten ± antimony deposits in Otago (including Macraes) and Marlborough.

Subduction ceased about 100 Ma, followed by separation of our continent from Australia and Antarctica at about 80 Ma. The Zealandia region was tectonically quiet for an extended period, and a series of sedimentary basins formed around the margins. These basins contain petroleum, coal and limestone deposits.

As the current plate boundary started to develop about 25 Ma and the landscape uplifted into mountain ranges, placer gold and coal measures were deposited in Otago and Southland. Active volcanism associated with the active plate boundary began in the Miocene and led to the deposition of epithermal gold-silver in Northland, the Coromandel and the Taupō Volcanic Zone, as well as porphyry copper. Seafloor massive sulfide mineralisation is found at several submarine volcanoes in the southern sections of the Kermadec volcanic arc.

Rapid uplift and erosion of the Southern Alps over the last 2–5 Ma formed gold placers in rivers and glacial outwash terraces in Westland and Otago. Ilmenite-garnet-gold placer deposits formed along and offshore of the west coast of the South Island. Titanomagnetite from the erosion of volcanoes formed placer deposits along and offshore of the west coast of the North Island. Phosphate was deposited on the Chatham Rise, and an extensive ferromanganese nodule field was formed at abyssal depths south of New Zealand adjacent to the Campbell Plateau in the southwest Pacific Ocean.

Future Exploration of New Zealand's Mineral Potential

Exploration to mining is a staged process that can take from 5 to 30 years. Ongoing mineral exploration is required to maintain the supply of mined materials. It is common for a succession of companies to explore each prospect, and it is crucial that previous results are available for current and potential new explorers. Fewer than 1% of prospects will result in a producing mine. Total expenditure on exploration in New Zealand since 2015 has been well below that for the previous decade.

This report summarises classification of resources (Section 7), onshore metallic minerals (Section 8), onshore aggregate and non-metallic minerals (Section 9), coal (Section 10), offshore metallic minerals (Section 11) and offshore non-metallic minerals (Section 12). More detail is provided in the Part 2 document of this report (Christie et al. 2024).

Challenges for Future Exploration and Mining in New Zealand

- International perception of New Zealand for mineral prospectivity and exploration investment.
- Reduction in minerals research and funding across New Zealand research organisations over the past decade with loss of capability.
- An out-of-date national minerals research strategy (NZMIA 2002; Straterra 2012) to guide research priorities.
- Limited post-processing and refining capability in New Zealand results in out-sourcing of value-added work overseas.
- Environmental concerns and public perception of the impacts of exploration and mining.
- Limited coverage of New Zealand by modern airborne geophysical and soil geochemical data.

Strengths and Opportunities for Future Exploration and Mining in New Zealand

- New Zealand has both ancient and currently active hydrothermal systems producing epithermal and orogenic gold deposits and is a natural laboratory that demonstrates mineral forming systems.
- World-class gold mines at Waihi and Macraes.
- Reported Joint Ore Reserves Committee (JORC) and N43-101 resources that include at least 10 million ounces of gold and 700 Mt (million tonnes) of iron ore.
- Availability of digital data for mineral exploration and the National Core Store.
- Modern mining operations and innovative extraction methods.
- Several prospects where sufficient exploration has already established potential for development leading to production (Section 15.5).

- **Short-term:** Hard-rock gold exploration at Wharekirauponga, Coromandel; Snowy River, Reefton; and the Rise & Shine shear zone, Otago.
- **Longer-term:** Hard-rock gold at Neavesville, Coromandel, and Sams Creek, Nelson; placer gold in the West Coast, Marlborough, Otago and Southland regions; West Coast heavy mineral sands and (with market development) non-metallic minerals, e.g. silica, bentonite, diatomite, limestone, perlite, pumice, serpentinite and zeolite.

- Numerous potential exploration prospects, including antimony from Reefton, new gold discoveries, offshore polymetallic mineral deposits, phosphorite on the Chatham Rise and ferromanganese nodules from the Southern Ocean.
- Potential for minerals research to suggest mineral deposit types currently not known in New Zealand.

Recommendations for Further Work

- Establish New Zealand's mineral wealth potential by undertaking a geologic and economic assessment to quantify the current known and estimated undiscovered mineral resources and their potential value.
- Develop a new national minerals research strategy following the release of the Critical Minerals List.
- Undertake new scientific research to demonstrate new mineral potential:
  - Green and critical mineral studies (e.g. for lithium, nickel, platinum group metals and rare earth elements) to advance understanding of New Zealand's endowment.
  - Evaluate (in 4D) regional metallogenesis of specific districts and regions in terms of tectonic setting, geological and structural evolution, genesis of metalliferous plutons and potential fertility of source rocks, with recognition of the influences and controls of these parameters on the formation of mineral deposits.
  - Identify metal sources, transport pathways and deposition mechanisms for mineral deposit formation.
  - Identify footprints and vectors of key mineral-deposit types to characterise exploration targets and their deposit architecture.
  - Encourage research and exploration of New Zealand's offshore resources to investigate their potential, including a holistic overview of prospective seafloor hydrothermal systems for their massive sulfide potential (copper, gold, zinc, barium, etc.).
  - Identify aggregate and sand sources closer to markets to reduce transport-related costs and carbon emissions.
  - Undertake materials research to develop new uses of minerals and greater share of the value chain in New Zealand.
- Streamline access to key mineral exploration datasets and relevant research.

Active mining:

Number of active mining operations and their production:

Aggregate	600	>40 Mt
Limestone	>68	1.2 Mt
Coal	17	3 Mt
Alluvial gold	120	31,700 oz
Hard-rock gold	2	182,800 oz
Hard-rock silver	1	120,100 oz
Ironsand	2	>2 Mt
Ilmenite sand	1	

- Other industrial minerals (more than 20 operations, including perlite, pumice, serpentinite and zeolite).
- By-product vanadium, garnet and rare earth elements.

Active production highlights:

- Aggregate – building our roads and buildings (250 t in the average house).
- Limestone – down on the farm with fertiliser and farm tracks.
- Ironsand – putting the roof over our heads with steel.
- Heavy mineral sand – providing industrial minerals and rare earth elements.
- Gold and silver for export revenues.
- Halloysite – the world's whitest clay for high-quality ceramics.
- Diatomite – for pozzolan cement, reducing our carbon footprint in concrete.
- Zeolite – diverse uses, including cleaning spills and pollutants, water treatment and filters, conditioners for sports turf and slow-release fertiliser.

Potential import substitution of fertiliser minerals:

- Phosphorous: eastern side of the North and South Islands and offshore on the Chatham Rise.
- Potassium: East Coast glauconite.
- Sulphur: Central North Island.

Assisting the road to carbon neutrality with exploration for:

- Lithium for electric car batteries.
- Diatomite for pozzolan cement, reducing our carbon footprint in concrete.
- Rare earth elements for wind turbines, electric car batteries, energy-efficient light bulbs and efficient motors/generators.
- Platinum Group Elements for catalytic converters to reduce emissions in petrol and diesel vehicles.
- Low-silica rocks for carbon dioxide sequestration.

Increased exports of niche market minerals, for example:

- Amorphous silica
- Diatomite
- Perlite
- Pumice
- Zeolite

Research on new applications for minerals:

- Inductive power charging of electric vehicle batteries using ironsand (GNS Science and University of Auckland)
- Converting coal to carbon foam for use in many thermal, mechanical and electrical applications (New Zealand Institute for Minerals to Materials Research [NZIMMR]).

Value-add to mineral exports:

- Increased processing in New Zealand for ironsands, ilmenite sand and some industrial minerals.

Research on new processing technology:

- Extraction of lithium and other metals from fluid used by the geothermal power industry (Geo40).
- Zero-carbon manufacture of iron using hydrogen instead of coal (Victoria University of Wellington).
- Improving recovery of gold in placer gold plants (NZIMMR)

1.0 INTRODUCTION

Compared with most other countries with a similar land area and population, New Zealand is relatively well-endowed with natural mineral resources such as construction aggregate, sand, limestone, gold, silver, titanomagnetite ironsand, ilmenite, clay, perlite, pumice, serpentinite and zeolite (Figure 1.1). On land, these commodities have considerable capacity for expanded production, whereas offshore within New Zealand's Exclusive Economic Zone (EEZ) and Extended Continental Shelf (ECS) there is potential for new discoveries and development of gold, ironsand, volcanogenic massive sulfides (copper, zinc, lead and gold) and ferromanganese deposits (manganese, nickel, copper, cobalt and other rare metals) (Figure 1.2).

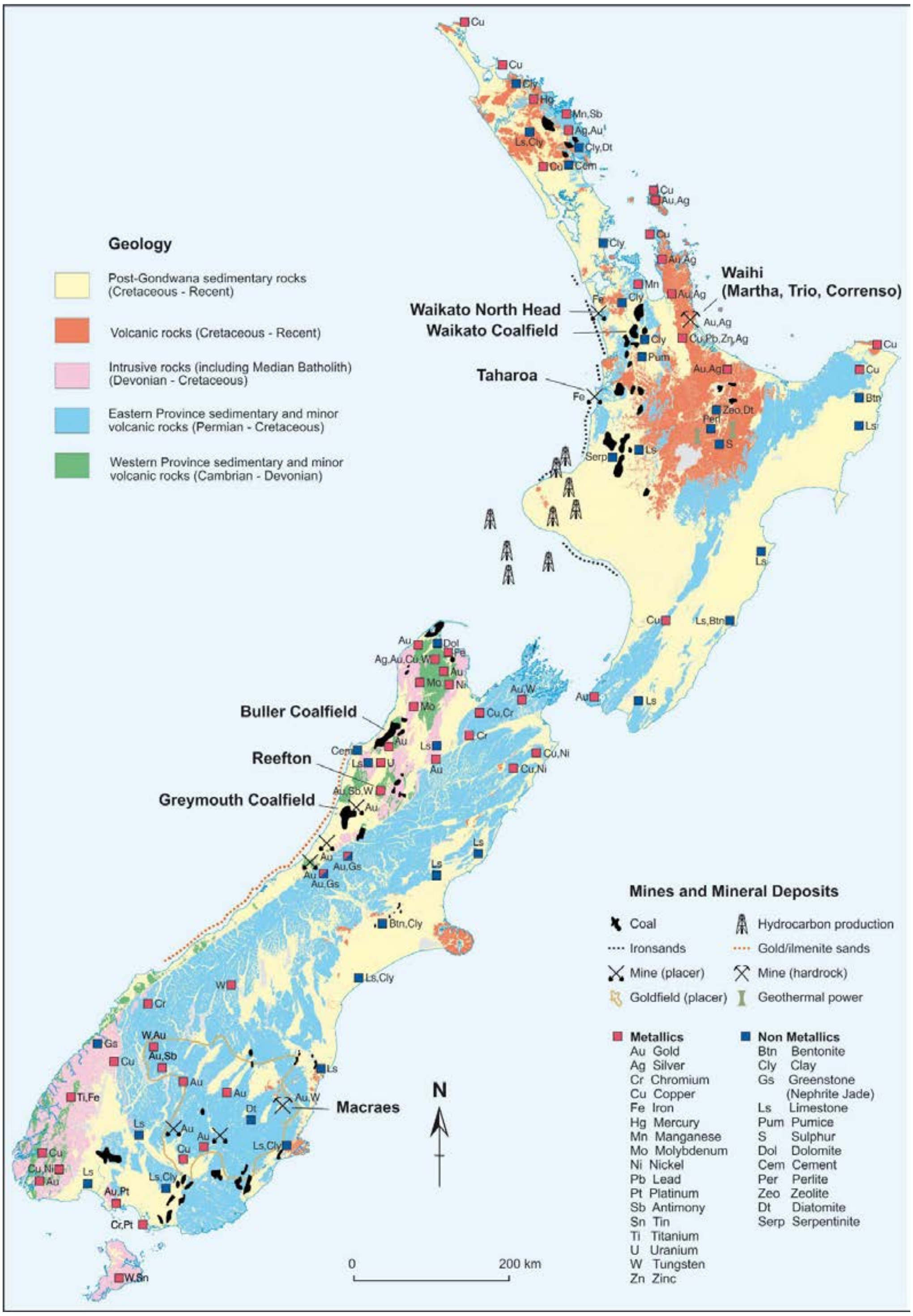

Figure 1.1 New Zealand geology and mineral deposits (after Christie and Barker [2013]).

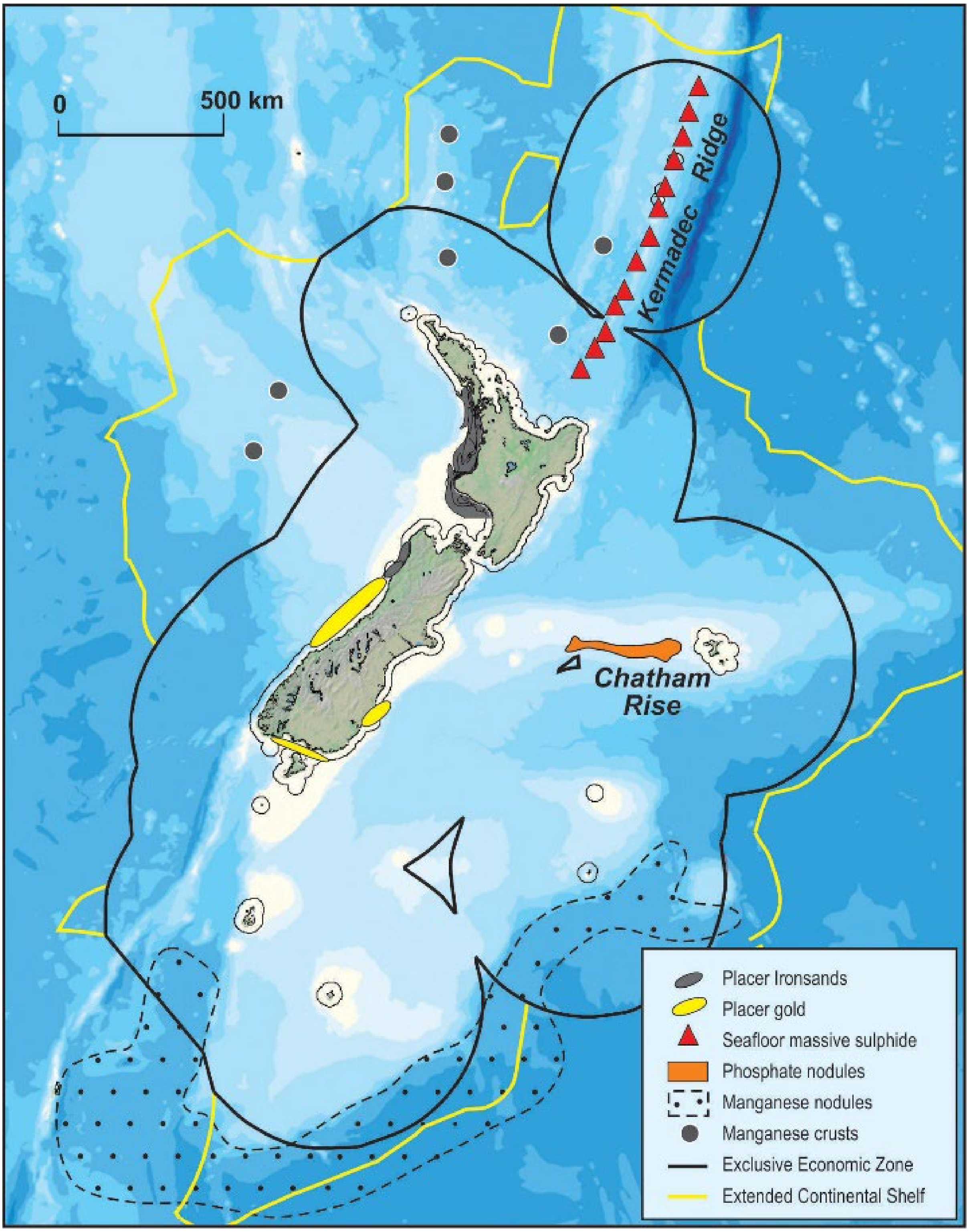

Figure 1.2 Offshore minerals (after Christie and Barker [2013]).

Mineral resource information is required in the management of New Zealand's mineral resources, particularly for (1) land-use planning, (2) making decisions of development versus preservation and (3) encouraging new mineral exploration. This report provides a review of New Zealand's aggregate, mineral and coal resources and notes previous work to quantify these resources (e.g. Christie and Brathwaite 1999).

In this report, 'mineral' is used in a broad sense and can include both materials (e.g. aggregate) and elements (e.g. tungsten).

1.1 Background, Scope and Report Layout

The Ministry of Business, Innovation & Employment (MBIE) contracted GNS Science to provide a comprehensive report describing New Zealand's aggregate, mineral and coal resources, indicating their in-ground mineral potential to identify opportunities and priorities for policy decisions and investment in the mining sector.

The scope of this study includes onshore and offshore (in New Zealand's EEZ and ECS) metallic and non-metallic mineral resources, as well as onshore coal. Hydrocarbons (oil and gas), mercury, uranium and other radionuclides are excluded. Also excluded is the potential production of minerals from geothermal fluids and sea water, which may be feasible in the future.

The report is divided into two parts, published as separate volumes. Part 1 provides background material, brief descriptions of individual mineral commodities and summaries of resource estimates. Part 2 is more detailed, giving in-depth descriptions of most mineral commodities. The Executive Summary, Recommendations for Future Work, and Conclusions for both parts are presented in Part 1. Each part finishes with a list of references cited in that part.

1.2 Geological Timescale

In this report, the ages of rocks and mineral deposits are stated in millions of years (Ma) or using the names of the specific Era, Period or Epoch on the international geological time scale (Figure 1.3).

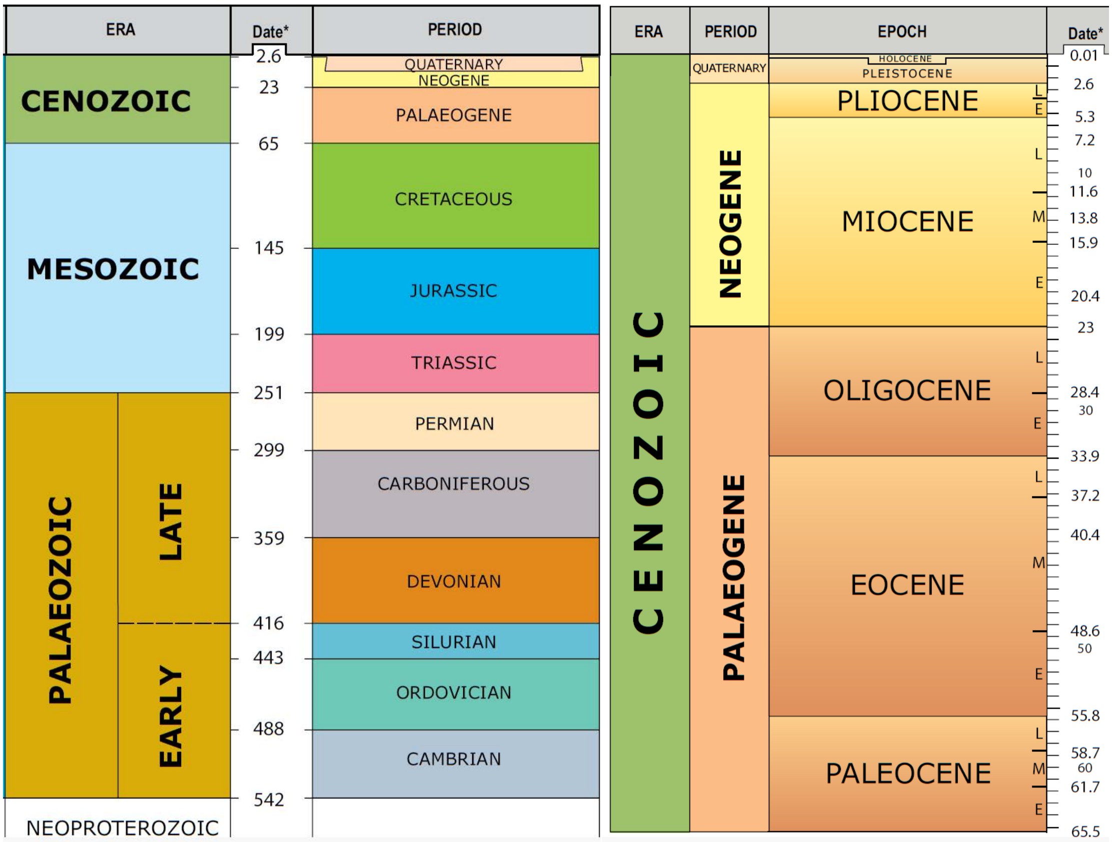

Figure 1.3 Geological timescale in millions of years (after the British Geological Survey[1]).

1 https://www.bgs.ac.uk/discovering-geology/fossils-and-geological-time/geological-timechart/

2.0 MINING HISTORY

The mining industry has been a major contributor to New Zealand's economic development since the arrival of European settlers in the 1840s. From the 1840s, coal mines were developed throughout New Zealand as a source of fuel. The gold rushes from the 1850s led to the settlement of much of the South Island, with gold rapidly becoming New Zealand's main export earner by the late 1800s.

Exploration for New Zealand's mineral resources began with Māori discoveries of pounamu (greenstone) and other rocks and minerals suitable for making weapons, tools, art and ornaments. Mineral exploration intensified when European settlers arrived in numbers in the mid-1800s. By 1869, gold, silver, copper and iron ores had all been discovered and worked, and numerous other metals had also been located (Hector 1869).

Gold was the most valuable mineral produced in New Zealand during the mid-late 1800s, being overtaken by coal in the 1930s and later by aggregate and non-metallic industrial minerals in the 1960s, when coal mine output declined (Figure 2.1). Prolonged government-funded investigations into making steel from the very extensive titanomagnetite ironsand deposits of the west coast of the North Island were eventually successful, and a mill established at Glenbrook began producing steel from ironsand in 1970.

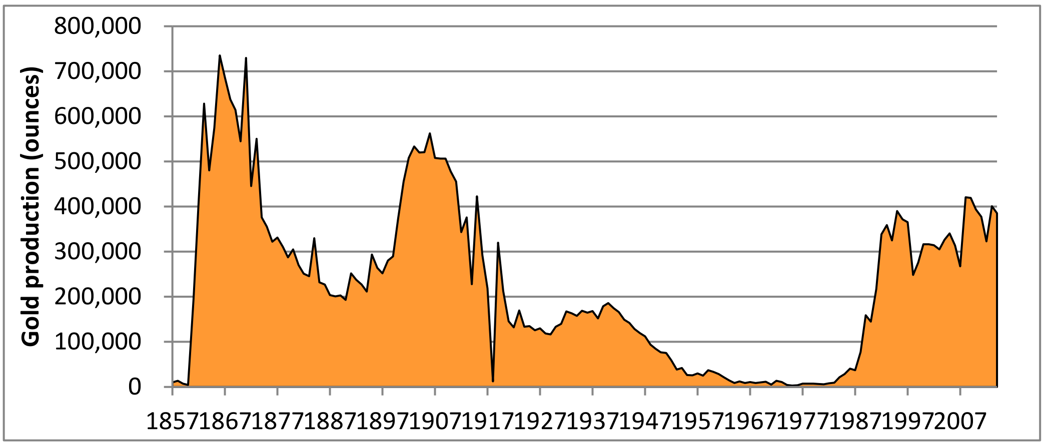

Figure 2.1 New Zealand gold production. New Zealand has produced gold in three main surges: sluicing and alluvial workings in the 1860s, dredging and hard-rock gold mining in the early 1900s and mainly hard-rock mining from the 1990s.

Over the past 50 years, the mining industry in New Zealand has grown strongly. A surge of investment in mineral exploration by the private sector, mainly by overseas companies in the 1980s, led to new mineral discoveries and new mines being developed. These included hard-rock gold mining operations at Golden Cross, Waihi, Reefton and Macraes, as well as alluvial gold mining on the West Coast and in Otago and Southland. Exploration has extended offshore, with programmes exploring for ironsand, gold, phosphate and seabed massive sulfide deposits.

The success of the mineral industry in New Zealand has depended on innovation and research. Major innovations include development of the bucket-ladder dredge in the late 1800s for working placer gold in the South Island, application of the cyanide process of gold extraction that was first used commercially at Karangahake near Waihi in the 1880s, making steel from titanomagnetite ironsands after a century of investigation, applying the results of extensive research into active geothermal systems for electricity generation to the exploration of epithermal gold deposits from the 1980s and undersea exploration for seafloor hydrothermal systems and massive sulfide deposits along the Kermadec Arc from the 2000s.

3.0 THE GEOLOGICAL SETTING OF NEW ZEALAND'S MINERAL RESOURCES

New Zealand's mineral potential is determined by its geological history and current tectonic setting. New Zealand is in a geologically active zone at the boundary between the Pacific and Australian plates (Figure 3.1). New Zealand represents just over 5% of the mostly submerged 4.9 million km^2 continent of Zealandia (Figure 3.1). New Zealand hosts a number of active volcanoes and areas of geothermal activity and also experiences frequent earthquakes. The Kermadec-Tonga, Lau-Colville and Macquarie ridges are intra-oceanic volcanic and tectonic expressions of the plate boundary. Past geological activity has produced deposits of gold and other metals, commonly as ancient hydrothermal systems, and a range of industrial minerals. During periods of geological stability, extensive peat swamps formed that have been deeply buried and converted to lignite and coal. Limestone was deposited across New Zealand when much of the country was submerged beneath the sea.

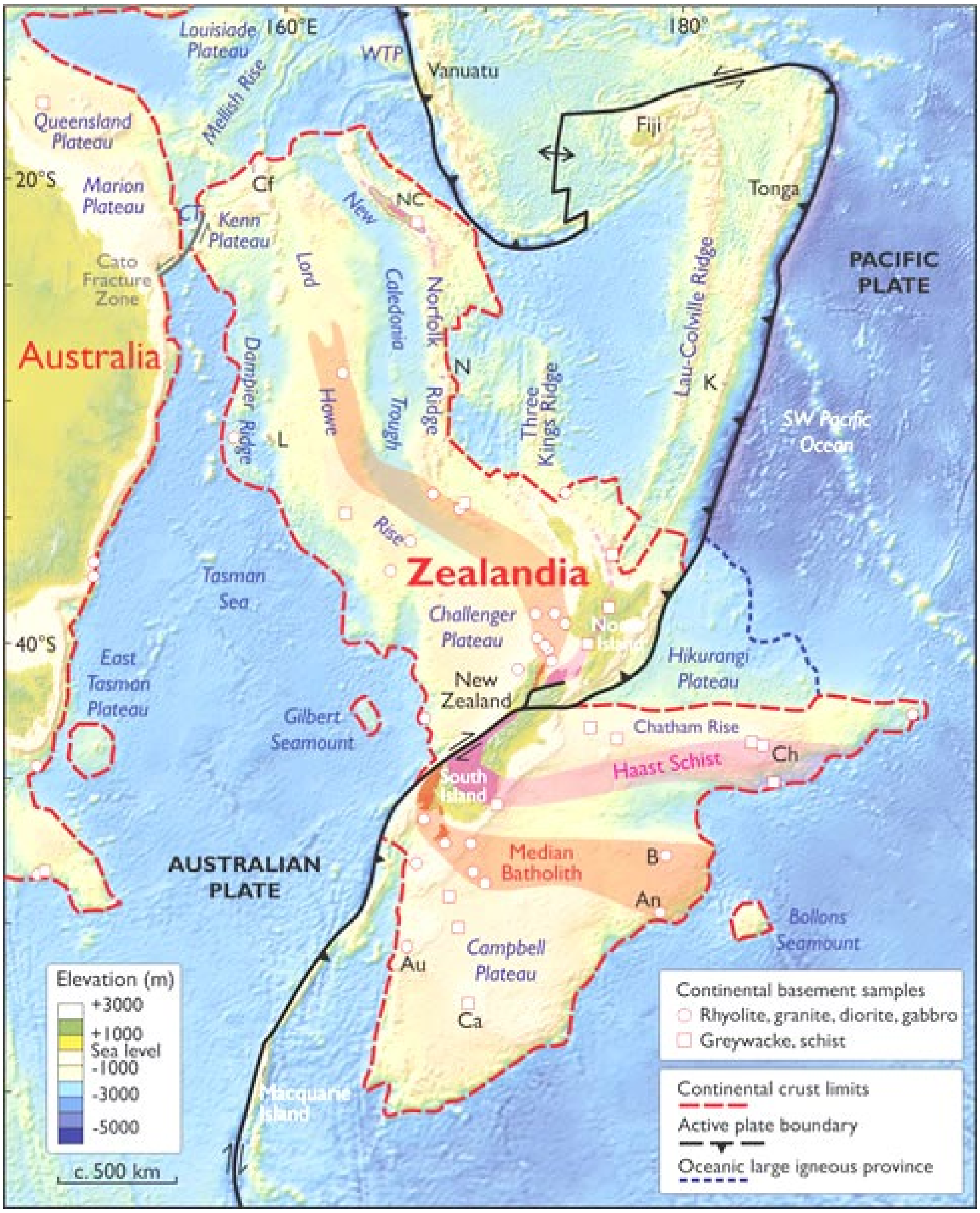

Figure 3.1 Extent and bathymetry of Zealandia. NC = New Caledonia (after Mortimer et al. [2017]).

3.1 Gondwana Association, ca. 510–80 Million Years Ago

The older rocks of New Zealand formed on, or near, the margin of Gondwana (Figures 3.2 and 3.3) and comprise three main basement elements: the Western Province (Early to Mid-Paleozoic), Eastern Province (Late Paleozoic to Early Cretaceous) and Median Batholith (Mid-Paleozoic to Early Cretaceous). In the South Island, these three units are displaced into northwest and southeast segments by 480 km of Late Cenozoic movement along the active Alpine Fault.

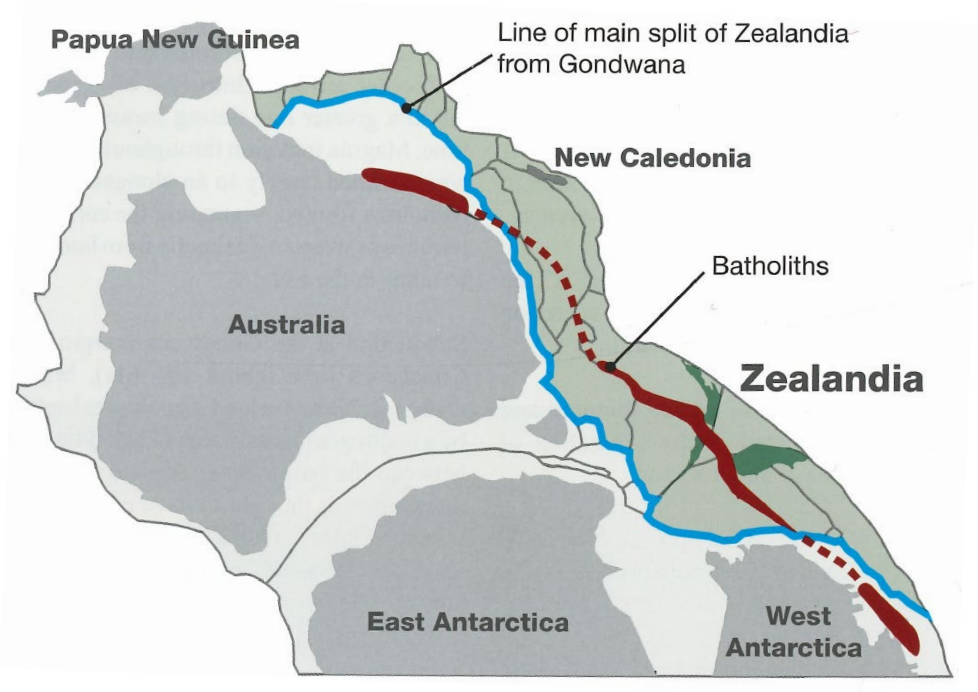

Figure 3.2 Reconstruction of Gondwana at about 90 Ma. The blue line marks where the main split between Zealandia and Gondwana would later occur. Aligned granite batholiths (dark red), developed above the Paleozoic–Mesozoic subduction zone at the Gondwana margin, track across Australia, Zealandia and West Antarctica (after Edbrooke [2017]).

3.1.1 Western Province

The Western Province rocks are found in the west and south of the South Island and on Rakiura / Stewart Island. They include metamorphosed sandstone, mudstone, limestone and volcanic rocks, intruded by granite batholiths and mafic–ultramafic igneous complexes. The main associated mineral deposits are orogenic gold-quartz veins hosted by Paleozoic greywacke and argillite (e.g. Globe Progress and Blackwater deposits in the Reefton goldfield). Other types of deposits present are volcanogenic massive sulfide zinc-lead; vein and greisen tungsten and tin; granite-related gold; and magmatic nickel-copper sulfide, platinum group element and magnetite–ilmenite deposits. Granodiorite stocks, intruded during the Early Cretaceous, have associated porphyry molybdenum mineralisation (Figure 3.3).

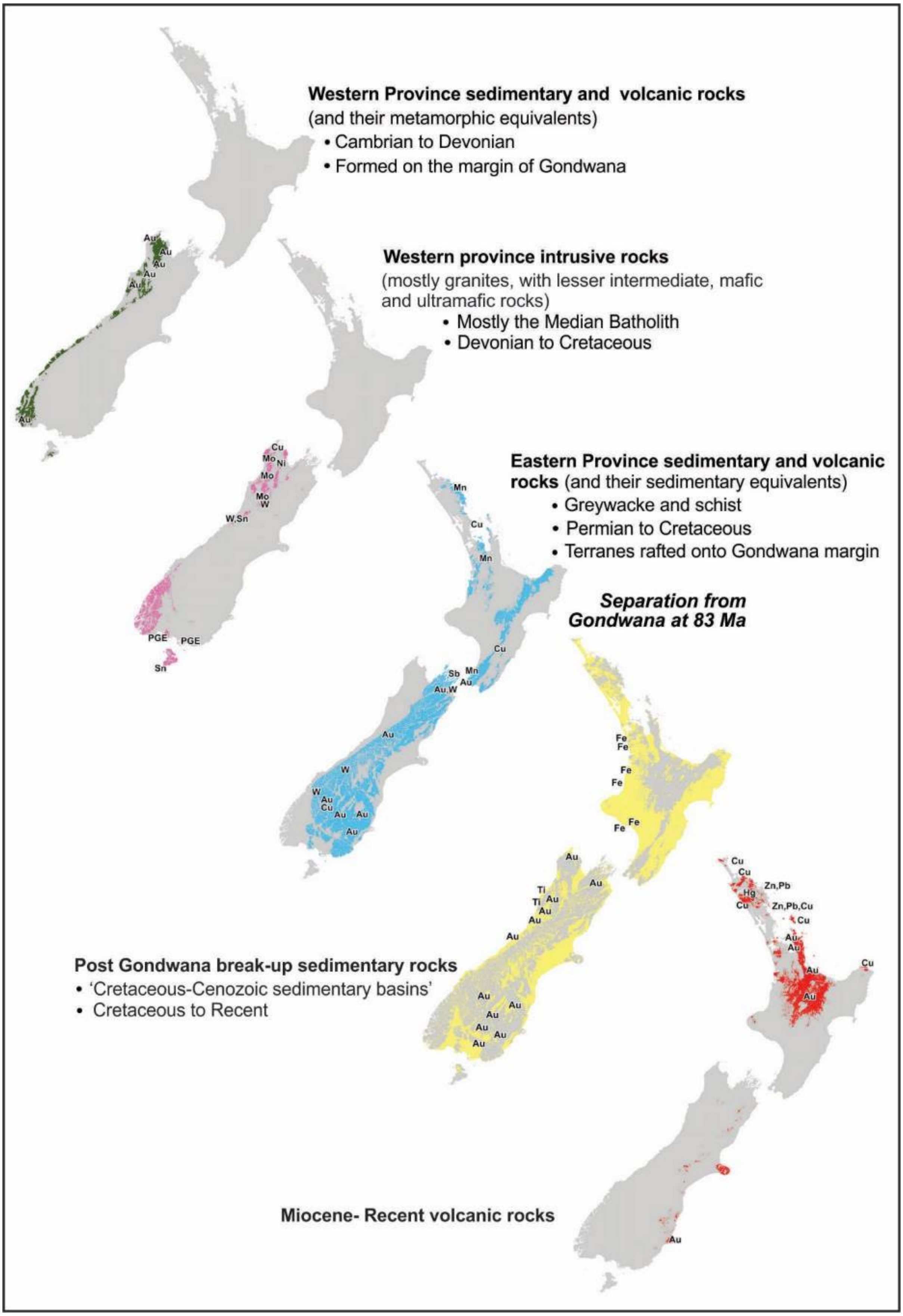

Figure 3.3 Geological evolution of New Zealand and associated metallic mineral deposits (after Christie and Barker [2013]). Au = gold, Cu = copper, Mn = manganese, Mo = Molybdenum, Ni = nickel, Pb = lead, PGE = platinum group elements, Sb = antimony, Sn = tin, Ti = titanium, W = tungsten, Zn = zinc.

3.1.2 Eastern Province

The Eastern Province includes the greywacke rocks forming the axial ranges of the North and South Islands, as well as a belt of schists in Marlborough, the Southern Alps and Otago. These rocks host volcanogenic massive sulfide copper deposits and volcanogenic manganese-chert deposits. A belt of Permian ultramafic rocks (Dun Mountain Ophiolite Belt) has associated copper and chromite deposits. Chlorite-zone schists in Otago and Marlborough contain widespread orogenic gold ± tungsten ± antimony mineralisation in shear-zones and quartz veins, including the large Macraes deposit in east Otago. Lenses of serpentinite with talc-magnesite occur in ultramafic schists in the Southern Alps.

3.2 Post-Separation from Gondwana

Separation from Gondwana and opening of the Tasman Sea resulted in the development of Late Cretaceous to Cenozoic sedimentary basins that contain New Zealand's economic petroleum, coal and limestone deposits. Gold-bearing quartz gravels associated with Miocene coal measures are widespread in Otago and eastern Southland. About 25 million years ago, a large volume of marine sediment that had been accumulating along the continental margin was lifted up high enough for them to gravitationally slide many kilometres south-westwards onto what is now Northland and East Cape. These include seafloor ophiolitic basalts and minor serpentinite that contain volcanic massive sulfide copper deposits.

From the Miocene, volcanic rocks occur in eastern South Island (e.g. intraplate basaltic volcanoes on the Banks and Otago peninsulas) and feature prominently as basalt-andesite-dacite-rhyolite arc volcanoes in the North Island (Northland, Coromandel, Taupō Volcanic Zone and its offshore extension along the Kermadec arc, Taranaki). Epithermal gold-silver deposits are associated with sub-aerial volcanism (Northland, Coromandel region, Taupō Volcanic Zone) and the shallow offshore where the seafloor is still composed of continental rocks (e.g. the Calypso hydrothermal field offshore Whakaari / White Island). Miocene porphyry copper mineralisation is associated with subvolcanic intrusive rocks in northern Coromandel and eastern Northland, where zinc-lead skarn mineralisation has also been found (Figure 3.3). Seafloor massive sulfide mineralisation has recently been discovered at several submarine volcanoes in the southern sector of the Kermadec volcanic arc.

From the Late Miocene to the present day, uplift along the Alpine Fault and related fault systems, as well as subsequent erosion, formed 'giant' gold placers in riverbed and terrace (glacial outwash) gravels in Westland and Otago, along with smaller placer gold deposits in West Nelson, Marlborough and Southland. Erosion of garnet schist along the Southern Alps has resulted in the formation of ilmenite-garnet-gold placer deposits along, and offshore from, the west coast of the South Island. Elsewhere offshore, phosphate was deposited on the Chatham Rise, and an extensive ferromanganese nodule field was formed at abyssal depths south of New Zealand adjacent to the Campbell Plateau in the southwest Pacific Ocean.

Erosion of the Taranaki andesite volcanoes and volcanic rocks erupted from the Taupō Volcanic Zone have shed titanomagnetite onto the west coast of the North Island, forming significant Holocene to modern coastal and offshore placer titanomagnetite ironsand deposits.

4.0 PRODUCTION

Statistics on mine production and exploration spending, compiled by New Zealand Petroleum and Minerals (NZP&M), MBIE, show that gold and ironsand are the highest-value mineral products, with the value of coal output declining as coal production declined in recent years. The value of construction materials, such as aggregate, is fairly consistent over time, broadly in line with gross domestic product (GDP) growth in the New Zealand economy. In addition, New Zealand produces a range of non-metallic minerals. Mine production data for 2021 and 2022 are summarised in Table 4.1. In recent years, production information for several commodities is withheld for reasons of commercial sensitivity, although absences of data for some non-metallic minerals may result from intermittent production.

Table 4.1 New Zealand mineral and coal production 2021 and 2022 (Source: NZP&M).

Minerals	2021		2022	
	Quantity (tonnes)	**Value ($NZ)**	**Quantity (tonnes)**	**Value ($NZ)**
Metals				
Gold	5.81458 t 186,964 oz	472,844,046	6.6735 t 214,582 oz	610,328,723
Silver	3.0546 t 98,219 oz	3,437,670	3.9217 t 120,100 oz	4,274,281
Magnetite (Ironsand)	N/A	N/A	N/A	N/A
Total	**8.87**	**476,281,716**	**10.60**	**614,603,004**
Non-Metals				
Building and dimension stone	494,443	9,614,490	11,609	2,208,270
Clay for brick, tiles, etc.	-	-	-	-
Clay for pottery and ceramics	Withheld	-	Withheld	-
Decorative pebbles, including scoria	27,989	1,451,997	1,916	$172,881
Dolomite for agriculture and industry	Withheld	-	Withheld	-
Limestone and marl for cement	Withheld	-	Withheld	-
Limestone for agriculture	503,135	20,253,918	625,832	27,221,533
Limestone for industry	507,906	34,750,645	628,176	38,965,744
Other industrial minerals*	1,571,021	19,728,718	1,259,570	17,480,588
Pumice	Withheld	-	Withheld	-
Rock for reclamation and protection	187,633	3,779,505	141,821	1,659,110
Rock, sand and gravel for building	8,605,212	178,777,199	11,475,419	270,301,278
Rock, sand and gravel for roading	15,411,650	214,984,226	15,746,576	265,371,802
Rock, sand and gravel for fill	393,599	3,749,667	590,093	3,722,245
Sand for industry	269,145	7,409,437	277,633	11,048,199
Total	**29,515,261**	**$502,293,537**	**20,944,649**	**641,912,760**
Coal	2,867,610	-	2,637,476	-
GRAND TOTAL	**32,382,880**	**-**	**33,582,135**	**-**

* Other industrial minerals include amorphous silica, bentonite, diatomite, perlite, serpentine and zeolite. Ironsand data 'N/A' is not available. Clay for brick, tiles, etc. is not listed for these years (Source: www.nzpam.govt.nz).

4.1 Gold and Silver

The total gross value of New Zealand's gold production – at least 38 million ounces from the 1860s to the present – at current prices (about NZ$3,800 per ounce; May 2024) is more than NZ$145 billion. Annual production from 1993 to 2022 is shown in Figure 4.1.

Gold production is currently dominated by hard-rock mines at Waihi in the North Island and Macraes in Otago, both operated by OceanaGold (see Part 2 of this report, Table 3.29). The underground mines at Waihi have been developed on epithermal quartz veins, near to the giant Martha gold-silver deposit that was re-developed as an open pit in the 1980s on historic underground workings dating from the 1890s. The Macraes operation began with an open pit on the Hyde-Macraes Shear Zone. Production has been maintained via a succession of open pits and two underground mines that work extensions of the mineralisation down-dip from the open pits.

Alluvial gold mines, located mainly on the west coast of the South Island, have been significant contributors, especially between 2013 and 2018.

New Zealand's silver production is as a co-product of gold mining. Approximately 95% is produced from Waihi, with the other 5% from Macraes.

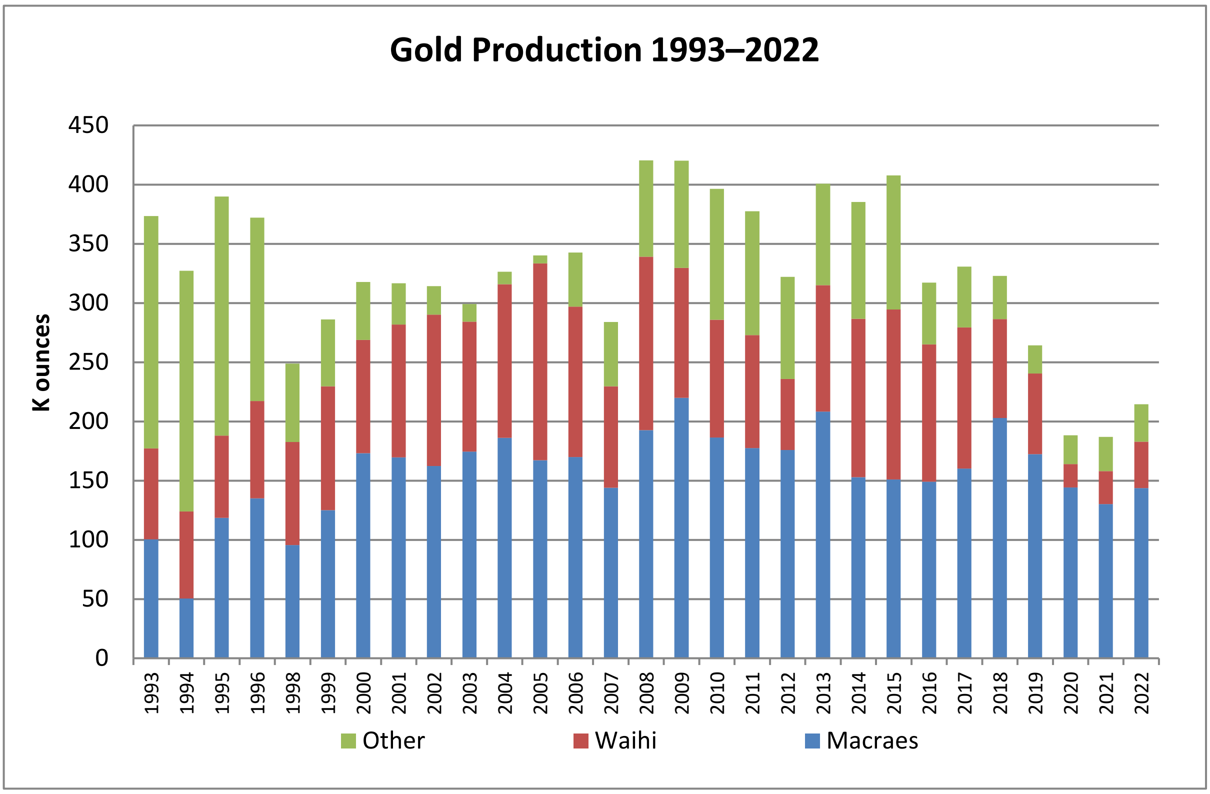

Figure 4.1 Gold production 1993–2022 (Source: NZP&M).

4.2 Ironsand

4.2.1 Titanomagnetite Ironsand

Total titanomagnetite ironsand concentrate production since operations began on the west coast of the North Island in 1971 is about 125 Mt. A price of $60 per tonne gives this production a current value of more than $7.5 billion. Production from 2000 to 2017 is shown in Figure 4.2.

Titanomagnetite placer black-sand deposits are mined at two locations on the west coast of the North Island: at the mouth of the Waikato River, for making steel at the nearby Glenbrook steel mill south of Auckland; and at Taharoa, 130 km to the south, for export. Titanomagnetite concentrate produced by these operations is rated as a high-grade, high-quality iron ore, especially for manufacture of stainless steel, and thus commands a premium price over the lower-grade hematite iron ore of Western Australia.

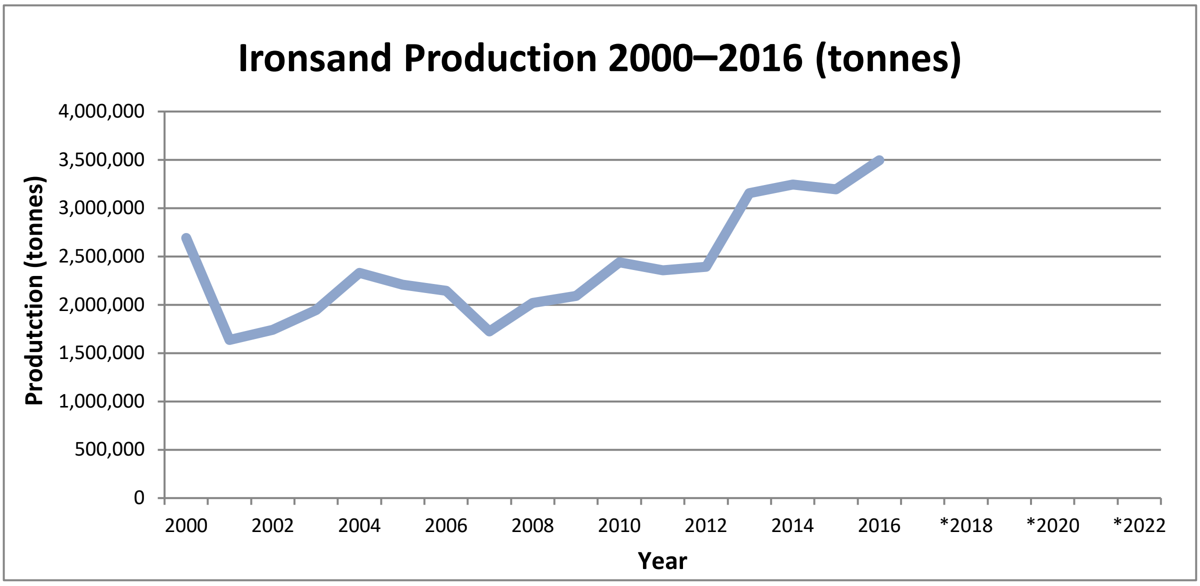

Figure 4.2 Ironsand production 2000–2016. Production data from 2016 to the present are withheld to maintain confidentiality (Source: NZP&M).

4.2.2 Ilmenite Ironsand

Westland Minerals Sands commenced mining and export of ilmenite placer black-sand concentrate, containing ilmenite, garnet, zircon and monazite, from Westport in 2023. In April 2024, TiGa Minerals & Metals was granted environmental consents to begin mining at its Barrytown ilmenite prospect. It plans to recover ilmenite, garnet, zircon and gold from the placer deposit.

4.3 Non-Metals

Non-metal production in New Zealand includes large volumes of aggregate and sand for the civil construction and roading sectors, as well as limestone as crushed lime for the domestic agricultural sector, and burnt and processed lime for domestic and export industrial markets (Figure 4.3). High-quality halloysite china clay has been produced since 1969 from Matauri Bay in Northland (Brathwaite and Christie 2016). Since the 1990s, zeolite has been produced from hydrothermal deposits in the active Taupō Volcanic Zone in the North Island (Brathwaite and Henderson 2016). Other commodities that have been produced on a smaller scale include amorphous silica, bentonite, building stone, kaolinite ‘brickmaking’ clay, decorative pebbles and scoria, diatomite, dolomite, perlite, pumice, serpentine and silica sand.

Demand for aggregate, limestone (for agriculture and cement-making) and many industrial minerals is used to under-pin domestic economic activity, where demand is determined by the size of the local market and generally increases in response to economic and population growth, particularly in the north of the North Island.

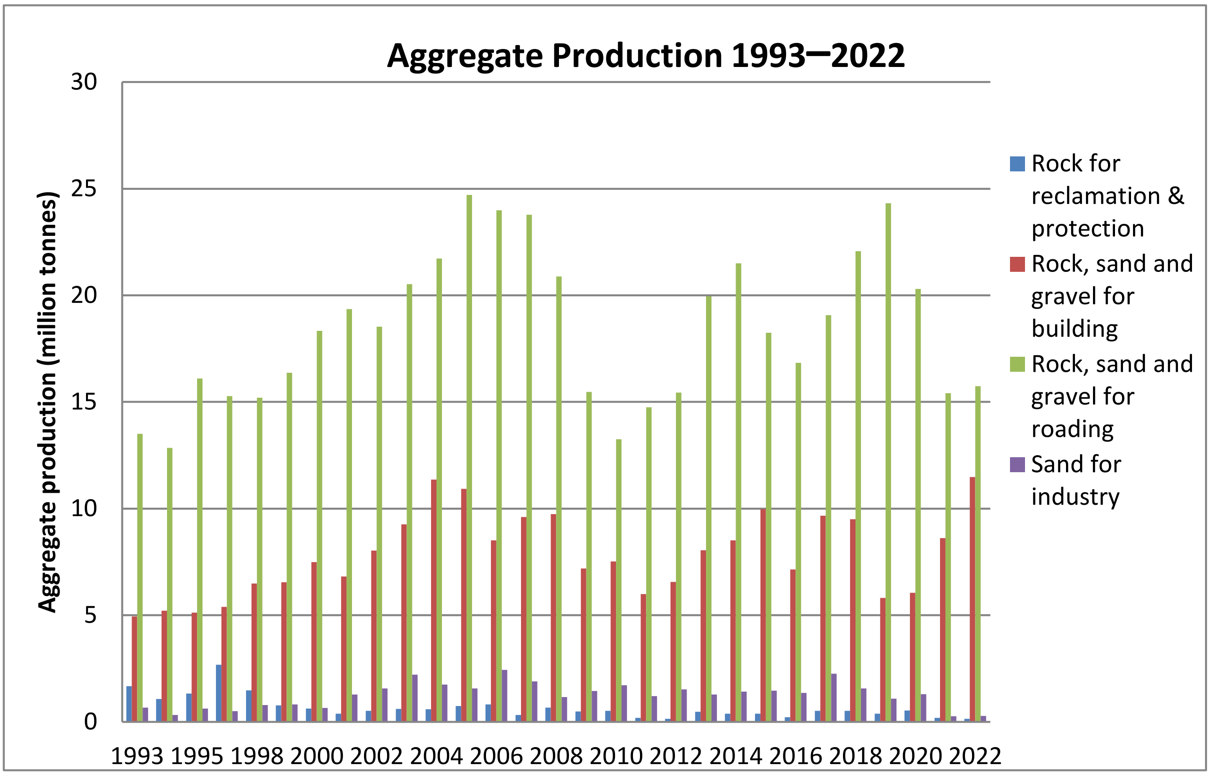

Figure 4.3 Aggregate production 1993–2022 (Mt) (Source: NZP&M). Each year, NZP&M surveys known aggregate producers and quarry operators. Those surveyed include holders of Crown minerals permits and operations for privately owned minerals. The survey is not a statutory requirement; as responses are voluntary, the data are incomplete. The percentage of respondents for 2022 was 53.81% (374 respondents out of 695 quarries surveyed), although the data includes the main aggregate-producing companies with the largest quarries.

4.4 Coal

Production from 1992 to 2023 is shown in Figure 4.4. Coal production is centred in:

- Waikato – mainly for several major industrial users and the Huntly power station.
- The West Coast – mainly for export.
- Otago/Southland – mainly for local industrial markets.

There were 14 operating coal mines at the end of 2022 (see Part 2 of this report, Table 5.1).

Coal production in the North Island is predominantly of sub-bituminous coal used for steel-making at Glenbrook, electricity generation at the Huntly power station, furnaces for milk powder processing and for industrial use. Most South Island production is higher-rank bituminous coal that is mostly exported, whereas sub-bituminous coal is used for milk processing and other industrial processes.

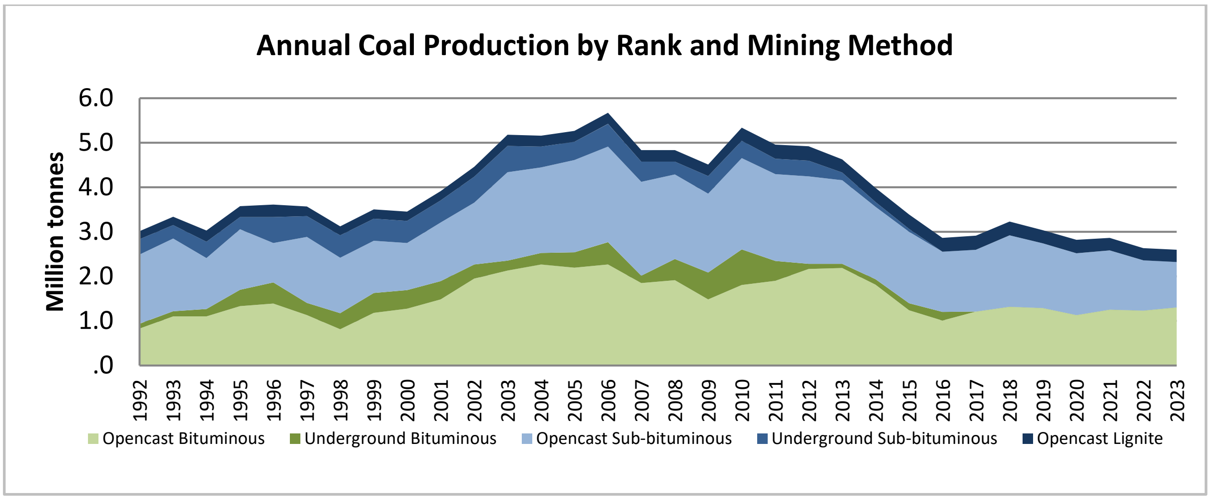

Figure 4.4 Coal production by rank and mining method (Mt) from 1992 to 2023 (Source: MBIE). Production statistics for 2023 are listed in Part 2 of this report, Table 5.2.

4.5 Exports

New Zealand exports all of its gold and silver production for refining overseas. Ironsand from Taharoa and ilmenite heavy-mineral-sand concentrate mined at Westport are also exported. New Zealand's main non-metallic mineral exports are halloysite clay (Northland), lime and limestone (Waikato) and bentonite clay (Canterbury). Lesser export items include peat, salt, pumice and zeolite. Coal continues to be a major export, with 1.2 Mt exported in 2023 compared with a maximum of 2.7 Mt in 2006 (Figure 4.5).

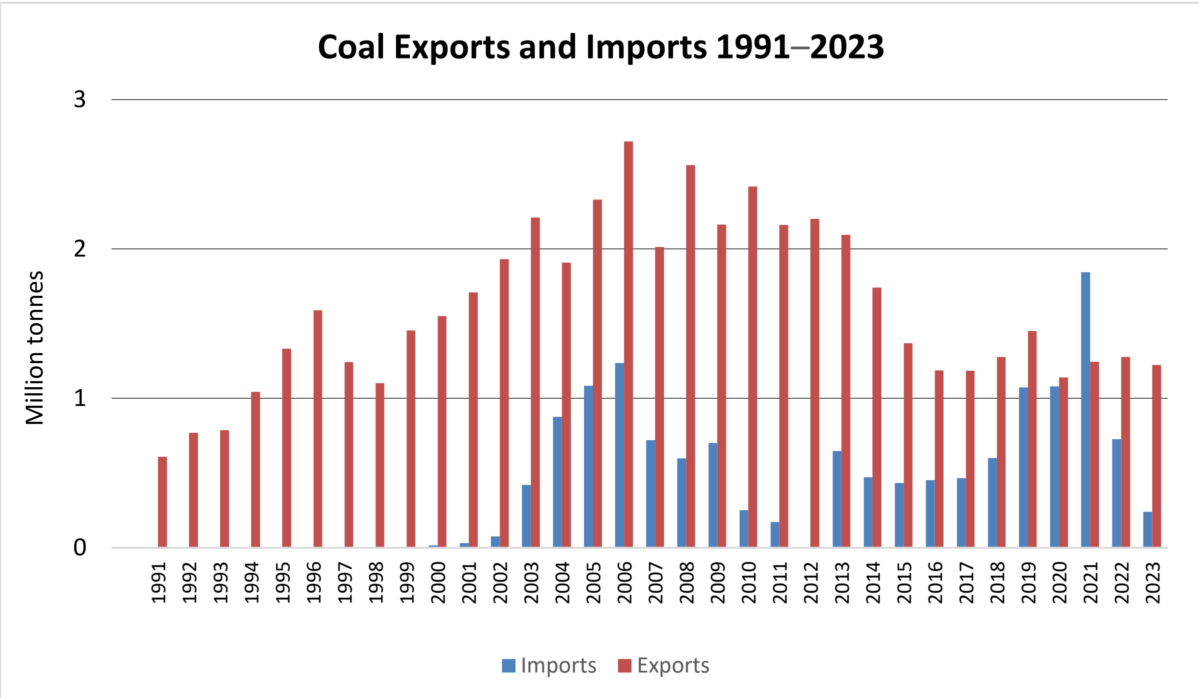

Figure 4.5 Coal exports and imports 1991–2023 (Source: MBIE).

5.0 THE PATH FROM EXPLORATION TO MINERAL PRODUCTION

Ongoing mineral exploration is needed to maintain the supplies of all mined materials. Operating mines explore for extensions to the deposits being worked, and new mineral discoveries are needed to maintain or expand output in the future.

Reports on the results of prospecting and exploration for Crown minerals are filed with the Government, and these become available to the public after a period of five years (or less if a permit lapses for any reason). NZP&M has a database of several thousand reports representing several hundred million dollars of mineral exploration investment by the private sector. These are available for download at no cost from the NZP&M website.

Exploration for minerals is typically carried out in stages: area selection, prospecting and exploration (Figure 5.1). An exploration programme typically starts with a large area that is progressively reduced by homing in on target areas that give positive results, or by eliminating less-prospective areas through negative results, for example, case studies by Hay (1989) and Henderson et al. (2016a, 2016b).

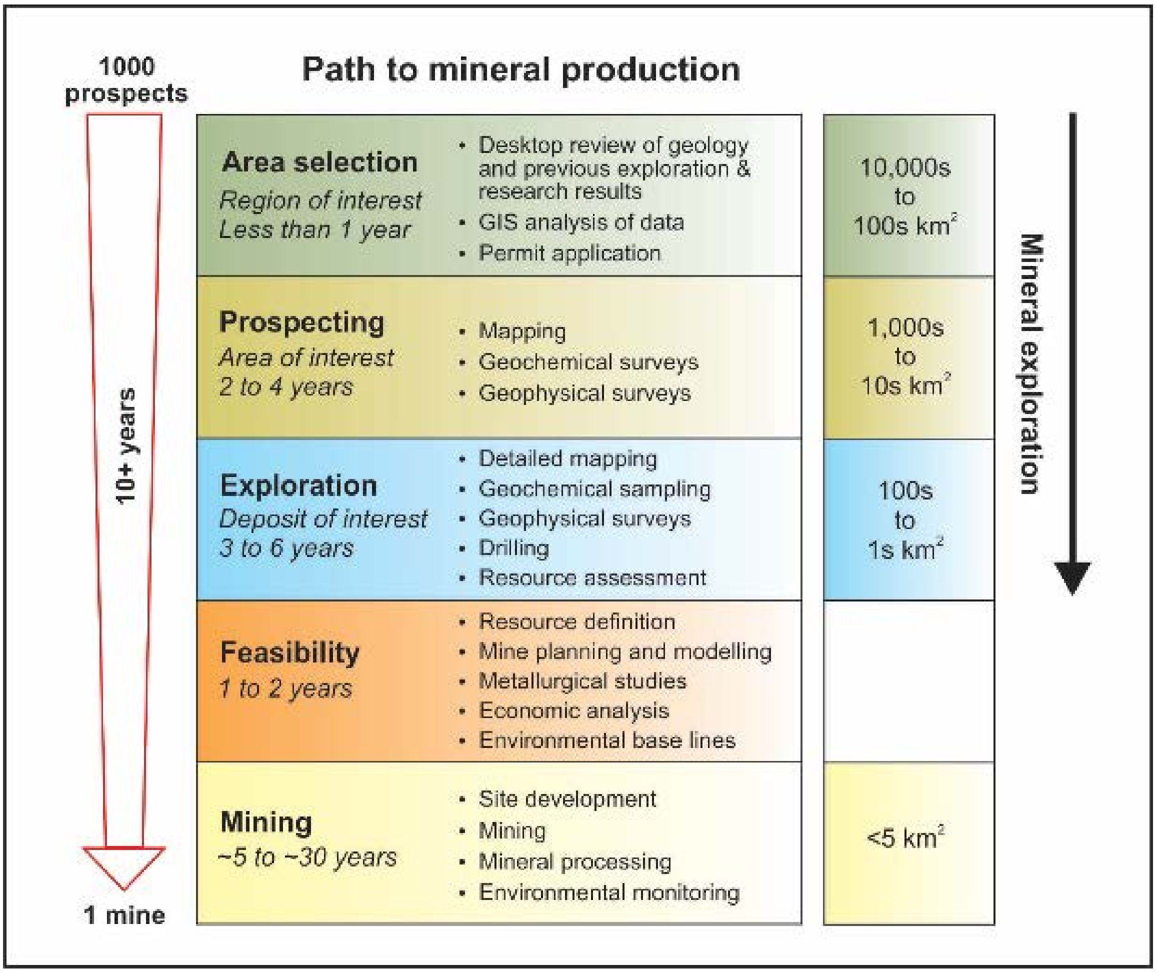

Figure 5.1 The stages of exploration through to mining and examples of work undertaken (after Christie [2019]).

Exploration is expensive and financially risky. The exploration success rate varies depending on the type of mineral deposit targeted and is lowest for metallic mineral prospects (high risk). It is common for exploration around a deposit to have been carried out by a succession of companies. Each company will use information from previous exploration, testing new models and often applying new techniques and technologies. It is critical to have access to results of previous work.

Total expenditure on exploration in New Zealand between 2000 and 2022 is shown in Figure 5.2. There was a large increase in total exploration spending in 2021 and 2022, but this is due mainly to an increase in 'brownfields' spending on mining permits. Prospecting and exploration permit-spending for new discoveries since 2015 has been well below that for the previous decade.

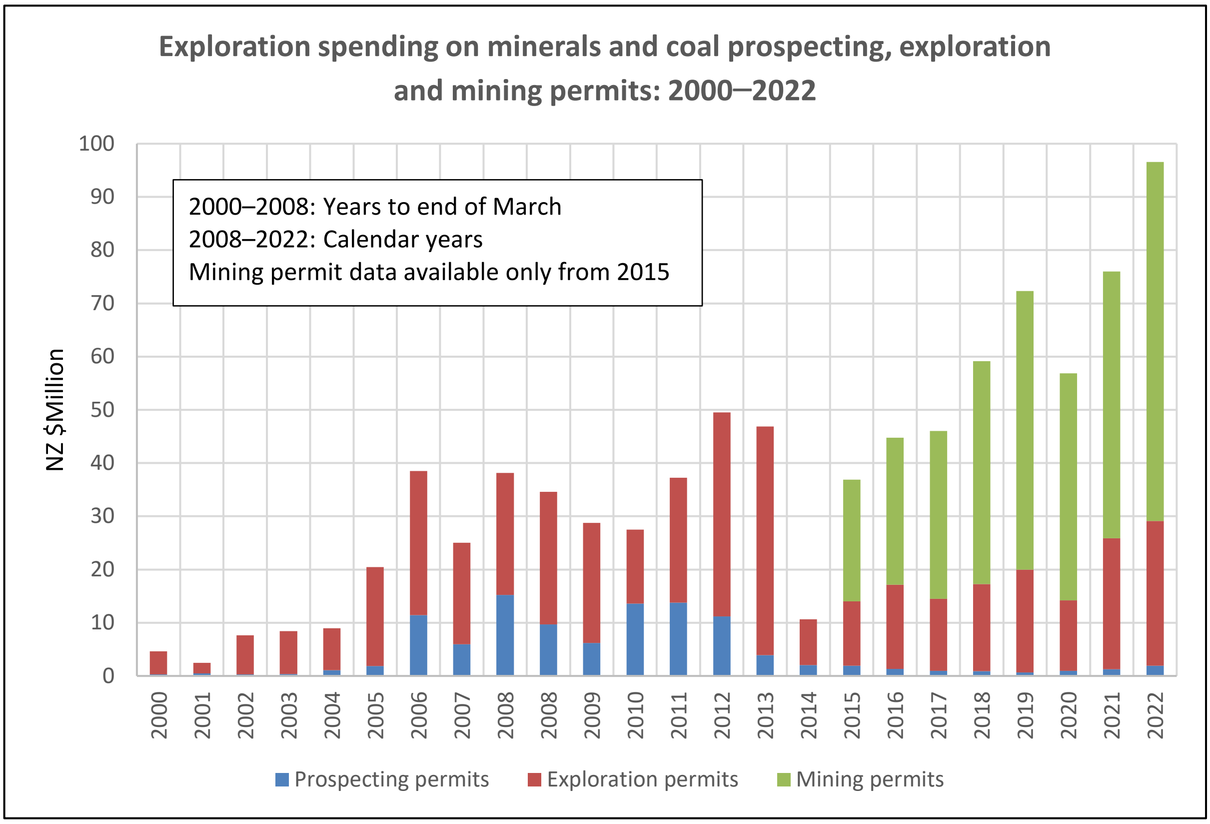

Figure 5.2 Exploration spending on minerals and coal prospecting, exploration and mining permits 2000–2022 (Source: NZP&M).

Note that:

- Spending on exploratory activities by holders of prospecting, exploration and mining permits is recorded and published annually by NZP&M.
- Prospecting covers low-impact activities, often over large area, for example, aerial surveys.
- Exploration may include those activities, but most spending is on more-detailed investigations, including drilling and proving-up mineral resources.
- Once a resource has been established, a mining permit can be granted, replacing an exploration permit, so spending on detailed pre-mine investigations and those carried out around existing mines is reported under mining permits. This has been published only since 2015. It is not available for prior years.

5.1 Onshore Exploration

Onshore metallic mineral exploration since the 1980s has mainly focused on targeting orogenic, epithermal and intrusion-related hard-rock gold deposits, placer gold deposits and placer ironsand deposits. Other targets have included placer ilmenite, platinum group elements, rare earth elements (REE), volcanogenic massive sulfide and, most recently, lithium prospects.

Brownfields exploration is that which occurs near known deposits or existing mines. Greenfields exploration occurs in areas where there is no known deposits or mines of the commodity or mineral deposit type being sought. Brownfields exploration can find extensions to a currently mined mineral deposit or exploration of new areas near existing or former mines.

Since the 1970s, brownfields exploration in New Zealand has been very successful, and greenfields exploration has made some new discoveries, the main one being the Sams Creek intrusion-related gold deposit in west Nelson that was discovered in 1974. Some examples of successful brownfields exploration include:

- **Waihi:** Exploration of the historic underground gold-silver mine at Waihi in the 1970s and 1980s identified lower-grade gold resources in many small veins between the former thick veins mined in the past. There were additional resources in parts of the thick veins that had been left for mine support, as well as in the waste rock and tailings used to backfill the voids left by underground mining. Subsequent near-mine exploration made new discoveries of the Favona (2001), Trio (2003) and Correnso (2009) veins and, more recently, new gold resources in veins beneath the Martha open pit.
- **Macraes:** This orogenic gold deposit was historically mined for tungsten and gold in quartz veins. Exploration in the 1980s identified the Hyde Macraes Shear Zone that hosted extensions of the mineralisation from the historic mining area. The shallow dip of the shear zone enabled the low-gold-grade deposit to be mined by open-pit methods. Continued exploration identified higher-gold-grade shoots that enabled underground mining at Frasers and now Golden Point.
- **Wharekirauponga:** Early phases of drilling from the 1980s discovered an extensive zone of stockwork quartz veins that were of uneconomic gold grade. However, in 2017, a hitherto unknown and extensive concealed vein system with much higher gold grades was discovered in the 42nd drill hole WKP42.
- **Rise & Shine shear zone:** Exploration on this shear zone based on the 'Macraes mineralisation model' discovered low-grade gold resources in several drilling campaigns. During planning for development of this low-gold-grade resource by open mining and heap leaching, Santana Minerals acquired the property and undertook additional drilling, eventually discovering extensive, locally high gold grade ore, enabling a re-interpretation of the deposit. A mine plan based on a substantial increase in the gold resources is now being developed.

5.2 Offshore Exploration

Since 2004, extensive offshore exploration programmes have been carried out for placer ironsand, placer gold, hydrothermal seafloor massive sulfide deposits and seafloor phosphorite nodules (Wood 2016). Earlier research highlighted the potential of seafloor ferromanganese nodules on the margin of the Campbell Plateau (Graham and Wright 2006). Exploration for ilmenite sands offshore from Waihi Beach has been proposed by several companies, but little work has been undertaken to date.

The main greenfields successes in terms of identifying mineable resources have been the ironsand deposits offshore from Taranaki and the phosphorite nodules on the Chatham Rise. Additionally, scientific research cruises and follow-up industry-sponsored cruises have highlighted the mineral potential of Kermadec Arc seafloor massive sulfides and Campbell Plateau Slope ferromanganese nodules.

6.0 THE EXPLORATION DATABASE

NZP&M's online library of prospecting and exploration reports, submitted by companies to Government, provides an invaluable resource of information for current and future explorers. This is supplemented by digital databases of geochemical and geophysical data and geological mapping that are managed by NZP&M and GNS Science, which are available online.

To encourage exploration on land, the government has funded airborne geophysical surveys over large areas of New Zealand. These include the Northland and Marlborough regions and parts of the West Coast, Otago and Southland regions (Figure 6.1a). These have used combined aeromagnetic and radiometric methods using fixed-wing and helicopter platforms, depending on the topography. These surveys supplement private company surveys, particularly Glass Earth's 2005 survey of the Taupō Volcanic Zone (Doyle 2004) and 2007 survey of Otago (Fugro Airborne Surveys Pty Ltd 2007) for gold exploration; Sinosteel's survey of the west of the Waikato region (Meyers 2009) and surveys carried out offshore by BHP, Trans-Tasman Resources (TTR) and other companies for ironsand exploration (Christie 2016a); and Seafield's offshore West Coast surveys for gold exploration (Youngson and Stevenson 2016). Regional soil geochemical surveys have also been undertaken mostly in the South Island (Martin et al. 2015, 2016, 2017; Turnbull et al. 2017a) (Figure 6.1b).

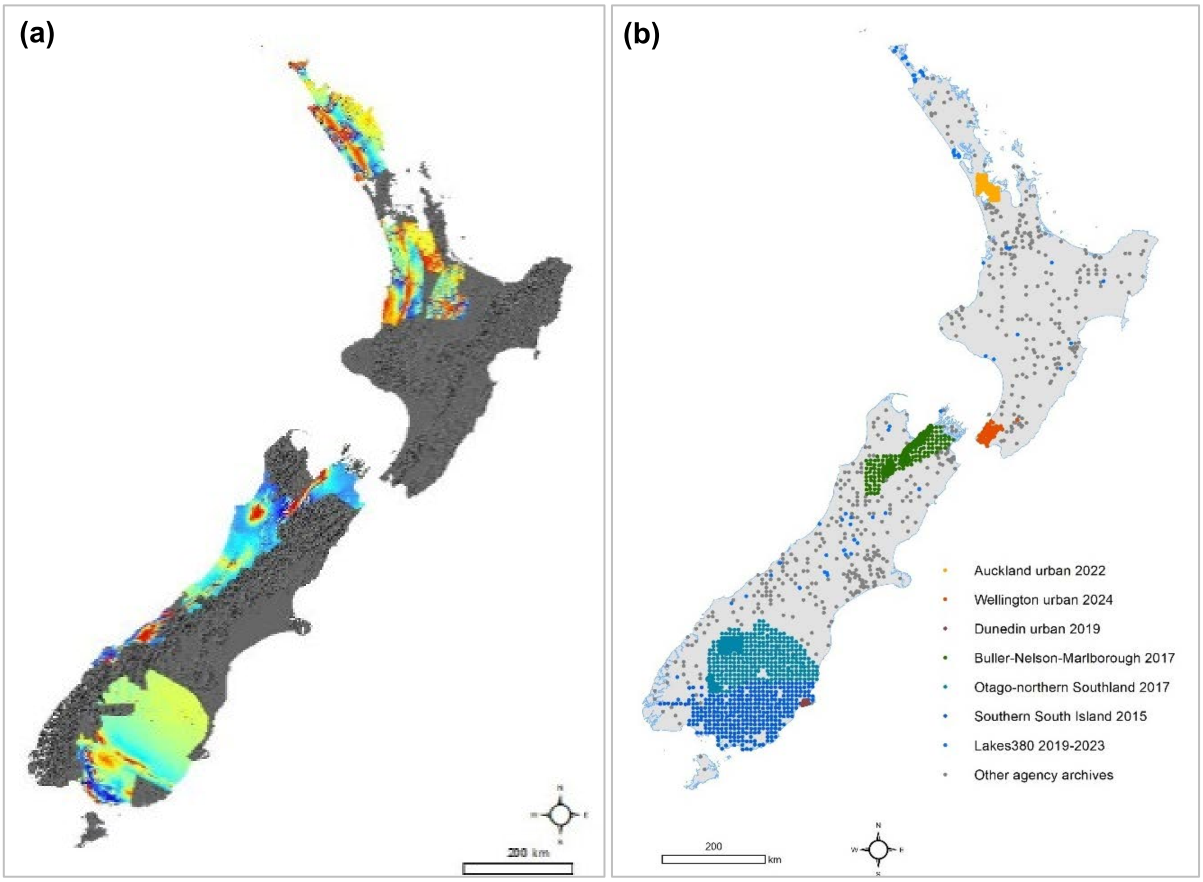

Figure 6.1 (a) Magnetic data from Government and exploration company regional airborne geophysical surveys showing the coverage of the surveys. The warmer colours in the sequence blue through yellow to red indicate increasing magnetisation of the rocks. (b) Coverage of Government soil geochemical surveys.

6.1 Prospectivity Studies

Several prospectivity studies have collated government research data and private exploration data and used these in Geographic Information System (GIS)-based prospectivity studies to rank areas for exploration potential for orogenic (mesothermal) gold (Crown Minerals 2002; Kenex 2011), epithermal gold (Crown Minerals 2003), lithium (Turnbull et al. 2018), REE (Morgenstern et al. 2018), nickel and cobalt (Durance et al. 2018) and aggregate (Hill 2021; Hill and Chilton 2024a–e). Maps from some of these studies are shown in the relevant mineral sections later in this report. Additionally, several prospectivity studies have been carried out by Kenex for exploration companies (e.g. Payne et al. 2015; Payne and Peters 2015; Peters et al. 2016). These are mostly proprietary and currently confidential, but most will become available over the next few years.

7.0 RESOURCES

7.1 Resource Classification and Reporting

Mineral and coal resources differ from other resources in two main ways. Firstly, mineral and coal deposits need to be discovered. Their extent is defined by what is located beneath the ground surface, as well as many other factors that are constantly changing. These include demand, commodity prices, available mining and processing technology, as well as the potential effects of their development, which encompasses a very wide range of factors. Secondly, mineral resources are constantly changing because of consumption, exploration and research defining new resources, as well as with economic and other changes affecting the feasibility of mining and processing minerals.

New Zealand has adopted the Australasian 'JORC' code for reporting mineral resources (JORC 2012). This code was developed primarily for reporting to investors or potential investors. It is produced by the Joint Ore Reserves Committee that comprises the Australasian Institute of Mining and Metallurgy, the Minerals Council of Australia and the Australian Institute of Geoscientists. It classifies resources as 'Inferred', 'Indicated' and 'Measured' as the level of geological knowledge and confidence about the resources increases (Figure 7.1). Parts of indicated and measured resources can be classified as 'Proven' and 'Probable' reserves once a range of economic and other factors (the modifying factors in the figure) are considered.

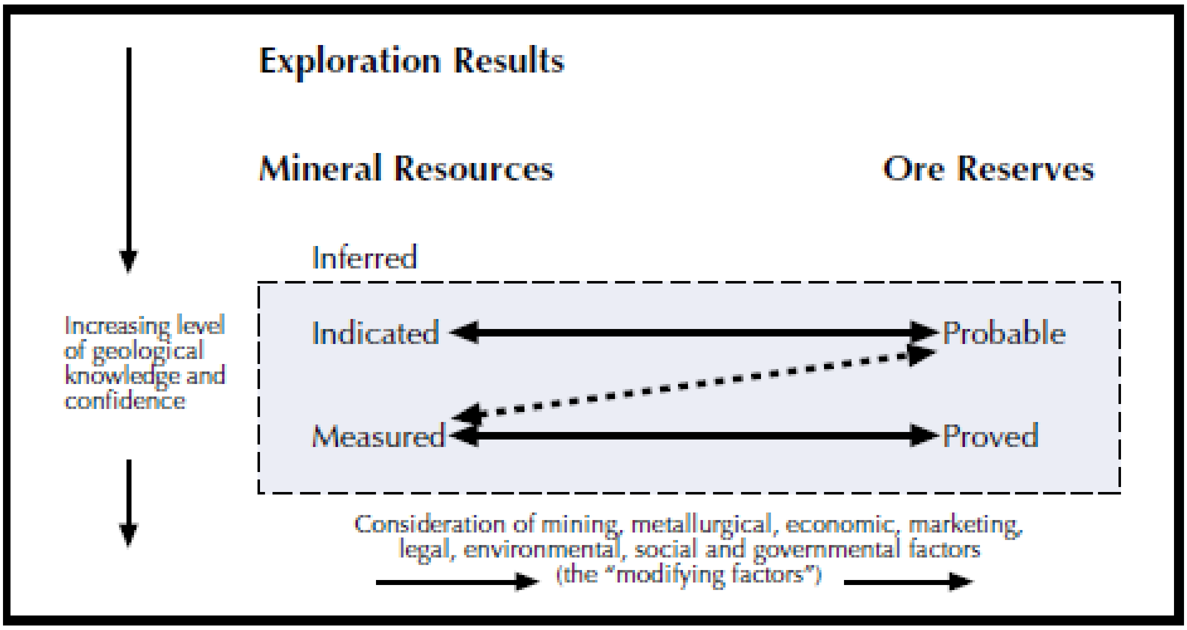

Figure 7.1 Joint Ore Reserves Committee (JORC) classification of exploration results, mineral resources and ore reserves (after Christie and Barker [2013]).

Resource assessments that comply with the JORC Code are mostly confined to advanced exploration projects or operating mines where there have been large drilling programmes. Elsewhere, resource estimates are less formal, ranging from speculative estimates through to estimates based on limited geological information to estimates based on limited drilling information. Being based on minimal information and so lacking the detail and robustness required by the JORC Code, these estimates are not reportable or classifiable to the JORC Code standard and thus require additional exploration, particularly drilling, to provide further information to determine mineable resources and reserves with specific levels of confidence. However, the estimates do provide an indication of potential and can be a guide to where the best return would be for exploration investment with regard to political and social constraints.

Sherwood (2019), in discussing coal resources, noted that there was a tension between resource classification for investment and that for strategic purposes when assembling a national resource inventory of in-ground resources. For this inventory, we have included some of the non-JORC-compliant resource estimates for comparative purposes. However, the authors take no responsibility for the accuracy of resource and reserve statistics quoted here. Following the Sherwood (2019) example, we have reported JORC-compliant resources and reserves capitalised as Mineral Resource, Coal Resource, Mineral Reserve and Coal Reserve, whereas non-JORC-compliant resources and reserves are noted all in lower case.

For reporting coal resources, Sherwood (2019) recommended using a modified version of the JORC Code, inserting the word 'Coal' for 'Mineral' and incorporating two levels of Inventory Coal and Exploration Targets (Table 7.1).

Table 7.1 Coal classification that is based on the JORC Code but splits Inventory Coal into two categories. Large quantities of coal in New Zealand do not meet the reasonable prospects test, and the two inventory categories separate what might be technically mineable (but for which extraction cannot be considered to be 'more likely than not') from that which is likely to be unmineable.

Coal In-Ground				**Exploration Targets**
Coal Reserves	**Coal Resources**	**Inventory 1**	**Inventory 2**	
		Excludes Coal Resources		
Coal that is the economically mineable part of a Coal Resource	Coal that has reasonable prospects of eventual economic extraction	Coal that does not meet the reasonable prospects test as a Coal Resource but is likely to be technically mineable and could be mined if land access, ownership or market conditions changed	Resources not meeting, and unlikely to ever meet, the test of reasonable prospects of future extraction	Hypothetical target or estimate based on extremely limited data

7.2 Regional Mineral Resource Assessments

Publication of a series of regional mineral resource assessments by GNS Science commenced in 1999 (Christie and Barker 2016), with a national mineral resource assessment by Christie and Brathwaite (1999). This was followed by several regional assessments: Coromandel (Christie et al. 2001a, 2008), Northland (Christie and Barker 2007) and the West Coast (Christie et al. 2010). The assessments used a United States Geological Survey three-step method, based on mineral deposit models of metallic and industrial minerals, to calculate in-ground resources and values by 'expert opinion'. These resource estimates do not have sufficient information to meet the standard of JORC Code requirement. The regional reports included some production scenarios to highlight the potential value of developing the mineral resources.

7.3 Resource Information

The extent of knowledge of New Zealand's mineral resources is quite variable from one mineral to another. Three commodities have had large exploration programmes that have provided resource estimates that are sufficient in detail to provide rough estimates of total resources. This then allows ranking of the size of the different deposits for each commodity, enabling comparisons to be made between them:

- **Titanonomagnetite ironsands:** Government-funded surveys of the titanomagnetite sands on the west coast of the North Island in the 1960s prior to setting up an iron and steel industry in New Zealand (Kear 1979). This has been supplemented by detailed work at the Waikato North Head, Taharoa and Waipipi mining areas and at the Aotea prospect.
- **West Coast ilmenite sands:** Carpentaria Exploration carried out systematic surveys of the West Coast ilmenite sands in the 1970s, with their work supplemented by detailed exploration of the largest ilmenite deposits at Westport and Barrytown by a number of companies, most recently Westland Mineral Sands and TiGa, respectively.
- **Coal:** Government funded the New Zealand Coal Resources Survey of 1975–1989, which included exploration in most coalfields and drilling in many, leading to definition of new resources (e.g. Barry et al. 1994). Total in-ground coal resources were estimated at more than 15 Bt, being about 12 Bt of lignite and nearly 4 Bt of sub-bituminous and bituminous coal. However, Sherwood (2019) noted that a large portion of these resources are non-recoverable and, using a JORC-style classification scheme (Table 7.2), estimated that Coal Reserves were 38.5 Mt for bituminous coal and 9.0 Mt for sub-bituminous coal and that Coal Resources were 230 Mt for bituminous coal and 66 Mt for sub-bituminous coal (Table 7.3). Equivalent estimates for lignite resources are unavailable for the same categories and therefore the in-ground estimate of 12 Bt of lignite is still used and represents New Zealand's largest known conventional energy resource.

New Zealand's known JORC-compliant resources are dominated by gold, with about 10 million ounces, and ironsand, with at least 700 Mt of iron ore.

A compilation of resource information for mineral commodities, taken from the literature and company websites, is presented in Table 7.2 and summarises more-detailed information on resource assessments presented in Part 2 of this report. Coal Reserves and Resources estimated by Sherwood (2019) are listed in Table 7.3, whereas Reserves and Resources reported to MBIE for the end of 2023 are listed in Table 7.4. Privately owned coal is not included in Table 7.4 because there is no requirement for reporting privately owned coal resource and reserve data.

Table 7.2 Resource assessments (see Part 2 of this report for detail).

Project Area	Type	Resource	Reference	Notes
Aluminium: Lateritic Bauxite				
Area between Kaeo, Kerikeri and Kaikohe	Estimate	30 Mt at 30% Al_2O_3	Kear et al. (1961); Evans (1963); Pearson (1973)	-
Antimony: Orogenic Quartz Vein Antimony				
Endeavour Inlet	Estimate	25,000 t at 15% Sb (3750 t Sb)	Price (2016)	-
Copper: Intermediate Sulfidation Epithermal Zn-Pb-Cu-Ag-Au				
Monowai	Estimate	1048 t Cu	Roberts (1989)	'Defined and estimated' resources
Tui	Estimate	700 t Cu	Bates (1989b)	-
Copper: Cu Skarn plus Porphyry Mo				
Copperstain Creek	Estimate	15,000 t Cu	Smale (1970); Wodzicki (1972)	-
Gold: Orogenic Gold Deposit – Paleozoic				
Supreme	JORC	103,000 oz Au	Siren Gold (May 2024)	Inferred Resources as of April 2023
Big River	JORC	105,000 oz Au	Siren Gold (May 2024)	Inferred Resources as of April 2023
Blackwater / Snowy River project	JORC	785,000 oz Au	Federation Mining (May 2024)	Indicated + Inferred Resources
Alexander River	JORC	170,000 oz Au	Siren Gold (May 2024)	Inferred Resources as of 2023
Gold: Orogenic Gold Deposits – Mesozoic				
Macraes underground and pits	JORC	1.74 Moz Au	OceanaGold (2024)	Resources (Measured + Indicated + inferred)
Bendigo – Ophir (Rise & Shine)	JORC	2.45 Moz	Santana Minerals (May 2024)	Based off drill results to January 2024 reported February 2024
Ophir	Estimate	10,500 oz Au	Christie and Youngson (2016)	-
Gold and Silver: Epithermal Gold Deposits (Hauraki Goldfield)				
Monowai	Estimate	169,000 oz Au 921,000 oz Ag	Roberts (1989)	'Defined and estimated' resources
Thames area	Estimate	894,000 oz Au 500,000, oz Ag	Mineral Resources of New Zealand (1998)	'Defined and estimated' resources
Neavesville	JORC	123,600 oz Au 509,100 oz Ag	E2 Metals Limited (2017)	Inferred Resource
Wharekirauponga	JORC	1.41 Moz Au 2.3 Moz Ag	OceanaGold (2024)	Indicated + Inferred Resources
Scotia, Waitekauri	Estimate	146,000 oz Au 100,000 oz Ag	Couper (1981a, 1982, 1983)	Inferred resources

Project Area	Type	Resource	Reference	Notes
Maoriland, Waitekauri	Estimate	96,000 oz Au 570,000 oz Ag	Couper (1981b)	Inferred resources
Maoriland, Waitekauri	Estimate	96,000 oz Au 570,000 oz Ag	-	-
Martha Underground and Martha and Gladstone pits	JORC	1.92 Moz Au 13.1 Moz Ag	OceanaGold (2024)	Indicated + Inferred Resources
Karangahake	JORC	350,000 oz Au	New Talisman Gold Mines (2022)	Indicated and Inferred Resources
Waioronogomai	Estimate	45,000 oz Au 270,000 oz Ag	Bates (1989b)	Inferred resources (plus Pb, Zn, Cu)
Muirs	-	219,000 oz Au	Grieve (2013)	Inferred resources
Monowai	Estimate	169,000 oz Au 921,000 oz Ag	Roberts (1989)	'Defined and estimated' resources
Gold: Intrusion-Hosted and Intrusion-Related Gold Deposits (Sams Creek, West Nelson)				
Sams Creek	JORC	807,772 oz Au	Siren Gold (June 2024)	Indicated + Inferred Resources
Iron: Onshore Titanomagnetite Ironsands (West Coast, North Island)				
Aotea	JORC	29.5 Mt magnetics	Wood et al. (2016)	
Taharoa	JORC	91.5 Mt magnetics	Mauk et al. (2016)	Measured + Indicated + Inferred Resources (for 2015)
Waikato North Head	JORC	120.5 Mt magnetics	Mauk et al. (2016)	Measured + Indicated + Inferred Resources (for 2015)
21 other ironsand deposits	Estimate	526 Mt conc	Kear (1979); Brathwaite (1990)	-
Iron: Offshore Titanomagnetite Ironsands (West Coast North Island)				
TTR offshore Taranaki (Pātea)	JORC	482 Mt at 48% Fe	Trans-Tasman Resources (May 2024)	Indicated + Inferred Resources; between 22 and 36 km offshore from Pātea in water depths of 20–42 m
Iron: Transported Residual Iron (Limonite)				
Several deposits?	Estimate	9.65 Mt at 40% Fe	Landreth (1946)	-
Titanium: Shoreline Placer Titanium (Ilmenite)				
17 deposits	Estimates	30 Mt at 3.2–15% ilmenite	Brathwaite and Pirajno (1993); Christie and Brathwaite (1999)	Estimated by Carpentaria from limited drilling
Zinc-Lead: Epithermal Zinc-Lead				
Tui	Estimate	13,159 t Zn conc, 7755 t of Cu-Pb conc	Bates (1989)	-

Project Area	Type	Resource	Reference	Notes
Bentonite				
Coalgate	Estimate	10 Mt	MacFarlan and Barry (1991)	'Proven reserves'; freshwater, non-swelling bentonite
Stoddarts Farm, Porangahau	Estimate	1 Mt	MacFarlan and Barry (1991)	Marine, swelling bentonite
Diatomite				
Mercer	Estimate	180,000 t	Waterhouse (1967)	'Diatomite and pumicite'
Ngakuru	Estimate	2 Mt diatomite (>505 containing >50% diatoms)	NZGS (1970)	-
Middlemarch	Estimate	5 Mt diatomite ore	Gordon (1959); Williams (1974)	-
Oamaru	Estimate	140,000 t diatomite ore	Edwards (1991)	-
Dolomite				
Mt Burnett	Estimate	70 Mt dolomite	Williams and Katz (1974)	-
Feldspar				
Ruakaka Flats, Northland	Estimate	400 Mt of sand	Thompson (1989)	-
Garnet				
Nine Mile North, Westport	Estimate	5.8 Mt garnet	Ritchie et al. (2019)	Estimated from Carpentaria ilmenite exploration data and ilmenite/garnet ratio
Nine Mile South, Westport	Estimate	4.1 Mt garnet		
Barrytown	Estimate	15 Mt garnet		
Ruatapu-Hokitika South	Estimate	9.2 Mt garnet		
Ross-Shearers Swamp	Estimate	1.7Mt garnet		
Hunts Beach	Estimate	7 Mt garnet		
Perlite				
Awana, Great Barrier Island	Estimate	100 Mt perlite ore	Thompson (1989)	7 Mt 'probable resources' and 100 Mt 'possible resources'
Maungati Dome (Cashmores)	Estimate	20 Mt perlite ore	Thompson (1989)	-
Phosphate				
Clarendon	Estimate	5 Mt at 11% P_2O_5	Douglas (1989)	-
	Estimate	1.6 Mt at 18% P_2O_5	Manhire et al. (2024)	Based on drilling results of drilled part (1/25th) of the deposit
Offshore Phosphate (Chatham Rise)				
Chatham Rise phosphorite	JORC	23.4 Mt of phosphorite at 18–19% P_2O_5	Sterk (2014)	Inferred Resources

Project Area	Type	Resource	Reference	Notes
Serpentine				
Greenhills, Bluff	Estimate	18 Mt serpentinite	Richards (1978)	-
Silica – Silica Sands				
Kokota Spit, Parengarenga Harbour, Northland	Estimate	120 Mt silica sand	Williams (1974)	-
Kaipara Harbour, Northland	Estimate	10 Mt silica sand	Williams (1974)	-
Mt Somers, Canterbury	Estimate	165,000 t silica sand at >99% SiO_2	Canterbury United Council (1984)	-
Hyde, Otago	Estimate	134,000 t silica sand	Canterbury United Council (1984)	-
Silica – Quartzite				
Appos Flat, Rockville, near Collingwood, Northwest Nelson	Estimate	1 Mt quartzite (97–97.6% SiO_2)	Riley (1972); Williams and Katz (1974); Thompson (1989)	'Possibly over 1 Mt'
Reefton	Estimate	600,000 t (85–96% SiO_2)	Young (1964); Williams (1974)	-
Silica – Quartz Gravels				
Pebbly Hills – Mabel Bush, Southland	Estimate	350 Mt quartz gravels averaging 98% SiO_2	MacFarlan and Barry (1991)	-
Silica – Amorphous Silica				
Lake Rotokawa	Estimate	4.5 Mt	Roberts (1997)	-
Sulfur – Elemental				
Lake Rotokawa	Estimate	4.9 Mt sulfur contained in 57 Mt lake sediments	MacFarlan and Barry (1991)	-
Sulfur – Pyrite				
Kauaeranga Valley	Estimate	15–20 Mt at 7–8% sulfur	Kear (1957)	-
Copperstain Creek	Estimate	10.5 Mt at 7.5% sulfur	Williams (1974)	-
Wollastonite				
Holyoake Valley, Northwest Nelson	Estimate	53,000 t wollastonite	Braithwaite et al. (1976)	-
Zeolite				
Ngakuru	Estimate	-	-	-

Table 7.3 Summary of Coal Resources, Coal Reserves and Inventory Coal by region (after Sherwood [2019]). P = Private Coal Resources and Coal Reserves; these are confidential.

Region	Rank	Coal Reserves (Mt)	Coal Resources (Mt)	Inventory Coal 1 (Mt)	Inventory Coal 2 (Mt)
Northland	Sub-bituminous	-	-	-	5.3
Waikato	Sub-bituminous	5.4	26	21	1890
Taranaki	Sub-bituminous	-	-	46	290
Nelson	Sub-bituminous	-	-	-	-
West Coast	Sub-bituminous	9.1	28	21	67
West Coast	Bituminous	39	230	150	120
Canterbury	Sub-bituminous	1.6	7.1	18	
Eastern Otago	Sub-bituminous	P	P	66	300
Eastern Otago	Lignite	-	-	-	800
Central Otago	Lignite	-	-	330	1160
Eastern Southland	Lignite	P	P	835	8360
Western Southland	Sub-bituminous	2.0	5.3	-	800
Subtotal	**Sub-bituminous**	**9.0**	**66**	**170**	**3350**
	Bituminous	**38.5**	**230**	**150**	**120**
	Lignite	**P**	**P**	**1170**	**10,300**
TOTAL				**1490**	**13,800**

Table 7.4 Coal Resources and Coal Reserves (JORC or N43-103 standards) reported to MBIE for the end of 2023 (Source: MBIE).

Rank	Coal Reserves (Mt)	Coal Resources (Mt)
Bituminous	10.5	144.5
Sub-bituminous and lignite	2.9	69.3

8.0 ONSHORE METALLIC MINERALS

This section briefly reviews the various onshore metallic mineral commodities, with summary maps presented in Figures 8.1 and 8.2. For more detailed descriptions – structured under mineral deposit types – the reader is referred to Part 2 of this report.

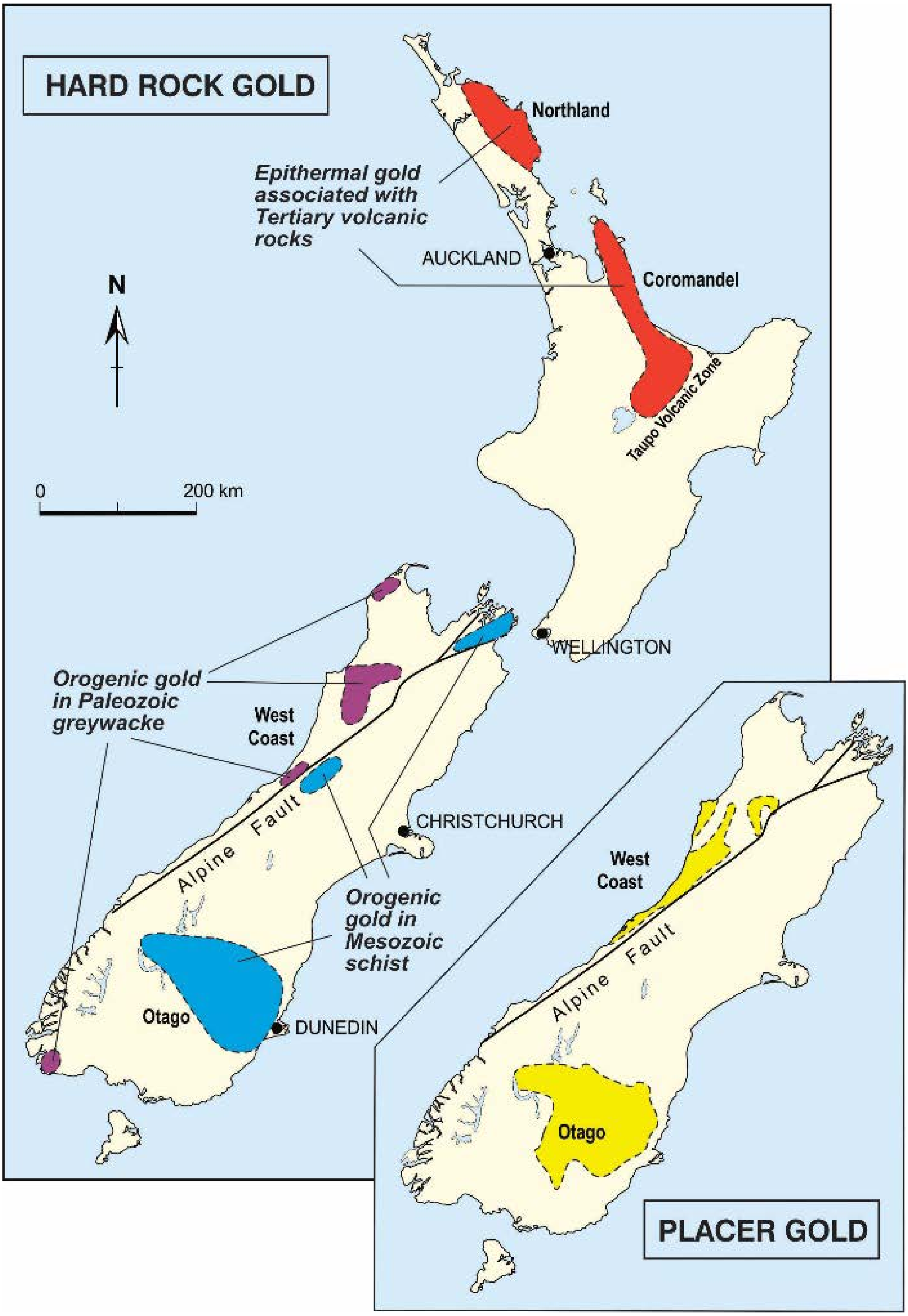

Figure 8.1 Location of gold occurrences (after Christie and Barker [2013]).

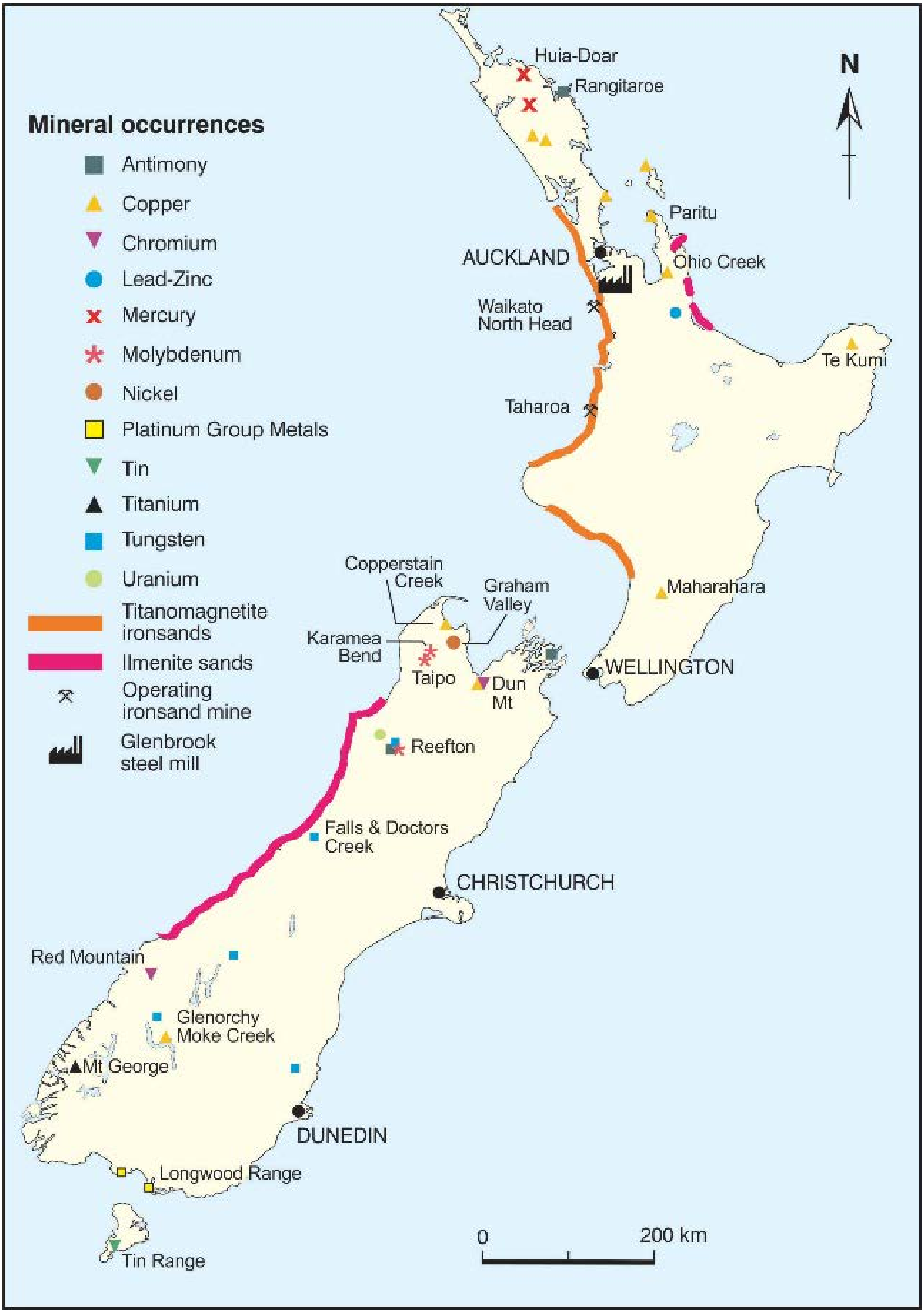

Figure 8.2 Locations of metallic mineral occurrences, excluding gold (after Christie and Barker [2013]).

8.1 Aluminium (Al) – *Lateritic Bauxite* Deposits

The aluminium ore mineral bauxite consists of a mix of aluminium hydroxide minerals produced by tropical weathering of rocks rich in aluminium silicate. Small deposits of bauxite occur in Northland within a triangular area between Kerikeri, Kaikohe and Kaeo. Resources of about 30 Mt have been estimated, although grades are low at 30% Al_2O_3 (alumina). Bauxite ore imported from Queensland, Australia, is smelted at Tiwai Point in Southland. There has never been any bauxite mining in New Zealand.

8.2 Antimony (Sb) – *Orogenic Quartz Vein Sb*; *Hot Spring Sb–As* Deposits

The antimony mineral stibnite (Sb_2S_3) has been recorded at many locations around New Zealand in a range of deposit types. About 3900 t of antimony ore have been produced from quartz veins at Rangitarore Hill in Northland and Endeavour Inlet in Marlborough (Figure 8.2). Stibnite is also found in quartz-vein gold deposits in Reefton and the Coromandel Peninsula (Hauraki Goldfield). Resources at Endeavour Inlet have been estimated at 25,000 t at 15% Sb (3750 t Sb). There is potential to produce antimony from quartz-vein deposits in the Reefton Goldfield, especially as a by-product of gold mining.

8.3 Beryllium (Be) – *Be Pegmatite* Deposits

The beryllium mineral beryl ($Be_3Al_2Si_6O_{18}$) occurs in the South Island in pegmatite dikes and quartz veins, as well as in trace quantities in West Coast beach sand. The main pegmatite occurrences are near Charleston on the West Coast and on the north shore of Paterson Inlet, Rakiura / Stewart Island.

8.4 Chromium (Cr) – *Podiform Chromite* Deposits

The main occurrences of the chromium mineral chromite [$(Mg,Fe)Cr_2O_4$] are in ultramafic rocks of the Dun Mountain Ophiolite Belt in east Nelson and northern Otago (Figure 8.2) (Brathwaite et al. 2012b, 2017a). About 6000 t of chromite ore (20–54% Cr_2O_3) were produced in the late 1800s from Dun Mountain, east of Nelson.

8.5 Cobalt (Co)

Some cobalt-bearing mineral occurrences have been reported in New Zealand (Railton and Watters 1990), but, worldwide, cobalt is mainly produced as a by-product of mining other metals, typically nickel. Durance et al. (2018) noted potential prospects for cobalt associated with nickel in New Zealand.

8.6 Copper (Cu) – *Volcanogenic Massive Sulfide (VMS) Cu*, *Porphyry Cu*, *Serpentine-Hosted Fe-Cu* and *Epithermal* Deposits

Modest production totalling 7500 t of copper ore has been historically mined in New Zealand since the country's first underground mine was opened on Kawau Island in 1842. This production was from deposits representing a variety of different mineral deposit types: Ophiolite-hosted (Cyprus type) VMS (Pakotai, Pupuke and Parakao), Ophiolite-hosted (Besshi type) VMS (Kawau Island, Maharahara, Moke Creek and Waitahuna), Porphyry Cu (Miners Head, Great Barrier Island), Serpentine-hosted Fe-Cu (Dun Mountain and D'Urville Island) and Epithermal Au-Ag-Zn-Pb-Cu (Tui). New Zealand has potential for copper deposits of additional mineral deposit types, for example, Cu skarn, porphyry Mo-Cu and gabbroid-associated Ni-Cu. The porphyry Cu deposits are likely to be the most prospective for future exploration (Turnbull et al. 2023).

8.7 Gallium (Ga)

Gallium is typically produced as a by-product of bauxite mining, although gallium has been reported from muds and sinters of geothermal fields of the Taupō Volcanic Zone (Crump 1994). However, with reported contents only up to 144 ppm, these occurrences may only be of scientific interest.

8.8 Gold (Au) – *Orogenic*, *Epithermal* and *Intrusion-Related* Hard-Rock Au and *Placer Au*

New Zealand gold deposits can be divided into two broad categories: placer and hard rock. Placer gold is found as grains of gold in river gravels that are eroded, transported and concentrated by rivers (alluvial gold), as well as, less commonly, glaciers (fluvioglacial gold), beaches and seabed processes. Gold is extracted from these deposits mainly using gravity separation methods. Gold in hard-rock deposits is encased within rocks. Deposits of this type account for most of the gold produced. Crushing, grinding and chemical treatment is usually needed to separate the gold from hard-rock deposits.

Total past gold production is about 20 million ounces from hard-rock gold deposits and 18 million ounces from placer gold deposits to date, making gold New Zealand's most valuable mineral commodity. Current production is from two hard-rock mining areas, Waihi southeast of Auckland and Macraes in Otago that produced 39,114 oz (1216.43 kg) and 143,688 oz (4468.70 kg) of gold in 2022, respectively, with placer mining contributing a further 31,776 oz (988.23 kg) of gold from more than 120 operations, mainly on the West Coast of the South Island.

8.8.1 *Orogenic Quartz Veins* in Paleozoic Metasedimentary Rocks

These gold deposits are found in Ordovician-age rocks of the Western Province, in the west of the South Island (Figure 8.3). The deposits consist of quartz veins that were formed in steeply dipping shear and fault structures in greywacke and argillite. The deposits are believed to have formed by hydrothermal fluids released during metamorphism (Goldfarb et al. 1995, 2005a, 2005b).

The most important deposits of this type in New Zealand are those in the Reefton Goldfield, where over 2 million ounces of gold was produced from 84 mines between 1870 and 1951. OceanaGold open-pit-mined the Globe Progress deposit from 2007 to 2015 to produce 536,494 oz of gold, additional to the 418,345 oz produced by historic underground mining there. Since the closure of the Globe Progress mine in 2015, there has been no mining of orogenic gold deposits in Paleozoic rocks. Recent exploration success by Tasman Mining (a subsidiary of Federation Mining) suggests that mining will resume soon, with estimated Indicated Resources of 780,000 oz gold for deep levels of the Birthday Reef below the former Blackwater mine at Waiuta, as well as continuation of advanced exploration projects by Rua Gold and Siren Gold.

Opportunities: The Reefton gold deposits can be correlated with those in Victoria, Australia, that are hosted by rocks of similar age, indicating the potential for large gold resources. Studies by Crown Minerals (2002) and Kenex (2011) have mapped and ranked prospectivity of the orogenic gold deposits in Western Province Paleozoic rocks based on a GIS-based study of research and exploration data.

The Reefton and Lyell goldfields have potential for:

- Exploration under the glacial sedimentary cover.
- Extensions of quartz veins, down-dip (e.g. Blackwater mine) and along strike.
- Disseminated gold discovered in the 1980s associated with some of the vein systems (e.g. Globe Progress).
- Exploration for other metals, especially as by-products to gold mining, for example, antimony and tungsten.

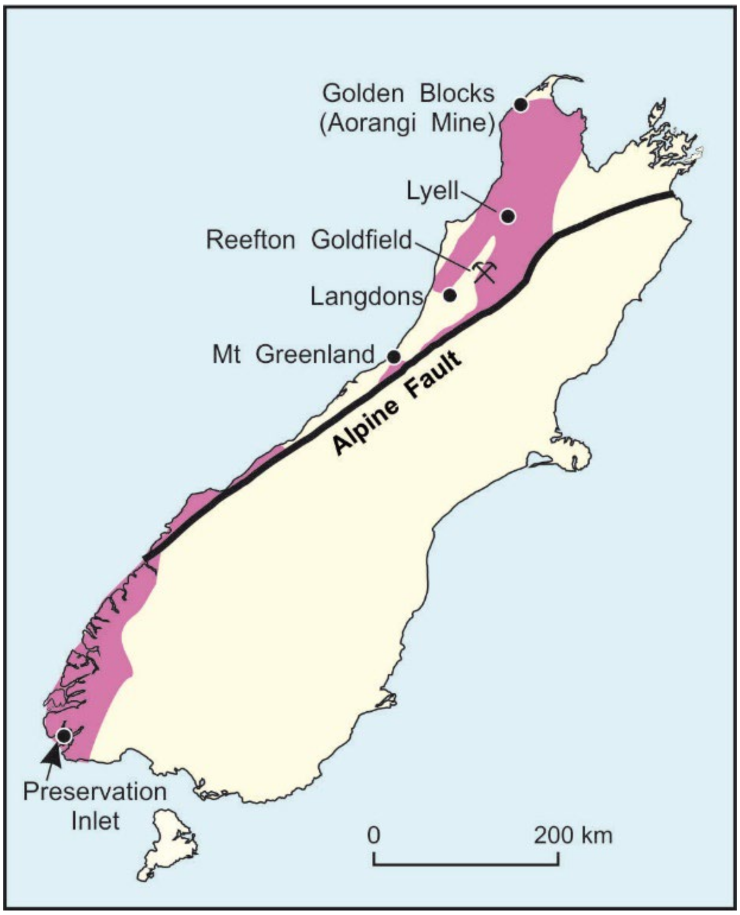

Figure 8.3 Orogenic gold deposits (black dots) in Western Province Paleozoic rocks (purple) (after Christie and Barker [2013]).

8.8.2 *Orogenic Quartz Veins* in Eastern Province Mesozoic Schist

Quartz-vein gold deposits are found in the Mesozoic schist of Otago, Marlborough and the Southern Alps (Figure 8.4). The gold-bearing veins typically occur as lenses, less than 1 m wide and localised along single or multiple parallel shear zones that generally dip steeply. In Otago, another style of gold mineralisation was recognised with the exploration of the Macraes area from the 1980s. In this area, mineralisation occurs in shear veins, stockwork veins and disseminated within the gently dipping (c. 30°) Hyde-Macraes Shear Zone. The shear zone is more than 26 km long, with gold ore produced from a series of pits and the Frasers and Golden Point underground mines. The current mining operation at Macraes began in late 1990 and the project has now produced more than 5 million ounces of gold.

The Rise & Shine shear zone northwest of Macraes has been explored as a potential Macraes-like deposit (Martin and MacKenzie 2016). After several drilling campaigns since the late 1980s that indicated a low-grade resource, extensive higher-grade quartz vein and disseminated gold sections were recently discovered by Santana Minerals, with significant resources proven to date. The company is continuing with resource definition drilling on some sections of the shear zone and exploration drilling on others.

Opportunities: The success of exploration on the Hyde-Macraes and Rise & Shine shear zones suggests that these continue to offer prime exploration targets along strike from the known mineralisation. New Age Exploration is exploring the southwestern side of the Otago Schist Belt for a 'mirror image' of the Hyde-Macraes Shear Zone.

Other potential includes:

- Extensions of previously mined quartz veins, down dip and along strike.
- Disseminated gold.
- Exploration for other metals, especially as by-products to gold mining, for example, antimony and tungsten.

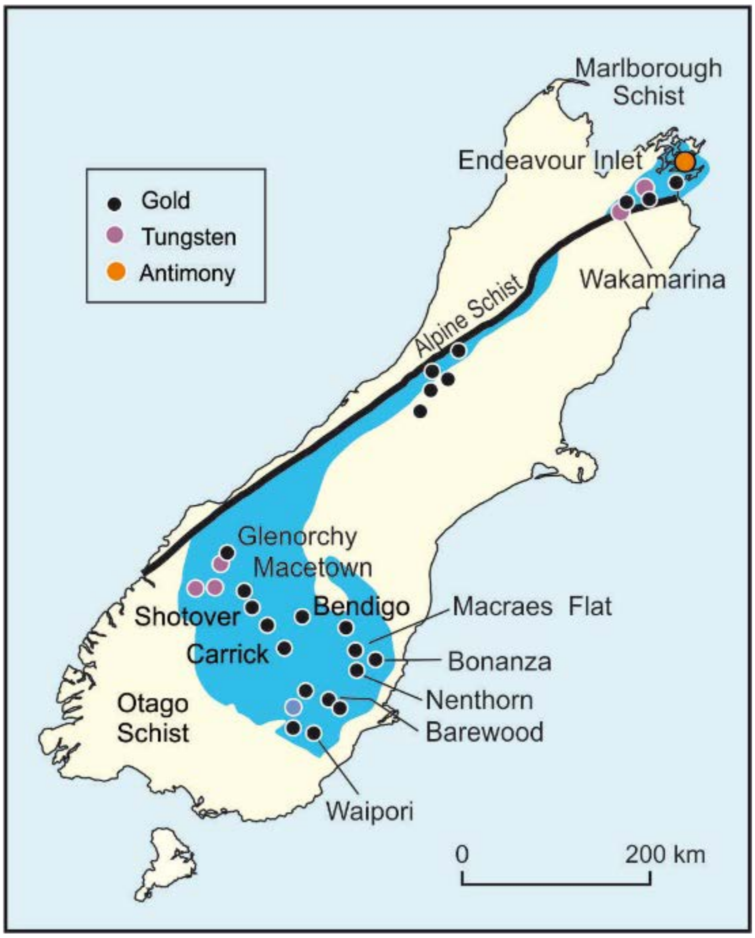

Figure 8.4 Orogenic gold deposits in the Eastern Province Mesozoic schist of Otago, Marlborough and the Southern Alps (after Christie and Barker [2013]).

8.8.3 *Epithermal Quartz Veins* in Cenozoic Volcanic Rocks

Epithermal gold-silver deposits in Northland and the Hauraki Goldfield (Great Barrier Island and Coromandel Peninsula) were formed in ancient geothermal systems associated with volcanism that was active during the Miocene–Pliocene (Figure 8.5). Gold is being deposited in modern epithermal deposits today in active geothermal systems of the Rotorua–Taupō area, associated with Quaternary volcanism.

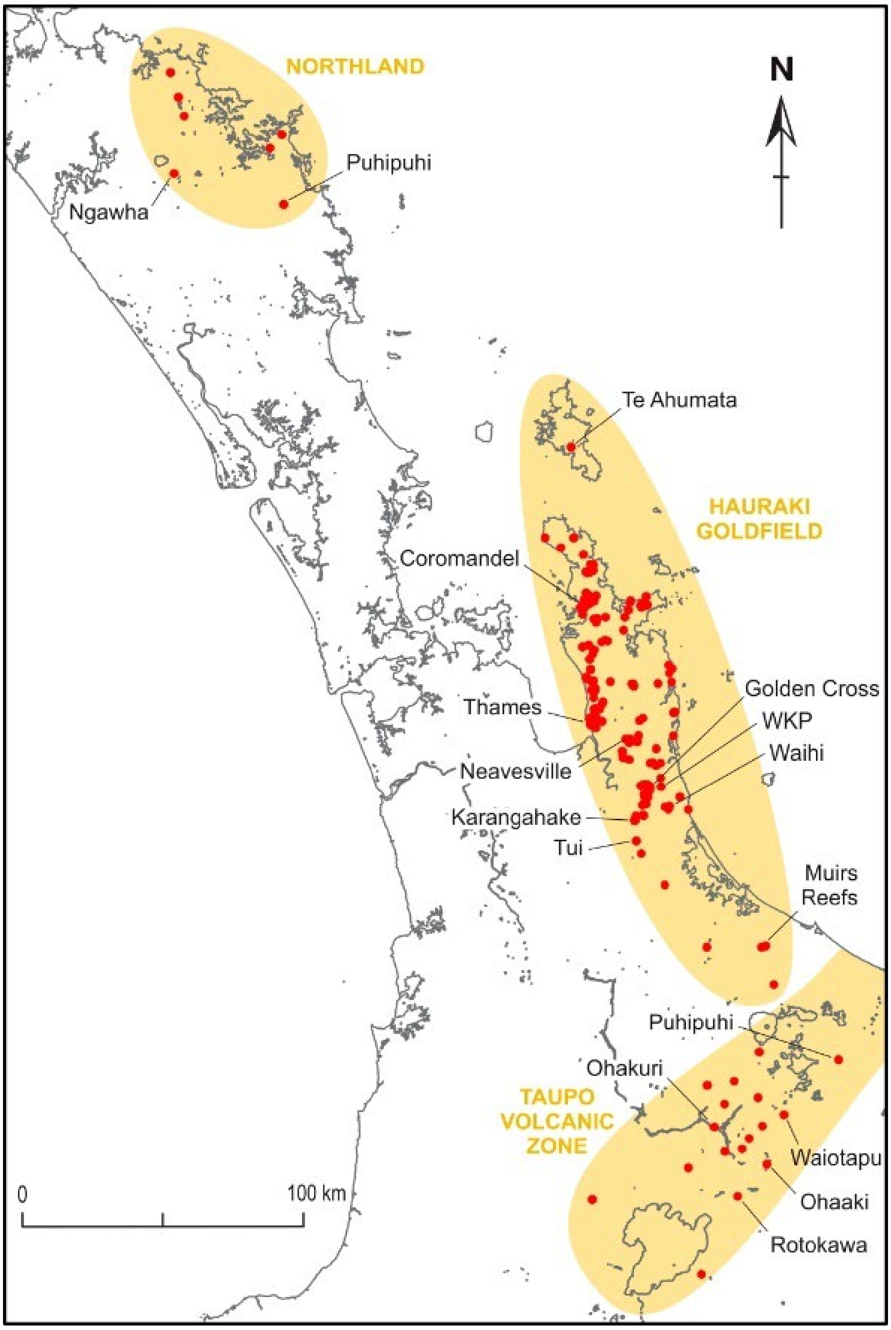

Figure 8.5 Location of epithermal deposits (after Christie [2016b]).

The Hauraki Goldfield contains about 50 known epithermal gold-silver deposits that produced about 45 million ounces of gold-silver bullion between the 1860s and 1952, mostly from vein deposits hosted by andesite and dacite (Brathwaite et al. 1989; Christie et al. 2007).

The Martha Mine is the largest producer in the Hauraki Goldfield, with 35 million ounces of gold and silver bullion being produced from underground workings between 1878 and 1952. The mine was re-opened in 1988 as an open pit. Underground mining since 2005 has targeted new vein discoveries (Favona, Trio and Correnso) and veins adjacent to and beneath the Martha open pit.

The Talisman Mine at Karangahake was also a historic large producer of gold and silver and has been explored by several companies since the 1970s. New Talisman Gold Mines Ltd is the latest company to do so, and new gold-silver resources have been identified for underground mining in extensions of the former mine.

In addition to the active deposition of gold and silver in geothermal systems of the Taupō Volcanic Zone (Figure 8.5), several epithermal gold-silver prospects have been identified in the region, including Ohakuri and Forest Road prospects.

Several hot-springs-type epithermal deposits are known in Northland. Small quantities of silver and mercury have been produced at Puhipuhi, north of Whangārei and mercury at Ngawha, near Kaikohe (Figure 8.5). Reconnaissance drilling to intersect feeder quartz veins at Puhipuhi intersected potentially economic gold grades (Grieve et al. 2006; Beach and Hobbins 2016).

Opportunities: The discovery of significant gold-silver resources at Wharekirauponga has demonstrated the potential of rhyolite in the Hauraki Goldfield to host significant gold deposits, whereas, formerly, apart from Komata, the deposits in rhyolite were considered to have low exploration potential, with most gold resources having been found in andesite and dacite host rocks.

In the Hauraki Goldfield there is potential for:

- Extension of veins down dip or along strike.
- Veins hosted in rhyolitic rocks
- Veins under cover of younger rocks, especially the younger rhyolites.

8.8.4 Alkaline Intrusion-Related Gold

Alkaline intrusion-related gold was discovered in 1974 by CRA in a 20-km-long peralkaline granite porphyry dike at Sams Creek in the northwest of the South Island (Figure 2.1). Exploration has advanced through several drilling programmes to define significant gold resources (see Table 7.1). The prospect is currently operated by Siren Gold.

Opportunities: Detailed exploration has been carried out in the main zone over only a small section of the 20 km length of the Sams Creek dike, so there is potential for additional discoveries along strike from the known main zone of mineralisation.

8.8.5 Placer Gold Deposits

Giant placer gold fields are present in Cenozoic gravel and sand in Westland and Otago/ Southland, while smaller placers are found in west Nelson and Marlborough (Figures 2.1 and 8.1; Part 2, Figure 3.19). More than 16 million ounces of gold were produced in the past during the gold rushes of the 1860s and 1870s, and later by sluicing and dredging operations (Figure 2.2). Since 1980, there have been many small- and medium-scale gold recovery operations using hydraulic excavators and mobile gold recovery plants, as well as some conventional open-pit mining (e.g. Ross). A bucket-ladder gold dredge has operated intermittently in the Grey River valley. These operations have added more than 2 million ounces to the total placer gold production.

Beach placers are found on the west and south coasts of the South Island in present day beaches, older postglacial beach deposits and the raised beach deposits of successive marine interglacials that underlie the remnants of coastal terraces. Gold is concentrated with other heavy minerals into lenticular beach placers, termed ‘beach leads’. Offshore deposits of placer gold are present off the Coromandel Peninsula and the West Coast near Hokitika.

Opportunities: There are many known prospects for small placer gold mining operations. The Grey River dredge has not worked for several years, and refurbishing and recommissioning the dredge would provide a larger-scale operation.

8.8.6 Other Types of Gold Deposits

Some other types of gold deposits that may be present in New Zealand, which are described in Part 2 of this report, are:

- Intrusion-hosted and intrusion-related Au (a separate model to the alkaline style described above).
- Gabbroid-associated Au-Ni-Cu.
- Sediment (carbonate)-hosted (Carlin) type.
- Au skarn.
- Detachment fault-related Au.

8.9 Iron (Fe) – *Shoreline Placer Fe*

New Zealand's main iron resources are titanomagnetite ironsands on the west coast of the North Island. Iron also occurs in small deposits of Bog Fe limonite in Northland and Transported residual iron deposits at Onekaka, Northwest Nelson (see Part 2 of this report). Magmatic magnetite-ilmenite segregations in gabbro and anorthosite are present at Mt Tapuaenuku in Marlborough and Mt George in Fiordland (see Part 2).

Ironsand deposits located along 480 km of coastline on the west coast of the North Island, between Kaipara Harbour and Whanganui, are among the largest known placer resources in the world (Figure 8.6). The ironsand is mined at two locations: Taharoa (near Kawhia) for export and at Waikato North Head (Figure 8.6) south of Auckland to supply the nearby steel mill at Glenbrook. Ironsand was also mined at Waipipi, near Waverley, between 1971 and 1987 for export. Annual production reached a peak of c. 3.5 Mt of concentrate (about 55% Fe) in 2016, but production figures since then have been withheld.

Quaternary andesitic volcanic rocks of western Taranaki are the main source of the titanomagnetite, which has been concentrated by marine currents, wave and wind action (Brathwaite et al. 2017b, 2021).

Onshore resources have been estimated at about 1.3 Bt of titanomagnetite (Table 7.2). Geological modelling of source rocks suggests potential for about 39 Bt of titanomagnetite eroded from the volcanoes, most of which will now be offshore (Christie et al. 2009). Extensive exploration of these resources was carried out since the 2000s using aeromagnetic surveys and drilling, both onshore and offshore (Meyers 2009; Christie 2016a).

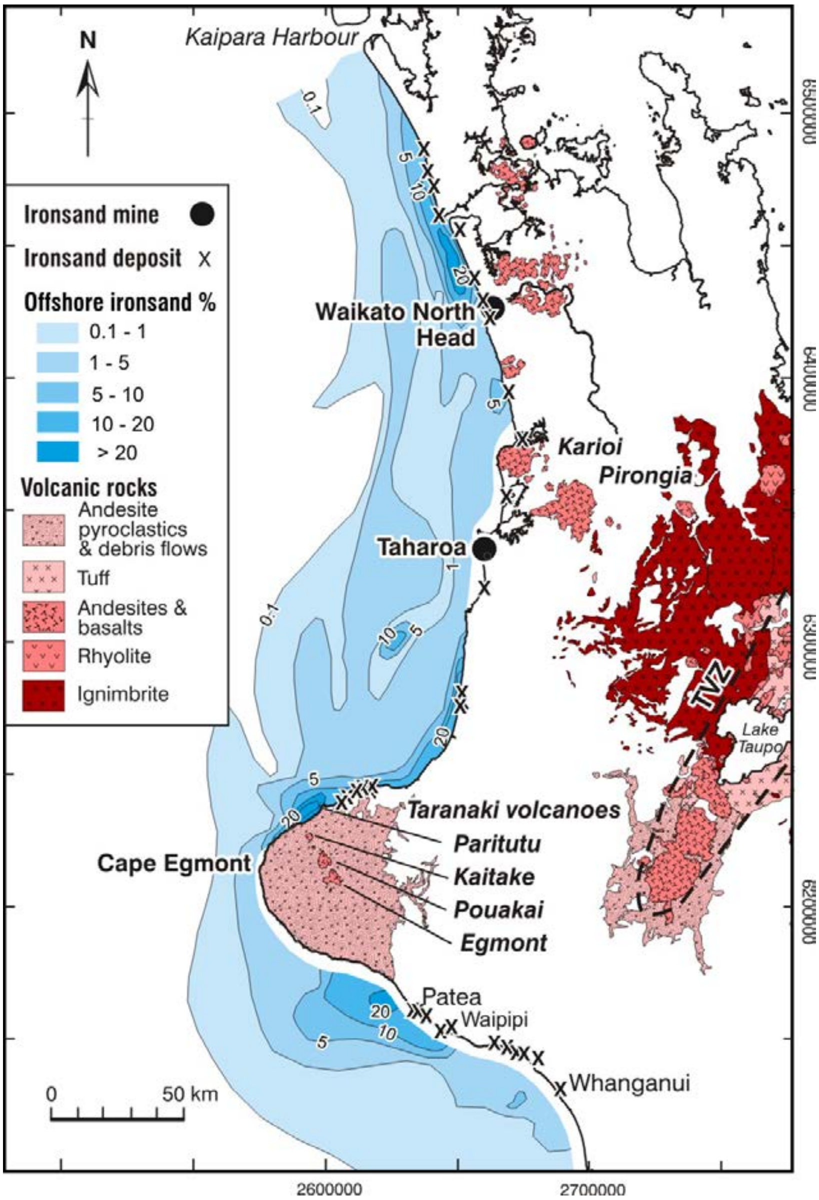

Figure 8.6 Titanomagnetite ironsand (black sand) occurs along the coast between Kaipara Harbour and Whanganui, both onshore and offshore. The offshore percent ironsand contours are based on bottom sampling reported by Carter (1980). The titanomagnetite is sourced from the erosion of volcanic rocks predominantly of the Taranaki area and Taupō Volcanic Zone (TVZ).

8.10 Lithium (Li) – *Li Pegmatites*, *Li-Bearing Hydrothermal Clays* and *Lacustrine Sediment* Deposits

There is potential for lithium resources associated with pegmatites and hydrothermally altered clays, the latter specifically in rhyolitic, lacustrine, sediment-hosted deposits (Turnbull et al. 2018; Figure 8.7). Pegmatitic rocks in New Zealand are primarily restricted to intrusive igneous rocks in the South Island, specifically fractionated felsic granitoids of the Hohonu, Paparoa and Karamea batholiths. Hydrothermally altered rhyolitic lacustrine sediments are present in the Taupō Volcanic Zone and have the potential to be enriched in lithium.

Additionally, there is potential to extract lithium from geothermal brines of the Taupō Volcanic Zone (Turnbull et al. 2018). The brines have median lithium concentrations of c. 7 ppm, although concentrations >32 ppm do occur (Millot et al. 2012; Reyes and Trompetter 2012; Bernal et al. 2014). Geo40 has a pilot plant for testing direct lithium extraction from Taupō Volcanic Zone geothermal brines at the Ohaaki geothermal plant.

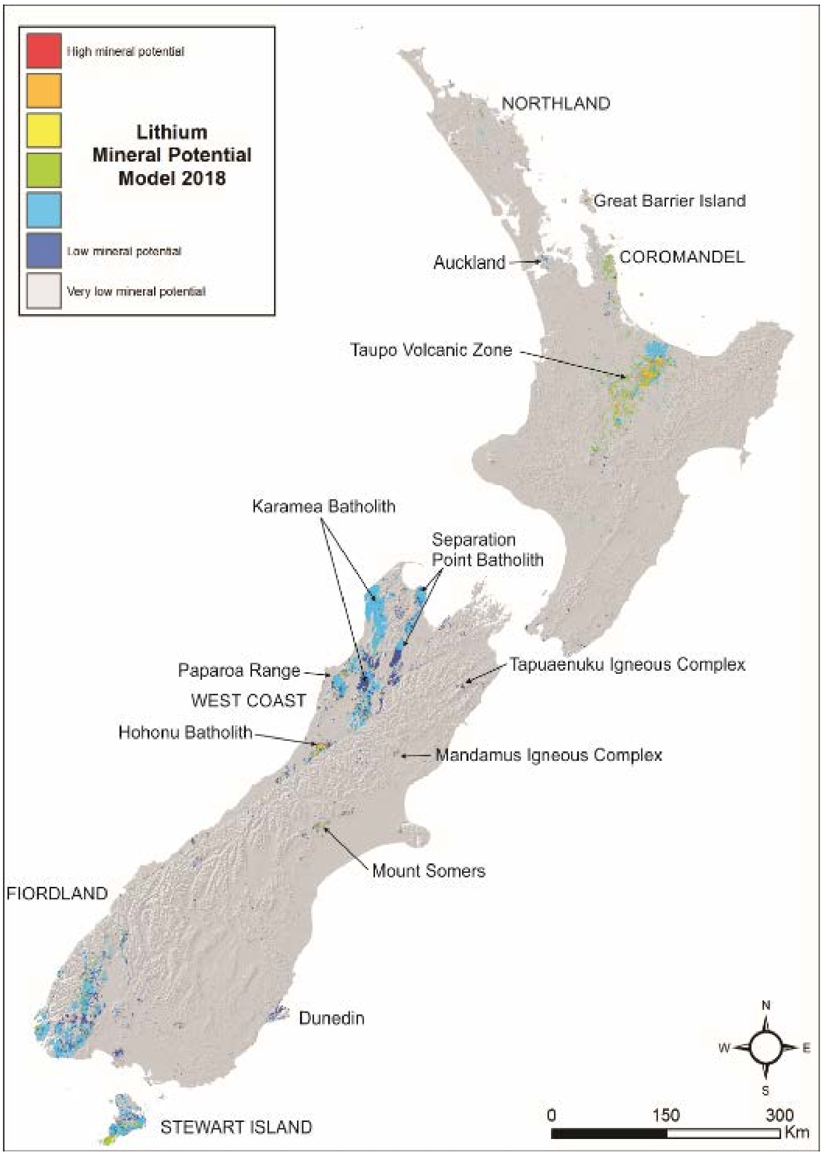

Figure 8.7 Lithium prospectivity map showing the potential for lithium mineralisation in pegmatites and hydrothermally altered rhyolitic lacustrine sediments. Warm colours represent higher potential (after Turnbull et al. [2018]).

8.11 Magnesium (Mg) – *Talc-Magnesite* Deposits

Magnesium is present as the mineral magnesite in talc-magnesite deposits formed by metamorphism of ultramafic rocks in Northwest Nelson, Westland, north Otago and Southland. The main deposits are in the Cobb-Takaka area in the Nelson region, where there are large lenses of talc-magnesite and quartz-magnesite in the Cobb Igneous Complex, which is of Cambrian age. Both talc and magnesite have been produced from the Cobb deposits for use as fertiliser, with a total recorded production of 108 t of talc and 21,802 t of magnesite. The last production of magnesite was in 1981 (308 t). Small pods of Pounamu Ultramafics in the Southern Alps, between Taramakau and Whitcombe rivers, also contain talc and magnesite.

8.12 Manganese (Mn) – *Volcanogenic Mn* Deposits

From 1842 into the 1900s, manganese oxide ore was produced in small quantities, totalling 26,000 t, from Volcanogenic Mn deposits associated with mafic lava, chert, jasperite and volcaniclastic argillite units in Permian–Jurassic greywacke sequences of the North Island, as well as their metamorphosed equivalents in the South Island (i.e. Haast Schist).

8.13 Molybdenum (Mo) – *Porphyry Mo* Deposits

Porphyry Mo mineralisation, in which the molybdenum mineral molybdenite (MoS_2) is found in stockwork quartz veins related to intrusive rocks, has been recorded from numerous localities in West Nelson and northern Westland. Many have been investigated by drilling in the 1980s, but the grades were considered too low to be economic. Molybdenite is also reported from gold prospects and mines in the Coromandel region (e.g. Neavesville and Waihi) and associated with porphyry Cu mineralisation at Ohio Creek.

8.14 Nickel (Ni) – *Dunitic Ni-Cu*, *Gabbroid-Associated Ni-Cu* and *Lateritic Ni* Deposits

Nickel has been found associated with mafic intrusive rocks in the Nelson and Marlborough regions, although no production is recorded. The main prospect occurs at Riwaka in the Graham Valley, west Nelson (Figure 8.8; Turnbull et al. 2017b). The deposit was explored in the 1970s, including by more than 30 drill holes (Bates 1989a).

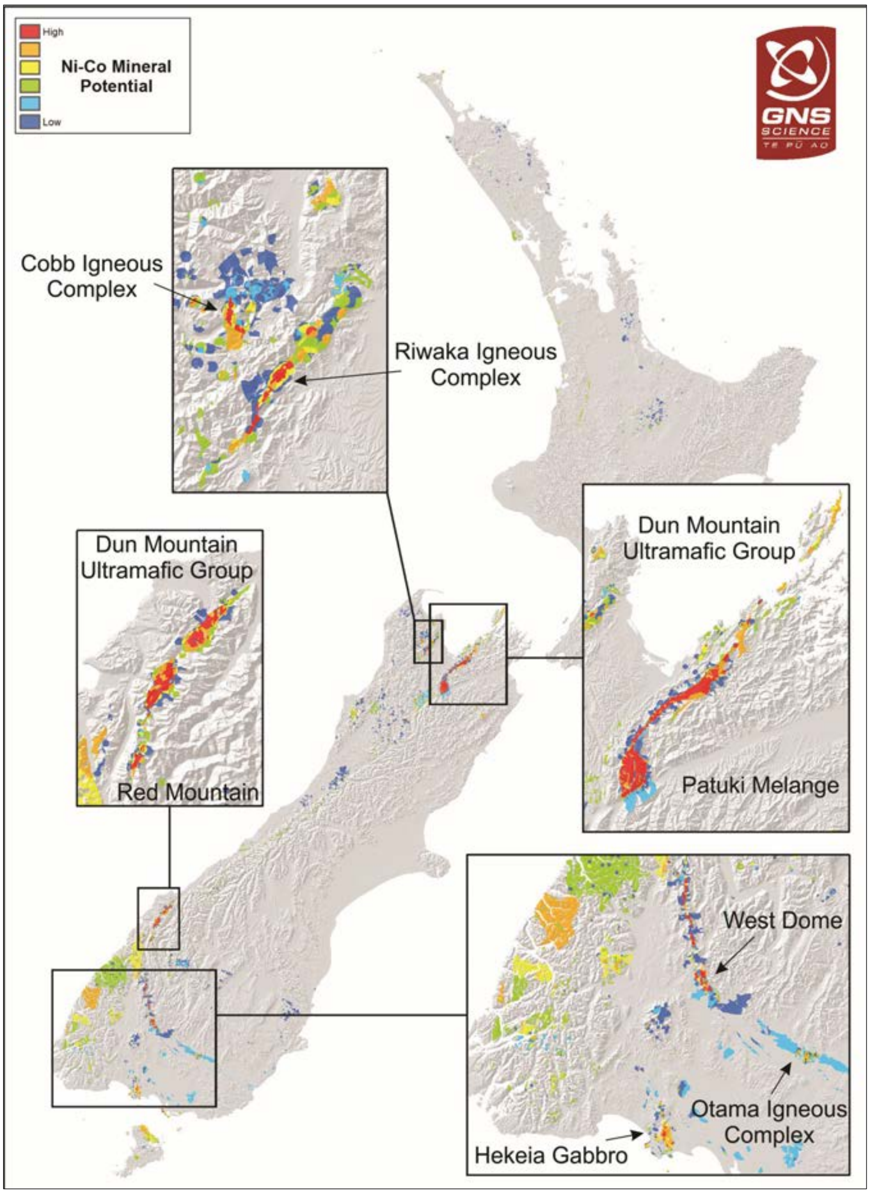

Figure 8.8 Mineral prospectivity map showing areas of Ni-Co mineral potential (after Durance et al. [2018]). Selected areas showing the highest mineral potential are shown as enlarged insets. Warm colours represent higher potential.

8.15 Platinum Group Metals (PGM) – *Magmatic PGM*, *Dun Mountain Ophiolite PGM* and *Placer PGM*

In New Zealand, PGM occur in three main geological environments: layered mafic igneous complexes, ophiolites (derived from sub-oceanic rocks) and in association with placer gold deposits (Figure 8.2). The PGM are platinum (Pt), palladium (Pd), iridium (Ir), osmium (Os), ruthenium (Ru) and rhodium (Rh).

8.15.1 Magmatic Platinum Group Metals

Several layered mafic igneous complexes have been explored for PGM formed during the crystallisation of the magma. Most of the complexes with PGM potential occur in the Median Batholith and include the Longwood (Permian), Bluff (Permian), Riwaka (Devonian) and Rotoroa (Jurassic) igneous complexes (Figure 8.9). The Blue Mountain and Tapuaenuku intraplate layered igneous complexes are exceptions, located in the northeast of the South Island.

The Permian–Triassic gabbros and ultramafic rocks of the Longwood Range are correlated with similar platinum prospective mafic plutons in the New England origin of Australia.

PGE exploration to date has been of a reconnaissance nature, with drilling at Longwood and Riwaka giving encouraging results.

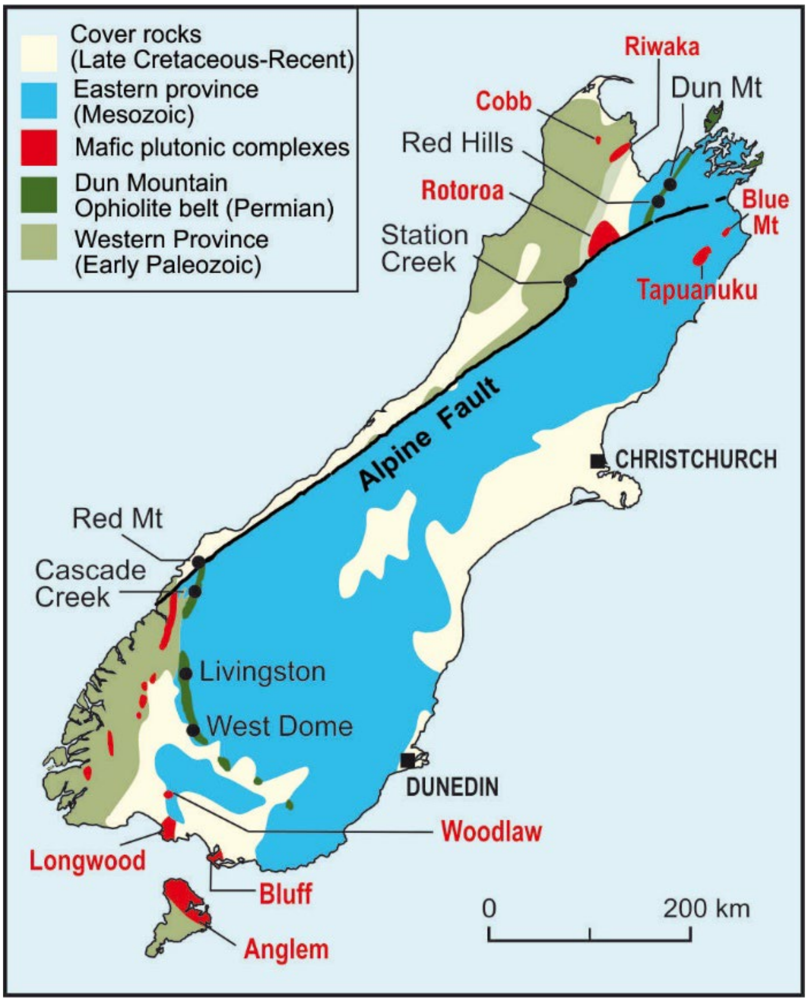

Figure 8.9 Platinum group element prospects, South Island. Red location labels are layered mafic igneous complexes, whereas black prospect location labels are mafic igneous rocks of the Dun Mountain Ophiolite Belt (after Christie and Barker [2013]).

8.15.2 Dun Mountain Ophiolite Platinum Group Metals

Sections of the Permian Dun Mountain Ophiolite Belt are present in the northeast and southwest parts of the South Island (Figure 8.9). Small quantities of copper and chromium ore were mined from the Dun Mountain area between 1859 and 1908, and several companies have explored in other areas of the Dun Mountain Ophiolite Belt for nickel, chromium and copper deposits. Exploration in the 1980s identified a number of geochemically anomalous areas, with PGE in the parts per billion range. No detailed follow-up exploration has been carried out on any of these prospects, although Brathwaite et al. (2012c, 2017a) investigated 14 Podiform Cr occurrences and concluded that Mt Baldy, and possibly Dun Mountain and Red Hills, may have potential for PGE-rich chromite ± sulfide mineralisation.

8.15.3 Placer Platinum Group Metals

Small quantities of PGM were recovered in the late 1800s and early 1900s as a by-product of placer gold mining in Southland (Craw 2012) and as osmiridium placers derived from the Dun Mountain ultramafics in east Nelson (Brathwaite et al. 2012c, 2017).

8.16 Rare Earth Elements (REE) – Carbonatite-Hosted REE, REE-Bearing Monazite in Granitic and Metamorphic Rocks, Placer REE Deposits

REE geochemical concentrations and minerals (e.g. monazite – [Ce, La, Y, Th] PO_4) are found associated with igneous rocks in Nelson, Westland, Fiordland and Rakiura / Stewart Island (Morgenstern et al. 2018) (Figure 8.10). Some of these occurrences were investigated by Strategic Elements (e.g. Price and Ryland 2011; Price 2013; Strategic Materials 2013; Morgenstern et al. 2017) and are being followed up by other companies, particularly those occurrences in alkaline granites (e.g. Mandamus Complex and Hohonu Batholith) and carbonatites. Monazite, containing REE, is found in heavy-mineral concentrates in ilmenite-bearing sands on the west coast of the South Island.

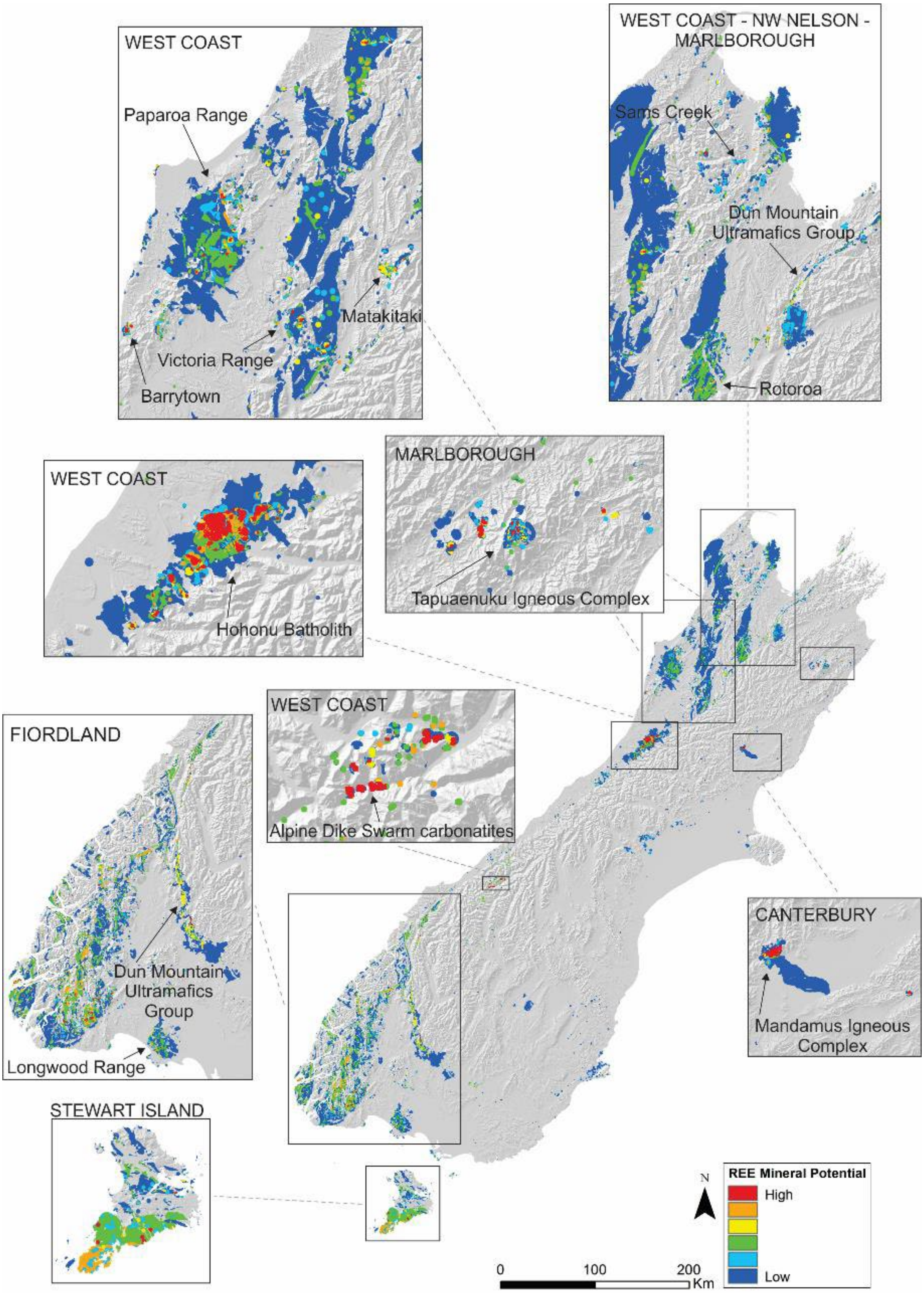

Figure 8.10 Prospectivity for rare earth elements in selected regions using a mineral systems approach. Warm colours represent higher potential (after Morgenstern et al. [2018]).

8.17 Silver (Ag)

The epithermal gold-silver deposits of the Hauraki Goldfield have produced much more silver than gold and are the main source of silver production in New Zealand. Silver also occurs in association with other metals, particularly zinc-lead and copper.

8.18 Tin (Sn) – *Greisen Sn* Deposits

The tin mineral cassiterite (SnO_2) is recorded in hard-rock and alluvial deposits associated with granitic rocks on the Tin Range in Rakiura / Stewart Island (Figure 8.2) and is also associated with tungsten in vein deposits in Westland. Historic production is 1 t of placer tin concentrate.

8.19 Titanium (Ti) – *Shoreline Placer Ti*, *Magmatic Fe-V-Ti* Deposits

The main titanium ore minerals are ilmenite ($FeTiO_3$) and rutile (TiO_2). The ilmenite-bearing beach sands of West Coast are the largest known potentially economic ilmenite deposits in New Zealand (Figure 8.2). Ilmenite also occurs with magnetite in magmatic rocks at several locations in the South Island, including Nelson, Kaikōura, Westland and Fiordland. The ironsand mineral titanomagnetite contains titanium but, despite past research efforts, the titanium is currently not separately recovered during iron- and steel-making at the Glenbrook steel mill and mostly ends up in the slag.

Ilmenite-rich black sands, with locally economic concentrations of gold, occur at intervals along 320 km of the west coast of the South Island. The ilmenite and other heavy minerals (e.g. garnet and minor zircon, with traces of monazite and gold) have been derived from erosion of garnet-grade Haast Schist in the Southern Alps. The two largest deposits, at Barrytown (Figure 8.2) and near Westport, have accumulated in embayments of the coastline where progradation has been protected by resistant headlands. Mining commenced at Westport in 2023 and is expected to commence at Barrytown in 2024–2025. A concentrate is produced and exported for processing overseas and recovery of its component minerals such as ilmenite, garnet, zircon and monazite.

8.20 Tungsten (W) – *Orogenic Scheelite-Bearing Quartz Veins*, *Greisen W-Sn*, *Stratabound W*

In New Zealand, tungsten occurs mainly as scheelite ($CaWO_3$) in three mineral deposit types: Orogenic scheelite-bearing quartz veins, Greisen tungsten-tin and Stratabound tungsten (see Part 2 of this report). The quartz scheelite-gold veins occur in greywacke in the Reefton Goldfield (e.g. Kirwan Hill) and in schist in Marlborough (e.g. Wakamarina) and Otago (e.g. Glenorchy and Macraes). Scheelite also occurs in quartz veins associated with granite in Nelson, Buller and Westland (Figure 8.2). Wolframite [$(Fe,Mn)WO_4$] accompanies the tin mineral cassiterite on the Tin Range in Rakiura / Stewart Island. New Zealand's historic production of 3828 t of tungsten concentrate was mined mainly from veins at Glenorchy and at Macraes.

8.21 Vanadium (V) – *By-Product V*

Vanadium occurs in association with iron and titanium in placer titanomagnetite deposits of the west coast of the North Island and magnetite-ilmenite deposits in Fiordland (see Sections 8.9 and 8.19 on iron and titanium, respectively). A vanadium-rich slag is produced by New Zealand Steel as a by-product of steel manufacture at the Glenbrook Steel mill and exported for processing overseas.

8.22 Zinc (Zn) – Lead (Pb) – *Epithermal Zn-Pb-Cu-Ag-Au*, *Zn-Pb Skarn*, *Polymetallic Veins*, *Sediment-Hosted Zn-Pb* and *Volcanogenic Massive Sulfide Zn-Pb* Deposits

Zinc (sphalerite; ZnS) and lead (galena; PbS) usually occur together in their dominant types of mineral deposits. In New Zealand, most of the known zinc-lead deposits are in hydrothermal veins, commonly associated with gold and silver. The only significant producer has been Tui, an epithermal deposit near Te Aroha, which was mined between 1967 and 1973, producing 7755 t of concentrate containing lead, zinc and copper and small amounts of gold and silver. Monowai and Sylvia are also zinc-lead-rich epithermal gold-silver deposits in the Hauraki Goldfield.

A sphalerite-galena-bearing pyroxene-garnet skarn of Oligocene age occurs in limestone at Motukokako (Piercy) Island in the Bay of Islands (Brathwaite et al. 1990).

In the South Island, there are a number of hydrothermal zinc-lead-quartz vein occurrences related to granite intrusions, as at Parapara Peak, Richmond Hill and Rolling River in Northwest Nelson and Bradshaws Reef in Fiordland.

Massive sulfide sphalerite-galena-pyrite-gold ore in quartz-sericite schist at Johnstons United Mine in Northwest Nelson was formerly worked for gold (1866–1897) and is a likely example of a metamorphosed volcanogenic massive sulfide deposit. Bedded sphalerite-pyrite mineralisation associated with graphitic schist at Mt Irene in Fiordland is interpreted as a metamorphosed shale-hosted zinc-lead deposit.

8.23 Zirconium (Zr) – *By-Product Zr*

Zircon is widely distributed as an accessory detrital mineral in titanomagnetite and ilmenite beach-sand deposits of the North and South Islands. Detrital zircon also occurs in alluvial placers in Westland, Otago and Southland.

9.0 ONSHORE AGGREGATE AND NON-METALLIC MINERALS

This section briefly reviews aggregate and various onshore non-metallic mineral commodities, with a summary map presented in Figure 9.1. For more detailed descriptions, the reader is referred to Part 2 of this report.

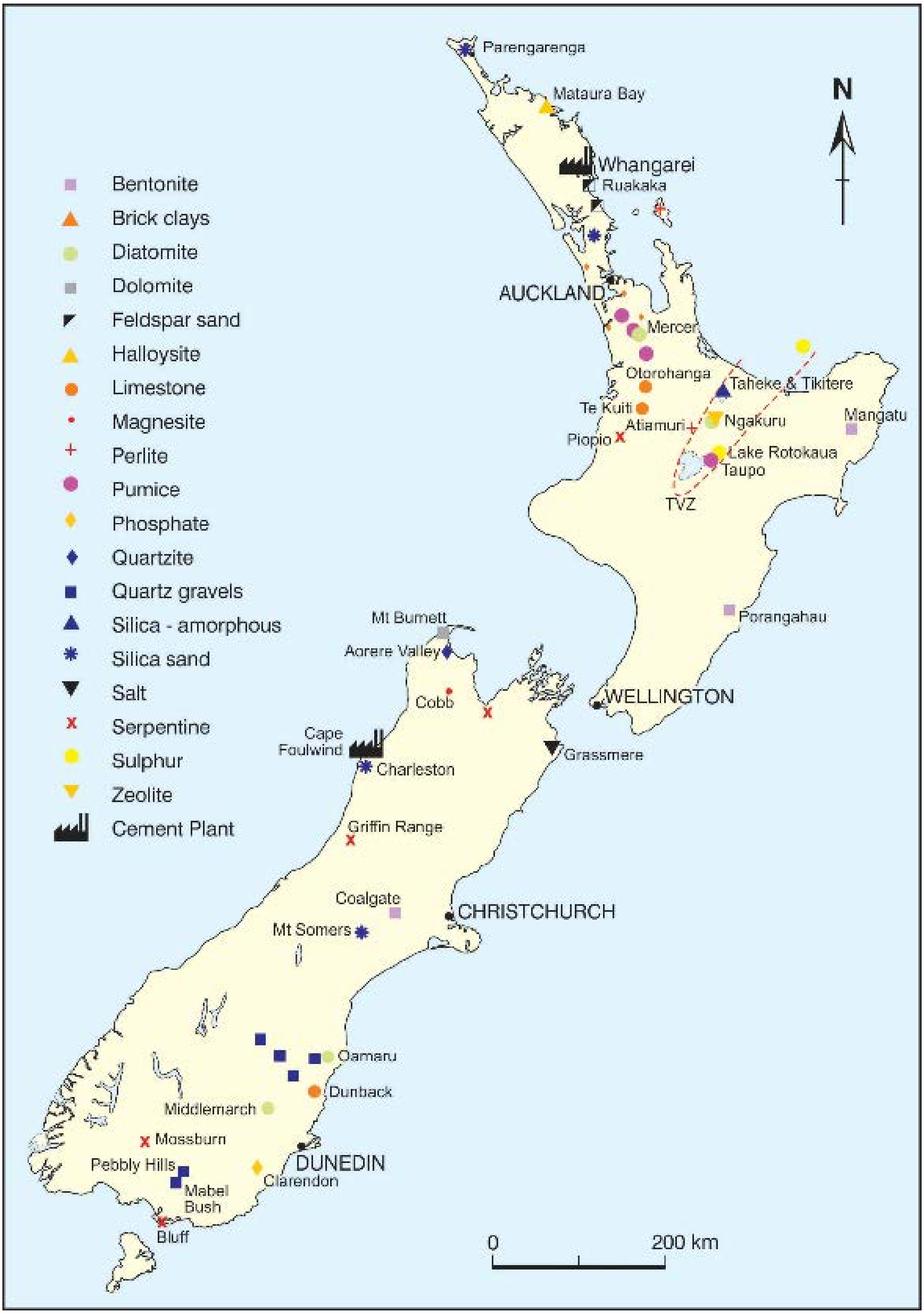

Figure 9.1 Locations of non-metallic industrial minerals (after Christie and Barker [2013]).

9.1 Aggregate and Sand

About 40–50 Mt of aggregate are produced annually and used for making roads, as well as in the construction of buildings, bridges and other structures (mainly as concrete), with lesser quantities used for reclamation, harbour protection and railway ballast (NZIC 2021; Wilson et al. 2022; McIlrath and Harris 2024). Greywacke is the main material used and is either quarried or extracted from riverbeds and alluvial terraces where natural transport processes have upgraded the quality through the breakdown of weaker material. Volcanic rocks (andesite and basalt) are used in the North Island, mainly around Auckland and Taranaki, while various other rock types are used in the south of the South Island in locations where greywacke is not available (MacFarlan and Bary 1991; Christie et al. 2001b). Domestic demand for aggregate is expected to increase markedly and will require increasing production in the next few years (NZIC 2021; Wilson et al. 2022; McIlrath and Harris 2024).

9.2 Barite ($BaSO_4$)

Barite is present in barite-fluorite-quartz-adularia veins in Arthur Marble at Thomson Hill, between the Wangapeka and Baton valleys in Northwest Nelson. There has been no production, and resources appear to be very small.

9.3 Building Stone

Stone blocks are quarried for use in constructing decorative walls and general paving (Hayward 1987). Hinuera ignimbrite near Putaruru, Oamaru limestone and Otago Schist are the main materials used currently, but a wide variety of materials have been used in the past, including sandstone, limestone, dolomite, basalt, tonalite, granite, norite and serpentinite (Hayward 1987).

9.4 Bentonite Clay [$(Ca,Na)0_{,3}(Al,Mg)_2Si_4O_{10}(OH)_2 \cdot n\ H_2O$]

Bentonite clay is formed by the alteration of volcanic ash layers and has the ability to swell when wet, making it useful as drilling mud and for sealing ponds and reservoirs. It is also used in paper-making, as a growing medium, as a stock feed additive and for treating wastewater and effluent. Bentonite formed in fresh water is mined near Coalgate, west of Christchurch. There are large marine bentonitic beds along the east coast of both the North and South Islands, and it has been worked in the past at Mangatu, north of Gisborne, and at Porangahau, southeast of Waipukurau.

9.5 Halloysite Clay [$Al_2SiO_5(OH)_4 \cdot nH_2O$]

Halloysite clay, reputed to be ‘the world’s whitest clay’, is produced from deposits at Matauri Bay, 100 km north of Whangārei in Northland (Figure 9.1), by Imerys Ceramics (Brathwaite et al. 2012a, 2014; Brathwaite and Christie 2016). The company also has deposits at Shepherds Hill, to the west of Matauri Bay, and Maungaparerua, 8 km west of Kerikeri. The clay is formed by subtropical weathering of Pliocene–Pleistocene-age rhyolite to produce a raw material comprising approximately 50% halloysite, 50% silica and minor feldspar (Brathwaite et al. 2012a).

Opportunities: Potential resources are present in other deposits at Shepherds Hill west of Matauri Bay and at Maungaparerua near Kerikeri.

9.6 Kaolinite Clay for Bricks, Pottery and Industry [$Al_2Si_2O_5(OH)_4$]

Kaolinite clays are found in many geological environments throughout New Zealand, formed mainly by weathering of various rock types, hydrothermal alteration of volcanic rocks or acid leaching of coal-measure sediments (fireclays).

Opportunities: High-purity kaolinite is imported by the New Zealand paper industry for paper coating and filling. There is potential for substituting kaolinite from a local source or alternatively substituting limestone for the kaolinite.

9.7 Diatomite (SiO_2)

Diatomite is a biogenic rock formed from the skeletal remains of diatoms (single-celled algae). Marine deposits of diatomite (Eocene age) occur at Papakaio near Oamaru and at Kaiwaka in Northland. Diatom-rich lake deposits occur at Pakaraka and Kamo in Northland; Kingsland in Auckland; Mercer, Lower Kaimai, Whirinaki (Ngakuru) and Lake Rotorua in the Waikato (all of late Tertiary or Quaternary age); and Middlemarch in Otago (Late Miocene).

9.8 Dolomite [$CaMg\ (CO_3)_2$]

Dolomite is mined at Mt Burnett in Northwest Nelson (Figure 9.2), where it is present in discontinuous lenses in a folded dolomite-marble sequence of Paleozoic age. Most of the product is used as an additive to phosphatic fertilisers, and the balance is used for aggregate and rip rap with large blocks used for river and coastal protection in the Wellington region. The exterior of the Te Papa Museum in Wellington is faced with this dolomite.

9.9 Feldspar ($NaAlSi_3O_8$, $CaAl_2Si_2O_8$, $KAlSi_3O_8$)

Feldspar deposits of possible economic potential occur in four main geological environments:

1. In pegmatite and aplite dikes in granites of Paleozoic and Mesozoic age along the western side of the South Island (e.g. Separation Point Granite, Deep Creek, Charleston).
2. In the weathered zone of granite plutons in Northwest Nelson.
3. In weathered feldspar-rich volcanic rocks in Northland, Rotorua–Taupō, the Malvern Hills and Dunedin.
4. In dune, beach and marine sands of Quaternary age at Ruakaka Flat south of Whangārei and near Kaipara Harbour.

9.10 Fluorite/Fluorspar (CaF_2)

Fluorite occurs in veins association with barite at Thomson Hill, with grades from 7.8 to 19.5% CaF_2. It is also found as veins in granites at Wekakura, near the mouth of the Heaphy River, in Kehu Stream, near the Buller Gorge, and as minor occurrences in the Sinclairs Castle area (Bates 1978). There has been no production, and resources appear to be very small.

9.11 Garnet [$(Mg,Fe,Mn)_3Al_2(SiO_4)_3$]

Garnet is a minor constituent in most Quaternary fluvial and ilmenite beach-sand deposits on the West Coast, but significant resources are present in raised beach deposits at Westport, Barrytown and Ruatapu south of Hokitika in north Westland, as well as at Bruce Bay and Hunts Beach in central Westland (Brathwaite and Christie 2006; Ritchie et al. 2019). The well-rounded garnet is derived from the garnet-zone schists in the Southern Alps and has been transported northwards by longshore drift. Also, some garnet may have been re-worked through intermediate deposits, perhaps Tertiary or Quaternary in age.

Global demand for garnet has increased dramatically to replace silica sand and slag as abrasives because of health risks associated with their use. In the 2010s, this generated a burst in exploration for garnet in New Zealand by various companies, including Hardie Resources / Hardie Pacific, NZ Garnet and Whitesails Minerals. In 2023, Westland Mineral Sands started mining heavy-mineral sands at Nine Mile, near Westport, for export and processing to produce ilmenite, garnet and other mineral products. Similarly, TiGa plans to commence mining ilmenite sands at Barrytown, also planning to recover garnet in its mining operation. A garnet resource at Ruatapu, south of Hokitika, is being progressed to the mining stage by Westland Mineral Sands.

9.12 Glauconite [$(K,Na)(Fe,Al,Mg)_2(Si,Al)_4O_{10}(OH)_2$]

Glauconite is an iron-potassium silicate mineral that contains up to 9% K_2O and can be used as a potential feedstock for production of potash, a potassium fertiliser and soil conditioner (e.g. in Brazil). Glauconite forms exclusively in marine settings, typically on the continental shelf in areas with slow rates of sediment accumulation.

In New Zealand, glauconite greensand occurs in Cretaceous–Miocene-age sedimentary sequences on the eastern parts of the North and South Islands, as well as the Chatham Islands. In the North Island, exploration has been carried out on deposits near Gisborne and in the Wairarapa, and, in the South Island, in northern Canterbury and near Oamaru. The deposits near Gisborne appear to have the highest grades of K_2O.

9.13 Limestone ($CaCO_3$)

Limestone is formed in marine environments as a sedimentary rock primarily consisting of remains of calcareous organisms such as shells and a fine-grained calcite cement. Limestone deposits are widespread throughout New Zealand (Figure 9.2), particularly in Northland, Waikato, southern Hawke's Bay, Wairarapa, Northwest Nelson, Westland, Canterbury and Southland.

Limestone containing more than 70% $CaCO_3$ is used for agricultural fertiliser and for roading aggregate. High-grade limestone and marble suitable for domestic and export industrial use are widespread. The best-quality, large-tonnage, deposits, containing 97.4–99.5% $CaCO_3$, are present in the south Waikato near Te Kūiti, where limestone is produced for a wide range of industrial uses and for making burnt lime (calcium oxide; CaO).

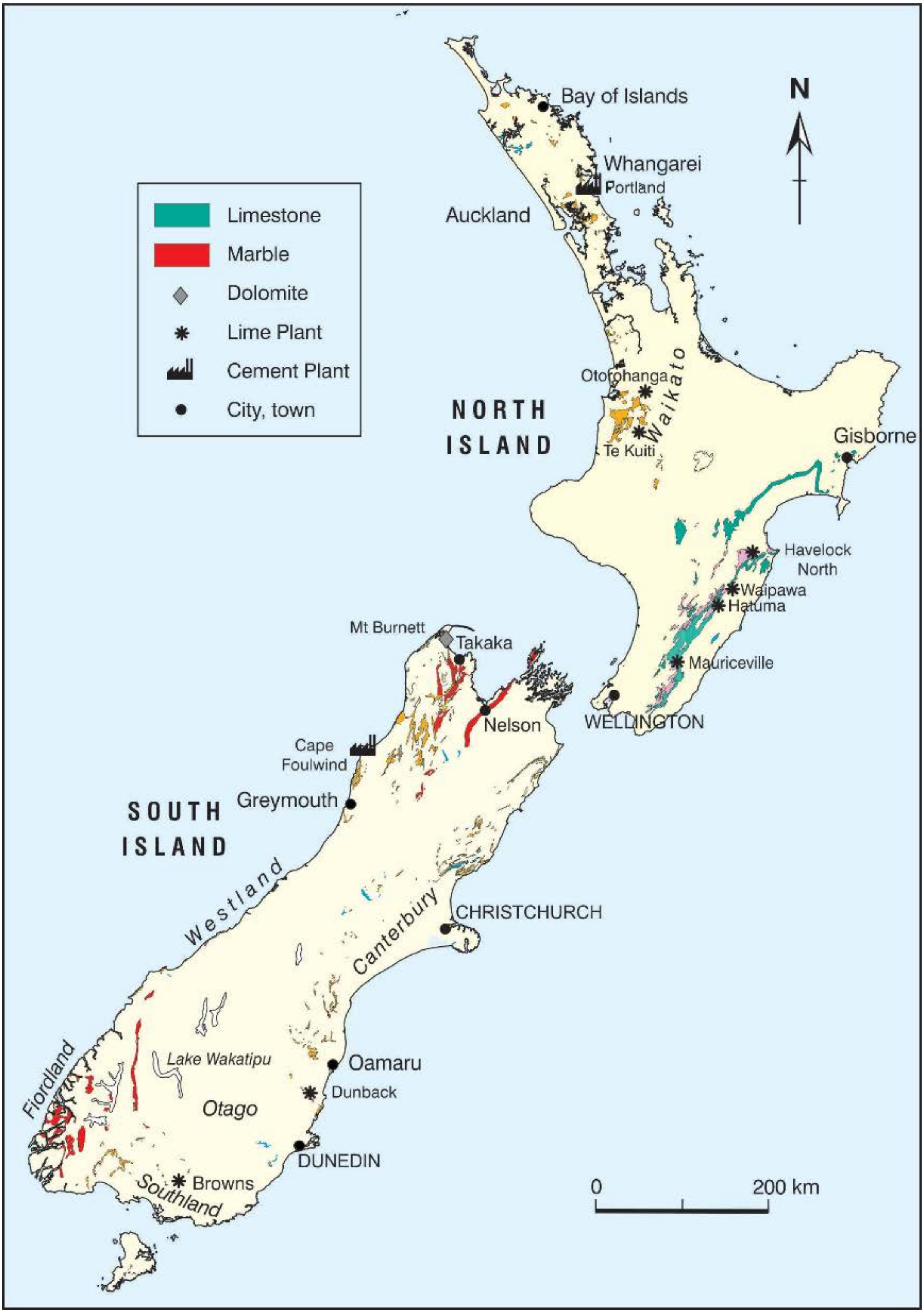

Figure 9.2 Locations of limestone, marble and dolomite deposits (after Christie and Barker [2013]).

9.14 Magnesite

See Magnesium (Section 8.11).

9.15 Marble [$CaCO_3$ and $CaMg(CO_3)_2$]

Marble, a re-crystallised (metamorphic) form of limestone, is found in Ordovician sedimentary sequences in Northwest Nelson (e.g. Takaka Hill and Pikikiruna Range) and Fiordland (e.g. Caswell, Doubtful and Breaksea sounds) (Figure 9.2). Production has been from quarries on Takaka Hill in Northwest Nelson, particularly the Ngarua quarry operated by Ravensdown, for use as building stone and in industry as a filler and for surface coating, as well as for agricultural lime.

9.16 Perlite

Perlite is a volcanic glass that occurs as near-surface layers on rhyolite domes and as perlitic flows of glassy rhyolite lava. It has a high capacity for expansion on heating, providing a lightweight material that is used as an inert insulator and filler and for horticultural / pot plant mixes. The main occurrences are in the Rotorua–Taupō area, at Cashmores Perlite quarry (Atiamuri) and on Great Barrier Island.

Opportunities: The high-expansion capacity of perlite from the Taupō Volcanic Zone, which results partly from its young age, makes it particularly good for filtration applications. There is potential for developing this market.

9.17 Phosphate (PO_4^{3-})

Between 1920 and 1940, phosphate for use as fertiliser was mined at Clarendon, south of Dunedin, from an Early-Miocene-age sedimentary sequence with glauconite. L&M is currently exploring the Clarendon deposit and also other prospects in North Canterbury, South Canterbury and Waitaki.

Opportunities: Substitution of imported phosphate by local production from onshore phosphate deposits. There is potential for a combined phosphate and glauconite operation at Clarendon, provided suitable processes and markets can be developed.

9.18 Pounamu (Greenstone)

Pounamu, also known as New Zealand greenstone and New Zealand jade, is nephrite, used by Māori to make jewellery, tools and weapons. Pounamu is found in western South Island typically as boulders in rivers and streams. It is formed by metamorphism of the contact zone between schist and ultramafic rocks or magnesium-rich carbonates. In 1997, the New Zealand Government returned the rights of pounamu ownership to Te Rūnanga o Ngāi Tahu.

9.19 Potassium (K) – Potash (KCl, K_2O)

Exploration for minerals that might be used to make potash has included glauconite greensands and feldspar in weathered Separation Point Granite. Glauconite offers the best potential for substituting for imports of potash.

9.20 Pumice

Primary pumice deposits are found in the Taupō – Bay of Plenty area and include Haparangi Rhyolitic Pumice and Waitahanui, Mihi and Rotoiti breccias. Secondary deposits consist of alluvial and slope-wash deposits found near Hamilton and on the Hauraki Plains, as well as alluvial pumice deposits along the Waikato and Whanganui rivers. The pumice is used as fill in road construction, for sand in concrete-block manufacture, in wallboard manufacture, for foundations and drainage ditches, for horticultural soil mixes and for stone washing of denim clothing.

9.21 Salt (NaCl)

Although there are no natural bedded salt deposits in New Zealand, salt is produced by Dominion Salt Limited at Grassmere, south of Blenheim, by solar evaporation of sea water. New Zealand imports about 75,000 t of salt annually and there may be potential to produce this locally.

9.22 Serpentinite [Serpentine $(Mg,Fe)_3Si_2O_5(OH)_4$]

Serpentinite has been mined from deposits formed in four main geological settings:

1. As part of the ultramafic rock sequence of the Dun Mountain Ophiolite Belt (Permian) in the South Island. The main deposits are on D'Urville Island, from Whangamoa to Red Hills in east Nelson and at Mossburn in Southland.
2. Layered bodies of serpentinised gabbro and peridotite of Permian age at Greenhills in Southland.
3. Lenses of metamorphosed ultramafic rock (Pounamu Ultramafics) occurring within medium-grade metamorphic rocks of the Alpine Schist in Westland.
4. Diapiric serpentinite bodies, up to 1 km in length and 60 m in width, emplaced vertically along a fault separating rocks of Mesozoic age from those of Oligocene age at Piopio in Waikato. Serpentine bodies in the Silverdale–Brynderwyn area have probably been re-deposited within a large landslide rather than intruded along fault planes.

Recent annual production statistics have been withheld, with the last reported in 2013 at 52,343 t. The production is from three quarries: Aria, 10 km south of Piopio, near Te Kūiti (Figure 9.1); Mossburn (GERM E44/e11; Reed 1950; Coleman 1966), at Black Ridge in Southland; and Greenhills, near Bluff in Southland.

Opportunities: Serpentinite is being investigated as a reservoir rock for the re-injection of CO_2.

9.23 Silica (SiO_2)

Silica of potential economic interest is found in four main geological environments:

- **Quartz-rich sand (silica sand) in dune, beach and shallow offshore marine environments:** Quartz-rich (silica) sand of Quaternary age forms dune, beach and shallow offshore marine sand deposits along the present-day coastline. The main localities are all in Northland, at Parengarenga Harbour on the east coast and around Kaipara Harbour on the west coast (Figure 9.1). Previously, about 40,000 tpa of sand were dredged from Parengarenga Harbour and processed into glass at a plant in Auckland. The sand is quartz-rich, with SiO_2 ranging between 95.7% and 97.7%, Fe_2O_3 between 0.05% and 0.42% and Cr_2O_3 between 0.004 and 0.013%.

- **Quartz-rich sand concentrated on erosional land surfaces and associated with coal measures:** Quartz-rich (silica) sands are concentrated on some erosional land surfaces associated with coal measures in the South Island. The main occurrences are at Mt Somers in Canterbury and at Charleston in Westland. There are other deposits in East Otago and Southland.
- **Quartz gravel:** Quartz gravels in Southland (Figure 9.1) are widespread and have potential for use in the production of ferrosilicon, or silicon metal (Williams 1974). Preliminary tests conducted on the raw silica from Pebbly Hills by a ferrosilicon producer have indicated the suitability of this material for that purpose. The availability of abundant low ash coal and hydro-electricity are other factors favourable to a ferrosilicon industry in Southland. Material from Pebbly Hills is presently being investigated by Silicon Metal Industries (NZ) Ltd as a raw material for silicon metal production. Similar deposits occur elsewhere in northern Southland and Otago.
- **Amorphous silica:** Amorphous silica is deposited by hot springs as silica sinter and also formed by hydrothermal alteration of rocks, mostly rhyolitic, in volcanically active areas. The alteration produces a low-density, white, porous rock composed primarily of amorphous silica and residual quartz phenocrysts. Three amorphous silica deposits have been explored recently, Tikitere and Taheke, near Rotorua, and Lake Rotokawa, near Taupō (Figure 9.1).

New Zealand's recent annual silica production statistics are withheld. The last reported production statistics were:

- **Amorphous silica:** last reported in 2016 at 29,531 t.
- **Silica sand:** last reported in 2019 at 34,320 t (113,231 t in 2010).

9.24 Sulfur (S)

Sulfur occurs mainly as native sulfur in volcanic areas and as the sulfide mineral pyrite (FeS_2). Native sulfur is associated with present-day and fossil geothermal areas in Northland at Ngawha and in the Bay of Plenty and Rotorua–Taupō areas, mainly on Whakaari / White Island, at Tikitere and Okere Springs near Rotorua and at Lake Rotokawa near Taupō.

Lake Rotokawa, 12 km northeast of Taupō, offers the best potential for sulfur mining, although the location of this resource within an active geothermal system and near a geothermal power plant poses some mining problems. The main resources are lacustrine sulfur present within a buried lakebed 25–75 m below the present land surface and extending under Lake Rotokawa.

Pyrite (FeS_2) is present in many types of metallic mineral deposits but, in New Zealand, only two have been investigated as a potential source of sulfur, one in the Kauaeranga Valley near Thames and the other at Copperstain Creek near Takaka. In the Kauaeranga Valley, high concentrations of pyrite are associated with hydrothermally altered andesitic lava and breccia and silty sediments of Miocene age. At Copperstain Creek, pyrite is present in a skarn deposit adjacent to an Early-Cretaceous-age granite that has intruded marble and biotite schist.

In total, more than 45,899 t of sulfur have been recorded as mined to 1993, mainly from Whakaari / White Island, Tikitere, Lake Rotorua and Lake Rotokawa. There is currently no mining of sulfur in New Zealand. Sulfur is used to make sulfuric acid for the manufacture of superphosphate fertiliser.

9.25 Talc-Magnesite

See Magnesium (Section 8.11).

9.26 Wollastonite ($CaSiO_3$)

In the Holyoake valley, west of Motueka, a reef-like body containing over 70% wollastonite occurs where the contact between Paleozoic-age marble and schist has been partly intruded by the Cretaceous Separation Point batholith. About 500 t of wollastonite were produced in the 1960s and used in ceramics.

9.27 Zeolite [$(Ca,K,Na)_2Al_2Si_2O_8.nH_2O$]

Zeolites are typically formed by relatively low-temperature (<200°C) hydrothermal alteration and metamorphism in tuffs and volcanic sandstones, as well as volcanic-rich lake and deep-sea sediments. The main occurrences are in:

1. Weakly metamorphosed marine tuffs and tuffaceous sandstones of Triassic age in Southland (Coombs et al. 1959).
2. Marine tuffs of Miocene age in Northland and Auckland (Sameshima 1978).
3. Hydrothermally altered tuffs and lake sediments of Quaternary age in the Taupō Volcanic Zone (Brathwaite 2003).

The main resources of zeolite are in group (3) above in the Taupō Volcanic Zone at Ngakuru (Figure 9.1), where a number of zeolite (mordenite-clinoptilolite) deposits formed in recently active (<39 Ka) geothermal systems by hydrothermal alteration of vitric tuffs in the 290 Ka Ohakuri ignimbrite (Brathwaite 2017; Brathwaite and Rae 2021). Another occurrence is at Ohakuri, where glass within the Ohakuri ignimbrite has been hydrothermally altered to the mordenite and clinoptilolite, as well as smectite and opal.

Pacific Blue Minerals produces 5000 tpa of mordenite-rich tuff from the Twist Road deposit at Ngakuru. The open-pittable resource of the Twist Road deposits exceeds 10 Mt. When compared with zeolite deposits mined in other parts of the world, those from Ngakuru are very young in geological terms (15–39 Ka; Brathwaite and Rae 2021) and, because of their high porosity, have exceptional properties of adsorption.

Recent annual production statistics are withheld, with the last reported in 2011 at 3523 t (21,750 t in 2009). The Ngakuru zeolites have wide applications as adsorbants and ion-exchangers, such as soaking up oil and chemical spills, water softening, sewage treatment, soil conditioning and pet litters.

10.0 COAL

Economically significant coals were formed between 70 and 30 Ma. Their age contrasts with most of the world's coals, which were typically formed between 350 and 300 Ma. Also, many of New Zealand's coalfields are geologically and structurally complex.

There are over 50 separate coalfields, with many now exhausted (Figure 10.1). Production in 2022 was from 14 mines (13 in 2024) in three areas (Part 2 of this report, Tables 5.1 and 5.2):

1. In the North Island, coal production is centred in the Waikato region, where large coalfields such as Maramarua and Rotowaro produce sub-bituminous coal.
2. Coal extracted on the West Coast of the South Island is mostly bituminous coal, along with some sub-bituminous coal. The bituminous coal is mostly exported for steel-making.
3. Otago and Southland production is sub-bituminous coal, with lower-energy lignite in Southland.

Most of New Zealand's premium bituminous coal is exported. It's valued internationally for its low ash and sulfur content and characteristics such as high swelling, fluidity and reactivity, which allow blending with other coals for use in the steel industry. Domestic uses of coal include: electricity generation at the Huntly Power Station; steel-making at the Glenbrook steel mill; cement and lime manufacture; food processing (e.g. furnaces for drying milk powder); industrial processes, including processing of timber, wool and leather; and heating of buildings. Substitution of other energy sources is reducing the use of coal. Investigations have looked at developing the Southland lignite resources with a variety of projects, including the production of liquid fuels and fertiliser and as a petrochemical feedstock. Coal mined in New Zealand could be substituted for imported coal. Coal resources are listed in Tables 7.3 and 7.4.

Challenges: Because of the need to reduce emissions through substitution of coal by renewable energy sources, the market for coal is generally declining. The viability of coal exports from the West Coast is primarily dependant on global coking coal prices, as well as access to resources and controlling costs in production and transport to markets.

Figure 10.1 Coal regions and main coalfields of New Zealand (after Christie and Barker [2013]).

11.0 OFFSHORE METALLIC MINERALS

New Zealand's Exclusive Economic Zone (EEZ) and Extended Continental Shelf (ECS) cover an offshore area of about 5.7 million km^2.

The offshore area is largely unexplored but has potential for seabed ferromanganese nodules, phosphate nodules, hydrothermal minerals (copper, zinc, gold and silver) and placer deposits of gold, as well as titanomagnetite and ilmenite ironsand (Figure 1.2) (Utting 1989; Wood and Wright 2008; Wood 2016).

11.1 Gold

Gold deposits in marine sediments have been recognised off the coast of onshore goldfields near Coromandel and Thames in the North Island, where a combination of natural erosion and 19th and 20th century mine tailings have produced near-shore placer deposits. These have been investigated in the past but not developed.

In the South Island, placer gold deposits are found offshore of the onshore gold placers of the West Coast and south coast and offshore from the Clutha River in Otago. The West Coast offshore placers were mostly deposited in fluvial and fluvioglacial systems when sea level was lower than present. These have since been re-worked during marine transgression. The West Coast placers have received the most exploration attention, with detailed exploration programmes carried out in the 1980s by CRA Exploration Ltd (Price 1983a, 1983b; Price 1985, Price and Coles 1985; Wotherspoon 1986; Corner 1989) and 2000s by Seafield Resources, in joint venture with DeBeers (Youngson and Stevenson 2016). A low-grade resource of about 400,000 oz of gold was defined by CRA in its Harvester prospect area offshore from Hokitika.

11.2 Titanomagnetite Ironsand (with Vanadium)

Ironsand accumulations offshore of the west coast of the North Island were revealed following reconnaissance sampling of bottom sediments by the New Zealand Oceanographic Institute in the 1960s and 1970s (Figure 8.6). Exploration from 2005, including aeromagnetic surveys, suggests that the ironsand is concentrated in 'ribbons', representing paleo-beach and dune systems and paleo-river channels formed at times of lower sea level. The 9000-year-old shoreline about 20 km off the present-day coast is recognised as a particularly important event for ironsand deposit formation. Following extensive exploration, Trans-Tasman Resources Ltd defined a JORC Resource of 482 Mt of ironsand concentrate (48% Fe), including 156 Mt Indicated and 325 Mt Inferred, in deposits located between 22 and 36 km offshore from Pātea in water depths of 20–42 m. A mining permit was granted to Trans-Tasman Resources in 2014, but a marine consent application to the Environmental Protection Agency was declined the same year. Subsequently, a new application was made and there have been several appeals. The company withdrew the application in April 2024.

Opportunities: Several other west coast offshore areas have potential for ironsand resources, as indicated by exploration by Trans-Tasman Resources, BHP and other companies.

11.3 Offshore Placer Ilmenite

Ilmenite occurs offshore associated with placer gold deposits on the east coast of the Coromandel Peninsula near Waihi Beach (see Section 11.1 above). Little is known of the deposits offshore from Waihi Beach, and, although several companies have proposed exploration, very little work has been carried out.

11.4 Offshore Volcanogenic Massive Sulfide Deposits

New Zealand is located on a convergent plate boundary that extends off the North Island towards Tonga, as defined by the Tonga-Kermadec volcanic arc (Figure 11.1). About 1200 km of this arc lies within New Zealand's EEZ. GNS Science and the National Institute of Water & Atmospheric Research (NIWA), and their international research partners, have undertaken many research cruises to survey the volcanoes by bathymetry and determine their volcanic and hydrothermal activity by plume surveys. This research has identified more than 30 major submarine volcanic centres comprised of either single large or several smaller volcanic edifices. The composition of the volcanic rocks can range from basaltic through rhyolitic, both between and within the different centres. Approximately 80% of the volcanoes are identified as hydrothermally active, expelling metal-rich fluids on the seafloor, and at least four of them are host to volcanogenic massive sulfide mineralisation. Manned submersible and/or remotely operated vehicle (ROV) dives have discovered and sampled mineralisation at these four volcanoes rich in copper, gold, lead, zinc and barium, with potentially economic grades. Brothers volcano is the best known of the volcanoes, being the most widely studied and sampled. It has an oval shape approximately 13 km long by 8 km wide, with a 3-km-wide summit caldera (Figure 11.2). The base of Brothers volcano lies at a water depth of ~2200 m, with the caldera rim situated between depths of ~1420 and 1520 m (de Ronde et al. 2005). Hydrothermal vents on the northwestern and upper caldera walls have formed large fields of 'black smoker' chimneys up to 20 m high. The 350-m-high volcanic cone inside the caldera is also host to active hydrothermal vents, although these are dominated by sulfur.

The Colville and Kermadec Ridges are ancient volcanic arcs lying west and east of the active Kermadec arc front, respectively. They conceivably host similar, ancient, hydrothermal systems that would require a different exploration approach (see de Ronde et al. [2010]).

Figure 11.1 Tectonic setting of the Kermadec arc/back-arc system, with the Australian and Pacific plates occurring west and east of the Tonga-Kermadec Trench, respectively. Flanking the Havre Trough are the remnant ~5 Ma Colville Ridge and Kermadec Ridge that form longitudinally continuous ridges. The Kermadec active arc front (≤0.5 Ma) lies within the Havre Tough northeast of New Zealand and merges with the Kermadec Ridge south of the Kermadec islands Raoul, Macauley and Curtis. Volcanoes of the Kermadec arc front occur within a 40-km-wide zone that extends for ~1300 km and is populated by 32 volcanic centres. TVZ = Taupō Volcanic Zone (after de Ronde et al. [2010]).

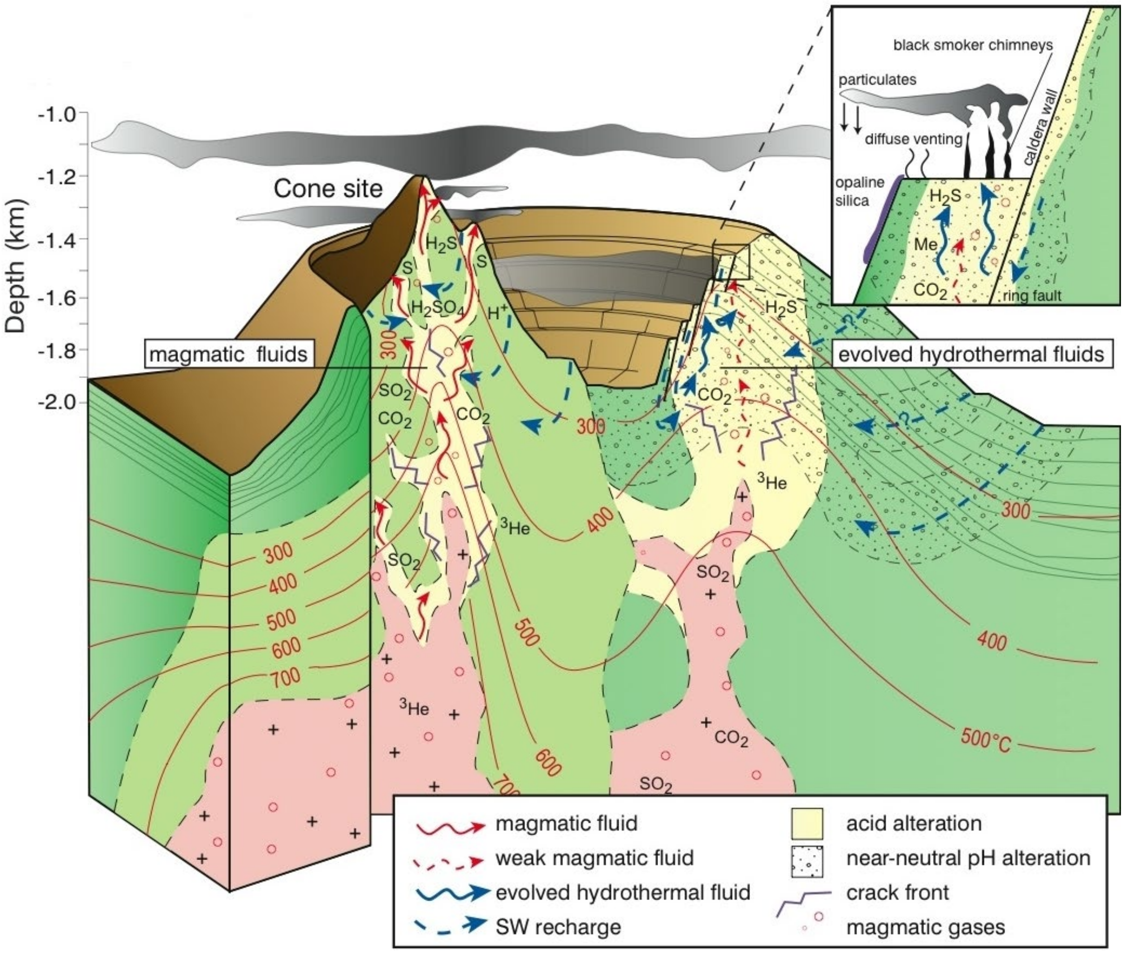

Figure 11.2 A section through Brothers volcano that shows the location of hydrothermal activity on the caldera wall and cone sites (after de Ronde et al. [2005]). Initially, the northwest caldera site was formed, followed by the emplacement of the volcanic cone in the southern part of the caldera, where a second hydrothermal field was formed. Originating from the magma below this field, gases eventually find their way to the sea floor, where they are expelled at temperatures up to ~320°C.

Opportunities: An assessment of the prospectivity of the major volcanoes of the Kermadec arc is described in Part 2 of this report and details the research required to generate a significant level of information to make them attractive mineral exploration targets. Currently, Brothers volcano would be the only one considered to have sufficient information that, if made available to exploration companies, would encourage them to tender for a prospecting (or exploration) permit.

Challenges: Using current technologies, geophysical surveys need to be undertaken from deep-sea vehicles (e.g. manned submersibles, ROVs, autonomous underwater vehicles [AUVs]) to get close to the seafloor to obtain the high resolution necessary to image features/ anomalies useful in exploration, involving commensurate expense. Similarly, precision sampling also needs to be done by these deep-sea vehicles.

11.5 Ferromanganese Nodules

Ferromanganese nodules occur in vast quantities on the floor of the deep ocean and form by direct precipitation from sea water. They are dense, nodular deposits that individually grow to several tens of centimetres in diameter and are composed largely of iron and manganese, although also containing high contents of minerals such as nickel, copper and cobalt, as well as REE. There are large deposits of these nodules within New Zealand's EEZ, the most studied of which are at abyssal depths in the deep ocean south of the Campbell Plateau (Figure 11.3).

A conservative estimate of the amount of ferromanganese nodules in the New Zealand EEZ is 283 Mt, containing about 1.5 Mt of nickel, cobalt and copper (see Part 2 of this report).

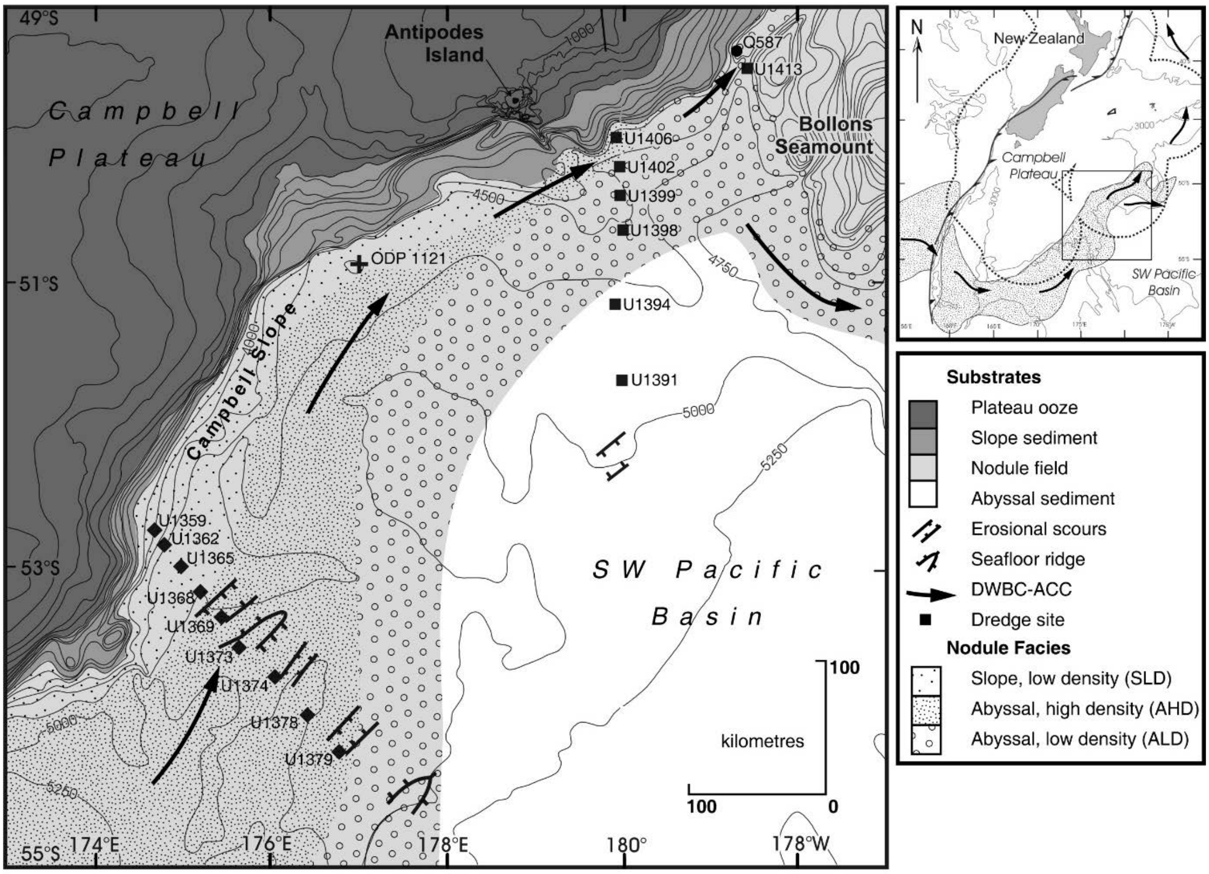

Figure 11.3 The northeast sector of the Campbell nodule field, showing dredge sites (U1359–U1413 from the southern and northern transects reported by Wright et al. [2005]; Q587 from Carter [1989]) and the distribution of the main seafloor substrates and nodule facies. Inset shows regional oceanographic setting of the Campbell nodule field (stippled area) in and around New Zealand's EEZ (dotted lines) and the location of the northeast sector (square box) as shown in the main map area (after Graham and Wright [2006]).

Challenges: The industry around ferromanganese nodule resources is only just beginning to take shape globally. As of April 2024, 19 contracts have been issued by the International Seabed Authority for the exploration of ferromanganese nodules (most for the Clarion-Clipperton Zone in the central-eastern Pacific[2]), but seabed mining has not yet begun. Technologies for extracting nodules from the seafloor are presently under development, but further advances in both mining technologies and extractive metallurgy are needed to make nodule mining commercially viable (e.g. Hein et al. 2020; Hong et al. 2021; Kang and Liu 2021; Cheng et al. 2023). Investigations of the deposits near the Cook Islands are well advanced, and these may be the first to be developed, providing a nearby opportunity to evaluate mining and recovery techniques.

The environmental impacts from nodule extraction on the seafloor and water column are uncertain, and this represents the greatest challenge associated with development of deep-ocean mining globally (Hein et al. 2020), with more research on these impacts needed.

2 https://www.isa.org.jm/exploration-contracts/

12.0 OFFSHORE NON-METALLIC MINERALS

12.1 Sand

Sand for construction and industry has been dredged from several locations offshore, with the main recent operations being at Kaipara Harbour (Atlas Resources) and Mangawhai-Pakiri (Mangawhai Heads; McCallum Brothers). The Mangawhai-Pakiri permit expired and, to date, applications for an Environmental Consent for the new operation have failed.

12.2 Phosphorite

Extensive phosphorite resources are present in submarine deposits along 400 km of the crest of the Chatham Rise, in water depths of about 400 m, 670 km east of the South Island (Figure 12.1). These consist of nodules, typically 10–40 mm in diameter, in a layer up to 70 cm thick within a glauconitic sandy mud matrix (Figure 12.2).

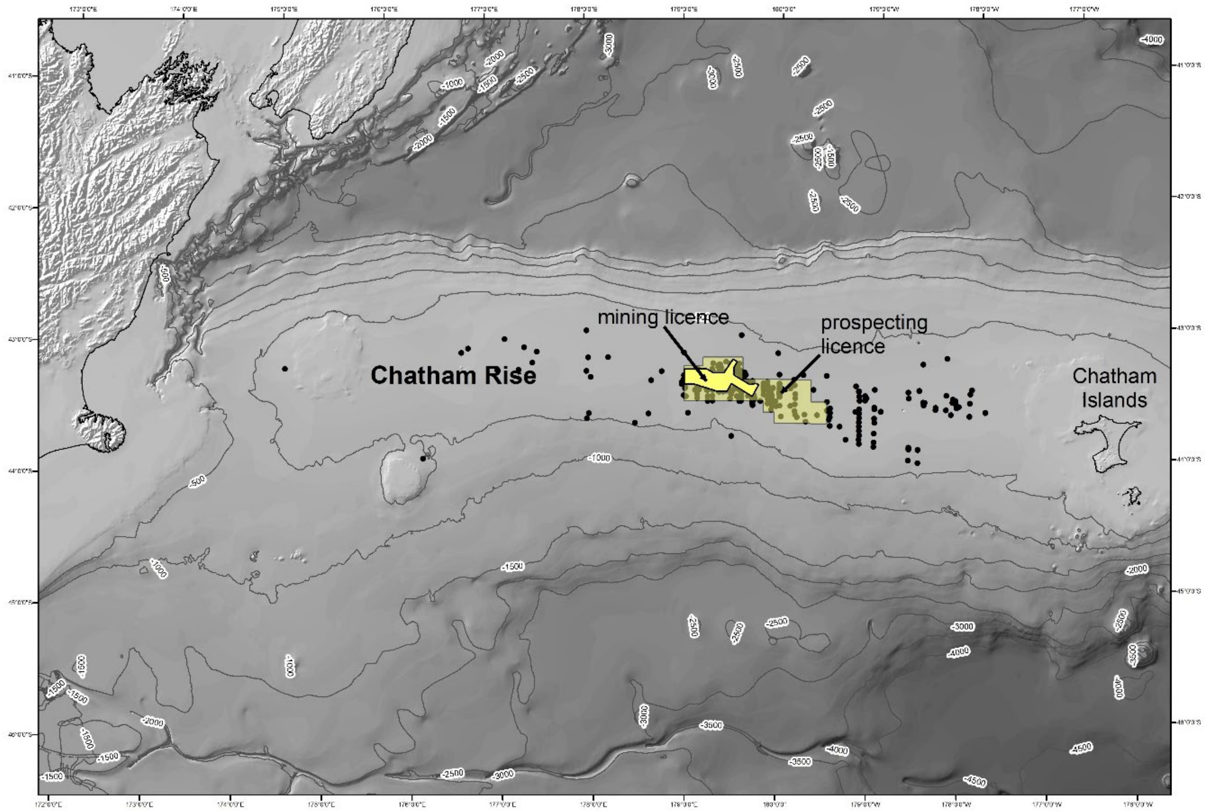

Figure 12.1 Samples that have recovered phosphorite from the Chatham Rise (black dots). The locations of CRP's prospecting and mining licences, covering the greatest concentration of the resource, are indicated (after Wood and Falconer [2016]).

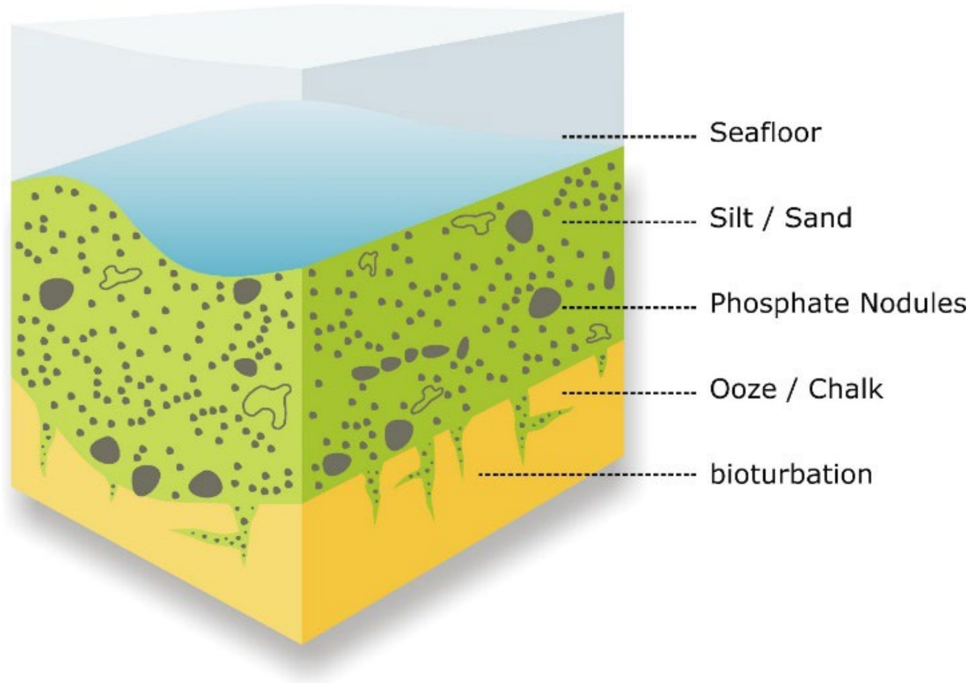

Figure 12.2 Schematic cross-section illustrating the distribution of phosphorite in the decimetre-thick silty sand layer overlying the older chalk layer (after CRP [2014]).

Resources: Sterk (2014) reported a global JORC Inferred Mineral Resource totalling 80 million m^3 at an average grade of 290 kg/m^3 at a cut-off grade of 100 kg/m^3 for a total contained 23.4 Mt of phosphorite.

12.3 Glauconite

The central Chatham Rise has significant concentrations of glauconite (Lawless 2012; Nelson et al. 2012) in addition to the phosphorite nodules previously described (Figure 12.3). The glauconite pellets formed 5–6 Ma due to increased primary biological productivity associated with upwelling along the Chatham Rise. The lack of subsequent sedimentation on the Chatham Rise allowed the modern deposit to form by the re-working of this material.

The sediment layer containing the mineral is estimated to have glauconite concentrations of 10–80 wt%, to be 10–200 cm thick and to cover an area of more than 4500 km^2. The area of greatest concentration lies westwards of the greatest concentration of phosphorite nodules (Figure 12.1). A conservative estimate of the size of the glauconite resource on the central Chatham Rise is of the order of 2 Bt (Lawless et al. 2011; Lawless 2012).

Glauconite has been described from other parts of New Zealand's offshore territory (e.g. Payne et al. 2010), but none are as well explored as the Chatham Rise deposit.

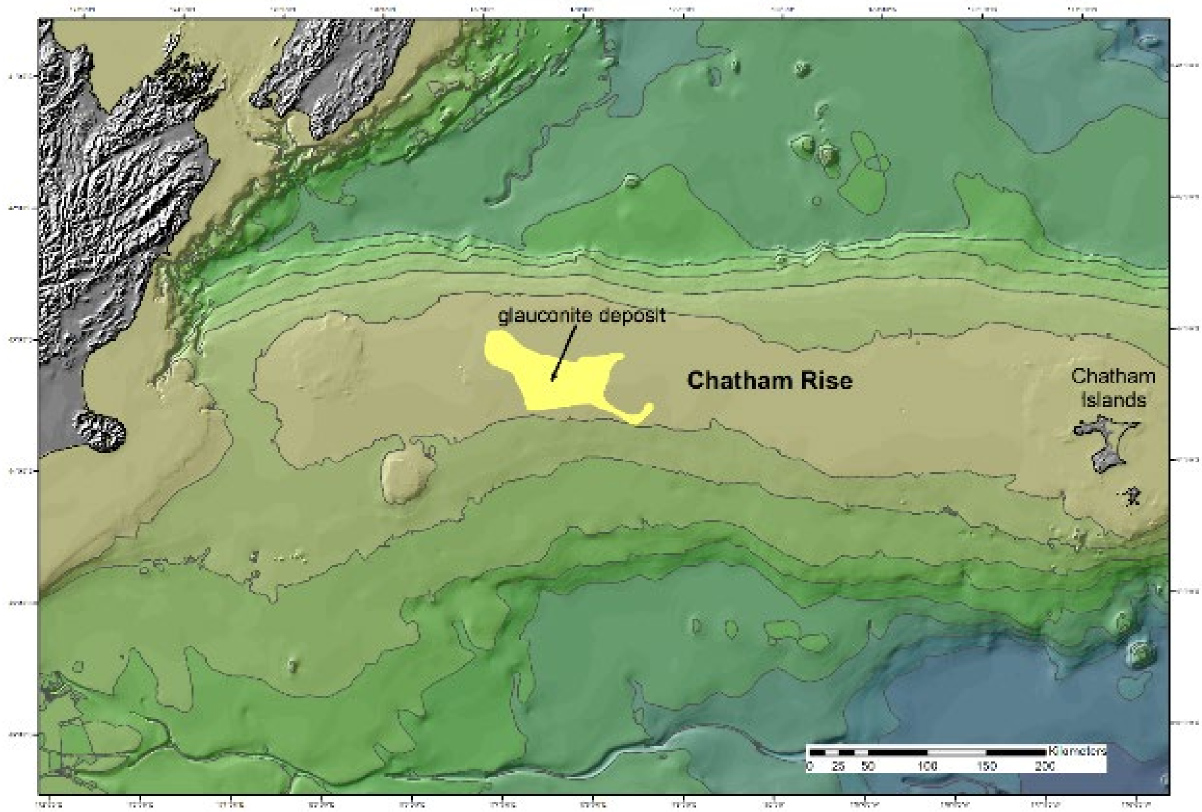

Figure 12.3 Area of greatest glauconite concentration across the central Chatham Rise (after Wood [2016], adapted from Lawless [2012]).

13.0 AN INTERNATIONAL EXPLORATION DESTINATION

Mineral exploration in New Zealand, especially for metallic minerals, relies on investment from overseas. Therefore, to maintain or increase the level of mineral exploration with a flow of overseas investment, New Zealand must continue to elevate its mineral prospectivity ranking in relation to other potential global exploration destinations.

13.1 New Zealand's International Ranking

Perceptions of the exploration investment attractiveness of mining jurisdictions (countries, states and provinces) around the world are tracked by the Canadian Fraser Institute Annual Surveys of Mining Companies (Figure 13.1). The survey includes three key indices:

- The Policy Perception Index (PPI) "serves as a report card to governments on how attractive their policies are from the point of view of an exploration manager" (Mejía and Aliakbari 2024).
- The Investment Attractiveness Index (IAI) measures whether a jurisdiction's mineral potential under the current policy environment encourages or discourages exploration.
- The Best Practices Mineral Potential Index (BPMPI) measures perceived 'pure' mineral potential.

In 2023, New Zealand ranked 50th out of 86 for PPI, 43rd out of 86 for IAI and 30th out of 58 for BPMPI (Mejía and Aliakbari 2024). The survey results show that past efforts to promote New Zealand's mineral potential have been effective in temporarily raising the IAI and PPI prospectivity scores. The dramatic improvement in all of the indicators in 2023 coincides with a likely change in government policies towards minerals investment, the well-publicised gold discoveries at Wharekirauponga (Coromandel Peninsula) and Rise & Shine (Otago) and emerging mining operations on the West Coast of the South Island for gold and mineral sands.

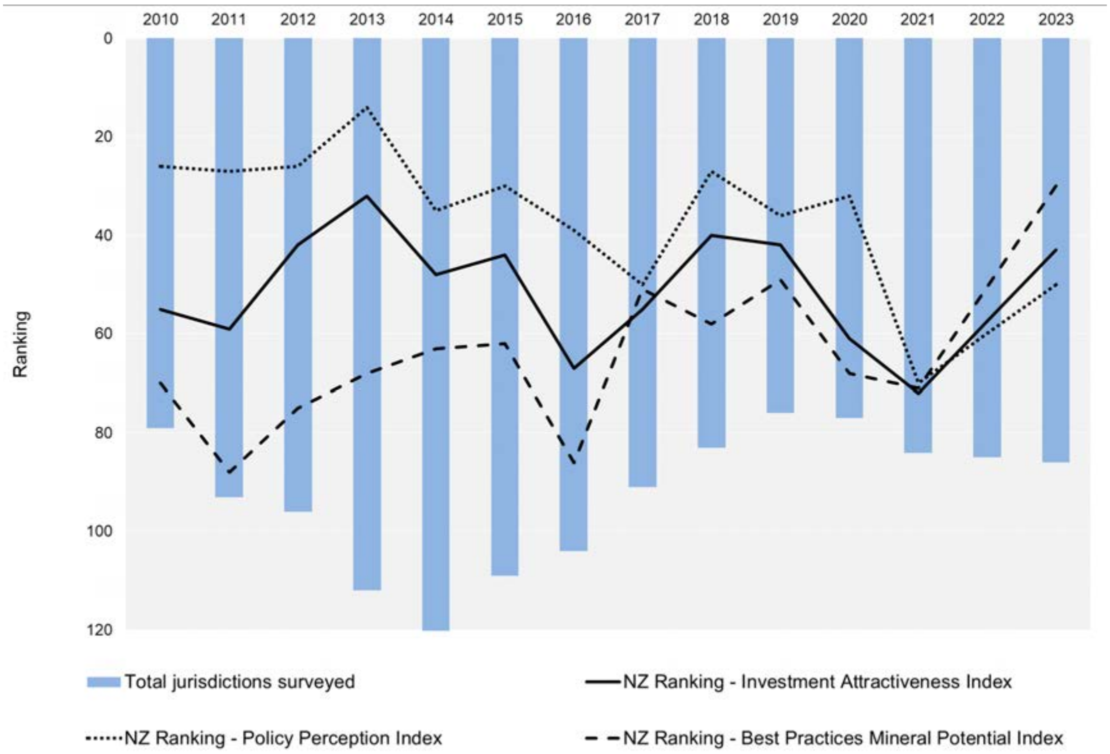

Figure 13.1 New Zealand's Fraser Institute Ranking, 2010–2023, with a ranking of 1 being best and the highest number worst. New Zealand was absent from the ranking in 2022, so the three index traces have been straight-lined between 2021 and 2023.

14.0 REALISATION OF NEW ZEALAND'S MINERAL POTENTIAL

14.1 Strengths and Weaknesses of New Zealand's Mineral Potential

New Zealand's technical strengths as an exploration destination include:

- The presence of a wide variety of different minerals and mineral deposit types resulting from active tectonics.
- A natural laboratory of modern analogues that demonstrate mineral formation processes, for example, geothermal systems for epithermal gold deposits and hydrothermal systems in the Southern Alps for orogenic gold deposits.
- World-class gold mines at Waihi and Macraes.
- World-class resources in North Island titanomagnetite and South Island ilmenite heavy-mineral sands.
- JORC-compliant resources of about 10 million ounces of gold, and at least 700 Mt of iron ore in onshore and offshore deposits.
- Availability of digital data for mineral exploration and management:
  - NZP&M online mineral exploration report library.
  - Geological maps compiled for 1:250,000 and 1:1,000,000 scales.
  - Airborne geophysical surveys over the most prospective regions.
  - Soil geochemical mapping over some prospective regions.
  - GERM national mineral deposit inventory database (Christie and Rattenbury 2016).
  - REGCHEM and other geochemical databases with partial or national coverage (Christie and Stewart 2016).
  - PETLAB rock catalogue with some geochemical and age-dating coverage (Strong et al. 2016).
- The Featherston National Core Store of exploration drill core and samples.
- Published prospectivity studies on orogenic gold, epithermal gold, lithium, REE, nickel and cobalt, copper and aggregate.
- Published mineral resource assessments for New Zealand, as well as the Northland, Coromandel and West Coast regions.

New Zealand's weaknesses as an exploration destination include:

- International perception of New Zealand's mineral prospectivity, for example, the Fraser Institute survey.
- Only partial coverage of New Zealand with modern airborne geophysical and soil geochemistry data.
- Reduced minerals research activity in New Zealand research organisations following reduction in funding focused on minerals research, resulting in loss of capability.
- The absence of a modern national minerals research strategy to update the NZMIA (2002) and Straterra (2012) strategies that provided guides to research priorities.
- Region-wide digital data useful for exploration is accessed from several sources, instead of the situation in many countries where it is easily accessible from one source.
- Public perceptions of minerals exploration and mining with concerns of perceived potential negative social, economic and environmental effects of new mining operations.

- A lack of awareness of the potential value of the resources, including by local government agencies.
- Limited post-processing and refining capability in New Zealand, with value-add work generally outsourced overseas (e.g. REE from heavy-mineral sands).

14.2 Mining and the Environment

Many of New Zealand's mineral resources coincide, because of the geology and tectonics, with areas of natural beauty, significant wilderness and conservation land, or with other land-use values (e.g. tourism, recreation). As a result of New Zealand's strong position on environmental protection, there are concerns about the potential impact on the natural environment through exploration and mining. Public perception of minerals exploration and mining in New Zealand are influenced by this rhetoric to some degree (Glassey et al. 2022, 2023).

There has been, and will continue to be, some environmental impact created by mining. The Resource Management Act 1991 (RMA) regulates to minimise impact by placing terms and conditions on mining and exploration operations. Most modern mining operations are relatively low impact or have been successfully rehabilitated. The land area affected by mining operations is significantly less than other modified land use, such as agriculture and plantation forestry. However, some detrimental effects can be ongoing (e.g. acid drainage), cumulative or delayed, for example, contaminating land and water (Clement et al. 2017). Environmental impacts of mining on the seabed are difficult to define and expensive to monitor.

Mining and environmental legislation, along with spatial land-use planning, have been identified as the two main policy tools that manage conflicts between mineral resource development and other land-use options (Gugerell et al. 2020).

14.3 Mining and Social Licence to Operate

Mine operators are tasked with monitoring the impacts of their operations in terms of economy, employment, community, property, health and wellbeing (Banarra 2014). Most companies have adopted Environmental, Social and Governance (ESG) sustainability reporting (Böhling et al. 2019).

A balanced approach for economic and environmental gains requires the long-term impacts of mining to be considered and managed carefully. A survey by Glassey et al. (2023) determined that mining of Critical Minerals for a net-zero carbon economy would be acceptable to New Zealanders, albeit with trade-offs regarding social equity and environmental protection.

Innovative extraction methods, multi-commodity mining and mine-waste mining have potentially less impact on the environment than traditional mining practise. Recycling, re-using and importing were common themes identified by Glassey et al. (2023) as alternatives to mining in New Zealand. However, Hund et al. (2020) estimate that recycling of minerals would only account for about 10% of the global demand by 2040.

14.4 Exploration and Development Opportunities to Replace Imports

New Zealand could increase its self-sufficiency in minerals that are essential to the New Zealand economy and additionally increase production of high-value commodities for earning export revenue. However, it is not possible to achieve 100% self-sufficiency because many commodities are imported in manufactured or processed forms that could not be duplicated by New Zealand industry because of limited local demand. Also, deposits of some mineral commodities may not be present in New Zealand for development. However, domestic opportunities include:

- Phosphate for fertiliser.
- Glauconite for potassium (potash) fertiliser.
- Sulfur for fertiliser
- Waikato coal for use at the Huntly Power station and Glenbrook steel mill.

14.5 Exploration and Development Opportunities for Export Revenue

There are some projects where sufficient exploration has already been conducted to establish a likelihood of development leading to export-revenue generation. Further exploration, resource definition, feasibility and/or environmental studies by industry may be required to advance these prospects to, and through, the mining consent and environmental consent processes.

1. Candidates with potential to advance in the short term include:
   - Hard-rock gold, for example, Wharekirauponga (Coromandel Peninsula), Snowy River (Blackwater; Reefton) and the Ophir-Bendigo project on the Rise & Shine shear zone in Otago.
   - Offshore titanomagnetite ironsand, for example,Taranaki.
   - West Coast heavy-mineral sands with ilmentite and co- and by-products of garnet, zircon and monazite (including REE), for example, Barrytown and Ruatapu.
   - Silica gravels in Southland for the manufacture of ferrosilicon and silicon metal.
2. Candidates with potential in the longer-term include:
   - Further hard-rock gold exploration, for example, Neavesville (Coromandel Peninsula) and Sams Creek (west Nelson).
   - Placer gold, for example, Grey River dredge and numerous targets for small operations on the West Coast and, to a lesser extent, in Marlborough, Otago and Southland.
   - Non-metallic minerals that have potential to increase exports if markets can be developed, for example, amorphous and processed silica, bentonite and halloysite clays, high-grade limestone, perlite, pumice and zeolite.

Looking to the longer-term, there is exploration potential in other mineral commodities and deposit types, including:

- Antimony – by-product of gold mining, for example, Auld Creek near Reefton.
- Copper (plus gold, zinc, barium and various trace metals), for example, Ohio Creek and other porphyry Cu prospects in the Coromandel Peninsula.
- Platinum group metals, for example, Longwood Range and Bluff in Southland.
- Tungsten deposits (e.g. Kirwin Hill) and as a by-product of gold mining (e.g. Macraes).
- Offshore polymetallic (Cu-Au-Zn-Ba) mineral deposits associated with seafloor hydrothermal systems, for example, Kermadec arc, Coville ridge and Havre Trough.
- Offshore seafloor ferromanganese nodules in the Southern Ocean.

15.0 RECOMMENDATIONS FOR FUTURE WORK

National mineral research strategies were developed by NZMIA (2002) and a draft version form by Straterra (2012). Some aims of the research strategies, such as airborne geophysical surveys and regional geochemical surveys, have since been partially fulfilled by industry and government. However, the development of a new national minerals research strategy would be timely following the release of the Critical Minerals List.

Steps that will facilitate exploration, with some potential broad research topics, are suggested below. A more detailed suite suggested by Christie (2019) to aid epithermal gold exploration is listed in Table 15.1.

1. Establish New Zealand's mineral wealth potential by undertaking a geologic and economic assessment to quantify the current known and estimated undiscovered mineral resources and their potential value, revisiting and expanding the study by Christie and Brathwaite (1999) and utilising 25 years of new information, including prospectivity studies and resource assessments.
2. Develop a new national minerals research strategy following the release of the Critical Minerals List.
3. Undertake new scientific research to demonstrate new mineral potential:
    a. Green and critical mineral studies (e.g. for lithium, nickel, platinum group metals and REE) to advance understanding of New Zealand's endowment.
    b. 4D evaluation of regional metallogenesis of specific districts and regions in terms of tectonic setting, geological and structural evolution, genesis of metalliferous plutons and potential fertility of source rocks, with recognition of the influences and controls of these parameters on the formation of mineral deposits. This would be assisted by new crustal-scale geophysical surveys.
    c. Identify metal sources, transport pathways and deposition mechanisms for mineral-deposit formation.
    d. Identify footprints and vectors of key mineral-deposit types to characterise exploration targets and their deposit architecture.
    e. Identify aggregate and sand sources closer to markets to reduce transport-related costs and carbon emissions (McIlrath and Harris 2024). These would expand on work by Hill and Chilton (2024a–e).
    f. Undertake materials research to develop new uses of minerals and greater share of the value chain in New Zealand, for example, current studies on ironsand for inductive power charging of electric vehicles and ultramafic rocks as CO_2 sinks and sources of natural hydrogen.
4. Encourage research and exploration of New Zealand's offshore resources to investigate their potential, including a holistic overview of prospective seafloor hydrothermal systems for their massive sulfide potential (Cu-Au-Zn-Ba etc).
5. Streamline access to key mineral exploration datasets and relevant research and adapt international minerals information management strategies, standards and tools for optimal data exchange.

Table 15.1 Examples of future research that would benefit exploration for epithermal Au-Ag deposits in New Zealand (after Christie et al. [2019]).

Research Topic	Research Sub-Topic
Geological Topics	
Refinement in age control of host rocks and mineralisation	Re-Os of sulfide minerals, Ar-Ar analyses of alteration minerals and Ar-Ar and U-Pb zircon analyses of host rocks.
Refinement of geochemical and mineralogical footprints and vectors	• Geochemical signatures and element dispersion models. • Adularia occurrence and abundance as vector. • NH_4-mineral vector. • Mineral chemistry vectors, for example, chlorite chemistry.
Structural localisation of deposits and structural controls on mineral deposition	Regional and deposit scale studies in Northland and the Taupō Volcanic Zone.
Lithological controls on mineralisation	• Volcanic facies and proximity to volcanic centres. • Identify intrusive host rocks (e.g. dacite at Golden Cross and rhyolite dike at Komata). • Compare lava versus pyroclastic versus intrusive rocks as host for veins.
Models for exploration under cover	• Structural mapping with modelling in 3D. • 3D modelling of cover thickness.
Origin of mineralising components and regional fertility	• Development of local 3D epithermal models from source to surface coupled with seismic and resistivity (e.g. magnetotellutic) interpretations of deep environment. • Fingerprint magma or greywacke basement sources of components by isotope analyses, coupled with analyses of key trace elements in unaltered rocks. • Characterise source magmas (melt inclusion studies) and their spatial distribution.
Exploration Technique Topics	
Hydrothermal alteration mineral analysis	• Hyperspectral SWIR continuous drill core scanning (e.g. Hylogger and Corescan). • Adularia mapping and quantification by pXRD and pXRF. • Automated SEM mineral recognition (e.g. TIMA) for alteration types and quantification.
Ore mineral analysis	Automated SEM mineral recognition (e.g. QEMSCAN) of ore minerals in individual veins and lateral and vertical spatial variation.
Exploration under cover	Geochemical and geophysical techniques to see through cover.
Exploration of deep structure	Testing of passive seismic techniques.
Geophysical surveys using drones	Conduct trial surveys when suitable equipment becomes available.

16.0 CONCLUSIONS

1. New Zealand has major quantified resources of gold, silver, titanomagnetite ironsand (with vanadium), ilmenite heavy-mineral sand (with garnet, zircon, monazite and gold) and coal.
2. Gold exploration offers prospects for future high-value production from known resources. In addition, there is potential for new discoveries, particularly in the Coromandel Peninsula (including silver), West Coast and Otago. Past experience would suggest that, with an increase in the level of exploration, new mineable hard-rock deposits could be found.
3. Production of antimony and tungsten may be possible as a by-product of gold mining.
4. Large resources of heavy-mineral sands are present onshore and offshore of the west coast of New Zealand. Onshore, titanomagnetite ironsand is currently mined at Waikato North Head and Taharoa, and there is potential at other locations on the west coast of the North Island, for example, Aotea and Waipipi.
5. Vanadium concentrate is a current by-product of ironsand mining, and there may be potential for also producing a titanium concentrate.
6. Large resources of titanomagnetite ironsand have also been defined offshore, and a project near Pātea in Southern Taranaki has a Mining Permit but requires a Marine Consent from the Environmental Protection Agency.
7. The West Coast beaches of the South Island have very large resources of heavy-mineral sands, with mining at Westport producing a concentrate for export and separation of ilmenite, garnet, zircon, monazite (with REE) and gold. Similar heavy-mineral sand mining operations are planned at Barrytown and at Ruatapu south of Hokitika. The Ruatapu sands are particularly rich in garnet, and high concentrations of garnet are also present in sands at Bruce Bay and Hunts Beach in central Westland.
8. Resources of phosphorite have been defined on the Chatham Rise east of Christchurch. They have potential for use as fertiliser, and ore processing may yield by-product minerals such as REE. The operation has a Mining Permit but requires a Marine Consent from the Environmental Protection Agency. Potential resources of phosphorite onshore in the eastern South Island are being explored.
9. There is near-shore potential for placer gold associated with heavy-mineral sands near Hokitika.
10. Offshore, the Kermadec Arc, northeast of the North Island, has seafloor Cu-Au-rich massive sulfide deposits, and the margin of the Campbell Plateau in the Southern Ocean, southeast of the South Island, has an extensive seafloor field of polymetallic ferromanganese nodules.
11. PGM prospects in the South Island have attracted reconnaissance exploration and have potential for more detailed exploration.
12. There is likely to be an increase in exploration for ‘green’ minerals required by renewable energy generation and storage, for example, lithium, REE, nickel, copper, cobalt and silicon. Many of these minerals have had minimal exploration in the past and more work is required to assess their potential in New Zealand. The forthcoming development of a Critical Minerals List should help in developing priorities and targets for exploration.
13. Increasing metal prices over the next few years could make exploration in New Zealand for many metals economically viable, including: copper, nickel, tin, tungsten and zinc-lead.

14. New Zealand has a variety of non-metallic industrial minerals, including high-grade silica sand, amorphous silica, bentonite, diatomite, dolomite, halloysite, limestone and lime, perlite, pumice, serpentinite, zeolite and a variety of brick clays. Most production is consumed locally, with the exception of halloysite, which is exported to world-wide ceramics markets. Over the last few years, there has been increasing production of amorphous silica, zeolite and, more recently, diatomite from the Taupō–Rotorua area. There are large resources of these commodities in the central North Island and also of diatomite in Otago. Development of new applications could increase their potential for export.
15. High-grade limestone is widely quarried for cement manufacture and for production of agricultural lime, burnt lime (quicklime, unslaked lime) and hydrated lime (slaked lime). There is potential to increase exports of high-grade limestone for industrial chemical applications.
16. Resources of many currently produced low-value or bulk minerals and aggregate are not well quantified but are generally large and sufficient to meet future local demand, provided that access can be maintained close to markets for affordable transport costs.

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