Mineral Commodity Report 21 - Limestone, marble and dolomite

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Origin of names

The name limestone is from *limus* (Latin) for mud. The name marble is derived from the Latin *marmor* and from Greek, which means a shining stone. Strictly the name applies to a granular, crystalline limestone, but it is also applied to a hard limestone that can be polished. Dolomite was named in 1794 after D. de Dolomieu, a French mineralogist.

History

Since early history, limestone has been used to produce lime for use as a cementing material and in agriculture as a soil conditioner and fertiliser. Lime mortar may have been used as long ago as 14,000 years in eastern Turkey, and more certainly in the Near East and the former Yugoslavia from about 8,000 years ago, and in Mesopotamia about 4,500 years ago (Miller, 1999). Hydraulic, cementitious mixtures have been used for the last 5,000 years, with the Egyptians incorporating lime and burnt gypsum mortars in the construction of the pyramids. Two thousand years ago, the Romans mixed sand with finely ground lime and with volcanic ash from nearby Pozzuoli to produce a strong, salt water resistant cement for use in the construction of block stone buildings. Some of these structures, such as aqueducts, theatres and baths still stand in Italy, Britain, France, Spain and Turkey. In the 1750s, John Smeaton, rediscovered hydraulic cement, and in the early 1800s, patents were issued to several individuals for the material. Portland Cement, the cement used today, was invented and patented by Joseph Aspdin in 1824, and named for the resemblance of the cement when set to Portland stone, a limestone from the Isle of Portland.

Limestone has also been used as a building stone from ancient times. For example, the pyramids at Gizeh, Egypt, were constructed more than 5,000 years ago from nummulitic limestone derived from nearby sources (Great Pyramid 2,700–2,600 BC). Since Renaissance time, soil acidity has been reduced by the addition of lime. Lime was first used between 1200 and 1300 AD to paint animal pelts for the easy removal of the hair.

Marble has been used for sculpture since about 6,000 years ago (Cycladian Islands, Greece) and for the construction of buildings since about 2,500 years ago, when temples around the Parthenon in Athens were constructed. The main varieties prized by the early Greek sculptors and builders were Pentelic marble from quarries of Mount Pentelikon in Attica (Greece), and Parian marble quarried chiefly at Mount Parpessa on the Grecian island of Paros. The Romans and Renaissance Italians used Carrara marble quarried in the region of Carrara, Massa, and Serravezza in Italy.

Minerals and properties

Limestone is a rock that contains a significant quantity of calcium carbonate ($CaCO_3$, calcite; Figure 1 and Table 1). The remaining constituents may include other carbonate minerals such as dolomite magnesite, *$(CaMg(CO_3)_2$* and less commonly aragonite ($CaCO_3$). Calcite and aragonite have the same chemical formula, but different crystal structures, orthorhombic and trigonal respectively. Pure calcite, dolomite, and aragonite are clear or white minerals. However, with impurities, such as sand, clay, iron oxides and hydroxides, and organic materials, the rock can take on a variety of colours. Consequently, limestone is commonly light coloured, usually tan or grey, although it has been found in almost every colour. Limestone is usually not very hard, and its strength depends upon the degree of cementation or recrystallisation.

	Formula	Colour	Hardness	Density	Lustre	Crystal system	Form	Transparency	Fracture
Calcite	$CaCO_3$	white, yellow, red, brownish	3	2.6-2.7	vitreous, pearly	trigonal	rhombohedral, columnar, tabular	transparent, translucent	brittle
Aragonite	$CaCO_3$	white, grey, yellowish, bluish green, red, black, multicoloured	3.5-4	2.6-2.8	vitreous	orthorhombic	fine-coarse grained, massive veins	semi-translucent	brittle
Dolomite	$CaMg(CO_3)_2$	colourless, white, pink, brown, black, green	3.5-4	3	vitreous, pearly	trigonal	rhombohedral, hexagonal	transparent, translucent	brittle, friable

Table 1: Properties of calcite, aragonite and dolomite.

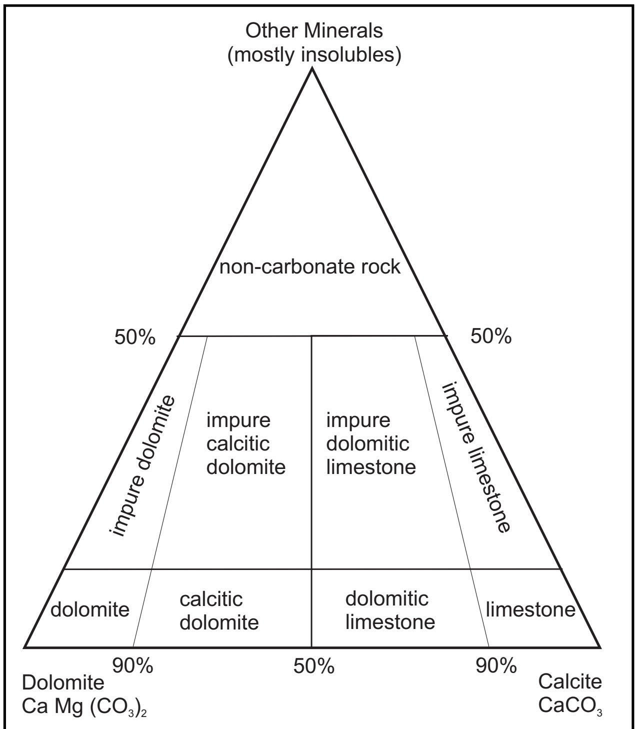

Figure 1: Mineralogical classification of carbonate rocks (after Carr et al., 1994).

Marble is metamorphosed limestone and therefore consists mostly of calcite, although some marbles contain varying proportions of dolomite or calc-silicate minerals. Marble is a crystalline rock, usually white, but mineral impurities add colour in variegated patterns. For example, hematite adds red, limonite - yellow, serpentine - green and diopside - blue. Marble is semi-translucent, fine- to coarse-grained and generally massive. It is capable of taking a high polish and is used principally for building stone, monuments and statues.

Marble is durable in a dry atmosphere and when protected from rain, but its surface crumbles readily when exposed to a moist, acid atmosphere. The purest form of marble is statuary marble, which is white with visible crystalline structure. The distinctive lustre of statuary marble is caused by light penetrating a short distance into the stone and then being reflected from the surfaces of inner crystals.

Dolomite is a rock consisting of the mineral dolomite, a calcium-magnesium carbonate. Dolomite is generally slightly harder and denser than limestone. Like limestone and marble, it is generally white, grey or buff in colour, but can have other colours related to impurities.

Formation

Naturally occurring calcium carbonate occurs in three common forms – chalk, limestone and marble.

Chalk is a soft rock consisting predominantly of coccoliths (microscopic shells of marine organisms). Chalk occurs over large areas of northern Europe, but is uncommon in the southern hemisphere.

Limestone is a sedimentary rock that constitutes approximately 10% of the sedimentary rocks exposed on the earth's surface. It is formed by the accumulation of shells and shell fragments, or by direct crystallisation of calcium carbonate from water. Most limestones are of marine origin, formed in shallow water, typically in depths of less than 20 m. A few were formed in lagoons or in fresh water. Limestones can be grouped as constructional, shell and metamorphic types (Table 2).

Two processes of diagenesis are important in the formation of limestone. One is cementation, in which calcium carbonate precipitates in the pore space between the loose grains of sediment and binds them together into a hard compact rock. The other process involves the alteration of the minerals, such as the transformation of the crystal from aragonite to calcite (orthorhombic to trigonal), and the dolomitisation of calcite by absorption of magnesium from surrounding water.

Marble is formed by the metamorphism of limestone. If the limestone contains other materials such as sand and clay, the calcite will react with them to produce calc-silicate minerals such as tremolite, epidote, diopside, and grossular garnet.

Dolomite is generally formed from limestone by dolomitisation, a diagenetic process involving replacement of calcium in the calcite with magnesium. This may occur either soon after limestone deposition, by exchange with seawater, or after lithification by exchange with magnesium-bearing solutions. The process is partly a function of the permeability of the rocks and can therefore be very selective, giving rise to interbedded limestone and dolomite. Dolomite is also deposited as a primary mineral in some sedimentary environments, in hydrothermal veins, in cavities in carbonate rocks, and in various sedimentary rocks as a cement. Sedimentary environments for primary dolomite formation include supra-tidal flats (Bahamas) and hyper-saline lagoons where it is associated with the precipitates of calcite, aragonite, magnesium calcite, gypsum, and anhydrite. Hydrothermal dolomite occurs in veins associated with lead, zinc, or copper ores, as well as with fluorite and barite.

Uses

Chalk is restricted in its use because of its softness and tends to find applications that exploit this characteristic. In industry, chalk is processed to form whiting used in putty manufacture and in some paint, food and plastic applications. Locally it is used as an agricultural fertiliser.

Limestone is used in road and building construction, as an agricultural fertiliser and in various industrial applications.

Limestone is an important building stone used as dimension stone, or more commonly as crushed stone, or aggregate, for general building purposes, roadbeds and railway track ballast. As dimension stone, its relatively soft nature is advantageous for decorative carving.

Limestone, as lime, is used in agriculture as a soil conditioner and fertiliser. In these applications the term lime encompasses many products, including processed lime (burnt lime, slaked lime; Table 3), pulverised limestone and magnesian limestone. For agricultural purposes, there is no definitive specification of calcium carbonate content, but the higher the $CaCO_3$ content, the less needs to be applied. A figure of 70% $CaCO_3$ was used as a lower cut-off point for a road transport subsidy in New Zealand.

In industry, limestone is an essential raw material in the manufacture of cement, iron and steel. Portland cement is

	Type	Formation	Remarks	NZ Locality	NZ Uses
Constructional	Coral	Skeletal remains of carbonate-producing polyps that produce a solid, coherent mass of limestone that is wave and surf resistant.		Waitemata Formation near Auckland	
	Chemical	Chemical deposition from carbonate-rich water, in contact with air, flowing over the land surface to form calcareous sinter or travertine, and as stalagmites and stalactites in caves.	Travertine is a porous or compact limestone deposit formed by the deposition of calcium carbonate from ground and surface waters. It is usually very pure.	Hawkes Bay, Nelson, Otago	Agriculture, industrial
Shell	Broken shell	A winnowed mass of shells tightly pressed together.	An impure, sandy, muddy or pebbly limestone consisting of broken shell material, especially bivalves and barnacles. Hardness (i.e. cementation) is very variable.	Northland, Hawkes Bay, Wairarapa, Otago, Chatham Islands	Agriculture, road aggregate, lime stabilisation, river protection, building stone
	Coquina	A loosely compacted, winnowed mass of shells tightly pressed together.	A soft (friable) to moderately hard, pure to impure, porous rock consisting of barnacle plates and other broken shell material.	Hawkes Bay, Wairarapa	Agriculture, road aggregate, filler, cement, lime stabilisation
	Sandy	A hard, shelly, limestone that contains appreciable quantities of sand. It commonly grades into calcareous sandstone.		Canterbury, Westland, Otago	Protection works, agriculture
	Argillaceous or Muddy (Marl)	Either a fine calcareous limestone of clay-sized particles or a fine grained limestone containing almost 50% of clay particles.	An impure limestone containing a considerable amount of clay minerals.	Northland, East Cape, Hawkes Bay, Wairarapa, Nelson, Marlborough, Westland, Canterbury, Southland, Fiordland	Agriculture, cement, protection works
	Algal	Either largely of the lime-rich remains of calcium-secreting algae or a rock in which calcium-secreting algae have bound together fragments of lime.	A hard, dense rock composed predominantly of calcareous algae.	Wairarapa, Nelson, Westland, Southland	Cement, road aggregate, agriculture, quick lime, industrial
	Flinty		Amuri Limestone.	Wairarapa, Marlborough, North Canterbury	Agriculture
Metamorphic	Crystalline	Shell material recystallised to consist mainly of calcite and/or dolomite crystals and in which the original depositional texture is not recognisable.	A hard, dense rock, “marble” in some areas.	Northland, Waikato, Coromandel, Wairarapa, Nelson, Westland, North Canterbury, Otago, Southland, Chatham Islands	Cement, agriculture, paper, steel, fillers, road aggregate, protection works, building stone (Hanmer), burnt lime
	Marble	A granular, crystalline rock or calcite and/or dolomite crystals. Original sedimentary textures not recognisable.	A hard, coherent, dense rock that can take a polish.	Northland, Nelson, Canterbury, Fiordland, Stewart Island	Building stone

Table 2: Limestone types.

	Composition	Formation	Use
Limestone	$CaCO_3$	Sedimentary deposition, mainly of shells in seawater, minor chemical deposition in fresh water	Aggregate, agriculture, building stone, filler, cement making
Lime, quick lime, burnt lime	CaO	Produced by heating (calcining) low-grade limestone to above 1000°C to expel CO_2 and water	Steelmaking, paper pulp manufacture, or mortar, soil stabilisation, and in the cyanide process in gold and silver mining
Slaked lime	$Ca(OH)_2$	Formed by the addition of water to quick lime	Sugar industry, water treatment and leather tanning
Hydraulic lime	Impure limestone containing silica and alumina, usually in clay-sized grains	Produced by heating to form a cement that will harden under water	Cement for concrete emplaced under water

Table 3: Commercial types of limestone.

manufactured by calcination of a carefully proportioned mixture of calcium carbonate and aluminosilicate minerals. The raw materials used in this process usually are limestone or chalk, and clay, shale or marl.

The manufacturing process of Portland cement consists of:

- fine-grinding the raw materials to give a homogeneous mixture;
- burning or firing the mixture in a kiln to produce a clinker; and
- fine-grinding the clinker with the addition of gypsum to adjust the setting time.

The general processes in use are known as wet and dry, depending on whether the raw materials are ground and mixed in a wet or dry state.

When mixed with water, the anhydrous calcium silicates and other constituents in the Portland cement react chemically with the water, combining with it (hydration) and decomposing in it (hydrolysis), and hardening and developing strength.

Speciality cements are produced by adding materials to Portland cement during its manufacturing process or when making the concrete mixture, to change the handling and setting characteristics of the cement and increase the durability of the finished product (Ellicott, 2000). For example, the addition of microsilica produces durable high strength concrete; metakaolin produces concretes with less drying shrinkage and bleeding plus improved sulphate, acid and drying resistance.

In the production of iron, lime is used as a basic flux. It forms a fluid slag in which impurities, such as silicon, aluminium and sulphur dissolve leaving the iron relatively pure.

Limestone is also important in paper and glass making, numerous chemical processes, as a mineral filler in paint, plastics, rubber, asphalt and carpet backings, in water treatment, and as a dusting agent in coal mining to prevent fires.

High-purity limestone has application as ground calcium carbonate (GCC) and precipitated calcium carbonate (PCC). The principal consuming industries for white carbonate (GCC/PCC) fillers are paper, paint and polymers (plastics, rubber). With the trend to replace kaolin with GCC/PCC for paper filling and coating, the demand for high-purity limestone will increase.

Lime is important in many water-treatment processes such as water softening, purification and to neutralise acid water.

Limestone deposits can be very permeable through joints and caverns, and as a consequence form reservoir space for oil, gas and water resources. Limestone and dolomite also react with metal-bearing hydrothermal fluids and host lead-zinc and copper sulphide deposits of the skarn, replacement, sediment hosted, and Mississippi Valley types (Christie and Brathwaite, 1994; Christie and Brathwaite, 1995).

Marble is used for building stone, sculpture, interior decoration, monuments and graveyard headstones. When finely ground, it is used as a whiting material in toothpaste, paint and paper and as a substitute for some limestone applications.

Dolomite is used mainly as a fertiliser for spreading on magnesium-deficient soils. Dead-burned dolomite is important as a refractory material for lining the furnaces and kilns used in many metallurgical operations.

Processing

Production technology varies depending on end use. Hard limestone and marble for construction purposes are usually cut to size on the quarry site. Agricultural lime is crushed and screened to size to suit the method of distribution e.g. hand, truck or aircraft.

Quick lime (CaO, lime or burnt-lime) is produced by heating (calcining) low-grade limestone to above 1000°C to expel CO_2 and water. Quick lime is converted to the more stable slaked lime $Ca(OH)_2$ by the addition of water, in which form it is more easily transported. Hydraulic lime is impure limestone containing silica and alumina, usually in clay-sized grains. On heating, it forms a cement that will set under water.

For fillers, the limestone or marble is crushed, then washed to remove mud or other colour-degrading material. In some instances it may then be sorted to remove pieces of darker coloured rock. Subsequent crushing steps produce a feed for wet or dry grinding circuits. Some grinding circuits incorporate a colour beneficiation step, usually selective flotation, which rejects undesirable minerals.

Surface treated limestone is prepared by treatment with organic chemicals and is used in the manufacture of paint, plastics and rubber.

World production

Extensive deposits of limestone are located in Brazil, China, Germany, Italy, Mexico, Great Britain, and in the United States, in Georgia, Tennessee, Vermont, Alabama, and Colorado. Accurate data on lime production is difficult to obtain, especially where good data collection is not practised. However, Miller (1999) estimated world lime production of 116 Mt in 1998 (Table 4). The reserves and reserve base are adequate for the fourteen countries listed.

Belgium	1.75
Brazil	5.7
Canada	2.51
China	21
France	2.8
Germany	7.6
Italy	3.5
Japan (quick lime only)	8.1
Mexico	6.6
Poland	2.5
Romania	1.7
South Africa (sales)	1.5
United Kingdom	2.5
United States	20.1
Other countries	28.1
World total	**116**

Table 4: World lime production (Mt) (after Miller, 2000).

New Zealand occurrence

Limestone

The limestone resources of New Zealand have been reviewed previously by Morgan (1919), Willett (1974), MacFarlan and Barry (1991) and Thompson et al. (1995), and regional reports were provided by Bishop (1966; Gisborne), Cooper (1966; Otago), Waterhouse (1966; Auckland), Warren (1969; Canterbury and southern Marlborough), Moore (1975; Wairarapa), Moore and Belliss (1979; southern Hawkes Bay), Moore and Hatton (1985; northern and central Hawkes Bay), and in the series of Geological Resource Maps of New Zealand (e.g. Christie et al. 1994), from which the following regional descriptions are largely drawn.

The distribution of limestone is shown in Figures 2-4, based on maps prepared by Turnbull and Smith Lyttle (1999) from the digital version of the 1:1 million geological map of New Zealand. Areas of rock described as containing limestone or marble were selected from the geological database, but it should be noted that these areas may also contain other rock types.

Limestone is abundant in many places in New Zealand, and its distribution can be summarised according to age. The main localities are in Northland, Waikato, southern Hawkes Bay, Wairarapa, Northwest Nelson, Westland, Canterbury and Southland (Figures 2-4). The oldest calcium carbonate deposits are marble formations of mainly Ordovician age in Northwest Nelson and Fiordland. The marble at Marble Bay in Northland and at Lee River in east Nelson is Permian in age, at Kakahu Bush it is Carboniferous, and at Dunback it is Triassic.

The limestone in Northland and the central North Island is mostly Oligocene in age. The Northland limestone is mainly argillaceous, although there are occurrences of crystalline limestone at Waiomio, near Whangarei and at Ruawai. South of Auckland, the limestone between Waikato Heads and New Plymouth is crystalline, and near Te Kuiti there is abundant high-grade limestone.

On the east coast of the North Island, from north of Gisborne to southern Wairarapa, the limestone is mainly shelly limestone and calcareous sandstone of Pliocene to early Quaternary age.

In the South Island, the bulk of the limestone is Eocene to Oligocene in age. An older limestone is the Late Cretaceous to early Oligocene Amuri Limestone, which occurs as a chalky to flinty limestone in Marlborough and north Canterbury. The extensive limestone in the Oamaru district is Eocene to Oligocene in age. The Oligocene limestone extends from near Takaka to South Westland in the west, and from North Canterbury to the Waiau Valley in Southland in the east. At Cape Foulwind, it is very high grade (92-98% $CaCO_3$). In Canterbury, Hanmer Marble, a pink-brown-cream, fossiliferous, hard limestone is exposed in the Waiau Gorge, whereas the limestone at Mt Somers is fairly soft. The commercial deposits of limestone in the Oreti and Waiau valleys of Southland are Oligocene to Miocene in age.

Quaternary age deposits consist of loosely compacted shell beds at Doubtless Bay in Northland and at Miranda on the Firth of Thames.

In addition to the commercial uses of limestone, limestone is important as an in-ground resource by providing many land forms that are important to New Zealand's tourist industry, including interesting outcrops such as blocks (Castle Hill; Figure 5), pancake rocks (e.g. Punakaiki), cliffs, bluffs, scarps (e.g. Te Mata Peak, Figure 6), karst topography and caves (e.g. Waitomo Caves, Harwoods Hole, Te Anau Au Caves).

The occurrence of chalk is rare in New Zealand, although an impure deposit occurs near Oxford in Canterbury where it is used as an agricultural lime.

Northland

Two distinct limestone units are present in Northland, namely the *crystalline* Whangarei Limestone and the

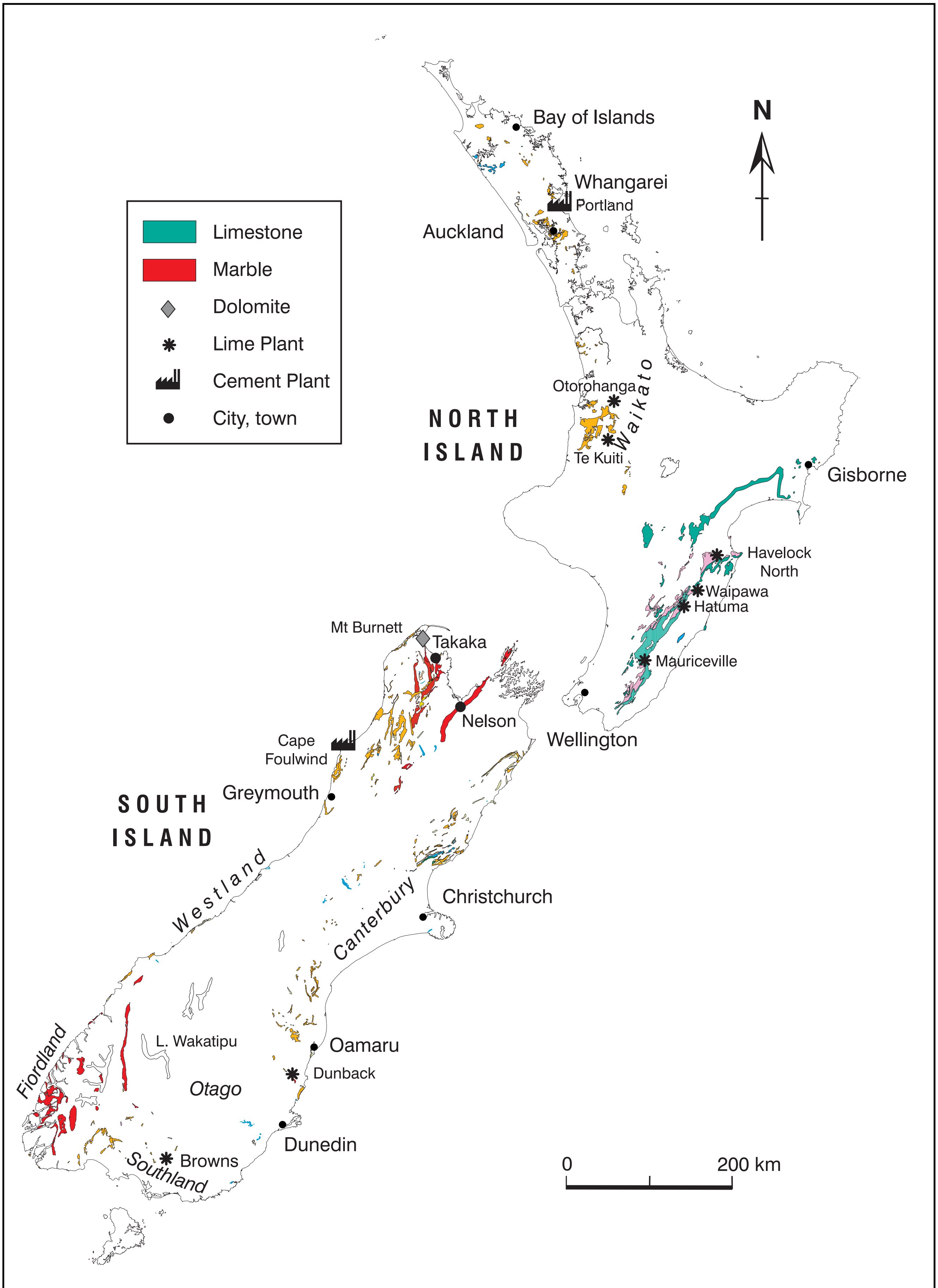

Figure 2: Location of limestone, marble and dolomite deposits in New Zealand.

argillaceous Mahurangi Limestone. The Whangarei Limestone is Oligocene in age and lies along the eastern side of Northland from the Bay of Islands to south of Whangarei. It is of shallow water origin, consisting mainly

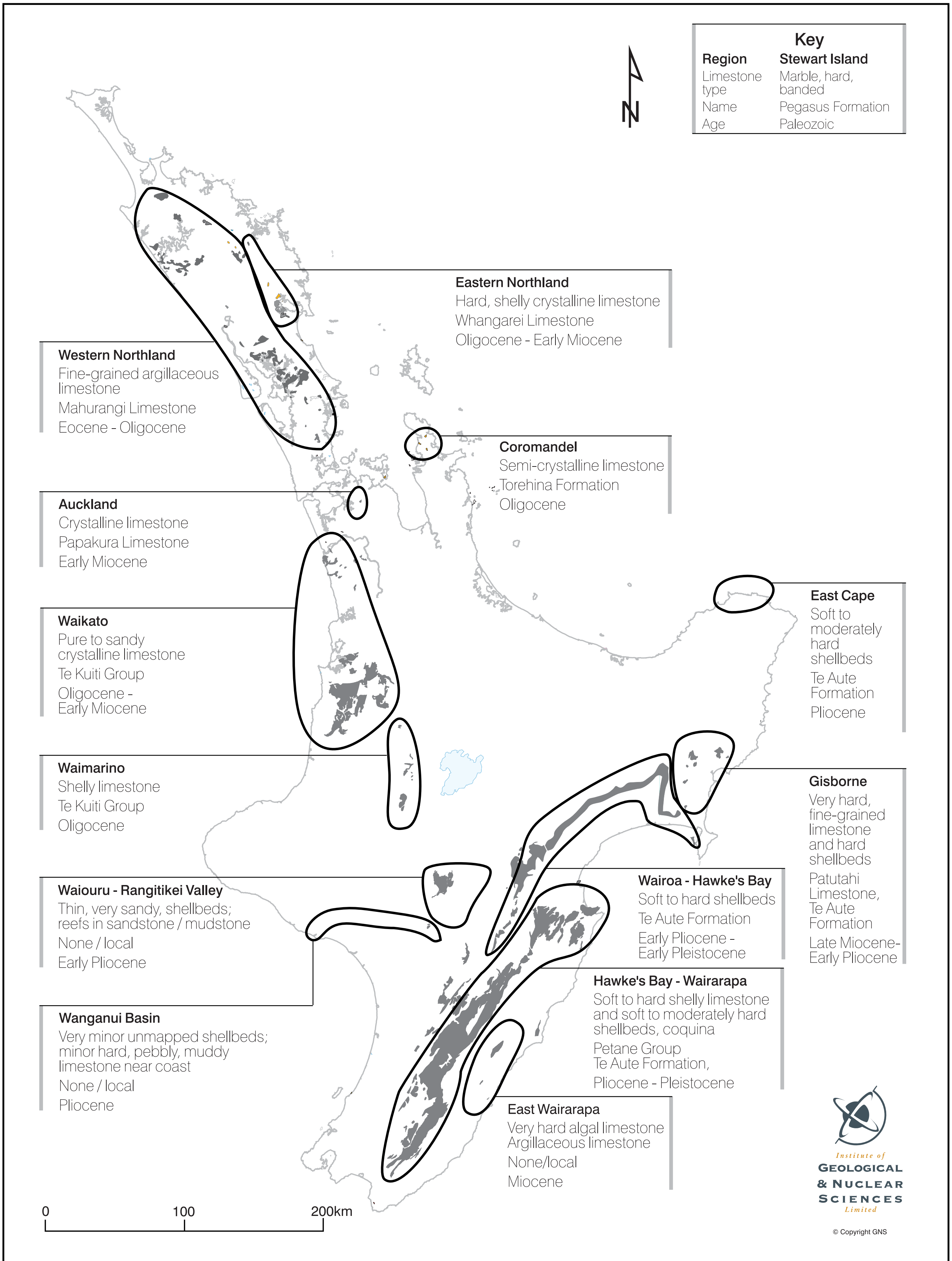

Figure 3: North Island limestones (modified after Turnbull and Smith Lyttle 1999).

of bryozoan, echinoid and foraminifera debris. The $CaCO_3$ content ranges from 75% to 95%. In general, it lies either directly on basement rocks or on the nearby coal measures.

The argillaceous Mahurangi Limestone, of Oligocene age, lies within the Northland Allochthon and is widespread throughout Northland to as far south as Albany. It consists

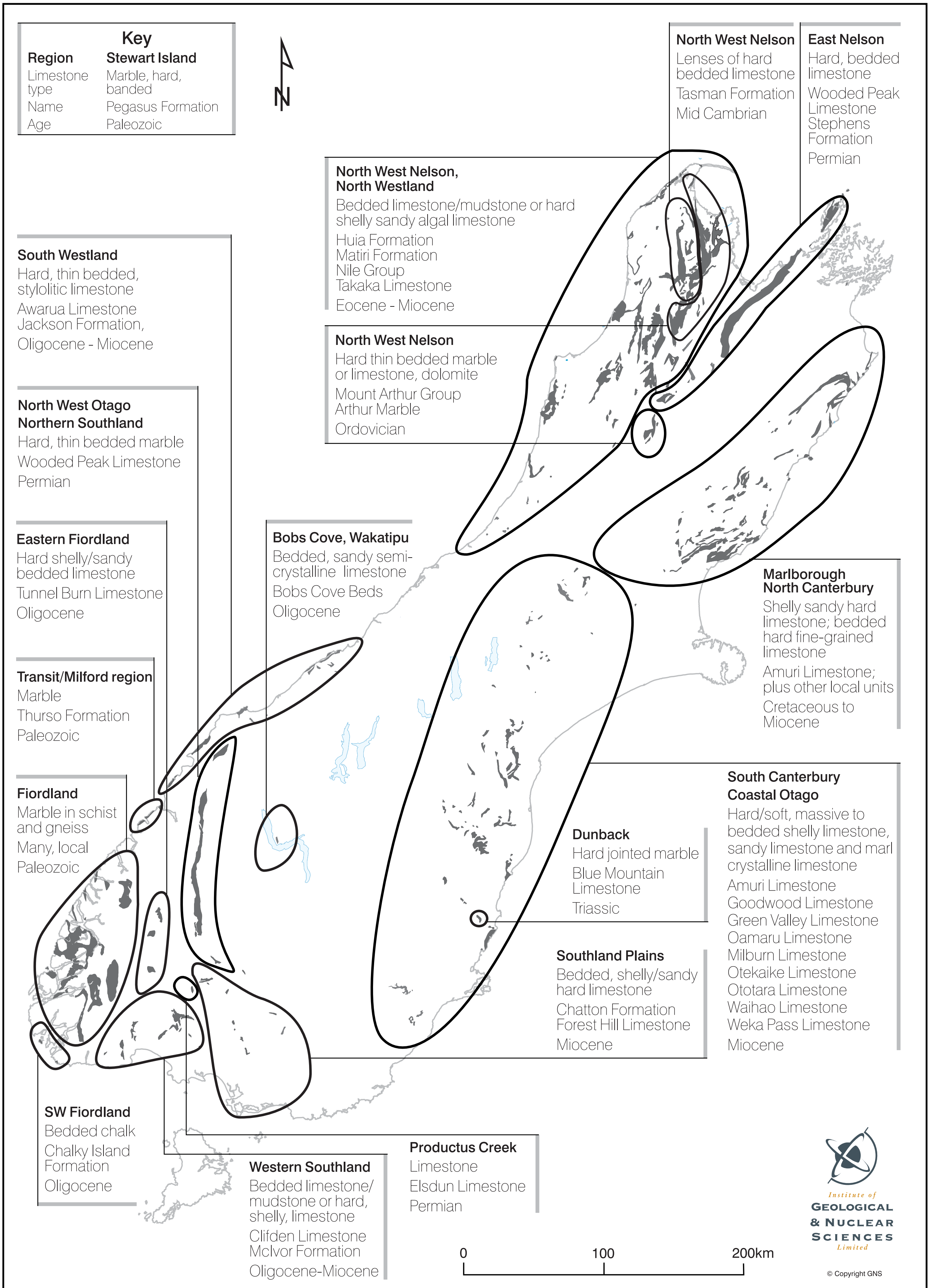

Figure 4: South Island limestones (modified after Turnbull and Smith Lyttle 1999).

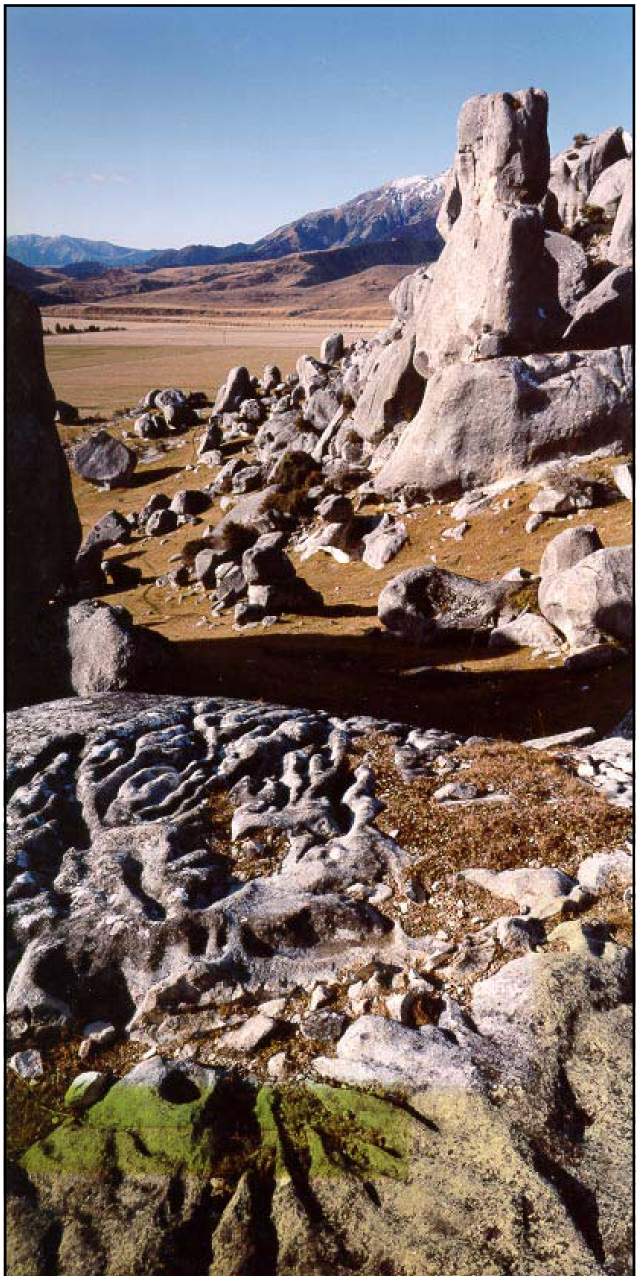
Figure 5: Outcrop of limestone at Castle Hill, west Canterbury, Photo: Lloyd Homer.

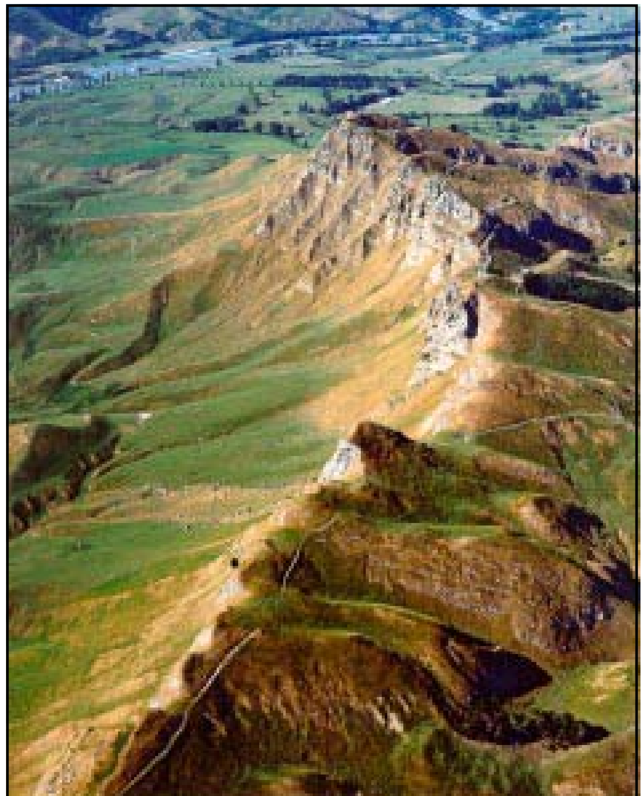
Figure 6: Limestone bluffs at Te Mata Peak, Havelock North. Photo: Lloyd Homer.

mainly of micritic coccoliths and foraminifera of bathyal origin, and contains a significant clay fraction. The $CaCO_3$ content varies between 40% and 76%.

Both types of limestone are used in the manufacture of cement and for agricultural fertiliser. Mahurangi Limestone is also used as a road aggregate, especially in areas where other aggregate materials of better quality are scarce. In 1999, 867,840 t of limestone and marl were produced for cement manufacture, 290,850 t for agriculture, and 54,120 t for industry in the Northland region.

Cement manufacturing started in 1850 in open kilns on Limestone Island, and in 1902, the New Zealand Portland Co. erected a cement-making plant on Limestone Island. Prior to 1929, Wilson's (NZ) Portland Cement Ltd manufactured cement at Warkworth (Figure 7), and Mappin's Silverdale Lime Co also operated a small plant (Ferrar, 1934). Quarries at Mt Tikorangi (Mahurangi Limestone) and Wilsonville (Whangarei Limestone) produce raw materials for the Golden Bay Cement works at Portland.

Prominent quarry operations in argillaceous limestone, providing lime for agricultural use and for roading, include: Pokapu Lime Works, Wairoa Lime Quarry, Mata Lime Quarry, and Paparoa Lime Quarry. Other quarries include Borrow's Lime, Redvale Lime, and Te Hana Lime. The argillaceous limestone is naturally shattered and is much easier to quarry and crush than the higher-grade (+80% $CaCO_3$) crystalline limestone south of Auckland City. However, in the argillaceous limestone, the rapid changes of calcium carbonate content and the limited lateral extent of the resource restricts the establishment of large-scale operations.

Auckland

Of the several small outcrops of the coarsely *crystalline* Papakura Limestone (Waitemata Group) (Early Miocene), only the small, historic quarry at Ardmore has been worked out. The calcium carbonate content varied between 55% and 85%.

Shell lime, forming beach ridges along the southern and eastern shores of the Manukau Harbour, was crushed and burnt until the 1950s. More extensive beach ridges lie between Kaiaua and Miranda and near Kopuarahi, along the southwestern and southern shore of the Firth of Thames (Waterhouse, 1966).

Waikato, Taranaki and Waimarino

Large areas of Oligocene, *crystalline*, Te Kuiti Limestone occur throughout most of the western Waikato and King Country (Nelson, 1978). In Taranaki this limestone is mostly buried by a thick sequence of younger sediments. The $CaCO_3$ content varies between 55% and 98%.

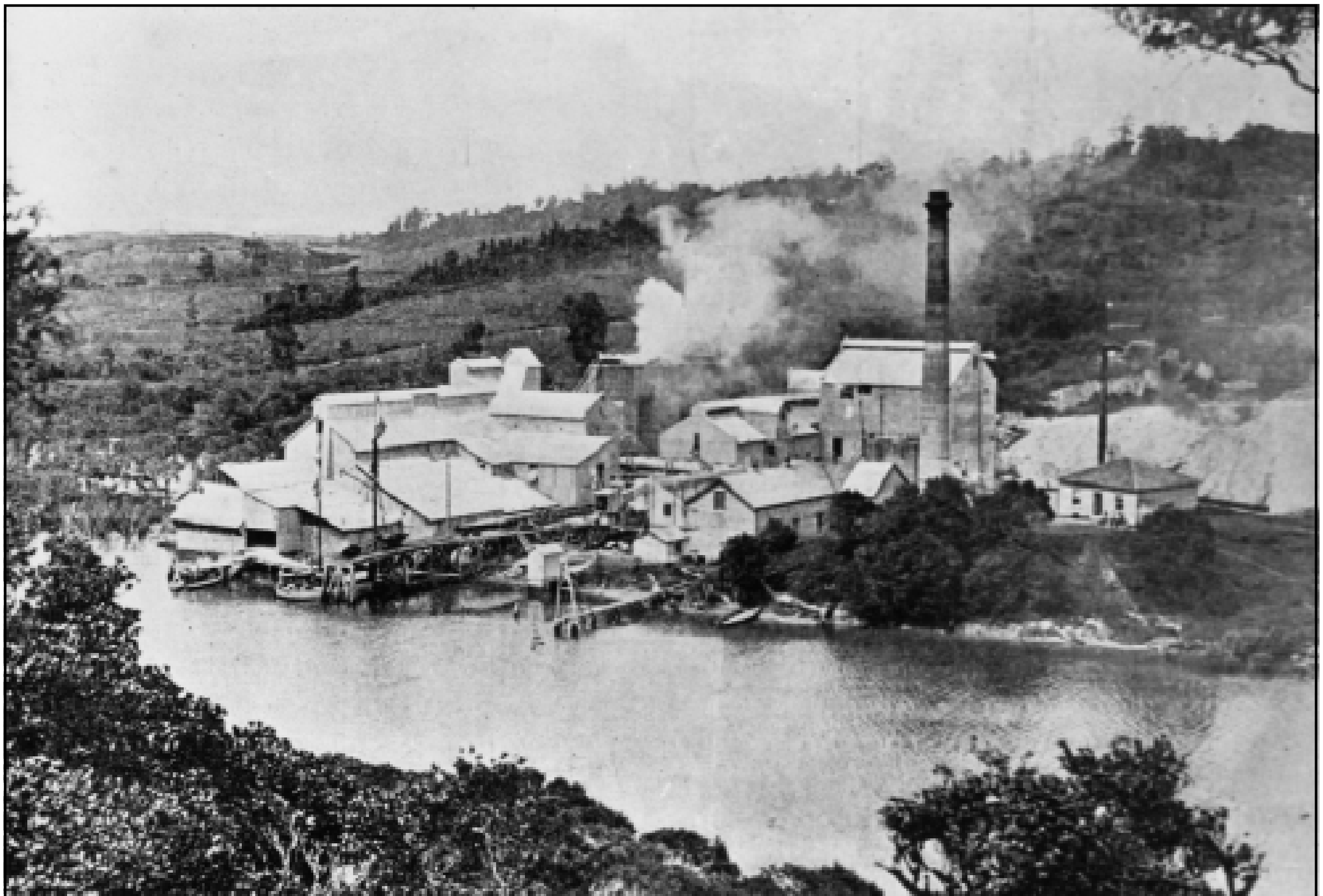

Figure 7: New Zealand's first cement plant at Warkworth in the 1890s with the vertical kilns at the centre of the photo. All product was dispatched in 100 lb sacks in coastal vessels. Photo: Alexander Turnbull Library F118157.5.

The limestone is worked extensively for agricultural lime in the Te Kuiti-Otorohanga area. High-grade deposits (95-98% $CaCO_3$) near Te Kuiti are used to produce high quality limestone for industrial uses, supplying the central North Island paper mills, the Glenbrook steel mill, and the mineral fillers market (e.g. in paint, plastics and carpet backing). Large limestone processing plants are located at Te Kuiti (McDonalds Lime and Omya) and at Otorohanga (McDonalds Lime).

In the north, one small quarry at Waikaretu has recently worked crystalline Waimai Limestone (Oligocene) for road aggregate.

In the Raglan County there is a deeply dissected sequence of extensive, flat-lying, Tertiary marine sediments (Te Kuiti Group) containing two flaggy limestone beds. The upper bed, Waimai Limestone, is purest (90%+ $CaCO_3$) and is up to 6 m thick, whereas the lower, Elgood Limestone, contains 75-85% $CaCO_3$ and varies in thickness from 6 to 18 m. The thick overburden and remote location of these limestones limits their commercial potential.

Southwest of Lake Taupo in the Waimarino District, hard, shelly, Oligocene age limestone containing 87% and 94% $CaCO_3$, lies close to the greywacke ranges (Gregg, 1960).

Coromandel

The hard, platy, *semi-crystalline* limestone in the upper part of the Oligocene Torehina Formation (Kear, 1955; Kear and Schofield, 1953; Skinner, 1976), near Amodeo Bay, Coromandel Peninsula, has a $CaCO_3$ content of 73.5-98.5% and a maximum thickness of 22 m.

It has been used locally for the patching of gravel roads, as base course or fill on secondary access roads, and in the case of the higher $CaCO_3$ variety, for agricultural lime.

A lime works has operated at Branch Stream in limestone (81-95% $CaCO_3$) with resources of 350,000 t suitable for agricultural use. Several other potential sites for quarrying occur in the immediate vicinity and each has estimated resources of between 20,000 and 60,000 t.

East Cape, Gisborne, Wairoa, Hawkes Bay and Wairarapa

Limestone, of Late Miocene to earliest Pleistocene age, is widely distributed on the eastern side of the North Island main ranges, and is also preserved in fault blocks. Seven different types of limestone have been recognised in this area, namely *algal, argillaceous, broken shell, coquina, crystalline, flinty and travertine* (Moore, 1975; Moore and Belliss, 1979, Moore and Hatton, 1985). The total resources are very large.

Lenses of *algal limestone* are preserved south of Porangahau, east of Pongaroa, in the Tinui Valley, and at a few other localities in eastern Wairarapa. Individual units are up to 15 m thick, and typically poorly bedded. The limestone is a very hard, dense rock of cream, grey or pinkish colour, with an average of about 85% $CaCO_3$. The algal limestone has previously been quarried mainly for road metal, although some agricultural lime was produced from McLean's quarry. It also has some potential as a decorative stone chip, for facing panels, and for ornamental purposes.

There are extensive deposits of *argillaceous* limestone near Weber, at Pongaroa, and in the Tinui Valley. The limestone is moderately hard, poorly bedded and light coloured. Because of the low $CaCO_3$ content (average 67%, maximum 74%), very little use has been made of this limestone, although small quantities were previously quarried at Pongaroa for agricultural lime.

Broken shell limestone occurs at East Cape in the form of minor lenses in sandstone bluffs that are too small to map. Further south, broken shell limestone was previously quarried at the eastern end of Manawatu Gorge, and south of Dannevirke.

In the Wairarapa the broken shell limestone consists mainly of broken barnacles and bivalve shells, and is commonly sandy or pebbly. The major quarries are at Makuri, Mauriceville, and Tauweru.

In economic terms, the Pliocene *coquina-shelly* limestone is the most important limestone. This limestone extends as a semi-continuous belt from near Dannevirke in the north, to south of Masterton. It is composed mainly of barnacle plates, is generally finer grained and of better quality than the broken shell limestone, and has an average of about 85% $CaCO_3$.

Major quarries at Hatuma and Waipawa produce agricultural lime, mostly for export for use outside the Napier region (Moore and Belliss, 1979). Other sources of coquina limestone include that at Pakipaki (Pliocene; Pakipaki Quarry), Te Waka (Pliocene), Titiokura (Pliocene) and Scinde Island (Plio-Pleistocene), which are quarried for agricultural lime as well as for roading, reclamation and fill, industry and for cement manufacture. There is potential for use of some limestone as building and facing stone (Moore and Belliss, 1979).

Increasing quantities of coquina and broken shell limestone are being used for roading purposes, both as a base course and in lime stabilisation. In the Gisborne area, where other sources of aggregate are poor, harder limestone is used for road metal. Some shelly limestones in Hawkes Bay may have potential for glass-making (Moore and Belliss, 1979). Large blocks of hard, cemented limestone are also useful as rip-rap in protection work.

Two small lenses of Jurassic *crystalline* limestone near Kaiparoro contain about 90% $CaCO_3$, but they are less than 3 m thick.

Very hard, well-bedded, white *flinty* limestone is restricted to an area between Homewood and Pahaoa, and between Tuturumuri and White Rock, in southeastern Wairarapa. It has an average of about 75% $CaCO_3$, but, because the limestone is generally interbedded with calcareous mudstone, it has not been exploited as a source of agricultural lime. In places, the limestone is well-jointed and easily worked, and could be used as a local roading material.

A 15 m thick layer of *travertine* near Havelock North was previously worked for industrial lime (Moore and Belliss, 1979).

Nelson and North Westland

Extensive limestone resources occur in the Nelson area. Permian Maitai Group limestones are exploited in the eastern part of the area, and were worked in the Lee Valley south of Nelson to produce agricultural lime. A small cement works formerly operated nearby. The limestones occur in the basal and uppermost formations, the Wooded Peak Limestone and Stephens Formation respectively. The Wooded Peak Limestone crops out almost continuously from near Mt Duppa, in the Whangamoa Valley, to the Hacket River. The limestone dips steeply and is up to 1000 m thick. A calcareous sandstone unit divides the limestone into two limestone members (Sclanders and Malita). Resources are very large, with grades of 85-90% $CaCO_3$, but access is difficult. Creeks draining the Wooded Peak Limestone in east Nelson commonly contain *travertine* deposits, which have been partly quarried in the Teal Valley (Johnston 1981, 1982).

Although the Stephens Formation is more accessible than the Wooded Peak Limestone, the limestone within it occurs as steeply dipping lenses. Lenses up to 1 km in length and 150 m in width, crop out in the lower Wairoa River, Lee Valley, Pig Valley, and Wakapuaka Valley. The largest production has been from the Lee Valley quarry. At Pig Valley a small quarry has been opened up on the western margin of a large lens of limestone. The amount of limestone readily available is large and an analysis gave 83% $CaCO_3$. A lens of limestone crops out on the eastern side of the lower Wakapuaka Valley and a small quarry has been established to provide blocks for river-bank protection.

Tertiary age limestones are of two types, *algal* and *crystalline*. Until 1988, Oligocene-Miocene limestone and marl (Takaka Limestone) were worked on a large scale for cement at Tarakohe. High-grade *crystalline* limestone is extracted for agricultural use at Murchison and *algal* limestone from the Tadmor Valley is used for agricultural lime. Huia Formation, Matiri Formation, Nile Group, and the limestone near Karamea are also Tertiary in age.

Huia Formation of Late Eocene to Early Oligocene age, crops out from the Wangapeka River south to the Tadmor River. In the north it is impure but in the head of the Sherry and Tadmor rivers it is a high-grade, *algal* limestone (96% $CaCO_3$) up to 60 m thick. It has been quarried intermittently from the Tadmor Valley as a source of quick and agricultural lime (Johnston, 1981).

Limestone of Oligocene-Miocene age crops out extensively in the Oparara area near Karamea. Its remoteness limits its potential use. It also contains caves of scientific importance as well as karst features, particularly arches, of international significance. Limestone outcrops elsewhere in the hinterland of northwest Nelson generally have difficult access and, particularly in the south, are of lower purity.

Newton Limestone, a relatively pure (98% $CaCO_3$) *algal* limestone of Oligocene age is quarried between Brown Creek and Newton River close to the Buller Gorge highway. Although used both for agricultural and industrial use, Suggate (1990) considered that the purity of the Newton Limestone could justify recovery in less accessible areas.

A low-grade limestone of Oligocene age, and of borderline agricultural quality, is available in the Matiri Valley downstream from the west branch of the Matiri River (Suggate, 1984).

Takaka Limestone (Oligocene-Miocene) of the Westhaven Group crops out in the Golden Bay area. It is a hard, flaggy, *crystalline* limestone, sandy in its lower half (Bishop, 1971; Grindley, 1971). At Tarakohe, the Takaka Limestone is up to 80 m thick, but about 45 m is more typical of the area (Bishop, 1971). Analyses quoted by Morgan (1919) range from 86.5-91.8% $CaCO_3$.

The major producer from this formation has been the Golden Bay Cement Company at Tarakohe, near Takaka, although the cement works are now closed. In 1988, the last year of cement production, 140,894 t were extracted, of which 94% was for cement manufacture, and 6% for harbour fill and roading. This limestone at Tarakohe, being adjacent to port facilities, is well sited for shipping to other parts of New Zealand or overseas.

Tertiary age limestone occurs near Nelson city, and although quarried in the 1840s, it is of small extent and impure.

Eocene-Oligocene limestone on the West Coast (Westland) is processed by several small limeworks to supply agricultural lime. Oligocene limestone and marl are quarried at Cape Foulwind, near Westport, to supply the large cement works there.

The belt of limestone between Cape Foulwind and Punakaiki (containing the Waitakere, Tiropahi, and Potikohua limestones) and the Cobden Limestone near Greymouth, are the most extensive and accessible limestone formations in north Westland, and account for the major part of production. The Waitakere Limestone is a hard, light-grey *algal* limestone, and has been quarried at Cape Foulwind for the past century. The high $CaCO_3$ content (92-98%) has led to a predominant use for cement manufacture. *Marl* in the lower part of the Late Eocene Kaiata Siltstone at Cape Foulwind (10-20% $CaCO_3$), is also quarried locally as a component in cement manufacture.

Milburn New Zealand Limited operate a cement plant at Cape Foulwind, 10 km west of Westport, producing 500,000 tpa (Figure 8). Limestone and marl quarrying operations are centred on a crusher facility near the cement plant. The thick, gently dipping limestone is overlain by a similar thickness of marl (Pettinga, 1993). Bulk cement is transported by ship, road and rail to cement supply centres throughout New Zealand.

Additional resources of cement-quality Waitakere Limestone are present in the area between the Little Totara and Nile rivers. Utilisation of the Waitakere Limestone for agricultural purposes and as rip-rap is also important in the region. Smaller quarries have been or are active at Little Totara River, near Charleston, and Nile River. Large resources of Potikohua Limestone are also suitable for uses requiring high-grade limestone (Nathan, 1975).

Figure 8: Limestone quarry (foreground) and cement plant (left distance) at Cape Foulwind, near Westport. Photo: Lloyd Homer.

The Cobden Limestone is well developed in the Brunner-Greymouth area where it is a hard, *massive*, *muddy* limestone. The steep, west-facing, dip slope east of Greymouth defines the western limb of the Brunner-Mt Davy anticline. The $CaCO_3$ content is generally between 70 and 75%, but may be as low as 44%. The resistant nature of the rock has led to extensive use as rip-rap and dimension stone in harbour and river protection works. Whilst not suitable for agriculture, such limestones could be used for cement manufacture.

Nathan (1978, p. 30) noted that "Bands of *foraminiferal* and *polyzoan* limestone near the base of the Stillwater Mudstone have a much higher carbonate content than the Cobden Limestone. A chip sample taken across the Tindall Limestone Member near the top of Tindall Hill contained 87% $CaCO_3$. This deposit contains easily worked reserves of only 25,000-40,000 t, but this could be sufficient to fulfil the needs of local farmers for several years."

Other less important limestones include the Oligocene Potikohua Limestone, Tiropahi Limestone, and Kowhiritangi Limestone. Substantial resources of Potikohua Limestone are found at Bullock Creek and north of Punakaiki. The rock is a hard, locally *sandy*, flaggy limestone, with 84-96% $CaCO_3$ (weighted average 92.4% $CaCO_3$) and has potential for agricultural lime. Predominant use has been for rip-rap in river protection works. In the Charleston area, Tiropahi Limestone (excluding the Madmans Siltstone Member) has 61-77% $CaCO_3$ (weighted average 68.0%). Near Kowhitirangi and Ross, white *crystalline* Kowhitirangi Limestone and similar limestones exceed 80% $CaCO_3$, and are utilised for agriculture and rip-rap. Other sites could be developed in this area.

Weathering and solution of limestone has developed several features used for recreational purposes. Caves and underground streams are present at a few locations, particularly Fox River (Fox River cave) and Bullock Creek (Xanadu). Pancake rocks and their associated blowholes, are famous tourist attractions situated at Dolomite Point, Punakaiki. Laird (1988) noted that "They are developed in Potikohua Limestone, underlying the 34 to 36 m terrace formed on Waites Formation, which is being stripped of its cover of marine gravels by salt spray thrown up by the breakers pounding against the foot of the cliffs, and by the heavy regional rainfall. The solution-sculptured rocks, etched by acidic soil waters from a flax bog developed on the terrace gravels, form a landscape of striking towers and minarets." Weathering has emphasised the flaggy nature of the limestone, forming the "pancakes".

Marlborough

Allochthonous blocks of very pure limestone occur within the Mesozoic Torlesse sediments in the Leatham River area of the Upper Wairau valley. A typical analysis of composite limestone from Enchanted Stream has 99.2% $CaCO_3$ and 0.093% P_2O_5 (Johnston, 1990). Despite their difficult access, such deposits are the main source of agricultural lime in the Marlborough area. A pink-coloured limestone at Wharanui has been quarried when required for an ornamental building stone (Williams, 1974).

The latest Cretaceous to Eocene Amuri Limestone is a close-grained rock that is, in places *chalky* or *flinty*. It crops out over a wide area of Marlborough, almost continuously from Cape Campbell to the Clarence River. The thickness is up to about 100 m and the $CaCO_3$ content is 60-95% in the hard limestone. Between the Ure and Clarence rivers the flint-free, 60-90% $CaCO_3$ content limestone is up to 300 m in thickness. Agricultural lime is the main product and is currently quarried near Ward.

North Canterbury

Canterbury limestones fall into two distinct categories, pre- and post-Cretaceous (ages). They are of widely different age, hardness, and importance.

Small outcrops of *crystalline* Permian, Triassic, or Jurassic limestone, few of which have been quarried, form lenses within the greywacke and argillite of the Torlesse Supergroup. Almost all are associated with volcanic rocks. Because of their small extent, their hardness, and their relative inaccessibility, most of these lenses are unlikely to be of economic significance in the foreseeable future.

A major source of agricultural lime is Amuri Limestone. It is diachronous, with the base becoming progressively younger toward the south (Browne and Field, 1985; Field and Browne, 1986). The age is latest Cretaceous to Eocene in coastal Marlborough, ranging up to early Oligocene in Canterbury. It is a thin-bedded *argillaceous* and *siliceous,* white limestone, and is worked for agricultural lime at Cheviot and Kaikoura.

The main deposits in Canterbury are the Oligocene and Miocene *argillaceous* and *sandy* limestone that forms part of the Tertiary sequence exposed on the inland edge of the Canterbury Plains. Much is of high quality (80% to 95% $CaCO_3$) (Canterbury United Council, 1984). For many years it has been quarried from a number of localities along the foothills of the Canterbury Plains and typically contains between 70% and 84% $CaCO_3$ (Warren 1969).

Most production at present is from the White Rock Lime Quarry near Loburn, although significant amounts of limestone have also been produced from Chalk Hill and Motunau Beach quarries. In the Castle Hill Basin, limestone is quarried from the Thomas Formation within a small outlier of Tertiary sediments.

The largest production comes from Mt Somers, where three lime works can produce up to 100,000 t per year. This limestone is worked for agricultural lime in several places, although some have produced a building stone.

In the Waiau district, the limestone most often quarried is the Late Oligocene Isolated Hill Limestone. Nearby, a red, *tuffaceous*, highly decorative limestone (Hanmer Marble) of similar age is keenly sought as a building stone, but also is used for agricultural purposes. Farther south in the Waikari district, Weka Pass Stone is the most commonly quarried limestone and typically contains between 52% and 86% $CaCO_3$.

South Canterbury

A small quantity of *marble* (Kakahu Limestone) has been quarried from a calcareous lens in Haast Schist (Torlesse greywacke) at Kakahu, near Geraldine. The marble is of relatively high grade and has returned an average value of 94.8% $CaCO_3$ for three samples (Morgan, 1919). Although up to 30 m thick at the quarry face it is of limited lateral extent (Hitching, 1979).

The main limestone quarried in South Canterbury is the *semi-crystalline* Otekaike Limestone, which is of Early to Middle Oligocene age and a probable correlative of Amuri Limestone farther north. The limestone is of moderate to high grade (Morgan, 1919), and is used principally for agricultural purposes. Several limestone quarries along the eastern face of the Hunter Hills south of the Opihi River provide agricultural lime with $CaCO_3$ values ranging from 69.2% to 83%.

Limestone suitable for industrial purposes has been quarried at Redcliff Gully, Blands Bluff, Caves Stream, and Kakahu Bush.

Oligocene Craigmore Limestone crops out in Gordons Valley, west of Timaru, and has been mined at Gordons Valley Lime Quarry and Craigmore-Gordons Valley Road Quarry of Maungati Lime Company Ltd for use in agriculture. Analyses of the $CaCO_3$ content of samples from these quarries range from 88% to 91% (Warren, 1969).

Coastal Otago

Three types of limestone are present in Coastal Otago: *crystalline limestone*, *"marble"* of Triassic age near Palmerston, and *bryozoan/shelly* limestone of Eocene-Oligocene age along the coast and in the Waitaki Valley.

Triassic "marble": Blue Mountains, 5 km east of Dunback, contain a hard, white to blue-grey, *crystalline* limestone ("marble") lens of probable Triassic age within argillite and greywacke. Analyses from the quarry range from 93% to 99% $CaCO_3$ and average 2.0% SiO_2, less than 0.32% Fe_2O_3 and 1.0% Al_2O_3. Resources in the region were estimated to be in the order of 150 Mt, most readily available for quarrying (Cooper, 1966).

The limestone has been extracted at Makaraeo Lime Quarry and was, until recently, used as a source of high-grade limestone for the Burnside Cement works in Dunedin. A coal-fired burnt lime (CaO) plant has recently been established at Makaraeo to supply lime to the South Island roading, meat processing, and mining industries, especially the nearby gold mine at Macraes Flat (Benbow, 1990; MacFarlan and Barry, 1991, p. 36; Harrington, 1992).

Bryozoan/ shelly limestone: Much of coastal North Otago and the Waitaki Valley is underlain by Late Eocene and Oligocene *bryozoan* and *shelly* limestones – 'Oamaru stone' (Gage, 1957; Cooper, 1966).

The following summary lists limestone deposits in order from north to south, and is based mainly on studies by Cooper (1966) and Warren (1969).

Near Oamaru, the Totara and McDonald limestones (Gage, 1957) and Ototara Limestone (Edwards, 1991) are massive, soft, and relatively pure *bryozoan* (polyzoan) limestones of Late Eocene to Early Oligocene. They are very porous, light weight, relatively strong, coarse textured, and easily cut. Their average $CaCO_3$ content is between 86% and 98%, with most containing 93% or more, making these some of the highest quality limestone in the Otago area (Cooper, 1966). Analyses from Taylor's Quarry average 97.2% $CaCO_3$ (range is 92.3-99.5%) and numerous analyses average 1% SiO_2, 0.43% Fe_2O_3 and 0.5% Al_2O_3. A resource of at least 450 Mt was estimated by Officers of New Zealand Geological Survey (1970), and these were considered to be readily available for quarrying.

These limestones are easily worked, and consequently they have been quarried extensively for use as agricultural lime, building stone and industrial lime. They have long been an important source of building stone (Oamaru stone) used in public buildings throughout the country (Hayward, 1987). Production is currently from Taylor's Quarry, Parkside Holdings or Gay's Quarry, and Weston Lime quarries at Weston. Former major quarries included Capsize Stone, Totara, and McDonalds quarries. Most of the current output of building stone is used as wall cladding and interior walls in houses and other small buildings.

In the Ngapara, Duntroon, Otekaike and Wharekuri areas, Oligocene Otekaike Limestone crops out and is extracted at Pringles Lime Quarry for use in agriculture. It differs from the Totara and McDonald limestones in its finer grain size, lack of bryozoa, and abundance of glauconite, echinoderms and mollusca. Material at Ngapara and Duntroon is of higher quality than that at Otekaike and Wharekuri: analyses average 77% and 93% $CaCO_3$ for different members in the Ngapara area, but only 68% in the Otekaike area and 53% in the Wharekuri area (Cooper, 1966). Resources of the separate deposits have not been estimated, although most are in the order of millions of tonnes and total resources are in the order of hundreds of millions of tonnes.

Waihao Limestone crops out in the lower Waihao Valley area and it is a moderately hard, slightly *glauconitic, sandy* limestone with an average $CaCO_3$ content of about 61% (Cooper, 1966). It has been mined at the Waimate Lime Quarry and Parkers Bush Road for use in agriculture.

In the upper Waihao Valley, small quantities of good quality limestone are present in the Pentland Hills area. The limestone is *shell and glauconitic*, but becomes *crystalline* towards its top, and has an average $CaCO_3$ content of 88.5%. Resources are in the order of tens of millions of tonnes (Cooper, 1966).

The Shingly Creek area has outcrops of calcareous sandstone to limestone overlying glauconitic sandstone. The limestone has an average $CaCO_3$ content of 70%. Resources are small, probably only several thousand tonnes (Cooper, 1966).

Green Valley Limestone, at the main section in the Shag Valley near Trig F, is a very hard, cream-coloured, well bedded, and fairly uniform, crys*talline* limestone with an average $CaCO_3$ content of 93%. Further west from the main section, it becomes more sandy and glauconitic, and passes down into glauconitic sandstone. Soft, *sandy* limestone has been worked for local agricultural use in a small lime pit near Green Valley School. Resources of high-grade limestone at Trig F are at least 10 Mt (Cooper, 1966).

Goodwood Limestone extends from Shag Point to Waikouaiti and is a soft, grey-brown, fossiliferous mudstone and sandstone, with moderately hard, *sandy*, limestone bands (Cooper, 1966). It grades downward into underlying Caversham Sandstone, which although calcareous is too low grade (average about 44% $CaCO_3$) for a source of lime.

In the Dunedin area, the upper Oligocene Milburn limestone at Milburn, north of Milton, was formerly worked for cement and quantities are still produced for agricultural use (Cooper, 1966; Robertson and Rabone, 1986; Bishop and Turnbull, 1996). The Burnside Marl was used for cement manufacture until the closure of the adjacent Burnside cement works.

Central Otago

There is little limestone present in Central Otago. A Pleistocene lake deposit of *calcareous ooze* has been worked occasionally at the southwest side of Lake Hayes, near Queenstown (Cooper, 1966).

At Bob's Cove (Lake Wakatipu) a *semi-crystalline*, very hard, light grey, jointed limestone forms the crest of a ridge on the north shore of the lake about 15 km west of Queenstown. The limestone, which forms the uppermost layer of a sedimentary sequence of Oligocene age, is at least 30 m thick at the crest and contains 2.5 Mt above water level. A lime kiln opened in 1878 at 12 Mile Point (Cox, 1879; Cooper, 1966).

Southland – Southland Plains, Western Southland and Productus Creek

Limestone in Southland is of three ages, Permian, Oligocene and Miocene.

Permian *Atomodesma* limestone occurs interbedded with sandstone and siltstone in the Maitai Group at Productus Creek, near Arthurton (Wood, 1956; Cawood, 1987). The limestone has been quarried for use as road metal (Wood, 1956), but the low calcium carbonate content (average 54.6%; Cooper, 1966) makes it uneconomic for agricultural use.

Oligocene limestone has been quarried at Elmwood (Cooper, 1966) and limestone of the Late Oligocene-early Miocene Chatton Formation is presently worked at Balfour, but the lower quality, *silty* limestone between Waimumu and Dolamore Park has been worked only intermittently.

Miocene limestones are found in several localities in Southland (Willett, 1950), and have been worked on a large scale for agricultural lime. Major lime works are situated at Browns near Winton, on the Oreti River, and at Clifden in the Waiau Valley. Bryzoan-brachiopod red *algal* limestone (mainly calc-arenite) of the Miocene Forest Hill Formation has a calcium carbonate content that varies from 87% to c. 50% in the underlying upper Te Karara Formation (Turnbull and Uruski, 1993). It is presently quarried for agricultural use at Clifden, Castle Rock, Centre Bush, Browns, and at several other sites near Winton. In addition to agricultural use, Forest Hill Formation limestone has in the past been used as a source of industrial lime, and, in the mid-1960s, limestone from Clifden supplied a cement works at Orawia (Wood, 1966).

The Forest Hill Formation extends west to Helmet Hill, where large reserves are readily accessible (Wood, 1969; Turnbull and Uruski, 1993). Wood (1969) also listed other limestone occurrences in the ridges northeast of the eastern arm of Lake Hauroko, in Wairaurahiri Valley and in Kaituna Stream. However, Turnbull and Uruski (1993) noted that many of these occurrences were of poor quality and are poorly accessible.

Fiordland, South Western Fiordland and Eastern Fiordland

Apart from some poorly accessible limestone of Tertiary age at Mt Luxmore, near Te Anau (see Figure 7 of Cooper, 1966) and within Fiordland National Park, the limestone resources of the area lie mainly in its southern part. Large quantities of limestone occur in the Chalky Island Formation (Oligocene) of Chalky Island (Chalky Inlet).

Marble

Marble occurs mainly in Ordovician sedimentary sequences in Northwest Nelson and Fiordland. There are minor occurrences within the Permian-Cretaceous greywacke sequences such as at Marble Bay, Bay of Islands, where several very thin bands are interbedded with basaltic pillow lava of Permian age.

Arthur Marble occurs in a large area of mountainous country between Takaka and the Buller River in West Nelson to Westland. It is generally medium- to coarse-grained and white to dark grey in colour, and occurs as lenses up to 1000 m thick and several kilometres in length. It contains an average of >96% $CaCO_3$ (Willett, *in* Williams, 1974; Suggate, 1990).

The marble on the summit of the Takaka Hill has been worked for many years for industrial quality marble to supply the Omya (NZ) Ltd works at Te Kuiti, and for agricultural lime and building stone. It has been quarried also for a variety of uses in agriculture, building, and manufacturing (Grindley and Watters, 1965), and locally as a source of agricultural lime. The two major quarries are Ngarua Quarry and Sollys. The material quarried at Ngarua has been used as building stone, such as for the old Parliament Buildings (Morgan, 1919) and the Lichfield Building in Christchurch (Hayward, 1987). Other smaller quarries in the Canaan Valley and on the west side of the Takaka Valley have supplied purple-grey and dark grey marble for use as decorative building panels (Hayward, 1987).

Arthur Marble is also quarried in the vicinity of Springs Junction.

In Fiordland, beds of coarsely crystalline marble of Paleozoic age occur intercalated with strongly laminated quartzo-feldspathic, calc-silicate gneiss at several locations in the sounds. The marbles are banded and at most localities they are strongly folded with a characteristic form (Benson, 1934, plate 42b). Calc-silicate minerals associated with the marbles include diopside, scapolite, wollastonite, tremolite, and in some areas, dispersed flakes of graphite and phlogopite mica.

The Caswell Sound Marble Co quarried marble from the south side of Caswell Sound between 1881 and 1887. However, the marble is badly flawed and does not weather well, making it unsuitable for dimension stone and causing the operation to cease (Morgan, 1919). The marble occurs as a band about 15 m thick. On the northern side of Caswell Sound, McKay (1882) described a 60 m thick band of grey or bluish marble as "is sound and free from joints, and apparently could be quarried in blocks of any size required". Scales of mica and graphite, as well as nests of pyrite, occur in much of the material.

At Kellard Point, Doubtful Sound, marble occurs in two layers, each 18 m thick that are traceable over a distance of a kilometre. Inferred reserves are 7.6 Mt of 98%, and 7.1 Mt of 95% $CaCO_3$ (Willett, 1950). The marble is white, but generally contains a few flecks of graphite and mica. Two samples collected by Willett (1950, p. 34) averaged 2.11% SiO_2, 0.91% MgO and 0.01% P_2O_5.

Bands of marble also occur at Helena Falls and Halls Arm in Deep Cove, Doubtful Sound. The Halls Arm marble contains some phlogopite (Turner, 1939).

For a short period marble was quarried from the south side of Dusky Sound between Fanny Bay and Coopers Island. It occurs as a 12 m thick band in gneiss or schist and consists of alternating bands of blue and white colour. Park (1888) considered it to be free from joints and flaws.

Dolomite

In New Zealand there is little magnesium in the widespread limestones of Tertiary age. One sample from the Ure River in Marlborough analysed 13.6% MgO and another from the Malvern Hills contained 17.2% MgO out of a theoretical maximum of 21.9% MgO.

The main New Zealand occurrences of dolomite are in marble formations of Paleozoic age on Mt Burnett in Northwest Nelson. At the Mt Burnett quarry, 6 km west of Collingwood, the dolomite occurs as horizons (Burnett Dolomite Member) within a folded sequence of Arthur Marble, which is in fault contact with Cambrian Wakamarama Schist (Bishop, 1967). Outcrop area is extensive. The main lens of dolomite is about 400 m in thickness, dips vertically, and was estimated in 1980 to contain about 50-100 Mt. The other lenses contain up to 1 Mt each.

Minor amounts of calcite are ubiquitous, resulting in the variable grade of the quarried dolomite. Analyses range from 68-91% $CaMg(CO_3)_2$ equivalent, with the majority above 80%. The better material contains between 18.1% and 19.6% MgO. Impurities include Fe_2O_3 (usually <0.3%, maximum 1.1%), Al_2O_3 (<0.3%, maximum 1.2%), and SiO_2 (<3.0%, maximum 12%). Resources were estimated at 70 Mt in 1969 (Bishop and Braithwaite, 1967).

Dolomite from the Mt Burnett quarry is used in agriculture mainly for magnesium deficient soils. Impure dolomite has been used for river bank and coastline protection, with relatively large quantities being shipped to Wellington in the early 1990s for seawalls at the southern end of Wellington airport and the Seaview Marina. Smaller quantities are used for a variety of industrial applications. The former glass industry in Whangarei required selectively quarried dolomite, analytically controlled for a low iron content. Physical and chemical analyses indicate that the Mt Burnett material would be suitable for refractories, insulation wool and magnesium metal production.

Production and resources

Limestone

Production

In 1999, 4.12 Mt of limestone, marl and dolomite valued at over $44.4 million at the quarry gate, were produced for four main uses - agriculture, industry, cement and roading (Figures 9 and 10).

Agricultural lime: Production of agricultural lime was formerly from many small limeworks located wherever a suitable grade of limestone could be obtained. With improved road transport the industry in most regions is now concentrated on a few larger plants (MacFarlan and Barry, 1991). In 1999, 1,977,950 t of limestone were quarried for use in agriculture.

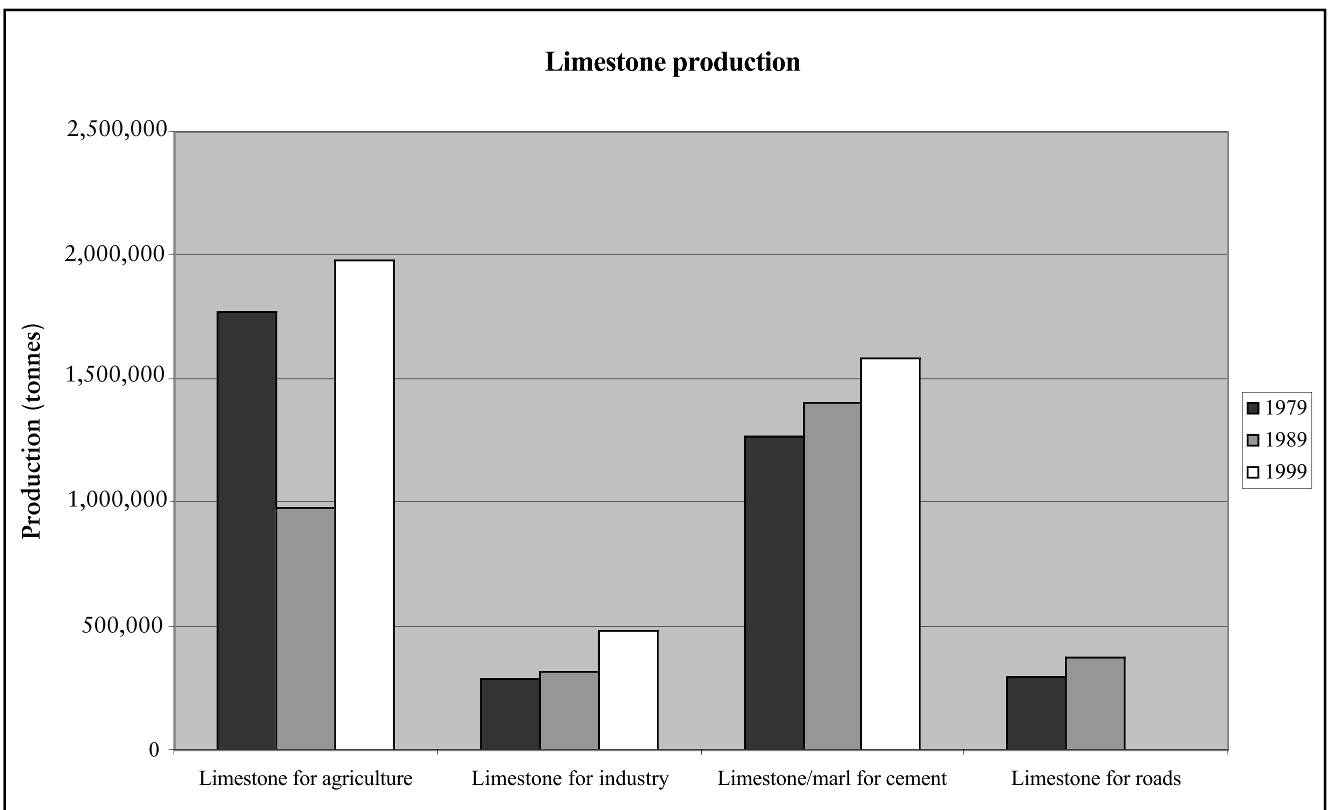

Figure 9: Limestone production and use for 1979, 1989 and 1999. The quantity of limestone used in roading is not available for 1999.

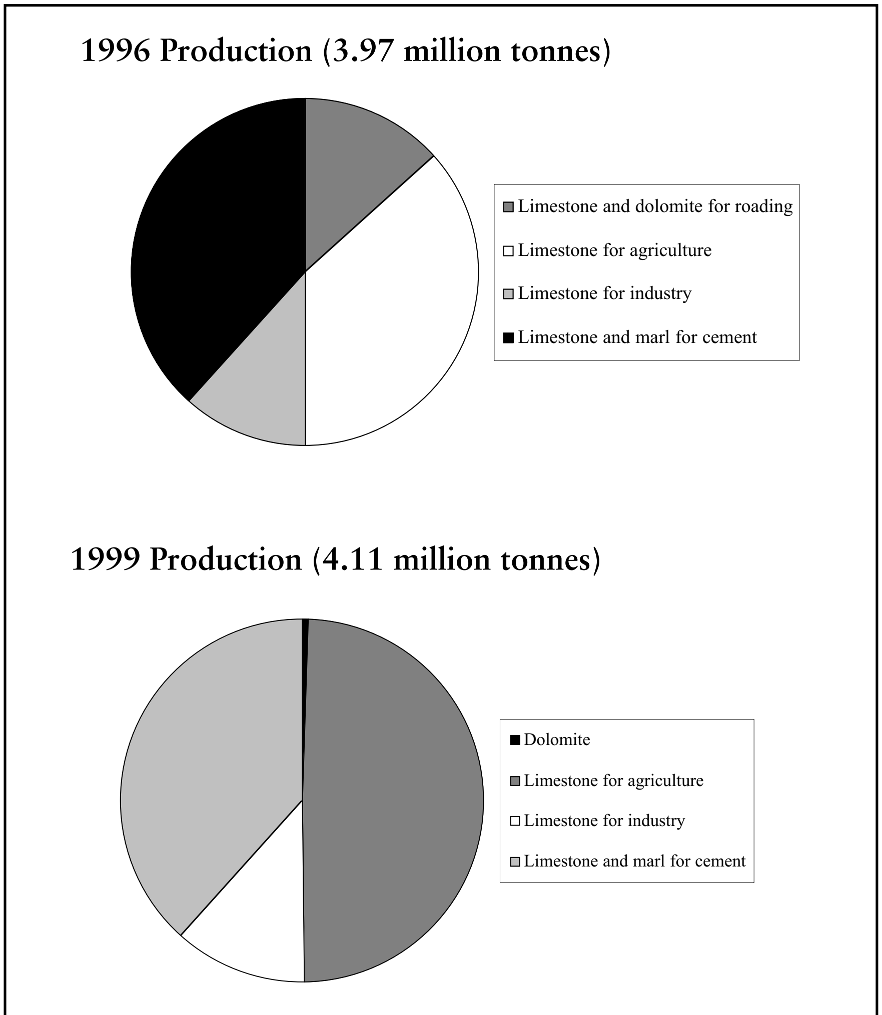

Figure 10: Limestone production and uses for 1996 and 1999. The quantity of limestone used in roading is not available for 1999.

with the company's lime division having a strong presence in both the North and South Islands via its subsidiary companies McDonalds Lime Limited and Taylors Lime Company Limited. Near Te Kuiti, McDonalds quarries high grade crystalline limestone producing about 124,000 tpa of burnt lime. This burnt lime (calcium oxide) is used in steelmaking at the Glenbrook mill operated by BHP New Zealand Steel, in neutralising acids in the processing of gold ore in large scale gold mining plants such as at the Martha Hill gold mine at Waihi and offshore at Lihir (Papua New Guinea) and Gold Ridge (Solomon Islands), in paper pulp manufacture at the North Island paper mills, in the sugar industry, in soil stabilisation of clays in road construction, and in sewage sludge and waste water treatment. It is also used for preserving hides and skins, and for neutralising acids to control pollution, especially in the meat industry. Other markets include water treatment, soil stabilisation, sewage sludge and waste water treatment, agriculture, plus an expanding market for finely ground limestone for the plastic, rubber and glass industries.

In the South Island, Taylors Lime operates a plant at Dunback (Makaraeo Quarry). The plant quarries a lens of crystalline limestone (96-98% $CaCO_3$) in Triassic age greywacke. This quarry used to supply the former Burnside Cement Works in Dunedin. Taylors now supply burnt lime and ground limestone mainly for use in processing gold ore at the Macraes Flat gold mine. A small quantity of limestone is also used as a feed additive in the poultry industry to maintain quality egg shell production.

West of Te Kuiti, McDonalds quarry produced 120,000 tpa of high grade limestone for industry and 247,000 tpa of ground limestone for agriculture. Additionally, 30,000 tpa of high grade limestone are used in animal feed, particularly for cows, poultry, pigs and horses, and in drenches for cows to increase milk production.

Another significant producer of agricultural or non-burnt lime is Hatuma Lime Company Limited, which operates three quarries - Hatuma (51,000 tpa), Waipawa (9,000 tpa) and Mauriceville (20,000 tpa) in the central Hawke's Bay and Wairarapa areas. All three quarries mine selectively to produce limestone with a purity ranging from 90% to 95% $CaCO_3$. The Hatuma limestone is notably low in iron (0.0185%). All output is sold solely for agricultural use within the domestic market.

Awarua Browns Lime Limited is producing agricultural lime from its main operation near Winton in Southland, as well as from other sites. Output from the operation is approximately 100,000 tpa. Limestone extracted from the quarry is crushed, dried, pulverised and classified. Milburn Lime Limited is working the resource at Milburn in South Otago, which is the site of the original Milburn Lime Company Limited.

Burnt lime and limestone for industry: In 1999, 481,620 t of limestone were quarried for use in industry. Milburn New Zealand Limited is a major producer of burnt lime,

Industrial-grade calcium carbonate is produced as a mineral filler to supply several industries. Colour and purity, especially low iron content, are important parameters. The major producer is Omya (NZ) Ltd, with its main works 5 km north of Te Kuiti (supplied by a nearby limestone quarry), and operations in the South Island at Takaka Hill (marble) and Coalgate (Canterbury). This company produces high grade limestone (98-99% $CaCO_3$) with a current output of more than 50,000 tpa. The material is used domestically as a filler in paper, plastics, paint and rubber, for paper surface coatings, and in glass. High grade limestone for industry is also produced by Robert Hall from the Te Kumi Quarry, located 5 km north of Te Kuiti. Production is about 9,000 tpa.

Other lime producers include Webster Hydrated Lime Limited, near Havelock North, and Mata Lime near Whangarei. Websters works shelly limestone, producing about 8,000 tpa of hydrated lime. Other smaller producers, include Austin Chalk Company Ltd, Redvale Lime Ltd, Valley Lime Ltd, Firth Industries Ltd and Springfield Lime Company Ltd.

A recent trend has been the acquisition of lime works by major trucking companies to provide back loads and by fertiliser companies such as Ravensdown, who now operate Te Mata lime works in Northland, and Valley Lime on Waitomo Road.

Cement: Cement is manufactured by Golden Bay Cement Company at Portland (near Whangarei; 550,000 tpa;) and by Milburn New Zealand Limited at Westport (500,000 tpa), using local limestone and marl. In 1999, 1,582,450 t of limestone were used for cement manufacture.

The Portland works is supplied by argillaceous Mahurangi Limestone (marl), which is quarried at a rate of 600,000 tpa from a quarry at nearby Mt Tikorangi (South et al., 1999; Miller, 1999). The main raw material feed consists of 75% marl (approx. 75% $CaCO_3$) and 25% crystalline limestone. The crystalline limestone (Whangarei Limestone) is sourced from the company's Wilsonville Quarry, 20 km north of Whangarei. Imported gypsum is used as a setting retardant. Bulk and bagged cement from the Portland plant is distributed locally by road, while the company's coastal supply ship transports cement further afield.

Milburn New Zealand Limited's quarry at Cape Foulwind produces about 700,000 tpa of limestone and marl for cement manufacture at the nearby Westport cement works (Figure 8; Pettinga, 1993). Bulk cement is transported by ship, road and rail to cement depots throughout the country.

Roading: Limestone is produced for use as a roading material in areas where there is no superior material locally available. In 1996, 520,212 t of limestone (and dolomite) were produced for roading. Corresponding statistics were not recorded for 1999.

Resources

There is no estimate of the total quantity of limestone available in New Zealand, and little exploration to prove the quantity available has been reported.

In known limestone areas the quantity available is large, mostly in the millions of tonnes, mainly depending upon the required minimum $CaCO_3$ content. For very high grade limestone ($CaCO_3$ 95%+) for industrial purposes, drilling to prove quantity and sample analyses to determine grade and colour, may be necessary to define the deposit. Drilling for quality control and to define the surface (karst) topography, is used at Wilsonville Quarry near Whangarei (Miller 1999).

Recently, some overseas companies have been interested in purchasing large quantities of limestone for use in industrial chemical applications. Several suitable limestone resources in the south Waikato, Nelson and Westland regions are close to transport links.

Marble

Production

The main production of marble has been from quarries on Takaka Hill. The Ngarua Quarry is operated by Omya (NZ) Limited and quarries 15,000-20,000 tpa of white marble with a calcium carbonate content greater than 98.6%. The product is processed at Te Kuiti for use as a filler for the surface coating industry, although about half of the production, consisting of lower grade material, is used for agricultural lime.

Resources

The main source of marble for the New Zealand market is from the Takaka Hill deposit. That at Ruatoki (Bay of Plenty) is worked out, and that at Marble Bay (Bay of Islands) is too small to be economically extracted.

The potential resources of marble are very large, particularly in the Pikikiruna and Arthur ranges, and Takaka Hill deposits will be a continuing source of marble for the New Zealand market. The marble in Fiordland is unlikely to be worked, mainly because of its location in Fiordland National Park and access difficulties. No quantities have been estimated for New Zealand marble resources apart from that at Kellard Point in Fiordland – about 15 Mt in 1930.

Dolomite

Production

Production of dolomite at Mt Burnett began in 1947 for addition to fertiliser. The current plant, owned by Omya has a capacity of around 100,000 tpa, although current output is of the order of 25,000-40,000 tpa. About 80% of the product is used as an additive to phosphatic fertilisers for spreading on magnesium-deficient soils and the balance is used for aggregate and rip rap. Physical and chemical analyses indicate that the Mt Burnett material would be suitable for refractories, insulation wool and magnesium metal production. The dolomite has formerly been used in glass manufacture and in the steel industry. Omya barges dolomite from nearby port facilities either direct to customers or to storage facilities at Wanganui in the North Island. Dolomite blocks have also been barged to Wellington for use in harbour breakwaters.

Resources

The main lens of dolomite at Mt Burnett is about 400 m in thickness and, in 1980, it was estimated to contain 50-100 Mt. The other lenses contain up to 1 Mt each.

Overseas trade

The main overseas trade in limestone products is centred on slaked and hydraulic lime and cement. In 1998, 423 t of limestone flux, slaked, quick and hydraulic lime valued at NZ$482,175 were imported, mainly from Australia and USA, and 43,395 t, valued at NZ$7,864,363, were exported mainly to Pacific Island nations and to the Falkland Islands. In 1998, 15,582 t of cement, valued at NZ$3,842,661, were imported mainly from Australia, China, Japan, Malaysia and Indonesia, and 67,442 t, valued at NZ$7,894,414 were exported, mainly to South Pacific nations.

Minor amounts of dolomite, 16.74 t valued at NZ$15,719 were imported from Australia and Germany. 59.74 t of marble/travertine valued at NZ$72,649 were imported from Italy, Portugal and United Kingdom. 21 t of dolomite valued at NZ$5,460 were exported to French Polynesia and less than 1 t of marble valued at $NZ 2400 was sent to Tonga in 1998. The total value of limestone products imported was NZ$5,381,340 and exports was NZ$15,767,501.

Future

Limestone will continue to be used in agriculture, but the volume of production for cement and steel manufacture is dependent on the state of the building industry. Its use on roads is in place of a local source of more suitable material. Its use in industry is related to the continued demand from manufacturers of paint, paper, plastics and steel.

Limestone has been increasingly used as a substitute for clay in filler applications such as in paper and plastics. A major growth area for lime is in environmental applications such as water treatment, in flue gas desulphurisation, and in wet and dry scrubbers. On the negative side, calcined gypsum is an alternative material to lime in industrial plasters and mortars. Cement and lime, kiln dust and fly ash are potential substitutes for some construction uses of lime. Magnesium hydroxide is a substitute for lime in pH control, and magnesium oxide is a substitute for lime in steelmaking.

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