Mineral Commodity Report 22 - Aggregate

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Definition

Aggregate, or mineral aggregate, is any hard, inert, construction material, such as sand, gravel, crushed stone, shells, or other material, used for mixing in various-sized fragments with a cement or bituminous material to form concrete or mortar, or used alone for railway ballast, road building or other construction. Aggregates composed of rock materials, which are used in their natural state, are referred to as natural aggregates, in contrast to artificial aggregates, which are byproduct (e.g. slag) or manufactured (e.g. expanded clay or shale) aggregates.

Aggregates produced from unconsolidated sediment may be classified according to size into various grades of gravel and sand. In the aggregate-producing industry, gravel consists predominantly of particles larger than 4.75 mm (retained on a US Standard No. 4 sieve), whereas sand consists of particles predominantly between 4.75 mm and 75 mm (passes through a No. 4 sieve, but is mostly retained on a No. 200 sieve). Gravel and sand aggregate, and aggregate produced from crushed rock, are classified into coarse aggregate that is composed of mostly gravel sized particles, and fine aggregate that is composed mostly of sand sized particles, as defined above.

Origin of names

The term aggregate has its origins in the 15th century from the Middle English *aggregat*, derived from Latin *aggregatus*, past participle stem of *aggregare* "to add to," literally "to bring into the flock," ultimately from the stem *greg-* "flock". As the name indicates, aggregates are rock fragments that are together in a mass.

History

Broken and crushed stone, gravel and sand have been used since ancient times for construction, probably beginning with landfill for eroded gullies in trails and roads. In fact, road building is probably the greatest contribution that civil engineering has made to the development of mankind. Overland trade routes, such as the 5,000 year-old route from Afghanistan, through Persia and Arabia to Egypt, depended on roads. At the height of their power, the Chinese had built about 3,000 km of roads, and the Roman Empire had 80,000 km, mainly for military purposes. The oldest paved road known was built in the time of King Cheops of Egypt, more than 5,700 years ago, to ease the transport of the large facing blocks of granite to the pyramids.

In New Zealand, in pre-European times, the Maori carried out extensive earthworks for a variety of purposes. For defence they dug ditches and built banks around their pas, and they built terraces to live on and grow their crops. Many of their gardens are recognised by the sand to coarse gravel-sized aggregate that was used to condition the soils for growing kumara and taro (McFadgen, 1980a). Such gardens cover hundreds of hectares in the Waikato and required the addition of many tonnes of gravel to make them. Other gardens are recognised by the presence of stone rows that were built either for heat retention to encourage plant growth, or simply dumped after they had been cleared from intervening garden plots (McFadgen, 1980b).

Following European colonisation of New Zealand, the history of aggregate use was related to the development of roads, railways and concrete manufacture. Immediately after 1840, communication between the scattered settlements was by sea and by unformed tracks. However, the discovery of gold and the Maori Wars in the 1860s, required better access to inland areas. Roads, some built for military purposes, and railway construction became important. In 1882 the advent of refrigeration expanded the export meat trade and made farming in the more inland areas economic. The arrival of the motor car in 1898 demanded better roads and since 1930 motorised graders, bulldozers, loaders and trucks have revolutionised quarry operations, road construction and the transportation of goods.

Concrete was first used in New Zealand following the importation of cement in casks from Great Britain in 1843. Early use of concrete included the construction of small buildings (1857), bridge piers (1859), a two storey house in Mosgiel (1862), and the valve tower and upstream face of the Karori water supply dam (1873-74). In the early 20th century, concrete was used more widely, notably the pumphouse at Waihi mine (1904), the arch span of the Grafton Bridge, Auckland (1910), and Arapuni dam (1930) (Thornton, 1989; Offer, 1997).

Uses

Aggregate is used in large quantities for roads and concrete, with lesser quantities for reclamation, harbour and river protection (riprap), earth dam construction and railway ballast. In most of these uses the aggregate basically takes up space (bulk), while providing compressive strength necessary in the final product. It also provides special characteristics such as tensile strength, surface texture, density, thermal and acoustical insulation, abrasion resistance, colour, and insulating value, when employed in special uses.

The use of rock or sand for industrial purposes such as plastering, foundry sand, sandblasting and glass manufacture is not included in this account. Dimension stone is also not included.

Minerals and properties

The main characteristics that make material useful as mineral aggregates are bulk, weight, durability and compressive strength, inert chemistry or lack of reactivity, and uniformity of composition. Aggregate materials must be stable against breakdown in use and in stockpiles; free from joint flaws and microcracking; strong enough to withstand loading applied in use (both tensile and compressive); of low porosity and permeability in individual particles and chips; non-plastic; chemically inert in use, not coated with any substance nor polished to a degree where adhesion of bitumen or cement is adversely affected; and not deeply weathered (Grant-Taylor and Watters, 1976; Dolar-Mantuani, 1983).

A large variety of rock types are suitable for aggregate, however some uses may require specific properties that meet stringent standards. For some purposes, such as reclamation fill, most rock types with grains larger than 0.016 mm (silt) are suitable, apart from those that swell, like bentonite, on the addition of water or react chemically with groundwater. Hard, chemically stable rocks are required for concrete aggregate, earth dam construction and sealing chips. Sealing chips for roads need to be resistant to abrasion and chemical attack, rough surfaced to prevent skidding on wet or oily surfaces, and able to bind with bitumen.

Standard tests have been established to determine the suitability of rock for use as aggregate (Table 1) and specifications have been established for various uses. For example, specifications and recommendations for specific applications in New Zealand are published by Standards New Zealand (www.standards.co.nz), Transit New Zealand (www.transit.govt.nz), the Cement and Concrete Association of New Zealand (www.cca.org.nz; de Bock, 1981) and the Building Research Association of New Zealand (www.branz.org.nz). The primary standards for roading aggregate are NZS4407 1991 (Methods of sampling and testing road aggregates), TNZ M/4 1995 (Specifications for base course aggregates) and TNZ M/6 2001 (Specifications for sealing chip). These standards are based on prescriptive rock properties, whereas Transit New Zealand has recently proposed some performance-based specifications (TNZ M/22 provisional 2000) to encourage the use of a wider range of materials for road aggregate.

PHYSICAL TESTS		
		Aggregate grading (size distribution)
		Aggregate shape, angularity, sphericity, roundness, surface texture
		Relative density, bulk density, unit weight
		Water absorption
		Aggregate shrinkage
MECHANICAL TESTS		
	Strength	
		Aggregate Impact Value
		Aggregate Crushing Value
		Ten Percent Fines Value
		Franklin Point Load Test
		Schmitt Rebound Number
	Durability	
		Aggregate Abrasion Value
		Aggregate Attrition Value
		Los Angeles Abrasion Value
		Polished Stone Value
		Slake Durability Value
		Sulphate Soundness
CHEMICAL TESTS		
		Chloride content
		Sulphate content
		Organic content
		Adhesion Tests

Table 1: Standard tests for aggregate (modified after Smith and Collis, 1993, p. 172).

Size

Mineral aggregates are used in many gradations and combinations of particle sizes. Fragment size is determined by use — large blocks of resistant rock (riprap) are needed for protection works on rivers, harbours or shorelines and smaller rocks for railway ballast. In base fill and railway ballast, aggregates may contain a range of particle sizes or gradations in particle size in order to provide stability and high compressive strength when compacted. In roading, a certain amount of non-swelling clay acts as a binder for ungraded material containing rocks of variable size in the basecourse, whereas topcourse and sealing chip material needs to be harder and more selectively size-graded.

Shape is also important, especially in road sealing chip, where rounded faces remaining on crushed alluvium may lower the skid resistance of the road. Rounded, polished surfaces may also not bond well with tar seal. Some very hard rocks may take a polish under wear, lessening their skid resistance. Uniformity of shape is important for concrete aggregate, because flat and elongate particles reduce the workability of the concrete, requiring additional water and cement to be added to the mix.

Inert chemistry or lack of reactivity

In concrete as well as other uses, mineral aggregates should not deteriorate or cause the products containing them to deteriorate, discolour, or degrade. Some rock constituents can cause serious problems and may be responsible for reactivity and chemical changes that impact on the durability of concrete and other aggregate products. These include zeolite veining, opaline silica, chalcedonic chert and matrix glass in volcanic rocks. Other problem constituents are clay, silt, dust, shell, organic matter, alkalis, chlorides, sulphates, sulphides and mica. Of particular note in concrete applications is the alkali-aggregate reaction, whereby there is a reaction between cement alkalis and unstable or non-crystalline forms of silica such as volcanic glass. This reaction can cause cracking in concrete. These deleterious properties, particularly relating to New Zealand concrete, have been discussed by Kear and Hunt (1969), Kennerley and St. John (1969), Watters (1969), Skinner (1970), St John (1988), Cement and Concrete Association (1991), Coote et al. (1994), St John and Frietag (1996), Goguel and Milestone (1997) and Frietag et al. (2000). The main problems are:

1. Expansion and cracking due to the alkali-aggregate reaction of portland cement with acid-to-intermediate volcanic glass, tridymite, chalcedony and opal (Watters, 1969; St John, 1988; Cement and Concrete Association, 1991; St John and Frietag, 1996). Greywacke, and basic volcanic rocks (e.g. basalt and basaltic andesite) are

usually unreactive with the cement alkalis unless glass is present, although basalt containing the alkali feldspathoid minerals nepheline and leucite, such as in some Auckland basalts, may show alkali reactivity (Goguel and Milestone, 1997). Care must be taken in selection of intermediate volcanic rocks (e.g. dacite) for concrete aggregate; acidic volcanic rocks (e.g. rhyolite) are generally unsuitable. Nevertheless, alkali-reactive aggregates may be suitable for other applications such as roading, building stone and asphalt applications.

2. Crumbling due to breakdown of constituent minerals (zeolite and clay in weathered or hydrothermally altered rocks, zeolite in greywacke, and clay in argillite).
3. Rust stains, loss of strength and volume changes that cause popouts and cracking due to oxidation in concrete aggregates that contain unstable iron minerals (e.g. pyrite).

Uniformity of composition

Uniformity in physical and chemical composition permits the design mix to maintain uniformity in the final product.

Special features

In some uses such as decorative surfaces, exposed or exterior walls, or floors, features such as colour, texture, or insulating value of the mineral aggregate are important. Terrazzo not only requires certain colour characteristics, but the surface should also hold a polish. Uniform texture is often important in walls, ceilings, and floors that will have a visual impact. Insulating values are often important in concrete block and lightweight concrete used in walls and floors.

Quarrying methods

Motor scrappers, and hydraulic excavators and dump trucks are used for removing overburden. The quarry face is generally drilled and blasted to fracture and break up the rock. Hydraulic excavators are generally used to load the broken rock onto dump trucks, although small quarries may use wheel loaders in the load-and-carry operation from the face to the plant. In some quarries, such as in many of the Wellington quarries, the rock may be naturally intensely fractured so that blasting is not necessary. The rock is excavated by ripping and blading with a bulldozer or by digging with a bulldozer or hydraulic excavator (Happy, 1993).

River bed, beach gravel and sand deposits are generally excavated directly by hydraulic excavator or loader tractors (Figure 1). Terrace deposits usually require stripping and may need ripping with a bulldozer before removal by a loader or hydraulic excavator.

Processing

Aggregate processing usually involves crushing and screening to produce a variety of products of different particle size. For large and medium operations, processing plants are generally fixed, whereas mobile or temporary plants may be used for sand and gravel operations, small quarries or short-term construction projects. A typical fixed plant, located near an urban area, may have a jaw crusher followed by a secondary cone crusher and a tertiary impactor or shaper, followed by screens. The material may also need to be washed at the screening stages to remove deleterious materials. For example, some New Zealand greywacke quarries have a high water usage for washing, requiring settling ponds and sediment disposal facilities (Happy, 1993). In contrast, a plant processing river gravel may be quite simple and consist of only a jaw crusher and screens.

Markets and transport - place value

Markets for aggregate are heavily dependent on population density and resulting demand for building and highway construction. Transport costs are a significant part of the end price and therefore a local source is desirable. Where smaller quantities of higher-quality rock are required, or there is no suitable local source, a higher unit price may be acceptable and material can be transported greater distances. These factors may determine the quality level of an acceptable rock and the distance it can be transported to an area devoid of suitable rock.

The availability of different types of transportation also has a major impact on the location of production. Quarries located on, or near major transportation routes are often able to reduce transport costs and be competitive in some markets. Truck haulage is the most common mode of transporting aggregate and is the preferred choice for distances up to 50 km. Backhaul arrangements may extend this range. Rail haulage is often used for intermediate distances of 50 km to 100 km, when producers have access to rail connections and stockpiles can be maintained in close proximity to mineral consumers. Water transport by barge or marine vessel is becoming more common for very long haulage, generally over 100 km, where water access is available.

Figure 1. Excavating gravel at the Pound Road quarry west of Christchurch. The greywacke gravel is easily extracted and loaded onto conveyors to washing and sizing plants. Photo: Fulton Hogan Ltd.

In New Zealand, truck haulage is almost the only form of transport used for aggregate. In the USA, 90% of aggregate is transported by truck, with an average truck haul of 50 km. Rail becomes cost effective at a distance of about 60 km. Rail use is slightly higher in the UK, at about 15%. Barging is the least used of the main forms of transport, although in the UK, there is an increase in sea-borne aggregate produced by coastal quarries and barged to cities. In general, road transport is more flexible and there are no intermodal costs. However, environmental effects of road transport and increasing traffic, particularly noise, have to be addressed.

Aggregate producers sell their output to the producers of concrete or concrete products, who, in turn, sell their output to the final contractors, builders, or agencies doing the actual construction work. The mineral aggregate producer is often vertically integrated into the ready mixed concrete or concrete products business. Similarly, many producers of road aggregates are vertically integrated with roading contracting businesses.

World production

Although mineral aggregates generally have a low unit value, their large consumption makes them one of the most valuable mineral resources in terms of total annual production. Per capita consumption in most developed countries is between 3 and 8 tonnes per annum (tpa), and is currently nearly 8 tpa in New Zealand.

World resources are large, although not necessarily at or near the locations where needed. Also, competing land-use and environmental restrictions further limit the quantity of available resources. Access, and quality requirements for some uses, are additional factors.

Substitutes for construction aggregates include expanded clay and shale, perlite, vermiculite, and slag produced during iron and steel manufacture.

Recycling of demolition concrete and asphalt is increasing, especially in large urban and industrial areas. This trend may be driven by increasing environmental awareness and a number of other factors, such as the availability and cost of local fresh aggregate, transport costs from quarry site and to landfill area, landfill fees and the relative quality of each product. Because of the variable quality of the recycled material, it is mainly used for road-base construction, backfill, or for protection works (Wilburn and Goonan, 1998).

Price

Aggregate is a high-volume, low-value commodity. Some representative prices in New Zealand for a cubic metre of aggregate (1.4-1.5 t) at the quarry gate are shown in Table 2. The price difference between the different regions listed is mainly driven by the availability and cost of the resource itself. Around Christchurch for instance, there is an abundance of alluvial resources, hence the lower prices compared with Auckland and Wellington, where aggregate is mostly quarried.

New Zealand occurrence

The aggregate resources of New Zealand have been reviewed previously by Kear and Hunt (1969), MacFarlan and Barry (1991), Happy (1993) and Thompson et al. (1995), and regional reports were provided by Bishop (1966a; Napier; 1966b; Gisborne), Ker (1966; western central North Island), Reed and Grant-Taylor (1966; Wellington), Skinner (1967; Otago and Southland), Skinner (1974; Hauraki) and Taranaki Catchment Commission (1981; Taranaki), and in the series of Geological Resource Maps of New Zealand (e.g. Christie et al., 1994).

The most important resource types used for high quality aggregate are greywacke sandstone, greywacke gravels, basalt and andesite (Figure 2). In areas that are devoid of these rock types, limestone or other rock types are commonly used.

Greywacke

Paleozoic to Mesozoic greywacke, with interbedded argillite and minor chert and volcanics, forms the basement rock and axial ranges of both the North and South Islands (Figure 2). Greywacke sandstone is commonly weathered to varying degrees particularly in the North Island. Where greywacke is unweathered, or the weathered overburden can be easily stripped, the greywacke can be used to produce high-grade roading and construction aggregate, commonly referred to in the industry as “blue rock” or “blue metal”. Massive greywacke is strong and durable. Joint spacing is variable and affects ease of quarrying and size of the product. Argillite is softer, breaks down readily to a pulp of its constituent clays, chlorites and micas, and is unsuitable for use as high-grade aggregate (Reed and Grant-Taylor, 1966; Reed, 1966; Skinner, 1974). Zeolite veining, if present, can cause disintegration under stress. Zeolites are common in the Murihiku Supergroup of the western Waikato and King Country, and in Nelson, Otago and Southland, where these rocks generally produce poorer-quality aggregate (MacFarlan and Barry, 1991). Calcite veins are also deleterious. However, Skinner (1974) noted that the incorporation of clay overburden in the aggregate may be of far greater significance in aggregate degradation than the internal properties of the rock itself.

Greywacke is either quarried or won from alluvial gravel. Breakdown of softer materials during movement in longer river beds results in an easily won, high-grade aggregate that has already been sorted and cleaned by washing. During river transport selective abrasion results in the removal of zeolite veins and coatings, and argillite is rare in the gravels in the lower reaches of the rivers. Roundness of the resulting aggregate produces an easily worked concrete, but smoothness of the smaller clasts can affect bond strength. Gravel extracted from small rivers and the higher reaches of larger rivers yields more angular material, but the argillite content is generally higher.

Product	Auckland area	Wellington area	Christchurch area
Sand	$19	$25	$15
Building aggregate	$24	$20	$10
Roading aggregate	$16	$11	$6.50
Sealing chip	$37	$24	N/a

Table 2: Generalised regional prices per m^3 of aggregate at the quarry gate in 2001 (R. Nyssen pers. comm.)

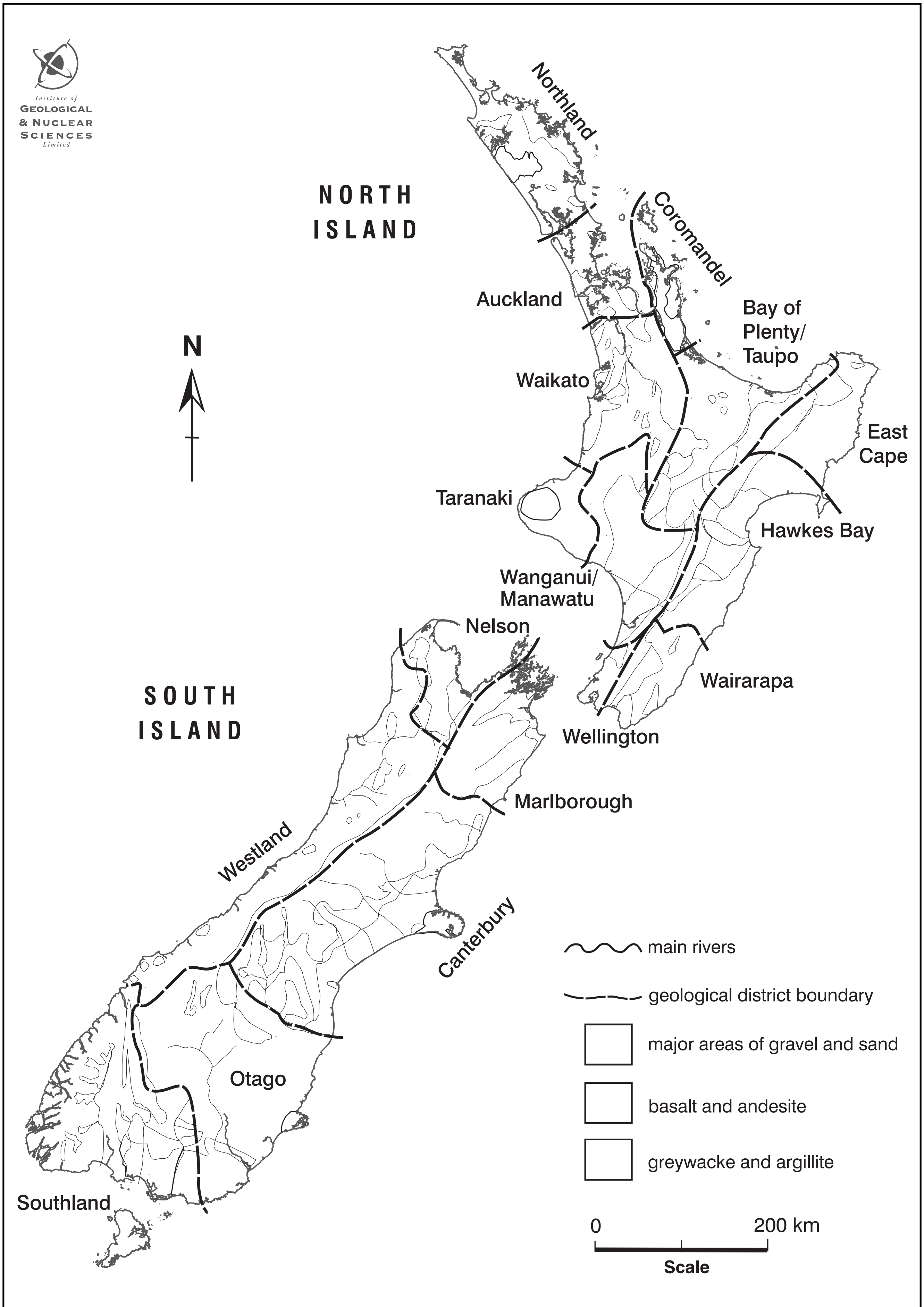

Figure 2. Location of the main rock types used in New Zealand for aggregate and the geographical boundaries used for the regional descriptions in the text.

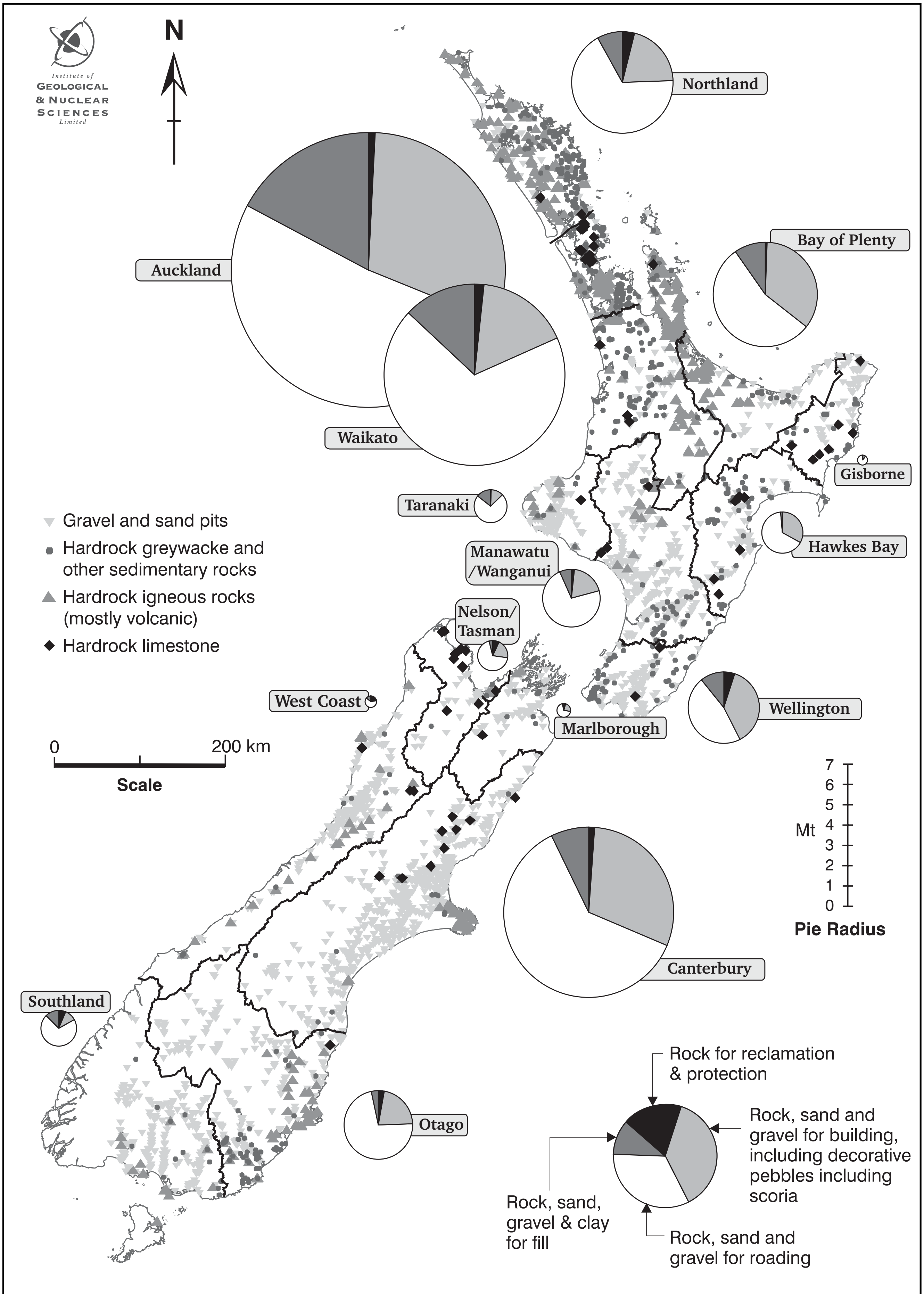

Figure 3. Location of aggregate quarries and pits with recorded production since 1967 (after the GERM database) and pie diagrams of aggregate production in 2000, by region.

River gravels are easily and cheaply extracted, but resources are limited by the rate at which the river can supply material from the eroding hinterland upstream (MacFarlan and Barry, 1991). Excess extraction can result in changes in the river and coastal regimes, such as lowering of the riverbed and erosion of river banks and coastal dunes. In other areas the rivers are aggrading, which may result in serious flooding, and extraction may be encouraged. Unlike many other minerals, alluvial gravel can be considered a renewable resource.

Volcanic rocks

A variety of volcanic rock types are used for aggregate, including andesite, basalt, dacite, phonolite, rhyolite and ignimbrite. Basalt is the preferred rock type, and is quarried in Northland, Auckland, Waikato, Canterbury and Otago. In Northland the most recent flows, from 10,000 to 700 years in age, are mostly unweathered, but the depth and degree of weathering of the surface layers of the older basalt increases with increasing age. Unweathered basalt is also present in the Auckland metropolitan area. Older basalt of Miocene age is exposed in western Waikato, Timaru, Oamaru and Dunedin. Massive basalt from lava flows is used for roading and concrete aggregate, whereas scoria is used for decorative and drainage applications.

Andesite of Tertiary age is quarried in Northland, Auckland, Waikato, Bay of Plenty, Taranaki and Banks Peninsula. Alluvial and laharic deposits are worked in Taranaki. Andesite is used for all grades of aggregate production. Some, however, is suitable only for low-grade products because of the presence of deleterious clay, clay-like minerals or glass. Clays may be formed from hydrothermal alteration and/or weathering, particularly smectites, and clays from overburden may also be incorporated during mining. Smectites result in rapid swelling and rock breakdown to a plastic fines-rich matrix, and clays directly increase matrix plasticity in the aggregate. These deleterious minerals are even more of a problem in dacite and rhyolite. For example, in rhyolites, Skinner (1974) noted that "Hydrothermal alteration producing clay minerals is very common and causes a high P.I. [plasticity index]. High, free SiO_2 as opal and opal-clay mixtures, derived in part by hydration of feldspars and volcanic glass, precludes its use as building aggregate, but do give to some rocks their self-cementing properties" when used in wet, sub-base course conditions. It is generally impossible to get well formed rock chips during crushing and many plastic fines are produced.

Plutonic rocks

Dolerite is quarried in Northland for use in road basecourse and concrete aggregate. Granite and gneiss are used in Westland for riprap and rockfill, and in Southland, granite is also used for riprap. In Southland dunite has been used as road aggregate.

Limestone

Limestone is used mainly for rockfill and riprap. Hard, crystalline varieties are used for road maintenance (but not for sealing chips), where more suitable rock types are unavailable. Argillaceous limestone is used locally on minor roads in Northland. Some limestone may be suitable for concrete aggregate up to strengths of 40 MPa (Happy, 1993).

Schist

Schist in Marlborough and Otago is a minor source of aggregate mainly because its foliated texture and abundance of micas renders it a relatively weak rock. Schist of higher metamorphic grade (textural zones III and IV) has well-developed foliation and mineral segregation banding, which act as planes of weakness that promote mechanical breakdown. Lower grade (textural zone II) and massive schist varieties are more durable and thus make better quality aggregate, particularly riprap.

Sand

Sand is obtained from beach and river deposits, and from near-shore dredging sites, especially on the east coast of the North Island from the Parengarenga Harbour to Gisborne. Also on the North Island, dune sand from the east coast has been used for concrete production, for which purpose the dominant iron sand of the west coast is unsuitable. Gravelly quartz sands of Cretaceous to Tertiary age in inland Canterbury and Otago are processed to produce sand suitable for concrete, masonry and industrial use.

Because of its fine grain size, only a small proportion of dune sand is used in the production of ready mixed concrete. Even then it is blended in with coarse sand. The result of using dune sand alone is a significant reduction in strength and this would need to be corrected by adding more cement, which is costly.

In areas where primary sand resources are scarce (e.g. Wellington), sand is produced as a byproduct of crushing rock.

Production and resources

Aggregate is the most valuable mineral produced in New Zealand. The location of past and presently producing aggregate quarries and pits are shown in Figure 3 along with 2000 production statistics on a regional basis (see Table 3 for the statistics). The regional statistics are based on a geographic cut-up using administrative regions. Total New Zealand aggregate production statistics for the year 2000 and for the years 1967-2000 are shown in Figures 4 and 5 respectively.

Construction and maintenance of roads is the dominant consumer of aggregate, followed by the building industry, and lastly rock for reclamation, fill and protection (Figures 4 and 5).

Production figures over the last 23 years (Figure 5) show a cyclic trend influenced by the state of the national economy and a number of large projects such as hydroelectric dam, housing subdivision and highway construction. For example the high figures in road and ballast aggregate in the late 1960s and early 1970s were related to the Auckland Motorway construction and the Manukau housing subdivision and its requirement for roads. A second boom in the mid-1980s was related to the buoyant national economy and consequent housing subdivision and road upgrading work. Similar trends are exhibited by the figures for building aggregate.

Current total production (Figure 4) is more than 29 Mtpa of which more than 70% is consumed in the North Island. There are a total of about 700 currently producing operations and more than 380 operators. Almost 65% of the total annual production comes from the medium scale operations (50,000-500,000 tpa) that make up only 20% of the total number of operations (Happy, 1993). The small

Use	Reclamation, fill & protection	Building	Roads & ballast	Roads	TOTAL (tonnes)
Material	Rock	Sand, rock & gravel	Sand, rock & gravel	Limestone	
1967	995,576	4,264,995	19,744,076		25,004,647
1968	837,921	5,190,957	20,453,807		26,482,685
1969	2,800,617	5,528,142	19,786,401		28,115,160
1970	1,250,912	5,382,014	21,490,547		28,123,473
1971	2,197,382	5,473,130	20,405,210		28,075,722
1972	625,326	6,464,543	21,245,755		28,335,624
1973	803,010	6,660,232	22,591,859		30,055,101
1974	2,131,953	7,525,424	20,054,246	134,217	29,845,840
1975	3,296,023	6,523,299	16,092,334	241,632	26,153,288
1976	3,737,504	6,068,573	14,716,461	273,782	24,796,320
1977	4,895,683	6,143,256	15,258,506	307,836	26,605,281
1978	2,286,710	4,961,652	15,171,498	250,140	22,670,000
1979	2,427,708	4,652,177	13,189,001	288,942	20,557,828
1980	2,246,198	4,286,350	13,559,413	228,747	20,320,708
1981	2,890,699	4,084,238	13,548,000	311,579	20,834,516
1982	2,324,825	4,169,302	14,153,591	375,482	21,023,200
1983	2,254,032	4,359,349	15,488,875	273,508	22,375,764
1984	2,519,800	5,029,027	16,501,432	359,352	24,409,611
1985	1,912,987	6,046,773	17,891,866	392,855	26,244,481
1986	2,026,836	7,087,270	16,742,999	430,029	26,287,134
1987	1,194,208	5,146,052	13,671,537	323,385	20,335,182
1988	1,358,615	5,806,226	12,455,202	396,817	20,016,860
1989	1,542,781	5,172,462	12,576,730	376,824	19,668,797
1990	2,162,742	4,121,218	12,060,869	410,207	18,755,036
1991	5,238,338	3,486,476	10,460,111	407,213	19,592,138
1992	1,513,640	3,838,213	12,520,311	523,092	18,395,256
1993	1,679,827	4,942,011	13,501,967	597,216	20,721,021
1994	1,075,183	5,218,833	10,862,898		17,156,914
1995	1,326,595	5,125,660	16,100,268		22,552,523
1996	2,673,306	5,733,812	15,274,350	530,212	24,211,680
1997					
1998	3,974,460	6,544,810	15,194,010		25,713,280
1999	3,567,840	6,626,991	16,376,760		26,571,591
2000	3,799,150	7,557,790	18,335,860		29,692,800

Table 3: NZ aggregate production (tonnes) between 1967 and 2000.

- Statistics from Crown Minerals and publications by its predecessor organisations
- No statistics were collected in 1997
- Limestone for roads was not reported in 1994 and 1995, and was incorporated in the Sand, rock, gravel for roads and ballast category in 1998-2000.

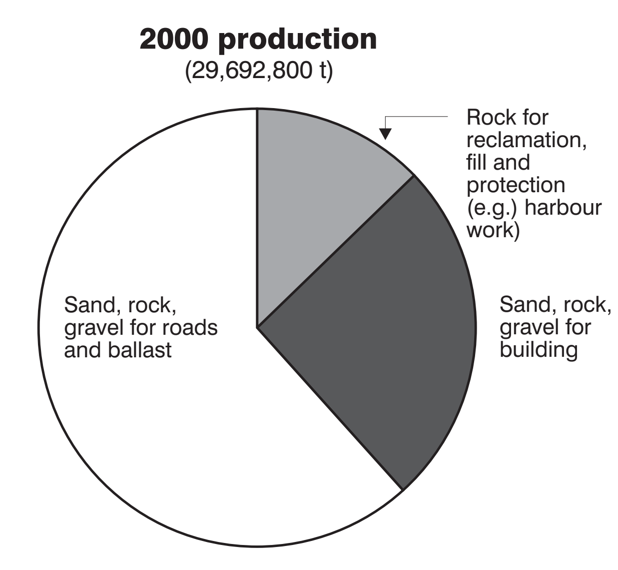

Figure 4. Relative proportion of the different end uses of the aggregate production in 2000 (see Table 3).

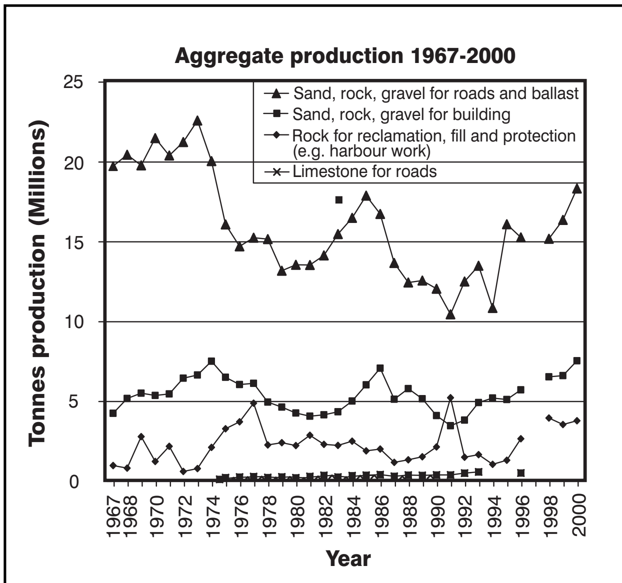

Figure 5. Trends in NZ aggregate production between 1967 and 2000 (see Table 3).

number of quarries with production capacities greater than 500,000 tpa account for about 20% of production, with the remaining 15% or so of production from numerous small scale operations (<50,000 tpa). Many of the smaller operations have intermittent production.

Figure 3 illustrates that most of the aggregate production in the Northland, Auckland and Waikato regions is from hard-rock quarries, whereas the other regions of the North Island have a mix of hard-rock quarries and gravel and sand pits. Most aggregate production from the South Island is from gravel and sand pits. Sand is produced from gravel and sand pits, and as a crushed rock by-product.

Although there are no detailed resource estimates on a national basis, there are extensive deposits of greywacke and volcanic rock to meet future national demand for aggregates. However, the quantity of rock available varies from area to area and there are some areas of demand, such as Taranaki and Gisborne, and to a lesser extent Nelson and Marlborough, where there are insufficient local supplies of high quality aggregate (Coote et al., 1994). Also, the Auckland area, with its large population and consequent high usage, is having to transport aggregate from farther afield as existing quarries are being worked out and nearer potential resources have been and continue to be sterilised by competing land uses (e.g. housing subdivisions).

There are also local problems of matching the variety of products produced to market requirements to fully utilise the resources available in individual operations. Large cities require mostly high quality aggregate for roads and building, and local quarries, particularly in the Auckland and Wellington areas, have difficulties selling lower grade products produced from accessing the high-grade rock or as a byproduct of crushing and sizing operations. For example, large quantities of fines may be produced in rock crushing, and there is insufficient market to use all of this material. Rural areas are better able to utilise lower grade materials in roads that have low traffic densities. Similarly some forestry roads can use very low-grade materials if they are used only periodically.

Most of the aggregate produced in New Zealand is supplied by a small number of major companies, with the large number of smaller producers catering primarily for local demand.

Winstone Aggregates Limited operates 20 extractive hard-rock aggregate sites and several sand, gravel and scoria plants throughout the North Island and three in the South Island. Total output from Winstone Aggregates' operations is currently around 7.5 M tpa, equivalent to about 25% of domestic annual aggregate output. Their 2-2.5 M tpa Lunn Avenue quarry at Mt Wellington in Auckland is the country's largest, but is expected to close in December 2001. As a partial replacement, Winstone Aggregates are in the process of securing consents to open a 1.5 M tpa quarry at Pokeno, with plans to transport most of the product to Auckland by rail.

Fulton Hogan Limited is the South Island's largest aggregate producer, and also has operations in the North Island (www.fh.co.nz). The company operates numerous quarries, with a current combined output of more than 1 M tpa, and its mobile units supplement production from its quarries and provide crushing and screening on contract to local authorities.

Three other large producers are W. Stevenson & Sons Limited (www.stevensons.co.nz), with several quarries in the Auckland area, J. Swap Contractors of Matamata, and Milburn New Zealand Limited (www.milburn.co.nz), one of New Zealand's two cement companies.

The following regional summaries are based on the areas noted in Figure 2, which differ somewhat from the regions used for production statistics shown in Figure 3. From 1967 to 1993, Crown Minerals and its predecessors published annual quarry production statistics, including statistics for most individual operations. From 1994 until the present, the individual quarry statistics are confidential and only regional summaries are publicly available, because of the Privacy Act and commercial sensitivity factors. Therefore, for this national summary, there was difficulty establishing the status of many operations and mostly pre-1994 data have been used.

Northland

In Northland, aggregate is supplied mainly from quarries in greywacke and volcanic rocks, although a wide variety of other rock types are also used. Northland has vast sand resources in coastal dunes and beaches, as well as offshore sands, both of which are utilised in producing sand for aggregate and industrial uses.

Greywacke

Waipapa Group greywacke (Permian to Jurassic) crops out mostly on the eastern part of Northland. Deep weathering results in high overburden stripping costs to access fresh rock (MacFarlan and Barry, 1991). Much of the greywacke is sheared, veined and altered, and therefore only a few quarries can supply a sealing chip to state highway standard. The main quarries in greywacke include Puketona, Otaika, Russell Rd quarry, and Doidge's quarry.

Volcanic rocks

Rangiawhia Volcanics (Cretaceous) basalt and keratophyre have been quarried in the Mt Camel and Karikari areas.

Tangihua Volcanics (Cretaceous-Early Tertiary) form prominent hills northwards from Dargaville and Whangarei. Constituent rock types include basalt, dolerite, gabbro and breccia. Generally these rocks are deeply weathered, and may be highly sheared, zeolitised or hydrothermally altered, with the joints filled with chlorite. Aggregate from the Tangihua Volcanics is generally of poorer quality than the best of the greywacke, so it is generally used as low-grade basecourse or sub-basecourse, or as high-grade fill material. The main quarries include Larmers Road, Masters quarry, Hicks quarry, Dark Creek quarry, and Turiwiri quarry.

Waitakere Group (Early Miocene) is a source of basalt and andesite. Basalt from the Waipoua Plateau is hard and durable, although the chlorite content, which is concentrated along the joints, tends to be high. It may weather to kaolinite. Overburden thickness is variable, but not generally high. Quarries include Tattersals and Clements, north of Dargaville. In southern Northland, andesite has been extracted from Weber's quarry, on Hukatere Peninsula.

Kerikeri Volcanic Group basalt (Pliocene-Holocene), where unweathered, provides good quality aggregate. The weathered zone, particularly in the older basalts, may be more than 30 m thick, which is greater than the thickness of many basalt flows. Quarries include Blackbridge quarry, Puketona, and Kerikeri Irrigation Quarries.

Cretaceous-Tertiary sedimentary rocks

Cretaceous-Tertiary sedimentary rocks, including siliceous mudstone, argillaceous limestone and sandstone have been locally quarried for aggregate. For example, near Kaitaia and Lake Ohia, more than 20 quarries have operated within the shale, mudstone, sandstone, and limestone of the Mangakahia (Cretaceous-Paleocene) and Motatau (Oligocene) complexes, generally producing low-grade aggregate. For example, Motatau Complex shale was produced from Dangen's Shale quarry and Paranui Shale Pit. Sandstone of the Te Kuiti Group has been quarried by the Whangarei Harbour Board.

Sand

The coastal areas of Northland contain very large onshore and offshore sand deposits of Quaternary age. Except for the silica sand of Hokianga North Head, sands of the west coast generally have approximately equal quantities of quartz and feldspar, whereas the east coast sands are silica sands with mostly quartz and minor feldspar (Schofield, 1970; Schofield and Woolhouse, 1969; Applied Geology Associates, 1982). The onshore resources are mostly in dune deposits that are generally moderately to well sorted, and fairly high in silica, with relatively minor shell material or clay. Beach deposits are slightly less well sorted, and are almost always contaminated with small amounts of shell.

On the west coast, large resources of sand are present in the North Kaipara Barrier (80 km long by 8 km wide) and along the eastern shores of Kaipara Harbour, where a deposit at Bradley's Landing has been worked (Officers of the New Zealand Geological Survey, 1970).

Some of New Zealand's largest sand deposits occur on the east coast, within the Aupouri Peninsula, between Cape Karikari and North Cape. The Kokoto Sandspit, which forms the south head of Parengarenga Harbour, is a large deposit of very pure quartz sand, which until recently was dredged mainly for glass manufacture. Ngakengo Beach, just north of Parengarenga Harbour entrance, is a similar quartz sand deposit. Sand has been extracted at Opononi (Northern Sand Ltd), Aupori Forest, the Kaitaia region, and at Ocean Beach (Bream Head).

A major offshore coastal sand deposit extends southwards along 23 km of coast between Bream Tail to Cape Rodney. Between Mangawhai and Pakiri, a suction dredge has extracted sand from a long-shore bar about 200 m offshore, in water depths of 4-8 m. This fine, well sorted sand has been used for building aggregate (Hilton, 1989). Sand for construction was extracted from a sand bar deposit at Waipu River mouth and nearshore deposits at Ocean Beach and in Bream Bay have been dredged in the past (Hilton, 1989).

River alluvium and sand have been worked on a small scale. Many of the Holocene alluvial deposits found in the river valleys have been investigated and worked, particularly in the late 1960s and early 1970s. Many gravels are composed of mainly basalt, dolerite, and volcanic breccia derived from the Tangihua Complex. Some clay-bearing sedimentary rock pebbles are also incorporated, increasing plasticity index, and decreasing aggregate quality.

Auckland

Auckland's aggregate industry is based primarily on volcanic rocks and greywacke.

Volcanic rocks

Basalt lava, scoria, and associated tuff (Auckland Basalt, Franklin Basalt): Many of the Auckland Basalt flows and scoria cones, erupted in the last 60,000 years between the Auckland International Airport and Takapuna, have been quarried for building and roading aggregate. These rocks consist of jointed lavas, vesicular (or frothy) scoria, pebbly lapilli, and ash.

All grades of aggregate are produced with few quality problems. Dense, unweathered lava is crushed for concrete aggregate, sealing chip, ballast, and base course aggregate. The more rubbly and vesicular varieties of lava, scoria, and lapilli have been used for lightweight aggregate, absorbent drainage systems, and temporary roading. Tuff, the associated pulverised ash, is mainly used as fill in land reclamation and construction sites.

In the Auckland metropolitan area, urbanisation is almost complete and quarrying is being phased out (Findlay, 2000). Winstone's quarry at Lunn Avenue, Mt Wellington, has been producing about 50% of Auckland's aggregate requirements, but is expected to close in December 2001. Other quarries in Auckland Basalt are at East Tamaki and Wiri. Scoria is produced at Three Kings, Puketutu Island and Wiri South quarries.

Although the Franklin Basalt of mid-Pleistocene age in the Bombay-Pukekohe-Pukekawa area is more extensive, it is older and more deeply weathered. Its market area lies in South Auckland and north Waikato. Quarries operate at Ridge Road, Bombay and Pukekawa, and there are plans to open another at Pokeno.

Basalt and andesite lava, breccia, and conglomerate of Waitakere Group: Several quarries have extracted basalt and andesite lava, breccia, and conglomerate of the Manukau Breccia (early Miocene). Generally, the material is not of high quality because of deep weathering, but current operations at the Waitakere quarry now produce a full range of high-quality products, and there are considerable resources. This andesite has been used for a long time as an important local source of roading aggregate. Other intermediate quality resources exist, but their extraction is restricted as the bulk of the material lies within regional parks, water catchment areas, or scenic reserves.

The conglomerates contain assorted pebbles and boulders of mainly andesitic material in a poorly sorted sandy matrix. The natural size grading requires minimal crushing and screening. Although specific deposits have been significant producers, the conglomerate is generally not considered a source of high quality material. Difficulties in removing the deleterious matrix material during processing have hindered its widespread use for concrete aggregate and sealing chip. However, if this problem is resolved these deposits will have a greater economic potential.

Tangihua Volcanics: The Tangihua Volcanics are of restricted occurrence within the Auckland area, and limited amounts of aggregate have been quarried. Aggregate from quarries at Mt Braeme and at Flat Top (Kaukapakapa) is used mainly as base-course aggregate for roads.

Sedimentary rocks

Greywacke: Mesozoic greywacke and argillite extends southwards along the east coast of the Auckland area from Cape Rodney to the Hunua Ranges, and includes the Hauraki Gulf islands. Although the greywacke is generally of lower quality than basalt, it is more extensive and represents the largest resource of aggregate in the region. Large quarries are established near Warkworth, Whitford, Hunua, and Drury.

The reddish brown, siliceous mudstone and chert, occurring in a small area in the greywacke-argillite sequence on Karamuramu Island and known in the industry as "McCallum Chip", is popular as a decorative stone for paving slabs, sealing chip, and exposed aggregate.

Crushed, unweathered greywacke is used for base course, concrete aggregate and sealing chip, and the quarry strippings are used for fill.

Albany Conglomerate: Localised deposits of diorite-dominated conglomerate (Miocene), of variable thickness and extent, occur within the alternating sandstone and siltstone sequence of the Waitemata Group. The conglomerate is composed mainly of igneous pebbles in a poorly sorted sandy matrix. When crushed, they produce a high quality aggregate. Small quantities are used for concrete aggregate, plastering and other industrial purposes. The main quarries are at Wainui and Coatesville.

Sand and gravel (shingle): The major sand deposits are the west coast dune sands in the Woodhill State Forest, East Kaipara, from the Kaipara Harbour, and other beach areas, and along the east coast and offshore deposits in the Hauraki Gulf (Schofield, 1970; Applied Geology Associates, 1982). Isolated pockets of shingle (stream gravel) comprising mainly fresh pebbles of greywacke and argillite occur just offshore from many low-lying coastal areas. Many of these deposits have a size grading suitable for concrete aggregate and have been extracted by dredging operations.

The Auckland concrete market is supplied with sand dredged from the sea to the north of Auckland and from the Waikato River to the south. The sea sand is dredged from a depth of approximately 10 m and is then screened to remove shells. This material has been used for concrete-plaster aggregate and trench backfill, as well as to supplement basalt and greywacke aggregates, which, when crushed, are usually deficient in sand fractions and need to be brought to a more complete size grading.

Waikato

Within the Waikato area, most of the quarries and shingle pits are concentrated in the northern half of the area, near the main population centres. Generally, there is an inadequate supply of easily obtainable first-class road-making aggregate (St George, 1959), even if the better quality material is extracted selectively. Poorer quality rock is therefore sometimes used, particularly for applications little effected by those deleterious properties that affect quality (Kear, 1965).

Rock types used for aggregate include greywacke, conglomerate, basalt, river gravel and limestone.

Greywacke

Mesozoic age greywacke forms two north trending belts in the west and central parts of the area, and is the predominant rock quarried for aggregate (Kear, 1965). In the western belt, west of the Waipa Fault, indurated siltstone (greywacke) and mudstone (argillite) (Murihiku Supergroup) are quarried from sites in the stratigraphically lower part of the Kawhia Syncline. The rock is hard, but contains zeolite and is inclined to fritter by wetting and drying. East of the Waipa Fault, Waipapa Group greywacke sandstone and conglomerate are the predominant lithologies quarried, although interbedded argillite is also present. In general, eastern belt rock produces the higher quality aggregate, although much contains prehnite with associated zeolite, which can be deleterious. Because of the swelling-clay content, the proportion of argillite must be kept to a minimum for good quality aggregate. The main quarries in the eastern belt are Whitehall and Taotaoroa, about 15 km and 17 km east of Cambridge respectively. A smaller quarry is worked at Waotu, on the east shore of Lake Arapuni, about 17 km northwest of Tokoroa. Greywacke at Taotaoroa is sheared and has a relatively high percentage of a mineral tentatively identified as zeolite, but this is removed by washing after crushing, producing good quality aggregate (N. Perrin, pers. comm. 2001). The greywacke at Whitehall and Waotu is very siliceous and hard. Blasting and ripping produces some unusual blade-like pieces (N. Perrin, pers. comm. 2001).

Volcanic rocks

Basalt (Alexandra Volcanics Group) is available from stream beds and quarries north and south of Pirongia and south of Te Awamutu in the Pirongia Range and at Te Kawa Hill, in the western part of the Waikato district. The fine-grained dark blue-grey or purple basalt makes first class aggregate when crushed. Overburden is generally thin.

Rhyolite, used in the construction of the Whakamaru and Maraetai dams, was obtained from an extensive boulder bed now submerged by Lake Whakamaru. Similar hard rhyolite was also quarried at Smythe's quarry at Ongaroto. In using rhyolite, care must be taken to avoid the friable pumiceous and glassy rock, present in some places in the outer rind on younger lava domes and flows. Very low-grade material is sourced from ignimbrite and pumice deposits.

Alluvium

Gravel: Alluvial deposits of the Waikato River are worked in the Waikato and central North Island regions. The material is gravelly sand comprising pumice, rock fragments and single mineral grains of quartz, feldspar, dark silicates and magnetite, derived from pumiceous, ignimbritic and rhyolitic rocks. Screening methods produce concrete sand (free of pumice), masonry and drainage sands and fine gravel, and various grades of pumice for horticultural and light-weight aggregate use.

River bed gravel derived from the dominantly soft siltstone and ignimbrite in the southeastern part of the area is extracted in several river shingle and gravel pits and supply most local needs for roading and building aggregate. Pits in the Waikato Lowlands, in the northeastern part of the area, also extract gravel and sand.

Sand: Currently, the main source of sand is from the bed of the Waikato River, with dredging operations at Puni and Tuakau. Much of the Hamilton Lowland is filled with sand derived from the central volcanic plateau and laid down in the several ancestral courses of the Waikato River (Kermode, 1973). Sand, with a pumice impurity, is obtained from the widespread Hinuera Sands of these lowlands (Schofield, 1965) for roading subgrade and building.

Other sources

A non-plastic crystal tuff (Late Miocene age) on the north bank of the Mokau River has been used on secondary roads and has potential for use in highway sub-basecourse (Ker, 1966; Kermode, 1973). Small quantities of crystalline limestone are used near Te Kuiti for secondary roads and for maintenance (Christie et al., 2001).

Coromandel Peninsula

Aggregate supplies for the Coromandel area are derived mainly from andesitic and dacitic volcanic rocks from the Coromandel Range, and from greywacke present in the northern Coromandel Peninsula (Skinner, 1974). Minor sources include limestone, soft ignimbrite, alluvial and beach sand and gravel, and mine tailings.

Sedimentary rocks

Greywacke: The Manaia Hill Group (Jurassic) contains medium hard, dark grey, interbedded mudstone (argillite), siltstone, sandstone, and conglomerate. Only the sandstone and some conglomerate are suitable for good quality aggregate, although sheared mudstone is used for patching and filling of secondary roads near Kuaotunu. Greywacke has been quarried intermittently from several small pits, with significant production from Tahuna and at Black Rock quarry. Resources of sandstone are probably substantial, especially south of Kirita Hill, but access is often poor.

Limestone: A small quantity of limestone from near Colville has been used for aggregate.

Alluvial and beach gravel and sand: A few shingle pits have operated in rivers and streams, and some aggregate has been extracted from coastal sediments. The materials have been used as building and lightweight aggregates.

Volcanic rocks

Andesite and dacite: The Coromandel Group (Miocene-Pliocene) is the main rock unit in the area. Andesite predominates, but the group also contains significant dacite. The different lithologies and textures present, much of which is hydrothermally altered, cause a wide variation in aggregate quality and type. However, volcanic breccia and conglomerate, the dominant Coromandel Group lithologies, are of poorer quality. Thick lava flows and intrusive dikes and plugs can provide high grade aggregate, particularly the columnar jointed rocks of Omahine Subgroup. The Omahine Subgroup andesite is usually well jointed and unaltered by the hydrothermal activity associated with the gold and silver mineralisation. However, because of flow-parallel platy jointing, it produces tabular chips unsuitable for roading aggregate.

Four quarries in Coromandel Group andesite account for a major part of the production of aggregate in the region — McBeths (Omahine Subgroup), Matatoki (Waiwawa Subgroup), Tirohia (Waiwawa Subgroup) and Waitawheta (Kaimai Subgroup). In the Waihi area, Barney's quarry (Waiwawa Subgroup) and Browns quarry (Kaimai Subgroup) supplied much of the aggregate required for mine development at Golden Cross from 1990-1995 (Brathwaite and Christie, 1996).

Rhyolite is used for aggregate where greywacke and good quality andesite are unavailable locally (e.g. in parts of the Whitianga and Tairua areas). Rhyolitic rocks of the Whitianga Group (Miocene-Pleistocene) are subdivided into Minden Rhyolite Subgroup and Coroglen Subgroup. Minden Rhyolite Subgroup has a widespread distribution in the eastern half of the Coromandel Peninsula and includes spherulitic, banded, and pink-grey, crystalline and lithoidal rhyolites, often with glassy perlitic rhyolite and obsidian in the outer margins of domes and flows. Rhyolite has been used locally as fill for harbour protection and for sub-base course.

Coroglen Subgroup contains rhyolitic ignimbrite, pumice breccia, and pumiceous sedimentary rocks. Some production has been achieved, such as a quarry at Opoutere for use on forestry roads.

Mine tailings

Aggregate has been derived from some old mine-tailings for use generally as rubble and fill, for example the Royal Oak, Tokatea Big Reef and Thames mine dumps. Mullock from the Grand Junction Shaft at Waihi was used extensively as basecourse in roads in the Waihi basin.

Bay of Plenty and Taupo

There is abundant, low-grade aggregate material throughout most of the Bay of Plenty and Rotorua areas, but there are inadequate resources of high-grade materials close to

Tauranga or Rotorua (Skinner, 1974). Most production is from hard-rock quarries in andesite and greywacke, although there is also minor production from quarries in rhyolite, dacite and ignimbrite, and from greywacke shingle pits. Production appears to meet local demand. Higher grade aggregate for Tauranga is also brought in from quarries near Katikati and Te Puke (andesite), the Waikato (greywacke), and from Galatea (greywacke gravel) (McFarlan and Barry, 1991).

Volcanic rocks

Andesite in this area provides good concrete aggregate and road sealing chips, and is quarried at many localities. In the Kaimai Ranges, andesitic flows and plugs are extensive, and some of these are accessible and of sufficient quality for high-grade roading and construction aggregate. Some of the largest andesite quarries are in the Tauranga Basin and southern Kaimai Range. Andesite from the southern Coromandel Volcanic Zone provides much of the aggregate used in the Tauranga and Te Puke areas (e.g. Okauia quarry, Wharawhara Road quarry, and Maketu quarry, Poplar Lane). North of Lake Taupo andesite has been quarried at Mokai and at Tauhara Forest quarry (Rolle's Peak Andesite). South of Lake Taupo the only source of quality aggregate is from stream-sorted, laharic material from the Tongariro volcanoes.

Ignimbrite and pumiceous tephra are some of the most common rock types in the Bay of Plenty area. These rocks contain powdery ash, pumice and minor hard rock, but are not suitable for either high-grade roading or concrete aggregate. On road surfaces, ignimbrite rapidly breaks down, but has been used locally because of the absence of more suitable alternatives at reasonable cost (Healy, 1962).

Rhyolite also crops out widely throughout the Bay of Plenty. It is generally inferior in quality to the andesite, but has been used for sub-base material on roads. It is also unsuitable for concrete aggregate because of its reactive glass content and the presence of free silica, as opal, lining vesicles. Rhyolite is extracted in the Tauranga area from the Minden and Mangatawa quarries. Maungatawa rhyolite was used for roading at Mount Maunganui and at Tauranga Airport as a basecourse. Rhyolite from quarries on Mt Ngongotaha and at Lake Okareka, is used extensively in Rotorua. Other smaller quarries near Rotorua also produce rhyolite and pumice for roading and fill material.

Dacite is quarried at the Tauranga quarry (formerly Don Robbin's quarry, Kaitemako) and was previously extracted in the Papamoa area. It was used near Tauranga for lower-grade basecourse. The dacite quarried at Mt Tauhara supplies most of the aggregate requirements of Taupo.

Greywacke

Apart from minor outcrops near Otamarakau, on the Bay of Plenty coast, and at Awakeri, most greywacke resources in the Bay of Plenty area are in the eastern greywacke ranges, remote from population centres. Much of the material in the Urewera and Ikawhenua ranges includes poorly indurated argillite unsuitable for good quality aggregate. The lower levels of the accessible ranges have a thick overburden of weathered rock and volcanic ash. However the gravel from the rivers draining these ranges provides a natural concentration of washed, durable material. Large quantities are extracted at Whakatane (McCoy's Pit), Taneatua, from the Waiotahi River, and in the Murupara-Galatea area (Horomanga River and Waimana River). Smaller quantities are removed from several rivers on the Raukumara Peninsula. East of Lake Taupo the Tauranga-Taupo River carries greywacke gravel.

Sand

The sand used in the Bay of Plenty area is derived from sand dunes at Matata and from harbour dredging at Sulphur Point.

Taranaki

Andesite

The source rock for most of the aggregate quarries and gravel pits in Taranaki is Quaternary andesite volcanic rocks from Mt Egmont. The currently worked deposits are mainly either lahars (volcanic avalanche or debris flows) or river terrace gravels, with lahar deposits (e.g. Egmont Road quarry) closer to the mountain and the terrace deposits (e.g. Waitara River) further away. No *in situ* andesite flows are worked because most lie within the Egmont National Park. In their unweathered state, these rocks are typically hard and are suitable for use as aggregates in a variety of applications. However, because of their relatively high iron (4.2-6.5% Fe) and magnesium (2.5-3.9% Mg) contents and common vesicular (scoriaceous) texture, they weather rapidly to poor quality material.

Aggregate was traditionally extracted from river bed gravels, but increased demand in the 1960s led to over-extraction of many Taranaki rivers. The consequent restricted quotas on river bed extraction prompted major developments of river terraces, lahars, and debris flow deposits.

The chief advantage of andesite is that it is easily extracted, clean, and relatively high quality. However, the andesite is commonly vesicular and glassy which restricts its use as a sealing chip and in concrete, because of the susceptibility of the vesicular and glassy particles to chemical and physical changes such as volume changes due to hydration (Brathwaite, 1997). At some of the quarries, andesite is passed through the crusher up to three times to eliminate the softer vesicular material and produce chips that make road sealing and concrete grade. The main producing quarries in 1997 were at Bell Block, York Road, Egmont Road and Wiremu Road.

Greywacke

High quality greywacke aggregate, particularly for highway sealing chips, railway ballast and concrete, is transported from Pio Pio (near Te Kuiti), Taumarunui or Waikato area sources for use in north Taranaki and from the Rangitikei River for use in south Taranaki.

Other sources

In Taranaki particularly, and in other areas remote from an adequate alluvial or hard-rock source of aggregate, alternative sources have been used. Historically some hinterland roads, e.g. between Stratford and Ohura, were constructed using burnt "papa" or siltstone. Also, Tertiary coal measure conglomerate has provided a range of materials varying from weathered greywacke gravel to pea-sized quartz pebbles. On some marine terraces (e.g. Ureti), and river terraces of the Tangarakau River, small, uniform-sized, quartz pebble deposits are the product of reworked coal measure gravels. Limestone is also used for aggregate.

East Cape

In the East Cape region, especially from Gisborne to Ruatoria, east of the main divide ranges, hard-rock resources, whether river gravel or bedrock, are very scarce. The main sources are limestone and greywacke, and a minor amount of basalt.

Limestone

Hard, recrystallised limestone, of Late Tertiary age, is the main quarry resource of roading and concrete aggregate and other hard fill (Bishop, 1966b). The four main hard rock quarries that work hard, crystalline limestone of late Miocene (Tongaporutuan) age are Waerengaokuri quarry, Huanui quarry, and the two Patutahi quarries.

Small, locally important quarries are in Eocene-Oligocene limestone, Miocene limestone or calcareous sandstone, and Pliocene limestone.

Greywacke

Most of the larger east-flowing rivers drain crushed, mudstone-dominant, greywacke bedrock that forms the western ranges. It is generally unsuitable for roading aggregate. Because the river beds carry limited volumes of gravels, there are a large number of small sites for gravel extraction. Where rivers carry significant amounts of gravel reworked from terrace deposits, the quality of aggregate is poorer.

A quarry at Motuhora is in indurated, alternating sandstone and siltstone (Jurassic to Cretaceous; Moore and Speden, 1974). Early Cretaceous age sandstone and Whangai Formation argillite is also quarried.

Other sources

Basalt: The Karakatawhero River (Hicks Bay) contains a large resource of basalt from the Matakaoa Volcanics (Cretaceous) and some greywacke.

Alluvium: Around the northeastem margins of the Waipaoa Flats (Gisborne) Matokitoki gravel — a silty, unconsolidated gravel of somewhat mixed quality and of late Quaternary age — was probably formed as a deposit of the ancestral Waipaoa River. It is used for hard fill.

Sand, suitable for concrete, is recovered from two Holocene age coastal deposits at Whangara and at Pouawa. Farther north on this coast, sand is generally of lower quality, and unsuitable for use in concrete.

Hawkes Bay

Greywacke

Greywacke ranges in the western part of the region supply major rivers with high quality aggregate. Greywacke is used mainly for roading and building aggregate, for ballast, reclamation, fill, and for concrete manufacture.

Because of the widespread distribution of rivers, and therefore aggregate supply, transport costs can be kept to a minimum. However, over-extraction, as on the Ngaruroro and Tutaekuri rivers, has led to a restriction on the extraction to the replenishment rate. Aggregate from the Mohaka River, and to a lesser extent, the Wairoa River, and beach gravels from Nuhaka, supply northern Hawkes Bay. Sand from the coastal dunes in the Nuhaka area supplies Gisborne (Crabbe, 1986).

Gravels from the rivers draining the Ruahine Ranges, including the upper Manawatu River, supply aggregate to central and southern Hawkes Bay.

Slightly weathered greywacke gravel from old river terraces has been extracted from some areas. The weathering results in a characteristic reddish-brown colour, hence the common name "red metal" for this material. Although it is of poorer quality than fresh, river gravel, it can still be successfully used as basecourse with lime stabilisation, as sub-base and as loose metal on roads.

Limestone

Limestone for roading is mainly obtained from the coquina limestones of the area. In remote areas of the eastern highlands to the south of Napier, such as around Wallingford and Omakere, Miocene algal limestone has also been used as aggregate for road metal with good results (Moore and Belliss, 1979; Moore and Hatton, 1985).

Wairarapa

Greywacke gravels carried by aggrading rivers draining the Tararua Range constitute the main source of high grade aggregate in the region. Limestone is also used locally.

Greywacke - alluvium

Gravel is obtained primarily from pits along the Ruamahanga and Waingawa rivers near Masterton, the Waiohine River near Greytown and the Tauherenikau River near Featherston. Potential resources are large.

Extraction of gravel from older river terraces is, at present, very limited, but resources are large and deposits are more widely distributed. However, the heavily iron-stained gravels may prove unsuitable for building aggregate. Some small gravel deposits in eastern parts of the region are generally inferior for roading, but the high cost of transportation from sources in the west makes their use reasonably cost-effective.

Limestone

Limestone is used for roading in northern Wairarapa and there is considerable potential for use of hard coquina and flinty limestone for aggregate in southern Wairarapa (Moore, 1975). Hard coquina limestone is probably more suitable for base course than for surface chip. Large blocks of rock, suitable for the protection of river banks and eroding coastal dunes, are available from some limestone quarries and from natural outcrops.

Algal limestone near Pongaroa and in the Tinui Valley was previously quarried for local roading material, but despite the existence of a significant resource the quarries have not been re-opened.

Sandstone and conglomerate

Sandstone, siltstone and conglomerate of Pliocene and Pleistocene ages are potential sources of road metal.

Wanganui and Manawatu

Aggregate is obtained from a variety of rock types, principally Mesozoic age greywacke and argillite either from hard-rock quarries or derived from the main ranges and carried as gravel by Holocene age rivers. Shell limestone and shell conglomerate are also quarried.

Greywacke

Almost all the quarries sited in Mesozoic greywacke and argillite are in the Tararua Ranges in the southern Manawatu (Horowhenua) area. Unweathered rock is mainly restricted to coastal cliffs, steep escarpments, and deep gullies, and the distribution of quarries reflects this. There is little massive greywacke. The softer argillite contains many microfractures, and it produces a flat, angular aggregate which is susceptible to weathering and breakdown, both in stockpile and in use. Concrete using argillite aggregate is more difficult to work and has a lower maximum strength (Rowe, 1980).

The main source of aggregate is from the rivers draining the main greywacke ranges to the east. Good quality, low cost, greywacke aggregate is obtained from the alluvial gravel forming the present-day floodplains and adjacent river terraces, mainly from the Wanganui, Whangaehu and Turakina rivers, and high grade aggregate from the Rangitikei River (Ker, 1966).

Near Taumarunui, aggregate, mainly greywacke gravel, is recovered from the upper Wanganui River and its tributaries. In the Wanganui and Rangitikei areas the aggregate consists mainly of greywacke and andesite, with a minor amount of rhyolite and pumice, mainly in the finer fraction of the sediment. Most aggregate produced in the Manawatu district is from present-day flood plain gravel of the Rangitikei River, where the gravel is well rounded, with a minor amount of andesite. Palmerston North also receives greywacke aggregate from the upper reaches of the Manawatu River in Hawkes Bay. Southern Manawatu is supplied with gravel from the Otaki River.

Limestone

Coquina limestone and shell conglomerate in the Waitotara area have been used locally for base course and on country roads.

Sand

Sand is a by-product of hard-rock quarrying and gravel extraction (e.g. Otaki). It forms Holocene age dunes (Himitangi Group) and the interglacial beach and dune deposits along the west coast of the Manawatu and Horowhenua districts. However, environmental considerations and transportation costs effectively rule out the use of these deposits.

Wellington

In the Wellington area, greywacke is the only source of aggregate, either from quarries in hard rock of Mesozoic age or from Holocene age alluvial gravel. The hard-rock resource is large, but is constrained by the location of the sandstone facies as opposed to the siltstone-mudstone variety, and to the land available for quarrying. The widespread crushing of the greywacke limits the maximum size of the aggregate produced, especially where the quarries are located near faults. Major quarries are Dry Creek, Belmont (Figure 6), Horokiwi and Kiwi Point (Ngauranga Gorge). These quarries are all close to and on the upthrown side of the Wellington Fault, where uplift has exposed fresh unweathered greywacke. Other large quarries are working near Plimmerton and Waikanae on the west coast. The Owhiro Bay quarry on the south coast of Wellington was closed in the late 1990s. The other local quarries have managed to offset the loss in production from the Owhiro Bay quarry, but a shortage of accessible resources is expected in the next 20 or so years unless a new quarry is opened (G. Cunningham, pers. comm. 2001).

Gravel has been extracted from the Hutt River, but, in the 1960s, over-extraction was recognised and quantity limits were imposed (Reed and Grant-Taylor, 1966; Grant-Taylor and Watters, 1976).

Large sized rocks suitable for riprap are relatively scarce in the Wellington greywacke deposits, although both Belmont and Horokiwi quarries produce some large joint blocks as riprap. Large greywacke boulders, used in protection works along the Wellington Urban Motorway and harbour reclamation, were obtained from raised beaches between the Orongorongo River and Cape Turakirae. Greywacke from quarries near Owhiro Bay was used in protection works for the Wellington Airport, and riprap from the Waingawa River near Masterton was used in the Upper Hutt Bypass Road (River Road). Large blocks of dolomite were barged from Golden Bay, Nelson, for protection work in the Hutt River and Seaview marina (Figure 7). Grant-Taylor and Watters (1976) noted that a medium-jointed greywacke on Haywards Hill Road would be suitable for use as riprap.

Gravel and sand have been obtained from present-day beaches between the mouth of the Orongorongo River and Pencarrow Head and between Owhiro Bay and Tongue Point, and from raised beach ridges at Fitzroy Bay. The gravel extracted from the beach near Owhiro Bay was initially quarried from a steep greywacke cliff and bulldozed into the sea. Longshore drift carried the material along the beach and abrasion produced a well-rounded aggregate (Anon, 1987).

Figure 6. Belmont Quarry, Lower Hutt produces greywacke aggregate, asphalt and ready mix concrete. Photo: Winstone Aggregates Ltd.

Figure 7. Riprap forming a breakwater for the marina at Point Howard, Seaview, Wellington. The blocks of Mt Burnett dolomite were barged across Cook Strait. Photo: Tony Christie.

for roading and fill. The aggregate produced is of suitable quality provided the rock is not too fine grained and is free of zeolite veins. The green volcanogenic sandstone in the Stephens Subgroup is a high quality aggregate (Rattenbury et al., 1998).

Schist is quarried for aggregate in central Marlborough. Non-foliated schist is used mainly in roading and for ballast. Foliated schist tends to split into tabular fragments making it unsuitable for aggregate. Selective abrasion during river transport results in a predominance of quartz-rich, schist-derived, alluvial gravel that is more suitable for use in aggregate.

Miocene conglomerate is quarried on the Taylor Pass Road in Marlborough, and dolomite from Mt Burnett has been quarried for riprap and used in the Wellington region.

Sand is dredged from the mouth of the Hutt River and from Porirua Harbour.

Nelson and Marlborough

Aggregate for the Nelson area is from several sources, and there is a shortage of high quality material, especially for Nelson city. The main sources are from hard-rock quarries and alluvial material from river beds or gravel terraces. Hard-rock quarries have increased in importance over the last few years, to balance decreasing production from alluvial sources.

Alluvium

Rivers draining hard rocks, for example, greywacke (Torlesse Supergroup) in the Wairau River, volcanogenic sandstone (Maitai and Pelorus groups) in east Nelson, and lower Paleozoic age sedimentary rocks in the west, give the highest quality aggregate. Schistose rocks of the Richmond Range and the ultramafic rocks of east Nelson, the weathered Moutere Gravel, and Separation Point Granite produce inferior material. Because of extensive weathering of the Separation Point Granite in the lower Motueka catchment, the lower Motueka River transports a relatively high proportion of sand.

The most easily obtainable and highest quality deposits are the beds of the major rivers, but in the Nelson, and to a lesser extent the Motueka areas, demand exceeds the rate of replenishment. Consequently gravel from the Waimea River system and from the lower Motueka River is restricted for use as high quality aggregate and sealing chips. Gravel has also been extracted from the Waimea Plains, both from floodplains and aggradation gravels forming terraces. The main rivers of the Marlborough area, especially the Wairau River and adjacent river terraces of Late Quaternary age, form the main supply of sand and gravel in Marlborough. There is a plentiful supply of aggregate in the Awatere, Clarence and other aggrading rivers south to near Kaikoura.

Hard rock

Indurated sedimentary and volcanic rocks of the Paleozoic-Mesozoic Brook Street Volcanics, and Maitai and Pelorus groups, are used locally in east Nelson and Marlborough

Westland

There are relatively few quarries in hardrock that produce aggregate in Westland owing to low demand. The bulk of the aggregate for roading is easily recovered from river alluvium, supplemented by smaller amounts from glacial outwash and alluvial terrace deposits.

Hardrock quarries

Aggregate is quarried from accessible outcrops of Greenland Group greywacke (Cambrian-Ordovician), Karamea Granite (Carboniferous-Cretaceous), Mt Arthur Marble (Ordovician), and Nile Group limestone (Oligocene-Miocene).

Sedimentary rocks

Alluvium: Easily worked gravel deposits of Holocene or Quaternary age consist of:

(a) glacial outwash and till deposits,

(b) raised beach deposits along the coastline,

(c) aggradational river terrace deposits (e.g. along the Buller, Grey and Hokitika rivers),

(d) modern river and stream channels and banks, and

(e) tailings from placer gold workings.

River alluvium, principally derived from Greenland Group greywacke and Devonian and Cretaceous granite and Torlesse Supergroup greywacke, along with locally derived gneiss and schist, provides the main source of aggregate west of the Alpine Fault.

Generally, in the north of the area, the Greenland Group is the major source of greywacke, whereas in the central and southern parts Torlesse and Haast Schist terrane detritus is supplied by rivers flowing from the Southern Alps. Gravel in the Grey and Buller river systems contains a high proportion of granitoid rocks because of the close proximity of the granites of the Karamea and Paparoa batholiths. At Charleston deposits consist mostly of gneiss. Near Ahaura gravels consist of greater than 80% greywacke, derived from the Torlesse Supergroup, and less than 20% granitoid rock.

Riprap: Frequent washouts and high flood levels on West Coast rivers make a continual demand for riprap for river and coastal protection work. Natural, large river boulders and large quarried blocks of granite, limestone, and lesser amounts of sandstone and schist are extracted from many of the same quarries and pits as aggregate or dimension stone, or from specific riprap quarries when required. In order to keep cartage costs to a minimum, a network of quarries is spaced approximately 40 km apart along the main roads.

The main source of riprap in southern Westland is the Haast Schist, with smaller contributions from Greenland Group greywacke and Tuhua granite. In areas distant from sources of solid rock, however, schist boulders in glacial outwash and river alluvium have been used. Otitia Basalt has been quarried for riprap adjacent to the Karangarua River. Limestone is rarely used for aggregate, although that from the Grey River is used for river protection.

Sand has been worked from deposits of the Little Totara Sand (Eocene).

Canterbury

Greywacke

The dominant source of aggregate is Torlesse Supergroup greywacke (Paleozoic-Mesozoic) of the Southern Alps, either directly from accessible outcrops or indirectly from river gravel. The region's rivers are continually supplying more material, and the resource is considered to be "inexhaustible" (Canterbury United Council, 1984). Supplies of aggregate are obtained predominantly from Torlesse-derived glacial outwash and river alluvium of the Canterbury Plains. The gravels, in particular, provide a cheap supply of readily accessible, high-quality, non-reactive aggregate for roading and concrete purposes. Quarrying operations are concentrated on the beds of major rivers, and numerous pits adjacent to main roads and towns are worked on an "as required" basis. The Pound Road quarry in Christchurch is the largest in the region and works gravels from a series of pits that are now one operation (Figure 8). Several central city parks in Christchurch were once the sites of aggregate quarries, which later were infilled with refuse. On Canterbury Plains, riprap from river beds and older river terraces has been used for construction of stop banks and flood protection barriers (e.g. groynes along the Waimakairiri River, north of Christchurch).

Few hard-rock quarries are worked. The most common rock type produced is greywacke, with lesser schist and basalt. The greywacke and basalt generally give good aggregate on crushing, except where weakened by alteration effects and by veins.

The construction of hydro-electric dams on the Waitaki River system required large quantities of aggregate. Most of the aggregate is extracted from alluvial gravels, either in existing river channels or in Quaternary terrace deposits and moraines. An estimated total of 115 Mt of earthworks materials were used (1971-1982) in the construction of the canals and dams of the Upper Waitaki Power Development. Approximately 1.75 Mt of aggregate, from a pit in outwash gravel at the southeastern end of the nearby Lake Ruataniwha, was used in the construction of concrete structures. A variety of gravel types, mainly from glacial outwash gravel and fan alluvium, were used to build the embankment, the dam core and the impervious canal lining and sub-lining. All materials were obtained locally within the Mackenzie Basin, where the maximum haulage distance was 15 km.

Limestone

Limestone also provides a useful source of aggregate, mostly from Amuri Limestone, with contributions from Isolated Hill Limestone, Hanmer Marble and Thomas Formation.

Andesite and basalt

Aggregate has been produced from volcanic rocks of Banks Peninsula and the Harper Hills, for example the large Halswell quarry in Port Hills Basalt. Basalt of the Lyttelton

Figure 8. Pound Road quarry west of Christchurch is the largest alluvial gravel pit in New Zealand. It produces about 40 different aggregate and sand products. This concrete aggregate and chip processing plant is one of three plants in the quarry. Photo: Fulton Hogan Ltd.

Volcanic Group is quarried for use as riprap in harbour reclamation and mole construction. Near Timaru basalt blocks have been used for river and coastal protection.

Schist

Schist is generally unsuitable for high-grade aggregate because of its relative softness and foliation. Moderately hard schist as cobbles in gravel can be found along the larger rivers and is preferable to quarried material. Some deposits of schist gravel include quantities of mica sand as fines, and these should be screened out where fill material or base course is required because of potential instability.

Sand

Sand has been quarried principally from Broken River Formation and Southburn Sand. The Broken River Formation has been worked at Whitecliffs, Mt Somers and Omihi (van der Lingen and Field, 1985). There is also an abundant resource of sand at Birdlings Flat (Browne and Wezenburg, 1988).

Otago

Otago is reasonably well supplied with aggregate. Greywacke gravel from the Waitaki River supplies North Otago, river and terrace gravels supply Central Otago, and greywacke quarries and gravel pits serve South Otago.

Greywacke

In south Otago, greywacke of the Tuapeka and Waipahi groups (Paleozoic) is the main source of aggregate. Where fresh and unaltered it makes good road aggregate as at the Balclutha quarry. The Murihiku Supergroup greywacke and argillite (Mesozoic) are softer and contains zeolite minerals. It is used for base course and on minor roads.

Schist

Schist is a minor source of aggregate, as its foliated nature renders it unsuitable for crushing. It is used for river protection riprap and for dimension (facing) stone. Haast Schist has been quarried for aggregate in northeast Otago and is also a component of many of the Holocene gravel deposits.

Basalt and phonolite

The basalts and phonolites of the Dunedin Volcanic Complex are a major source of high-quality aggregate. Material is quarried from Logan Point (Palmers, North East Valley) and Blackhead, and from several smaller quarries. The rocks are hard and polish readily. Uses of Logan Point basalt include sealing chip, but the low polished stone values make the material unsuitable for some sealing chip applications, which are catered for by greywacke aggregate from the Balclutha quarry.

Alluvial gravel derived from greywacke and schist

Older gravels tend to have a higher clay content, and, especially in the schist-derived material, the proportion of weathered and unstable rock rises with the increasing age and depth of weathering of the rock type. The ready breakdown of schist prevents its use as a sealing chip or as a concrete aggregate. Greywacke for sealing chips is available from alluvial gravel near Oamaru.

Gravels of the Taratu Formation (Late Cretaceous-Oligocene) quartz pebble conglomerate and Silverstream Gravels (Late Quaternary) are used on country roads where traffic is light, and as highway base course (Skinner, 1967). Taratu Formation material is also used as building aggregate.

In the Te Anau Basin, the most resistant gravels are those from the Holocene age, river flood plains. Road works use outwash gravels from small pits, and sealing chips are produced from a few sources where the gravel is specially treated.

The Queenstown area is well endowed with aggregate resources in most of the major valleys. Most gravel pits work alluvium in modern river beds or Late Quaternary fluvioglacial terraces.

The massive construction programme at the Clyde Dam used the old dredge tailings at Earnscleugh as aggregate. These ready-washed and screened, young, outwash gravels were further screened.

Sand

Sand and gravel from the Taratu Formation, Caversham Sandstone (Early Miocene), and local beaches has been used for building material. Much comes from the Fairfield-Walton Park area (Williams, 1974).

Southland

Greenhills, Caples, Maitai and Murihiku groups

Greenhills Group tuff (Permian) has been used in large quantities for local road, railway, and harbour work. The rock is extremely hard and resistant to weathering, and is suitable for road or concrete aggregate (Skinner, 1967). Caples Group (Permian-Triassic) greywacke also generally makes good aggregate. Maitai Group (Permian) and Murihiku Supergroup (Permian-Jurassic) sandstone and conglomerate are zeolitised and not normally suitable for high-grade aggregate, but they have been used in applications where lower grade material is acceptable (Skinner, 1967).

Bluff Norite

Bluff Norite has been quarried for aggregate. Although suitable for basecourse roading work, the presence of zeolite veins and the coarse grain size make it unsuitable as coarse aggregate or for sealing.

Alluvial gravels

Alluvial sand and gravel are abundant in the river beds and terraces of the Southland Plains, and have been used for roading, construction and horticulture. High-quality aggregate is present in the Mataura and Oreti river plains.

Large quantities of quartz gravel and sand accompanying the Gore Lignite Measures (Miocene) are available at Grove Bush, Pebbly Hills, Waimumu, and Waikaka. The gravels have been used locally for roads and paths, and for decorative ornamental facings (Wood, 1966; Skinner, 1967).

Large resources of quartz gravel of Late Quaternary age form raised beaches at Awarua Bay and Woodend. The gravels have been used for roads and may be suitable for concrete aggregate. Terrace gravels have been extracted from the Ardeer Burn Gravel Pit for fill, and for metalled roads (Skinner, 1967). The material consists of loosely compacted, round, resistant pebbles of diorite, granite, gneiss, and schist, in sand and silt that is easily worked. Fiordland-derived granitic and gneissic gravels, mixed with greywacke and volcanic rocks, are available in large quantities from Late Quaternary terraces and Holocene alluvium in the Waiau River valley. The material, a good, resistant aggregate suitable for roading (Wood, 1969), is worked in a number of places. Aggregate was extracted from the head of West Arm, Lake Manapouri, for the Manapouri Hydroelectric scheme.

Stewart Island

The settlement at Half Moon Bay is without a permanent source of aggregate for either roading or for concrete aggregate. Small quarries around Half Moon Bay have produced granite and diorite aggregate, but weathering has reduced the quality of the rock. Granite and diorite from the Anglem Complex have been quarried at Horseshoe Bay, but further quarrying and processing of this and other suitable rock close to the settlement is constrained by the small size of the island community (Doole et al., 1989). Some aggregate has been brought from the South Island.

Recycling

The recycling of demolition material, mainly large blocks of concrete, is becoming acceptable for river and inner harbour protection. Blocks of demolition concrete and brickwork have been used as riprap for protection of reclamation works along the western side of Wellington Harbour. In the Auckland region, there are currently about a dozen companies that crush concrete for use as roading and concrete aggregate, the largest being Ward Demolition and Adam's Landscaping Ltd. Adam's Landscaping Ltd had sales of 40-50,000 t in 1999 (Calvert, 2000).

Substitutes

Substitute materials may be a necessary source of aggregate for those areas distant from an acceptable resource. The burning of mudstone for road aggregate in the remote parts of Taranaki has been mentioned.

Slag from the Glenbrook Steel mill is made into artificial aggregate by SteelServ Ltd. Two types of slag are produced. Iron-making slag, termed Melter Slag, is similar in appearance to vesicular volcanic rock such as scoria and is used in a crushed form as road making materials as well as a variety of drainage aggregates and clean fill materials. Trials and long term service use have shown that this slag is zeolitic in nature, with the ability to filter water on the molecular level. As a result, the material has been used as filter beds in two municipal waste-water treatment plants and is being trialled by NIWA as filter materials for processing dairy shed effluent.

Steel-making slag, termed KOBM slag, is in a powdered form similar to lime and cement. The principal end use is for road stabilisation in highway construction, developed over a number of years by Hiway Stabilizers in Albany. Smaller quantities of KOBM slag are also used as a soil conditioner in the horticultural business.

Lightweight aggregate has been manufactured by firing expansible clay and shale. Perlite, an artificial pumice, is formed by heating glassy rhyolite. It has been used in New Zealand as an inert, insulating material and as a potting mix.

Exports/imports

Overseas trading in sand and gravel, in both exports and imports, is small. In 1998, 44.7 t of quartz and silica sand worth $7,536 (FOB) and 6,203 t of gravel and pebbles, worth $1,267,748, were exported. The sand was exported mainly to Taiwan (40 t, $5,098), and American Samoa (2.35 t, $700), and the gravel and pebbles mainly to USA (1,462 t, $847,610) and Australia (4,307.3 t, $227,048).

Imports grossed 62,436 t worth $4,749,682 (CIF). Quartz and silica sands were imported mainly from Australia (61,109.2 t, $3,636,787), Norway (700 t, $504,788), USA (202.3 t, $319,220) and Spain (331.4 t, $223,674). Gravel and pebbles were bought mainly from USA (36.4 t, $1,249), China (25 t, $10,026) and Australia (13.6 t, $10,023).

Future trends

The demand for aggregates is a function of the level of activity of the construction industry, which is in turn dependent on the economy. There are likely to be continuing problems of urban encroachment on existing deposits, forcing longer distance haulage and increased delivery costs in many urban markets. The Auckland area, with its large population and consequent high volume of use, is now trucking aggregate from farther afield as existing quarries are being worked out. An important factor is the general increasing demand for road transport and ability of the road systems to cope with increasing road traffic and associated noise problems. Road congestion on the Auckland Harbour Bridge will effectively divide the Auckland market into northern and southern zones (George Cunningham, pers. comm., 2001). The northern zone will require sources from the north, where there is currently an inadequate supply of high-quality aggregate to meet this expected demand. There may be potential to barge aggregate in from distant sources such as the Coromandel Peninsula to serve both the northern and southern markets of central Auckland.

In the southern Auckland area, the declining available basalt sources are being replaced by quarries in greywacke (Findlay, 2000). However, these greywacke quarries have overburden and low-grade material that must be excavated to access the high-quality unweathered "blue" rock. Markets need to be developed to utilise this lower grade material.

The establishment of new quarries is becoming increasingly difficult and taking longer periods of time from exploration to permitting, because of increased controls on development and increasing requirements for consultation with landowners, Iwi, regional government, and other regulatory authorities. This trend must be balanced with longer term planning and earlier identification and permitting of new quarry sites to avoid a gap in local production between the closing of major operations and opening of new replacement sites.

There is an increasing demand for higher levels of quality assurance in aggregate producing operations and some of the largest operators are now Telarc registered and operating to ISO standards.

Increased environmental controls (e.g. dust, noise, water quality) on operations in the last 20 years have increased compliance costs and thereby raised the cost of production. Some companies have taken a pro-active approach to environmental issues, establishing company environmental policies and in some instances internally operating to the international ISO 14001 standard.

Transit NZ is developing new standards for sealing chip that requires a higher proportion of broken faces than in the material currently used. Many operators that produce sealing chip from alluvial material expect to have difficulties meeting this standard, which may marginalise some production and, in others, cause the production of increased fines because of the increased amount of crushing required to meet the new specifications.

Worked-out stone quarries can be used as water reservoirs, storage sites, recreation facilities, or as landfills. Reclaimed sand and gravel operations will become increasingly valuable as sites for residential and commercial development after extraction of the mineral values.

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