

ECONOMIC GEOLOGY OF THE WAIKATO

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Abstract

The Waikato contributes between 20 and 25 per cent of New Zealand's mineral production.

Aggregate from Mesozoic rocks ranges from good (greywacke) to poor (argillite), with detailed differences being related to the position of the deposit within the New Zealand Geosyncline. Tertiary sediments show rapid facies changes that are reflected in the variability of important coal and limestone deposits. Petroleum and natural gas prospects are marginal at best. Upper Cenozoic deposits include sand, ironsand, pumice, perlite, aggregate, and building stone.

Ground water is of vital importance, and is warm or hot in some areas. Good clays are available.

INTRODUCTION

Since the palmy days of major exports of gold and kauri gum, the New Zealand mineral industry has settled down to providing essential mineral raw materials for local consumption, both regionally and nationally. In this new scene, the Waikato Region is most important, for it provides between a fifth and a quarter by value of New Zealand's total annual mineral production.

Economic Geology is the science that studies mineral resources. It should describe their location, quality and quantity, and particularly should explain these features within the particular geological environment. Thus it should assist in understanding the origin and variability of deposits, in discovering extensions and entirely new areas, and in forecasting the probable value of concealed resources as a guide to the economic expediency of a prospecting problem. It should also attempt to keep ahead of demand, and consider what new uses might be found for presently produced materials, and what unexploited minerals and rocks might have some unrealised potential. Thus this present study describes the essential features of the geology not only of the Waikato Basin itself, but also of the surrounding hills. This is necessary, firstly because an understanding of their geology is essential to understand fully that of the Basin itself, and also because the surrounding area supplies certain essential mineral products that are used in industries of the Basin, or that are complementary to the minerals found there.

An attempt is made here to describe the mineral resources at lengths compatible with their value rather than their glamour.

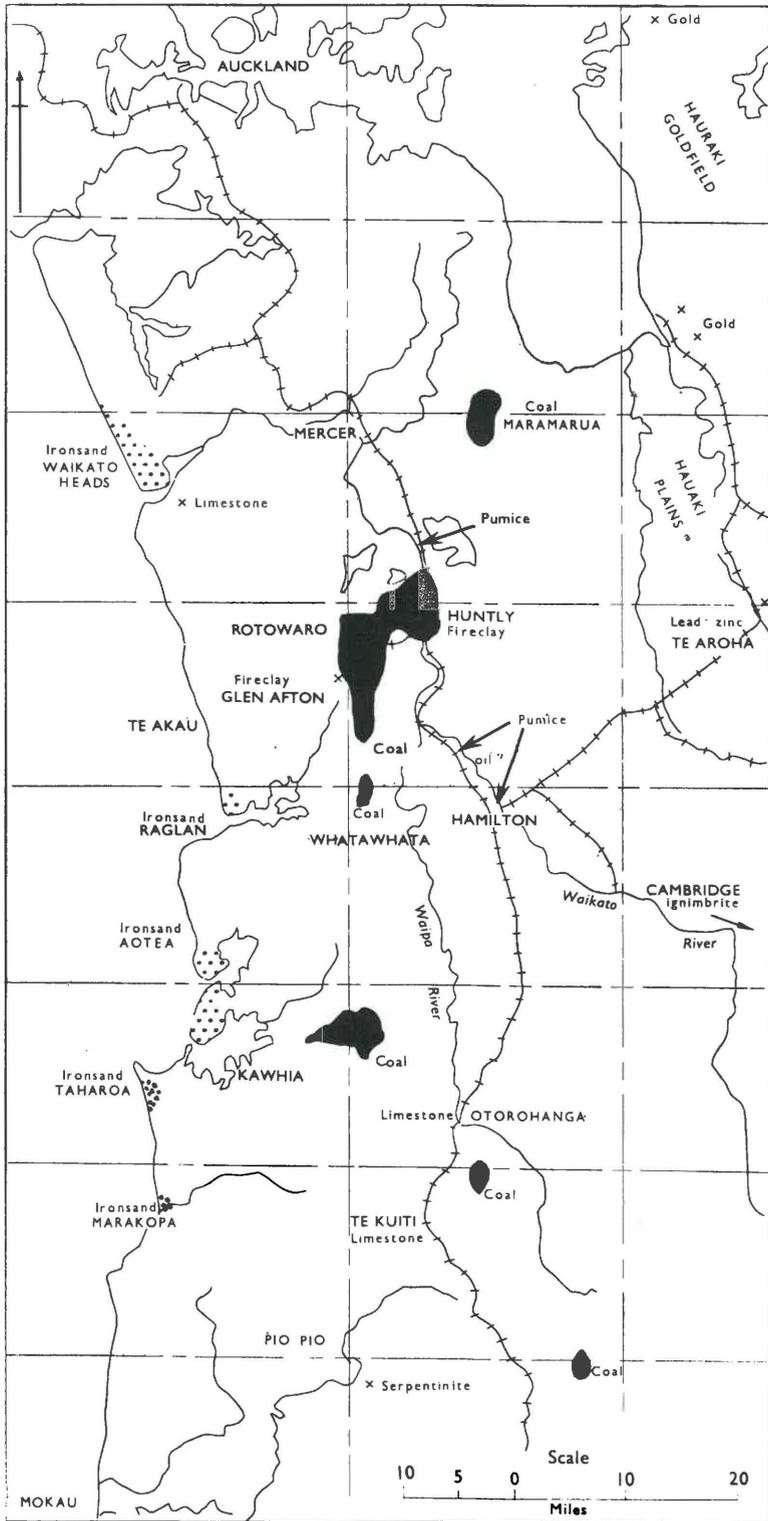


Figure 1 shows the distribution of the main deposits.

GEOLOGICAL SUMMARY

The rocks of the Region can be usefully divided into four major units. Hard, Mesozoic, broadly-folded, wacke-type rocks, originating in the New Zealand Geosyncline, form the basement of all areas, and are exposed in the eastern and western ranges. They are overlain, unconformably, by softer, Tertiary, gently dipping, sedimentary rocks which are exposed in the western hills, and lie concealed below some of the central lowlands. These central lowlands are floored by near-horizontal upper Cenozoic sediments, largely deposited by the Waikato River and its ancestors, and largely derived from the fourth group of rocks—the Upper Cenozoic volcanics, some of which appear in the hilly ranges surrounding the Waikato Basin.

Some mineral resources are associated with each of these units, and a further group of minerals, of which ground water is the most important, occur in all.

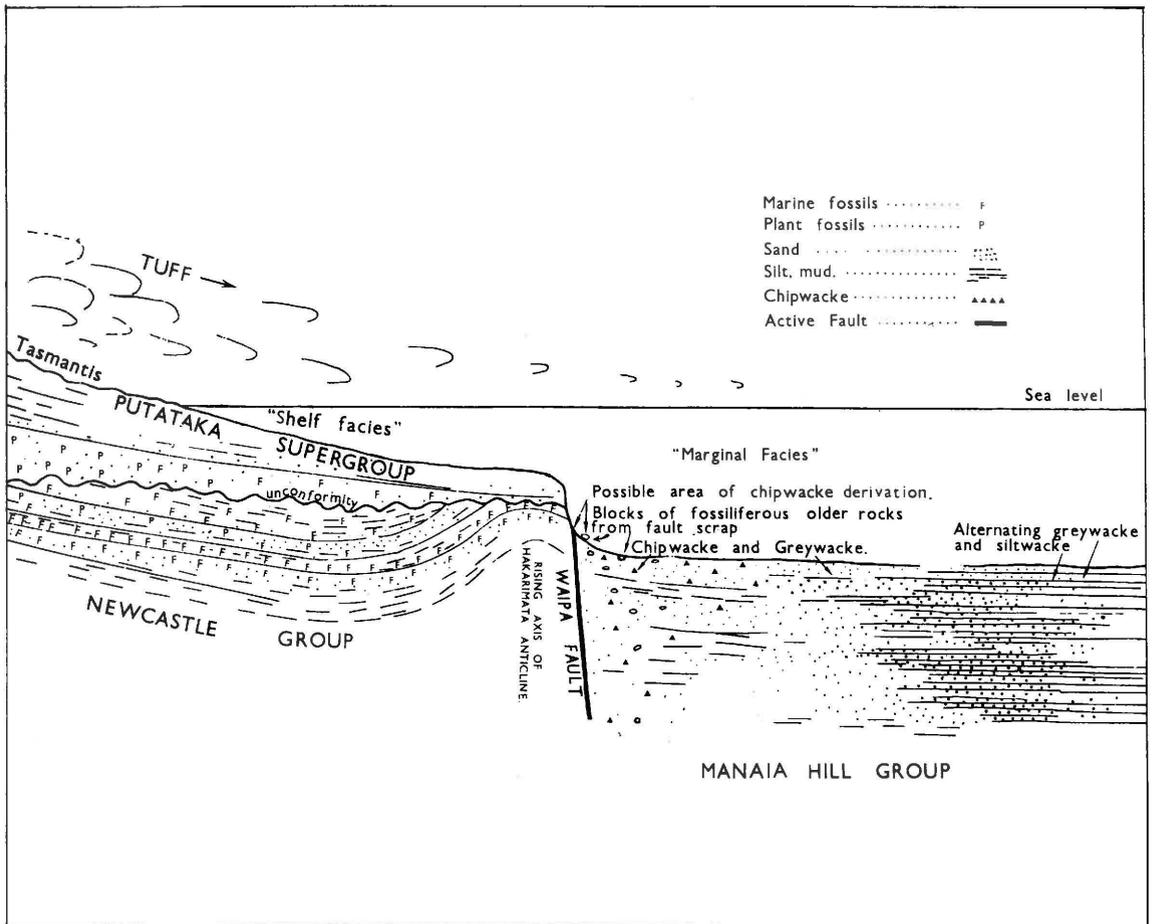


Figure 2 shows the distribution of the Newcastle Group (Triassic to Lower Jurassic) and of the Putataka Supergroup and Manaia Hill Group (both Upper Jurassic). The former two, of continental "shelf" facies, were separated by Waipa Fault from the latter, of "marginal" deeper water facies. Serpentinite has been intruded up Waipa Fault plane at Piopio.

MESOZOIC MINERAL DEPOSITS

Geological Setting

The Mesozoic sediments were laid down in the New Zealand Geosyncline to the eastward of a major land mass that can be equated with Tasmantis (Bryan, 1933). The resulting rock sequence, 12 to 20 kilometres (40,000-60,000 ft.) in thickness, shows that volcanic activity was pronounced in the coastal area.

The Waikato Region spans the area of the 20-40 kilometre wide Mesozoic continental shelf in the west, the steep fault-controlled continental slope, and some 20-40 kilometres of the landward edge of the ocean deep in the east. At times, the coastline of Tasmantis moved sufficiently eastwards for non-marine facies to extend well into the area of the present western hills.

The rocks of the continental shelf area in the west are readily subdivisible into two major units by a mid Jurassic unconformity (Kear, 1966); but the presently exposed rocks of the area of the foot of the continental shelf in the east are equivalent only to the younger unit (Fig. 2). There are thus three major units for consideration as crushed rock for concrete aggregate and road metal, their only current use.

Potential uses in the ceramics and expanded aggregates fields are discussed in the final major section. The western rocks comprise the Upper Triassic to Lower Jurassic Newcastle Group below the unconformity, with the Middle to Upper Jurassic Putataka Supergroup (Kear, 1966) above. The precise stratigraphic succession around the time represented by the unconformity has yet to be fully elucidated. The partly-terrestrial Rengarenga Group represents at least some of this time. The rocks of the eastern areas are classed within the Manaia Hill Group.

Crushed Rock (Aggregate, Road Metal)

General

The value of crushed rock as aggregate or road metal depends upon several factors (see also Ellen, 1958; St. George, 1959).

Hardness, or resistance to abrasion, is the most fundamental factor, and is best measured by the Los Angeles Abrasion Test. The following are Test result of samples, collected by the author and determined by Ministry of Works laboratory, Hamilton.

Group	Depth of Burial (Km)	L.A. Test (%)
Putataka	.... 3.5- 7.7	18.7-28.9
Rengarenga	.... 7.7- 8.6	16.5-18.4
Newcastle	.... 8.6-12.5	10.0-30.8
Manaia Hill	.... ? 15-20 ?	11.1-29.0

The above show that the maximum resistance to abrasion increases (i.e. L.A. test value decreases) as the depth of burial increases. Other values show that even minor amounts of weathering decrease the resistance appreciably.

Weathering is probably the first problem to be considered by the quarryman, for he can predict the probable unweathered metal hardness from the stratigraphic position and therefore the locality. Generally, weathering is too deep, of the order of 30 m (100 ft.), for quarrying to be economic; and quarries need to be sited where special geologic conditions have reduced this thickness to manageable proportions. Most common sites

are on fault-controlled scarps (e.g. eastern side of Hakarimata Range) and in deep valley bottoms. Weathered rock is readily identifiable by the breakdown of iron-bearing minerals to produce a brown oxidised stain. As a result of initial weathering in a zone immediately above the unweathered "blue metal", the rock remains reasonably hard, and is saleable as "rotten rock" for farm use etc.; but as a result of subsequent weathering in an equally-thick near-surface zone, the rock is altered to a brown clay and is currently stripped to waste.

It is most important that brown staining on joint surfaces, that can wholly coat lumps of perfectly unweathered rock, usually of true greywacke, should be differentiated from the brown colour of weathered rock. Material of the former type makes excellent road metal; that of the latter type is at best second grade.

Rock type is perhaps the most important factor in determining performance differences of road metal. Argillite (siltwacke) has failed (degraded) in a number of instances on the road; and some argillite, hard and sound when crushed, can be broken with the fingers after stock-piling for a period of months. Greywacke (sandwacke), does not appear to fail in this way. The reason for failure is uncertain. Laumontite content has been suggested, with the necessary forces being supplied by volume changes resulting from its wetting-drying reversible reaction to leonardite. It seems more likely, however, that the argillaceous nature of rock is the basic reason for failure, for all argillites and no greywackes are currently known to degrade. Greywackes certainly remain preferentially as hillside outcrops and stream pebbles. The precise physical and mineralogical reasons for failure have yet to be determined.

Unweathered hard argillites are not known to fail as concrete aggregate, and indeed would not be expected to do so, by analogy with their position within solid unweathered rock.

Jointing. All wacke-type rocks that are sufficiently hardened by burial to be useful as road metal and aggregate, are complexly jointed—the argillites rather more so than the greywackes. The jointing causes the rock to break into angular multi-flat-faced fragments from an inch to a few feet across. In theory, jointing could reach such proportions near major faults as to cause the rejection of material; but this has proved to be of no consequence in practice, and the jointing simply reduces crushing costs.

Veining and Secondary Mineralisation. Secondary minerals, such as zeolites and prehnite occur both in veins and in the rock matrix (Dr W. A. Watters, pers. comm.). They are discussed further below. There is no positive evidence that their mere presence contributes to road metal degradation, but where veining is intense, and this would apply to small areas only of a single quarry, the crushed rock is physically weak and possibly useless.

Newcastle Group as Crushed Rock

The Newcastle Group, the older major unit of the west, comprises argillites and subordinate greywackes, together with less common coarse tuffaceous sediments and vitric tuffs.

Limestones are rarely associated with the latter. The beds are moderately fossiliferous, and include, as their oldest beds, coarse granitic conglomerates on the west coast near Marakopa and inland at Honikiwi. The group is best exposed in the Taupiri, Hakarimata and Kapamahunga Ranges, where a stratigraphic thickness of 4-5 kilometres (12,000-15,000 ft.) has been measured.

The Group is predominantly composed of argillite, and this has been worked extensively for crushed rock, principally in the Taupiri Gorge and in the fault-controlled hills west of Ngaruawahia. These quarries provide good concrete aggregate, and metal for roads with low density traffic, but care must be exercised for main highway use. Quarries normally commence at a true greywacke outcrop with good characteristics, but, because these are of very limited extent, the quarry soon produces argillite and the quality for road metal drops.

Rengarenga Group and Putataka Supergroup as Crushed Rock

The younger Mesozoic rocks of the west are abundantly fossiliferous, and typical of shelf sedimentation. They are noticeably less indurated, softer, and less resistant to abrasion (see L.A. test above), than the Newcastle Group.

They include sandstone and conglomerate formations, hundreds of feet thick, as well as siltstones. The latter break down rapidly into small fragments and then clay in artificial exposures and are useless as crushed rock. Sandstones retain their induration longer, and have some use on minor roads. Conglomerates are used more extensively, because, although the matrix is soft and breaks down rapidly, the granitic, volcanic, and metamorphic pebbles are hard, and make moderately good road metal.

Manaiia Hill Group as Crushed Rock

The present position of Waipa Fault corresponds closely with the eastern boundary of the shelf facies in upper Jurassic times. Eastwards from there, the rocks are dark argillites, greywackes, chipwackes and conglomerates that are presumed to have accumulated at and beyond the foot of the continental slope. The conglomerates include large blocks of fossiliferous Triassic rocks that are unknown in the shelf facies. It is inferred that the facies boundary was the site of a faulted continental slope, and that Triassic rocks were exposed and eroded from this submarine fault scarp (Fig. 2).

All lithologies occur in beds that may be many hundreds of feet thick.

Greywackes, chipwackes and conglomerates predominate over argillites, and all the former make excellent road metal. Thus a number of good quarries have been established in the ranges from the Pokeno-Paeroa highway through Tahuna, Morrinsville, and Cambridge to Waipapa and Mangapehi. Many additional good quarry sites are available.

Serpentinite

General

Serpentinite is an unusual part of the basement rocks of the North Island. Its use began during the Second World War, as an additive to superphosphate to conserve phosphate supplies. Doubts have recently been expressed regarding its nutritional value to plants, but it undoubtedly improves the physical characteristics of superphosphate, particularly for aerial top-dressing. It may always be of value for magnesium-deficient pastures.

The quarry at Piopio (Fleming, 1948) has probably produced over 40 per cent of all serpentinite quarried in New Zealand. Its output has diminished in recent years, as the problems of quarrying a vertical lenticular body at depth have increased.

Geology

Serpentinite has been intruded cold up the plane of the major Waipa Fault (Kear, 1960) which separates the shelf from the marginal facies of

the Mesozoic rocks. The intrusion has locally tipped the Oligocene limestone from near-horizontal to vertical, and at least two periods of intrusion are recognised from the fact that the limestone itself contains serpentinite pebbles. Whether intrusion is quasi-continuous, or whether it has occurred only during the Rangitata and Kaikoura Orogenic cycles, is unknown.

Wellman (1959) has traced an aero-magnetic anomaly northwards from known outcrops of Paleozoic ultramafics in the northern part of the South Island. This passes through the position of the Piopio mass, and presumably therefore corresponds to a concealed outcrop of these ultramafic rocks. Thus extensions to the known deposit are likely only where major faults, and perhaps only Waipa Fault, cuts this band of anomaly. None is known, and it appears at present that the increased dangers and costs of working deeply down the fault plane, will cause the closing down of the Piopio venture, and that it will not be replaced.

TERTIARY MINERAL DEPOSITS

Geological Setting

The pre-Pliocene Tertiary rocks of the Waikato comprise gently-dipping (5° - 15°) siltstones, sandstones and limestones, with rarer conglomerates, coal seams and tuffs. They were deposited on an irregular floor of Mesozoic rocks, and were thickest in a wide fossil valley, corresponding more or less to the central Waikato lowlands between the coastal highlands of the west and the hills that separate the Waikato from the Hauraki depression in the east.

The rocks are exposed only in the western hills, where they commonly form low but prominent bluffs, and their preserved thickness ranges up to 500m (nearly 2,000 ft.). They are also present, but concealed, below the lowlands, and there may reach thicknesses of up to 2,000 m. They are not preserved in the eastern hills.

They are soft, never closely-jointed, but commonly calcareous. The irregularity of the basement, the common proximity of shorelines, and a series of minor tectonic events, all serve to create common facies and thickness changes. Detailed recognition of formations (e.g. Kear and Schofield, 1959) is essential to reconstruct the geological history or to prospect efficiently for concealed mineral deposits such as coal.

The sequence of formations is from Eocene basal coal measures through to open-water marine conditions (Te Kuiti Group), followed by a widespread unconformity, and then thicker, less calcareous beds that are tuffaceous locally (Waitemata Group) in the north, and deeper water in the south (Mahoenui Group).

Fireclays

Geological Background

The Waikato Coal Measures are predominantly composed of carbonaceous siltstones, known locally as "fireclays". All siltstones are to some extent refractory; but the depletion in bases increases stratigraphically downwards, and the most refractory are those from below the coal seam, often 5m (20 ft.) or so in thickness. The leached Mesozoic rocks beneath the coal measures, perhaps 8m (25 ft.) thick, can also make excellent fireclays. Leaching was widespread before, during, and after coal formation, and the carbonaceous siltstone that constitutes the bulk of the coal measures was formed by erosion of the higher country around the coal basin.

Uses and Reserves

Coal measure fireclays have been worked for firebricks at Huntly, at one of New Zealand's two such plants, and for white wear products at small potteries at Glen Afton. Building bricks have also long been made at Huntly from clays higher in the coal measures; but as the clay is very deficient in bases, they are characteristically of a very light colour, and may have argillite fragments added to give them a speckled appearance of darker coloured patches.

Fireclay reserves are extensive throughout the Waikato, wherever coal itself is found, and in adjacent areas. Fireclay will continue to be used for the production of firebricks and building bricks, and will be freighted away from the Waikato for mixing with, and improving, clays of other areas. Firebrick usage will increase considerably when the steel industry is fully set up.

Quality

Analyses of fireclays from Huntly are as follows (figures are percentages—see Henderson & Grange, 1926):

SiO ₂	....	....	....	41.40	49.99	60.91
Al ₂ O ₃	....	....	....	39.40	27.95	23.33
Fe ₂ O ₃	....	....	....	1.60	1.48	2.44
CaO	....	....	....	0.20	0.03	0.34
MgO	....	....	....	0.10	0.16	—
TiO ₂	....	....	....	—	—	0.92
K ₂ O + Na ₂ O	....	....	....	0.50	0.32	0.60
Water + organic	....	....	....	16.80	20.07	11.86

Coal

General

Apart possibly from groundwater, coal is the most important mineral of the Waikato, and the Waikato Coal Region is the most important in New Zealand. In recent years it has produced nearly 1½ million tons of coal annually, about 50% of the country's output. Coal was discovered at Huntly before 1859 (Hochstetter, 1864), and about 40 million tons have since been worked in the Maramarua, Huntly, Rotowaro, Glen Massey, Whatawhata, Kawhia and Otorohanga coalfields.

Geological Background

The geology of the coalfields is described in two bulletins that are being prepared for publication (Kear & Schofield, in press; Kear, in press) and the results have been summarised by Willett (in Williams, 1965).

The Waikato coal was formed in Eocene times and is a shiny, brown-black, sub-bituminous coal (Peneseler, 1930), which ignites easily, but also breaks down to slack quite readily on exposure to the air. It contains common lumps of resin.

Seam thicknesses are very variable, and can be considerable locally. They exceed 25m (80 feet) in a few parts of the Maramarua, North Huntly, and Callaghans area of the Rotowaro coalfield.

More commonly, the seams average about 5m (15 ft.) in thickness, and are relatively gently dipping, dips of more than 15° being anomalous and dips of 10° being more usual. Faults are normal and widely spaced.

Occurrence

The original eastern limit of the coalfield is not known, because all Tertiary rocks have been stripped from the uplifted eastern hills, and no

coal is known there. To the west, the original coalfield was limited by high hills of Mesozoic rocks, and the coal measures are either non-existent there, or contain only unworkably thin seams of coal. Thus the western limit of the coalfield is quite clearly defined by thinning seams which do not extend economically beyond Renown, Glen Afton, Glen Massey, and Whatawhata. Within the central north-trending zone containing workable coal reserves, there is normally only the one Kupakupa Seam. This is present about 8m (25 ft.) above the base of the coal measures, and its location is known in considerable detail, not only from mine workings but also from over 6,000 exploratory drillholes. In a few districts such as parts of the Huntly Coalfield, at Renown mine, and at Glen Massey, coal seams (Renown and Kemps Seams) are known to occur above the Kupakupa Seam, but these are invariably thin and are only workable in only a very few places. They do not contribute greatly to the total quantity of coal in the Waikato Coal Region.

In some localities the Kupakupa seam itself splits into two, and these have been worked separately in the centre part of the Rotowaro and the south-western part of the Huntly Coalfield.

Much more important is the occurrence of an earlier coal seam (Taupiri Seam) which can be distinguished from the younger seams both by its contained microflora (Couper, 1960), and in its depositional location.

Couper (1960) classed the older coal measures (then known as Rotowaro, but now known as Lower Waikato) as of Bortonian-Kaiatan age, in contrast to the younger coal measures (then Huntly, now Upper Waikato) which were classed as of Runangan age.

The older coal measures were restricted in their occurrence to a narrow fossil valley extending from the Callaghans section of Rotowaro Mine through to the Alison Mine. Extensive drilling has shown that this reached 1,000 feet deep, but was little more than $\frac{1}{4}$ mile wide. Two points of considerable interest arise. First, the important change, from widespread leaching and stability of the Upper Cretaceous and Paleocene times, to coal measure deposition in the Eocene, may have been caused by tectonic uplift locally which caused temporary down-cutting of the streams and rivers. This was to be followed by gradual depression which eventually brought about the Te Kuiti transgression. Second, there may be more narrow valleys with thick lower Eocene coal seams, concealed elsewhere in the Waikato, beneath apparently thin upper Eocene coal measures. The policy of continuing drillholes for coal through to basement is therefore strongly endorsed, and the advantages of an even more detailed gravity survey than that of Dr S. H. Hall (see below) could be considerable.

Coal seams are also known from the Mesozoic rocks of Port Waikato. They are only a few inches thick at most, and are much too dirty to be workable. They are of interest however in being bituminous in contrast to the sub-bituminous coals of the Tertiary rocks. They appear to have been buried to stratigraphic depths of about 10,000 ft., as opposed to about 5,000 ft. for the latter.

Reserves and Prospects

Reserves of coal are relatively large totalling about 275 million tons, of which 77 million are at Maramarua, 133 million at Huntly and 52 million at Rotowaro. Of these figures, opencast reserves total 23, 8, and 15 million tons respectively.

A few million tons are known to be present in the Glen Massey and Kawhia coalfields, and the latter may prove to be even more important after further drilling. Reserves are less than a million tons at Whatawhata and Otorohanga.

On balance, the prospects for the industry seem good. Production reached record levels in the nineteen sixties, even with the conversion to oil of many major customers; but the fluctuating demands for power from Meremere have produced significant differences between individual yearly totals. Opencast mining is of increasing importance. Whereas 13% of Waikato production was opencast in 1945, and 46% in 1955, the percentage rose to 60% in 1965. Over 200 ft. of over-burden is stripped off a seam averaging 35 ft. thick at Maramarua, and over 300 ft. may be removed in the future.

Perhaps one of the most important factors for the future, both of the Waikato Coalfields and of the Basin, has been that this coal has been selected for use in the steel industry based on the Waikato Head ironsand deposit. This will ensure not only a market for coal, but also that the Waikato consumer will be close to the steel mill.

Other future coal markets will include Waikato and Auckland householders (coal and "carbonettes"), dairy factories, hospitals and power stations. The coal is produced as cheaply as anywhere in New Zealand, and Waikato State mines made a profit of over £400,000 in 1965.

Analyses

The following figures illustrate typical rounded analyses for average coal samples of the areas noted.

Area	Moist.	Vol. Mat.	Fix. Carb.	Ash	S	Cal. Val.
Maramarua	20 %	37 %	38 %	5 %	$\frac{1}{4}$ %	9,400 B.t.u./lb
Huntly	16 %	37 %	41 %	6 %	$\frac{1}{4}$ %	9,700 "
Rotowaro	15 %	39 %	42 %	4 %	$\frac{1}{4}$ %	10,250 "
Glen Massey	13 %	39 %	43 %	5 %	$1\frac{1}{4}$ %	10,900 "
Whatawhata	15 %	40 %	41 %	4 %	3 %	10,200 "
Kawhia	21 %	38 %	34 %	7 %	$3\frac{1}{2}$ %	9,100 "
Otorohanga	20 %	39 %	35 %	7 %	2 %	9,200 "

Limestone and Cement

General

Limestone has long been a most important product in the Te Kuiti and adjacent areas, and, being one of the most versatile of all mineral products, it has played a significant part in industrial and constructional development.

No complete figures for past production are available, but over 200,000 tons of limestone are now produced annually in the Waikato, and it is likely that the grand total, since the arrival of Europeans, is of the order of 5,000,000 tons.

Geological Background

Limestone occurs quite commonly in the lower to middle Tertiary rocks of the western uplands, five separate stratigraphic horizons being recognised at Te Akau (Kear, 1966). A number of small local lime burning plants were established in the last century. In more recent times, the pattern of production has changed. Larger companies now work larger quarries in the thickest limestone areas. Whereas beds of limestone of little more than 10m (30 ft.) were once worked on the shores of Raglan and Kawhia harbours, at Karamu and in many other areas, recent production has been predominantly from the Te Kuiti area where beds exceed 60m (200 ft.) in thickness.

Uses

Undoubtedly the most important use over the years has been that of crushed lime for agriculture, and current production runs between 80,000 and 130,000 tons annually. The Te Kuiti quarries provide limestone not only for the Waikato, but also for much of the Auckland province.

Since the Second World War, the increased use of cement has demanded the establishment of new works, including one at Te Kuiti, and nearly 100,000 tons of limestone are now produced annually for cement. Marl, the other main ingredient, is also available close to Te Kuiti. The combination of local cement, aggregate and sand is the basis for a most important and ever-expanding local concrete industry.

Limestone has had a host of minor uses over the years—for making burnt lime, as a low to moderate grade road metal, in various chemical industries where pure calcium carbonate is required, as an industrial filler when crushed, and, particularly in recent years, as a building stone. Small amounts have been used as a flux in the Auckland scrap-metal steel plants, and in glass making. In all, about 25,000 tons of Waikato limestone are used annually for these "industrial" purposes, nearly half of that used in the whole country.

Large quantities of limestone, either from Te Kuiti, or from closer deposits in Raglan County, will be used in the proposed ironsand steel industry; and the chemical uses, particularly of high quality stone in paper-making, will certainly increase in the future. Both these latter uses could eventually be of similar importance to the present uses for agriculture and for cement.

Limestone is one of the few minerals with recreational and tourist potential. Many speleologists enjoy tramping, crawling, and climbing through solution caves in these rocks, and Waitomo Caves is an important, internationally known, all-weather, Waikato tourist attraction.

Quality

Most limestones are white or light grey in colour, but their purity ranges widely. The basic slag works at Huntly, which closed down over 10 years ago, used a low grade limestone from Rotowaro with little more than 50 per cent calcium carbonate. Limestones of all qualities exist, however, ranging from this poorest material up to that at Te Kumi a few miles north of Te Kuiti which contains 98 per cent calcium carbonate. The latter is of great potential value for "industrial" uses.

Because of the wide variety of uses, specifications also vary widely. All good limestones tested have been low in phosphorus and sulphur as required for a steel industry, but both elements would have been acceptable to the farmer.

Perhaps the greatest contribution economic geology can make for limestone is in establishing patterns of analytical changes in these and associated sedimentary rocks.

Where industry is seeking specific materials (e.g. limestone and silica) a suitable rock may be available locally that supplies the whole of one requirement and much of the other(s) far more cheaply than hauling the pure materials longer distances. The following shows probable ranges of analyses of main constituents of some of the more relevant Te Kuiti Group rock units (Kear & Schofield, 1959; Kear, 1966), and is a useful starting point in a search for a rock of a specific composition.

Formation or Member	CaCO ₃	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃
Otorohanga Limestone	96 %	2 %	½ %	¼ %
Waitomo Sandstone (south)	81 %	4 %	?	?
Carter Siltstone	56 %	24 %	7 %	1 %
Raglan Limestone (north)	80 %	?	?	?
Orahiri Limestone (south)	93 %	4 %	1 %	¼ %
Waimai Limestone	88 %	6 %	2 %	1 %
Whaingaroa Siltstone	54 %	?	?	?
Glen Massey Sandstone (north-west)	44 %	35 %	8 %	2 %
Glen Massey Sandstone (south-east)	56 %	27 %	6 %	4 %
Dunphail Siltstone	38 %	35 %	9 %	5 %
Elgood Limestone (east)	72 %	16 %	6 %	2 %
Elgood Limestone (west)	86 %	7 %	2 %	2 %

Two factors complicate the determination of quality at any one site. First, glauconitic beds, an inch more or less in thickness, can vitally affect the content of minor unwanted elements, averaged over the rock as a whole. These beds tend not to outcrop and outcrop samples can give misleading values for such elements as phosphorus and sulphur. Second, the limestones weather chemically very readily, and their solution holes are commonly filled with red-brown volcanic clays which must be thoroughly washed from the stone if a high-grade product is required that matches the analysis of carefully taken samples.

Reserves

Reserves amount to several million tons in the Te Kuiti area, within ready access to the Main Trunk Railway. Further major deposits exist elsewhere, particularly in the hills west of Te Kuiti, but road haulage from them will imply slightly higher costs.

Petroleum and Natural Gas

Mesozoic rocks are too indurated; and Tertiary rocks of the western uplands, as well as all Quaternary rocks, are too thin, to yield petroleum and natural gas in industrial quantities. Prospects are therefore limited to the thick Tertiary sequences concealed beneath the Hamilton Lowland, apart from minor amounts of natural gas from Quaternary rocks (q.v.).

Gravimetric geophysical prospecting by Dr S. H. Hall (in Kear & Schofield, in press) showed that the basin beneath the Hamilton Lowland was irregular and probably cross-faulted, but that it probably contained up to 8,000 ft. of post-Mesozoic rocks—e.g. at Te Rapa. Drilling by N.Z. Petroleum Exploration Co. Ltd. showed a depth of some 5,400 ft. of post-Mesozoic sedimentary rocks at Te Rapa overlying Manaia Hill Group rocks. Of these, the upper 400 ft. may well be Quaternary, judged by evidence from Frankton (Couper & Harris, 1960). Neither oil nor gas was found, and the prospects for finding them must therefore be considered poorer than previously. But the drilling was most valuable in confirming the presence of thick concealed Tertiary rocks, and it may be followed in the future by further exploration aimed at testing other buried structures where sequences may be thicker and slightly different.

UPPER CENOZOIC SEDIMENTARY MINERAL DEPOSITS

Geological Setting

The Upper Cenozoic (Pliocene-Quaternary) deposits are of two facies.

The Tauranga Group of the inland area comprises predominantly volcanic sediments associated with Waikato River alluviation (e.g. Hinuera Sands, Taupo Pumice Alluvium), as well as greywacke gravels, peats and rare marine beds that have been encountered in drillholes at Frankton, Horotiu and Huntly. The Kaihu Group of the west coast are essentially coastal sands with rarer pumice siltstones and peats. All beds of both areas are near-horizontal, but contain a number of erosional unconformities that record changes in sea or river base level, and/or volcanic sediment supply.

Pumice

A major eruption near Taupo about 130 A.D. caused pumice to flood down the Waikato River, and this is now present at a number of places within the river valley. Schofield (1965) has shown that the sorting action of the river caused the deposition of rhyolitic sand in the central valley, with pumice on the flanks and up the valleys of tributary streams. Quite large amounts of fine pumice have been worked from pits at Melville (Hamilton) and Horotiu for use in sandsoap and in filling; and larger lump pumice for insulation and light-weight concrete were once worked at Rangiriri.

The demand for fine pumice will continue, but the supplies are not inexhaustible. Those of lump pumice have already virtually given out in the Waikato, and it has been necessary to go further afield—to the Hunua Basin and Wanganui or Mokau Rivers for fine pumice, and to the Wanganui River or to the Central Volcanic Region (currently, for example, near Rotorua) for lump.

Sand

Sand is widely available from the Waikato River bed, and large plants have been established at Hamilton, Mercer and elsewhere. Sand can also be obtained, with a pumice impurity, from the widespread Hinuera sands of the Hamilton Lowlands and upper Hauraki Plains. (Schofield, 1965). This is already used widely as fill material; and a cheap means of separating unwanted pumice from the rhyolite-obsidian-quartz-feldspar-ferromagnesian residue would ensure a literally endless supply in the future.

Extensive deposits of Kaihu sand exist along the coast (Kear, 1964).

Ironsands

Although the ironsands to be used in the proposed steel industry are outside the Waikato Region (on the north side of the Waikato Heads) the many coastal Kaihu deposits to the south of there represent important reserves for the future.

Major deposits exist at Kawhia, Taharoa, and perhaps Mokau, with minor deposits at Raglan, Aotea and Marakopa. These aggregate at least 300 million tons of concentrate, in sands averaging 8 per cent, or better, of the ore mineral titanomagnetite. Additional tonnages will exist in lower grade sands, and, probably, in buried rich sands at some localities (Kear, 1965).

These latter rich sands appear to have been formed as marine or littoral concentrations at a time when sea level was 135 ft., or slightly more, higher than at present. In all cases, the titanomagnetite is assumed to have been derived by attrition from hornblende andesites of Mt. Egmont and similar extinct volcanoes as far north as Kawhia, and perhaps Raglan (Kear, 1965).

The closeness of the ironsand industry is important to the Waikato, not only because the finished product will be cheaply freighted, but also because Waikato coal, limestone, and perhaps refractories will be used in the mill.

The titania impurity in these iron ores, representing 8-9 per cent of the concentrated mineral, has prohibited use until the post-war development of new pre-reduction processes.

This impurity will be concentrated in the iron slag, and may be used in the future as a source of titanium white, or even titanium.

A much smaller vanadium impurity may also prove usable.

Peat

Peat areas are extensive in the Waikato Lowlands. They mostly represent depressions in the extensive surface of the Hinuera sands, which were originally poorly drained and damp. Once peat growth began, it continued, and formed raised bogs. Recent attempts of Rukuhia soil station to control peat drainage, and to farm more than the fringes of swamps, have proved successful.

Peat, however, is also a useful "mineral" product. It has recently been harvested and bagged for sale, and large quantities are available for the future.

Natural Gas

Peats and buried peats are potential sources of marsh gas. In New Zealand, such gases have been commonly encountered in drillholes, up to a few hundred feet in depth, particularly near hot spring areas (e.g. Helensville, Hauraki Plains). All are essentially of methane, with the possibility of minor amounts of higher hydrocarbons, presumably when the temperatures become highest.

Such gases are known to exist subsurface at Horotiu, from depths approximating stratigraphically to the Pliocene-Pleistocene contact. Peat and lignite beds are not uncommon (Hetherington, 1915).

UPPER CENOZOIC VOLCANIC MINERAL DEPOSITS

Geological Setting

The Waikato Basin is on the fringe of the Central Volcanic Region of the North Island, and the distal portions of ignimbrite sheets reached this area from there, even as far north as Ngaruawahia (Kear & Schofield, in press). Local volcanoes are predominantly basaltic, although andesitic rocks exist as the earlier episodes of Mounts Pirongia and Karioi in the west, and represent the bulk of volcanism in the east (e.g. Pukekamaka, Tahuna, Kiwitahi and Maungatautari). The well established trend of younger and more acidic volcanics being in the east, is shown here.

The economic potential of the volcanic rocks is mainly as bulk materials; but the volcanic activity also emplaced mineral lodes, as at Te Aroha, and has hot water as a residual effect.

Aggregate

Basalt tends to make the best aggregate.

That of Smeeds Quarry near Tuakau is the best known, but others have been worked widely as at Ohuka Valley, Karamu, Raglan, Te Kawa, and Turitea Stream on the southern flank of Pirongia. Nearly 70,000 tons of basalt are worked annually.

Andesite quarries are present in the east from Mangatarata to Maungatautari, on the western side of the Hauraki Plains, and are very commonly present on western flank of the Coromandel Ranges to the east of the Plains. Andesites are slightly but only slightly inferior to basalts, and over 30,000 tons are produced annually.

Additional deposits are limited to flows in areas mapped as basalts or andesites on geological maps. Even in such areas, most rocks are fragmental (e.g. Pirongia Mountain) and careful prospecting must precede the selection of a quarry site. In some areas, volcanic rocks may have been inferred from surface form alone, and are not necessarily present (e.g. near Koromatua, Kear & Schofield, in press; 1965).

Lightweight Aggregate, Perlite

Pumice (q.v.) is an admirable material for lightweight aggregate. However, future trends are towards "expanding" a rock, by heating, to increase its volume and reduce its density.

In the Waikato, the need and desirability of turning to such materials as argillite and bloating clays has not yet arisen. A plant at Atiamuri expands a glassy rhyolite, "perlite" (Thompson et al., 1954), to ten times its original volume by heating it to 1,000°C. It processes about 1,000 tons annually. Further perlite deposits are known in the Central North Island and in the Coromandel Ranges.

Expanded perlite can be used in insulation, plastering, and in horticulture.

Building Stone

Although limestones have also been used, most Waikato building stones are volcanic. They are especially suited to the modern trends towards rough, angular or irregular blocks in which each has its own individual colour. The ignimbrites from Hinuera, Putaruru and elsewhere, and the hot-spring highly-coloured rocks from such places in the volcanic region as Atiamuri, are all ideal. They find markets well beyond the Waikato.

The Coromandel "granite", a tonalite, will no doubt long be used as a tomb-stone, along with other imported and polished varieties, but the trend of the immediate future is to decorate with rough surfaced or rough-cut New Zealand materials, and the Waikato can supply many of these.

Ignimbrites account for about two-thirds of the annual output of nearly 4,000 tons. They are easily cut, and have been given the honour of being imitated in cement.

Non-Ferrous Metals

Although the Coromandel Ranges are only on the fringe of the "Waikato", a resurgence of mining activity there must have an effect on the Basin itself. The success of the prospecting at Tui base-metal Mine, Te Aroha, is important. It has found over 100,000 tons of zinc-lead ore, and development continues. It may cause the prospecting of other base

metal and gold-silver areas of the Hauraki (Coromandel Ranges) Goldfield. This has as good ore potential as anywhere in the country, and better access than any alternative.

Hot Water - Steam

Hot water, and even steam, could be an important "mineral" of the future. Many drillholes in the Waikato have found warm or hot water—especially near the known hot springs of Whangape, Waingaro, Te Aroha, Matamata, Okoroire and elsewhere. Some areas, however, show no obvious signs of surface warmth. Warm groundwater is widespread at Orini, and has been usefully obtained (72°-86°F.) in drillholes below 500 ft. at Frankton and in the centre of Hamilton. (Kear, Schofield & Kermodé, 1965; Schofield, in press).

The heating of offices and swimming pools, and the community heating of houses, may come to depend more upon warm or hot water from the ground in the future, so long as its development costs prove competitive with more conventional means. The distribution of hot water is not understood as yet, but may well be connected with extinct volcanism. Reports refer to hot water in drillholes at Horotiu, and the possible occurrence of a buried extinct volcano at Kerepehi in the Hauraki Plains (Kear & Schofield, in press) suggests that deep drilling there and elsewhere might find hot water, or even steam, at economic depths.

Geothermal steam is causing a revolution in thinking of energy provision throughout the volcanic countries of the world, and the finding of hot water and steam, even in areas where there are no immediate signs of geysers, hot springs or volcanoes, is a great challenge for the future.

MINERAL DEPOSITS OF ALL ROCKS

Ground Water

Ground water is of prime importance in an agricultural region like the Waikato Basin. It has a potential far in excess of present usage. Although no figures of value are available, it is probably the Waikato's most important mineral resource and one in which future expansion is simple and attractive.

The occurrence of ground water is adequately described elsewhere (Taylor, 1935; Schofield, 1956; in press). Variations are too local to give adequate treatment here, but the main facts may be summarised: drillholes in most flat areas of Taupo or Hinuera sediments usually find ground water in large quantities quite close to the surface, although sites near peat swamps may yield water with a high iron content; drilling into the hills within the central Waikato lowlands, i.e. of older Tauranga Group sediments, usually produces a reasonable flow of good water, from somewhat deeper depths than in the case of the younger deposits; and drilling elsewhere has very variable results—e.g. excellent in limestones encountered below water table, good in Tertiary sandstones and in volcanics, but poor in greywackes, argillites and Tertiary mudstones. Water can be found in the weathered zone on greywackes and argillites, but only in quantities of up to 200 gallons per hour.

Ground water is used for farm homestead supplies, for animal water troughs, and for general farm use. It is used in industry and for town supplies at Ngaruawahia, Huntly, and elsewhere.

Its greatest potential, however, probably lies in its use for spray irrigation (Annett, 1951a, b), to obtain even higher summer production of grass, etc.

Clay

Fireclay has been described above under Tertiary Mineral Deposits, and that account covers the local Huntly brick industry.

Clays for making pipes and bricks are not particularly uncommon; and an efficient small plant, established at Ngaruawahia, ensures an adequate supply of field tiles to the Waikato. It uses a young local alluvial clay, which is essentially derived from Mesozoic argillites.

If additional brick or pipe plants were contemplated in the future, they would probably use weathered argillites, such as are present in most of the western and central ranges of hills, as their main material. The higher alumina coal measure clays could be used as additives.

PRODUCTION SUMMARY AND PROSPECTS

The following table shows the appropriate tonnage and value figures for the 1965 mineral production:

	Approximate Tonnage	Approximate Value	% of Total for N.Z.
Groundwater	Very High	Very High	?
Coal	1,257,000	£3,600,000	47 %
Aggregate and sand:			
(a) building	400,000	£280,000	7 %
(b) roads	1,360,000	£600,000	7 %
(c) sand for industry	130,000	£50,000	50 %
Limestone:			
(a) agricultural	122,000	£120,000	7 %
(b) industrial	23,000	£50,000	48 %
(c) cement, with marl	120,000	£45,000	10 %
Clays	52,000	£30,000	15 %
Serpentine	15,000	£20,000	12 %
Building stone	4,000	£17,000	90 %
Perlite	1,100	£13,000	100 %
Pumice	1,000	£1,000	1 %
Peat	?	?	?
Warm Water	?	?	?
Total	3½ million	£4.8 million	20 %

On the basis of present output, the Waikato is one of the most important mineral regions in New Zealand. Its most important mineral products—ground water, coal, aggregate and sand, limestone and clays are all present in such quantities that expansion is possible. In every case expansion, perhaps spectacular, seems likely. Although deposits of serpentine and pumice are limited, there may well be expansion in the production of building stone.

Although perhaps strictly outside the Waikato, the proposed steel industry, based on the Waikato Heads ironsand deposit, is likely to influence the Waikato mineral industry profoundly; and the successful prospecting for zinc and lead at Te Aroha might herald the beginnings of a new era in New Zealand's premier metalliferous region—the Hauraki Goldfield. Success there could affect the Waikato indirectly.

Although the three recent dry holes have reduced hopes of oil, hot water from deep drilling is a mineral with a speculative future for the heating of commercial buildings and communal home services, and natural gas has been located, in at least small quantities, at Horotiu.

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