DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH

NEW ZEALAND

BULLETIN No. 88

FIRECLAY AND GANISTER
IN NEW ZEALAND

BY

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Issued under the Authority of the Hon. D. G. SULLIVAN
Minister of Scientific and Industrial Research

WELLINGTON, N.Z.
E. V. PAUL, GOVERNMENT PRINTER
1943

Price 2s. 6d.]

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EPUB ISBN: 978-0-908328-55-0

PDF ISBN: 978-0-908331-51-2

The original publication details are as follows:

Title: Fireclay and ganister in New Zealand

Author: Henderson, J. (John)

Published: Govt. Printer, Wellington, N.Z., 1943

FIRECLAY AND GANISTER IN NEW ZEALAND

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Summary

In this account of what is known of the composition and distribution of fireclays and ganisters in New Zealand emphasis is placed on the probable origin and general qualities of the material from different regions rather than on the chemical and physical properties of particular deposits. Some clays that can hardly be classed as refractory are mentioned in order to show that samples from some districts have been tested and are unsatisfactory.

The reports of the Dominion Laboratory are freely quoted ; without them, indeed, this account could not have been compiled.

INTRODUCTION

Clays are earthy materials in an exceedingly fine state of subdivision derived from the decay of older rocks, the disintegration being due partly to chemical and partly to physical causes. Percolating water hastens it by removing soluble minerals, heat expands the rocks and cold contracts them, as well as disrupting them by the freezing of contained water ; the oxygen and carbon dioxide of the air and the organic acids of plant-growth and decay attack resistant silicates. The relatively insoluble materials, if sufficiently fine grained (less than 0·01 mm. in diameter) constitute clay. Particles ranging between 0·01 mm. and 0·025 mm. across are silt and those between 0·025 mm. and 1 mm. are sand. On these definitions clay, silt, and sand are classed on particle size and not on chemical composition. But as the finest particles of rock decay nearly always consist largely of kaolinite, the chemical and physical properties of what is popularly "clay," even if containing much finely divided quartz, are in the main due to this mineral. On the other hand, most sands consist predominantly of quartz, and the term "sand," without specific designation, implies that the material consists chiefly of silica.

If left as a deposit where the original rock disintegrated the clay or sand is termed residual, but if removed by water or wind and accumulated elsewhere it is transported or sedimentary.

The rocks of the earth's crust—igneous, sedimentary, and metamorphic—consist of mixtures of minerals. The two last mentioned are derived from the first or on ultimate analysis from the minerals that are found in igneous rocks. There are five groups of these minerals—quartz, feldspars, micas, ferromagnesians, and accessories.

Quartz occurs in granite, gneiss, rhyolite, and other igneous rocks, as well as in most sedimentary and metamorphic rocks. It is an abundant hard resistant mineral practically insoluble in the cold dilute solutions of the earth's surface.

The feldspars are essential and considerable constituents of nearly all igneous rocks, and crystals and grains are abundant in many sediments and schists. They are compound silicates of alumina and potash soda and lime. They are the principal source of the kaolinite of clays which is a product of their weathering. Orthoclase, the potash feldspar, and feldspars high in lime decompose much more readily than albite, the soda feldspar, and feldspars containing much soda and little lime.

The micas are a group of complex silicates abundant in granite and related rocks as well as in many schists. Potash-alumina mica—muscovite and sericite—is resistant to weathering, but biotite and phlogopite, which contain iron and magnesia in addition, break down much more readily.

The more common ferromagnesian minerals—hornblende, pyroxene, and olivine—are essential constituents of most basic igneous rocks, and the first two also occur in schists. They are silicates, mostly complex, containing alumina, iron, magnesia, lime, and other bases. They weather fairly readily, and products of their decomposition are widespread in sedimentary rocks.

Magnetite, an oxide of iron, ilmenite, a titanate, and pyrite, a sulphide, are present in most igneous rocks. Other accessory minerals occur very sparingly.

Weathering and leaching cause the less-resistant minerals to break down, the soluble constituents are removed, and, should the altered rock be eroded, water sorting tends to separate the coarser from the finer particles; deposits of sand or clay may be derived from the same mass of rock and, according to the degree of leaching, clays of different composition may result.

FIRECLAYS AND GANISTERS

Fireclays

Fireclay is an indefinite term standing in general for clays that do not fuse, or rather soften, except at high temperatures. Though no exact limits are set, clays that withstand a temperature of 1,670° C. are classed in Britain as of first grade; second-grade clays withstand 1,580° C. but fail at or below 1670° C. The term "fireclay" signifies only that the clay is refractory, and fireclays have wide ranges in plasticity, texture, colour, tensile strength, shrinkage on burning, and chemical composition. The value of a fireclay can be determined only by a test of its refractoriness, but a chemical analysis is useful as indicating the amount of fluxing material, such as iron oxide, lime, magnesia, alkalies, and titania in the clay. The fired colour, strength, shrinkage, porosity, and vitrification range cannot be inferred from the analysis, no matter how complete. When physical tests are not satisfactory, the chemical analysis will often indicate to what the trouble is due and suggest the remedy.

The heat-resisting qualities of a clay are measured by means of slender pyrometric cones, or rather tetrahedra, composed of materials that soften and fuse at known temperatures. Similar cones of the clay to be tested are heated in the furnace beside standard cones mounted on plaques of refractory material. The softening-point of a clay is that temperature at which a cone of the clay bends until it touches the base on which it stands; the fusion point is the temperature at which complete loss of the original shape occurs; and the deformation point is the temperature at which alteration of the original shape begins.

A good-grade refractory clay remains porous to a high temperature, but at some point the fluxes it contains melt, and, as more and more fused material is produced, the pores are filled and the mass becomes impermeable. This occurs at the vitrification point. Some clays lose their shape before vitrification takes place, but the more valuable clays have a long vitrification range—that is, they become completely impervious at a temperature considerably below their deformation point. Bricks and other articles must all contain some vitrified matter, as without it they would be so weak as to be useless.

The ideal clay substance is taken to be kaolinite, a crystalline mineral containing 46·3 per cent. of silica, 39·8 per cent. of alumina, and 13·9 per cent. of water. If pure, this mineral is highly refractory, its softening-point being above 1,800° C. Fireclays are usually regarded as mixtures of kaolinite and quartz, with small quantities of iron hydrates, silicates of iron, lime, magnesia, and the alkalies and some titania, as well as minor constituents that act as fluxes and cause the clay to melt at temperatures that, in general, are lower as their aggregate amount increases.

Recent investigations into the crystal structure of clay substances separated and purified by all known methods suggest that clay is a mixture of alumino-silicic acids in which an ion of alumina is combined with one, two, three, or more ions of silica as well as with water. On this theory a clay containing more aluminia than required to form kaolinite with the silica would be considered to contain a proportion of the allophane molecule (Al_2O_3 SiO_2 xH_2O). On the other hand, the rational mineral composition, deduced from the analysis, of a clay with more silica than required to saturate the alumina as kaolinite (Al_2O_3 $2SiO_2$ xH_2O) might be considered not as consisting of kaolinite and free quartz, but as containing molecules of alumino-silicic acids with higher percentages of silica, such as Al_2O_3 $3SiO_2$ xH_2O (natrolite), Al_2O_3 $4SiO_2$ xH_2O (pyrophyllite), Al_2O_3 $5SiO_2$ xH_2O (chabazite), or Al_2O_3 $6SiO_2$ xH_2O (orthoclase, albite).

Silica has a melting-range (1,600° to 1,750° C.) rather than a melting-point, the latter being usually put at about 1,650° C. On heating, kaolinite loses water and becomes Al_2O_3 $2SiO_2$, which melts at 1,830° C. At high temperatures silica acts as a flux to kaolinite, thus the mixture Al_2O_3 $5SiO_2$ melts at 1,750° C. and Al_2O_3 $10S_2O_2$ at 1,690° C.; but with more than 90 per cent. of silica the temperature of fusion rises again. In general, first-grade firebricks contain less than 60 per cent. of silica and second-grade bricks have more than 60 per cent. of silica in ultimate composition.

Fireclay goods have to stand rough treatment, violent changes in temperature, oxidizing and reducing flames, the chemical action of flue dusts and gases, vaporized substances and slags, the abrasion of ores and fuels; in fact, severe conditions of service. Clays consisting largely of kaolin yield strong bricks with dense compact structure, but shrink and tend to distort in burning and crack in use. In order to overcome these defects coarsely ground grog (old firebrick or clay calcined for the purpose) are mixed with the raw clay up to twice its weight or more. The resultant bricks and tiles, though they keep their shape, shrink little in burning, and are less likely to crack, are not so strong and resistant. Saw-dust and coke breeze are also used with clay, the mixture yielding porous bricks suited to some uses. An admixture of quartz grit and coarse sand reduces volume change in burning, and, on account of the small proportion of surface to weight in coarse quartz fragments, the mixture may produce a more useful brick which shrinks and warps less and even withstands a higher temperature. Thus fine silica added to some clays may reduce their refractoriness, though an equal amount of coarse silica may increase it.

Fluxes in Fireclays

Iron is one of the most widely distributed elements in clay and in fireclays is objectionable. Several minerals may serve as its source, but it usually occurs as hydrate (limonite), sulphide (pyrite), or complex silicate (biotite, glauconite, hornblende, pyroxene, garnet, &c.). In analyses the iron is usually reported as ferric oxide, though in some minerals it is present in the ferrous form. In general, if containing up to 1 per cent. of ferric oxide, the clay burns white or nearly so, up to 2 or 3 per cent. buff, and above this proportion red. But there seems to be not a few exceptions, and authorities are not agreed as to the effect of iron on the colour of the ware or on the refractoriness of the clay. A clay in which the iron is uniformly distributed as oxide may be highly refractory if heated in an oxidizing atmosphere, but may fail in a reducing atmosphere because ferric oxide will not combine with silica, whereas ferrous silicate is readily formed and fusible. Again, iron sulphide, if present even in minute particles, gives rise during burning to ferrous silicate which is absorbed by the brick leaving a small hole surrounded by a black stain (A. H. Sexton and W. B. Davidson (1921): "Fuel and Refactory Materials," p. 334). Such a brick may be quite satisfactory.

The alkalies, soda and potash, are the most powerful fluxes that a clay commonly contains. They usually are present as residual particles of feldspar. The lime-soda feldspar fuse at lower temperatures, but are less common than orthoclase.

White or potash mica, found in many clays, vitrifies at 1,370° C., but if finely divided may produce softening at as low as 1,210° C. It is a mineral highly resistant to weathering and tends to occur in relatively large flakes, which, when the clay is calcined, maintain their individuality. Thus, in general, potash if present in a clay as mica is not so strong a flux as potash present as orthoclase.

Lime in fireclay is found in residual feldspar, epidote, garnet, or other complex silicate. These are less objectionable than the calcite or gypsum that occur in some clays. Lime is said to draw the points of incipient fusion and viscosity close to each other (H. Ries (1906): "Clays, Their Occurrence, Properties, and Uses," p. 79).

Magnesia, though also a strong flux, tends on the other hand to widen this gap and increase the temperature range between vitrification and deformation. It is usually present in clays in complex silicates such as biotite, chlorite, amphibole, or pyroxene.

Titania is usually more abundant in the clay than in the rock from which the clay was derived. It is probably present as leucoxene, a titano-silicate of lime, and is not a strong flux.

Bischof and others have sought to relate the refractoriness of a clay to its ultimate chemical composition. "Although the refractoriness of a clay is to a certain extent dependent on its composition, it does not at present seem possible to obtain any 'factor' which can adequately represent its power in this respect and be deduced from the analysis of the clay" (A. B. Searle (1921): "The Clayworker's Hand-book," p. 287). Ries (*op. cit.*, p. 146) quotes, "As a broad rule, the fusibility increases as the bases increase; but there is a great range of fusibility according to the bases that are present. The alkalies are more readily fusible than the ferrous oxide, and this in turn than the lime and magnesia. Again a mixture of bases is more fusible than a single base, and the greater the number of bases the greater the fusibility." Ries gives the following average percentages of fluxes in tested fireclays: Fe_2O3, 1·506 (p. 71); CaO, 0·655 (p. 79); MgO, 0·513 (p. 82); and alkalies, 1·46 (p. 82). There is a considerable range in these percentages. Sexton and Davidson (*op. cit.*, p. 335) state that the sum of the fluxing bases must not exceed 6 per cent. A. B. Searle (*Industrial and Manufacturing Chemistry: Inorganic* (1920) 2, 230), writes: "Though the composition of a fireclay as revealed by anlaysis will not necessarily indicate its refractoriness, it may be generally understood that all the more refractory clays do not contain more than 3 per cent. of basic oxides such as lime, magnesia, potash, and soda. Iron compounds behave peculiarly in fireclays, but it is seldom that more than 2 per cent.—reported as ferric oxide—is permissible."

Ganister

The original ganister is a fine-grained siliceous rock occurring in the coal-measures of Yorkshire, which, after being reduced to a coarse powder, is rammed around a pattern or used in brick form. It may be mixed with small proportions of milk of lime or fireclay to make it bind and is used in fettling cupolas and other steel furnaces.

Ganister contains from 87 to 96 per cent. of silica, the remainder being chiefly kaolinite. In composition and general properties it corresponds to pure quartz mixed with about a tenth of its weight of fireclay, and any material of such composition may be termed "ganister."

Silica bricks contain a maximum of siliceous material and a minimum of bond and are prepared from crushed ganister quartzite or sand bound together with milk of lime or a good fireclay. Owing to the substantial volume changes that take place during the conversion of silica at high temperatures from quartz to tridymite and cristobalite the burning of these bricks requires care.

Distribution of Fireclays

Fireclays underlie many coal-seams, and such clays are plausibly considered to be the old soils on which the vegetation now forming the seams had flourished and from which percolating solutions containing humic acids had leached most of the fluxing materials. They are also found in coal-seams or overlying them or interbedded in the group of strata constituting the coal-measures and not in contact with any seam. Moreover, they are not confined to coal-measures, many clays in coal-measures are not fireclays, and some coal-measures contain no fireclay. Nevertheless, refractory clays are commoner in coal-measures, and especially below seams than elsewhere and economically much more important.

According to Dr. D. White (in "Treatise of Sedimentation" by W. H. Twenhofel and collaborators (1926), p. 271), "the stratigraphic and depositional evidence in the important coalfields of the world shows that the coals were laid down in swamps on broad coastal or inland plains—lacustrine or fluvial—during stages of relative or approximate base level; that the regions were undergoing intermittently slow subsidence or, in the case of inland deposits, filling of the basins; and that the swamps were generally forested." In insular New Zealand the "broad plains" are greatly reduced, in the littoral region chiefly to bay-head and deltaic flats, and inland to valley flats and lake margins. While the swamps were in being, though the soil waters were acid, the ground was waterlogged, the circulation stagnant, and there was little chance of mineral leaching. Such leaching probably took place prior to the depression that brought about swamp conditions. In a general way leached soils are more likely to occur among valley deposits than in littoral accumulations, though exceptions may easily be postulated.

Again, soils are likely to be more thoroughly and deeply leached on lands that are well sculptured and mature than on those with steep slopes and rapid erosion. The most important coal-measures of New Zealand range in age from Late Cretaceous to Middle Tertiary. During these periods there were uplifts and depressions, but on the whole denudation predominated over elevation; at each cycle the land progressively became more mature and, toward the close of the periods, was peneplained. These three sets of coal-measures reflex the progress of denudation. Those of Late Cretaceous age consist largely of conglomerates and grits; in the Eocene measures the conglomerates are less prominent, are not so coarse, and are of quartz and other slow-weathering rocks; in the Oligocene coal-measures conglomerates are scanty and local, and mudstones and argillaceous sandstones are abundant. Fireclays are less common on the first group than in the second, and in the second than in the third.

In places clays of the present cycle are refractory, the rocks having been leached during the present cycle of erosion during an earlier cycle, and, in places, during both.

NORTH AUCKLAND

In North Auckland, as in other parts of New Zealand, refractory clays are interbedded in coal-measures. The coalfields are small and scattered, and several are no longer worked. The principal areas are Kawakawa, Hikurangi, Kamo, and Kiripaka, as well as a few very small patches. Fireclays occur also on or near and derived from hills of volcanic rock approaching rhyolite or dacite in composition. Highly siliceous products from the same volcanic rocks are also known as well as cherty bands in the basement rocks. Argillites in the basement rocks are also in places decomposed to refractory clays.

Coal-measure Clays

The coal-measures of North Auckland rest on and are derived from a basement of greywacke and argillite, rocks largely made up of grains of quartz and feldspar with a minor amount of ferromagnesian minerals and some clay. They are marine sediments consisting of particles of igneous rocks in part weathered and set in a matrix of fully weathered material. There is a considerable range in texture, and as the grains decrease in size the proportion of quartz lessens, that of clay grows, and the rock grades from a greywacke to an argillite. Of the rock constituents that are not readily leached out and that tend to increase during weathering the silica ranges from 70 to 55 per cent., the titania between 0·5 and 1·5, and the alumina from 10 to over 20 per cent. The other constituents are in percentages in each rock approaching those in igneous rocks containing silica in similar amount.

Fireclay is not abundant in the North Auckland coalfields, which are of Oligocene age and of the bay-head type. In general, the coal-measures are thin and contain but a single workable seam which is separated from the basement rock by a few feet of clay, shale, sandstone, or conglomerate.

Of the Kawakawa field McKay (*R.G.E.* (1884), *16*, 123) notes that at coal outcrops "where artifically exposed there is seldom more than 1 ft. to 3 ft. of fireclay underlying the coal between it and the older rock." The coal-measures are thicker to the dip, and in one bore the driller records 14 ft. of fireclay (*R.G.E.* (1877), *10*, 137) and two thinner bands in about 90 ft. of measures. Another records 12 ft. 5 in., and a shaft sunk in 1879 passed through 7 ft. of tough brown fireclay (*R.G.E.* (1884), *16*, 133–134). Pond (*Trans. N.Z. Inst.* (1876), *8*, 349) records that Bay of Islands (Kawakawa) fireclay was used in Auckland.

Little coal has been won since the mine was closed as exhausted in 1913.

Except for drillers' "fireclay" in bore logs there are no references to fireclay in the main mines of the Hikurangi Coalfield. The Inspectors of

Mines report that a co-operative party extracted 2 ft. of fireclay under a 3 ft. coal-seam left unworked in earlier years. An open-cast pit with a face of 15 ft. is now being worked for fireclay, which is used locally for making bricks.

Fireclay from the Kamo Coalfield is used for making refractory goods at the Kamo brickworks, but the thickness and extent of the clay-beds are not known, and no reference to the fireclay has been found in the literature.

The coal of the Kiripaka area has been exhausted for many years. According to Ferrar (*N.Z.G.S. Bull. No. 27* (1925), p. 117), 5,287 tons of fireclay was sent to Auckland during the years 1907–9, and the Inspector of Mines reports in 1940 and 1941 that fireclay from an open cast 30 ft. high was shipped, but does not state the amount.

There are only three analyses available of fireclays reported as occurring in the coal-measures of North Auckland. They are from Kawakawa, Kamo, and Kiripaka. These are astonishingly similar and show a range in composition no greater than would be expected in three samples taken from the same deposit. Analyses of five other samples from the Whangarei district (44/13, 45/17–18, 61/12),* closely corresponding in composition, may well be from the coal-measures, but are possibly clays derived from volcanic rocks (see below). The average composition of the three undoubted coal-measure clays is given in No. 1 of Table A.

Since the above was written a sample, collected by the Inspector of Mines from clay 10 ft. thick mined at Kiripaka by underground methods and used by the Auckland Gas Co., has been tested in the laboratory. No. 2 of Table A shows the clay to be rather more siliceous than most North Auckland clays. At 1,250° C. the test-brick was very hard, of a yellow-cream colour, and not at all vitrified.

Fireclays from Volcanic Rocks

A number of hills in North Auckland consist of volcanic rock containing so little ferromagnesian minerals and iron oxides as to be essentially a mixture of quartz and alkaline feldspars. The rocks contain 60 per cent. or more of silica, from 5 to 30 per cent. of free quartz, and 60 per cent. or more of feldspar. Lava of this kind is highly viscid, and bubble-shaped mounds and domes are often formed at the end of an eruption. The principal known masses are Putahi Hill, near Kaikohe; Maungaparerua, in the south-west corner of Kerikeri Survey District; Hikurangi, near the town of the same name; Maungarei, overlooking Kamo; Pakahaki, at Whangarei; and the low hill at the north end of McLeod Bay. Several other smaller masses are known in the districts that have been mapped in detail in North Auckland (see *N.Z.G.S. Bull. No. 8*, p. 73, and *Bull. No. 27*, pp. 59–61), and still others may be present in parts not yet thoroughly explored.

Volcanic domes of this kind are usually much fissured, and thermal gases may extensively decompose the rocks in the same way as is now taking place at Rainbow Mountain, in the Rotorua district. There are hot springs on the flanks of Putahi (*Bull. No. 8*, p. 37) and old steam-vents on its crest (p. 27). The deep but irregular alteration of the rocks at Maungarei and McLeod Bay suggest past thermal action at these points. It should be noted that volcanic gases and springs contain in general carbon dioxide which

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* This and similar references are from the annual reports of the Dominion Laboratory. The number of the report is given first, then the page.

would be effective in removing iron lime and magnesia as soluble bicarbonates. Such thermal action is analogous with the pneumatolytic processes that kaolinitized the granites of Cornwall and Devon that are so extensively worked for china clay. The alteration is decidedly patchy; at McLeod Bay quite fresh rock outcrops within a chain of the face of the clay-pit. From Putahi and Maungarei fresh samples have been analysed, as well as others from the same masses consisting essentially of quartz and kaolinite. Without doubt rock of different degrees of kaolinitization occurs in these deposits; probably more partly than completely altered rock occurs. Such partly altered rock, though containing too much feldspar to be refractory, may well vitrify to a white or nearly white body and be valuable as a pottery clay.

The most northerly known deposit of clay derived from acidic volcanic rock is crossed by the Kaeo Road about three miles north of Waimate North. As mapped (*Bull. No. 27*, Kawakawa Survey District), the deposit covers about 100 acres and crops out from beneath basalt (p. 60). The sample analysed (p. 98) is nearly pure kaolin, and as it had "good plastic properties" (p. 99) was probably a sedimentary clay. The analysis is No. 3 of Table A.

Putahi (1,261 ft.) is described (*Bull. No. 8*, p. 27) as a hummock-shaped hill with smooth slopes showing few outcrops of rock. It lies about two miles north of Kaikohe, occupies about a square mile, and rises 200 ft. to 300 ft. above the surrounding country. Narrow shaftlike holes up to 100 ft. deep and apparently old steam-vents occur at many points toward the summit of the hill, and there are hot springs on its eastern and southern slopes (p. 37). Mr. N. H. Taylor, of the Soil Survey, who collected the clay sample, No. 4, Table A, obtained it at a point two miles from Kaikohe from a large deposit beside or near the Te Pua Road, which passes along the east base of Putahi. The analysis of the fresh rock quoted by Clarke (p. 73) suggests that the altered rock would contain over 30 per cent. of free quartz, but as the norm or theoretical rational mineral composition of the clay analysed shows no free quartz and nearly 92 per cent. of kaolinite it may consist of halloysite. This mineral resembles kaolinite in composition, but is amorphous, contains more water, and occurs as secondary veins. At Maungarei and McLeod Bay halloysite forms septa an inch or more thick, and irregular bands in the decomposed rocks and similar veins are probably present at Putahi.

Hikurangi Mountain covers about a square mile of country and rises precipitously to 1,204 ft. a mile west of Hikurangi township. The rock resembles that of Putahi, its norm containing 27 per cent. of free quartz and over 62 per cent. of feldspar (*Bull. No. 27*, p. 67). Areas of decomposed rock are not known, but a sample of highly siliceous fireclay may well be from a bed of sedimentary clay derived from the rocks of Hikurangi (No. 5, Table A).

Maungarei, a compact group of steep-sided dacite hills three miles in area, towers above Kamo, from which the trig. (1,260 ft.) lies a mile and a half north-west. The fresh rock is similar in composition to those of Putahi and Hikurangi (*Bull. No. 27*, p. 75), the normative composition showing 28·56 per cent. of quartz and 58·53 per cent. of feldspar. Parts of Maungarei are deeply altered, probably by thermal action. No hot springs are known on the mountain; mineral springs discharging carbon dioxide at Ruatangata half a mile from its south-west foot are probably connected with a period of vulcanism later than that during which Maungarei came into being. From time to time the Dominion Analyst has examined samples of clay collected from the neighbourhood of Maungarei, approaching kaolin in composition, and probably residual or sedimentary clays derived from the rock forming it. As a rule these samples were not more precisely located than as being obtained from Kauri or Kaurihohore; the railway-station, Kauri, is half a mile from the north-east corner of the mountain. No. 6, Table A, is the average of nine samples.

The brickworks at Kamo are supplied with clay from a pit on the lower north-east slopes of Maungarei, 60 chains south-west from Kauri Railway-station. The face, 100 ft. long and 20 ft. high, shows much-jointed pale-grey greatly decomposed rock. The joint prisms, 4 in. to 6 in. across, are separated by bands of white halloysite up to 1 in. thick. When visited, slip material concealed most of the lower part of the face, but at the point last worked a 2 ft. band of white clay, the decomposed pug of a shear, dipped into the hill at 70°. Without clearing the face and cutting channels a representative sample would be difficult to select. The sample taken, No. 7 of Table A, is probably more nearly representative than others from this locality (see No. 6), which were essentially kaolin. When burnt the clay shrinks considerably, and in making refractory bricks the burnt clay is crushed and a mixture of two parts grog and one part raw clay is used. The saggars at the New Lynn potteries are made of three parts Kauri grog bonded with one part Glen Afton fireclay, which is much more plastic than the Kauri clay. Kauri or Kamo bricks are claimed to be the most refractory produced in New Zealand. They are used to line cement-kilns, except in the hottest zone, where magnesia bricks are used.

Alluvial clays derived from Maungarei occur in the neighbourhood. A cut on the main highway, 15 chains south-west from Kauri Railway-station, exposed 10 ft. to 12 ft. of pale-grey clay for several chains. The bed rests on an old land surface marked by stumps, roots, and a carbonaceous layer. The composition of the clay is shown in No. 8 of Table A.

Parahaki (794 ft.) covers about two square miles north-east of Whangarei, the trig. being a mile and a half from the railway-station. It is a dome of acidic rock similar to those of other volcanic domes of the district, though no analysis of the fresh rocks seems to have been made. Most outcrops on the top and flanks of the hill are greatly decomposed, and the four analyses available show an unusually low percentage of titania. No. 9 of Table A shows the average of these four analyses. No. 10 is a detrital clay derived from Parahaki, forming a deposit at the railway culvert 20 chains south from Whangarei.

A dacite dome, less than a square mile in area, forms a low hill (370 ft.) east of the north end of McLeod Bay, the central of the three inlets on the west side of the south-jutting peninsula on the east side of Whangarei Harbour. An analysis of the fresh rock is given on p. 75 of *Bull. No. 27*, but, in general, the rock is deeply decomposed. Analyses show that this rock contains very little titania. A clay-pit on the coast yields a feldspathic clay used in the New Lynn potteries, but outcrops on the road across the dome are more thoroughly decomposed, the sample tested being highly refractory (No. 11 of Table A).

In North Auckland the basement rocks over large areas consist chiefly of pale-grey argillites, usually referred to the Cretaceous period. Ongley (*N.Z. Jour. Sci. & Tech.*, 7, 178) suggests that such Cretaceous beds had a peneplained land as their source; as such they would be fairly well leached before deposition. Some residual and sedimentary clays derived from these rocks have been tested and found refractory. Mr. N. H. Taylor, of the Soil Survey, collected the sample, No. 12 of Table A, a white mealy-textured clay residual on an extensive area of Cretaceous rocks, between Whangaroa and Mongonui inlets. There is a large quantity of the clay which grades down into argillite. No. 13 of the table is a sedimentary clay, which Mr. Taylor states occurs in pockets 4 ft. to 5 ft. thick and passes down into pinkish clay with rusty partings; the material of the deposit or deposits has been washed in from hills of Cretaceous rocks.

At the Puhipuhi Mercury Mine, twenty miles from Whangarei, the argillite, under the cinnabar-bearing silicified quartz grit that forms the ore, has been altered by thermal solutions to a white clay. The deposit is probably large, having been cut into to a depth of 20 ft. and having been penetrated by drills over an area of several acres. No. 14 of Table A shows that the material is probably refractory.

The basalt cap at Puhipuhi, which forms a plateau of two square miles, has deeply weathered in the warm, wet climate. In places a layer of white- or cream-coloured massive halloysite up to an inch thick has formed under the soil. This is mentioned not because it is thought to indicate the existence of deposits of economic value, but to suggest the possible source of some very good-grade clay material forwarded from Puhipuhi (42/17) and other parts of North Auckland (43/10, 52/22). Probably of somewhat similar origin is the remarkable clay, No. 15 of Table A, collected by Mr. N. H. Taylor and said by him to form the subsoil over five or six square miles of the Waipapa-Kerikeri Flats, which lie about ten miles north of west from Russell. The light-coloured clay as analysed is probably only 2 ft. or 3 ft. thick and grades down into iron-stained material. The high content of Cr_2O_3, 0·06 per cent., of V_2O_3, 0·03 per cent. and of titania 2·35 per cent. indicates that this clay is derived from the basalt that underlies the flat rather than from the dacite of Maungaparerua, which rises a few miles to the west. Bricks from the clay would contain nearly 50 per cent. of alumina and would, no doubt, be highly refractory; a small percentage of iron would probably not be objectionable for this use. The theoretical rational analysis shows the sample tested as containing 5·67 per cent. of alumina more than required to combine with the silica as kaolinite; some other compounds of alumina containing more water and less silica than kaolinite are probably also present.

The Amalgamated Brick and Pipe Co., of Auckland, use a black swamp-clay occurring at New Lynn and derived by normal weathering from the argillaceous sandstones and mudstones of the Waitemata Beds as a ball clay in the manufacture of pottery. It is from 6 ft. to 8 ft. thick, covers several acres, and underlies 20 ft. of clay used in making building bricks and sewer pipes. The analysis, No. 6 of Table A, suggests that the clay contains about 10 per cent. of carbonaceous matter and is probably a second-grade fireclay.

SOUTH-WEST AUCKLAND

The coalfields of South-west Auckland extend into northern Taranaki and occupy considerable areas on the hilly country and lowlands between the west coast and the series of depressions that stretches south from the Firth of Thames to the upper basin of the Mokau. The coal-measures are of Oligocene age, those occurring near Huntly contain large amounts of refractory clay and are slightly older than those found in the Kawhia and Te Kuiti districts, from which so far fireclays have not been collected. The old rocks from which the clays have been derived are the same in both areas, and the differences between the Huntly and the Kawhia - Te Kuiti clays are due to differences in conditions of accumulation of the coal-measures. Prior to their deposition the Huntly area was a land of low relief with a deeply weathered surface. Drainage was so sluggish that only the finest particles were transported, and a mantle of clay, in part residual and in

Table A.—Analyses of Clays from North Auckland

—	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.*	16.†
SiO_2	62·48	65·32	38·54	40·90	79·31	39·52	52·90	62·90	64·28	70·84	61·03	52·96	56·03	59·80	33·82	49·61
Al_2O_3	23·06	20·83	33·58	35·22	9·04	33·66	29·02	20·76	21·40	15·69	25·02	30·35	26·63	27·38	32·99	23·20
Fe_2O_3	0·89	1·56	0·72	1·92	1·86	2·49	1·40	1·16	0·92	1·83	0·85	0·79	0·70	0·25	1·91	1·68
CaO	0·32	0·24	0·19	Nil	0·48	0·25	Nil	0·09	0·12	0·07	0·05	0·31	0·32	0·31	0·26	0·33
MgO	0·36	0·55	Nil	0·11	0·71	0·17	0·02	0·41	0·22	0·53	0·11	0·19	0·20	0·54	0·18	0·41
Na_2O	1·00	0·21	0·15	0·02	1·33	0·11	0·02	0·35	0·19	0·24	0·04	0·02	0·03	0·26	0·12	0·33
K_2O	0·77	0·96		0·14			0·34		0·12	0·76	0·07	0·17	0·14	1·62	0·05	0·29
TiO_2	0·98	1·16	1·15	1·86	..	0·97	0·60	1·32	0·22	1·14	0·09	0·62	0·76	1·20	2·35	0·74
H_2O+	10·03	7·66	13·75	14·27	5·90	..	11·70	8·68	8·53	7·15	10·09	11·90	10·24	8·41	16·71	19·21
H_2O-		1·78	11·91	5·47	1·37	..	4·15	4·29	3·82	2·06	2·39	3·00	5·20	0·04	11·90	4·15
	99·80	100·27	99·99	99·91	100·00	..	100·15	99·96	99·82	100·31	99·74	100·31	100·25	99·81	100·29	99·95

* The alumina includes 0·06 Cr_2O_3 and 0·03 V_2O_3, and the combined water 0·09 of sulphur. † The combined water includes much organic matter.

No. 1.—Average of three comparable fireclays from the coal-measures of North Auckland—*i.e.*, Kawakawa (55/17),* Kamo (46/17), and Kiripaka.

No. 2.—Clay 10 ft. thick mined at Kiripaka. (Lab. Memo. 11/8/42.)†

No. 3.—Plastic clay, Kaeo Road, three miles north of Waimate North (55/20).

No. 4.—Clay, Te Pua Road, two miles north of Kaikohe, collected by N. H. Taylor. (Lab. Memo. 7/10/41).

No. 5.—Clay, Hikurangi Mountain (45/18).

No. 6.—Average of nine comparable samples, probably all from Maungarei (42/18, 43/10, 45/18, 52/22, 58/12).

No. 7.—Decomposed dacite, quarry on Maungarei Mountain, 60 chains south-west from Kauri Railway-station. (Lab. Memo. 7/10/41.)

No. 8.—Alluvial clay, disused clay-pit, 10 chains south-west of Kauri Railway-station. (*N.Z.G.S. Bull. No. 27*, p. 98).

No. 9.—Average of four samples of clays from Parahaki (54/20, 59/15–6, 61/12).

No. 10.—Detrital clay (washed), railway culvert, 20 chains south of Whangarei Railway-station. Clay is derived from surrounding hills and Parahaki (54/22).

No. 11.—Clay from 5 ft. cut on side of road between Parua and McLeod Bays, near centre of dacitic mass. (Lab. Memo. 7/10/41).

No. 12.—White mealy clay, Kaeo–Mongonui Road, on top of first hill past Whangaroa Inlet. (Lab. Memo. 21/7/42).

No. 13.—White clay, Matauri Bay Road, 1½ miles south-west from Matauri Bay, which is 10 miles east of Whangaroa. Clay, 4 ft. to 5 ft. thick. (*Ibid.*)

No. 14.—White clay, Puhipuhi Mine. (Lab. Memo. 2/7/42).

No. 15.—White clay forming sub-soil of Waipapa-Kerikeri flats, road a mile east of Waipapa. (Lab. Memo. 21/7/42).

No. 16.—Black carbonaceous clay, New Lynn potteries. (Lab. Memo., 11/8/42).

* This and similar references are to the annual reports of the Dominion Laboratory. The number of the report is given first, then the page. † This and similar references are to manuscript reports from the Dominion Analyst on the files of the Geological Survey. The figures give the date of the report.

part sedimentary, covered the land. Later, drainage, probably owing to depression, became still more sluggish, and vast swamps spread over the lowlands and gentle bordering slopes. Continued depression allowed the area to be buried, first by estuarine muds and later by marine clays. The sea advanced on the neighbouring Kawhia and Te Kuiti areas and stripped off the weathered mantle. Masses of vegetation accumulated at bay heads, but the underclays are thin, sandy, and unleached, and marine sediments overlie the seams. Thus in the Huntly basin the coal rests on fireclay which may be many feet in thickness and is overlain by thick massive semi-refractory clay which grades up to blue clay of marine deposition. On the other hand, in the Kawhia and Te Kuiti districts the coal-measures, though but little younger and belonging to the same group of beds, are much thinner and contain little or no refractory clay.

Huntly Fireclays

The Huntly basin extends from Glen Massey, ten miles south-west from Huntly, north to Drury, a distance of 40 miles, and probably covers an area of 300 square miles. It is best exposed in the neighbourhood of Huntly, but the greater part of the coalfield is concealed beneath the young pumiceous deposits of the lower valley of the Waikato. At Huntly the term " fireclay " is applied to the non-laminated grey and brownish-grey clays at the base of the Tertiary sequence. These range up to 300 ft. thick, but are usually about 100 ft. In their lower part they contain one or two thick seams of coal. The greater part of these clays, though pale-burning, are not sufficiently refractory to be classed as fireclays. These latter form most of the beds between the lower seam and the basement rock, but also underlie parts of the upper seam, where this is present. Usually there is 10 ft. to 20 ft. of clay above the understone, but at Kupakupa 100 ft. of clay occurs, and at the Huntly brickworks at least 50 ft. Little is known of the fireclay beneath the upper seam, but at one point at Rotowaro it is at least 11 ft. thick. It must be pointed out that at Huntly, and indeed at most coalfields, very little is known of the beds of fireclay. On the surface, clays are too soft to form good outcrops, and in the mines the floor of a seam is not broken unless there is sale for fireclay or the grading of a roadway necessitates the cut. At Huntly, however, what evidence there is suggests the presence of large amounts of fireclay.

The Huntly fireclays are derived from the decomposition and leaching of the greywackes and argillites that form the basement of the region. These are mostly of Triassic and Jurassic age somewhat younger than the similar rocks of North Auckland. There is a large proportion of feldspar in these rocks, especially in the greywackes, and near the Wilton colliery one such rock, containing conspicuous Triassic fossils, has been decomposed in place to a kaolin of fair grade (Table B, No. 1).

In chemical composition the Huntly fireclays are similar to the coal-measure fireclays of North Auckland, though the available analyses show a somewhat wider range in composition. If a single highly siliceous sample be omitted, the analyses of ten samples of Huntly fireclays, one from the Bombay district, show that silica ranges from 68 to 57 per cent. and alumina from 19 to 26 per cent. The average given in the table (No. 2, Table B) of ten analyses is almost identical with the average of fireclays from the North Auckland coal-measures ; there is a little more iron in the Huntly clays and a little less alkali.

The Huntly Brick and Tile Co., established many years ago, makes firebricks, refractory tiles, and gas retorts from the under-coal clays that form low hills at Huntly. The weathered fireclays contain irregular partings and layers of halloysite up to a fourth of the total mass and is superior to the unweathered clays. The company uses producer gas for firing the kilns. In 1925 a company was formed to make pottery from the weathered fireclay of a low hill in the Akatea valley less than half a mile north from Glen Massey; it shortly failed. Another concern, using the fireclay at Glen Afton, has been taken over by Messrs. McSkimming, who make sanitary ware at the works. The Amalgamated Brick and Pipe Co., of New Lynn, Auckland, use a considerable proportion of Huntly fireclay in some pottery mixtures. The Wellington Gas Co. used to obtain fireclay from the Rotowaro Colliery for the manufacture of firebricks and other refractory ware.

No. 3 of Table B shows the composition of the grey, flaky fireclay that forms three-fourths of the body mixture used in the manufacture of sanitary ware at the Glen Afton potteries. The 18 ft. face at the back of the works shows :—

4–8 ft. soil and surface clay.
4 ft. grey clay.
1–2 ft. coal and carbonaceous shale (Pukemiro seam).
8 ft. brown-grey blocky clay with iron-stained partings.
2–3 ft. dark flaky clay.
4 ft. brown-grey blocky clay.
4 ft. (no bottom) grey flaky clay (sample).

The clay-pit at the back of the Huntly ovens shows up to 50 ft. of clay in irregular lenticular bands up to 8 ft. thick, but usually not more than 4 ft., consisting of pale-brown blocky clay and grey flaky clay separated by thinner bands of darker clay and carbonaceous shale which, in places, grades to coal. In the lower half ironstone nodules occur in the blocky clay. A coal-seam overlies, which farther in the hill thickens to a workable height. Pumice sand 8 ft. to 10 ft. thick overlies and truncates the different beds on the hillside. Only the ironstone nodules and coal are rejected, firebrick and other refractory goods being made of the selected grey and brown clays and building bricks of the carbonaceous clays and pumice sand; about a third of the output is made into refractory material. At the south end, about 15 ft. over the highest coal-seam, banded brown and grey siliceous clays occur. Nos. 4 and 5 of Table B are of samples of these siliceous clays. They are in all about 30 ft. thick and have not yet been used.

Kawhia - Te Kuiti Clays

Coal-measures are found in several relatively small patches under the extensive sheet of limestone outcropping about Raglan, Aotea, and Kawhia inlets, in the depression drained by Mangapu and Mokau rivers, and on the uplands separating these areas. In general, the coal rests on sandy beds close to the unweathered basement of Mesozoic sediments, but at Hauturu, near the head of Kawhia Harbour and at Mangapehi, 20 miles south-east from Te Kuiti, layers of clay are present. A sample, collected by Mr. J. Hadcroft from thick extensive clay directly under the coal at Mangapehi, was recently examined in the Laboratory. Though the clay contains only 4·12 per cent. of fluxes, at 1,300° C. it was well vitrified to a greyish-cream stoneware; it is certainly too fusible to be considered refractory (see No. 5 of Table B). Clays from other coal-bearing area in this area have not yet been tested.

The Mesozoic sediments underlying the Tertiary coal-measures also contain carbonaceous layers. A sample of a white clay interbedded with carbonaceous bands outcropping in the Manganui valley in the south-west corner of the region was tested (No. 6 of Table B), but contained too high a proportion of fluxes to be classed as refractory. The sample was from the upper 6 ft. to 8 ft. of a 20 ft. bed of white clay in parts iron-stained. Fire-clays may occur in the Mesozoic rocks, especially in areas where carbonaceous bands are prominent, as at Port Waikato, in the Urewera Country, and in the McLennan, Waikawa, and Hokonui districts of Southland.

TARANAKI

The Taranaki Coalfield covers large areas in the basins of the Mokau, Ohura, and Tangarakau rivers in the northern part of the province, and there is a considerable coal-bearing area in Wellington at the head of Retaruke River. The coal-measures are of Miocene age, younger than those of Auckland, and were formed under different conditions. Apparently the period was one of gradual depression interrupted by minor oscillations of sea-level, and the coal vegetation accumulated on raised sea-floors and was covered with marine sands and silts that in places contain shells. The leaching of the underclays was for the period of plant-growth only, and seems to have been insufficient to reduce the fluxes to the point necessary in refractory clays, none of which is known to occur.

Volcanic material from Egmont and other centres of eruption covers several hundreds of square miles in Taranaki, but the rocks are entirely andesitic and contain from 6 to 10 per cent. of iron oxides, so that even where they are greatly decomposed the products are likely to be too high in this flux to be refractory. Nevertheless, there is some material that may have value in industry.

Coal-measure Clays

The clays with the coals of Taranaki are in general blue-grey in colour and usually contain about 8 per cent. of fluxes, which, though less than the amount present in ordinary clays (10 to 25 per cent.), is much too high for refractory ware. Analyses of clays from Mokau, Tatu, and Tangarakau are given in Table B, and two other analyses of clays from the Ohura area are published on page 76 of *N.Z. Geological Survey Bulletin No. 24.*

Volcanic Clays

" On the Smart Road considerable deposits of exceedingly decomposed and bleached volcanic rock occur. Similar deposits are also to be found near the upper waters of the Huatoki Stream, whence they extend at intervals towards the base of the Pouakai Range " (*Bull. No. 14*, p. 52). Smart Road extends for four miles along the east side of the lower valley of the Waiwakaiho, a stream that enters the sea a mile or so east of New Plymouth, and the Huatoki is a stream seven miles long that flows through that town. The clays, which are reported to be about 15 ft. thick and to occur two miles south from the railway, approach kaolin in composition, and are, perhaps, due to hydrothermal action similar to that which decomposed the rocks of North Auckland to high-grade white-burning clays. Here, however, the rocks are andesites which contain much more iron than the rhyolites and dacites of North Auckland. So far the best material examined is kaolin rather high in iron. The average of four samples, probably all from the same locality, is given in No. 10 of Table B. Dr. C. O. Hutton, who recently visited the area, considers that the chance of large deposits being found is small.

TABLE B.—ANALYSES OF CLAYS, SOUTH-WEST AUCKLAND, ETC.

—	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.
SiO_2	47·71	62·40	57·03	80·30	74·35	56·58	47·94	55·78	59·10	51·15	56·39	35·95
Al_2O_3	29·95	23·06	26·28	11·53	13·78	20·80	23·95	18·17	20·02	21·45	23·52	28·62
Fe_2O_3	0·98	1·65	1·10	0·64	0·72	5·28	1·20	2·48	2·08	3·60	1·38	2·08
CaO	0·11	0·33	0·32	0·07	0·19	0·10	0·14	1·30	0·70	1·15	0·64	0·49
MgO	0·12	0·16	0·31	0·12	0·29	0·90	0·44	2·00	1·25	1·76	1·14	0·31
Na_2O	0·10	0·17	0·18	Nil	0·14	0·15	0·24	} 0·46	3·73	{ 1·04	0·26	} 1·24
K_2O	0·22	0·54	0·42	0·30	0·67	0·72	1·10			2·05	2·76	
TiO_2	0·83	0·85	1·10	0·65	0·69	0·83	1·00	..	..	1·25	0·93	1·33
H_2O+	11·99	8·09	10·17	5·15	7·90	9·71	19·15	7·19	} 13·12	{ 11·05	9·05	} 30·53
H_2O-	8·11	2·81	3·04	0·78	1·42	4·85	4·71	12·81		5·65	3·92	
	100·12	99·66	100·26	99·54	100·15	99·92	99·87	100·19	100·00	100·15	99·99	100·55

No. 1.—Clay residual from feldspathic rock and containing casts of *Pseudomonotis*, Te Pake Road, near Wilton Colliery. (*N.Z.G.S. Bull. No. 28*, p. 87).

No. 2.—Average of ten comparable fireclays, Huntly (50/17, 55/21, 56/17-8, 57/19, 58/15, 62/16) and Bombay (58/17) districts.

No. 3.—Grey flaky clay, Glen Afton, used in potteries. (Lab. Memo. 11/8/42.)

No. 4.—Siliceous clay, Huntly brickworks (62/15).

No. 5.—Siliceous clay, 30 ft. thick, Huntly clay-pit. (Lab. Memo. 11/8/42.)

No. 6.—Grey-brown clay above the coal, Waikokowai, Huntly. (*Bull. No. 28*, p. 90.) This is what is popularly termed fireclay at Huntly. It contains about the same amount of iron as ordinary "papa," but much less lime, magnesia, and alkalies.

No. 7.—Black-grey clay underlying coal at Mangapehi, collected by Mr. J. Hadcroft. (Lab. Memo. 6/1/42.)

No. 8.—General sample of upper layer 6 ft. to 8 ft. thick of a 20 ft. bed of clay, white except where iron-stained, on road 60 chains south of Ballacraggan Homestead, Manganui Valley (*N.Z.G.S. Bull. 24*, p. 75).

No. 9.—Clay, 4 ft. thick, underlying 3 ft. coal-seam outcropping 14 chains up Mangangarungaru Creek, Mokau River (52/23). The clay was highly plastic and burned to a yellow-white colour.

No. 10.—Clay, 8 ft. thick, underlying coal at Tatu Mine. Collected by Mr. J. Hadcroft. (Lab. Memo. 6/1/42.)

No. 11.—Composite sample of clay (2 ft. 6 in. to 3 ft. 9 in. thick) underlying and overlying the 27 in. seam of coal exposed on the right bank of the Tangarakau, above the railway-station, for over a mile. Collected by Mr. W. Shanks. (Lab. Memo. 12/10/37.)

No. 12.—Average of four comparable impure kaolins, two from Smart Road (*Bull. No. 14*, p. 52) and two from probably the same but unspecified ocalities (40/14, 42/19).

HAURAKI, ROTORUA, AND OTHER PARTS OF THE NORTH ISLAND

A strip of greywacke and argillite showing great differences in width extends through the eastern half of the North Island, the old rocks being overlapped at many points by Tertiary strata. Nowhere, however, do coal-measures or thick terrestrial beds occur at their base or within the sequence, and, so far, no refractory clays are known from the Tertiary rocks. Weathering of the present cycle has produced some clays from the feldspar of the old rocks, and semi-refractory material from several localities has been examined. A highly siliceous clay occurs at Horokiwi, near Porirua Inlet, a few miles north of Wellington. Two samples have been examined, one in the Dominion Laboratory and the other at the Imperial Institute, London. The latter reports that the material " would be a satisfactory fireclay and could be employed in the manufacture of earthenware " (*Technical Reports and Scientific Papers* (1903), pp. 35–36). The extent and exact locality of the deposit is not known. Similar clay is reported to form a large deposit near Carterton (39/10).

Hauraki Peninsula and the range continuing it south for fifty miles toward Rotorua are largely built of andesitic rocks of composition similar to those of Taranaki. Magmatic gases and solutions intensely decomposed in depth masses of rock during the formation of the gold-silver veins of the region, but iron was not removed and the alteration product of the feldspar was sericite rather than kaolinite, so that refractory material was not formed. Emanations of steam and carbon dioxide toward the end of vulcanism and near the surface are likely to produce kaolinite and remove fluxes, and the infrequent deposits of kaolin and fire-resistant clay in this region may be attributed to the last phases of volcanic action.

The precise locality and the extent of the deposit near Rocky Point, Thames, from which a sample of good-grade kaolin (No. 2, Table C) was obtained, is not known. Possibly it was collected from the vertical 15 ft. zone of crushed and decomposed andesite that outcrops for at least half a mile in the basins of Tararu and Ohio creeks, streams that join about a mile and a half east of Rocky Point. An analysis is given, on page 37 of *N.Z.G.S. Bull. No. 10* (1910), of a sample of clay, there termed " fuller's earth," from this zone.

From Hikutaia a sample from a deposit reported as large had the composition shown on No. 3 of the table. This sample was a mixture of quartz and kaolinite in subequal amount and had the composition of a fair-grade fireclay. The precise locality is not known. The lower valley of the Hikutaia, a considerable stream entering Waihou River twelve miles south of Thames, is in andesitic rocks, but fragmental rhyolites are abundant about its headwaters and probably furnished the quartz and also most of the kaolinite of the clay. The basin of the Tairua River, the stream across the divide, is almost entirely in rhyolitic rocks, and clays from Puketerahi, near its estuary, are similar but inferior, to that of the Hikutaia deposit. No. 4 of Table C is the average of three samples. There is no information as to the amount of clay present or of its occurrence in the field.

On the Thames–Paeroa Road, about two miles north of Hikutaia and 100 yards south of the Wharepoa Road junction, there is a cutting through a hill of andesitic material. The cutting shows flat-lying pale-grey clay 2 ft. to 3 ft. thick grading down into pink-grey clay with iron-stained partings and up to 4 ft. thick with no bottom showing. There is a sharp division over the grey clay, probably an old soil, and reddish decomposed rock up to 25 ft. thick extends to the present surface. The grey clay is probably the upper subsoil of an old weathered surface of andesitic rock. No. 5 of Table C shows its composition. At 1,250° C. the test brick was cream with brown mottlings, steel hard but not vitrified. From the analysis the clay is probably a second-grade fireclay.

Acidic volcanic rocks cover thousands of square miles in the north central part of the North Island, and in the great structural depression that extends south-west for ninety miles from the Bay of Plenty through Rotorua to Taupo innumerable active and extinct fumaroles and hot springs have silicified or altered large masses of rock. The volcanic emanations, which are predominantly alkaline in depth, bring silica to the surface, where they deposit sinter; they become acid by absorbing oxygen and decompose feldspar and volcanic glass with the production of kaolinite. The Dominion Analyst has examined samples of kaolin from Pukeroa Hill, Rotorua, that are rather high in iron (No. 5, Table C). Nothing is known of the extent or exact locality of the deposit.

Maungakakaramea (Rainbow Mountain) and Maungaongaonga, about fifteen miles south-east from Rotorua, are domes of acid volcanic lava similar to Parahaki, Maungarei, and other domes in North Auckland in origin and composition as well as in degree and nature of alternation that here is still in progress. The analysis (*N.Z.G.S. Bull. No. 37*, p. 67) shows that the fresh rock contains a low percentage of iron and alkaline earths, and as calculated from this analysis more than half the rock consists of feldspar. In the sample of decomposed rock tested in the Laboratory (No. 6, Table C) the alkalies and alkaline earths had been removed, iron oxide was about the same and silica was a little higher. "The decomposition over the greater part of these two mountains [Maungakakaramea and Maungaongaonga] and in other localities in the subdivision has produced clays of various colours—white, cream, purple, red, &c. The clay on the western side of Paeroa Range contains 8–7 per cent. of clear quartz particles, and if this fraction is excluded the clay has the composition set out under [No. 7, TableC], which agrees very closely with kaolin. The red clay from the steaming ground near Karapiti also consists largely of kaolin [No. 8, Table C; No. 9, Table C] and can be taken as representative of the composition of acid mud volcanoes and mud-pots" (*ibid.*, p. 121).

The volcanic eruptions of the central North Island through later Tertiary and post-Tertiary times continued on a vast scale, deposited thick beds of fragmental acidic rocks in the Rotorua-Taupo and adjoining regions. Air-borne tuff was more widely distributed, and streams carried the material still farther from its source, so that deposits of pumiceous sands, silts, and clays are found on the west coast from Manukau to Kawhia and Wanganui, on the north along the Hauraki Gulf and the Bay of Plenty, on the east from Hicks Bay to Hawke Bay, and in the Dannevirke, Woodville, and Pahiatua districts to the south. Water-laid beds are thick and extensive in the Waikato and Rangitaiki basins and in the Hauraki depression. In general, the finer-grained deposits consist of volcanic glass and crystal fragments not thoroughly decomposed, which, even though white, fuse to dark masses at relatively low temperatures. In places completely weathered material occurs, and in the water-laid older beds veinlets and thin layers of light-coloured halloysite occur near the surface, probably arising from the decomposition of the volcanic glass. Two analyses of clays are cited, No. 10, Table C, the ordinary light-coloured clay, and No. 11, probably a sample of halloysite. Other analyses, probably of samples of clays of this kind from Horahora, near Maungatautari, and from Manukau are given in Lab. 46/17. Nothing is known of the extent of any of these deposits or of the quantities of clay available in each.

Table C.—Analyses of Clays, Hauraki, Rotorua, and other Parts of the North Island

—	1.	2.	3.	4.	5.	6.	7.	8.	9.*	10.	11.	12.
SiO_2	80·61	48·5	65·45	64·48	53·97	41·10	68·55	45·70	43·17	56·71	62·54	41·54
Al_2O_3	10·60	38·6	20·77	14·32	28·14	39·30	16·20	36·85	30·02	25·77	19·67	26·32
Fe_2O_3	0·83	2·0	0·77	2·03	2·77	2·40	3·76	1·02	6·36	1·43	3·60	1·60
CaO	0·10	0·5	0·21	1·15	0·15	Nil	0·13	0·10	0·46	0·10	1·25	0·27
MgO	0·59	Nil	Nil	0·62	0·06	Nil	0·06	0·03	0·30	0·06	0·10	0·37
Na_2O	0·82	} 0·1	0·25	} 2·13	0·14	} 0·20	0·12	0·02	Nil	0·21	} 4·67	0·87
K_2O	1·21		0·07		0·03		0·31	0·11	Nil	0·25		
TiO_2	0·24	..	0·19	..	0·94	..	0·66	0·67	0·64	0·46	0·74	..
H_2O+	3·36	10·3	8·33	7·65	11·14	} 16·60	7·48	14·02	10·71	12·60	4·82	12·53
H_2O-	1·58	..	4·13	7·64	2·80		2·00	1·09	8·01	1·61	2·61	16·50
	99·94	100·0	100·17	100·02	100·14	99·60	99·27	99·61	99·67	99·20	100·00	100·00

* In *Bull. No. 27* the silica of this sample is incorrectly given as 56·17 per cent.

No. 1.—Average of two comparable siliceous clays, Horokiwi (58/16 and *Imp. Inst., Rep. & Pap.* (1903), p. 35).
No. 2.—Kaolin, Rocky Point, Thames (52/21).
No. 3.—Fireclay, Hikutaia (62/18).
No. 4.—Average of three samples from Puketerahi, near Tairua (50/19).
No. 5.—Clay, 2 ft.–3 ft. thick, road-cutting two miles north of Hikutaia. (Lab. Memo. 11/8/42.)
No. 6.—Kaolin, Pukeroa Hill, Rotorua. This sample was labelled " white clay "; the sample of " red clay " contained more iron (51/20).
No. 7.—Cream-coloured rock near hot springs, Maungaongaonga Mountain. The rock contained also P_2O_5, 0·10 per cent., and SO_3, 0·58 per cent. (*N.Z.G.S. Bull. No. 37*, p. 122.)
No. 8.—Thermally altered rhyolite breccia, western side of the north end of the Paeroa Range, three miles west of Waiotapu. The analysis has been recalculated to exclude 8·7 per cent. of clear quartz particles. The sample contained also ZrO_2, 0·07 per cent.; P_2O_5, 0·07; MnO, 0·01; BaO, 0·07; and S, 0·23. (*Ibid.*)
No. 9.—Ferruginous kaolin from steaming area near Karapiti Blowhole, Wairakei. The sample contained also MnO, 0·26 per cent.; BaO, 0·03; and S, 0·02. (*Ibid.*)
No. 10.—Grey clay, mud volcano on Main Road, Whakarewarewa. The sample contained also ZrO_2, 0·04 per cent.; P_2O_5, 0·05; MnO, 0·01; BaO, 0·05; and S, 0·52. (*Ibid.*)
No. 11.—Clay, Mangatea Stream, near Ohinewai, five miles north of Huntly (50/16).
No. 12.—Clay, Maungatautari, a few miles up Waikato River from Cambridge (47/19).

GANISTERS OF THE NORTH ISLAND

The basement greywacke-argillite rocks of North Auckland and the mountain axis of the North Island contain, in several known localities, and not uncommonly, discontinuous bands of quartzite and chert, as well as many silicified grit layers and shatter-belts. These outcrop chiefly on hilltops and along ridges. The only available analysis of these rocks, which may have value as ganisters, is of a sample from North Auckland (No. 1, Table D). The greywacke-argillite series of south-west Auckland, the Raukumara Peninsula, and east Wellington containing fossils showing their Mesozoic age are not known to contain siliceous material similar to that of the rocks mentioned above.

Sedimentary rocks of late Cretaceous and Tertiary age, though they cover the greater part of the North Island, do not seem to contain sandstones with little enough argillaceous or calcareous material to allow of their use as ganisters.

In North Auckland and in the Rotorua-Taupo region the acid volcanic rocks, by weathering, have yielded fine-grained, highly siliceous material. Hot springs have deposited opaline silica in large sheets of sinter at many points, and in some places formed deposits of minute, rounded particles of the same material. In other parts rhyolitic rocks, widespread in the region and containing, if unaltered, about 70 per cent. of silica, are strongly silicified, as at Huka Falls and Atiamuri (fine-grained lake-beds) and Ohakuri (breccias). In addition, at Coromandel, Thames, Te Aroha, and elsewhere in the Hauraki district, there are great massive quartz lodes and belts of

TABLE D.—ANALYSES OF POSSIBLE GANISTERS, NORTH ISLAND

——	1.	2.	3.	4.	5.	6.	7.	8.
SiO_2	94·35	96·25	87·79	92·15	97·50	96·45	93·52	98·81
Al_2O_3	0·60	1·97	1·05	} 2·58	{ 0·83	} 2·90	{ 3·57	0·19
Fe_2O_3	2·40	0·33	0·14		0·80		0·20	0·22
CaO	1·01	Nil	0·45	0·15	Nil	Nil	0·10	Nil
MgO	0·40	0·01	0·04	0·20	Nil	0·65	0·29	0·02
Na_2O	..	0·30	0·42	} 1·04	Nil	..	0·26	{ Nil
K_2O	..	0·26	0·21					Nil
TiO_2	..	0·30	0·18	..	..	..	..	0·36
H_2O+	} 0·39	{ 0·78	4·91	} 3·73	{ 0·48	} ..	2·06	0·30
H_2O-		0·11	4·25		0·12			
	99·15	100·31	99·44	99·85	99·73	100·00	100·00	99·90

No. 1.—Quartzite, Whakarara Hill, seven miles north-east from Kaeo, North Auckland, contains also 0·85 per cent. of CO_2. (*N.Z.G.S. Bull. No. 8*, p. 44.)

No. 2.—White earth "Neuberg Chalk," flank of Parakaki Mountain, Whangarei. (Lab. Memo. 7/10/41.) The analysis of similar material from Hukerenui, nineteen miles north of Whangarei, is given in 47/13.

No. 3.—Average of four sinters, Rotorua District. The sinters average also ZrO_2, 0·02 per cent.; P_2O_5, 0·01; MnO, 0·01; BaO, 0·08; and S, 0·18. (*N.Z.G.S. Bull. No. 37*, p. 118.)

No. 4.—Sinter, Ngawha, North Auckland. (*N.Z.G.S. Bull. No. 8*, p. 60.)

No. 5.—General sample of sinters capping hills at Ohui, north-east corner of Tairua S.D., Hauraki. (*N.Z.G.S. Bull. No. 15*, p. 61.)

No. 6.—White earth, Porridge Pot, Wairakei, Taupo. The material consists of exceedingly fine rounded grains (55/27); another sample from the same locality is reported on in 52/25.

No. 7.—White earth, Puhipuhi, North Auckland (51/20). Analyses of two other samples of similar material from the same locality are given in 52/25.

No. 8.—Sand, Bradley's Landing, Dargaville (62/25). This is a highly siliceous sand. Analyses of samples from other localities in North Auckland, and probably all of similar origin, are given in 57/32 (Parengarenga and Awanui), 66/25 (Dargaville), 59/30 (Wade), and 62/25 (Albury).

highly silicified rock practically barren of metallic minerals. The above-mentioned siliceous materials are not of the kind usually employed as ganisters or for refractory ware, and they may be unsuitable, especially the extremely fine-grained deposits from the hot springs. Massive quartz from barren lodes is used as a ganister at Price's Foundry, Thames.

The volcanic regions have also yielded vast quantities of sand, which streams have carried to the coasts, where wave attrition has eliminated the dominant glass and feldspar particles and the coastal drift and winds have separated out the grains of iron-ore and ferromagnesians and accumulated the great tracts of sands at Kaipara, Parengarenga, and other parts. Much of this material may be classed as glass sand, but it could also be used in the making of silica bricks. Analyses of samples of some of the several materials are given in Table D.

WEST NELSON AND WESTLAND

The coal-measures of West Nelson belong to several periods of accumulation and occur in several large coalfields as well as in many scattered patches. The basement rocks are ancient argillites, greywackes, quartzites, marbles, schists, and gneisses, and these beds are intruded by vast masses of granite and related rocks as well as by basic plutonics in smaller amount. Fireclays are known at many points, a deeply weathered schist is used as a refractory, and the abundant quartzites and siliceous grits may be useful ganisters.

North-west Nelson

In North-west Nelson coal-measures cover a large part of the land projection ending in Cape Farewell, underlie the Takaka estuary, extend up the valley of that stream, and form parts of fault-involved strips among the mountains in the upper basins of the Takaka, Karamea, and Wangapeka rivers. They also occur along the east margin of the highlands in the lower valleys of the Baton and Sherry streams. Most of these coal-measures are of Oligocene age, but seams in older measures have been worked at Mount Burnett, Pakawau, and Puponga. In this area Oligocene marine beds extend as a narrow strip for thirty miles along the west coast from Cape Farewell to Kahurangi Point; the underlying coal-measures of this age outcrop along the west shores of Westhaven Inlet and in the basins of Mangarakau, Paturau, Turimawiwi, and Anaweka streams.

The older coal-measures consist of massive conglomerates overlain by grits and sandstones; even with the coal-seams there is little clay or shale. The rocks "consist of schist-and granite-waste deposited close to its place of origin. The sandstones contain flakes of schist and angular quartz pieces and simulate granite in appearance. The common mudstone is brown or grey and contains much mica" (*N.Z.G.S. Bull. No. 25* (1923), p. 25). No fireclays from these coal-measures are known, but a sample of carbonaceous shale (18/45) and another of clay (47/18), both probably from them, suggest semi-refractory material.

The Oligocene coal-measures are more widely distributed than those of older age, but, in general, are thin and patchy under their extensive cover of marine strata. They are, for the most part, of the littoral type, of small thickness, and deposited on hard little-weathered rock on the margin of a sea advancing over an intermittently sinking land of low relief. Only at Takaka and Baton are terrestrial beds of more than a few feet thick known to occur. In these localities the coal-measures are chiefly made up of waste from the granite that outcrops over large areas in both districts, and, in part, underlies them. The fine-textured strata contain much kaolin and the coarser consist largely of quartz grains and fragments. Analyses are available of clays from Appo Flat (37/10), Onahau, Dry, and Ellis creeks (41/16), Motupipi (46/17), and Ligar Bay (Lab. Memo. 4/9/41), as well as of three other clays not more precisely located than as from Takaka, in all eleven samples. The silica ranges from 56 to 45 per cent. and the alumina from 28 to 37 per cent., the respective averages being about 50 and 32 per cent. (see No. 1, Table E). In a general way the fluxes, especially the alkalies, are rather high for good-grade fireclays. The alkalies have been separated in two analyses only, the soda in these two averaging 0·23 per cent. and the potash 1·59, a proportion that suggests the presence of potash mica rather than of feldspar. The titania in the same two clays averaged 0·74 per cent. The clays have not yet been used to make refractory ware. With the addition of feldspar they should be useful in stoneware bodies; in the Baton area the clays from the Tertiary basal beds are strongly feldspathic, and similar clays may exist in the Takaka district.

The strongly altered granites of Cornwall and Devon have been used in the manufacture of refractory ware. The shattered decomposed granite at the Baton recently sampled as a possible source of kaolinite feldspar and Cornish stone have been found to contain too much fluxing material to resist high temperatures.

Weathered micaceous schist outcropping on the Takaka–Collingwood road, half a mile south of Parapara Inlet and close to Trig. AA, has been successfully used as a fireclay in the Onekaka blast furnace and at the Wellington gasworks. The analysis (No. 2 of Table E) suggests that the clay contains about 8 per cent. of muscovite and about 45 per cent. each of kaolinite and quartz, and laboratory firing tests indicate that it is a good-grade refractory. The fresh rock, a feldspathic schist, is thoroughly weathered to a depth of at least 10 ft. Basal Tertiary rocks outcrop close at hand, and the alteration, in part at least, probably took place during Tertiary time.

Murchison Basin

The Murchison Basin, an intermontane depression in the highlands of western Nelson, fifty miles long and eight miles wide, is filled with Tertiary rocks of which at least two sets are coal-bearing. The more important contain the Miocene coals worked at Owen, Murchison, and elsewhere. These measures are similar in age and origin to those of Mokau and, so far as known, contain no fireclays. The older coal-measures are of the littoral type, and no fireclays have yet been found.

Inangahua District

The Inangahua lowland, a structural depression similar to and lying west and south from the Murchison Basin, is also floored with Tertiary rocks containing coal-measures. In large part these are concealed under post-Tertiary gravels. At the north end of the depression the gravel veneer is thin, and here also the Tertiary rocks overlap the uplands to the west and extend west down the Buller Valley and south for some miles along the west edge of the lowland. On the eastern side there is another narrow strip seven miles long at Reefton, and farther east on the higher country considerable isolated areas of Tertiary strata and coal-measures. The coal-measures found in the region belong to the Miocene, Oligocene, and Eocene periods, those at Reefton being of the last-mentioned age. Only with them have clays approaching fireclays in composition yet been found; ganisters may also occur. The basement rocks of the region are Palæozoic argillites and greywackes intruded by granites, which latter form the bulk of the highlands on both sides of the depression and from which the waste now forming the Reefton coal-measures is obviously derived. Some quartzites in the old rocks may yet prove useful as ganisters, and some clays in the post-Tertiary detritus may be refractory.

The Reefton coal-measures, which are from 400 ft. to 650 ft. thick, consist of conglomerates, grits, sandstones, and shales with several coal-seams. The coarser beds are more abundant at the northern end of the field and the finer beds are found near Reefton, but even here underclays are not abundant and seem to be decidedly lenticular. At Burke Creek a bed, up to 3 ft. thick, underlies No. 3 seam ; No. 3 of Table E is the average of three samples, probably from this bed (40/13 and 48/17). These clays are too high in alkalies to be classed as of first-grade fireclay and too high in iron to be good pottery clays. Another clay, under the 4 ft. coal-seam outcropping within the Reefton town boundary, is decidedly more siliceous and is also high in alkalies (No. 4, Table E). Others, a good deal less siliceous (40/13 and 48/16), are objectionably high in carbonaceous matter. Several clays underlying seams in other localities examined in the laboratory were found to be too high in fluxes to be refractory. The 30 ft. bed of clay overlying the 14 ft. seam worked within the town boundary of Reefton contains over 5 per cent. of pyrite. All the clays from the Reefton coal-measures are relatively high in alkalies ; in the fireclays these were not separated, but in some other clays the proportion of soda and potash suggests that these fluxes are present as feldspar rather than as mica. In nearly all samples, also, as iron was rather high, the calcined product was too dark coloured for most pottery.

A white clay from a high terrace at Lankey Creek, three miles up the Inangahua from Reefton, was found to be decidedly siliceous (No. 5, Table E). It is refractory and may be useful in pottery mixtures.

Westport District

The important coalfield extending south from Mokihinui for twenty miles, nearly to the Buller, is included in the Westport district, as also is the area about Charleston, ten miles south of the river. The coal-measures of the Westport coalfield belong to the Eocene period, are up to 500 ft. thick, consist chiefly of shales, sandstones, grits, and conglomerates, and rest for the most part on gneissic granite. The Oligocene measures at Charleston are similar, but are thinner in most localities. They overlie a planed surface of gneiss in places weathered to clay.

" Very little fireclay is associated with the coal-seams of the Westport district. In places the dark shales interbedded with the grits, sandstones, and coal-seams with or without admixture of other materials may be found suitable for the manufacture of firebricks, &c. A light-coloured very soft and plastic clay from the vicinity of the haulage road to the old Cardiff Mine, Seddonville [No. 6, Table E], about half a mile from the State Coal-mine bins, has been used in a small way as a fireclay with some success " (*N.Z. G.S. Bull. No. 17* (1915), p. 129).

A bed of clay of very similar composition, ranging from 1 ft. to 3 ft. thick, occurs in places in the seam worked at Mokihinui. Under this seam a bed of fireclay, about 2 ft. thick and of unknown extent, was used for bricks at the Granity coke-ovens. The area is now worked for coal by Quinn Brothers and party, and Mr. T. Quinn supplied the sample of which No. 7, Table E, is the analysis. This suggests a rational mineral composition of about 56 per cent. of kaolinite, 27 per cent. of sericite, and small amounts of quartz and feldspar. The Analyst remarks that such a clay "cannot be expected to stand up to severe service at high temperature for long periods."

For many years the Westport Coal Co. used, with good results, a fireclay from the Ironbridge Mine at Denniston in the power-plants of their collieries. This clay was obtained from a 2 ft. bed occurring in places between the two thick seams worked at Ironbridge Mine. No analysis is available.

At Charleston no fireclays are known in the coal-measures, the bed under the single thick seam consisting of about 20 ft. of argillaceous micaceous sandstone which rests on deeply-weathered gneiss. Some bands in this gneiss are light coloured and highly feldspathic, but, in general, the rock is grey and rich in biotite. The alteration of the gneiss seems to be due to Tertiary and not to Recent weathering, for it is most thorough under the coal-measures; and, over areas where erosion has stripped these off, the basement may be quite hard. The weathered material is well exposed along the small stream and water-race between the township and Constant Bay, and also at White Horse Creek, six miles farther south.

A sample of clay derived in place from a light-coloured band in the gneiss near the township and recently examined in the laboratory contained over 50 per cent. of coarse material, chiefly angular grains of quartz. The fine-textured residue or clay was essentially kaolin (No. 8, Table E). Other samples from the district (57/15) consisted chiefly of kaolinite, with substantial amounts each of quartz, feldspar, and mica. No. 9 of Table E is one of these samples. The Analyst remarked that the clay had good refractory qualities, and, if washed, would be a good stoneware clay. Without doubt, careful washing of deposits in this district would produce kaolins and feldspathic kaolins of value in the ceramic industry.

Greymouth District

There are several sets of coal-measures in the Greymouth district ranging in age from upper Cretaceous to the Eocene, the total maximum aggregate thickness being about 4,000 ft. The lower groups are largely conglomeratic, but the upper contain much arkositic grit and sandstone. The basement rock is Palæozoic greywacke, which supplied the waste of the conglomerates, but granites outcrop over large areas at no great distance to the north, east, and south, and from these rocks the quartzose beds and micaceous shales of the higher measures seem to have been derived in chief part.

Fireclays are found only in the two upper sets of coal-measures—the Brunner and Point Elizabeth groups. Even in these less coarse-textured strata beds of underclay are usually absent or thin, though in some localities the patches are extensive. The clays range considerably in composition, some consisting chiefly of kaolin and others being decidedly siliceous. Mica seems to be present in all; some show numerous conspicuous flakes, others, in which chemical analysis proves a considerable percentage of potash, show no visible mica.

Clays containing large proportions of kaolinite underlay much of the now-exhausted coal worked in the Brunner (22/45, *N.Z.G.S. Bull. No. 13*, p. 96) and North Brunner collieries. This clay made excellent refractory ware, and the latter company, after all the coal was extracted, manufactured bricks for years from the clay (No. 10, Table E) mined while the colliery was open. At Brunner the clay was up to 5 ft. thick. Similar clay occurs in the Seven-mile area (52/22) and in the Wallsend Mine. Mr. M. Gage reports (7/11/41) that only a few inches of clay are present on the dip side of the main-haulage road of the Wallsend Mine, but in A, B, and C panels on the rise side road-grading proved that at least 2 ft. of clay occurs, the full thickness being unknown. A bore in the floor of a disused main-haulage road, near No. 4 panel, showed 13 ft. 6 in. of fireclay above a thin band of coal with clay of unknown thickness underlying. Mr. Gage took three samples from B and C panels; all showed mica, one in conspicuous flakes. The average of these is No. 11 of Table E (Lab. Memo. 7/1/42). There is a small brick-kiln at Brunner which uses clay from near-surface remnants of the old Brunner underclay and from Wallsend, coarsely-ground ganister from the neighbourhood being mixed with the clay.

Roughly, the above clays consist of from 70 to 80 per cent. of kaolinite, 20 to 10 per cent. of muscovite, with feldspar, quartz, &c., in minor amount. The Analyst in his report of 7th January, 1942, remarks that the Wallsend "clays are characterized by high true-clay content, high mica content, and low free quartz. The absence of quartz is an advantage in that firebricks made from such clays would not be subject to the destructive spalling and cracking in service, caused by inversion of quartz to tridymite and cristobalite, as well as by reversible temperature-volume changes.

"The presence of the mica is responsible for the vitrification that takes place about 1,300° C. Somewhere below 1,180° C. muscovite breaks up into a mixture of tridymite and orthoclase; at about 1,200° C. the orthoclase melts and binds the whole into a hard, more or less impervious, mass.

"The indications are that for moderate temperatures refractories of high strength and impermeability to molten slags could be made from the clay. In view of the high mica content, however, the clays would not appear to be very promising for high-temperature work, especially where the bricks have to carry a load.

"For high temperature work the Wallsend clay would be considerably improved by mixing with a refractory clay of the Kamo type [No. 7, Table A] and with grog made therefrom. Conversely, Kamo fireclay bricks might be improved in strength and impermeability to slags by addition of a small proportion of Wallsend clay (not over 10 per cent.).

"The use of fireclay grog instead of coarsely-crushed ganister would appear to be preferable for firebricks of the highest grade."

Clays similar, in ultimate chemical composition, to the Brunner-Tyneside clays, except that they contain about 5 per cent. of potash (equivalent to more than 40 per cent. of muscovite), underlies parts of the James Seam, in the Dunollie section of the Greymouth coalfield. The beds range from a few inches to a foot or more in thickness, and Baddeley and party some years ago made a short-lived attempt to produce bricks for the local market from this clay (C.–2, p. 48, 1927). Four samples of these clays have been examined in the laboratory, two from Baddeley's old mine (56/20), one from the adjoining No. 4 Tunnel, Point Elizabeth, and one Mr. Gage recently collected from the area worked by Smith and party. No. 12, Table E, is the average of these four samples. A clay of such chemical composition probably consists chiefly of the minerals, muscovite, kaolinite, and quartz in about the proportion of 4, 3, and 1. These clays are not refractories.

Beds of underclay, containing from 60 to 70 per cent. of silica, are fairly widespread in the Greymouth coalfield. Samples of these clays from Tyneside (49/18), Dobson (Lab. Memo. 27/6/23), and Point Elizabeth (38/10) collieries have been examined by the Dominion Analyst. There are six samples in all, the average composition being given as No. 13 of Table E. Burning tests of some of these samples suggest that they are fireclays of fair quality. On the assumption that four-fifths of the rather high alkali content of all these samples is present in muscovite, they will contain 15 to 20 per cent. of mica, the bulk of the remainder being kaolin and quartz in sub-equal amount. More siliceous clays also occur, three samples containing over 70 per cent. of silica from Brunner and Dunollie having been examined in the laboratory. They also seem to contain a good deal of muscovite, and burning tests show that they fail at too low a temperature to be classed as fireclays.

Westland District

The Westland highlands consist of quartzites, greywackes, argillites, schists, and gneisses. To the west in some parts lie lower masses of granite and greywacke, more or less separated from the main ranges and from each other by lowlands of gravel and moraine, which in some areas overlie Tertiary rocks that are exposed chiefly along entrenched streams.

There are coal-measures in the Paringa basin and carbonaceous layers in the basal Tertiaries of other localities, but fireclays are not known to occur.

Mount Rangitoto, near Ross, consists largely of granite, and at its northern base, four and a half miles south of the township, the "decomposed granite outcropping along the McLeod's Terrace Sluicing Co.'s water-race, about half a mile from their claim, has given rise to some white clay which it was thought might be suitable for chinaware" (*N.Z.G.S. Bull. No. 6* (1908), p. 150). A sample analysed was too high in fluxes to be refractory. Another sample, No. 14, Table E, examined by the Dominion Analyst (46/16) was a white clay with the composition approaching kaolin from Redman Creek, a small stream entering Mikonui River from the east, a little more than two miles south-west from Ross.

West Nelson Ganisters

In West Nelson the rocks that may be useful ganisters are quartzites and siliceous schists of Palæozoic age, and grits and sandstones of the Tertiary coal-measures. Both kinds of materials occur in vast amount. Quartzites are abundant close to roads in the Takaka, Wangapeka, and Reefton districts, and Tertiary grits and sandstones in the Takaka, Baton, Reefton, Westport, and Greymouth areas.

The schists and quartzites of the Takaka district are usually fine-grained and strongly cemented with secondary silica, so that when crushed are likely to yield the angular fragments of different shapes and sizes desirable in ganisters. The quartzites near Reefton are rather less silicified. Analyses of fine-grained cherty quartzites outcropping in the Tukurua and Onekaka creeks near Takaka are given in Table F, and one of a quartzite from near Rainy Creek in the Reefton district. Practical tests of the rocks are required, and the crushed material will need to be bonded with slips of fireclay or milk of lime.

There is a wide range in the hardness and degree of consolidation of the Tertiary sandstones and grits. In the Takaka district many of these beds are loose and friable; at Reefton and Westport they form prominent cliffs that fret on weathered surfaces; and at Brunner they are so strongly cemented as to justify the term quartzite. Analyses of possible ganisters from the coal-measures of Takaka, Reefton, and Greymouth are given in Table F. The Takaka material is an incoherent sharp sand, that from Reefton a friable, and those from Brunner coarse and fine-grained quartzites. The fragments in the Reefton sample were slightly water-worn and ranged from 0·1 in. to 0·25 in. across; a few flakes of mica were present and a

TABLE E.—ANALYSES OF FIRECLAYS, WEST NELSON

—	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.
SiO_2 ..	49·58	68·90	60·34	70·70	71·40	60·13	47·70	46·44	60·89	45·20	43·44	45·46	64·22	47·56
Al_2O_3 ..	32·03	21·71	21·37	18·38	17·90	23·42	32·61	38·04	23·38	38·55	34·92	32·88	22·86	32·45
Fe_2O_3 ..	1·58	0·30	2·74	0·32	1·40	2·52	1·76	0·50	1·57	0·32	0·57	1·39	1·55	1·51
CaO.. ..	0·48	0·33	0·42	0·60	0·30	0·10	0·05	tr.	0·25	0·60	0·72	0·60	0·19	2·58
MgO ..	0·31	0·33	0·66	1·10	0·70	0·53	0·68	tr.	Nil	0·65	0·18	0·65	0·27	1·24
Na_2O ..	1·69	Nil	2·94	2·20	2·60	2·55	0·51	0·06	0·93	1·98	0·27	0·46	2·73	..
K_2O ..		0·92					3·11	0·27	2·47		1·75	5·01		
TiO_2 ..	0·74	0·96	..	..	..	n.d.	1·00	0·20	0·47	..	0·96	0·97	0·88	..
H_2O+ ..	13·32	6·71	..	6·70	5·70	8·80	10·17	13·33	6·04	11·85	16·39	11·51	7·66	..
H_2O- ..		0·39				2·25	1·78	1·05	3·83	0·85	0·85	1·48	..	14·66
	99·73	100·55	..	100·00	100·00	100·30	99·94	99·89	99·83	100·00	100·05	100·41	100·36	100·00

No. 1.—Average of eleven comparable strongly kaolinitic clays, Takaka district (37/10, 38/8, 39/8, 40/14, 41/16–7, and Lab. Memo. 4/9/41).
No. 2.—Weathered micaceous schist, roadside half a mile south of Parapara Inlet (58/18).
No. 3.—Average of three samples, probably all from 3 ft. seam of clay under No. 3 Seam, Burke Creek, Reefton (40/13, 48/17).
No. 4.—Siliceous clay, underlying coal-seam outcropping within Reefton Town boundary (53/24).
No. 5.—Clay from high terrace, Lankey Creek, Reefton (40/12).
No. 6.—Clay, near haulage road to old Cardiff Mine, Seddonville (48/17).
No. 7.—Clay, 2 ft., under coal, Quinn and party's lease, Mokihinui. (Lab. Memo. 8/6/42.)
No. 8.—Kaolin, Charleston. This sample is the fine portion (45 per cent.) of the gritty sample received. (Lab. Memo. 30/9/40.)
No. 9.—Clay, Addisons, near Charleston (57/15–6).
No. 10.—Clay, North Brunner Colliery (53/23).
No. 11.—Wallsend, average of three samples. (Lab. Memo. 7/1/42.)
No. 12.—Average of four samples from Baddeley and party's mine (56/20), Point Elizabeth lease (38/10), and Smith and party's mine, Dunollie. (Lab. Memo. 6/1/42.)
No. 13.—Average of six clays from Tyneside (49/18) and Point Elizabeth (38/10) collieries and from Dobson No. 3 Bore. (Lab. Memo. 27/6/23.)
No. 14.—Kaolin, Redman Creek, Ross (46/16).

little clay, perhaps sufficient to bond the material. Mason and Porter, manufacturing engineers, of Auckland, write that they find the grit overlying No. 2 Seam at Burke Creek worked by the Reefton Coal Co. a useful refractory, if mixed with a proportion of clay, where large bulk is needed. This is the same material as No. 5, Table F.

Some of the high-level raised beaches of the Charleston district contain sands that may be useful as ganisters. No. 10 of Table F shows the chemical composition of one of these sands.

TABLE F.—ANALYSES OF POSSIBLE GANISTERS, WEST NELSON

——	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
SiO_2 ..	90·33	94·90	96·59	97·95	95·70	99·0	99·25	99·0	96·0	96·25
Al_2O_3 ..	3·71	1·08	1·53	1·10 (Al₂O₃ + Fe₂O₃)	2·35	0·75	0·5	0·75	2·5	1·29
Fe_2O_3 ..	1·68	0·88	0·29							2·08
FeO ..	0·94	1·30	0·18	..	..	..	..	..	..	..
MnO ..	0·67	..	tr.	..	..	..	..	..	..	..
CaO ..	0·62	0·58	0·16	tr.	tr.	tr.	tr.	tr.	tr.	n.d.
MgO ..	0·15	0·43	0·17	0·02	0·08	tr.	tr.	tr.	0·2	n.d.
Na_2O ..	..	..	0·16	n.d.	0·20	..	..	..	..	n.d.
K_2O ..	..	..	0·46	n.d.	0·81	..	..	..	..	n.d.
TiO_2 ..	0·37	0·05	0·16	..	..	..	..	..	..	n.d.
CO_2 ..	0·52	0·42	tr.	..	..	..	..	..	..	..
SO_2 ..	n.d.	0·14	tr.	..	..	..	..	..	..	..
Loss on ignition	0·54	0·10	0·54	0·55	0·70	0·15	0·15	0·15	0·15	0·35
	99·53	99·88	100·24	99·62	99·84	..	..	..	..	99·97

No. 1.—Rusty cherty quartzite, Tukurua Stream, Takaka district. (*N.Z.G.S. Bull. No. 3* (1907), p. 40.)

No. 2.—Dark-grey chert, road round Parapara Inlet, Takaka district. (*Ibid.*)

No. 3.—Quartzite, south bank, Inangahua River, near Rainy Creek, Reefton district. (Lab. Memo. 29/1/40.)

No. 4.—Friable sandstone, iron-stained along joints north end of No. 1 Cut, near Parapara River, Takaka district. (Lab. Memo. 17/7/39.)

No. 5.—Coal-measure grit near No. 2 Seam, Morrisvale, Burke Creek, Reefton. (*Ibid.*)

No. 6.—Coal-measure quartzite with coarse somewhat rounded grains, Coolgardie Track, Brunner. (Lab. Memo. 16/6/39.)

No. 7.—Fine-grained quartzite, Coolgardie Track. (*Ibid.*)

No. 8.—Fine-grained quartzite, slightly iron-stained along partings (R_2O_3, mainly Fe_2O_3), Coolgardie Track. (*Ibid.*)

No. 9.—Fine-grained quartzite, duller greyer and softer than No. 8 (R_2O_3, mainly Al_2O_3), Mount Watson, three miles and a half north-west from Blackball. (*Ibid.*) The Analyst quotes J. A. Audley in "Silica and the Silicates" (1921) as follows: "From experience it is found that for strong bricks the quartzite should be hard, and when crushed should not give rounded grains, but angular fragments of different shapes and sizes. The rock should contain 96 to 98 per cent. of silica, with alumina and iron oxide together not exceeding 2·5 per cent. (usually about 1·75), and less than 0·5 per cent. of alkalies. It is remarkable that pure quartzite containing as much as 99 per cent. silica has not proved satisfactory for making silica bricks . . . Unsuitable quartzites, especially coarsely crystalline varieties, crack badly when heated, and expand considerably after the first firing."

No. 10.—Sand from Black (? Back) Lead, Charleston (57/32).

CANTERBURY

In Canterbury, fireclays and ganisters are known only from the coal-measures, and these occur chiefly in the isolated areas of Malvern Hills, Mount Somers, Kakahu, and Waihao. The basal rocks of the region are the siliceous greywackes and argillites of the highlands, but in the first two areas extensive sheets of volcanic rock underlie the coal-measures and contributed material to them. At Malvern Hills the coal-measures are of the Cretaceous age and at the other areas belong to the Eocene. No samples of fireclay or ganister seem to have been received from the Waihao basin and examined in the laboratory.

Malvern Hills

The front of the Malvern Hills, which edge the Canterbury Plain between the Waimakariri and Rakaia rivers, consists of volcanic rocks that underlie, and in places intrude, the coal-measures that outcrop in patches separated by faulting, denudation, or the deposition of moraines and gravel. The higher part of the hills is carved from greywacke and argillite. The chief exposures of coal-measures extend north-east and west from Glentunnel, but there are several small fault-involved strips among the greywackes and, at Rakaia Gorge, an area in part concealed by gravels. The measures are up to 5,000 ft. thick and massive conglomerates, containing chiefly pebbles of rhyolite, occur.

Professor R. Speight (*S.I.R. Geol. Memo. No. 1* (1928), pp. 56–8), described the sequence and field distribution of the clays, and these notes are taken from his account. The better clay-beds occur at two horizons—one close to the base of the coal-measures just about the greywacke basement, and the other above the dominant conglomerates and closely associated with the principal or Glentunnel coal horizon. The clay-beds are variable; lenses peter out in a few yards, and, on account of the gravel cover, will be difficult to prospect. The pit at Steventon seems the most promising. As by far the greater part of the conglomerates consists of material derived from the rhyolites, it is reasonable to infer a similar origin for the inter-stratified finer-grained sediments. The presence of biotite in the clays, an important constituent of the rhyolites, supports this view.

Mr. S. Page, in the same report (pp. 58–63) described the physical characteristics, chemical composition, and behaviour-on-burning of a series of sixteen samples of clay and two of sand from different deposits in the area. In addition, analyses and burning tests of a sand and six clays made in the Dominion Laboratory are cited. These analyses show that bricks made from the clays would contain from 65 to 80 per cent. of silica. Mr. Page discusses the possible uses of the clays, and remarks (p. 63): "All have too much colour to be suitable for paper filling or for fine pottery. For firebricks the bulk are not refractory enough; a few might serve for medium- or low-grade firebricks if the quantity and availability are sufficient. For drainpipes some are already in use, but the high contraction and relatively low softening temperature makes it difficult to keep the shape true in large sizes or considerable lengths." An analysis of a sample from Robb's open-cast pit, north-west of Mount Misery (*Geol. Memo. No. 1*, pp. 64–5), is quoted; the Dominion Analyst notes that this "clay is suitable for the manufacture of second-grade firebricks" (No. 1, Table G).

Mount Somers

The Mount Somers district lies on the margin of the Canterbury Plain between or near the branches of Ashburton River, a stream that drains the eastern zone of the highlands between the Rakaia and Rangitata rivers. The basement rocks of the region are greywackes and argillites, but thick extensive masses of acid and intermediate volcanic rocks, similar in composition and age to those at Malvern Hills, underlie the coal-measures.

These last occur as many patches, mostly small, where the foothills meet the plains, beneath the gravels of which they extend for unknown distances. Fault-involved strips and inconsiderable outliers that have escaped erosion occur in the hills at the back.

The measures, which are overlain by marine strata of Eocene age, are up to 700 ft. thick and consist predominantly of grits and sands, though arenaceous shales and beds containing quartz pebbles or consisting largely of rhyolite waste also occur. Argillaceous beds are not abundant, and, according to Speight (*S.I.R. Geol. Memo. No. 3* (1938)), from whose account this description is drawn, " the clay deposits are apparently the least important of the economic minerals " in the district. Speight (p. 40) gives evidence to show that in one area at least the beds under the coal are derived chiefly from the underlying rhyolite, and again, discussing the mineral composition of the thick widespread sands of the coal-measures, found (p. 80) that the heavy residues consist chiefly of ilmenite with only occasional crystals of zircon and very rare grains of tourmaline. The zircon and tourmaline support the other suggested origin—namely, that they are derived from the Otago schists and were transported north by littoral drift ; no doubt material from both sources is present. The clays, however, are probably essentially of local origin. In general, they are poorly plastic, have a wide range in chemical composition, and some are gritty with grains of feldspar, all factors supporting a local source.

Few analyses of refractory clays from the district are available. An analysis of a sample consisting nearly of kaolinite, and, according to Speight (p. 81), probably obtained from the old Evandale workings, about three miles south-west from Mount Somers township, is given in No. 2 of Table G ; there are no particulars of the thickness and extent of the deposit. A similar clay used by Timaru Potteries, Ltd., is obtained from about " ten miles from Mount Somers," probably from the coal reserve on the south side of the Ashburton, opposite the junction of Stour River. No. 3 of Table G shows the composition of a sample the writer took from the stock pile at the works.

Other clays at Mount Somers are decidedly siliceous, as the carbonaceous clay in the 4 ft. seam on the hillside west of Chapman Creek (Speight, p. 82), of which the composition is given in No. 4 of Table G. No. 5 is the white clay " with the coal on the lowest terrace where the measures show " on the coal reserve opposite the Stour junction. Timaru Potteries use a decomposed rhyolite breccia from the same reserve ; probably from the weathered understone below the measures. A sample the writer selected from the stock pile and showing no iron-stained partings had the composition shown in No. 6 of Table G. This material consisted of many coarse crystals of quartz set in white clay and contained numerous larger white patches, one of which on analysis was found to be nearly pure kaolinite ; these without doubt were originally feldspar crystals. The siliceous clays from Mount Somers (Nos. 4, 5, and 6 of Table G) are unusually low in fluxes, and on account of their small iron content should have value in the ceramic industry.

Kakahu District

South of Rangitata River, the Four Peaks Range, a great spur diverging from the Canterbury highlands, separates the basins of the Orari and Opihi rivers. The greywacke that forms the mass of this range extends south to the middle valley of the Kakahu, a stream discharging to the Opihi, and Tertiary strata outcrop round the end of these old rocks in a way suggesting that they are folded in a wide anticline that plunges south at a low angle. On the east flank of the structure the beds pass under the gravels of the

Canterbury Plain, but westward Tertiary rocks extend to the Fairlie district and southward for many miles, the older strata of the group outcropping along the base of the Hunter Hills.

At Kakahu there is at least 100 ft. of beds between the greywacke and the coal which rests on a greasy clay from 4 ft. to 5 ft. thick. This clay is pinkish-grey to brown in colour, is highly plastic, and an analysis shows that it contains 6 per cent. of fluxing impurities. It is used as a ball-clay at the Temuka potteries. The ball-clay grades down into massive fine-grained sandstone, and pale-grey silty rock from 10 ft. to 20 ft. below it, known as the "hard white fireclay," is used at the potteries for making saggers and firebricks, as well as an ingredient of stoneware body; it contains nearly 80 per cent. of silica. The Analyst found that 60 per cent. of the material could be washed through a No. 240 B.S. sieve, the residue being mostly clean quartz. The analysis of the material washed through the sieve is given as No. 7 of Table G.

A siliceous clay, No. 8 of the table, of almost the same composition is mined at Sutherlands, on the railway four miles from Pleasant Point, for use in the mixtures for firebrick and stoneware made at the Timaru Potteries. Nothing is known of the amount available or of the mode of occurrence of this clay.

The only other sample of refractory clay from this district is one from the Opuha, a stream that cuts across the coal-measures a few miles west of the Kakahu clay-pit. The clay examined (No. 9, Table G) approaches kaolin in composition; nothing is known of the precise locality or of the quantity present.

Ganisters in Canterbury

Extensive thick deposits of clean, friable sandstones occur in the Malvern Hills, Mount Somers, Kakahu, and other coal-bearing areas of South Canterbury. At the first two localities they occur chiefly above the coal-horizon, but at the others below it. Underlying rhyolites probably supplied the waste at Malvern Hills and Mount Somers, but similar rocks are not present at Kakahu, or, so far as known, at any other part of South Canterbury. As judged from the coeval beds of the North Island, the greywacke basement of this region would not supply the necessary kind of waste, and the most probable source of the siliceous detritus at Waihao and Kakahu is the Otago schists from which sand would be carried by coastal drift in early Tertiary times.

Analyses of sands from Malvern Hills and Mount Somers are available (see Table G). The exceptionally high-grade sand from the latter locality was used by the defunct Southern Cross Glass Co. at their Ashburton works, and there seems no reason why the sand from any of the localities mentioned should not be suitable for making silica bricks; also suitable may be the white sands that form a 50 ft. face at Mangati, twenty miles south-west from Timaru.

OTAGO AND SOUTHLAND

The dominant rocks of Otago and Southland are the schists that cover 10,000 square miles of the north central portion of the area. It is a region of broad highlands and wide depressions floored with gravels and lacustrine beds. Round the margin of the terrain the schists grade to greywacke, and thick fluviatile deposits covered with marine Tertiaries overlap their eastern border. Along the south-west sides lies a broken triangular tract of Mesozoic conglomerates, greywackes, and argillites forming about 2,000 square miles of upland country. On the west the schist highlands merge into the rugged mountains of Fiordland, which occupy 5,000 square miles, project south for sixty miles beyond the schist area, and consist of granite

Table G.—Analyses of Fireclays and Ganisters, Canterbury

—	1.	2.	3.	4.*	5.	6.	7.	8.	9.	10.	11.	12.
SiO_2	66·97	37·16	44·25	64·28	70·20	66·10	68·30	70·80	52·2	97·20	98·60	97·30
Al_2O_3	20·65	30·19	33·90	18·95	20·59	23·25	20·40	16·68	32·3	..	0·65	1·46
Fe_2O_3	1·20	2·24	2·85	0·32	0·13	0·30	1·40	1·54	1·7	0·65	0·07	0·07
CaO	0·09	0·27	0·56	0·10	0·07	0·05	0·18	0·42	0·7	..	0·23	0·28
MgO	0·23	Nil	0·05	Nil	0·04		0·56	0·44	0·3	..	tr.	0·10
Na_2O	Nil	0·13	0·04	Nil	Nil	0·20	0·26	0·52	0·1	..	0·02	..
K_2O	0·44		0·05	Nil	1·06	0·25	1·60	0·60		..	Nil	..
TiO_2	0·77	1·25	1·74	0·17	0·26	0·25	0·50	0·50	..	..	0·05	..
H_2O+	7·97	10·88	13·90	12·01	7·60	8·00	6·78	6·62	12·4	..	0·34	0·31
H_2O-	1·52	18·55	2·90	3·90	1·03	1·10	0·51	1·72				
	99·84	100·67	100·24	99·73	99·98	99·50	100·49	99·84	99·7	..	99·96	99·52

* Combined water includes about 5·5 per cent. of carbonaceous matter.

No. 1.—Light-coloured clay, 3 ft. seam, north-west side of Mount Misery, Malvern Hills (61/16).

No. 2.—Clay, probably from old Evandale workings south of Hinds River, three miles south-west from Mount Somers Railway-station (55/16-7). This clay consists essentially of kaolinite and is probably a first-grade fireclay.

No. 3.—Grey clay, Mount Somers Coal Reserve; used at Timaru Potteries. (Lab. Memo. 14/9/42.)

No. 4.—Carbonaceous clay, near Chapman Creek, Mount Somers (65/12).

No. 5.—White clay containing much fine quartz grit. Terrace south side of Ashburton River, eight miles north-west from Mount Somers Railway-station (66/18).

No. 6.—White siliceous rock, probably decomposed rhyolite, same locality as No. 5. (Lab. Memo. 24/9/42.)

No. 7.—" Hard white " clay, after about 40 per cent. of fine quartz sand had been removed on a 240 B.S. sieve, New Zealand Insulators' clay-pit, Kakahu. (Lab. Memo. 23/7/41.)

No. 8.—Siliceous clay, Sutherlands, used at Timaru Potteries. (Lab. Memo. 14/9/42).

No. 9.—Clay, Opuha River (51/20).

No. 10.—Sand, Hart's pit, Malvern Hills. (*S.I.R. Geol. Memo. No. 1*, p. 61.)

No. 11.—Sand, Mount Somers (66/25).

No. 12—Sand, Mangati. (Analyst, H. G. Black.)

and other plutonic rocks intruded into greywacke and schist. Over against the southern portion of this mountain mass, on the east side of the Waiau valley, highland groups, built largely of basic igneous rocks, rise along the west side of the Southland lowlands which extend from them east and north-east to the Mesozoic hills. The plains are gravel-covered, but coal-measures and marine Tertiaries appear in places along their margin.

The fireclays of the region occur with the youngest groups of rocks which range in age from the late Cretaceous to the youngest Tertiary. For convenience of description the refractory clays are grouped under areas characterized by differences in source, rocks, or geological history. These areas are Central Otago, East Otago, Pomahaka-Waimea, and Southland.

Central Otago

For the purposes of this report Central Otago is roughly defined as lying north of lines joining Kingston to Roxburgh and Roxburgh to Macraes, and between meridians through the first and last of these places. The extensive structural depressions of the region are floored with terrestrial deposits of late Tertiary age and consisting in upward sequence of quartzose gravels, coal-measures, and lake silts unconformably overlain with brown and yellow fluviatile gravels of late Tertiary age. The underlying metamorphic rocks supplied practically all the inorganic detritus of the older group of these beds which extend with no essential change in their constituents beyond the schists and rest on the greywackes that supplied the material of the younger group. The schists are of low grade, the dominant constituents being quartz, albite, sericite, chlorite, and epidote. Of the above minerals, quartz and sericite are extremely resistant to weathering, and the coal-measure clays and lake silts are nearly always decidedly micaceous.

In places the schist beneath the Tertiary beds is deeply weathered. No. 1 analysis of Table H shows the composition of this residual material, which consists essentially of quartz, sericite, and kaolinite in sub-equal amount; at 1,300° C. the sample vitrified to a yellowish-grey steel-hard brick of good shape. No. 2 is a similar residual clay from another locality. These micaceous clays have a long vitrifying range, but cannot be classed as refractory. No. 3 of the same table is also a residual-schist clay containing about 5 per cent. of sericite and a large proportion of kaolinite; it is probably refractory in spite of the high iron and titania content. An analysis of a clay residual on schistose greywacke at Wingatui is given on p. 80 of *N.Z.G.S. Bull. No. 38*. The residual and generally strongly micaceous clays of Central Otago and neighbouring districts occur in immense quantity. They have a wide range in composition depending on the composition of the original rock and on the degree of weathering it has undergone.

The sedimentary clays interbedded in the Tertiary quartz conglomerates and coal-measures of Central Otago are, in general, similar in composition to the clays residual on the schist. No. 4 of Table H shows the average composition of two samples from a bed of white pipeclay 30 ft. to 40 ft. thick at Conroy Gully, near Alexandra. Compared with its source material, No. 1 of the table, the analysis differs only in that it shows a decidedly lower content of potash.

The average composition of six sedimentary clays of this group from deposits in the Maniototo and Strath-Taieri depressions is given in No. 5 of Table H. The relatively high percentage of the alkalies and alkaline earths suggest that undecomposed sericite, albite, epidote, and chlorite derived from the schist are present in the clay. The sample from the clay-pit beside the railway, a mile east of Hyde Post-office, of which the analysis given on page 125 of *N.Z.G.S. Bull. No. 39*, shows a better grade material than the others. The clay from this pit is probably the clay used in Dunedin foundries for repairing cupolas, and tested by the Dominion Analyst, who (61/15) states the highly micaceous material to be a fireclay of at least second-grade quality.

There seems to be no analysis of a clay underlying or interbedded with the lignite of Central Otago. A sample from a clay band in the thick lignite at the Idaburn Pit at Oturehua was tested in the Laboratory, bricks being calcined at several temperatures; at 1,580° C. a buff-coloured product resulted, the clay was vitrified, and the edges appreciably softened (Lab. Memo. 20/6/27).

East Otago

The younger rocks of East Otago stretch from the Waitaki to the Clutha River and extend irregularly inland for a maximum distance of about thirty miles. They range in age from the Upper Cretaceous to the Middle Tertiary and contain many kinds of fluviatile and marine sediments of which the terrigenous content was derived from the schists, semi-schists, and greywackes that occupy so large an area to the west and also extend beneath the younger rocks.

The lowest group of the younger series contain thick beds of conglomerate and breccia-conglomerate as well as minor sands, and, in places, coal-measures. The coarse material consists of fragments of schist and greywacke and is present in large amounts in the Shag Point, Henley, Lawrence, Kaitangata, and Naseby (Central Otago) districts. Coal-seams are found at Shag Point and Kaitangata, and drillers report fireclays in both areas. The only sample of clay from this group of beds so far analysed is from a 6 ft. to 8 ft. bed occurring above the coal at Kaitangata. This analysis is given in No. 6 of Table H. The clay is not refractory and at 1,300° C. completely fuses to a dark-chocolate mass. As in Nelson and Canterbury, the rapidly accumulated, incompletely weathered, and, in general, coarse textured strata of late Cretaceous age are not known to contain fireclays.

The next group of beds are quartz conglomerates, sands and clays, in places coal-bearing, overlain by marine deposits, which are of different ages in different districts, ranging from the topmost Cretaceous to the Middle Tertiary. The coalfields of the Oamaru district, of Moeraki, Green Island, Tokomairiro, Tuakitoto, and Benhar belong to this group. Clays, under or near the seams, have been reported by drillers and others, and a few samples have been tested in the Laboratory, but the composition and behaviour on burning of the clays from several of the districts is quite unknown.

Plastic micaceous clays from Ngapara, fifteen miles north-west of Oamaru, that at 1,250° C., almost vitrify to hard yellow-grey brick are not fireclays (Lab. Memo. 20/7/38). No analysis is available.

The Dominion Laboratory seems to have made no tests or analyses of clays from the coal-measures in the quartz conglomerates of the Moeraki, Green Island, and Tokomairiro areas, a fact that suggests that the clays with the seams of these well-known and long-worked coalfields are scanty or unsuitable. At Green Island the coal-measures are from 100 ft. to 140 ft. thick and contain several layers, up to 9 ft. thick, of what is termed "micaceous fireclay" (*Rep. Geol. Explor.* (1876–77), p. 146). Grange, in his "Account of the Geology of Green Island Coalfield" (*Trans. N.Z. Inst.*, *53*, 174), states that "the clays associated with the coal-seams were tested at the Abbotsford Tileries, and found not to withstand a sufficiently high temperature to be called fireclay."

Remnants of the quartz-conglomerate formation let down along the Shag Valley fault-zone extend north-west from the coast to the head of Shag

River and into the Maniototo depression of Central Otago. A sample of clay outcropping in a gravel-pit half a mile west of the bridge across Pigroot Creek, Swinburn Survey District, approaches kaolinite in composition. The thickness and extent of this clay, which is probably refractory, is not known. Its composition is given in No. 7 of Table H.

According to Ongley (*N.Z.G.S. Bull. No. 38*, p. 78), the clays at the southern end of the outcrops of the quartz-conglomerate series of East Otago form an extensive field that stretches continuously north from Benhar for eight miles to Crichton, reaching nearly half a mile wide at the outcrop along the west of Lake Tuakitoto. It is a definite set of beds low in the group of quartz conglomerates and coal-measures. These clays have been used for many years at the brickworks and potteries at Benhar. The Dominion Analyst has made analyses and firing tests of three samples of highly plastic clay used in the potteries—one from the pit behind the works and the other two from the pit half a mile farther west. All vitrify at about 1,250° C. and are of similar composition. The average of the three samples is given in No. 8 of Table H.

The analyses of two comparable clays from the east side of Lake Tuakitoto and probably somewhat higher in the sequence are averaged in No. 9 of Table H. They contain more silica and soda than the Benhar clays, but are otherwise chemically similar to them. Both vitrified at about 1,290° C. and that from the east side of the outlet of the lake softened at 1,530° C. These clays are not refractory.

Pomahaka-Waimea

A structural depression extends north-west from Balclutha through the Clinton, Waipahi, Waikaka, Riversdale, and Lumsden districts. Mesozoic conglomerates greywackes and argillites rise steeply on the south-west in the Kaihiku, Hokonui, and Taringatura hills; to the north-east the sub-metamorphic rocks flooring the depression rise in gentle slopes to the high schist ranges of Central Otago. In places, mid-Tertiary coal-measures, with their overlapping cover of marine sediments, lie on the basement rocks; unconformably over them and more widely overlapping are late-Tertiary coal-measures and other terrestrial beds; the whole is in part concealed beneath post-Tertiary gravels and loess.

Small areas of mid-Tertiary beds are exposed in the western or Waimea section of the depression and the known clay deposits occur in the late-Tertiary beds, which are extensive in both sections. These latter are approximately coeval with the late-Tertiary strata of Central Otago, and, like them, consist chiefly of detrital quartz and other material stable to weathering and derived from schist; lake silts are not present. As the deposits are farther removed from the source rocks the beds in general are thinner, the quartzose members finer in texture, and the clays relatively more abundant.

The young Tertiary coal-measures form many square miles of low terrace country between the Clutha and lower Pomahaka, whence they extend south-west to Tapanui and Pukerau and along the Waikaka valley. The beds lie flat, and in many places the streams have cut down to the sub-schistose rock on which they rest. A general sequence of the beds shows 20 ft. of coarse gravel, resting on 3 ft. of white clay, underlain by woody lignite from 3 ft. to 20 ft. thick (*N.Z.G.S. Bull. No. 38*, p. 62). In this district the gravels and clays may be in part a rewash from earlier Tertiary quartzose beds that may have extended over the low country between their outcrops in the Waikaka and lower Clutha valleys. Analyses of three samples, apparently from points eight to nine miles north-north-east of Clinton, are available. The average of these three is given in No. 10 of Table H. The clays are refractory, and the best of the samples (59/16–7) showed no sign of softening at 1,580° C.

Table H.—Analyses of Clays from Central and East Otago

—	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.
SiO_2 ..	59·73	53·37	46·55	69·04	61·99	60·45	45·94	63·35	68·81	61·28	62·11	79·10
Al_2O_3 ..	23·28	23·00	31·43	16·56	18·73	19·75	34·88	20·91	15·82	22·15	22·34	11·22
Fe_2O_3 ..	1·73	2·40	2·90	1·23	3·51	3·55	1·06	2·15	1·93	1·62	2·00	1·18
CaO ..	0·25	3·20	0·17	0·26	1·59	0·52	0·81	0·26	0·28	0·29	..	Nil
MgO ..	1·23	1·25	0·50	1·16	1·29	1·84	0·17	0·81	0·78	0·57	1·21	0·60
Na_2O ..	0·53	0·88	0·52	0·54	1·93	1·22	0·16	0·06	1·07	} 1·53	1·12	} 0·10
K_2O ..	3·33	2·72	0·62	1·57	2·24	2·15	0·22	1·82	1·46	}	0·77	}
TiO_2 ..	0·85	0·80	3·85	0·68	0·73	1·15	0·37	0·92	0·68	1·00	0·44	..
H_2O+ ..	6·98	11·02	12·26	6·22	4·92	7·55	12·62	8·41	5·33	8·91	7·54	} 7·80
H_2O- ..	1·33	1·23	0·96	2·79	3·24	2·05	4·17	1·47	3·95	2·77	2·33	}
	99·24	99·87	99·76	100·05	100·17	100·23	100·40	100·16	100·11	100·12	99·86	100·00

No. 1.—Residual clay 3 ft. from surface, Milne's Claim, Conroy Gully, near Alexandra. (Lab. Memo. 5/7/32.)

No. 2.—Residual clay, Wilson's Farm, Omakau. (Lab. Memo. 22/11/35.)

No. 3.—Residual clay, 3 chains east of old hotel, Black's No. 3, Ida Valley. (*Ibid.*)

No. 4.—Average of two samples from 30 ft. to 40 ft. bed of white pipeclay, Milne's Claim, Conroy Gully, near Alexandra. (Lab. Memo. 5/7/32.)

No. 5.—Average of six samples of clay from localities in Swinburn, Maniototo, and Upper Taieri survey districts. The deposits are up to 50 ft. thick. (*N.Z.G.S. Bull. No. 39,* p. 125.)

No. 6.—Clay 6 ft. to 8 ft. thick in the coal-measures, probably above the coal, Kaitangata. Collected by Mr. F. Carson. (Lab. Memo. 6/1/42.)

No. 7.—Clay from gravel-pit half a mile west of bridge over Pigroot Creek, Swinburn Survey District (67/16).

No. 8.—Average of three clays from Benhar, one from pit in white clay behind the potteries and the others from the pit in pink and buff clays half a mile to the west. (Lab. Memo. 28/8/41.)

No. 9.—Average of two clays, one from the east side of the outlet of Lake Tuakitoto (57/20-1) and the other from Tuakitoto Mine (Lab. Memo, 16/7/34), four and a half miles to the north.

No. 10.—Average of three samples of clay from points near Pomahaka River between eight and nine miles from Clinton (54/19, 56/16, and Lab. Memo. 31/1/41).

No. 11.—White clay, Woodward's Claim, Moffat Gully, Wakaia (56/21).

No. 12.—Siliceous fireclay, Wakaia (52/21).

A similar clay, apparently of good thickness, is found in beds, probably of the same age, at Moffat Gully, Wakaia (No. 11, Table H). The fluxes are high for a refractory clay, but the Analyst (56/22) found that, though completely vitrified at 1,560° C., the samples showed no sign of softening. Another sample from the Wakaia district (No. 12, Table H) was decidedly more siliceous; nothing is known of the locality and extent of the deposit. Clay, underlying coal, forwarded from Balfour, and probably from the Terrace Mine, contained too large a proportion of fluxes to be refractory.

SOUTHLAND

The parts of Southland in which clays are most likely to be found are the Waiau Valley and the Southland Plain. The former lies between the mountains of Fiordland and the Livingstone, Takitimu, and Longwood ranges, and is filled with thick Tertiary strata. In the northern portion of the depression the rocks consist largely of conglomerates derived from the western highlands, and in the southern part of marine sands, clays, and limestones. Coal occurs at several points in the depression, chiefly along or near its eastern side and is mined at Orepuki and much more extensively at Ohai and Nightcaps in the gap between the Takitimu and Longwood highlands. Here "the coal-measures are characterized by a great thickness of clayey beds" (*N.Z.G.S. Bull. No. 23* (1921), p. 57); several boreholes have penetrated from 350 ft. to 450 ft. of fluviatile sands, clays, and coal. The analyses of only one clay associated with the coal is available (No. 1 of Table I). It contains too much fluxing material to be refractory, but as it occurs above a coal-seam some of the underclays may well be of better grade; the only one tested, the 10 ft. seam under the coal at the bottom of the dip, Black Lion Mine, Ohai, contained 9·8 per cent. of fluxes.

TABLE I.—ANALYSES OF CLAYS FROM SOUTHLAND AND SANDS FROM OTAGO

——	1.	2.	3.	4.	5.	6.	7.	8.
SiO_2 ..	52·11	59·43	75·92	96·16	97·14	96·06	98·18	87·36
Al_2O_3 ..	24·78	27·26	14·31	2·16	1·51	2·22	0·88	6·58
Fe_2O_3 ..	2·76	0·88	0·77	0·06	0·19	0·07	0·05	0·43
CaO ..	0·45	0·10	0·13	0·20	0·17	0·24	Nil	0·26
MgO ..	0·80	0·19	0·14	0·03	0·02	0·03	Nil	0·17
Na_2O ..	0·25	0·05	0·06	1·11	0·60	n.d.	n.d.	0·72
K_2O ..	1·42	0·56	0·25	0·03	0·08	n.d.	n.d.	2·49
TiO_2 ..	1·23	1·38	1·15	0·03	0·06	0·07	0·04	0·27
H_2O+ ..	12·49	9·34	5·80	0·34 (H₂O+ and H₂O−)	0·41	0·28	0·32	0·86
H_2O- ..	4·28	0·95	1·13					0·67
	100·57	100·14	99·66	100·12	100·18	98·97	99·47	99·81

No. 1.—Tough plastic clay overlying "rosin" seam, Quested's, Nightcaps. (*N.Z.G.S. Bull. No. 23*, p. 72.)

No. 2.—Average of four clays, Mako (52/20 and Lab. Memo. 3/8/41). From the high proportion of potash to soda, finely-divided mica, as the analyst notes, is probably present.

No. 3.—Siliceous clay, probably higher in sequence than No. 2. (Lab. Memo. 3/8/41.)

No. 4.—Sand, Block I, Bannockburn Survey District (61/36), 80 per cent. of the grains were between 0·05 and 0·1 mm. across.

No. 5.—Sand, overlying lignite, Deaker's Pit, Oturehua. (Lab. Memo. 12/3/29.) About 50 per cent. were of grains ranging between 0·1 and 0·25 mm. across.

No. 6.—Sand, Coal Pit Gully, Naseby. (Lab. Memo. 28/11/35.) About 70 per cent. of the grains ranged between 0·1 and 0·25 mm.

No. 7.—Sand, Hyde, east side of Taieri River, 25 chains north-west from Trig. P. (*N.Z.G.S. Bull. No. 39*, p. 127.) About 50 per cent. of the grains were between 0·1 and 0·25 mm. across and 30 per cent. between 0·25 and 0·5 mm.

No. 8.—Sand, coal-measures, Waitati, north of Dunedin (61/35). About 45 per cent. of the grains were between 0·1 and 0·25 mm. across and 25 per cent. between 0·05 and 0·1 mm.

The Ohai coal-measures resemble in texture, thickness, and sequence those of the Huntly district, were probably formed under similar conditions, and are of the same age. The analogy of the Ohai-Orepuki district to the Huntly-Kawhia district is strengthened by the occurrence at Orepuki of coal in thin arenaceous measures, conditions similar to those in the Kawhia-Te Kuiti area. At Orepuki no fireclays are known, and, as at Kawhia, the overlying marine beds overlap on the basement rocks.

The Southland Plain edges the coast for forty miles between Riverton and Fortrose and extends inland for an average distance of twenty-five miles. The Longwood Range rises on the west, the Taringatura and Hokonui hills on the north, and the uplands beyond the lower Mataura valley on the east. The first mentioned consists of Palæozoic sediments and basic igneous rocks, and the other hills groups of argillites greywackes and conglomerates of Mesozoic age.

Surface deposits and the flood-plain and terrace gravels of the Aparima, Oreti, Makarewa, and Mataura rivers conceal most of the underlying rocks, but widely scattered bores and lignite pits and some considerable rock exposures show that late Tertiary strata underlie much of the lowlands at shallow depth. These beds, which no geologist has yet studied in detail, are probably to be correlated with the lignite-bearing deposits of the Pomahaka district. At Gore and Waimumu thick bands of greenish micaceous sand in the coal-measures show that material from the schist region of Otago has been carried across the belt of Mesozoic strata. Micaceous clays also occur, but no sample of refractory clay from the young lignite-bearing beds of Southland seems to have been examined in the Dominion Laboratory.

In the Limehills-Winton district, north of Invercargill, limestone of mid-Tertiary age forms low hills ; north-east of the limestone are scattered outcrops of the underlying beds of this group ; and right at the foot of the Hokonuis occur a few patches of the fluviatile coal-measures at the base of the series. Coal was formerly mined near Mako, twenty miles north of Invercargill. Here on the east side of the Makarewa River massive flat-lying clay is mined for the potteries at Benhar and the brickworks at Waikiwi (near Invercargill). Mr. R. W. Willett (31/3/41) reports that the pit shows :—

10 ft. of surface clay and gravel.
3 ft. to 8 ft. of white greasy clay.
5 ft. of pale red-brown slightly sandy clay.
10 ft. with no bottom of grey slightly sandy clay.

The sandy clays are used at Waikiwi and the greasy clay at Benhar. Formerly also Mako clay was used at the Wellington Gasworks. Samples from the three beds of clay tested in the Laboratory proved to be chemically very similar, and, together with a comparable sample from Mako analysed in 1919, are averaged in No. 2 of Table I. From its composition (No. 3 of Table I) a siliceous clay, exposed 10 chains north of the pit on the other side of Makarewa River and probably a little higher in the sequence, is also refractory.

Ganisters of Otago and Southland

Practically all the schists of Otago contain quartz as an essential mineral and, in many, folia and segregations of quartz are conspicuous. So far as known, however, none of these rocks are sufficiently siliceous to be used as ganister, though suitable rock may occur. Weathering through geological ages has produced vast quantities of detrital quartz which ranges in texture from pebbles inches across to the finest silt or even clay, and thick extensive beds of this material have accumulated within the structural depressions of the schist region and south-east and north beyond its margin.

The analyses were made to test the suitability of the material as glass sand rather than for use as ganister or silica brick. Those available are from Bannockburn, Idaburn, Hyde, and Waitati and are given in Table I.

At many places in Otago Central chalcedonic quartz cements the sands grits and quartz conglomerates described above into hard concretionary masses (chinamen) and bands. If crushed, such material would yield sharp angular fragments suitable for use as ganister. No analyses are available.

CONCLUSION

Refractories are of increasing importance in modern life. They are used in many key industries, and the efficiency of manufacture, the capacity of the plant, and the useful life of the equipment are dependent on the quality and lasting properties of the refractories used. Different industries have different requirements. In most, the mere ability to withstand great heat is not enough ; in one industry the refractory must not fail under pressure, in another it must not spall with violent changes of temperature, in another it must resist physical wear, in another the chemical action of gases and slags, and in still others combinations of the above. Different refractories are used for different requirements, and if the raw material is not suitable it is processed and blended to produce the desired result. Fireclay and silica are by far the most largely used, though bauxite, talc, magnesia, zirconia, chromite, artificial silicon carbide, &c., have their special functions.

In the foregoing preliminary account of New Zealand's resources in fireclays and ganisters the geological factors determining the origin and distribution of these materials have been brought forward rather than the chemical composition, the physical properties, or the behaviour on burning of the clay of any particular deposit. The many analyses are cited in order to indicate the kind of material likely to be found in any district. Little is said of the physical and burning properties of the raw materials ; any one interested can consult the reports of the Dominion Analyst for what information is available ; and, again, processing, likely to be introduced into the industry, may yield products with properties very different from those of the raw material. As far as known, the size and extent of the deposits, the precise localities, and the means of access to them are stated, but it must be pointed out that in some cases the only information is that the Dominion Analyst received a sample of material of such-and-such composition from such-and-such a district. Again, some non-refractory clays that occur in coal-measures or in other situations where refractory material is often found are mentioned to show that samples from such localities have been tested and found wanting.

In the North Island large amounts of refractory clays have been derived from the argillites and feldspathic greywackes that form the basement rocks of this part of New Zealand. These old rocks, at one point in the Awakino basin, are known to contain semi-refractory clay deposited with them, and in other districts, during the present cycle of erosion, have given rise to fireclays at Horokiwi and elsewhere. But by far the greater part of the greywacke-derived fire-resistant clays were produced during Tertiary time while coal-measures accumulated on a peneplaned land. Thick, extensive beds of fireclay of chiefly sedimentary deposition then formed about Huntly and in much less quantity in the patchy coal-measures of North Auckland. These fireclays are terrestrial strata that resulted from long periods of normal atmospheric weathering. But there are no fireclays in the coal-measures of Kawhia, Te Kuiti, Mokau, and Retaruke formed during eras of more rapid land movement, and there are no fireclays in the vast thickness of Tertiary sediments flanking the greywacke axis that stretches through the eastern part of the island.

The Tertiary volcanic rocks of the North Island, especially those of acidic composition, have given rise to valuable refractory clays. Some are sedimentary clays due to ordinary weathering and separation by running water, but most were formed from the rock in place by its decomposition by hot volcanic gases, a process still in active operation in the Rotorua district. From their mode of origin such deposits are more patchy and irregular, both in extent and composition, than the beds of sedimentary fireclay of the coal-measures. The principal deposits of clay formed by the action of heated gases on acid volcanic rocks are in the North Auckland and Rotorua districts. In the former area they are extensively utilized, in part owing to their being nearer to fuel and centres of population. The clays from the more basic volcanic rocks of Hauraki and Taranaki are, in general, too high in fluxes to be suitable refractories.

The greywacke series in the South Island are, in general, older than those of the North and much too hard and siliceous to yield clay in quantity. But in Southland, where there are extensive areas of Mesozoic greywacke and argillite comparable in age and composition with those of the Huntly district, an excellent fireclay in the coal-measures is worked at Mako. In South Canterbury patches of the same greywacke group may have yielded material to the clays of the coal-measures, but fireclays in this district are decidedly siliceous, possibly because in part derived from the extensive older greywacke of the region or from the schists of Otago. In the Mount Somers and Malvern districts the principal source rocks of the coarser beds of the coal-measures and, by analogy, of the fireclays are the acid pre-Tertiary volcanic rocks overlying the basement greywacke. In western Southland the great quantities of basic igneous rock intruded into the Palæozoic greywackes may explain why fireclays are not known in quantity in the coal-measures of Ohai and Nightcaps.

Mica and quartz from the schist area of Otago are abundant in all the younger sediments of this region, which range in age from the Cretaceous to Recent. Most of the clays contain too much flux to be refractory, but in places beds consisting of thoroughly weathered and perhaps twice weathered material contain second-grade fireclays.

In West Nelson, as in Otago, the coarser-textured quickly-accumulated lower beds of the covering strata contain no refractory clays. Waste from the granites of the region become prominent in the next group of coal-measures and the clays in the different coalfields all contain finely-divided white mica in greater or less amount. In places granite and gneiss were deeply weathered during Tertiary time, and, where preserved, such material may, as in Cornwall, yield kaolin on careful washing.

Siliceous materials that may be useful for ganisters and silica bricks are abundant in New Zealand and are of several types. There are large amounts of quartzose schist in Otago and of quartzites in West Nelson. Other less-strongly bonded quartzites occur in North Auckland. The West Nelson coal-measures contain vast quantities of quartzose grits in places strongly cemented and in places friable. In Otago quartz conglomerates and grits and sands occur loose or silicified to tough masses with chalcedony. The beaches and sand-dunes of the Dominion will yield great quantities of silica sand. The sinters of North Auckland, Hauraki, and the Rotorua-Taupo region may have value, as also may the great barren quartz lodes of Hauraki.

ACKNOWLEDGMENTS

In this account of the fireclays and ganisters of New Zealand the geological setting, the mode of origin, and the rock formations that yielded the material of the deposits are emphasized. The information is taken chiefly from the reports of officers of the Geological Survey, though data from other sources are also used. The descriptions are given under geographical heads, a region usually containing materials of different ages and origins. The obvious inequalities of treatment arise from the fewness or complete lack of data from some districts.

The chemical analyses are nearly all the work of the Dominion Analyst and his staff. The annual reports of the Laboratory contain most of them, but a number are from memoranda on the files of the Geological Survey. Analyses of clays from a deposit or of similar clays from a locality or district are averaged, references being made to the sources of the several analyses. The results of burning tests are rarely mentioned, and those interested should consult the published accounts.

Appendix II of the *Dominion Laboratory 57th Annual Report* is the only serious account of New Zealand clays yet issued. In this notable contribution Mr. W. Donovan, sometime Dominion Analyst, describes the methods of examination adopted in the Laboratory and classifies the clays tested there during the years 1919 to 1923 inclusive.

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