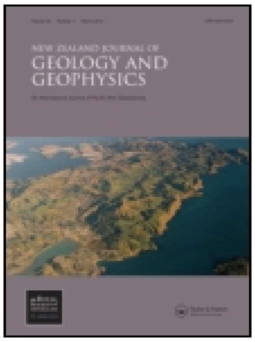

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The geology of the Cape Rodney — Kawau district, Auckland

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THE GEOLOGY OF THE CAPE RODNEY – KAWAU DISTRICT, AUCKLAND

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Summary

Five lithological groups overlain by Recent deposits are recognised. Otaian (Oligocene) sandstones and mudstones with associated andesitic agglomerates overlie argillaceous limestones of probable Bortonian (Eocene) age. These strata, with gently undulating or horizontal attitudes lap on to highly-sheared, siliceous claystones resting on a basement of deformed Mesozoic greywackes and argillites which contain interbedded spilites, chert bodies and ores of manganese, iron and copper. The interrelations and origin of the spilitic lavas, chert bodies and copper are discussed. The basement rocks have attained a grade of regional metamorphism equivalent to the chlorite-1 zone of the Otago Schists. The sequence is intruded and overlain locally by Pliocene Basalts.

INTRODUCTION

The district described lies 25 miles north of Auckland, and comprises the mainland east of the Warkworth-Pakiri divide, together with off-shore islands (Fig. 1).

Hochstetter (1864) briefly described the Tertiary sandstones and basement rocks of Kawau Island which was later mapped by Hector (1869) who described the basement rocks ('Paleozoic Slaty Rocks'), the Tertiary sandstones and the rocks associated with a copper lode on its west coast. The first systematic geological description of the whole area was published by Cox (1881). Ferrar (1934) mapped the area and correlated the greywacke and argillites with the Waipapa Series of Bell and Clarke (1909) and the Tertiary sandstones with the Waitemata formation of Auckland City.

The great depth of weathering makes difficult interpretation of any but coastal outcrops and, because of the scarcity of fossils, mapping has been based on lithology.

The groups described are:

Waipapa Group:	greywacke sandstones and argillites.
Mangakahia Group:	highly sheared concretionary sandstones and mudstones.
Opahi Group:	hydraulic limestones, greatly sheared and fractured.
Waitemata Group:	Waitemata Sandstone (sandstone and mudstone) and Manukau Breccia (andesitic debris).
Ti Point Group:	basalt flows, plugs, sills and dykes.
Pleistocene and Recent Deposits	sands, muds and gravels.

All groups are separated by marked unconformities. The basalts intrude and overlie the Waitemata Group but are overlain in turn by the deposits of the Pleistocene and Recent.

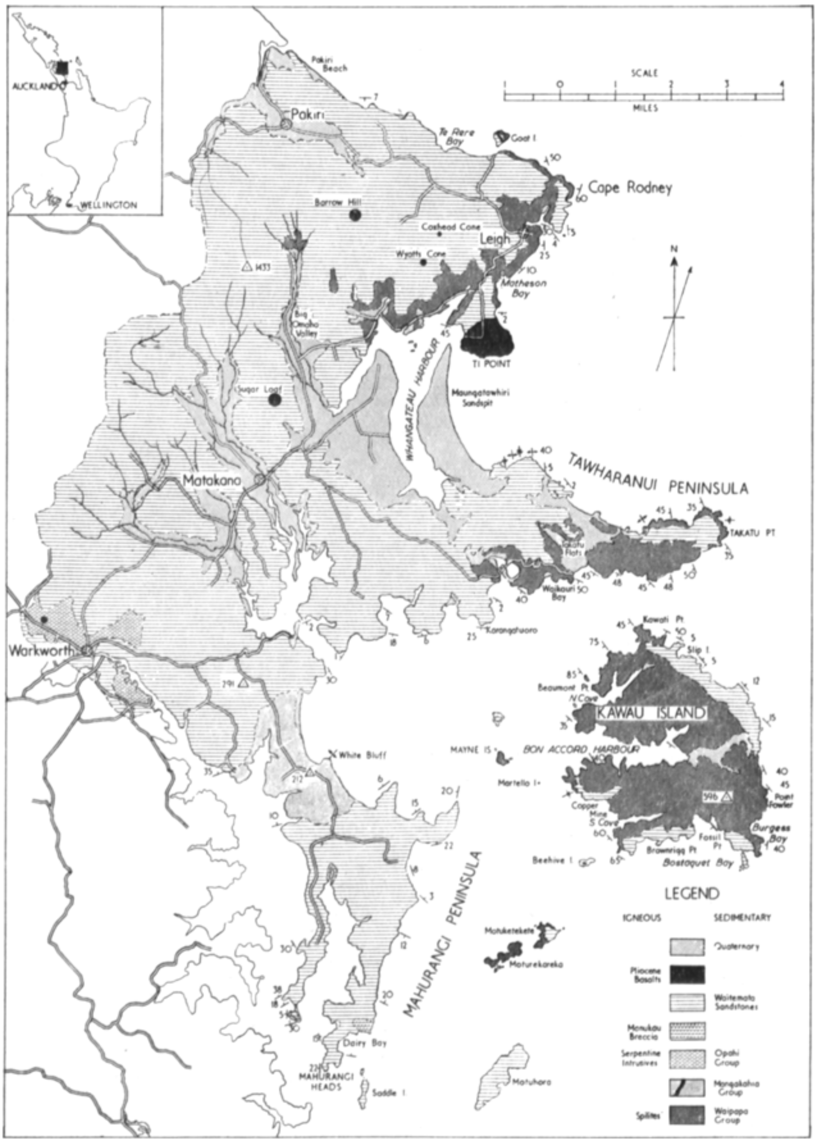

FIG. 1—Geological Map of Cape Rodney - Kawau.

WAIPAPA GROUP

In this field, rocks of the Waipapa Group are chiefly dark grey argillites and strongly indurated grey and green greywacke sandstones, the latter, as a rule being highly silicified. The group includes red, brown and grey banded cherts and jaspillites, and also spilitic lavas with limestone lenses commonly associated with deposits of manganese oxide. Of lesser importancê are grit beds, and igneous and intra-formational conglomerates. A thickness of approximately 8,500 ft was estimated for the group in this area.

Waipapa rocks are exposed in coastal sections between Tawharanui Peninsula and Cape Rodney and on Kawau Island. Elsewhere they are generally covered by younger formations. Their structure at Tawharanui Peninsula was discussed in an earlier paper (Hopgood, 1960) where it was shown that the major structure consists of an overturned anticline plunging at 10° north-west. Later folding produced minor corrugations with axes oblique to those of the larger fold and developed shear fractures. The corrugations plunge at angles of approximately 45° on a bearing between S.S.E. and South.

Greywacke Sandstones

Massive sandstones, ranging in colour from light grey-brown through greenish-brown to dark greenish-grey, are important members of the sequence. Bedding is either absent or indistinct and only where the texture is gritty, is grading of stratification evident. The beds are then seen to dip steeply to the south-west concordantly with the other strata of the group. Joints occur both as closely spaced cracks and as isolated wide fractures in which secondary deposition of quartz, chlorite, and occasionally epidote, has taken place. Three sets of joints, longitudinal, cross, and shear, were recognised in the field; shear planes persist for great distances. Where intense, shearing has formed zones of parallel planes separated by layers of brecciated sandstone cemented by secondary quartz and chlorite which show slickensides that indicate the direction of movement. As the shear zones are easily eroded, they tend to produce gaps several feet wide on shore platforms. Crush zones of green mylonite in lensoid masses resemble volcanic rocks but are distinguishable by their lighter colour.

Where spilitic lavas occur in the sequence, neighbouring sandstones acquire a distinctly green colour due to the introduction of chlorite. This change is so pronounced in places that the sandstones may easily be mistaken for lavas, especially in those areas with marked silicification of the country rock. The abundance of silica in the sandstone members constrasts strikingly with the extreme deficiency of this mineral in the argillites.

Breccias of dark argillite fragments in a sandstone matrix are present at several localities. These are interpreted as having been formed before consolidation by the scouring of turbidity currents flowing over soft semi-compacted muds so that the top layers were shattered, picked up and redeposited together with the sands carried by the current. The fragments, which range from 2 to 10 cm in length, sometimes show common alignment in planes parallel to the bedding, thus indicating the direction of current flow.

Thin sections show the sandstones to be composed of equant, angular detrital chips, 0·25–3 mm across, set in a matrix of similar but finer fragments. Most of the fragments are monomineralic, but rock chips are common. The growth of secondary quartz, chlorite and sericite has frequently altered the original boundaries of detrital grains. Fibrous chlorite replaces ferromagnesians and biotite, and is most abundant where it replaces chips of volcanic rocks. Leucoxene is abundant and both pyrite and magnetite are scattered throughout the matrix of the sandstones, and in fragments of lavas. Detrital quartz in sharply angular to slightly rounded grains, serrated and clouded by marginal solution, makes up between 50% and 60% of the total rock fragments present.

Detrital feldspars, subequal in amount to the quartz, are of two types. In one extinction angles vary from 0° to 18° indicating plagioclase with An content about 30%. In the other fresher looking individuals have small extinction angles and display polysynthetic twins in which the range of An content, as determined by the method of symmetrical extinction, varies from 0% to 15%. A zonary arrangement of dust-like inclusions parallel to crystal faces is common in feldspars which have been clouded by saussuritisation. Occasional large crystals of orthoclase and abundant authigenic white mica in fine shreds were also noted. In some sandstones, as observed by Brothers (1956), prehnite forms ramifying veins and clusters.

Constituent rock fragments are mostly limonite-stained sedimentary rocks, with greywacke sandstone more common than argillite. Fragments of igneous flow rocks are also fairly common; they have abundant leucoxene and magnetite and bright green chlorite replacing the groundmass. Ghost phenocrysts of feldspar can be recognised from original crystal outlines. Many were basaltic in character; others were porphyritic, altered andesites. In the least porphyritic lavas, reconstitution and silicification has developed a texture in which chlorite and quartz pseudomorphs after feldspar are scattered throughout a fine mosaic. In all rock fragments plagioclase feldspars have small extinction angles probably as a result of the replacement of calcic plagioclase by diagenetic albite. For this reason precise determination of original rock types is not possible. Chips of slate with strong alignment of bladed and rod-like minerals are also present.

Conglomerates were found in three localities on Kawau Island. One, on the coast east of Kawati Point, dips at 47°–245°, is 40 ft thick, and contains pebbles of spilitic lava as well as of sandstone and argillite. The matrix is a fine greenish mudstone which shows signs of having been sheared subsequent to consolidation. The other conglomerate bands, one 50 ft thick and the other is 25 ft thick, outcrop on the east coast north of Burgess Bay, and are about 100 yd apart. They resemble the Kawati conglomerate but contain silicified pebbles of basaltic rock in addition to the sedimentary rocks. Nevertheless it is probable that the Kawati conglomerate is the lateral extension of one or both of the bands.

Rocks recognised in the conglomerates included:

(1) Spilites of the same type as occurs within the greywackes;

(2) Volcanic rocks with trachytic texture;

(3) Vesicular basalt similar in appearance to that of Ti Point;

(4) Altered andesites: (a) with porphyritic structure, (b) showing strong flow banding;
(5) Altered trachytic rock containing sodic plagioclases and iron ores;
(6) Greywacke sandstone.

Argillites

Argillites are mostly well-bedded. They range in colour from black to light grey with an occasional stratum of pale green. Beds are commonly 1 cm thick alternately fine and coarse. The beds are broken by numerous tiny normal and reverse faults. Scalloped bedding planes where minute load-casts have been preserved by later sediment covering the undulations are seen in many places and flow-casting is also common in many of the layers: the latter has been used as criterion in determining the order of deposition. These structures have shown that the sequence in part of the area is overturned and thus explains the fact that the beds are less sheared and deformed towards the east, although the dip is westwards.

Where greywacke beds alternate with the argillites, boudin-like lenses of sandstone have been developed by shearing stresses acting parallel or subparallel to bedding planes (Fig. 2). The argillites have yielded by plastic flow around the greywacke masses and have accommodated themselves to deformation by flexure rather than by fracture. Small symmetrical folds, of wavelengths ranging from a few inches to two or three feet, plunge obliquely to the general dip of the strata, and are cut by major high angle

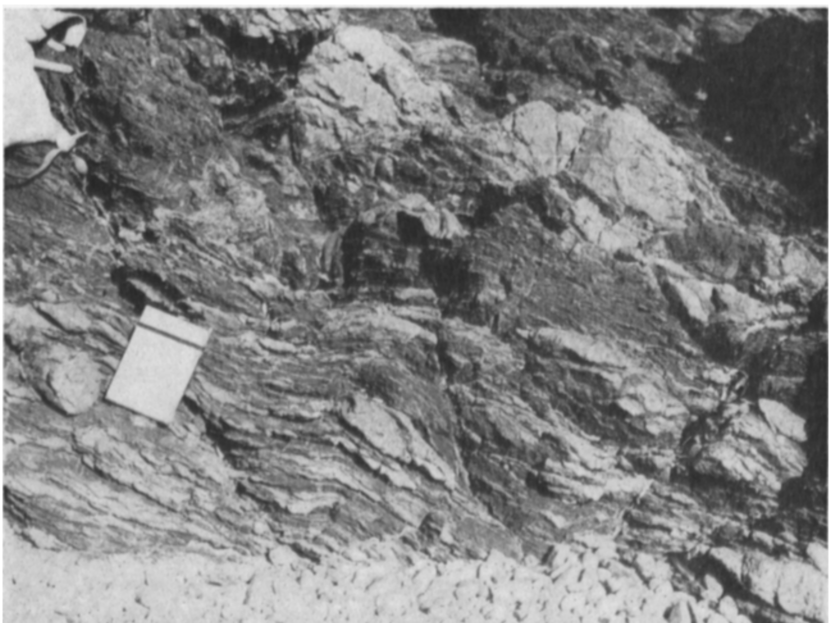

FIG. 2—Sheared (S_1) alternating greywacke and argillite showing oblique shearing (S_2) and corrugations (B), Tawharanui Peninsula.

shear planes which transect both rock types. It is suggested that movement on these shears was either rapid – allowing insufficient time for beds to adjust by plastic flow – or of great extent, thereby stretching the argillites beyond their elastic limit. Secondary minerals similar to those in the sandstones have been formed along and parallel to the planes of movement.

Thin-section examination shows that the argillites have the same constituents as the sandstones, but have achieved a more advanced state of reconstitution. Bedding planes are emphasised by a strong foliation resulting from the growth of sericite flakes. Quartz, feldspar and chlorite have also recrystallised from the matrix. Lensoid quartz mosaics form pods and minute corrugations at the intersections of shear planes with the bedding.

The greywacke sandstones and argillites are regarded as equivalent in grade to the Chlorite-1 sub-zone of Otago (Turner, 1938) in that they show a lack of cataclasis and of definite planar schistosity, but exhibit much reconstitution of the matrix, and saussuritisation and sericitisation of the feldspars. Brothers (1956) suggests that prehnite developed in preference to pumpellyite because reconstitution has taken place in sandstone lenses where shearing stress, hydrostatic pressure and possibly temperature would be low.

Spilitic Rocks

The most important outcrops are immediately north of the copper mine and at Point Fowler on the east coast of Kawau Island. They occur also east of Waikauri Bay and at a small beach a mile east of Takatu Flats, Tawharanui Peninsula. The rocks which outcrop in lensoid masses intersected by numerous calcite veins are grey-green to leek-green in colour, fine in grain and extremely hard.

In some outcrops calcite occurs as pockets in the body of the rock and in others, as veins and lenses overlying them. At Point Fowler and at Waikauri Bay, in masses of pillows 30 ft thick (Fig. 3), individual pillows vary greatly in size from 3 ft in diameter to only an inch or two across; most are somewhat flattened.

At all other exposures spilites occur as narrow lenses and stringers of lava between bedding planes. They exhibit no pillow structures and probably are merely marginal tongues from larger masses. The lavas, although less shattered, show the same deformation as the sedimentary members.

In thin section the spilites are seen to be hyalopilitic in texture, with rare aggregates of plagioclase feldspar set in a groundmass of minute crystals of pyrite and small acicular laths of feldspar in random orientation. The phenocrysts are water-clear plagioclase, with a composition of 0–5% anorthite as determined on a universal stage from Turner's (1947) curves. Both normal and parallel twins are present in phenocrysts which average 0·75 mm in length and 0·2 mm in width. Incipient flow structure is apparent where minute laths of feldspar are arranged in sub-parallel groups. Minute vesicles are usually occupied by calcite amygdules or by chlorite while a few of the larger vesicles are completely filled by one or more large crystals of calcite. Some of the chlorite-filled vesicles are rimmed by a thin layer of crystalline quartz. Calcite veins are built of crystals on the walls

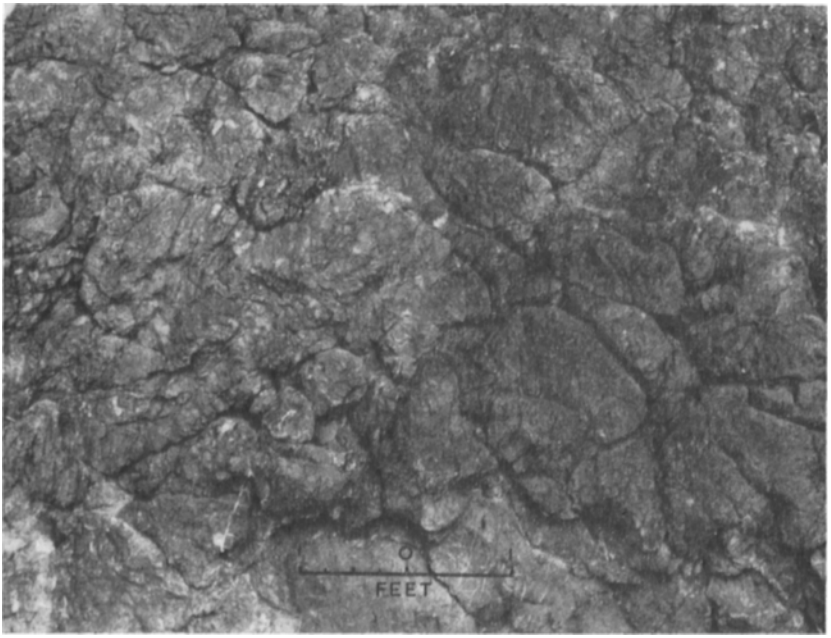

FIG. 3—Pillow Lava. Point Fowler, Kawau Island.

of fractures the central parts of the veins being filled by larger crystals aligned parallel to the vein walls. Some crystals, showing undulating extinction project into the vein at acute angles; this suggests that crystal growth has continued during movement along the fractures.

At Waikauri variolitic structures form a pisolitic type of skin on the pillows. The varioles are up to 5 mm across and have a concentric structure with an inner, dark sphere about half the diameter of the whole structure, a lighter-coloured, intermediate shell, and an outer, darker one. The darker areas are composed of glassy groundmass and brown cryptocrystalline pyroxene. Feldspar laths typical of the enclosing mesostasis have been included by the varioles. The lava itself is mottled with iron ore which has been excluded by the varioles. It would seem that the lavas were extruded as a fluid from which only iron ore and perhaps olivine had crystallised, and that feldspar crystallisation took place mainly after the variolitic texture had developed. After crystallisation of iron ore, and before separation of feldspar, minute segregations of pyroxene microlites accumulated around centres and grew outwards, thrusting aside the larger aggregates of iron ore. The varioles grew in three stages in the manner described by Buckley (1951, p. 501); i.e., following the growth and the segregation of the first microlites, the surrounding fluid was depleted "so that a metastable condition of slow growth" followed; later growth of a new concentric shell completed the structure.

The local lavas display most of the diagnostic features of the Spilitic Suite of Dewey and Flett (1911) in that they are variolitic in texture, have a brown glassy base, and contain a little albite and pyroxene but lack olivine. They are similar in texture to those described from Waiheke by Halcrow (1956) and to the variolitic pillow lavas described by Wellman (1949) from the Red Rock Point, Wellington. Most other New Zealand spilites differ in that they are coarser in texture and contain pyroxene phenocrysts.

Some authors (e.g., Sundius, 1930) after consideration of the ratios An/Ab/Or have concluded that the existence of a primary spilitic magma is possible. Like Eskola (1935), Sundius (1930) suggests that there is also good evidence for albitisation, and concludes that spilites have a composite origin involving both primary and secondary processes. The frequent evidence for alteration in spilitic rocks is stressed by authors who favour hypothesis of secondary replacement of anorthite by albite (Eskola, 1935; Park, 1946).

In view of the freshness of albite phenocrysts, and indeed of the rocks as a whole, together with evidence of replacement afforded by vesicles infilling by calcite and chlorite, the writer is inclined to regard the Cape Rodney - Kawau lavas as having been affected by late magmatic metasomatism. Basic magma is postulated as experiencing a petrogenetic trend similar to that suggested by Turner and Verhoogen (1951, p. 210) in which crystal settling of early-formed olivine and, in the present instance, pyroxene (since this is rare in this field) took place. Extrusion of the residual magma followed, together with subsequent enrichment in soda as it came in contact with the comparatively soda-rich greywacke sediments, themselves saturated with sea water. A low temperature "stewing" of the extrusion in a sodic environment led to concomitant albitisation of feldspars, formation of chert and calcite, and ores of iron and manganese (Eskola, 1935; Park, 1946).

Banded Cherts and Jaspilites

Siliceous rocks crop out on Kawau Island, on many of the small peninsulas in Bon Accord Harbour, and on the hill to the north-east; banded cherts are exposed on the shore platform at the old copper mine, at Beaument Point (Fig. 4), and along the shores of North and South Coves. On the mainland, however, the only exposure of such rocks is in the headland east of Waikauri Bay.

East of Waikauri Bay, at the old copper mine and at Beaumont Point, spilites intrude the sequence, but at the other localities cherts are not seen to be associated with lavas. Nevertheless, it seems likely that lavas do accompany the cherts in all cases and that where not observed the lavas may be considered as merely obscured.

Cherts and jaspilites occur in bands of 1–3 in. in thickness making up composite bodies as much as 200 ft thick. They are generally brown or red but the colour may range from white to black through grey, yellow, orange, red and brown, depending on the content of iron oxide in the layers. The grey cherts are composed of pure cryptocrystalline silica and rare, minute particles of crystalline silica which possibly represent organic bodies. The bands are generally concordant with adjoining strata but discordant folds

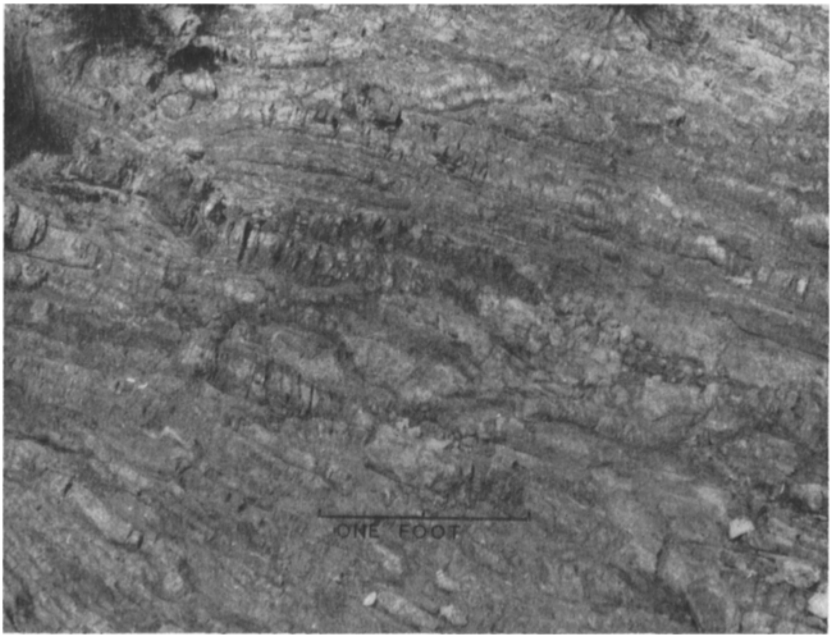

FIG. 4—Banded cherts. Beaumont Point, Kawau Island.

ten feet or more in amplitude may be seen. Bands within the chert bodies seldom exhibit the lensoid structures observable in sandstone and argillite members.

Manganese ores are associated at all localities, the manganese oxide occurring as a "bloom", or in small patches and veinlets, or in greater quantity. At Waikauri Bay the ore is an encrusting deposit an inch thick and at Beaumont Point forms large mamillary masses a foot or more across and several inches thick.

Mylonites

At several localities crushed greywacke occurs in pale green lenses of slightly porous, but comparatively hard rock, which, although bearing some resemblance to spilitic lavas in the field, may be distinguished from these by its lighter colour and more open texture. It is possibly equivalent to the 'green mylonites' of Waiheke Island (Halcrow, 1956).

Origin of the Waipapa Group

The rocks of the Waipapa Group are clearly of geosynclinal origin and the presence of interbedded volcanics suggests that they may be classified as typical eugeosynclinal deposits. Local variation in the rate of deposition is suggested by the presence of conglomerates and by great thicknesses of massive sandstones as at Kawau and Tawharanui. These features imply temporary shallowing of seas or proximity of land, causing the finer fraction of redeposited sediments to bypass the area and be deposited nearer the axis of the geosyncline. The inclusion of spilite pebbles and greywacke in the conglomerate bands suggests operation of the "cannibalistic" process of Krynine (1948).

It would seem that the bulk of the Waipapa Group of sediments was deposited in the moderately deep waters of a late Palaeozoic or early Mesozoic mobile geosynclinal belt whose axis ran parallel to the present east coast of the North Auckland peninsula.

From their content it is concluded that the sediments of the Group have been derived from an igneous and metamorphic terrain. The strongest evidence for this lies in the nature of conglomerates (found at Great Barrier Island and elsewhere outside the area) which include granitic and other acidic igneous rocks. Pebbles in the Kawau conglomerates are commonly silicified volcanics with marked trachytic texture and are probably derived from terrestrial basalt flows. Some of the micro-breccias contain altered metamorphic rock fragments and chips of indeterminable silicified volcanic rock.

The dark colour of shales interstratified in New Zealand greywackes has been attributed by Broadgate (1916) to the presence of plant material, an opinion apparently endorsed by Brodie (1953). No definite plant fragments have been seen by the writer in the present area, although Mr D. Kear (pers. comm.) reports finding vegetable remains in slabs at Kawau. Brothers (1956), however, showed the carbon content of an argillite from Tawharanui to be negligible and suggested that the dark colouration was due to the high content of iron oxides (23·3%). This figure is abnormally high in comparison with the average percentages of Pettijohn (1949) of 4–6% ($FeO + Fe_2O_3$) for shales.

Despite the view of writers (Benson, 1923; Wellman, 1952; Brodie, 1953; Halcrow, 1956), who postulate a western area of provenance for New Zealand Mesozoic greywacke it is suggested that the material of the local greywacke was derived from the east. The following evidence is cited in support of this view:

(i) The conglomerates in greywackes of Great Barrier Island contain igneous boulders up to 18 in. in diameter (Bartrum, 1921) whereas igneous pebbles in the conglomerates at Kawau rarely exceed 2 in. in diameter.

(ii) Seismic studies of the South Pacific by Officer (1955) show that the thickness of the crust along the East Cape - Kermadec - Tonga Ridge reaches 20–25 km, whereas west of New Zealand the thickness of the crust appears to be only 5 km, the same as that in the south-west Pacific basin. Officer therefore dismisses the possibility of there ever having been land in the area now occupied by the Tasman Sea.

The features shown by the spilites – fineness of grain, pillow structures and intimate association of sediments at the margins – all indicate that the lava was extremely fluid. Probably some of the lavas were extruded on the sea-floor whilst others were intruded into soft wet sediments below the floor. Additional evidence supporting the subaqueous emplacement of the flows is afforded by calcareous ooze and fine fossiliferous muds found between pillows.

The absence of baking in the adjacent sediments is possibly due to one or more of the following reasons: lack of sufficient heat in the lava to bake the sediments, which were saturated with, and surrounded by, cold sea-water; poorly conducting glassy skins on individual pillows insulated the bodies; the greywacke sediments have since been strongly indurated so that visible effects of early baking would be difficult to detect.

The Origin of Cherts and Jaspilites

The theories that have been advanced to explain the origin of silica and the manner of its deposition in such rocks are as follows:

(a) *Syngenetic Deposition:* Syngenetic deposition from organic remains implies partial solution of organic silica and its subsequent deposition as chert. Inorganic processes likely to produce cherts require the silica either to be in ionic solution, or as a sol, and until recently the idea of flocculation of a colloidal suspension was favoured by most authors. For example, Taliaferro (1933) regarded cherts as consolidated gels formed by loss of water. More recently Roy (1945), pointed out that earlier writers had accepted the experimental results of Kahlenberg and Lincoln (1896) who had erred in assuming a colloidal form for silica. Harman (1925–26–27), had earlier shown that silica existed in the ionic form SiO_3. Roy concluded that silica in natural waters existed as a solution or crystalloid rather than as a colloid and that the evidence, pointed to an ionic state. He also stressed that marked changes in pH are likely to cause changes in solubility.

Twenhofel (1950), considered that deposition of chert in shallow seas resulted where silica-bearing waters met the ions necessary to cause precipitation and concluded that "If chert and flint exist in rocks that were deposited far from mouths of streams, it seems best to postulate an origin other than syngenetic or refer the silica to magmatic derivation."

However, other authors (e.g., Ruedemann and Wilson, 1936) have postulated a deep-water origin of cherts because they are associated with geosynclinal sediments, spilitic lava and radiolaria. The cherts described by Ruedemann and Wilson are considered to be of primary origin as they occur in bands separated by thin shale partings – a combination unlikely to form as a result of secondary silicification.

(b) *Penecontemporaneous Deposition:* Theories of penecontemporaneous deposition postulate precipitation of silica along with normal sediments followed by solution and, through later concentration, re-deposition. In this way nodules and highly siliceous sediments might be explained but well-banded cherts with sharp boundaries against other rocks must owe their origin to some other cause.

(c) *Epigenetic Deposition:* Epigenetic deposition depends on waters circulating in the already consolidated rock to transport silica which is later precipitated in joints and along fault zones. Twenhofel (1950) doubts the feasibility of this process if applied to the zone of cementation below the water table but agrees that it is more likely to take place in the zone of weathering above. Red cherts of the south-west

Wellington district may well have originated in this way, and veins of silica throughout the greywacke sandstones of the present field are undoubtedly of epigenetic origin.

In assessing these different views with respect to the cherts and jaspillites of Kawau it would seem that a syngenetic origin is the most likely. It is favoured because of the sharp, rhythmical banding and the sharp horizontal contacts without gradation into the adjacent sediments. Furthermore, there is no evidence of replacement of original sedimentary features, nor is there an association with faults, with the possible exception of the occurrence at the old copper mine, where cherts form bands parallel to, but not within, a fault zone.

The association with lavas in most places seems to be more than coincidental. Park (1946) concluded that the jaspers associated with the spilites and basalts of Olympic Peninsula were the result of precipitation of silica during extrusion of lava and subsequent fumarolic activity. He suggested that solutions rich in silica would have been set free during the "stewing" of these lavas in hot aqueous solutions and primary zones whence albitisation took place. Eskola (1935) has shown that under these conditions anorthite is converted to albite. Siliceous solutions, on reaching the top of the flow, would begin to precipitate silica, according to Park.

Compared with the spilites of Olympic Peninsula, those of Tawharanui Peninsula are small in volume, and any fumarolic activity associated with them would probably have been slight. On the other hand, it is generally agreed that the solubility of silica in aqueous solution decreases with increase in pH. The writer suggests that with the extrusion of lava, carbon dioxide would be released in quantity and this would form carbonic acid, so that precipitation of the silica already present in sea water in the ionic form advocated by Roy (1945) would occur. Circulation of sea-water by convection would ensure a continuous supply of silica solution. Thus, release of silica solution from the lavas would not be entirely necessary. Periodic break-through of the lava from its glassy selvedge would cause intermittent release of carbon dioxide as new surfaces were exposed, and in this way the banding of the cherts would be explained.

A feature of the cherts east of Waikauri, is that iron staining is greatest adjacent to the lavas. Moore and Maynard (1929) found experimentally that on mixing iron and silica solutions, the iron and about half the silica were precipitated. In the case of the red cherts or jaspilites iron solutions were probably derived directly from the lava so that precipitation would have begun immediately the solutions mixed with sea-water. Overall decrease of iron oxide in the chert with increasing distance from the lavas is consistent with the mode of origin.

Manganese oxide encrustations on cherts and lavas at Kawau were in the past sufficiently abundant to be mined. Their mode of occurrence suggests, contrary to Park's (1946) theory, that this mineral has been deposited after all the others. It is possible that the encrustations are simply alteration products due to weathering of original manganese mineral contained in lavas.

Copper: The copper ores at Kawau Island occur in a crush zone striking at 45° and dipping at 65° towards 135° immediately south of a parallel belt of banded jasperoid cherts at Copper Mine Point. The fault zone, from 6–15 ft wide (Ferrar, 1934), has been mined for a length of 400 ft, yielding ores containing an average of 16% copper. The sulphides and ores, are of the "red bed" type according to Henderson (1939), and include chalcopyrite and pyrite, with some bornite. They are similar to those at Maharahara and the Raukotere Basin near Gisborne and at Great Barrier Island. The lode is capped by gossan and manganese oxides underlain by lenses and irregular masses of pyrite and chalcopyrite; the surface of the lode is coated with a blue and green efflorescence of copper carbonates.

For purposes of comparison, the writer has visited the old workings at Great Barrier and Maharahara. At Great Barrier, the lode was similarly located in a crush zone (Bartrum, 1921) and appears to have been similar to that at Kawau. The only difference noted was the presence of veins of crystalline quartz at Great Barrier which, probably have arisen from subsequent andesite intrusions. At Maharahara the ore body is associated with cherts and jaspers (Lillie, 1953) and spilitic rock similar to that at Kawau (collected by the writer). Drilling at Kawau has revealed the presence of spilitic rocks close to the lode, as was expected from the occurrence of such boulders on the beach nearby.

An hypothesis suggesting sedimentary origin for the copper ores, as advanced for those of Arizona (Finch, 1935) and New Mexico (Lindgren, 1910), requires that the sediments should have been deposited at a time when a copper-bearing igneous terrain was being actively eroded. Although the possibility of sedimentary origin appears feasible it has been noted that the metal does not occur commonly in the greywackes which are notably fractured and faulted. Furthermore, should the copper be confined to one or two horizons then ore bodies would be expected parallel to the strike at the intersection of fault zones cutting these strata. This, however, is not the case and the idea of a sedimentary origin for the ore is consequently discarded.

If the ore were of later igneous origin, veins or intrusion cutting through the greywacke in the vicinity of the lode should be evident. No such veins exist. The possibility of a primary igneous origin, contemporaneous with enclosing sediments is supported by the presence of nearby spilitic lavas which contain copper.

If the copper was derived either from later intrusion or from coeval lavas, concentration of the ore would be necessary. Circulating underground waters, by solution would tend to carry soluble salts to the fissures or porous beds where redeposition could take place. Supergene enrichment would then occur after exposure to atmospheric weathering and the action of meteroic waters.

The fact that copper ore bodies are found at only one locality in the Cape Rodney - Kawau area may well be due to the fact that only at this place are the lavas cut by a fault zone along which the copper minerals could be concentrated and enriched. Similar conditions exist at Great Barrier.

The writer is of the opinion that the deposits of banded cherts, limestone, the iron and manganese ores, and the copper lode, are all genetically linked. The cherts are probably a precipitate largely from sea-water, but the manganese and iron oxides, calcite and copper are considered to have been derived directly from the spilitic lava.

Age and Correlation of the Waipapa Group

Direct evidence of the age of the group in the Cape Rodney - Kawau area is lacking. The only fossil found, too crushed and leached to be of diagnostic value, shows a series of concentric ribs of asymmetrical cross-section and bears some resemblance to the species, *Inoceramus haasti* and *Maitaia trechmannii,* (Dr C. A. Fleming, pers. comm.; Milligan, 1959). Greywackes stretch with little interruption from Whangaroa in the north to the Hunuas, south of Cape Rodney, forming what may be regarded as a regional anticlinal area (Fleming, 1953). Permian fossils have been found in the beds at Whangaroa and the Triassic fossil *Hokonuia* and Jurassic fossils (Milligan, 1959) have been found at localities south of Cape Rodney.

Too little is at present known of general structure to decide on structural or stratigraphical grounds whether the rocks of the Rodney-Kawau area are Permian, Triassic, or Jurassic in age. Some of the greywacke in the district is very similar to that of the Tokatea Hill and Moehau Series of Coromandel (Fraser and Adams, 1907) which underlie fossiliferous Jurassic greywacke. The writer is inclined to assign to at least some of the local rocks a Permian age; the less deformed bedded greywackes and argillites are regarded as possibly Triassic or Jurassic.

Mangakahia Group

The term Mangakahia is adopted, following Hay (1952) for rocks with lithologic similarity to those formerly called Otamatea beds by Ferrar (1934).

The beds of the group are exposed in this region only in the central part of Mahurangi Peninsula. No fossils were found by the writer. On the west coast of the peninsula the rocks are sheared, fissile mudstones and siltstones, usually of dark grey colour. On the east coast strata are much lighter in colour and sandier, with occasional grit and pebble bands. Bedding, difficult to see except where pebble bands and brown limestone beds occur, is best exposed at White Bluffs and gives the impression of being disposed with extreme irregularity along a strike which averages approximately 135°. The rocks are fractured by fairly close-spaced joints which trend nearly parallel to the strike and following the line of the coast.

Conglomerates and grits are composed mainly of fragments of brown limestone and dark grey mudstone, together with smaller pieces of greywacke, set in a matrix of similar, but finer sandy material. The bands are only 5–6 in. thick and lens rapidly along the strike. Most of the sandstones are fairly even-grained and contain a small amount of glauconite. Concretions are rare and mostly found on the beach at the foot of siltstone cliffs from which they have weathered. They consist of hard, coarse sandstone cemented by calcite; the maximum diameter is about 4 ft. Associated with the concretions in the dark grey siltstones, is a yellow efflorescence that is similar to the melanterite replacing pyrite nodules found at Coverham which Wellman (1955) cites as evidence for correlating these beds with the Upper Cretaceous Whangai Shales of the North Island. None of the cone-in-cone barite concretions, so typical of the group elsewhere, were found, nor were any of the following, which were regarded by Ferrar (1934) as characterising the Otamatea formation: septarian nodules, native copper, fragmental vegetal material, ammonites and Inoceramus.

If, as appears clearly in some places, the beds are nearly everywhere horizontal, a maximum thickness of rocks exposed above sea-level would be of the order of 200 ft. Contacts with other groups were not seen.

The lithologic features suggest deposition in a nearshore environment. The sandstones and mudstones were probably derived from a predominantly greywacke terrain. It seems likely that the source lay to the east since the Mangakahia Group attains its greatest thickness to the west in the Kaipara district where seas were presumably deeper offshore.

Opahi Group

The name Opahi Group, proposed by Hay (1952) to replace Ferrar's (1934) Onerahi Beds, was originally intended to cover Bortonian claystones, argillaceous limestones, greensands and mudstones with flint lenses which outcrop in the Mangakahia Subdivision; it has been extended here to include rocks of the present district. The argillaceous limestone of the Warkworth district is included in the Opahi Group purely on grounds of lithological similarity as diagnostic faunas have not yet been found. Strata of the group outcrop over an area of approximately one square mile along the south side of Mahurangi Estuary, immediately below Warkworth. Another irregular outcrop of about two square miles, north of the township, has been intruded by a mass of serpentinite. The rocks are shattered off-white argillaceous limestones without visible bedding. Calcite veins in the rock suggest correlation with the "upper argillaceous limestone of Pahi" which contains lenses of crystalline limestone and is Whangaroan to Waitakian in age (Arlidge, 1955). Exposures are few so that neither upper nor lower boundaries were seen, nor could the thickness be estimated.

Weathering and alteration have obscured most of the original texture in the serpentinite so that the bulk of the rock is now composed of pale green fibres of chrysotile, bronze-coloured pseudomorphs of iddingsite and fibrous lamellar antigorite after olivine. Original fractures in the olivine crystals are represented by seams of magnetite and chromite.

The fine-grained and highly calcareous nature of the sediments suggests that the area of provenance was one of low relief and probably far removed from the area of deposition. Although part of the parent land may have been greywacke, the rocks of the Opahi Group were derived principally from a low-lying area of Mangakahia mudstones and claystones. The presence of cross-bedding in the Kaipara district (Arlidge, 1955) precludes the possibility of deep-water deposition, and a shallow, shelf sea environment is postulated during deposition of the Opahi Group.

Waitemata Group

Waitemata Sandstone and Maharangi Grit: The nomenclature used here is in accordance with that of Ferrar (1934) and Brothers (1954a) and is applied to alternating unfossiliferous felspathic sandstones, ripple-marked mudstones, and carbonaceous shales, containing interbedded fossiliferous Mahurangi Grits, and basal conglomerates.

The formation, the most widespread in the Cape Rodney - Kawau district, is thickest to the west and thins laterally at Tawharanui Peninsula, Kawau Island and Cape Rodney. Close to Warkworth it overlaps on the argillaceous limestone of the Opahi Group but the nature of the contact with the Mangakahia group at Mahurangi Peninsula is not known.

Most of the sandstone layers are about a foot thick but many of the thicker layers measure up to 20 ft (Fig. 5). On the other hand, the mudstones and siltstones rarely exceed a few inches in thickness. Laminae of

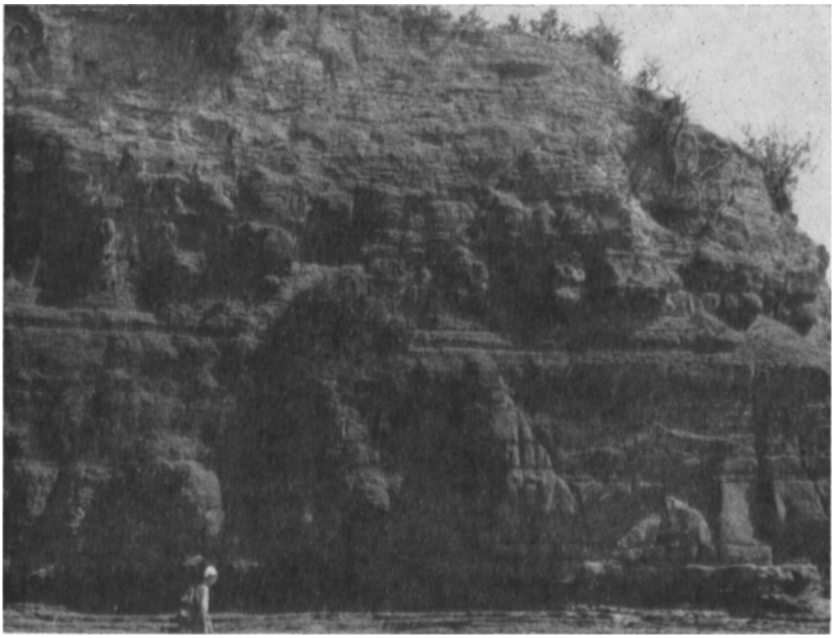

FIG. 5—Typical sub-horizontal Waitemata Sandstone strata showing spheroidal weathering of coarse sandstones and grits, jointing and small-scale faulting. Part of the shore platform is visible in the foreground. Tawharanui Peninsula.

carbonaceous material, associated with fine shales and mudstones in many places, contain flakes and twigs crowded together in an indeterminate mass, too obscure to be useful in correlating. Roots are often preserved as thin calcite shells infilled with mudstone, and rocks containing these are invariably grey sandstones which probably represent leached soils. Wherever plant fragments are found, ripple marks are a common feature in adjacent beds and the ripple mark index, λ/a (Shrock, 1948) indicates that the sediments have been deposited from aqueous currents. Cobbles of white mudstone, included in the shale members of the group suggest erosion of local areas of Mangakahia rocks.

Basal members of the Waitemata Sandstone are notably different in lithology from the rest of the formation and comprise coarse conglomerate, block and pebble bands, green and yellow sandstones and impure limestones. They are fossiliferous at Fossil Point and Brownrigg Point, Kawau, and on the mainland south of Cape Rodney and Matheson Bay. The cliff sequence at Brownrigg Point (Fig. 6) shows a perfect cross-section of the ancient Otaian strand-line. The lowest member of the sequence is composed of fallen greywacke blocks, up to 6 ft across, lying against the old cliff face of greywacke bedrock. Similar debris is exposed in the shore-

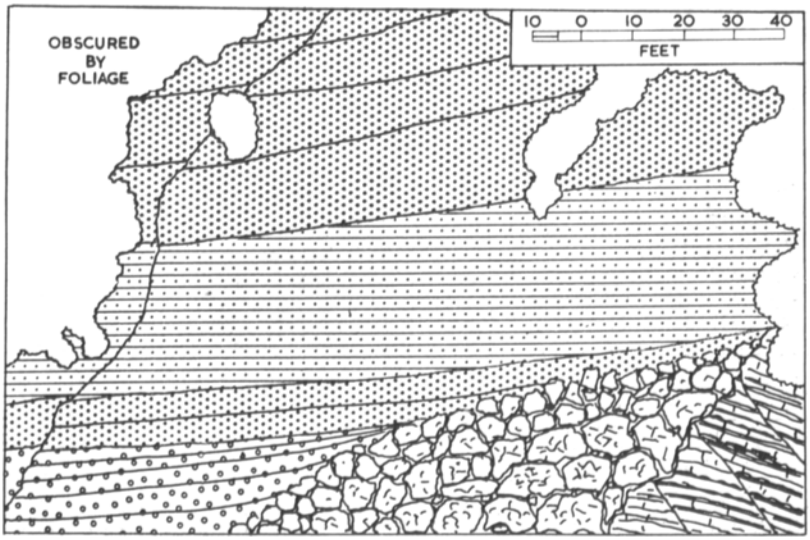

FIG. 6—Succession at Brownrigg Point, Kawau Island.
50 feet coarse yellow sandstone.
35 feet sandstones enclosing greywacke cobbles.
10 feet yellow grits and fine conglomerates.
20 feet conglomerate.
Greywacke blocks.
UNCONFORMITY.
Greywacke basement.

platform at Cape Rodney, along the east coast of Kawau, and at the east end of the Tawharanui Peninsula; it resembles detritus at present accumulating on the shore-platform south of Tawharanui.

Syngenetic and allogenetic calcareous concretions, of varying size and sphericity are common and those near Warkworth have been described by Cox (1881) as "cannon-ball" concretions. They are best developed in greensands as at Fossil Point, Kawau. The syngenetic concretions are not fossiliferous but frequently have nuclei of small pebbles. Lens and disc-shaped concretions in the basal beds which are increasingly calcareous towards the centre appear to be allogenetic, since they do not break cleanly from the surrounding rock.

Along the coast near Te Rere Bay, Pakiri, veins of crystalline calcite with well-developed nail-head and dog-tooth spar seam the grits and coarse sandstone of the cliffs. Joint planes, also, are covered by layers of small, perfectly formed crystals of 2 cm average length which, where they have originated from common centres form almost perfect rosettes.

Intercalated fossiliferous grit horizons throughout the lower part of the sequence could equally well be beds of Manukau Breccia. They are here considered as members of the Waitemata Sandstones because they are interbedded with the rest of the sequence but are distinct from the massive grits associated with the strongly disturbed sandstone and mudstone strata of the formation. These blue-grey beds, described as the Mahurangi Grits are composed of small andesitic lapilli containing pyroxene crystals up to 4 mm long, polyzoan fragments, pieces of small lamellibranchs and fragments of bone. Abundance of foraminifera, high glauconite content and presence of white mudstone fragments are also characteristic. Two closely similar grit horizons were noted but others may well have been unrecognised because of the lack of distinctive features. Grain size, the proportion of volcanic debris, fossil content and thickness of the beds increase towards the southern part of the area where Manukau Breccia is exposed.

The greatest height reached by the strata where the sequence is known to be uninterrupted, is 1,000 ft near Goat Island, Pakiri, where the dip is approximately 5°, so that the thickness is close to 1,000 ft. Although the base of the formation rises towards the east the attitude of the strata is generally close to horizontal and the whole sequence undulates gently, dipping in random directions from 0 to 3°. Exceptions to this are found in sections, locally tilted, where dips may be in excess of 10°. In the extremely contorted strata, associated with lenses of massive grits, or in those lying close to the basement, beds are often vertical or even overturned.

Such contorted strata occur close to the greywacke basement at Karangatuoro, on the south side of Tawharanui, where they are associated with basal conglomerate, on the north coast of the peninsula, and at Kawau Island (Fig. 7). Contortions adjacent to coarse massive grits are exposed on the west side of Ti Point. In all cases where such beds are near conglomerates the attitude of the plications shows that they have slumped away from the ancient coast. Tilted beds also dip off the old Miocene shoreline at Bostaquet Bay, Kawau; they form recumbent folds overturned in the direction of slump, thus indicating the direction of the ancient shoreline.

Pre-consolidational slumping in beds adjacent to grits took place where the latter were deposited on a sloping sea floor. Large volumes of ash and sand, travelling across the sea floor, gouged into, and ploughed up, the still plastic sediments, rucking them into characteristic sharp folds and convolutions. Brothers (1954a) has suggested that the Parnell and other grits of Auckland City were derived similarly from volcanoes on the site of Waitakere Hills. Primary dips are due either to compaction of the strata after deposition, or to the slope of the initial sea floor. Where the initial slope was steep, slumping of unconsolidated sediments took place until stable equilibrium was reached at angles of rest no steeper than about 5°. Angular unconformities are common between groups of strata and in many cases are due to the prevalence of subaqueous slumping in the unconsolidated strata. Several fine examples are exposed in the north side of Tawharanui Peninsula. Current bedding is more common in the coarser massive sandstones but occasionally is seen in the thinner, finer beds.

FIG. 7—Slump structures in Waitemata Sandstones. Kawau Island.

Minor faulting resulting from adjustment of unconsolidated sediments to stresses during compaction is common in all members of the formation. Cross-faulting formed by intersection of faults dipping at about 60° results from readjustment or beds that have moved laterally in response to tension of compression. Segments were thus enabled to move up or down to adjust to the change in area of the strata. Along the larger fault planes, drag has caused bending of the severed ends of the strata and it is along these faults that most of the small springs and seepages occur. Although faulting on a minor scale is common, the total resultant displacement is negligible since distinctive bands may be followed for some distance through several different fault segments.

Manukau Breccia: The writer has followed Ferrar (1934) and Brothers (1954b) in the use of the name Manukau Breccia to include andesitic breccias and conglomerates similar to those of the Waitakere Hills west of Auckland. The only two exposures of rock of this formation are at Mahaurangi North Head. On the west side of the head there is a 15-ft stratum of cobbles of andesite, limestone and dolerite, and of an anorthite-bearing volcanic rock. This bed is correlated with andesitic breccia north of Dairy Bay on the east.

Rounding of many of the cobbles suggests that they have been transported, or subjected to rolling on a shallow sea floor. An alternative and preferred hypothesis is that the material has been caught up from a deposit of Albany Conglomerates (Bartrum, 1920b) during eruption. This would explain not only the presence of doleritic rock amongst predominantly andesitic material but also the rounded form of the cobbles, as well as the presence of pebbles of porphyritic rock with some flow structure. The porphyritic rock is similar to an andesite but composed almost entirely of plagioclase with subsidiary iron ore and small brown patches of a pleochroic cryptocrystalline mineral. The composition of the plagioclase phenocrysts ranges from An 88–90% to An 78–82%. The limestone fragments are very similar to some from the Motatau Group (Hay, 1952) and may have been derived from this source. Blocks of similar limestone associated with andesitic debris at Whangaparaoa and Motuhora have been described by Turner (1928) but these are of much greater size than the cobbles (2–3 in. diameter) of Mahurangi Peninsula.

The blocks of andesite in the eastern exposure contain well-formed radially-infilled calcareous amygdules up to ¼ in. across. Blocks of andesitic breccia up to 4 ft across are common, and the whole represents a true volcanic agglomerate grading laterally, by decrease in size, into the Mahurangi Grits.

Origin of the Waitemata Group: The area supplying the detritus of the Waitemata Sandstone comprised Opahi, Mangakahia and Waipapa rocks, since fragments of all these have been found incorporated in the strata close to the contacts. The writer agrees with Turner and Bartrum (1929) that the region of provenance lay to the north-west and considers that a large proportion of the sediments was derived from land distributed much as it is at present. The Mahurangi Grits are considered to be derived from the same source as the Manukau Breccia. The size and angularity of blocks on Mahurangi Peninsula and Motuhora Island indicate clearly that the source of the breccia was located nearby. Either erosion has removed a volcanic edifice extending between the above localities, or else there was little or no cone-formation associated with eruption. Other centres of eruption have been located close to Whangaparaoa Peninsula to the south (Turner, 1928) and at Maitaia Peninsula on the Kaipara (Ferrar, 1934).

That the sediments and pyroclastics of the Waitemata Group were deposited in shallow seas is shown by the presence of carbonaceous shales, plant fragments and pieces of carbonised wood, and by ripple marks, current bedding, and intraformational conglomerates.

Turner and Bartrum (1929) considered that the current-bedding and shallowness of water is indicative of a deltaic environment in which sands and muds were deposited. The writer concludes that the Waitemata Sandstones were laid down in an environment which was partly transitional and partly neritic, in a region similar to the present Hauraki Gulf at a time when vulcanicity was widespread. Intermittent downsinking caused local changes in environment and facies. Although andesitic tuffaceous material was widely distributed at the time, subsequent erosion removed nearly all traces of the centres of the eruption.

Age and Correlation: Fauna from the basal beds and the higher Mahurangi Grits of the Cape-Rodney – Kawau District strongly suggest an Otaian age but in view of the general lack of age-determinative faunas, correlation of the strata with rocks outside the Auckland district is premature at present.

The following assemblage has been determined by Mr Hornibrook of the Geological Survey:

Sample N 34/505:

Calcarina mackayi,	*Eponides repandus,*
Cibicides perforatus	*Cassidulina* aff. *arata,*
Vaginula recta,	*Notorotalia* n. sp.
Buninga creeki,	*Glomospira* sp.

Ti Point Group

Basalts cut through the Waitemata Group in several localities but the only large extrusion is at Ti Point, south of Cape Rodney. Other outcrops are in four conical hillocks, a dyke and a sill. The Ti Point basalt flow has a general westerly slope away from the east coast where the vent was probably located. The rock, seamed by irregular layers of vesicles is unusually light in colour for a basalt, and is remarkably like that of Stony Batter, Waiheke (Halcrow, 1956).

The typical rock is a vesicular olivine basalt with marked trachytic texture. Large idiomorphic crystals of olivine are set in a finely holocrystalline groundmass of feldspar laths and tiny augites. A few small irregular phenocrysts of augite are present. The extinction angles of the groundmass feldspar laths are high, ranging between 30° and 40°, and determinations made from sections cut normal to (010) show the composition to be that of labradorite. The olivines generally have yellow edges due to deuteric alteration to iddingsite, and brown haematite stains along the fractures. The groundmass is sprinkled with small flecks of magnetite.

A narrow dyke which cuts through the middle of Goat Island at Cape Rodney has a similar composition and texture to the basalt of Ti Point but less pronounced flow structure. The Sugar Loaf, Barrow Hill and two conical hills in Wyatt's and Coxhead Creek valleys are formed of considerably darker basalt. A 10 ft thick sill of amygdaloidal basalt is exposed in a quarry at the head of Big Omaha Valley. This sill, or offshoots from it, is undoubtedly responsible for the presence of numerous boulders in neighbouring gullies. These basalts are characterised by the high anorthite content (80–90%) of the plagioclase feldspars and by the clots of clinopyroxene and olivine (about 2 mm diameter), which impart to the hand specimen a dark grey mottled effect.

The Sugar Loaf basalt is porphyritic in texture and contains large glomeroporphyritic clots of augite set in a groundmass of plagioclase feldspar, fine pyroxene crystals and minute flecks and rods of magnetite. Moderately large phenocrysts of zoned plagioclase are common and these have an anorthite content of 83–85%, determined by Turner's (1947) method. Rarely, small irregular crystals of olivine are present. The groups of large pyroxene phenocrysts show marked undulose extinction evidently due to strain set up during the final more viscous stages of the emplacement of the basalt.

The texture of the Barrow Hill basalt is intergranular to trachytic. Moderately large phenocrysts of augite and olivine set in a groundmass of plagioclase laths and small pyroxene crystals, have corroded edges and are marginally altered to iddingsite. This rock is intermediate in texture between the basalt from Ti Point and that from the Sugar Loaf.

The sill at Big Omaha Valley is porphyritic in texture and is very similar to the Sugar Loaf basalt. Remarkably symmetrical arrangements of four or more large augite crystals ($2V_z = 50°$) in the form of a cross are common in thin-section, the crystals being twinned with composition plane parallel to (100). Olivine is lacking in this basalt, except for one extremely altered phenocryst. Amygdules are present along the contacts with the adjacent Waitemata Sandstone.

Residual boulders exposed now in open paddocks are strongly fluted (Fig. 8). The lapiez and solution pits are similar to those described by Bartrum and Mason (1948) from Hokianga and by Halcrow (1956) but

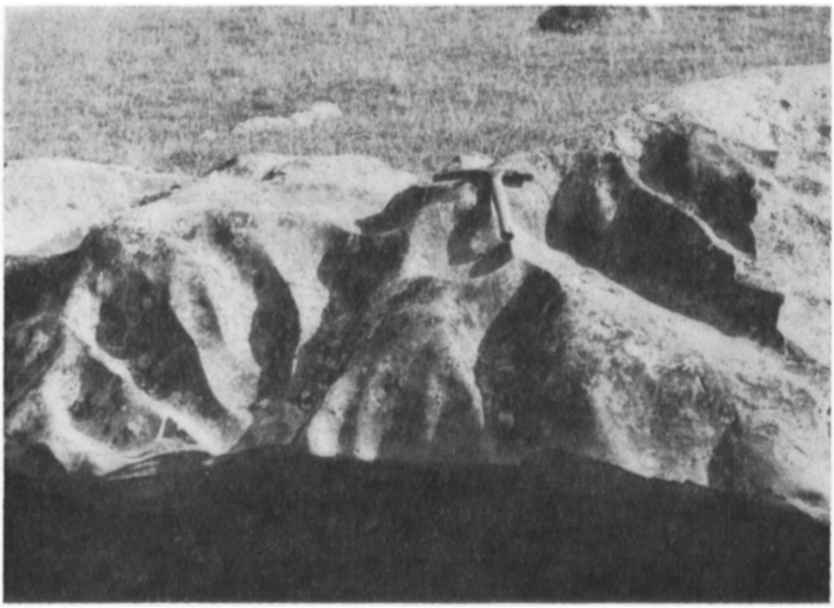

FIG. 8—Fluting in basalt. Ti Point.

probably at an earlier stage of development. Solution of the rock is ascribed to acid solutions dripping from mosses and epiphytes in trees of surrounding bush.

Since the basalts baked sediments of the Waitemata Group, and have evidently flowed over a topography eroded in them at Ti Point, they are probably Pliocene in age.

Pleistocene and Recent Sediments

The Flandrian Transgression resulted in a considerable accumulation of estuarine sands and muds in the Cape-Rodney – Kawau district.

Ferrar (1934) relegated a small patch of weathered conglomerate at the south-west end of Whangateau Harbour to his Pliocene Purua Beds but the present writer regards this as Pleistocene and correlates it with the formation of the 15–25 ft erosion surface of Brothers (1954). A surface of the same height is also found at Matheson Bay. Banks of fixed sand with gently seaward sloping surfaces at 8–12 ft, and interpreted as formed during the Flandrian maximum, are preserved in inlets of Kawau Island and on the south side of Tawharanui Peninsula. Fixed sands along the north side of Tawharanui Peninsula and at the west side of Whangateau Harbour are also probably late Pleistocene in age.

Above present high water mark modern shell deposits occur near the end of Takatu Point and at Fossil Point, Kawau. Drifting sands mark the north coast of Tawharanui, Maungatawhiri sandspit, and Pakiri Beach, while boulder beaches occupy heads of inlets in greywacke at Cape Rodney, Tawharanui and Kawau are replaced by gravel beaches in sheltered water such as Bon Accord Harbour. Blocks and slabs cover the short platform of the less exposed beaches eroded in Waitemata Sandstones but on the more open beaches, sands have accumulated. Throughout the area mud flats and mangrove swamps are common, notably those at Takatu Flats and Christian Bay. The valleys of the larger streams are mantled by alluvium accumulated in modern times.

Outline of the Geological History of the Area

During the Upper Paleozoic a steep granitic and metamorphic terrain is postulated as having lain east of Auckland Peninsula. The climate of this ancient land was sufficiently mild, at least in part, to support vegetation and off its western coast the sediments of the Waipapa Group accumulated in a rapidly sinking trough; fluctuation of the rate of downsinking of the geosyncline caused lateral shift of the main axis of deposition, thus introducing lithological variation in the sequence. Short periods of still-stand are marked by the presence of sandstone layers interbedded with finer, darker argillites desposited when erosion was reduced and plant growth was better established. Renewed uplift is marked by the thick sequence of coarse marine sandstones.

From time to time, and probably early in the history of the geosynclinal cycle, lavas were extruded on to the sea floor and these initiated the deposition of thick, banded cherts. During orogenies when there was shallowing of the trough subaerial outpourings of basalts and andesites took place and provided a source of rock chips in the grits and pebbles in the conglomerates.

Towards the end of the Mesozoic, uplift of the basin began, and was followed by the onset of compression from the west which continued intermittently up to Tertiary times. Beds were folded into steep isoclinal folds which ultimately became overturned. A second set of folds – the B-corrugations – arose in response to oblique shear, when flexural slip ceased after bedding-plane shear became inoperative because of the closely appressed nature of the major folds.

The newly raised greywacke land was eroded and later deposition took place in a shallow basin formed further towards west. Gradual rise in sea level occurred during the Upper Cretaceous along with uplifts and downsinkings of the land during which the Piripauan Mangakahia Group, the Opahai Group and finally, in Tertiary times, the Waitemata Group were laid down.

The continued compression from the west after uplift of the Opahi Group resulted in further deformation of the greywacke and shearing of the Mangakahia and Opahi Groups in late Cretaceous times. At this time serpentinites were intruded into the argillaceous limestones of the Opahi Group.

Downsinking of the land and contemporaneous erosion of the sediments of all three of the above groups, contributed to the sediments of the Waitemata Group. Soon after submergence set in, submarine and subaerial andesitic eruptions began and these continued intermittently until the close of Southland time.

In the Upper Miocene, uplift again took place and the strata of the Waitemata Group were eroded. The Miocene covering strata were uplifted on a series of greywacke fault blocks at the time of the late Pliocene Kaikoura Orogeny and this resulted in marked difference in trend between structures on Tawharanui Peninsula and Kawau Island. Following this the basalts of Ti Point were extruded and this outpouring was followed by the injection of basaltic sills, dykes and plugs.

Present topographic features are largely the result of oscillatory movements of the sea during subsequent glacial and interglacial periods of the Pleistocene when changes of sea-level were recorded by extensive terraces around the coast. However, Recent erosion has left clear traces of only two of these oscillations – that responsible for the 15-25 ft terrace and the Flandrian maximum.

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