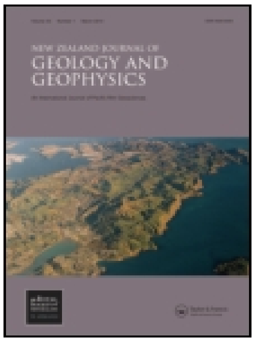

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G. G. C. Claridge

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MINERALOGY AND ORIGIN OF THE YELLOW-BROWN SANDS AND RELATED SOILS

By G. G. C. CLARIDGE, Soil Bureau, Department of Scientific and Industrial Research, Wellington.

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Summary

Soils formed from wind-blown sand are found throughout New Zealand. In order to study their genesis the mineralogy of a large number of these soils from the Manawatu, Waverley, Dargaville, Ruakaka, Ahipara and the Canterbury Plains has been examined.

The Manawatu and Waverley soils were similar in clay mineralogy, the clay minerals being micas, hydrous micas and vermiculite, with traces of halloysite. The pattern of clay content was consistent with the theory that most of the clay in these soils is derived from loess-like material blown in from the beaches after being eroded from older soils in the vicinity. A similar picture was found in a sequence from Dargaville, for the younger soils which were clearly wind-blown and had a clay mineral distribution very like the Manawatu soils. The older soils, however, appeared to be derived from water-deposited rather than wind-blown sand, and contained kaolin and gibbsite, but these also were derived from the sediment and not formed *in situ*. The Ruakaka soils were very similar to the youngest members of the Manawatu soils, except there was a little more kaolin because of the greater prevalence of kaolin in the soils of North Auckland. Although only one site was examined from Houhora in the far north, and so no sequence was possible, the one profile examined could be related to the Dargaville sequence.

The Canterbury Plains soils are derived from sands of river origin as well as marine sands, but the similarity between the soils showed that all these sands must have a common origin. The mineralogy differed from that of the North Island sites in that the dominant clay mineral was clay vermiculite but this was to be expected as this mineral is more prominent in the soils of the hill country from which debris and clay is carried by the rivers.

INTRODUCTION

Soils formed on wind-blown sand are found throughout New Zealand. Most of them are classified as yellow-brown sands by Taylor (1948) but there is considerable variation within the soils of this group. During the general survey of clay minerals in New Zealand (Fieldes, 1957), the yellow-brown sands were not dealt with because of their variability and their generally low clay content. However, as these soils make up 2% of the total area of the soils dealt with in the General Survey of the Soils of the North Island (*N.Z. Soil Bur. Bull.* 5, 1954), it was thought desirable to examine their mineralogy. It was expected that because of variations in parent material, and rapid leaching conditions caused by the excessive drainage characteristic of soils on sand dunes, that some interesting details of the formation of clay minerals would be found in the course of this study.

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SAND-DUNE AREAS

The areas studied in the North Island are shown in Fig. 1. The principal area of soils on wind-blown sand occurs in the Manawatu - West Wellington district, where an almost continuous belt of sand is present along the coast from Paekakariki to Wanganui. This sand varies considerably in composition, containing much more magnetite and ferromagnesians further north and gradually becoming the ironsands characteristic of Taranaki (Oliver, 1948). An important part of this sand country agriculturally is in the Horowhenua-Manawatu area, and this area was studied closely. Isolated patches of sand soils are found along the coast from Wanganui north. Only two of these areas were studied: a sequence on ironsand high in magnetite from Waverley; and a site from the Waikato heads also containing magnetite and other minerals. Large quantities of sand are also found along the western coast of the North Auckland peninsula, from the Manukau Heads north. The greatest extent of these sand dunes and soils is on the coast west of Dargaville and this was one of the areas studied in detail. Another area of sand is found on the east coast near Marsden Point, Whangarei Harbour, which has some points in common with the sand dunes west of Dargaville. A site near Waipapakauri in the far north was taken as representative of a large area of sand country along the North Auckland peninsula north of Kaitaia. In these areas the effect of climate was expected to be far more marked than in the southern areas.

An isolated area of sand near the mouth of the Waipaoa River in the Gisborne district was studied because of the nature of the parent sand. The rocks in the headwaters of this river are all bentonitic and this was expected to have an important bearing on the nature of the mineralogy of the sand. In the South Island, sand dunes are found on the Canterbury Plains on terraces above the river beds and along the coast. The only dunes studied were those around the Waimakariri River.

EXPERIMENTAL PROCEDURE

The air-dried soil samples were treated with hydrogen peroxide to remove organic matter and separated into sand, silt and clay fractions by dispersing in sodium hydroxide at pH 10 and centrifuging. In some cases, iron oxides were removed and determined by the method of Aguilera and Jackson (1953), prior to clay separation; in others, a separate determination of the extractable iron was made. In beach-sand samples where less than 0·1% of clay was expected, clay and silt were removed together and later separated. The sand fractions of some of the soils were sieved to obtain the particle size distribution within the sand fraction.

The clay fractions were examined using X-ray diffraction, differential thermal analysis and electron microscopy. The X-ray equipment used was a Norelco geiger spectrometer. The differential thermal analysis equipment used was that used by Fieldes (1957). Quantitative analysis for kaolin and gibbsite was carried out on this equipment by comparison with standard mixtures. Electron micrographs were obtained by the courtesy of the Director, Dominion Physical Laboratory.

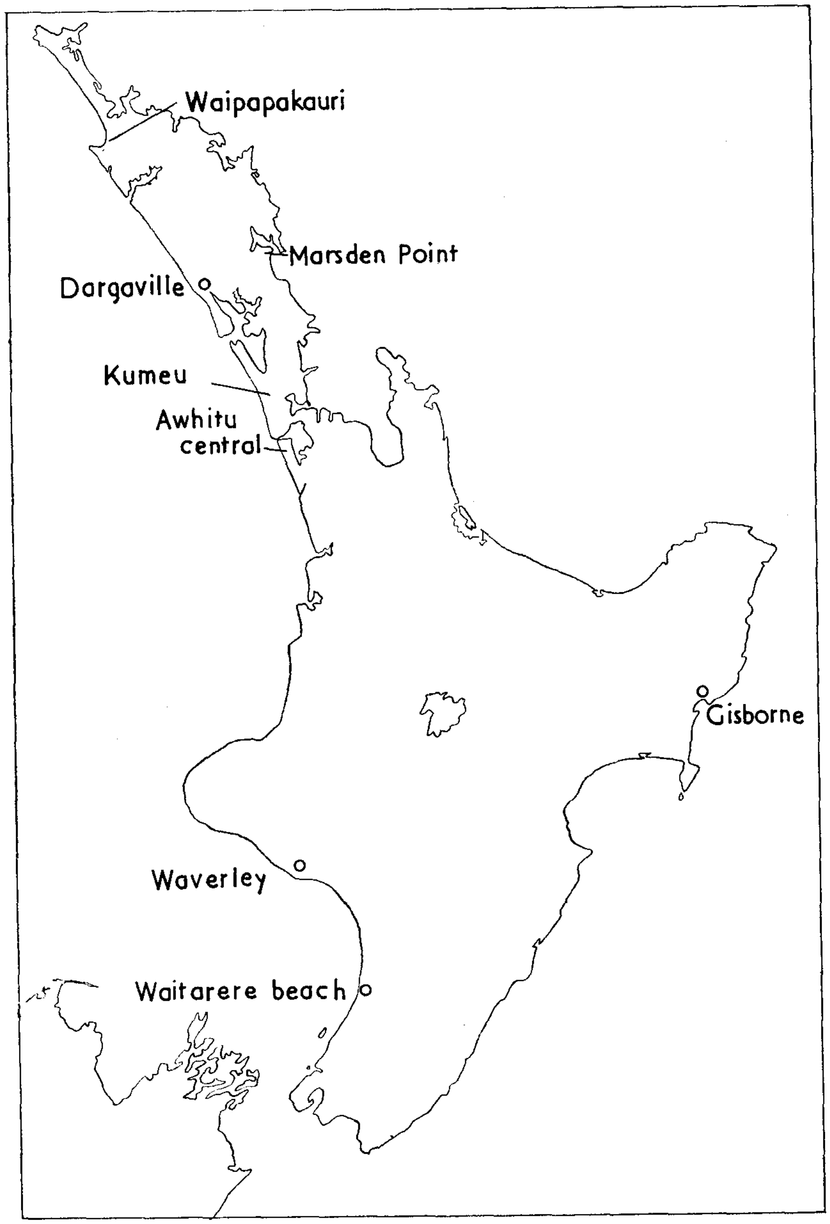

FIG. 1—Map showing sites sampled in the North Island.

The sand and silt fractions were examined by X-ray diffraction. Heavy minerals were separated from some of the sand fractions using bromoform as the heavy liquid and examined with a petrological microscope. Magnetite was separated magnetically.

Sand Soils from the Manawatu

In this region the sand-dune topography is very well developed, four distinct dune-building periods being represented, on which four sequences of soils showing increasing soil development may be recognised. In three of these dune-building periods a very characteristic pattern has been built up. The basic dune form consists of two long almost parallel ridges meeting at their eastern edge and enclosing a gently sloping sand plain. The water table lies well below the surface under the dunes and the higher eastern edge of the sand plains but emerges near the western edge, giving rise to swamps or even to lakes. This pattern has been discussed by Cowie (1957) who also described the soils formed in these drainage sequences. The relationship between the soils of this area can be shown diagrammatically as follows:

Waitarere sand		Hokio sand
Foxton dark grey sand	Himatangi sand	Pukepuke black sand
Foxton black sand	Awahou sandy loam	Carnarvon brown sandy loam
*Koputaroa sandy loam		
Increasing age downwards		Increasingly gleyed across

Waitarere sand is formed on the loose sand dune sands along the coast and represents the youngest soils of the sand country, while Hokio sand is the corresponding soil of the sand plains. Very little weathering of the mineral grains appears to have taken place as the sands are uniformly grey in colour except where they are stained with organic matter. The Waitarere sequence is formed on what is termed by Cowie (1958) the younger dune complex, which has been correlated by Te Punga (1954), with an increase in the amount of sandy debris in the rivers derived from the Taupo ash showers of about 1,700 years ago. The soils of this sequence must therefore be less than 1,700 years old and are thought by Cowie (pers. comm.) to have been stabilised only about fifty years ago.

The Foxton dark grey and Foxton black sequences are formed on an older dune complex which Te Punga places as not older than 3,000 years. The Foxton dark grey sequence is less weathered than the Foxton black sequence as the soils are looser and not so highly stained with iron from the weathering of ferromagnesian minerals in the sand.

Koputaroa sand is the oldest sand in the district derived from sand and is found on isolated remnants of dunes on terraces further inland than the rest of the sand soils. These soils are probably more than 3,000 years old.

Samples Analysed

The samples studied are listed in Table 1 together with the locality from which they are collected. All of the samples studied except Hokio sand came from the Horowhenua district. Samples were collected from Waita-

*Provisional soil name.

rere beach near Levin and from several sites inland from this to cover a range of age and drainage sequences. Hokio sand came from near the coast two and a half miles west of Oroua Downs. However, examination of this sample shows that it was mineralogically comparable with other samples and could be compared with them.

Results

The results of particle-size-distribution determinations are shown in Table 1. The two youngest soils investigated – Waitarere sand and Foxton dark grey sand – have similar particle-size distribution and have probably been derived from the same source of sand. Foxton dark grey sand shows a much larger proportion of coarser sand than the Foxton black sand, showing that the sand forming the former dune was coarser than that forming dunes of the Foxton sequences. However, there is very little sand coarser than 350 μ present in any sample.

The amount of clay in the topsoils of these soils, shown in Fig. 2, increases with increasing age of the soil, from 0·1% for raw beach sand to 20% for Koputaroa sandy loam. The clay content increases down the drainage sequence also, the wetter the soil the more clay it contains. In all these

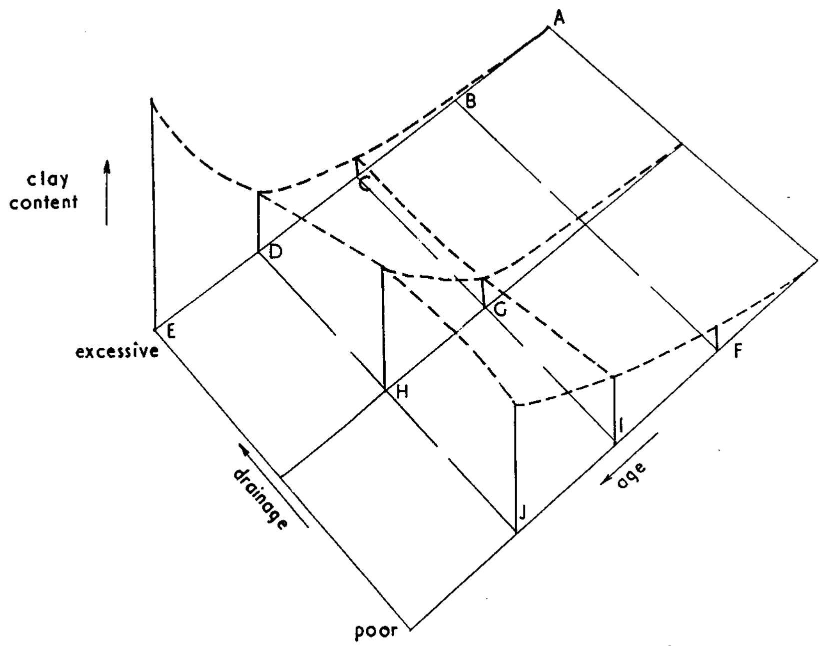

FIG. 2—Clay contents of Manawatu sand country soils.

TABLE 1—Sand Soils from the Manawatu

Sample No.	Depth, in.	Sand				Silt 20–2μ	Clay <2μ	Extr. Fe	Heavy Minerals in Sand Fraction	
		>350μ %	350–150μ %	150–76μ %	76–20μ %	%	%	%	Non-Mag. %	Mag. %
Beach sand, Waitarere beach, between low- and high-tide marks. N152, 717119										
6939 ..	–	(99·75)				0·16	0·09	–		
Waitarere sand, ½ mile south-east of Waitarere Beach. N152, 722113										
6812 ..	0–6	0·6	42·2	55·0	1·2	0·6	0·3	0·24	10·5	0·7
Hokio sand, 2½ miles W. of Oroua Downs. N148, 793339										
6192 ..	0–2	1·0	47·5	42·3	3·3	2·4	3·5	–	13·3	2·2
Foxton dark grey sand, ¾ mile east of Waitarere Beach. N152, 728116										
6813A	0–6	–	36·0	57·0	2·7	2·4	1·6	0·35	8·8	0·8
B	5–12	0·1	32·0	66·0	1·0	0·5	0·5	0·22		
Himatangi sand, 1 mile south-south-east of Waitarere Beach, N152, 735133										
7264A	0–6	(95·4)				2·1	1·9	0·58		
B	8–14	(98·8)				0·3	0·6	0·32		
C	14–20	(99·0)				0·3	0·4	0·34		
Pukepuke black sand, 1 mile east of Waitarere Beach, N152, 734131										
7265A	0–6	(88·0)				6·4	5·0	0·63		
B	8–14	(98·8)				0·4	0·3	0·47		
C	14–20	(99·0)				0·3	0·5	0·19		
Foxton black sand, 2¾ miles north-west of Koputaroa. N152, 813113										
6811A	0–6	–	12·5	59·5	9·5	14·0	4·0	0·53	13·5	1·5
B	14–30	–	23	71	2·4	3·3	1·0	0·33		
C	30–36	0·5	19·5	75·5	2·3	1·1	0·9	0·26		
Awahou sandy loam, Waitarere Beach road. ½ mile from junction with Levin-Wanganui main highway. N152, 775102										
6814A	0–6	0·1	17·2	44·5	14·0	11·8	11·7	0·65		
B	16–21	0·6	35·0	60·0	1·0	2·4	0·9	0·57		
Carnarvon brown sandy loam, Levin-Foxton Rd, ¼ mile S. of Poroutawhoa School. N152, 788111										
6815A	0·6	–	16·4	38·5	17·6	17·6	9·2	0·71		
B	9–15	12·5	16·6	42·0	13·3	5·8	8·0	1·78		
*Koputaroa sandy loam, ¾ mile N.N.W. of Poroutawhao. N152, 846094										
6810A	0·6	–	19·8	29·8	19·8	9·9	19·8	0·96	14·6	1·8
B	9–15	0·1	34·0	38·0	8·5	4·2	13·8	1·37		
C	25–33	0·2	25·4	29·8	13·9	11·9	17·9	1·16		

Figures in brackets refer to the whole sand fraction (>20μ). *Provisional soil name.

soils there is a concentration of clay in the topsoil. The clay content falls considerably not very far below the surface, except in Koputaroa sandy loam where the soil is relatively old, and in Carnarvon brown sandy loam where the lowest horizon sampled is just above the iron pan, through which it was not possible to dig. The extractable iron content of the soils is not high, showing that there has been little weathering, even in the oldest soils. Some of the iron weathered out has gone to stain the sands the characteristic brown colour of the older sand soils, and some has moved down in the drainage water and has been deposited in the subsoil of such soils as Carnarvon and Pukepuke, this being the probable source of iron for the prominent iron pan of the Carnarvon soil.

Microscopic examination of the sand showed that quartz and feldspar together made up about 90% of sand fraction. Mica was present in all sands except that from Koputaroa sandy loam, but in small quantity only. Heavy minerals were separated from some of the sands, and the magnetic fraction removed with a magnet. The magnetic fraction consisted of magnetite, while the non-magnetic fraction was mainly augite, with hornblende and hypersthene. The ferro-magnesians appeared to be quite fresh.

X-ray evidence shows that the dominant clay mineral in these soils is illite, together with partially expanded micas and vermiculites. Differential thermal analyses (Fig. 3) were difficult to interpret because of retained

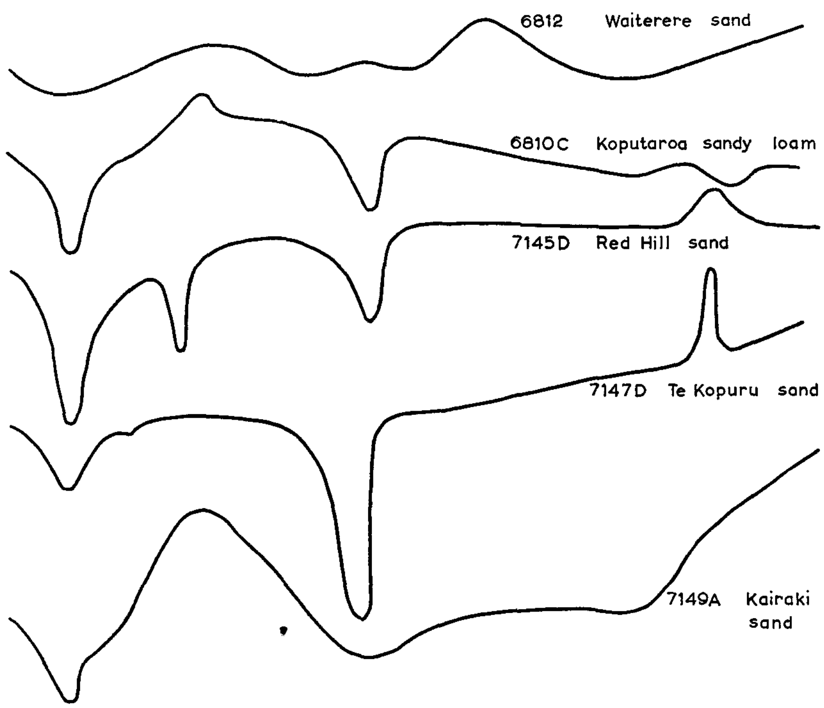

FIG. 3—Characteristic differential thermal analysis patterns of clays from some sand soils.

organic matter, especially in Foxton black sand. It seems characteristc of these soils that the humus is very resistant to peroxide treatment, and in this respect they are very similar to soils on pumice. X-ray patterns of the clays of some of these soils are shown in Fig. 4.

There is an increase in the amount of hydration of the mica, from the youngest to the oldest soil, showing that there is some weathering of the clay minerals themselves. In the soils of medium age (Foxton black sequence) which show retention of organic matter, there is probably some

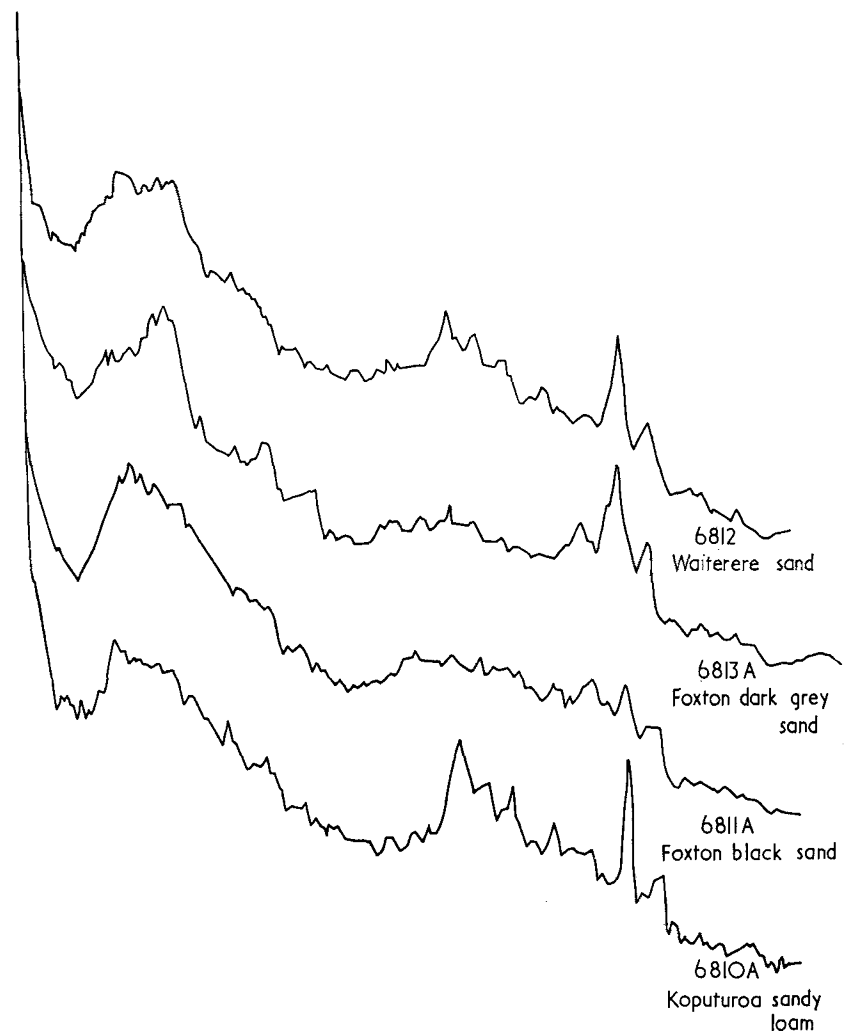

FIG. 4—X-ray diffraction patterns of clay fractions from some Manawatu sands.

clay size hydrated amorphous silica and alumina weathered from quartz or feldspar fragments which has combined with the organic matter in a fashion similar to the younger forms of allophane (Fieldes, 1955).

In the Koputaroa soils, halloysite was also present, the electron micrograph showing this to be in tubular form. Electron micrographs of clays of the other soils show that they contain silica fragments, mica and illite particles and thin vermiculite-like plates, and that clays of the older soils become progressively finer in particle size.

Thermal analysis of the iron concretions in the subsoil of Carnarvon brown sandy loam showed a peak of 230°C which could be attributed to amorphous iron oxides as well as peaks characteristic of micaceous clay minerals. X-ray examination of the iron pan showed only quartz and feldspar patterns, showing that the iron oxides were amorphous. Attempts to separate the clay from the iron pan failed because of the large amount of iron oxides present (at least 25%). These iron oxides cement together sand grains and clay, forming concretions and, in places, a hard pan.

Discussion

The clay mineralogy of the sand soils is somewhat similar to that of the soils in the surrounding district. The soils clearly form an age sequence, in the transition in the clays from coarse micaceous material to the rather finer and more hydrous micas of the Foxton black sand. Since Koputaroa sandy loam occurs only in isolated patches surrounded by soils known to have received contributions from andesitic ash, the presence of small amounts of halloysite may indicate contamination with, in this case, ash material.

There does not appear to be much change in the nature of the clay minerals along the drainage sequences despite the range in conditions from very excessively drained to very poorly drained, and despite the increase in clay content down the drainage sequence. It is therefore postulated that most of the clay content of these soils is derived from windblown dust picked up from the beaches. It was found that there is in sand below the high tide mark, a small amount of clay, which would be picked up and carried inland by the prevailing wind. Being lighter, it would be carried much further than sand, and would be deposited over older dunes that were no longer receiving contributions from blown sand. Thus, the older sand dunes would receive more of this fine material than younger dunes, and wetter areas would be expected to retain more of the fine material than the drier dune tops.

This fine material would consist largely of clay and silt derived from the surrounding soils by erosion and carried in suspension by sea water to be deposited on beaches. Its mineralogy would be similar to that of the surrounding soils, which in this vicinity are largely derived from greywacke or Tertiary alluvium. The clay minerals to be expected in these soils are largely micaceous, either illite or hydrous micas being the dominant mineral, together with halloysite in the soils from ash. The micaceous clay minerals are most likely to survive marine transport and would appear on the beaches, together with fine particle size quartz and feldspars formed by the grinding of sand grains. These would therefore become the main clay minerals of the younger sand soils. Alteration by weathering after deposition has resulted in an increase in the hydration of the clay minerals and formation of a little amorphous silica. It is possible that the weathering of fine feldspar grains has released alumina as well and that this has combined with silica to form halloysite, although a more likely explanation seems to be that there has been contamination by andesitic ash in these soils.

The silt fractions are also wind carried, in the same manner as the clay fraction but silt fractions usually show the same mineralogical features as the sand fractions; this was observed in these soils also. The amount of silt increases with age of the soil in the same manner as the amount of clay and for the same reasons.

It could be argued that most of this evidence can be interpreted solely by weathering in the soil as opposed to the postulated wind-blown origin for the clay. There is, for instance, an increase in the clay content in the topsoil with age of the soil which would naturally be interpreted as caused by greater weathering, but if this were so, a breakdown in some of the sand grains should be apparent, which is not shown by examination of the sand fraction. The grains are all fresh and unweathered and only show smoothing due to an abrasion during transport. Koputaroa sandy loam shows an increase in the proportion of coarser sand which could be interpreted as caused by the weathering of the finer particles to form clay. However, since the Koputaroa dunes are all old and are only the residuals of dunes, there has been ample time for the sand to pick up large quantities of fine material; the increase in the amount of coarse material is more likely to be caused by a difference in composition of the original sand forming the dune.

However, the conclusion that a large proportion, if not all, of the clay is of wind-blown origin was confirmed by the study of sand dune soils in other parts of the country, although the dune form was nowhere else as highly developed so that complete age and drainage sequences could not be found.

Sand Soils from Waverley

Three samples of sand and soil from iron sands near Waverley were studied. The iron sand extends from the Manukau Heads to the Wanganui River so that the Waverley dunes are representative of the sands of the southern part of this area. The dunes do not form as regular a dune pattern as that shown by the Manawatu dunes, and samples were taken only from dune soils and not from sand plains.

The dunes from two series – a younger and an older – which were sampled, together with a beach sand. The samples taken and the results of the analyses are shown in Table 2.

The sands are of markedly different composition. Mineralogical examination of the sand shows a very high proportion of magnetite and other heavy minerals: augite, hypersthene and hornblende. Although these minerals are also present in the Manawatu sands, they are present in larger amounts and different proportions. In the Waverley sand, magnetite and ferromagnesians make up most of the sand fraction, while there is a much higher proportion of magnetite than ferromagnesians.

TABLE 2—Sand Soils from Waverley

Sample No.	Depth, in.	Sand				Silt 20–2μ %	Clay <2μ %	Extr. Fe %	Heavy Minerals in Sand Fraction	
		>350μ %	350–150μ %	150–76μ %	76–20μ %				Non-Mag. %	Mag. %
Beach sand, Waverley Beach, N137, 186985										
7235 ..	0–3	(92·3)				4·2	2·6	0·83		
Waverley sand, Waverley Beach, Cliff dune. N137, 187986										
7234A	0–6	2·3	54·1	37·6	1·9	1·4	1·4	1·35	29	46
B	14–20	2·9	60·5	34·3	0·5	0·3	0·6	0·84	36	47
Patea sand, Wairoa Rd, Waverley. N137, 176015										
7236A	0–6	13·8	56·0	17·1	5·4	4·2	2·6	0·83	61	24
B	10–14	13·1	56·5	22·4	2·1	2·5	2·2	0·76	53	31
C	16–24	38·4	55·0	6·0	0·4	0·2	0·3	0·30	68	22

Despite the high proportion of ferromagnesians rich in bases, the clay minerals are still rather poorly ordered micas, with a little kaolin or halloysite showing in differential thermal analysis. Retention of organic matter and increase in hydration is present, but not to such a great extent as in the Manawatu sands.

These results confirm the general theory that the greater part of the clay is derived from nearby sediments. The micaceous minerals would originate in soils from Tertiary mudstones forming the headwaters of most of the rivers of the district, while the halloysite is derived from the yellow-brown loams from andesitic ash on the coastal plains. There is a little amorphous mineral-organic complex derived from weathering of the fine particle size quartz and feldspars. The high proportion of basic minerals has not had any great effect on the nature of the clay minerals.

Sand Soils from Dargaville

A large belt of sand dunes extends from Anawhata, just north of the Manukau Harbour, to north of the Kaipara harbour and in patches to the Ninety-mile Beach. The region studied in detail lies west of Dargaville, but the soil and sand pattern is typical of most of the area. The main soils of this region are:

(1) Pinaki sand – a very young soil formed on very recent sand dunes;
(2) The Red Hill soils – sands formed on older sand dunes, but the dune pattern still shows:
(3) Tangitiki and Te Kopuru soils – soils formed on slightly consolidated sandstones of late Pliocene or early Pleistocene age.

These soils can be correlated with the geology of the region. According to Brothers (1954), the region between the South Kaipara head and the Waitakere ranges consists of a thick deposit of horizontally bedded and massive sandstones, pumice silts and muds with interbedded dune sands and lignites. The whole formation (Kaihu formation) is considered to be of late Pliocene or early Pleistocene age and is known from south of the Manukau harbour to the Ninety-mile Beach.

Near the coast low terraces cut in this formation have been covered with wind-blown sand and still have the irregular sand-dune topography. Brothers terms this the South Head formation and gives it a mid-Pleistocene age correlating it with a lowering of sea-level during the penultimate glaciation. Recently, sand has started to blow inland again and a coastal strip of shifting sand is at present being formed.

Pinaki soils are found on the youngest dunes and have all the characteristics of young yellow-brown sands. The soil is very shallow – a few inches of humus stained sand, held together by a mat of roots with a small amount of clay, followed by brown unconsolidated sand.

The Red Hill sands lie inland from the Pinaki sands and, although showing irregular dune topography, the dunes are more subdued than the Pinaki dunes and obviously much older. The Red Hill soils are mapped as being formed on the South Head formation of Brothers, near Kaipara South Head and are formed on similar formations in other places. A typical Red Hill profile consists of several inches of dark brown sand with a sharp boundary to a brown sandy clay loam, which gradually becomes more compact and grades to a red sandy clay, sometimes containing white nodules, on slightly consolidated sands.

Poorly drained hollows are found amongst Red Hill sands, as in most dune areas, and peats and peaty sands are found in these hollows. One profile on the edge of a peaty hollow consists of about 7 in. of greyish brown sandy topsoil on 6 in. of white weakly consolidated sand (the A_2 layer of a ground water podzol), below which is about 8 in. of dark brown sand on a weakly cemented pan about 3 in. thick.

Inland from the Red Hill sands, the underlying Kaihu formation comes to the surface. This is rather variable, consisting mainly of water deposited sands with old dune sands, lignites, pumice, etc., interbedded, and probably has rather a mixed history. There are two soils formed in this area: Tangitiki, a strongly leached sandy yellow-brown earth; and Te Kopuru, a sandy podzol. These grade into each other, although in general the Tangitiki soils are found on the slopes and Te Kopuru on the ridge tops and plateaux. The Te Kopuru podzol is one of the more spectacular podzols of North Auckland. A typical profile consists of 8–10 in. of dark grey sand on a greyish white silica sand pan about 10 in. thick, which is strongly indurated and massive. Below this is an indurated humus and iron pan about 8–9 in. thick and reddish brown to black in colour, on pale brownish yellow sandy clay, grading into looser sands below. The Tangitiki soil, on the other hand, consists of several inches of dark grey sand on yellowish brown to brown sand and sandy clay grading down into slightly consolidated sands similar to those below the Te Kopuru profile. The difference between these two soils is related to the vegetation pattern as well as to slope.

Relationship of Sands in the Dargaville Area

Soil type		Geological formation
Beach Sand Sand		} recent dunes
Pinaki Sand		
Red Hill Sands		South Head Formation
Te Kopuru Sands	Tangitiki Sands	Kaihu formation

Samples

Samples were collected from all these soils as well as one from a recent sand drift as shown in Table 3. The Tangitiki and Te Kopuru profiles were later resampled – Te Kopuru profile being found close to the original Tangitiki site, and a Tangitiki close to the original Te Kopuru site. These samples were analysed, using the usual methods and the results are also quoted in Table 3.

The particle-size distribution figures show that the younger sands are slightly coarser in texture than the Manawatu sands, but there is a rapid increase in the amount of clay in the older sands.

There is little difference in clay mineralogy between the beach sand, and Pinaki sand, although there are differences in the amount of fine sand and heavy minerals. The clay fractions of these soils contained quartz, feldspars and partially hydrated micas, i.e. the glycerol treated samples gave a number of peaks between 10 and 14 Å. Pinaki sand also contained a little kaolin.

The Red Hill sand is considerably older, as is shown by the clay content and extractable iron figures. This profile shows evidence either of clay shift or of a break in the profile at about 10 in. Other evidence for this break is that although no gibbsite was found in the upper parts of the profile, in a cutting not far from the profile site, gibbsite nodules were found at a depth of from four to five feet.

The clay fraction of the Red Hill profile was similar to Pinaki sand in composition, but the lowest horizon contained considerable gibbsite, which agrees with the presence of discrete gibbsite nodules at this level.

The Tangitiki profile is clearly similar to the Red Hill in clay content and particle size distribution, and appears to have undergone a similar type of weathering. The micas are now fully expanded to 14Å in the upper part of the profile, and there is considerable kaolin present – up to 75% of the total clay fraction in the lowest part of the profile. There is also some gibbsite present up to 20% in one horizon.

The Te Kopuru profile shows all the features of a podzol: clay shift down the profile, iron movement and a cemented silica sand pan. The minerals of the clay fraction of the bleached layer are quartz, feldspar and micaceous minerals, without any kaolin; below the pan, large amounts of kaolin are present. No trace of gibbsite was observed in this profile. In Fig. 5 the X-ray diffraction patterns of the horizons of this profile are shown.

In order to determine whether the absence of gibbsite was caused by the podzolising process, further sites were sampled. As the Tangitiki and Te Kopuru soils form a complex, it was possible to find a Tangitiki soil within half a mile of the Te Kopuru profile originally sampled, and a Te Kopuru

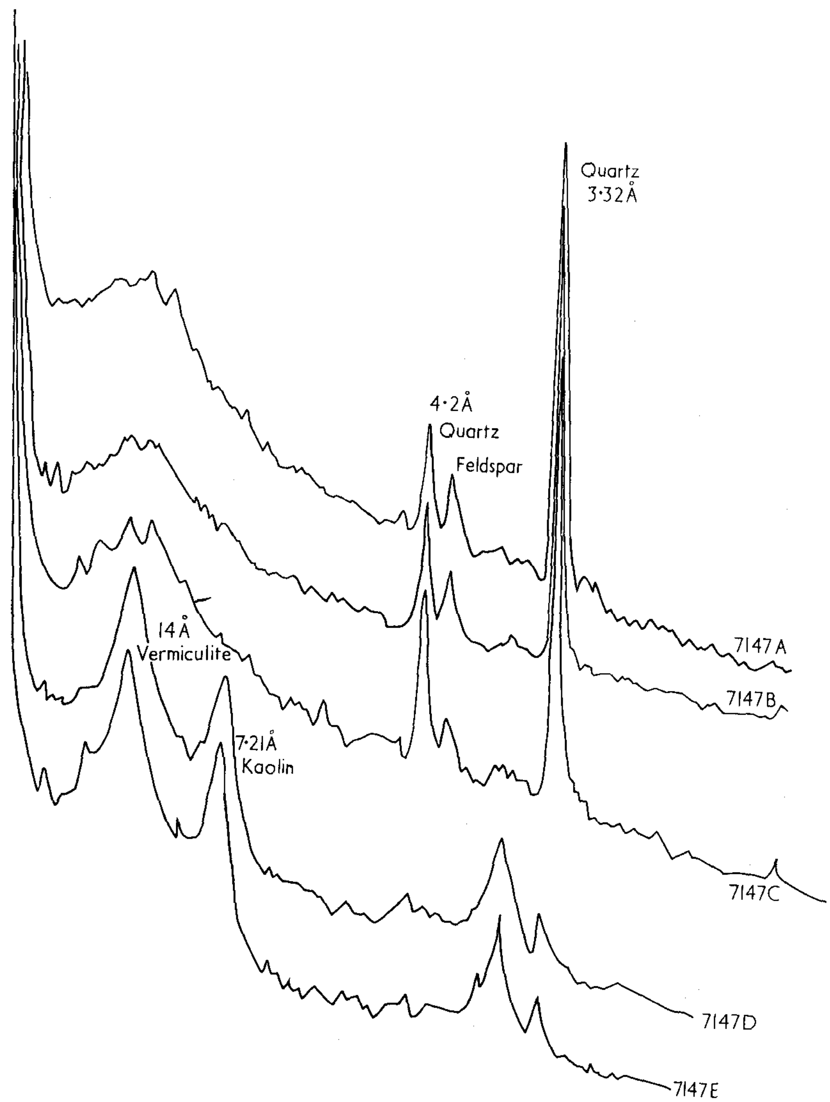

FIG. 5—X-ray diffraction patterns of clay fractions from Te Kopuru sand.

close to the Tangitiki profile originally sampled. Analysis showed that the second Tangitiki profile contained kaolin but very little gibbsite, whereas the second Te Kopuru profile contained gibbsite in the lower horizons. From these analyses it appears that gibbsite is present in some of the beds of the Kaihu sandstone and not in others, but is not forming in the soil at present.

TABLE 3—Sand Soils from Dargaville

Sample No.	Depth, in.	Sand > 350 µ %	Sand 350–150 µ %	Sand 150–76 µ %	Sand 76–20 µ %	Silt 20–2 µ %	Clay < 2 µ %	Extr. Fe %	Heavy Minerals in Sand Fraction Non-Mag. %	Heavy Minerals in Sand Fraction Mag. %	Clay Fraction Kl %	Clay Fraction Gb %
Beach sand, Hardings Rd, Mahuta. N23, 333613												
7143 ..	0–36	0·23	71·1	26·9	0·4	0·2	0·9	0·23	2·5	0·02		
Pinaki sand, Rehutai Rd, Dargaville. N23, 302650												
7144A ..	0–5	–	53·2	40·3	4·1	1·3	0·7	0·40	13·5	0·5		
C ..	10–20	0·1	52·8	44·8	1·0	0·4	0·6	0·25				
Red Hill sand, Baylys Coast Rd, Dargaville. N23, 288684												
7145A ..	0–5	1·7	26·6	33·2	12·8	14·1	10·4	1·26	4·1	0·3		
B ..	5–10		(64·4)			15·4	15·8	4·36				
C ..	10–20		(71·4)			3·3	21·7	3·75				
D ..	20–36	3·3	48·3	15·9	2·4	4·9	24·3	0·93				
E ..	42+	10·8	62·2	19·7	1·0	2·1	3·2	0·95	7·6	0·4		
Peaty Hollow in Red Hill sand, ½ mile N. of 7145												
PC250 ..	6–12		(78·7)			17·5	3·7	0·10				
PC251 ..	12–24		(83·2)			8·9	6·9	0·96				
Tangitiki sand, Hardings Rd, Mahuta. N23, 386673												
7146A ..	0–5	75	51·9	15·1	5·7	10·9	6·0	2·84	0·7	–	7	2
B ..	6–12		(71·6)			9·7	14·0	4·60				
C ..	14–26	4·8	39·7	13·9	6·3	10·0	22·6	1·60			12	20
D ..	34–44		(71·2)			8·5	19·7	0·60				
E ..	96+	4·2	37·6	26·3	14·0	8·2	9·7	0·09	0·1	–	75	1

Tangitiki sand, Hokianga Rd, 1 mile N. of 7147												
PC256 ..	18–21			(69·5)		9·7	19·6	1·16				
PC257 ..	24–31			(57·5)		7·8	34·0	0·72			50	2
PC258 ..	60+			(66·0)		13·8	19·8	0·42			60	–
Te Kopuru sand, Hokianga Rd, Dargaville. N23, 377715												
7147A ..	0–8	–	12·3	48·2	24·2	12·9	1·6	0·82	0·1	–	–	
B ..	8–18	–	16·1	46·6	19·4	17·8	0·1	0·01			–	
C ..	18–27	–	18–7	45·6	17·6	13·9	4·2	0·01			–	
D ..	27–37	–	7·0	17·7	6·6	9·6	58·2	0·82			56	
E ..	37–65	2·0	4·9	13·5	6·3	8·6	62·1	2·60			77	
F ..	60+	–	20·5	40·2	4·5	8·2	25·8	0·78	0·1	–	60	
Te Kopuru sand, Hardings Rd, Mahuta, ½ mile W. of 7146												
PC252 ..	7–12			(76·2)		13·6	10·0	0·17			56	
PC253 ..	24–36										90	
PC254 ..	60+			(67·8)		8·8	21·1	2·25			30	14

That considerable mineral weathering has taken place is borne out by mineralogical examination of the sand fractions. In the beach sand and Pinaki sand, the mineral grains are rounded and show no signs of decomposition. The heavy minerals are mainly augite and hornblendes, with some magnetite. The surface horizon of Red Hill is similar in appearance to Pinaki, but contains less heavy minerals. In the lower horizon, the augites show marked signs of decomposition and this could be taken as evidence of a break in the sequence with a greater degree of weathering at depth.

The Tangitiki and Te Kopuru soils contain only a very small proportion of heavy minerals, probably caused by the disappearance of much of the less stable ferromagnesians during the sand's history, and, as a consequence of this, more zircons and apatites are visible. Ferromagnesians show signs of marked decomposition in the Tangitiki profile, and are rare in the Te Kopuru profile. The light fraction of the sands was made up of quartz and feldspars.

Origin of soils

The youngest soil, Pinaki, is obviously of aeolian origin and the clay minerals are consistent with the theory that these are mainly derived from loess-like material. The presence of kaolin in these clays is not unexpected as kaolin is a common constituent of many of the soils of North Auckland, and would be expected to be amongst those minerals carried in suspension in sea water. The Red Hill sand appears to be derived from sand of similar origin to the other soils as shown by its particle size distribution, but it has been subject to considerable weathering in the past, as shown by the presence of gibbsite in the lowest horizon and the presence of nodules. The gibbsite may, however, have been present in the original sand. It is possible that this profile is a two-story one, with the lower portion being weathered since the mid-Pleistocene, when according to Brothers (1954) these sands were deposited. They were then covered by a later but still old mantle of sand which has not weathered so much; and the clay mineral content is in large part derived from wind-blown material.

The Tangitiki and Te Kopuru soils are formed not on true windblown sands but on loosely consolidated sandstones, probably of estuarine origin, although there are some blown sands included in the sequence. These sands have been subjected to considerable weathering as shown by the decomposition of the sand grains and the formation of large amounts of kaolin in the soil. Because of the permeable nature of the sands and the relatively small amount of clay minerals contained in them, the effect of the podzolisation process is very marked. The Tangitiki soils were formed under a mildly podzolising podocarp forest but where the vegetation changed to the very strongly podzolising kauri forest, the strongly podzolised Te Kopuru soils are found. These soils grade into each other and form an intricate pattern related to the vegetation pattern. Tangitiki soils show some shift in clay and iron oxides showing that these soils are weakly podzolised although quite strongly weathered.

It is difficult to determine whether kaolin is forming in the present day soils or whether it is derived from the parent material. The proportion of kaolin in the clay fraction increases with depth in these soils and if it were forming in the soil it would be expected to be larger in amount in the upper horizons where weathering is greater. The distribution of gibbsite has been shown to be a parent material effect in the Tangitiki and Te Kopuru soils and gibbsite is not forming to any extent under the present environment.

Sand Soils from Marsden Point

South of Whangarei harbour, extending from Marsden Point to Ruakaka, are a set of recent sand dunes with a sequence of two soils. The youngest soil is Marsden sand, a very young soil on recent sand dunes, with peaty sands and peats in the hollows (Marsden complex (peaty sand)). Further inland is an older set of dunes, over slightly consolidated sandstone, which resembles those on the west coast. The soils on these sands are named Red Hill sands on analogy with the west coast sands of the same name. In addition, there is a small area of soil at One Tree Point, a few miles to the west of Marsden Point, formed on a peaty sandstone. This profile consists of a black peaty sand on a consolidated, humus-stained massive sandstone. (One Tree Point peaty sand.)

Samples

Samples of these soils (as well as from a beach sand) were collected from the sites quoted in Table 4 and analysed. The results of these analyses are also quoted in the table.

Results

The clay content increases from 0·1% for the beach sand to 4% for the Red Hill sand. The lower clay content of the top six inches of the Red Hill sand is probably the result of a recent accumulation of sand and the 6–12 in. horizon is probably a better approximation to the topsoil of this profile. There is considerable clay accumulation in the topsoil of the peaty phase of Marsden sand as would be expected if the wetter areas were trapping more clay blown across by the wind.

The extractable iron figures are normal, low in Marsden sand but higher in the horizons of Red Hill sand containing more clay. Very little iron is found in the peaty phase of Marsden sand, probably because of the lack of oxidising conditions to cause weathered iron oxides to be deposited as ferric oxides.

The sand size fractions vary somewhat in composition, ranging from two to twenty per cent of heavy minerals, but the mineralogy of each density fraction is similar. The light fraction consists of quartz and feldspar, and the heavy fractions of augites, decomposing and full of dark inclusions, but well rounded and of opaque minerals not identified. There is only a trace of magnetic material, even in the samples with a high heavy mineral content. The reason for the high content of ferromagnesians in the Marsden sand is not known.

The dominant clay mineral is micaceous in nature, either a hydrous or partially expanded mica, or else a completely expanded vermiculite. A little kaolin is present, as well as clay size quartz and feldspar. The sands of this area appear to follow the same pattern as those of the Manawatu sand country. Two groups of soils can be distinguished and the clay mineralogy of these soils and the beach sand associated with them are all similar. Once again, the clays are derived largely from loess-like material blown in from the sea and with very small contributions from mineral weathering. The decomposition of the ferro-magnesians has in this case probably taken place during the breakdown of the rock to form sand, the absence of magnetite showing that the sands have a different origin from the west coast sands.

One Tree Point Peaty Sand

The profile of One Tree Point peaty sand, which covers a small area of the west of Marsden Point, was studied. Where examined the soil profile consists of about 6 in. of loose peaty sand on a black to dark red cemented massive sandstone which is supposed to be the B horizon of a very old ground water podzol. In places the A_1 horizon has long since eroded off and has supplied the debris to form the Marsden dunes, and the soil is formed on the cemented B horizon (N. H. Taylor, pers. comm.). The clay content is comparatively high in the profile but the extractable iron content is low. Sand minerals are very similar to those of the Marsden sands, except that there is perhaps a little more magnetite. The clay minerals are similar to the other soils except for a trace of cristobalite.

Although these sands are similar to the Marsden sands, they have had a more complicated history. The actual soil is formed by loosening of the surface of the consolidated sandstone and some blowing about of the sand. The consolidated sandstone already contains clay, which like that in the Te Kopuru profile, is mainly poorly oriented micas, but during the process of soil formation the micas have recrystallised sufficiently to enable their identification as hydrous micas.

Other Sand Soils of the Auckland Province

Samples were available from other areas containing sand soils, and were also studied although only one site was sampled in each case.

Houhora Sand

Houhora sand forms a long coastal strip inland from the Ninety-mile Beach. It is formed on deep weathered sands or sandstones, slightly consolidated. It is probable that these sands are of the same age and nature as those of the South Head formation referred to above. One profile was sampled from near Waipapakauri; samples were collected down to eight feet to characterise the profile, and the results are listed in Table 4.

The proportion of heavy minerals in the sand is very low. Only a trace of magnetite was present. The heavy minerals present are mainly augite with some hornblende.

The clay minerals present are vermiculite, gibbsite and kaolin. There is only a small amount of kaolin present, about five per cent, and about twenty per cent of gibbsite, the rest being vermiculite and clay size quartz and feldspar. There seems to be little differentiation throughout the profile, but the deepest sample (7240G) which was collected a short distance from the other samples in a road cutting, is very different. This contains about 60% kaolin and an unexpanded mica, instead of 14Å vermiculite found in the other samples of the profile.

TABLE 4—Sand Soils from Marsden Point, and Other Areas in the Auckland Province

Sample No.	Depth, in.	Sand >20μ %	Silt 20–2μ %	Clay <2μ %	Extr. Fe %	Heavy Minerals in Sand Fraction	
						Non-Mag. %	Mag. %
Beach sand, Marsden Point. N24, 010835							
7276	0–18	99·5	6·2	0·1	–	2	–
Marsden sand, 2 miles south of Marsden Point. N24, 975798							
7277A	0–3	97·6	1·0	0·8	0·43	22	tr.
B	6–14	99·0	0·4	0·3	0·35		
Peaty phase of Marsden sand, near 7277. N24, 975798							
7278A	1–6	76·2	18·2	5·6	0·05	13·1	tr.
B	10–20	99·2	0·3	0·5	0·03		
Red Hill sand, Takahiwai Rd, Marsden Point. N24, 972813							
7279A	1–3	96·2	1·7	1·5	0·56	3·5	–
B	9–14	93·2	1·1	4·0	1·68		
C	48–75	99·5	0·3	0·2	0·07	7·9	tr.
One Tree Point peaty sand, One Tree Point. N24, 967857							
7275A	0–6	81·4	16·0	2·4	0·14	7·7	–
B	7–12	86·2	7·8	5·8	0·10		
C	36–42	96·3	1·6	2·1	0·01	3·7	tr.
Houhora sand, Waipapakauri – Ninety-mile Beach Rd. N9, 714799							
7240A	0–3	83·0	8·2	7·3	1·46	1·8	–
B	3–6	82·4	11·4	4·3	2·08		
C	7–11	82·4	8·4	8·3	1·30	0·7	tr.
D	11–20	80·8	8·0	9·8	1·37		
E	20–31	84·9	8·0	5·4	1·73		
F	40–46	87·2	6·3	5·2	1·38	0·5	–
G	180	90·8	3·6	4·7	0·91	0·5	–
Red Hill clay loam, Awhitu Central, Franklin County							
1240A	0–4	43	8·5	43	5·75	20	13·0
B	6–12	34·0	6·5	52·7	7·35		
Red Hill sandy clay, Kumeu							
800	0–5	50	28·5	20	1·50	2·4	
801	9–13	56	10·5	31	2·6		

The extractable iron content is fairly high for a sand, showing that some weathering of the mineral grains has taken place. The uniformity in texture of this profile appears to indicate that very little mineral weathering and clay formation has gone on since the sands were laid down as the upper horizons would be more weathered than the lower if much weathering of the soil had taken place on the site. The clay content is therefore probably derived from a previous cycle of weathering before the sands were deposited. This would also offer an explanation for the difference in mineralogy between sample 7240G and the rest of the profile.

Other Red Hill Soils

Samples were available from two sites on the west coast, and these were examined, the results being shown in Table 4. Red Hill clay loam from Awhitu Central, near the Manukau South Head, is on a sand high in magnetite and other heavy minerals as would be expected from a site in this region. This site is near the northern end of the iron sand range. Halloysite is found amongst the clay minerals, but this could have been derived from a topdressing of ash, as the soils further inland are derived from Hamilton ash. The other clay minerals are illite and quartz.

Red Hill sandy clay from Kumeu is similar to the Red Hill soils further north around Dargaville which were discussed above, except that there is a large amount of halloysite visible in the electron micrograph of this sample, which was not seen in the samples from near Dargaville. It would appear from this that the sand from which this soil is derived has had a considerable contribution from ash. A few shards of glass were observed in the sand fractions which would confirm this hypothesis.

Sand Soils from Gisborne

In order to check the hypothesis that most of the clay in a young sand soil is derived from wind-blown dust and not from weathering taking place in the soil, two profiles of Opoutama sand from Gisborne were examined. The principal source of debris for the beaches is the Waipaoa River, and the alluvium carried by this river contains large amounts of montmorillonite (Claridge, 1960). It would therefore be expected that montmorillonite would be found in these soils. In the four samples studied, the clay minerals found were montmorillonite and micaceous minerals of varying degrees of hydration. This is what would be expected from a knowledge of the clay mineralogy of the sediments, except that more montmorillonite would be expected.

The sand itself contains about 5% of heavy minerals, such as augite and hornblende, some very slightly decomposed, and about 1% of magnetite. The rest of the sand consists of quartz and feldspars, with opaque aggregates that could be broken under pressure, and probably consisting of harder fragments of the argillites that make up much of the hill country. The heavy minerals and some of the quartz and feldspars are probably derived from the mantle of rhyolite ash that covers this district.

Sand Soils from the Canterbury Plains

On terraces bordering the rivers of Canterbury and along the coast are sand dunes, the sand bordering the rivers being blown out of the wide river beds by the prevailing north-west winds. On the plains there are a series of terraces which have been related to stages in the glacial era (W. T. Ward, pers. comm.), and the dunes found on the edges of these terraces must be younger than the terrace itself. Three sets of terraces are known, and the soils on the two youngest of these were sampled. These were Paparua loamy sand, on the intermediate terrace, correlated by Suggate (1958) with the Blackwater glaciation of Gage (1958), and Waimakariri sand, on the youngest terrace which has been dated by Suggate (1958) as 5,000 years old. An older soil, Lismore sandy loam, dune soil, was not sampled because of possible loess contamination.

There are also coastal dunes, and soils from two sets of these were also investigated. These were Waikuku sand of about the same age as Waimakariri sand, and Kairaki sand, a more recent sand. These sands, although coastal, are derived from debris carried to the coast by the rivers and hence should be very similar to the river sands.

Results of Analysis

The results of mechanical analysis of these soils are quoted in Table 5. These figures show a sharp variation in clay content, the lower horizon of all profiles containing about 1% of clay, and the upper horizons containing up to 10%. This probably represents contamination with loess, to a greater or lesser degree. The extractable iron content is low, indicating that little weathering of the primary minerals is going on.

The heavy mineral content of these sands is low, about 1%, and very different from the assemblage found in the North Island sands. These sands are derived mainly from greywacke alluvium and contain very few augites or hornblendes but mostly epidotes, with apatite and zircon.

TABLE 5—Sand Soils from near Christchurch

Sample No.	Depth, in.	Sand				Silt 20–2μ	Clay <2μ	Extr. Fe	Heavy Minerals in Sand Fraction	
		>350μ %	350–150μ %	150–76μ %	76–20μ %	%	%	%	Non-Mag. %	Mag. %
Kairaki sand, Waikuku Beach. S76, 068850										
7149A	0–2	–	40·8	38·4	1·9	10·5	8·1	0·28	2·4	–
B	4–9	–	44·9	52·1	1·1	0·5	1·2	0·19		
Waikuku sand, near Kaiapoi. S76, 029772										
7148A	0–3	–	46·9	50·2	0·9	1·2	0·6	0·19	1·2	–
B	5–9	–	33·5	62·3	0·6	0·4	1·0	0·19		
Waimakariri sand, 2½ miles N.E. of West Melton										
7150A	0–4	–	21·7	32·1	30·2	9·7	5·8	0·46	1·2	–
B	16–22	0·2	33·6	54·1	9·4	1·1	1·4	0·25		
Paparua loamy sand, dune soil, ½ mile north of West Melton										
7151A	0–3	0·5	20·7	30·5	30·6	10·8	6·9	0·39	0·7	
B	9–12	1·9	26·1	26·1	25·1	11·3	7·5	0·48		
C	16–22	0·4	48·0	43·8	4·4	0·9	1·5	0·15	1·2	

The composition of the clay fraction is identical in all of the samples and consists of hydrated and partially hydrated micas and chlorite. Differential thermal analyses show a characteristic pattern of fusion at about 900° which has been identified as clay-vermiculite by Fieldes (1955), a common component of many South Island soils. This thermal effect was better developed in these samples than in any other South Island soil, and was not observed in any of the other sand soils studied. This marked difference in clay mineralogy is related to the origin of the fine clay size material which, in this case, is derived largely from finely crushed rock flour rather than from previously weathered soil material. This implies that the clays are of loessial origin, in common with most of the soils of Canterbury. It is obvious that from observations made during north-westerly conditions that a considerable quantity of wind-blown dust is being deposited on all the soils of the plains, and the clays of these soils would be derived from this source, rather than from weathering in the soil.

Although these soils are on terraces of considerable age, compared with the oldest of the Manawatu soils, they have not accumulated much clay size material, even though there is much fine material being blown over the soil, and they may mean that the soils are considerably younger than the surfaces on which they have accumulated.

CONCLUSIONS

The principal conclusion to be drawn from these results is that the greater part of the clay minerals of a sand soil are not formed in the soil but blown in. The existence of sand dunes means that there is a source of sand, usually a beach, kept supplied with sand by coastal drift or other means, while prevailing winds blow the sand inland. Any fine material carried in suspension by the sea would also be blown inland once it had dried out, as this would be carried further than the sand it would be deposited in a loess-like fashion over older sand dunes and other soils. This clay would be derived from material eroded from the surrounding country and carried down to the sea in rivers and streams, and therefore would contain the same clay minerals as the soils of the region, modified by alteration during transport in the streams and in the marine environment. As the greater part of New Zealand soils contain micaceous clay minerals, these are the minerals found in the clay fractions of sand soils. The sand grains themselves would be ground up, producing clay size quartz and feldspar particles, which are common, if not universal, minerals of the clay fractions of sand soils. Where there are other clay minerals locally present, e.g., halloysite in Taranaki and Waikato soils, kaolin and gibbsite in North Auckland and montmorillonite in the Gisborne region, these minerals are represented in the sand soils as well.

This is borne out by the variations in clay content shown in the soils of the Manawatu sand country, but also recognisable in other areas. The older the soil the longer it has to collect a topdressing of fine material.

Similarly, the more moist a soil is, the more of this clay it will be able to retain. This effect may also be related to the better growth of vegetation in moist sites.

Weathering of the clay in the soil is negligible in South Island sand soils, and there are no obvious differences in the mineralogy along the age sequences. The sequence from the Manawatu sand country shows some differences caused by weathering of the clay minerals. In the younger soils these appear to be amorphous material combining with the organic matter derived from solution of the fine quartz and feldspar particles. The clay minerals themselves show increasing hydration with age. A little tubular halloysite is found in the oldest soil of the sequence, but this could be caused by the presence of a little ash in this soil.

Even in the soils of North Auckland micaceous minerals are present, but other minerals, halloysite, kaolin and gibbsite, are present, and sometimes even dominant. However, the picture is complicated by the fact that the older sands where examined are not wind-blown but water deposited. At first sight it would appear that the presence of kaolin and gibbsite is related to the age and weathering of the soils, but as the distribution of gibbsite shows, these minerals are already present in the parent sandstones, and their ultimate origin cannot be determined. They are also present in the clay mineral assembly in younger soils, but in these cases they are derived from erosion of the older sands which outcrop on the coast.

The mineral-organic matter complex was not observed in the North Auckland soils, probably because such soils as Pinaki and Marsden are too young to develop any large amounts of organic matter, and older true wind-blown soils are rare.

THE POSITION OF THE SAND SOILS IN THE GENETIC CLASSIFICATION

Soils derived from coastal sand drifts are termed yellow-brown sands in the New Zealand Genetic Classification of Soils (Taylor, 1948; Taylor and Cox, 1956). They are in the intra-zonal group because of their youth; the soil has not had time to develop the characteristics of the zonal soils that would form under similar conditions of climate and vegetation. This means that in time, zonal soils will form on such sands, and this is observed in the most weathered of the soils discussed in this paper.

The clay mineralogy of yellow-brown sands, therefore, should be characteristic of an earlier stage of weathering than found in zonal soils of the same district. As has been shown in this paper the clays of the younger sand soils are not derived to any large extent from weathering *in situ* but are transported, with their ultimate origin mainly in zonal soils of surrounding areas. Hence the clay minerals are in general in harmony with their environment, in type if not in quantity. In the sands from Canterbury, for example, the clay minerals are similar to those found in the yellow-grey earths of the Canterbury plains while in the sand soils of the Manawatu district the clay minerals are characteristic of weakly weathered yellow-brown earths.

In North Auckland, however, where weathering processes are stronger, soils from sand show more variation. The soils classified as yellow-brown sands still show to some extent the youthful nature of the soil. However, a gradation is seen from soils where clay is low and most of it derived from airborne dust to soils where some of the clay is derived from weathering and affected markedly by weathering processes. For this reason the Tangitiki and Te Kopuru soils are not classed as yellow-brown sands but as a sandy yellow-brown earth and a sandy podzol respectively. Because the clay minerals of these two soils are largely inherited from the parent material, these soils are not truly zonal from a clay mineral aspect, but morphologically they are close to zonal soils.

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