SOIL DEVELOPMENT IN RELATION TO STRANDED BEACH RIDGES OF COUNTY LOWAN, VICTORIA

By G Blackburn, R. D. Bond and A. R. P. Clarke

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SUMMARY

The peculiar distribution of sandy and non-sandy soils in County Lowan can be explained by reference to (1) the existence there of stranded beach ridges with predominantly siliceous deposits of late Cainozoic age; (2) the irregular occurrence on lowlands of calcareous clays with illite and montmorillonite, which are related to early drainage of the littoral area; (3) disruption of the early drainage system by tectonic movement; (4) localised aeolian movements of (i) siliceous sands and (ii) calcareous clays.

The sandy areas are dominated by podzols and lateritic podzolic soils, which show no evidence of the aeolian deposits of calcareous clays found in non-sandy areas. The latter are dominated by grey soils of heavy texture, solodised solonetz soils, and red-brown earths.

The position of stranded beach ridges are shown on a map in relation to other geomorphic features. Numerous results of laboratory determinations on soil and rock samples are presented, particularly those for particle size composition, including fractionation of sands by sieving, and for clay mineral composition.

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I. INTRODUCTION

County Lowan (see Fig. 1) covers a large Victorian segment of the Murray Basin Plains defined by Hills (1960). Its soils are typical of many southern parts of this basin, but their distribution is peculiar. A zone of soils predominantly with clay surface forming an east-west strip in the northern part is sandwiched between two large zones of sandy soils known as the Big Desert and Little Desert. In the south there are several similar sandy areas separated by clay. The aim of the investigation reported here was to determine reasons for the irregular distribution of the contrasting soils, i.e. sands and clays.

Different suggestions for the origin of the larger sandy areas have been given, principally by Hills (1939) and Crocker (1946), but little attention has been given previously to the clay areas. The present investigation started with an attempt to establish the origin of the sands of the Little Desert by testing the views of Hills and Crocker. New information obtained from the field and laboratory work concerned with the Little Desert led to studies of the landscapes and soils in other parts of the county. Special attention was given to the distribution, deposits, and soils of the broad, parallel ridges trending north-west, which were termed Lowan ridges by Hills on account of their widespread occurrence in this county. Eventually, it was concluded that these parallel ridges were stranded beach ridges and that the origin of the peculiar distribution of soils could be understood only by evaluating soil development in relation to these ridges. This consideration involves reference to data obtained on geomorphology and geological deposits as well as on soils.

The Big and Little Deserts are neither specially arid nor lacking in vegetation. This is shown by climatic data, e.g. the rainfall distribution map (Fig. 2), and the vegetation map of Australia (Williams 1955).

II. GEOMORPHOLOGY AND GEOLOGY

The major part of the county is covered by portion of the Murray Basin Plains. Low mountains with altitudes not exceeding 1500 ft occupy small areas in the south-east and east. Deep valleys associated with the Glenelg River occur in the south. Drainage elsewhere goes to lakes and swamps. The oldest rocks outcrop in the low mountains and deeply dissected areas but are buried elsewhere by Cainozoic sediments, as described by Johns and Lawrence (1964). These authors also refer to tectonic activity affecting the county.

The main concern of the present paper is with soils on the plains, so no special concern is given here to the pre-Cainozoic rocks. The older Cainozoic deposits have little significance in this paper, since outcrops are limited to the dissected areas in the south. The late Cainozoic deposits have so far received less attention than other rocks, but some of them have been identified recently by Lawrence (1966).

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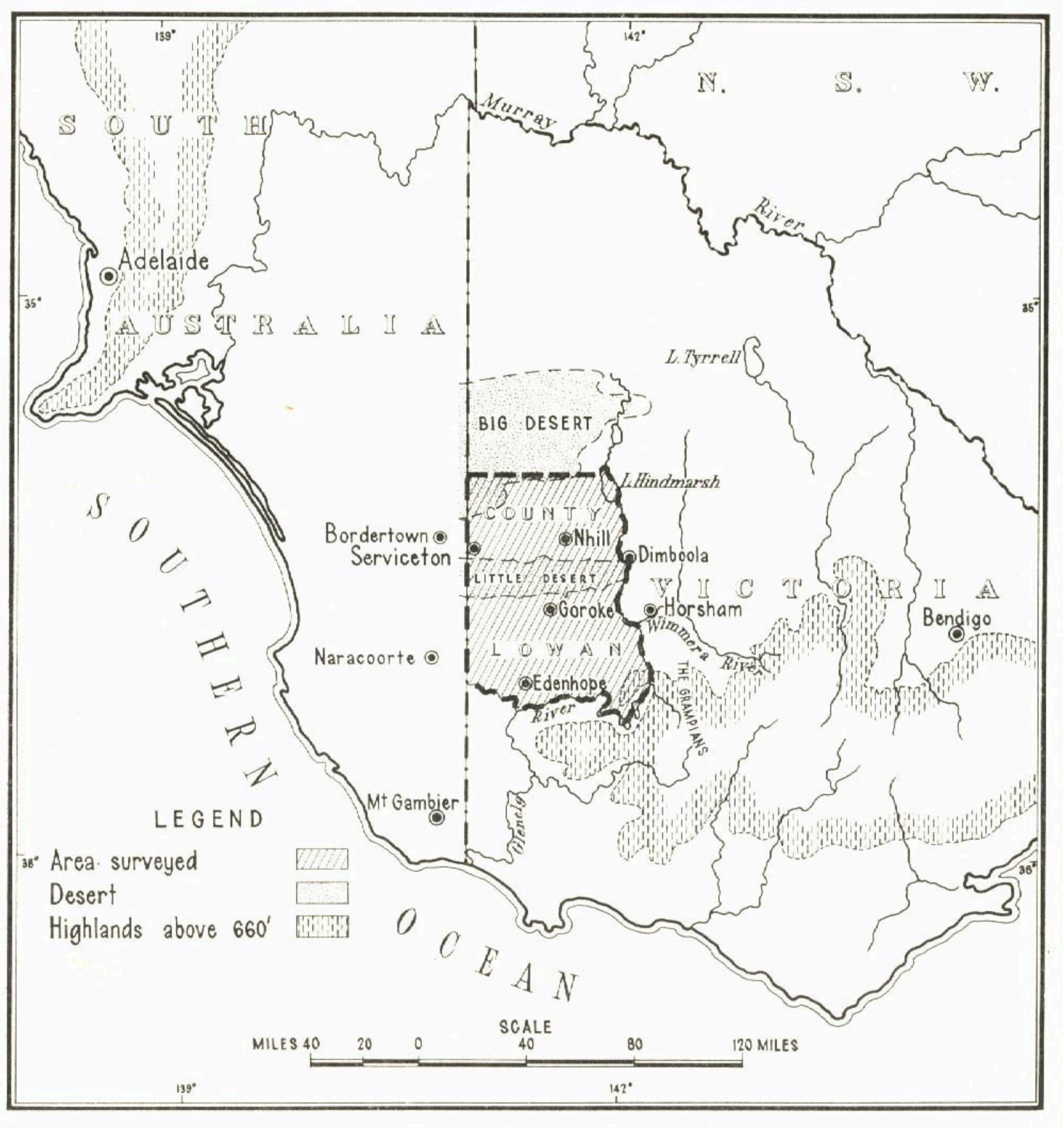
Fig. 1. – Locality plan.



(a) Geomorphic Features

(i) Murray Basin Plains

The major topographic features are the distinctive parallel Lowan ridges (Hills 1939) and the intervening valleys or lowlands, all having a trend approximately NNW-SSE. The minor features are east-west sand ridges or dunes, lakes, lunettes (Hills 1940), and drainage channels. The altitude of the plain is about 600 ft in the south, but it slopes to less than 400 ft in the west, north, and east, as shown by Hills (1939). A few hills not more than 200 ft high in the south-east are isolated outcrops of bedrock.

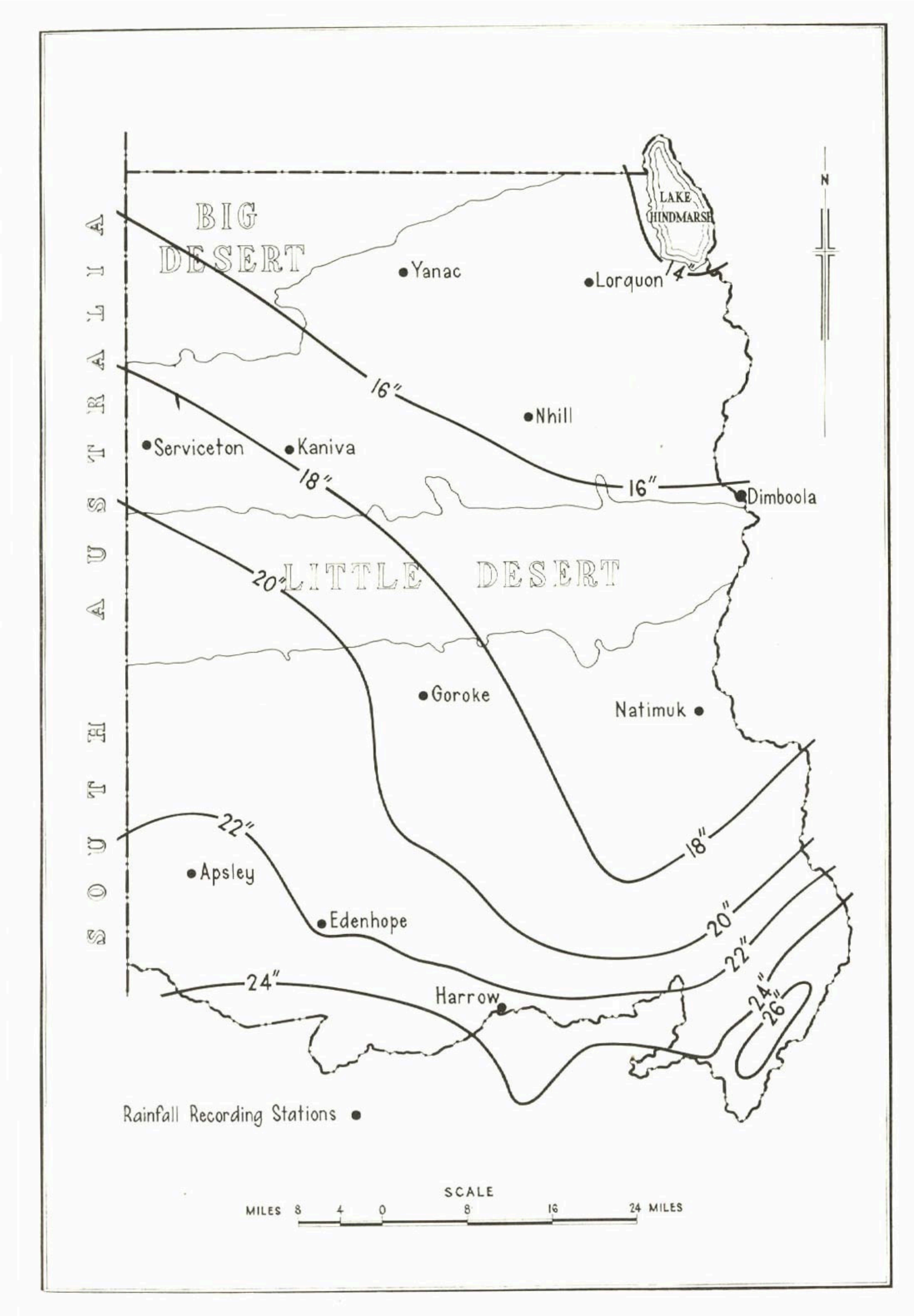


Fig. 2 – Isohyets of mean annual rainfall, County Lowan, based on records of Commonwealth Bureau of Meteorology.

(1) Major Topographic Features

The ridges are generally continuous for several miles, but isolated segments occasionally appear as hills. Their height is generally 20-100 ft, and their width rarely exceeds 1 mile. The ridges are highest in the east, particularly in the centre where their crests vary in altitude from 650 to 750 ft. In the west and north-west their altitudes are only 400-500 ft. Examples of their spacing, variable height, and approximate symmetry are indicated in Figure 3.

The axial positions of many of these ridges, established from field traverses and aerial photographs, are shown on the accompanying map (in wallet at back). This shows the following features.

(1) All ridges are approximately parallel. A ridge known in the Kaniva-Nhill district as the Lawloit Range does not turn west in the centre of the Little Desert as indicated by d'Alton (1914) but runs direct through this desert and continues south beyond the Mitre-Goroke railway.

(2) The curvature of the ridges is concave to the west, a feature that is more distinct in the southern part.

(3) The curvature of the ridges is variable, as shown particularly near Mt. Arapiles.

(4) Gaps of varying size occur in the ridges. In the east there are no ridges in a wide valley described below as the Lowan Salt Lake valley. Small gaps in the west are occupied mainly by creeks draining to the west.

(5) Ridges occur in both the Big Desert and Little Desert.

The strips of lowland in the inter-ridge corridors are generally from 0.5 to 1 mile wide. Their natural drainage shows that their lower side is always at the west and that they slope down to the north-west.

(2) Minor Topographic Features

The four typical features are as follows.

(1) East-west sand ridges or dunes are generally 10-20 ft high but occasionally up to 50 ft. Their width is generally not more than 0.1 mile, and they are usually separated by wider strips of flat land. Occasionally, however, the ridges are very close together and may even join to give an irregular mass of sand. Sand ridges and dunes occur on both types of major topographic features in most of the sandy areas shown on the accompanying map, but large proportions of the lowlands in these areas contain no obvious dunes.

(2) Lakes and swamps are common in the lowlands. Their greatest depth does not appear to be more than 10ft, and their maximum area is a few square miles. Deeper depressions have regular margins and are appropriately ovate. The distribution of the larger depressions, shown on the map, is almost restricted to the non-sandy areas.

(3) Lunette ridges occur on the eastern side of most lakes and many swamps. Their height varies from 20 to 80 ft. Multiple lunettes occur at some lakes

(4) Drainage channels are mainly shallow watercourses ending in lakes and swamps. Distinct channels occur on the flanks of many Lowan ridges and in those western and northern areas shown on the map where there are more elaborate drainage systems.

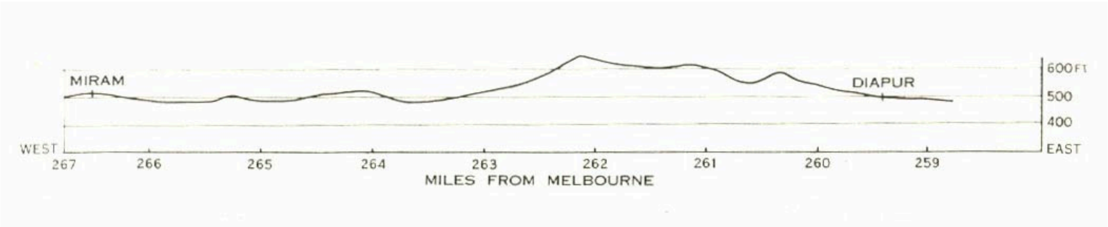


Fig. 3. – Cross section of stranded beach ridges along railway between Miram and Diapur, County Lowan.

(ii) Low Mountains

The Black Range in the south-east (see map) is the main mountain area. Its crest, Mt. Byron, has an altitude of approximately 1500 ft and is the highest point in the county, though only about 900 ft higher than adjacent lowlands. It has been grouped by the Department of Mines, Victoria (1960) with the higher Grampian mountains to the east. Mt. Talbot is a prominent landmark near the northern end of the Black Range.

Mt. Arapiles lies 20 miles north-west from the above range but is related to it and the Grampians by altitude (1176 ft), steep slopes, and similar rocks. Near its base there are low-level outcrops of the same rocks. Low hills between the Black Range and the Glenelg River also consist of hard, old rocks.

(iii) Dissected Areas

The plain is deeply cleft along the valley of the Glenelg River and its tributaries. At Harrow this river lies 300 ft below the plain, and tributaries such as Salt Creek also occupy deep valleys. In the east the dissected areas occupy conspicuously near the Wimmera River and a tributary, Norton Creek. This river turns north on entering a major valley running from Salt Creek in the south to Lake Hindmarsh in the north. The whole valley as shown on the map will be referred to here as the Lowan Salt Lake valley. The southern part of it has been referred to by Hills (1939) as the White Lakes valley. The floor of the entire valley lies below the level of the nearest inter-ridge corridors; for instance, the altitude of the railway bridge across the Wimmera River near Dimboola is 318 ft, whereas altitudes along the railway between Gerang Gerung and Nhill are nowhere below 410 ft.

The Lowan Salt Lake valley has similar breadth to the Glenelg River valley but is not so deep. Its slope down to the north is similar to the general fall of the country from south to north. Much of the floor of this valley is occupied by salt lakes or swamps. There are only a few freshwater lakes, as shown on the map, but none is a terminal lake. The largest and best known is Lake Hindmarsh at the extreme north-east of the county. It receives water from the Wimmera River and overflows occasionally to the north. This valley passes through the Little Desert, in which sector it retains the same general features as to the north and south except that there are few saline areas in this tract and its surface is generally sandy.

(b) Late Cainozoic Deposits

The main deposits dealt with in this section are: the sandstones forming the core of the Lowan ridges; the deposits of calcareous clay; the superficial loose sands of sand ridges and sand plains; gravels and pebbles; and superficial limestones and marl. The first of these has been defined by Lawrence (1966) as Diapur Sandstone.

(i) *Diapur Sandstone*

This is exposed in many quarries that generally are not deeper than 20 ft. The deepest exposure, about 40 ft, occurs in the railway cutting on the Lawloit Range west of Diapur. Small outcrops of this rock are fairly common on Lowan ridges in the Little Desert, and they also occur in the Big Desert and in sandy areas south of the Little Desert. Hills (1939) referred to this deposit as red sandstone and considered that the ridges are composed of this material. Evidence from deep bores, e.g. Crespin (1946), is consistent with his claim. Red sandstone as reported by Hills occurs below the surface of the inter-ridge corridors.

(1) Field Characteristics

The main constituents are rounded and subangular quartz grains. Many are stained on the surface and cemented together. Weathered mica grains are noticeable occasionally, but other minerals are inconspicuous. Washing of the crushed material yields a small proportion of clay. Large grains of quartz are rare, and waterworn quarts pebbles were found in this rock only at one site, near Salt Creek. Observations agree with those of Hills (1939) regarding its horizontal or gently dipping beds, although there is some evidence of small scale contortions resembling slump structures. No fossils have been reported yet in this sandstone.

Many outcrops of this sandstone are indurated, and the hardness of the upper layers generally warrants blasting in quarries. The material at depth is relatively soft. The upper layers also are much redder than lower ones and contain many hard red inclusions not found below. These frequently stand out on exposed surfaces due to differential weathering and even accumulate on surfaces as rounded gravel coated with iron oxide. Fracture of this gravel shows a core of softer sandstone. Other differences between the upper and lower layers are the occurrences only in the former of (I) vertical pipes containing the ferruginous concretions and (ii) veins or tubes of a white, light grey, or light green siliceous deposit.

(2) Laboratory Determinations

Particle size analyses of several sandstone samples, given in Table 1, show the preponderance of sand particles (especially coarse sand), the small proportions of clay and silt, and the absence of particles larger than 2 mm diameter. Sand fractions from sandstone samples obtained throughout the county were divided into 18 size classes by sieving through B.S.S. test sieves and the percentages by weight determined.[*]

The cumulative percentages from 20 to 2000 μm were plotted against the particle size, and these curves were used to estimate the grain size diameters for the quartile percentages by weight and the corresponding sorting coefficients (Krumbein and Pettijohn 1938). Results given in Table 2 show that the median diameters of the sands range from 230 to 510 μm and that the sorting coefficients ranged from 1.2 to 1.6.

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[*] Copies of data used in this report are available on application to the Division of Soils, CSIRO, Adelaide.

Table 1 - Particle Size Composition and Carbonate Content Of Diapur Sandstone, Lowland, Lunette, and Upland Clays, County Lowan

Sample	**Depth below Surface (in.)**	**$CaCO_3$ (%)**	**Particle Size Composition (< 2 mm)** Coarse sand 2.0 – 0.2 mm (%)	Fine Sand 0.2 – 0.02 mm (%)	Silt 0.02 – 0.002 mm (%)	Clay < 0.002 mm (%)
Diapur Sandstone						
A816(a)/9	144	-	79	13	2	5
A816(a)/11	210	-	74	16	4	6
A817(a)/9	120	-	84	14	2	1
A817(a)/11	204	-	80	11	0	8
A818/5	48	-	84	1	0	16
A819/8	115	-	65	27	4	4
A819/9	280	-	69	17	3	10
A931/19	182	-	57	31	2	10
Lowland Clay						
A827/8	36-42	15	5	12	1	64
A829/7	33-40	12	13	12	4	56
A832/7	36-45	9	13	14	5	58
A832/11	68-73	0.8	19	18	5	56
Lunette Clay						
A18/3	24-26	23	5	13	4	56
A19/4	38-40	26	19	12	2	41
A20/3	33	33	22	13	2	28
A933/7	27-36	4	1	7	3	85
Upland Clay						
A819/3	26-44	0.6	25	36	6	28
A931/4	29-31	14	17	26	6	37
A934/5	25-32	7.4	22	22	5	43

Size-frequency distribution curves Fig. 4) were prepared from cumulative percentage diagrams, using 20 equal intervals, in order to show their modal diameters and to make comparisons with other sands. These diagrams show that very small proportions of sand were finer than 76 µm.

Sand fractions from sandstone samples at the locations A600, A816, and A817 (see Fig. 5) and rock specimens from the extreme north-west of the county were submitted for mineralogical examination at the Australian Mineral Development Laboratories, South Australia. Quantitative reports were given on sand samples passing sieves of 0.85 mm aperture, and observations were made on the coarse sand fractions and rock specimens. The dominant mineral was shown to be quartz, and except for opaques the total concentration of any other light mineral constituents (felspar, zircon, and altered chlorite) did not exceed 1% of the fine sands examined.

Table 2 - Median Diameters and Sorting Coefficients for Sand Fractions of Diapur Sandstone and Lowland, Lunette, and Upland Clays, County Lowan

Sample	Median Diameter (μm)	Sorting Coefficient
Diapur Sandstone		
A816(a)/9	360	1.3
A816(a)/11	300	1.4
A817(a)/9	300	1.2
A818/5	510	1.2
A819/9	400	1.6
A931/19	250	1.4
A934/14	330	1.5
Misc. VII (Lemon Springs quarry)	230	1.5
Misc. IX (Big Desert)	290	1.4
Misc. XI/2 (Lawloit quarry)	340	1.3
Misc. Nhill 1 (Netherby quarry)	310	1.4
Misc. Nhill 2 (Little Desert "Crater")	320	1.5
Lowland Clay		
A827/8	140	1.8
A829/7	220	1.9
A832/11	210	1.6
Lunette Clay		
A18/3	150	1.5
A19/4	240	1.4
A20/3	260	1.6
A933/7	140	1.5
Upland Clay		
A819/3	180	1.6
A931/4	170	1.6
A934/5	210	1.8

The proportion of heavy minerals varied from 0.4 to 1.4% and at least half the amounts were provided by black and red-brown opaques. If these opaque heavy minerals consisting mainly of iron oxide are excluded, the total proportions of others such as tourmaline, rutile, zircon, apatite, monazite, and andalusite were generally 0.2 or 0.3% but never more than 0.6% of the fine sand samples.

The nature of the harder sandstones near the surface was investigated in connection with the preparation of samples for particle size determinations. Treatment with boiling hydrochloric acid was unable to overcome the aggregation completely, but it removed the iron oxide coating the quartz grains. Residual aggregation of the quartz grains was overcome by boiling with approximately 10% sodium hydroxide following the acid attack, indicating that siliceous cementation was important in these samples.

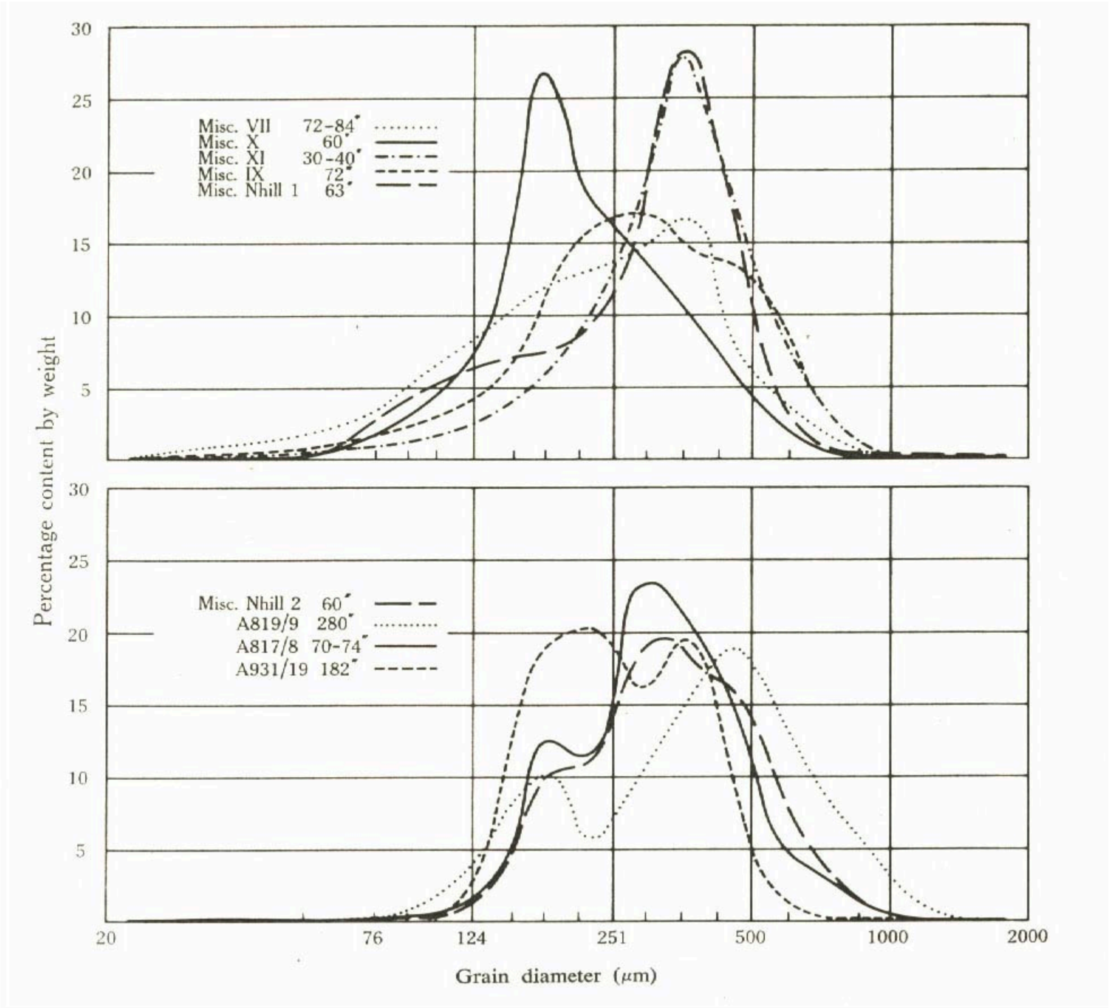

Fig. 4 – Size frequency distribution curves[*] for sand fractions of Diapur Sandstone, County Lowan.

Another feature of the hard samples is their higher content of iron. Six determinations of iron (Fe) were made by X-ray spectrography in hard samples of sandstone at 4-6 ft below the surface and in soft samples from 6 to 17 ft deeper. The results for three sites, A816, A819, A600, were 3.8, 4.1 and 4.1% Fe in the respective harder samples, and 1.4, 1.8 and 1.3% for the underlying samples.

Analyses of several sandstone samples showed no evidence of calcium carbonate, and pH values of 4 or 5 were not exceeded in the lower sandstone layers. Significant amounts of soluble salts, mainly chlorides, were determined in several samples collected beneath clay layers.

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[*] For these and other size-frequency distribution curves reported here, the percentage content by weight is that for each of 20 equal intervals on the abscissa and is plotted against the mid point of the interval.

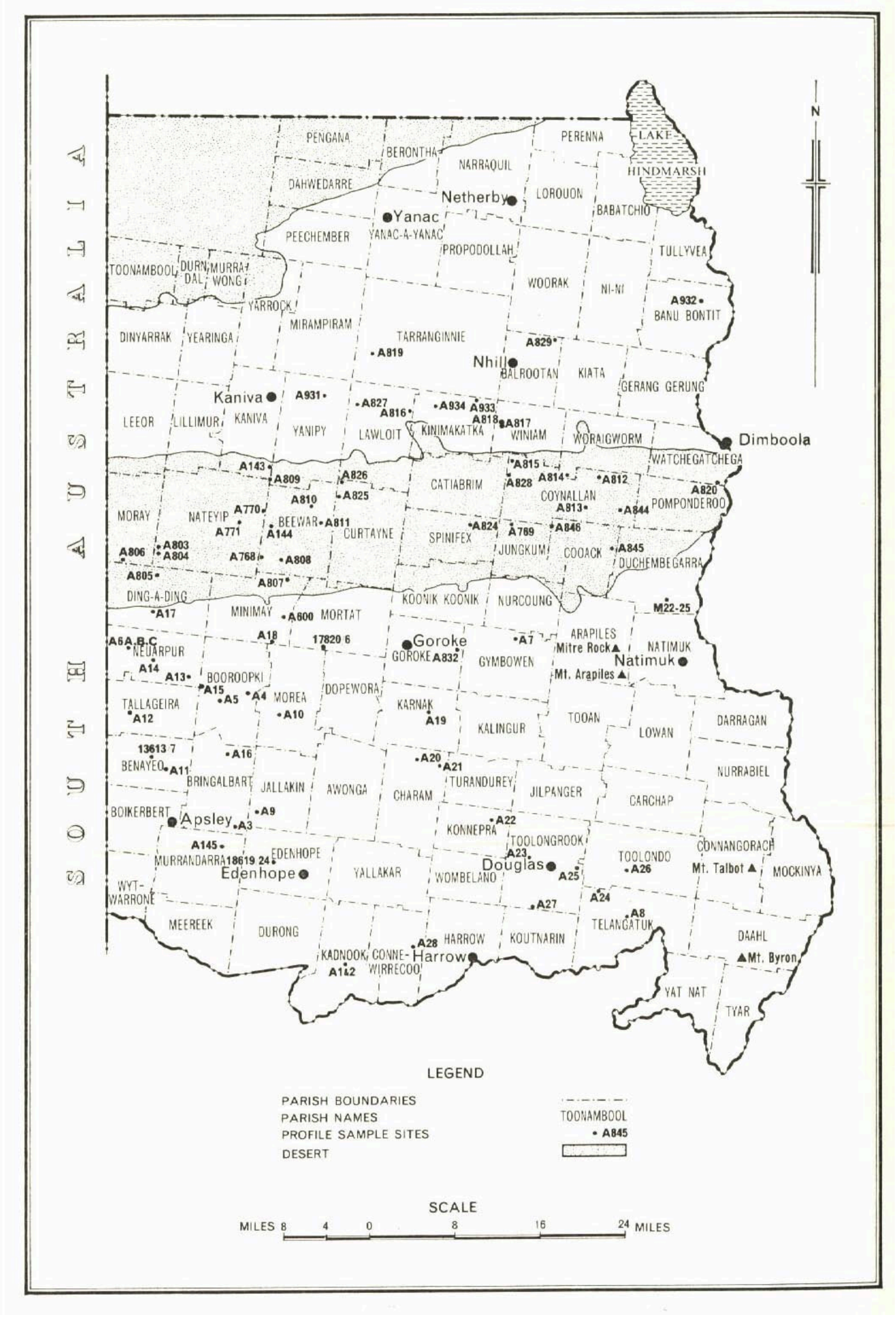


Fig. 5 – Sites of soil profile samples, County Lowan

Minerals in the clay fraction of sandstones more than 12 ft below the surface at sites A768, A819, A931 and A934 were determined by X-ray methods. Kaolin was the predominant mineral in all samples, quartz and randomly interstratified material were always present, and small proportions of illite or montmorillonite and haematite or goethite were also detected.

(ii) Calcareous Clay

Three types of calcareous clay are described below. Reference is made to laboratory determinations on samples below the soil profiles, which show more correspondence with geological deposits.

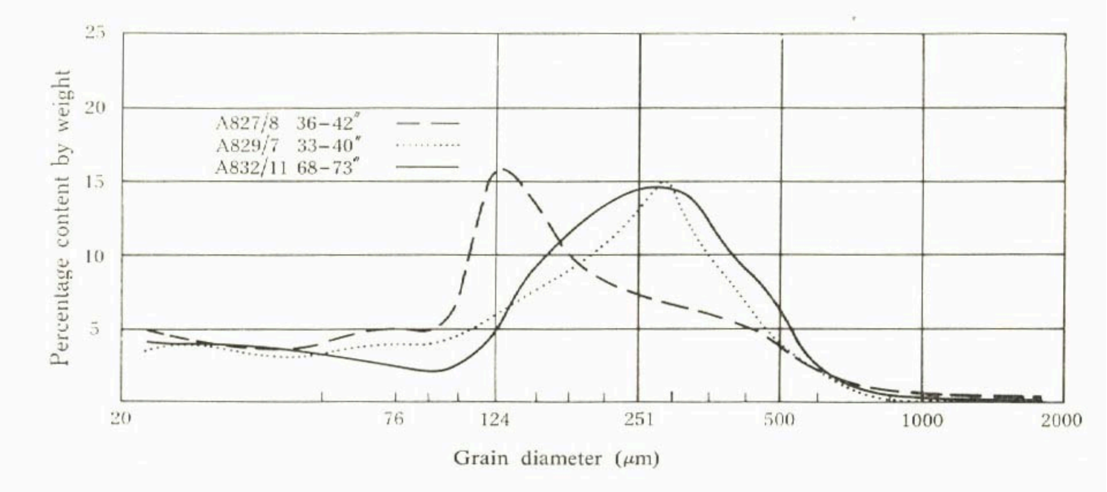


Fig. 6 – Size-frequency distribution curves for sand fractions of lowland clays, County Lowan

(1) Lowland Clay

Hills (1939) referred to the occurrence of clay on the inter-ridge lowlands and described it as overlying red sandstone. This clay has no obvious bedding; no waterworn pebbles have been found in it; the only material coarser than 2 mm diameter consists of calcium carbonate apparently deposited *in situ*. All the clay examined was distinctly calcareous throughout. The colour of the clay beneath the darker soil layers is light grey or yellowish grey. The thickness of such clay is shown in the numerous dams excavated entirely in this deposit to depths of at least 10-15 ft. The maximum depth so far observed is 26 ft a few miles west of Nhill. Deep boring at other site s showed the occurrence of sandy deposits below this clay at a depth of 10 ft in one instance and of hard calcareous rock or hard red sandstone in others.

This calcareous clay was found in all lowland sites. It rarely occurs at the surface in the Little or Big Deserts. Deep boring at intervals across the lowland plain west of the Lawloit Range in the centre of the Little Desert showed no evidence of this clay to depths of 16-26 ft below the surface but revealed non-calcareous red and yellow sandy clays or sandstone within these depths.

Particle size analyses and contents of carbonate for deep-lying samples of this clay are given in Table 1, showing the high proportion of clay and relatively low proportion of silt. The results of sieving determinations on the sand fractions from these samples were used to find the medium diameters and sorting coefficients given in Table 2 and to construct the size-frequency distribution curves given in Figure 6.

(2) Lunette Clay

Many of the lunettes in the county apparently consist of calcareous clay. Since in these situations there can be no doubt that aeolian transport is responsible for these deposits, they may be identified with a component of the Woorinen Formation of Lawrence (1966). Generally, they are light grey to yellow-grey in colour. Samples obtained by auger and from cutting vary considerably; some are easily penetrated and appear very friable, but others are relatively compact and tough. Lunette clays occur in association with lowland clays only. The lunettes studied in the Little Desert consist of sandy deposits.

Particle size composition and carbonate contents for lunette clay samples are shown in Table 1, and the size characteristics of the sand fractions are given in Table 2 and in Figure 7.

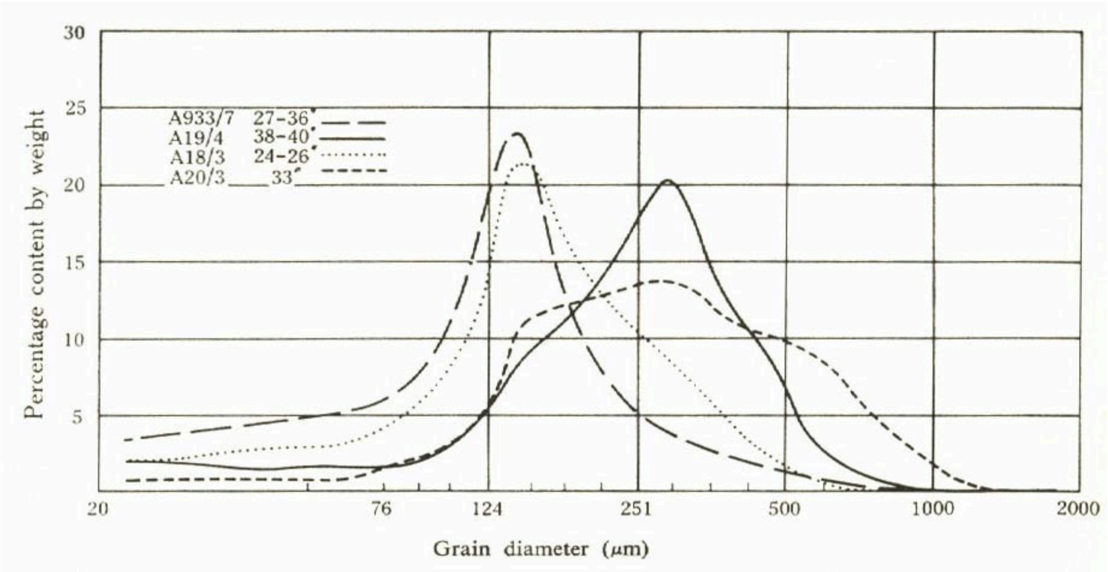


Fig. 7. – Size-frequency distribution curves for sand fractions of lunette clays, County Lowan

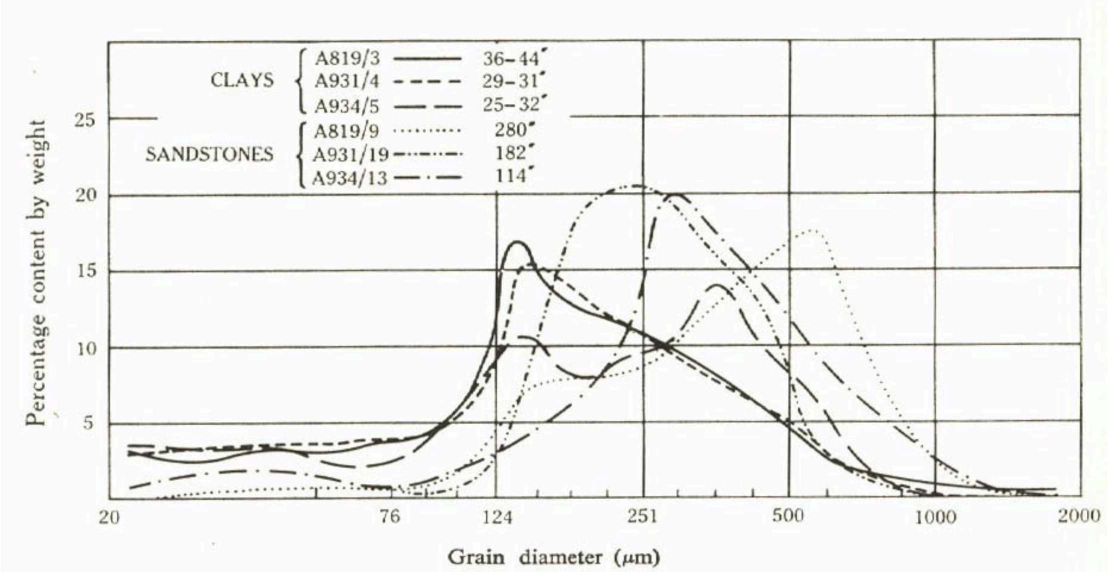


Fig. 8. – Size-frequency distribution for sand fractions of upland clays and underlying Diapur Sandstone, County Lowan

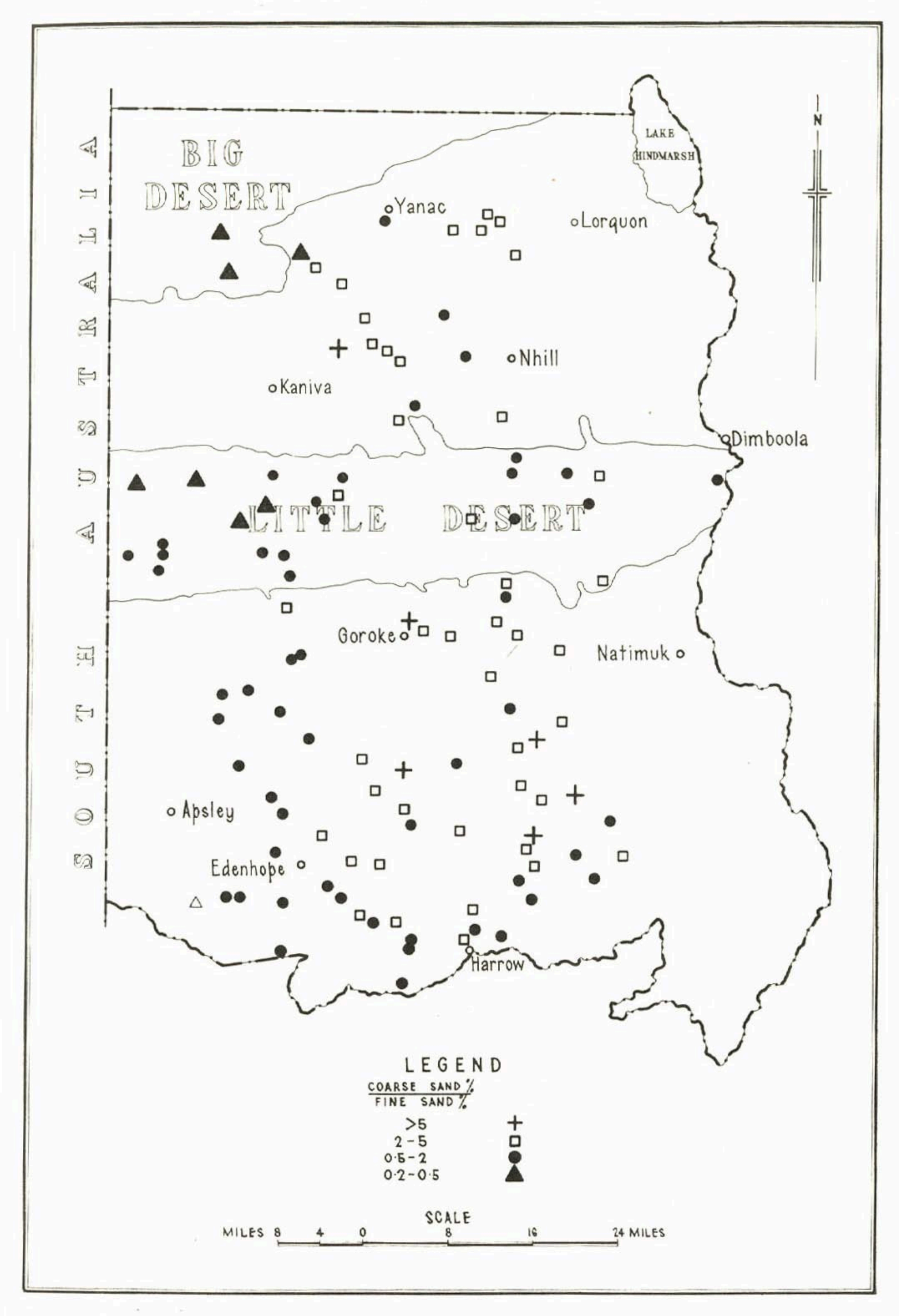


Fig. 9. – Ratios of coarse to fine sand for subsurface samples of loose sand (Lowan Sand) in sandy areas, County Lowan

(3) Upland Clay

Calcareous clay occurs on many of the Lowan ridges, but Diapur Sandstone occurs below it usually at 8-15 ft beneath the surface. This clay generally does not appear to rest directly on this sandstone but is separated from it by a layer of non-calcareous red clay, so that the thickness of calcareous clay usually does not exceed 6 ft. Further attention is given to this underlying red clay later in connection with soils.

This upland clay occurs in positions near the lowland clay but with differences in altitude commonly exceeding 100 ft. Such clay has not been observed in the sandy areas except at one point in the Little Desert, in Coynallan parish.

The proportions of sand, silt, clay, and carbonates in three samples of this deposit are given in Table 1. Sand size characteristics are given in Table 2, and the size-frequency distribution curves are shown in Figure 8.

(iii) Siliceous Loose Sand (Lowan Sand)

Relatively deep, loose sands varying in colour from white to yellow are common in the central and southern sandy parts, as shown on the map. They have been identified by Lawrence (1966) as Lowan Sand. This material occur both in sand ridges or dunes and also in flat sand plains between the Lowan ridges. It consists almost exclusively of quartz grains. The general lack of clay indicated by the single grain character of the deposit is confirmed by particle size analyses showing no more than 3% of clay plus silt. No evidence of carbonate has been found in this sand, and water-worn gravel is absent.

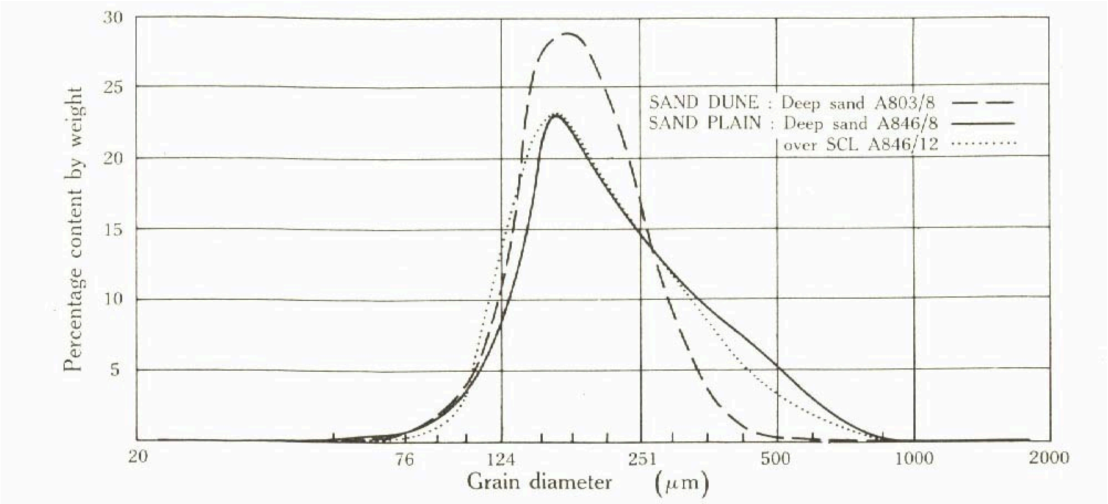


Fig. 10. – Size-frequency distribution for sand fractions of Lowan Sand, County Lowan

The main variation noticeable in the field apart from colour is in the size of grains. The ratios of coarse sand content to fine sand content in subsurface samples of loose sand from various parts of the county are shown in Figure 9, indicating that the coarsest sands are mainly in the south-east and the finest sands mainly in the north-west.

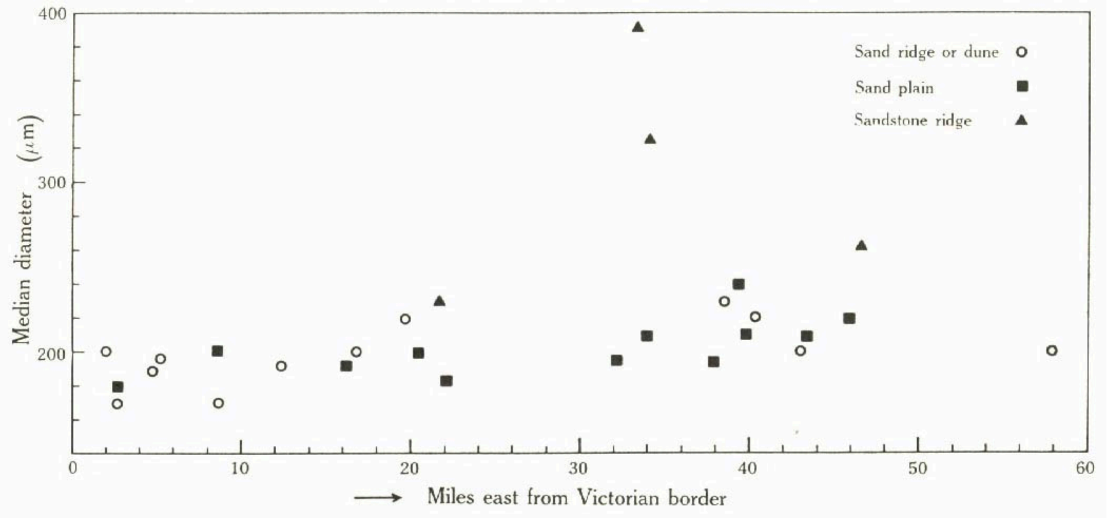


Fig. 11. – Variation of median diameter of loose siliceous sand with distance along axis of Little Desert east from Victorian border, County Lowan

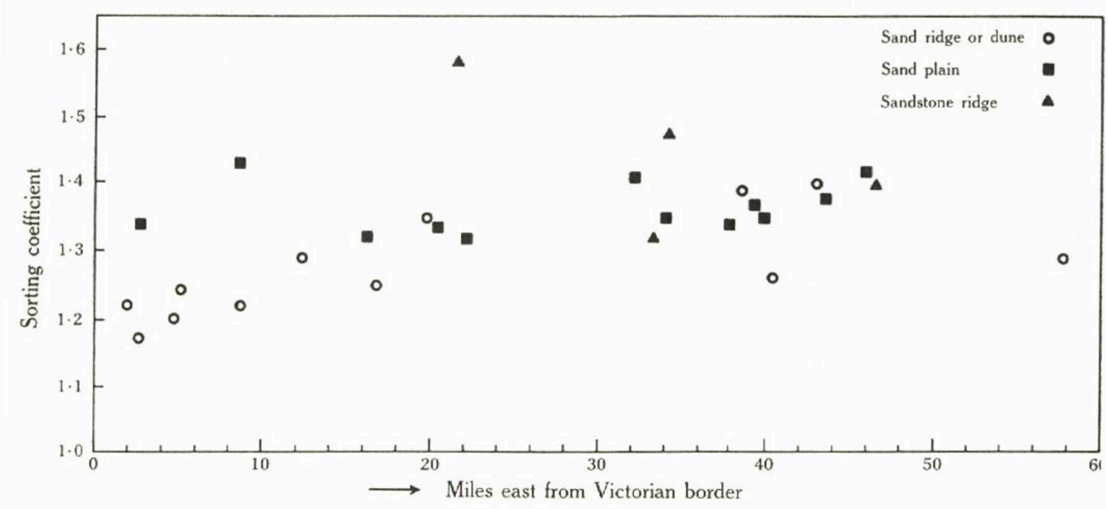


Fig. 12. – Variation of sorting coefficient of loose siliceous sand with distance along axis of Little Desert east from Victorian border, County Lowan

Variations in the size characteristics of sand in the Little Desert were studied by determining the median diameters and sorting coefficients of subsurface samples from 28 sites along the length of this sandy strip. Size-frequency distribution curves for three typical samples are given in Figure 10. The values of median diameter (Fig. 11) show a slight trend to coarser sands in the east. The sorting coefficients (Fig. 12) show that there is a slight trend to less sorted sands in the east, even when samples from Lowan ridges are excluded.

(iv) Gravel, Pebbles, and Boulders

The most common gravel is ironstone concretions that occur in many soil profiles at the change from sandy subsurface to clay subsoil horizons. This type of gravel is often prominent on the surface of Lowan ridges in the Little Desert and has been striped in such places for road-making. All of it is regarded as formed in the soil and should not be confused with coarse materials mentioned below which have undergone transport. These consists mainly of quartz and are roughly rounded, but they are not common in this country having been observed at only six sites, all in the south. The largest exposure there is an alternation of fine-textured and coarse steeply bedded sediments. The latter contain rounded white pebbles, mostly not larger than 1 cm diameter. Similar quartz gravel is exposed in shallow pits in the Kadnook district and about 2 miles south of White Lake. It also occurs occasionally in soil profiles a few miles south-west of White Lake.

Deposits of large, round, quartz pebbles and boulders occur in a valley 3 miles east of the Powers Creek settlement and also on the southern slopes of Mt. Arapiles. The latter deposit, used for road metal, includes a variety of sizes from large boulders to small pebbles. All these quartz pebbles occur at altitudes above 450 ft, i.e. well above the present rivers.

There is one other significant type of occurrence of quartz pebbles, 1-2 cm in diameter. These are the only coarse materials apart from ironstone gravel found on Lowan ridges. Such pebbles occur in isolated groups of up to a score, each group usually lying within 1 square yard. Specimens are smooth but generally not round. All samples were near the crests of ridges in the Little Desert at altitudes from 600 to 750 ft. No such pebbles have been found in Diapur Sandstone exposed in many quarries. These surface deposits could be due either to transport by aboriginals or by birds, e.g. emus, as gizzard stones.

(v) Superficial Limestones and Marl

Non-fossiliferous limestone and marl are present at several places in the north, north-east, and east, where much use has been made of them for road construction. The limestone is an indurated surface or subsurface rock identified here as kunkar and occurs as part of the soil profile. The relatively soft material with a proportion of clay is regarded here as marl. Kunkar on marl occurs only is association with lakes, either on the floor of an existing lake, e.g. near Douglas; on the floor of a former lake or lagoon now dry; or on the bank or lunette at the east side of a contemporary or former lake.

The main area of such limestone and marl is in the Lowan Salt Lake valley. Limestone in the Douglas area of this valley was reported by Gregory (1904). Similar stone is associated with salt lakes near Mitre and Natimuk; further north along this valley in the Little Desert sector; and further north between Dimboola and Lake Hindmarsh. Other deposits of kunkar are on a lunette near the county boundary north of Netherby; near lake depressions north-west of Kaniva; and on the Western Highway a few miles north-east of Serviceton.

(c) Origins of Geomorphic Elements and Late Cainozoic Deposits

The question of the peculiar distribution of sand and clay soils in this county involves consideration of the origins of (i) Lowan ridges, (ii) Lowan sand, and (iii) the calcareous clay. Attention to the general problem of soil variations and soil development in the county requires study of the relative ages of different land surfaces.

(i) Origin of Lowan Ridges as Stranded Beach Ridges

Different suggestions on the origin of these ridges have been given by Dennant (1886), Fenner (1918), Hills (1939), Department of Mines, Victoria (1961), and Blackburn (1962).

Dennant regarded the ridges as representing the old deposits found in Mt. Arapiles, the Black Range, and the Grampians. Fenner believed that the inter-ridge lowlands were old river courses. Hills distinguished the ridge sandstone from the Grampians sandstone, regarding the former as Tertiary deposits overlying buried strike ridges of the latter. However, although his view on the age of the ridge sandstone is confirmed by data from bores, his suggestion of buried strike ridges is not supported by these data (Johns and Lawrence 1964).

Both of the recent suggestions on the origin of the Lowan ridges (Department of Mines, Victoria, 1961; Blackburn 1962) concern their identity with dunes, but only the latter’s suggestion is specific. The ridges are unlikely to be desert dunes owing to lack of widespread evidence of their convergence, a feature noted for the long sand ridges of Australian deserts (King 1960), and owing to the fact that traverse dunes of such regularity are not associated with desert conditions. The formation of Lowan ridges as coastal dunes is suggested by their general height and by comparison with the distribution of stranded beach ridges in adjacent areas of South Australia (Blackburn, Bond, and Clarke 1965). Both these sets of ridges show the same general direction, approximate parallelism, and marked curvature or convergence only near bedrock outcrops. However, the South Australian ridges show their coastal affinities by their content of calcareous beach sand containing marine fossils, but no fossils have been found in Diapur Sandstone and the ridges have not yielded unmistakable evidence of beach or dune deposition. On the other hand, the widespread lack of coarse material in Diapur Sandstone and its grain size distribution are consistent with its origin from a sandy beach. The fact that stranded beach ridges in South Australia are highly calcareous while the Lowan ridges are not as important in determining the origin of the latter, considering that many Australian beach deposits are non-calcareous (Jennings 1959).

One fact that hinders recognition of these ridges as stranded coastal dunes or beach ridges in that the Murray Basin Plain slopes down from south to north and the western margin of any ridge is not level. This situation led to the suggestion by Fenner (1918) concerning former parallel rivers in this county. However, a similar slope occurs on the coastal plain of south-east South Australia which is occupied by stranded beach ridges. Both that part and County Lowan are considered to be affected by diastrophism in the late Cainozoic era (Hills 1939; Hossfeld 1950; Sprigg 1952; Johns and Lawrence 1964), and there is general agreement that the southern parts were moved higher than the northern ones.

At least 40 ridges have been identified in County Lowan, and 30 Pleistocene strand lines are known in south-east South Australia. The Lowan ridge near Dimboola containing deposits examined by Crespin (1946) is apparently not older than upper Pliocene, so the other ridges to the west in this county may be regarded as Plio-Pleistocene. No attempt was made at correlation of any ridges with glacial-eustatic changes of sea level, owing to the difficulties in reconstructing the levels of the plain before the tectonic activity responsible for its tilt. The age sequence of the ridges appears to be from oldest in the east to youngest in the west.

The siliceous deposits in the Lowan ridges may have been derived largely from old sandstones and quartziles as exposed at Mt. Arapiles, the Black Range, and the Grampians. Introduction of such material to coastlines in this region apparently involved fluviatile deposition, and on this basis it is understandable that the coarser quartz pebbles are mainly in the south and east near the margin of the Murray Basin. Their occasional occurrence there in material similar to Diapur Sandstone is regarded as indicating coarse beach deposits. The only obvious complication concerning quartz gravels is their steeply bedded occurrence in a quarry south-east of Natimuk, but this deposit occurs at the foot of a Lowan ridge and is not identical with Diapur Sandstone

It is concluded from the above that (i) the Lowan ridges were formed at former strand lines and at least the higher members are coastal dunes; (ii) Diapur Sandstone was formed subsequently in these ridges; (iii) the whole area covered by ridges has moved tectonically since their formation.

(ii) Origin of Lowan Sand

Two suggestions have been made concerning this sand. Hills (1939) believed that the sands are weathering products of the sandstones in the Lowan ridges. Crocker (1946) claimed that the sands of the Big and Little Deserts were blown there from South Australia. The data presented above on these sands give little support to Hills' suggestion and are not consistent with Crocker's view. The difficulty with the first suggestion lies in accounting for the relatively fine sand on sand plains between the Lowan ridges. This is not sufficiently comparable with the material from Diapur Sandstone sampled in the ridges to support Hills' view. However, there are coarser sands on the ridges, which match these sandstone materials (cf. Fig. 11 and Table 2), indicating the derivation of sand from sandstone at these sites. Crocker's view of aeolian movement of sand from South Australia is not supported by the evidence of a trend to slightly coarser and less sorted sands in the east of the Little Desert (Figs. 11 and 12). The other objections to his view are that (i) sand ridges or dunes are by no means prevalent in all parts of the Little Desert, and (ii) although the sands of the Big and Little Deserts are continuous with sandy areas in South Australia there are many other substantial patches of sand in the southern part of the county (see map) that are discontinuous.

It is concluded that movement of sands from South Australia cannot account for all the extensive sandy areas in the county and that Hills' view can account for only a proportion of the loose sand deposits. However, if a stranded beach origin for the ridges is conceded, it follows that considerable variation in sand deposits may have occurred and that finer sands could be expected on inter-ridge corridors, possibly associated with tidal movement in sheltered waters.

(iii) Origin of Calcareous Clay

Very little attention has been given to this matter previously, apart from the suggestion by Fenner (1918) of previous river courses along the inter-ridge corridors. His suggestion would indicate that deposits of lowland clay should be continuous along lowlands. The fact mentioned above that they were not found by boring in the Little Desert is regarded as significant, particularly since allowance was made for the slopes of the corridors and the differences in altitude along them within and beyond this Desert. Moreover, the general lack of lakes in the Little Desert as compared with areas to the north and south, as shown on the map, does not indicate the occurrence of retentive clay layers there.

One significant feature of this clay is that it generally contains sands relatively finer and less sorted than either Diapur Sandstone or Lowan Sand (Table 2 and Figs. 11 and 12). There is some indication that some sand from lunette samples might be derived from local deposits such as Diapur Sandstone, but this is not shown for the lowland clay. The evidence from sand characteristics, therefore, supports the field evidence on soils and geology that the lowland clay is not related to Diapur Sandstone. This clay is considered to have been introduced to the county as the coast retreated to the west and to have been deposited behind stranded beach ridges. Before tilting and dissection of the plain bearing these ridges, the prevailing drainage would have been from east to west. The apparent distribution of lowland clay is though to represent zones of estuarine and lacustrine deposition behind the ridges; the characteristics of its sand fractions are consistent with such deposition. The geographic separation of the clay deposits, particularly by the Little Desert, is probably due to the previous existence of separate drainage channels whose zones of deposition either rarely or never overlapped in the Little Desert.

The formation of lunettes by aeolian movement of the lowland clay is obvious from the nature of the lunette ridges and their deposits. It suggests that clay movement in these instances involved clay aggregates similar in size to sand grains, since the accumulation is similar to a dune and is close to the source. The sands from lunette clays have many similarities to those of the lowland clays, as shown in Table 2 and in Figures 6 and 7. The upland clay is also considered to be derived mainly from the lowland clay by aeolian movement, probably similar in process to lunette formation but on a much larger scale. The restriction of the upland clay to the vicinity of the lowland clay, its separation by heights of up to 100 ft, and its absence from similar elevations on ridges in the Little Desert all lead to the conclusion that the upland clay must have reached such positions by aeolian movement from nearby sources. It cannot be claimed that all upland clays have been deposited by aeolian action, for lakes may have existed between the higher ridges deep enough to drown some of the lower ridges. The close relationship of the upland clay with lowland and lunette clay is indicated by particle size characteristics given in Tables 1 and 2 and in Figures 6, 7, and 8.

III. SOILS

(a) Nomenclature, Field Characteristics and Distribution

The occurrence of several types of soil in this county has been shown on maps covering all or part of it (Prescott 1944; Blackburn and Gibbons 1956; Northcote 1960; Skene 1960, 1961; Stephens 1961). The soil samples identified in Figure 5 cover the range of soils but were taken mainly in the central part in order to study the Little Desert and adjacent districts. The profile samples given particular attention are listed in Table 3 together with appropriate names, all but one of which are those adopted by Stephens (1962). The field characteristics of representative soil profiles, shown in Figure 13, supplement the general descriptions given by Stephens and also indicate the features of one soil, the red earth, not dealt with by that writer.

Table 3 - List of Profile Samples and Soil Names, County Lowan

Profile Samples	Soil Class Name
A6, A827, A829, A832	Grey soil of heavy texture (lowlands)
A819, A931, A934, A844	Grey soil of heavy texture (uplands)
A803	Podzol
A826, A828, A846	Podzolic soil
A7, A768, A770, A816, A825	Lateritic podzolic soil
17820/26, 18619/24, A769, A771, A804	Solodised solonetz soil
A18, A19, A20, A933	Red-brown earth
A932	Solonised brown soil
A845	Red earth
M22-M25	Solonchak

The distribution of different soils in typical landscapes of the county is shown in Figure 14. Despite differences in the soil maps referred to above, they all indicate that the Big and Little Deserts have sandy soils contrasting with other parts. Prescott (1944) and Skene (1960) showed areas of grey and brown soils of heavy texture between the Big and Little Deserts. Blackburn and Gibbons (1956) indicated the extensive areas of calcareous clay soils immediately south of the Little Desert and the sandy nature of the latter. Northcote (1960) and Stephens (1961) showed the similar characteristics of clay soils occurring north and south from the Little Desert.

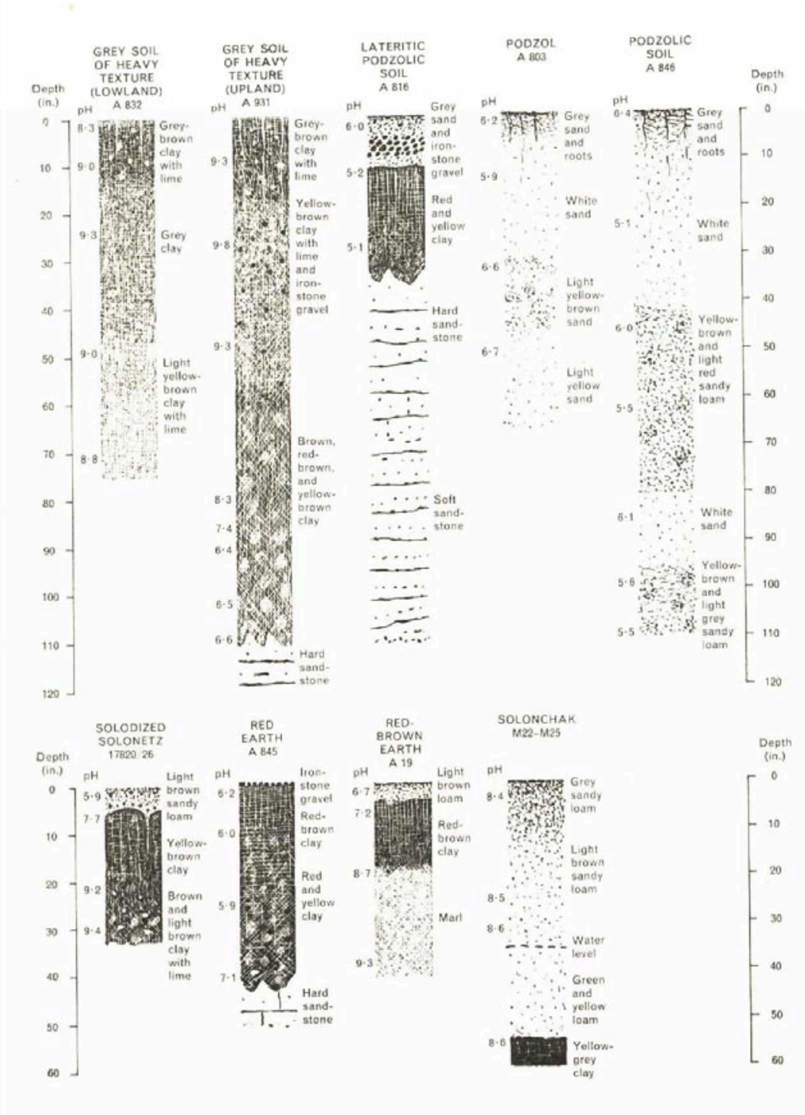


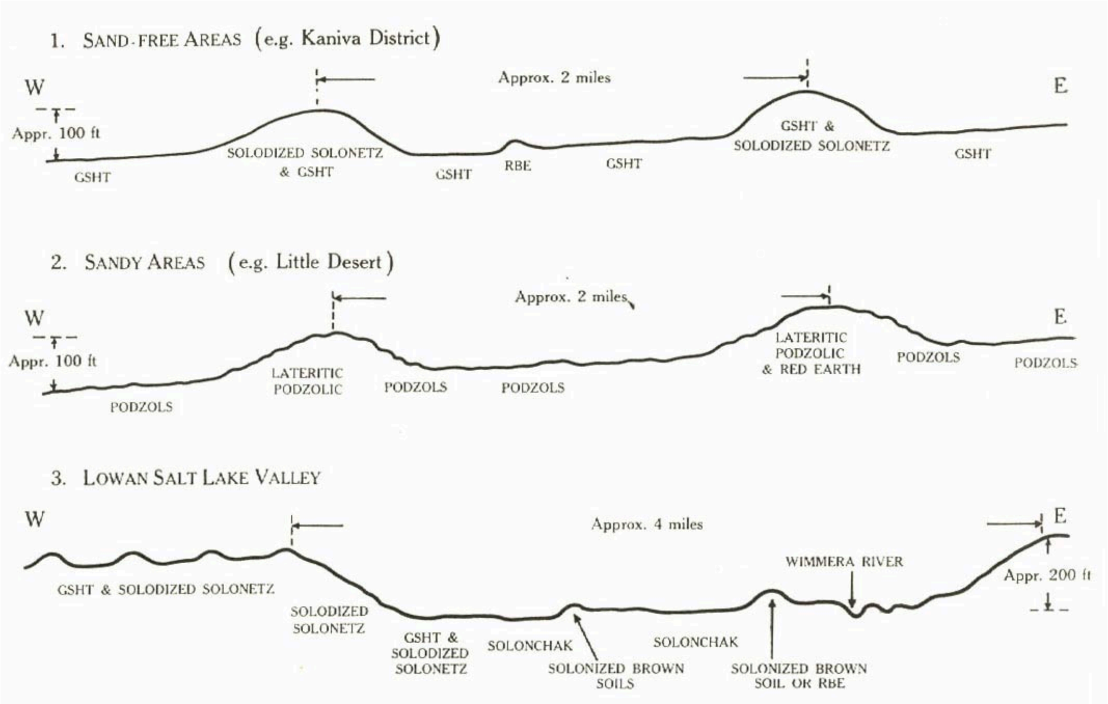
Fig. 13 – Diagrammatic representation of characteristic soil profiles, County Lowan

The occurrence of highly calcareous soils identified here as solonised brown soils is shown by Prescott, Northcote, and by Stephens to be important only in the north-east. Traverses during the investigation indicated that these soils are common only in the Lowan Salt Lake valley but occur there both in its southern portion, e.g. near Natimuk, Mitre, and Douglas, as well as in the northern parts. Elsewhere they occur only sporadically to the north of the Little Desert, e.g. north of Netherby and north-west Kaniva. This soil is associated exclusively with dry lake or lunette areas.

The main extent of lateritic podzolic soils shown by Stephens is in the northern portion in two strips which coincide with the Lawloit Range and another high range east of Nhill. However, it was found that similar soils occur extensively on stranded beach ridges in the Little Desert and Big Desert and also in the south of the county. In the Little Desert they are common as far west as the Kaniva-Goroke road.

The solodised solonetz soil is widely distributed but does not dominate extensive areas. Its distribution in the south was indicated by Blackburn and Gibbons, who referred to it then as solonetzic soil. In the south it is common both between and on the stranded beach ridges, but further north it occurs mainly on these ridges. Profiles of this type found between ridges are relatively grey near the surface and yellow in the subsoil, but those on ridges are relatively brown near the surface and red-brown in the subsoil. The latter colour features are also common to the red-brown earths. Most of the dominantly red soils indicated by Skene and Northcote in the Nhill district are regarded here as solodized solonetz of the brown to red-brown colour type. The fact that solodized solonetz soils often occur mixed together with grey soils of heavy texture was recognized by Blackburn and Gibbons, who identified this mixture as a gilgaied solonetzic soil complex.

Red-brown earths were found in this investigation only on lunettes. They are scattered widely through the country but do not occur as extensive areas. The distribution shown by Skene for this type is believed to refer mainly to solodized solonetz, as mentioned above, but there are a number of lunettes in Skene's area of red-brown earth which certainly have soils not identifiable with solodized solonetz.



1. SAND-FREE AREAS (e.g. Kaniva District)

2. SANDY AREAS (e.g. Little Desert)

3. LOWAN SALT LAKE VALLEY

Fig 14 – Schematic distribution of soil types in west-east sections, County Lowan.
(GSHT = grey soil of heavy texture; RBE = Red-brown earth)

Table 4 – Particle size composition and carbonate content of profile samples from characteristic soils, County Lowan

Sample	Depth (in)	Gravel (>2 mm) (%)	Particle Size Composition of Non-calcreous Fine Earth Fraction				$CaCo_3$ in Fine Earth (%)
			Coarse Sand (%)	Fine Sand (%)	Silt (%)	Clay (%)	
Grey soils of Heavy Texture – Lowland Sites							
A827/1	0-3	2(L)أ	8	15	7	70	8
A827/2	3-6	3(L)	6	13	2	77	11
A827/4	9-16	5(L)	5	13	0	79	16
A827/6	20-29	2(L)	6	14	1	76	16
A827/8	36-42	7(L)	6	14	1	76	15
A829/1	0-3	-	17	15	12	53	8
A829/2	3-7	-	16	14	8	59	6
A829/5	19-25	-	14	13	5	67	13
A829/7	33-40	-	15	14	5	64	12
A832/1	0-3	-	17	22	10	49	1
A832/2	3-6	-	15	17	5	59	2
A/82/3	6-12	-	12	16	3	67	5
A832/5	21-31	-	13	17	2	66	2
A832/7	36-46	1(L)	14	16	6	64	9
A832/9	52-60	-	16	17	6	59	1
A832/11	68-73	-	19	18	5	57	1
Grey Soils of Heavy Texture – Upland Sites							
A844/1	0-1½	-	11	19	12	54	5
A844/4	8-18	-	16	20	12	50	1
A8448	40-47	-	24	22	11	40	-
A844/9	47-57	-	18	19	13	45	-
A844/10	57-64	-	28	26	8	34	-
A844/11	64-71	-	33	21	9	33	-
A819/1	12-18	4(L)	16	40	10	32	3
A819/2	24-33	2(I)	25	47	6	22	1
A819/3	36-44	-	26	37	6	27	1
A819/5	50-60	-	29	39	5	26	-
A819/7	75-80	-	69	23	7	1	-
A819/8	111-116	-	65	27	4	4	-
A931/1	12-15	7(I)	13	26	8	53	20
A931/4	29-31	16(I)	20	30	5	43	14
A931/7	48-54	1(I)	22	35	7	35	1
A931/9	66-75	-	23	31	7	38	-
A931/11	81-87	-	25	32	4	40	-
A931/14	103-111	-	40	34	2	24	-
A934/1	0-4	-	27	25	5	41	7
A934/3	12-19	-	26	23	6	44	9
A934/5	25-32	-	24	24	5	46	7
A934/7	43-53	-	32	25	6	37	1
A934/9	72-79	-	32	24	7	37	-
A934/10	79-88	-	39	24	4	32	-
Podzol							
A803/2	3-9	-	45	54	2	1	-
A803/5	32-38	-	42	57	1	2	-
A803/8	55-65	-	35	64	1	2	-
Solodized Solonetz Soil							
18619	0-2	-	42	38	14	6	-
18620	4-7	10(I)*	39	1	13	7	-
18622	12-14	5(I)	19	20	6	53	-

Sample	**Depth (in)**	**Gravel (>2 mm) (%)**	**Particle Size Composition of Non-calcreous Fine Earth Fraction**				**$CaCo_3$ in Fine Earth (%)**
			Coarse Sand (%)	**Fine Sand (%)**	**Silt (%)**	**Clay (%)**	
18623	24-29	7(I)	28	27	10	35	-
18624	42-45	12(I)	23	26	11	37	0.3
A804/2	2½-5	2(I)	46	51	0	3	-
A804/4	7½-11	-	29	37	3	31	-
A804/6	16-23	-	27	39	3	30	-
A804/9	35-38	-	19	21	0	59	2
A769/1	0-3	4(I)	43	49	2	6	-
A769/2	3-6	6(I)	43	51	1	4	-
A769/3	6-7	1(I)	28	37	3	31	-
A769/4	7-15	2(I)	31	29	0	39	-
A769/5	15-27	-	19	33	0	46	-
A769/6	29-36	2(I)	29	21	0	48	0.4
A769/7	36-45	-	19	33	0	46	-
A769/8	45-50	5(I)	32	25	2	41	-
A769/9	50-56	I(I)	31	30	1	39	-
A769/10	56-61	-	26	35	1	36	-
A771/1	0-4	-	28	66	2	4	-
A771/2	7-12	-	22	36	1	41	-
A771/3	15-18	-	31	23	0	46	-
A771/4	22-24	-	12	29	0	59	-
A771/5	30-32	-	15	26	0	60	-
A771/6	36-40	-	18	25	0	58	-
Solonized Brown Soil							
A931/1	0-4	-	46	44	2	8	2
A931/2	4-7	-	40	51	1	8	1
A931/3	7½-9	-	10	64	6	20	3
A931/4	9-12	-	37	41	3	18	7
A931/6	17-24	-	37	40	5	19	19
A931/8	34-39	-	49	31	2	18	19
A931/11	70-74	-	47	31	3	19	10
Lateritic Podzolic Soil							
A768/1	0-2½	6(I)*	32	57	5	7	-
A768/2	3½-6	37(I)	36	58	3	4	-
A768/3	6-9	10(I)	17	24	2	58	-
A768/4	11-14	4(I)	15	19	0	66	-
A768/5	14-22	3(I)	16	18	0	66	-
A768/6	22-27	17(I)	31	20	2	45	-
A768/7	27-32	5(I)	30	19	1	48	-
A768/8	32-36	14(I)	49	23	2	26	-
A770/1	0-1½	7(I)	32	57	2	9	-
A770/2	1½-5	35(I)	28	63	1	8	-
A770/3	5-7	29(I)	33	60	1	5	-
A770/4	8-11	1(I)	28	39	1	31	-
A770/5	11-18	1(I)	14	22	0	64	-
A770/6	18-29	2(I)	15	24	0	60	-
A770/7	29-37	6(I)	16	28	1	55	-
A770/8	29-37	6(I)	16	28	1	55	-
A770/9	45-54	10(I)	21	31	1	46	-
A770/10	60-66	-	21	14	3	61	-
A770/11	66-71	-	33	20	4	43	-
A816/1	0-5	2(I)	61	32	4	4	-
A816/2	5-8	60(I)	53	36	4	8	-
A816/3	8-11	1(I)	42	26	3	29	-
A816/4	11-17	-	30	13	1	55	-

Sample	Depth (in)	Gravel (>2 mm) (%)	Particle Size Composition of Non-calcreous Fine Earth Fraction				CaCo$_3$ in Fine Earth (%)
			Coarse Sand (%)	Fine Sand (%)	Silt (%)	Clay (%)	
A816/8	17-22	-	16	8	0	75	-
A816/6	26-30	-	23	10	0	65	-
A816(a)/5	55-57	-	38	11	1	46	-
A825/1	0-3	58(I)	47	2	10	14	-
A825/2	3-6	33(I)	46	29	3	18	-
A825/3	6-8	4(I)	29	18	8	46	-
A825/4	8-11	1(I)	25	15	9	53	-
A825/6	14-18	-	36	16	8	40	-
A825/8	20-25	2(I)	54	20	6	19	-
Red-brown Earth							
A18/1	0-3	-	20	57	6	14	-
A18/2	3½-8½	-	11	22	2	66	-
A18/3	24-26	-	6	17	5	72	23
A19/1	0-3	-	42	38	7	12	-
A19/2	3-6	-	28	20	3	50	-
A19/3	18-20	-	18	12	3	65	39
A19/4	38-40	-	26	16	3	56	26
A933/1	0-1½	-	14	48	11	22	-
A933/2	1½-4½	-	5	21	8	66	-
A933/4	10½-14	-	2	9	4	85	-
A933/7	27-36	-	1	7	3	89	4
Red Earth							
A845/1	0-1	32(I)*	17	23	10	48	-
A845/4	9-11	-	15	9	1	72	-
A845/6	15-24	-	24	13	2	57	-
A845/7	24-32	-	27	13	3	54	-
A845/9	43-45	3(I)	41	22	4	32	-
Podzolic Soil							
A826/3	7-15	-	42	56	1	2	-
A826/6	35-38	-	22	30	0	48	
A826/7	38-42	-	28	35	0	46	-
A828/3	8-16	-	47	52	0	1	-
A828/5	22-32	-	39	60	0	1	-
A828/9	55-59	-	42	38	0	20	-
A846/1	0-3	-	54	44	2	1	-
A846/3	8-19	-	49	50	1	1	-
A846/5	33-43	-	46	52	0	2	-
A846/6	43-52	-	45	41	0	12	-
A846/7	52-60	-	37	47	0	13	-
A846/8	62-68	-	47	37	0	14	-
A846/9	68-79	-	46	43	0	10	-
A846/10	82-95	-	38	60	1	2	-

*I – Ironstone gravel
أ L – Limestone gravel

Podzols occur in the sandy areas and are a feature only of deep sands. Their occurrence is mainly in the Little Desert and further South. In all sandy areas there are also some deep sands that show only very slight development of the podzol features. These "immature" podzols are more prevalent in the northern sandy areas than in the south. The profiles referred to as podzolic soils have distinctly finer-textured subsoils below a few feet of sand, but these soils generally contain only enough clay to give textures from clayey sand to sandy clay loam. These profiles occur only in the large sandy tracts.

The solonchak and red earth types occupy only a small proportion of the country. Neither had previously been reported for the northern part of the country. Solonchaks occur only in the Lowan Salt Lake and are distinguished by high proportions of sodium chloride and gypsum. Red earths were found only in the Little Desert.

(b) Laboratory Determination on Soil Profile Samples

Attention was given particularly to samples in and near the Little Desert in order to establish the particle size and clay mineral characteristics of the main soil types.

(i) Particle Size Composition

The particle size data refer both to the entire samples and to the sand fractions that were subdivided by sieving.

(1) Entire Samples

The contents of gravel and of coarse sand, fine sand, silt, clay and carbonate determined in the fine earth of many samples are given in Table 4. The main features shown by these results are as follows:

Gravel – The lateritic podzolic soils contains moderate proportions of pisolitic ironstone gravel in upper parts of profiles. Small proportions of such gravel occur in the grey soils of heavy texture on uplands but not in those on lowlands where the only gravel is limestone is present mainly in subsoils. Ironstone gavel also occurs in solodized solonetz and red earth soils.

Fine Earth – This generally comprised at least 80% of individual samples. Carbonate was found commonly in samples from grey soils of heavy texture on lowlands, solonized brown soil, the upper horizons of grey soils of heavy texture on uplands, and the lower horizons of red-brown earth and solodized solonetz. Four soil types lack carbonates. The clay fraction is dominant in grey soils of heavy texture and red earth and in subsoil horizons of solodized solonetz, lateritic podzolic soils, and red-brown earths. Sand is dominant in podzols and in upper horizons of several soil types. Silt is present only in very small proportions in several soils; it is more plentiful in grey soils of heavy texture and red-brown earths, but only a few determinations showed more than 10% of this fraction in the noncalcareous fine earth.

These results show that the grey soils of heavy texture fall into two distinct groups.

Those on lowlands have higher clay content, common occurrence of carbonate, and similar ratios of coarse to fine sand throughout each profile. The upland group contain less clay and have carbonates only in the upper layers; the coarse to find sand ratios vary within the profile. The lateritic podzolic, solodized solonetz, and red-brown earth soils have general similarities with respect to profiles of clay percentage, but they differ in their silt and carbonate contents. The red earth resembles the lower part of a lateritic podzolic profile. The solonized brown soil (Table 4) is distinguished from other sandy soils by its carbonate content and from all soils by marked profile variation in the ratio of coarse to fine sand.

(a) solodized solonetz and red-brown earths
(b) lateritic podzolic soil and red earth
(c) grey soil of heavy texture, lowlands and uplands
(d) podzol, podzolic soil and solonized brown soil

Fig 15(a)

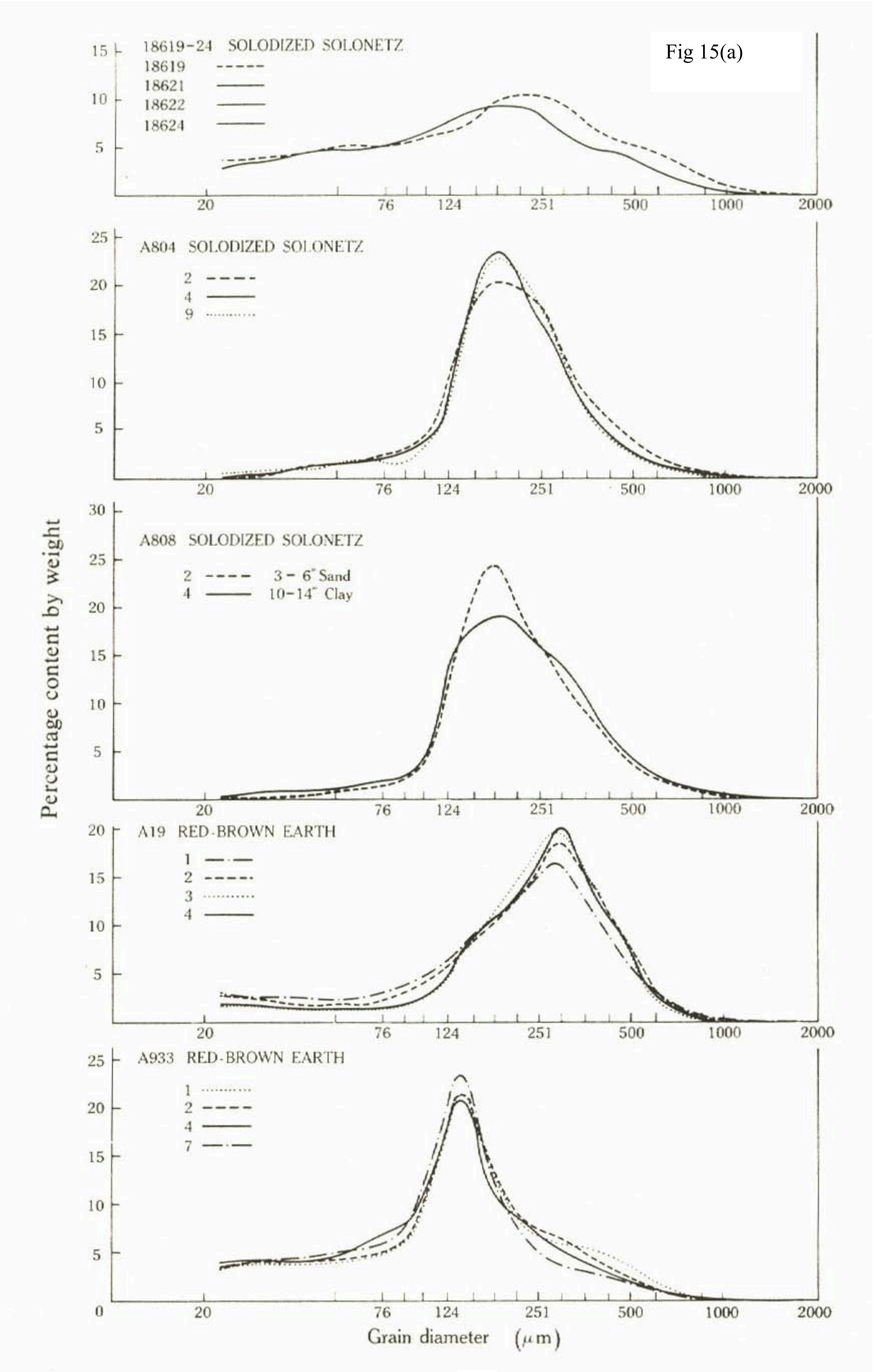
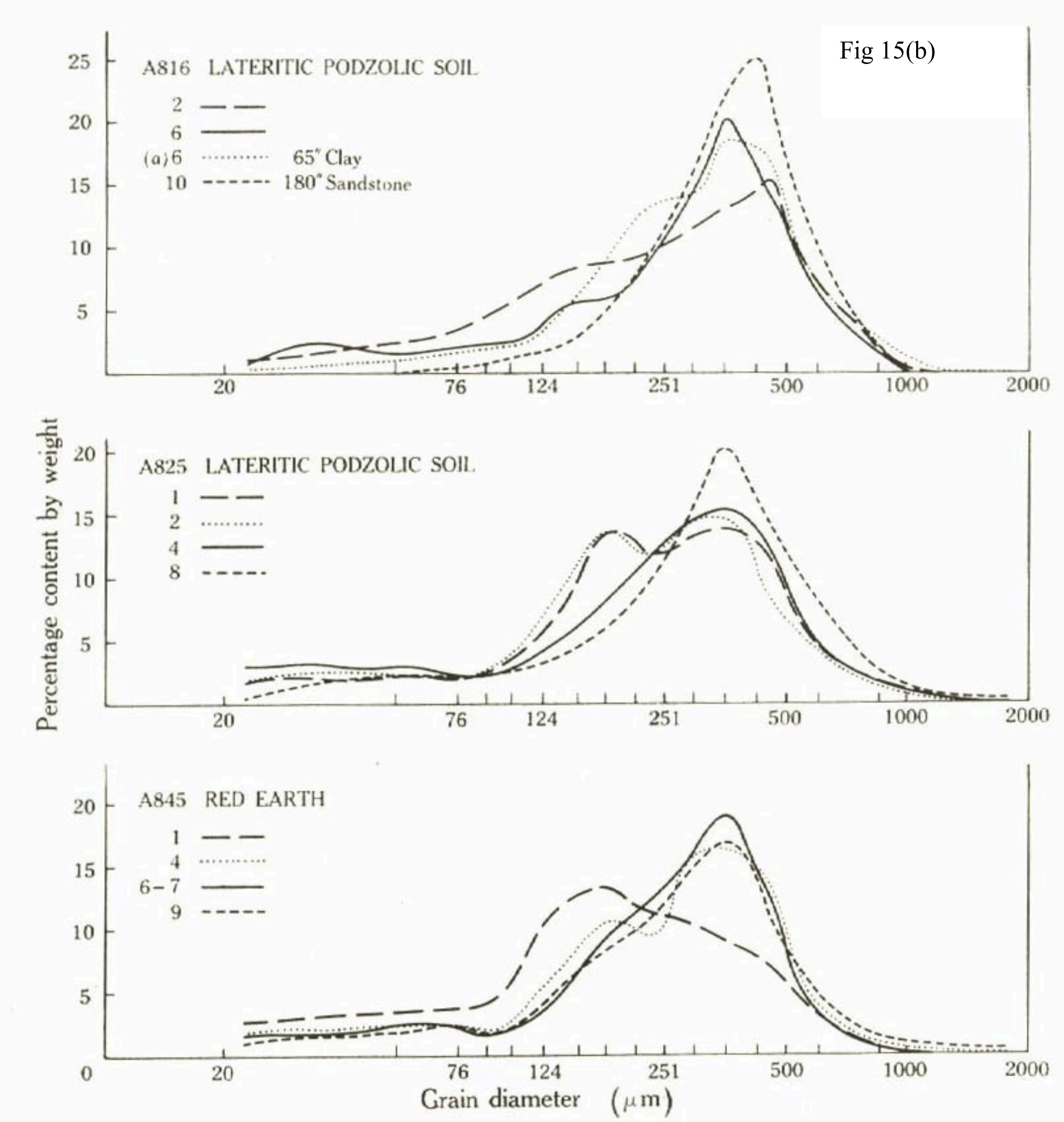


Fig 15(a) - 15(d) – Size frequency distribution for sands in profiles of characteristic soil types, County Lowan.

Fig 15(b)



(2) Sand Fraction

Sieving determinations on sand fractions from different soil types were used to construct cumulative percentage curves. These curves were divided into 20 equal intervals in order to prepare the size-frequency distribution curves given in Figures (15(a) – 15(d).

The curves for solodized solonetz and red-brown earths (Fig 15(a)) show that each profile has almost the same size grading of sand in different horizons. Both of the lateritic podzolic profiles (Fig 15(b)) are more variable than the profiles of Fig 15(a); this differences arises from the inclusion of curves for thesandstone below the soil and from the contrast between sands from the A and B horizons of the profile. In the red earth (Fig 15(b)) there are also differences between the upper and lower horizons. Similar modal diameters and proportions of fine sand occur in the red earth and lateritic podzolic soils.

The curves of grey soils of heavy texture (Fig 15(c)) are relatively similar within each lowland profile, but those from upland sites show considerable variation. One element of the latter variation is due to the underlying sandstone, but if curves relating to it are disregarded there is still much more variation than for the lowland sites. All curves shown in Fig 19 (c)) for soil material indicate less sorting of sands than for those in Figs 15(a) and 15(b). Most curves in Fig 15(c) show the presence of appreciable proportions of sand finer than 76 µm. Such fine sand is not a feature of all profiles in Figs 15(a) and 15(b).

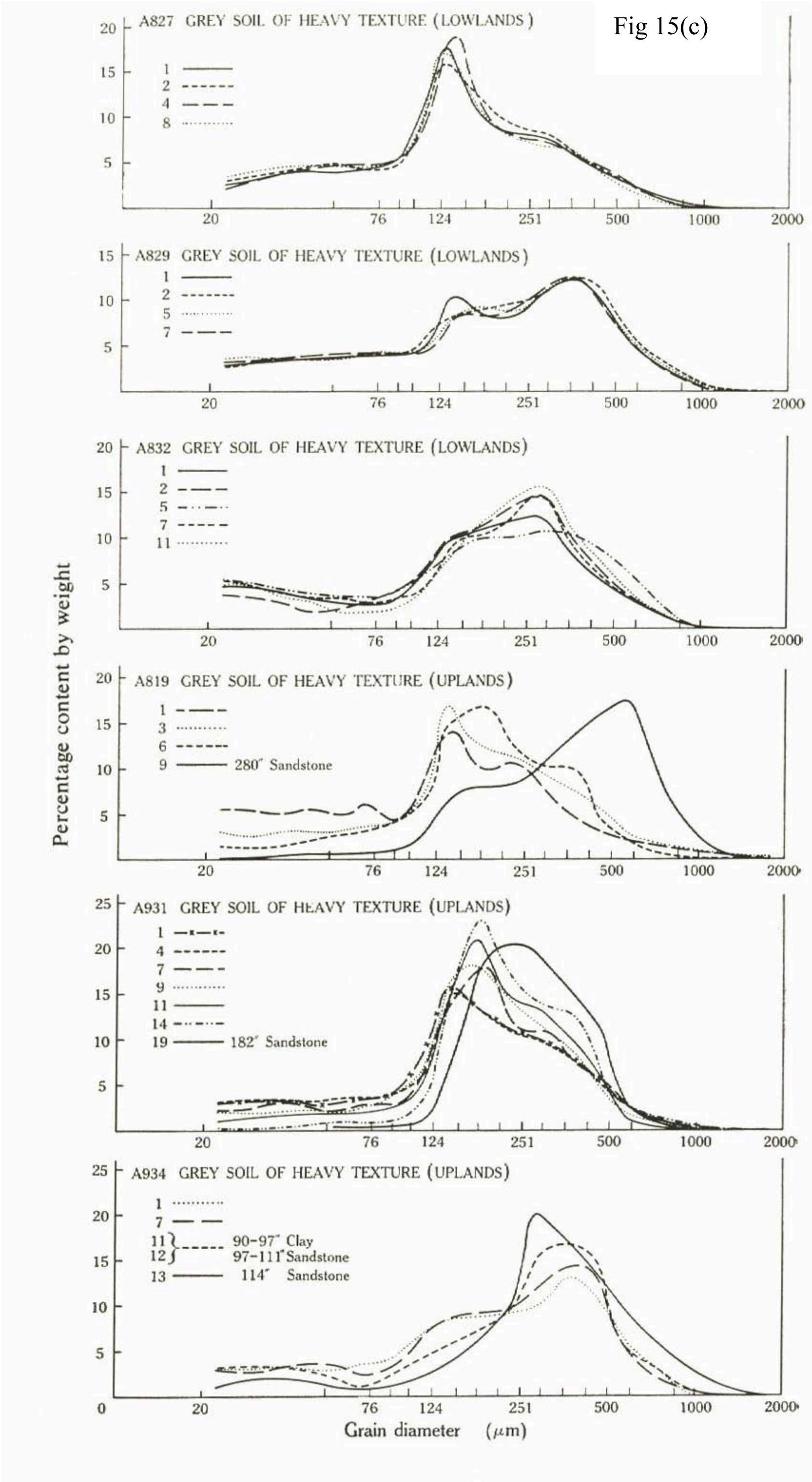


Fig 15(c)

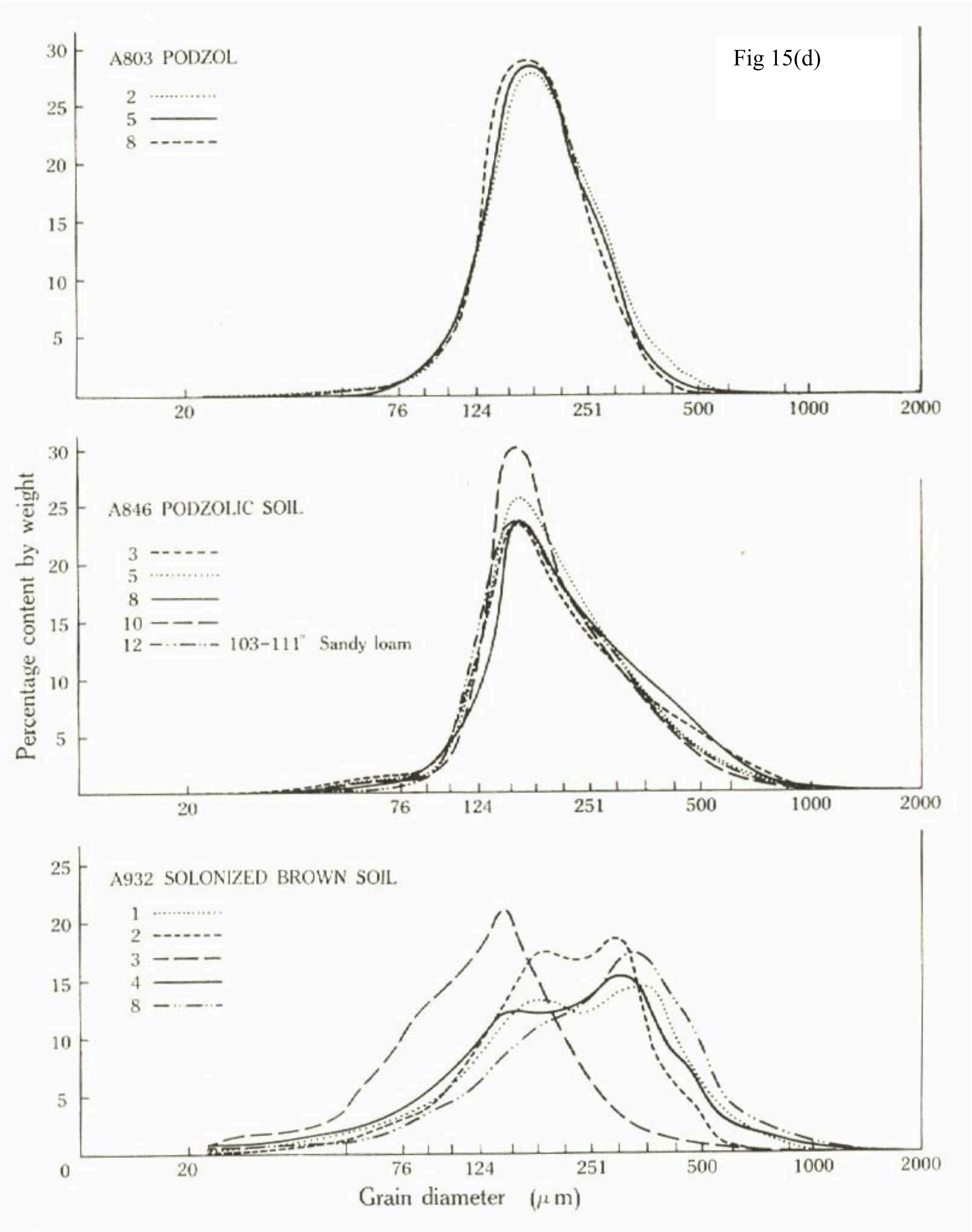


Fig 15(d)

The curves for the podzol and podzolic soil (Fig 15(d)) are similar within each profile, regardless of any texture variation. These sands are well sorted and do not contain very fine sand. The solonized brown soil (Fig 15(d)) shows considerable variation within the profile.

Notwithstanding the texture variation in the red-brown earth and solodized solonetz profiles (Table 4 and Fig 13), the sand characteristics of these types shown in Fig 15(a) indicate that the profiles have resulted from soil processes and not from deposition of sand or loam over clay.

(ii) pH and Soluble Salts

The profile trends of pH shown in Fig 16 indicate that deep subsoils of upland grey soils of heavy texture, of lateritic podzolic soils, and even of some solodized solonetz soils are more acidic than surface layers. Values down to pH 5 were determined in several subsoil samples; the minimum pH 4.5

occurred at 55 inches in a solodized solonetz profile. High pH values were recorded in several calcareous horizons.

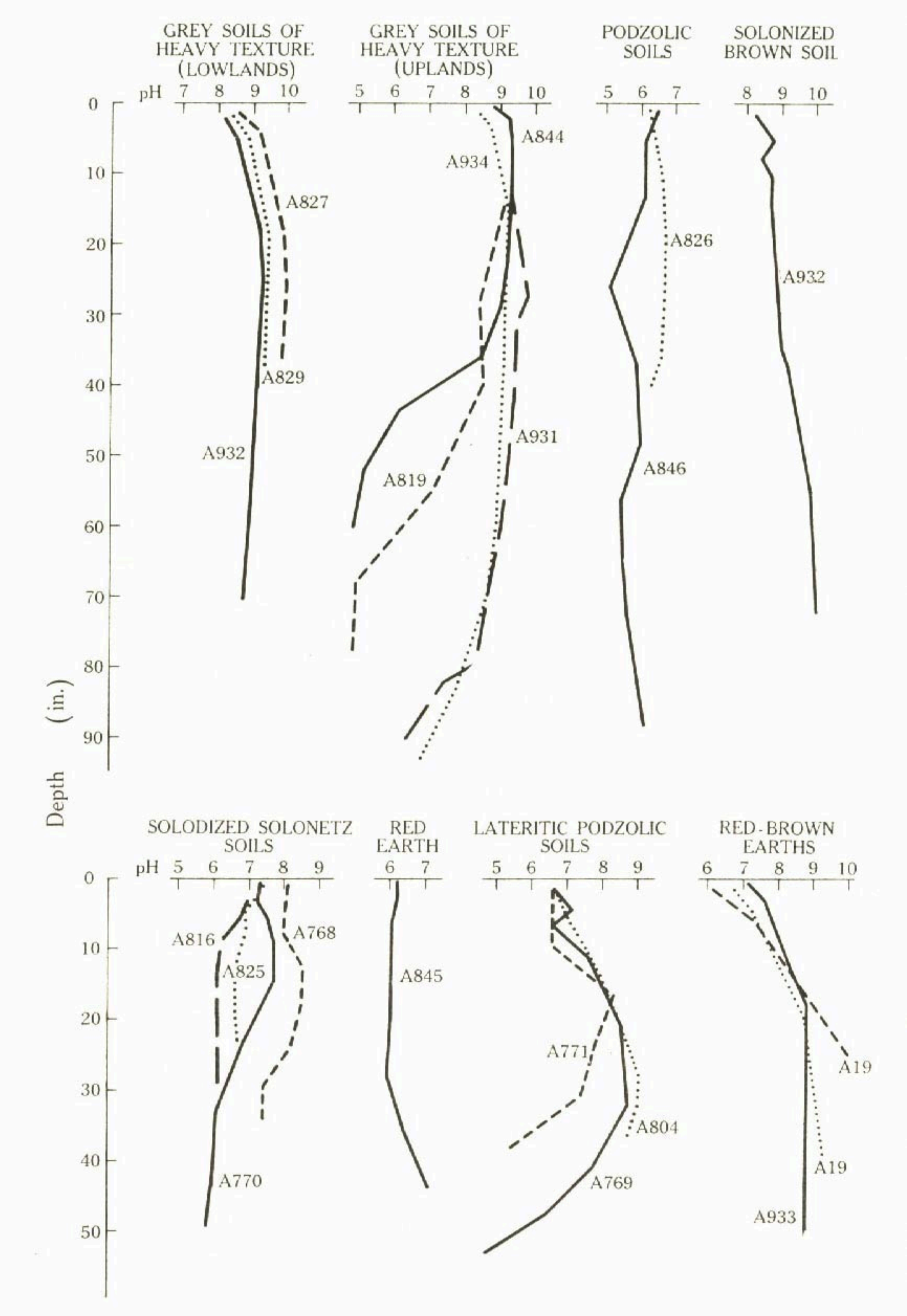


Fig 16 – pH trends in soil profiles, County Lowan

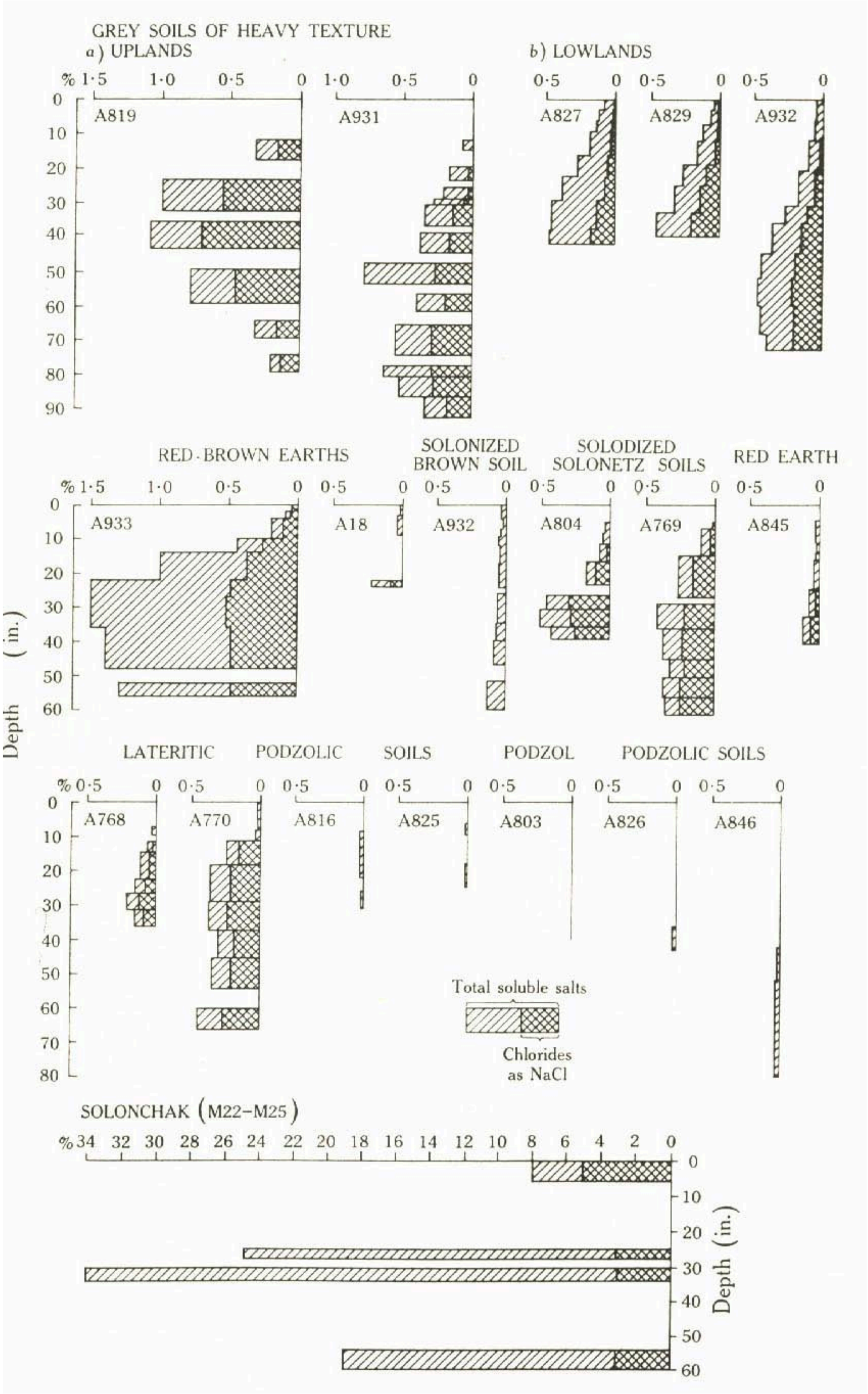


Fig 17 – Salinity, variations in soil profiles, County Lowan

Soluble salts (Fig 17) varied from (I) high in the solonchak which contained high proportions of gypsum as well as chlorides to (ii) low in lateritic podzolic soils, red earth, solonized brown soil, and podzolic soils and (iii) extremely low in podzols. Other soil types contained singificance amounts of soluble salts in their subsoils.

(iii) Clay Minerals

Determinations of minerals in clay fractions from 16 profiles were made by X-ray methods and are set out in Table 5. The major minerals are kaolin, illite, and montmorillonite, with small amounts of quartz and haematite or goethite. Randomly interstratified material was present in all samples.

The clays are dominated either by illite, illite and montmorillonite, or by kaolin associated with quartz and haematite or goethite. The latter combination is typical for the lateritic podzolic, red earth, and some solodized solonetz soils, and also for the deepest samples from upland profiles of grey soils of heavy texture. Other clays are dominated by illite sometimes with montmorillonite.

(C) Soil Variation on Stranded Beach Ridges

(i) Variation along Ridges

Two of the five soil types on the ridges are shown in Fig 14 as representing the sand-free areas and three the sandy areas. This pattern of soils is repeated on many ridges. The main contrast in these soils is that between the grey soils of heavy texture and the lateritic podzolic soil. The latter have well-differentiated profiles, yet the sand fractions in different horizons are alike and resemble the sand from underlying sandstone (Fig 15(b)). Such profiles may have been developed fro the Diapur Sandstone with later modification of the surface sand. The grey soils of heavy texture also overlie this sandstone, but there is no indication from the sand characteristics (Fig 15(c)) or the clay mineral data (Table 5) that they have developed from this rock alone. The grey calcareous clay in the upper parts of these profiles contains fine sand, carbonates, and clay minerals not common to the sandstones. This clay is regarded as an aeolian deposit on the ridges. The underlying non-calcareous clay in this profiles contains higher proportions of coarse sand than the surface layers, as shown in Table 4, and it represents soil material existing before the aeolian deposition of calcareous clay and fine sand. Movement of this deposit into the older soil is indicated by the presence of carbonate in the upper layers of the red or brown clay and by the occasional occurrence of darker clay in natural cracks of this deep subsoil.

One of the reasons for soil variation along the ridges is the formation of a younger soil in aeolian deposited on certain parts of the ridges and the existence of elsewhere of lateritic podzolic soils. There are objections, however, to concluding that the non-calcareous clay in the profiles of grey soils of heavy texture represents that in the lateritic podzolic soils. Examination of the curves representing sands of the latter profiles (Fig 15(b)) and those of the upland grey soils of heavy texture (Fig 15(c)) shows that the deep subsoils of the latter have sands relatively finer than those of the former, yet all the sandstones are characterised by coarse sand. The clay mineral data in Table 5 show that non-calcareous clay of two relevant grey soils of heavy texture contain moderate proportions of illite and montmorillonite but that the lateritic podzolic clay have little or non of either mineral. The clay percentages in the non-calcareous clays from the two soil types are also different (Table 3).

Table 5 – X-Ray Determination of Mineralogy of Carbonate-free Clay Fraction (<0.002 mm) from profile samples of characteristic soils, County Lowan

Sample	Koalin	Illite	Montmorillonite	Quartz	Haematite or Goethite	Sample	Kaolin	Illite	Montmorillonite	Quartz	Haematite Or Goethite
Grey Soil of Heavy Texture - Lowlands						***Lateritic Podzolic Soils***					
A827/2	Little*	Much	-	-	-	A825/4	Much	Trace	-	Mod.	Little
A827/8	Little	Much	-	Little	-	A825/8	Much	Little	Little	Trace	Little
A829/2	Little	Much	-	Little	-	A768/3	Much	Little	-	Little	Little
A829/7	Little	Much	-	Little	-	A768/5	Much	Little	-	Little	Little
A832/2	Little	Much	Mod.	Little	Trace						
A832/9	Little	Mod.	Mod.	Little	-						
Grey Soil of Heavy Texture – Uplands						***Sandstone***					
A819/1	Little	Mod.	Mod.	Little	-	Near A768	Much	?	-	Trace	Trace
A819/3	Little	Mod.	Mod.	Little	-	A770/5	Much	?	-	Little	Little
A819/6	Little	Mod.	Mod.	Mod.	-	A770/11	Much	Little	-	Little	Mod.
A819/7	Much	-	Little	Trace	Trace	***Red Earth***					
A819/9	Much	Little	Little	Trace	Little	A845/2	Much	-	-	Little	Little
(Sandstone)						A845/9	Much	-	-	Little	Little
A931/1	Mod	Mod	-	Little	-	***Red-brown Earth***					
A931/4	Mod	Mod	Little	Little	-	A18/2	Little	Much	-	Little	-
A931/11	Mod.	Little	Little	Little	Trace	A19/2	Little	Mod.	-	Little	-
A931/14	Much	Trace	Little	Little	Little	***Solodized Solonetz***					
A931/15	Much	Trace	Little	Little	Little	17823	Mod.	Little	-	Little	Trace
A931/19	Much	-	Little	Trace	Little	18622	Mod.	Mod.	-	Little	-
(sandstone)						A769/5	Much	Little	-	Little	Little
A934/2	Mod	Mod	Mod	Little	-	A769/10	Much	Little	-	Little	Little
A934/5	Mod	Mod	Mod	Little	-	A771/3	Mod	Mod	-	Little	-
A934/10	Mod	Mod	Mod	Little	-						
A934/11	Mod	Mod	Mod	Little							
A934/12	Mod	Mod	Mod	Little	-						
A934/14	Mod	Little	Little	Little	-						

The existing data are inadequate for determining the relationship of these non-calcareous clays to the Diapur Sandstone. One of the limitations of the data for the latter is that in several profiles the upper sandstone layer in contact with the soil was too silicified for extraction of clay be chemical treatment, and consequently only the underlying softer sandstone could be used for studies of its clay fraction. The description presented earlier of the Diapur Sandstone gave some indication by reference to iron oxide concentrations that its upper hard layer may be an old soil horizon. This possibility reduces the value of comparisons between the clay layers of the soil and the sandstone. Obviously, the problem of their relationship requires further investigations on additional profiles, including attention to variation in composition of the sandstone and to the possible lateral movement of clays on ridges.

Another expression of soil variation along the ridges is shown by the occurrence of solodized solonetz in the sand-free areas only. This soil has many characteristics of the lateritic podzolic type, yet they differ in subsoil structural features and in the occurrence of carbonates and soluble salts. The close association of the solodized solonetz with the grey soil of heavy texture suggests that aeolian deposits of calcareous clay affecting the development of the latter would also have affected the former. In view of the considerations given previously, it is unlikely that the solodized solonetz has been derived from a lateritic podzolic soil that received additions of calcareous clay, but it is possible that it developed from the type of non-calcareous clay found in subsoils of grey soils of heavy texture on ridges.

The points to be considered in dealing with soil variation on ridges, which can be attributed to the effects of aeolian deposits of clay, are that (i) such deposits were not necessarily a uniform blanket but show attenuation as in lunette margins further from source materials, and (ii) such deposits are likely to have been stripped from parts of the ridges by erosion.

Podzols on the ridges are virtually confined to areas of deep siliceous sand. In some instances the sands show similar features to those of nearby lateritic podzolic soils and Diapur Sandstone. The latter two therefore appear to have been important sources of sand for this soil type on the ridges, but local movement of sands from adjacent inter-ridge corridors may also have been an important source in parts of the sandy areas.

The red earths are restricted to sectors of ridges in the desert areas. Their occurrence on high parts in proximity to lateritic podzolic soils and podzols indicates origin by truncation of the lateritic soil. The relevant data for particle size characteristics and clay minerals are consistent with this view.

The main reason for marked soil variation along the ridges is that aeolian deposits of calcareous clay were available for soil formation only in particular zones of the country.

(ii) Variation on Ridges of Different Ages

The conclusion that the Lowan ridges are stranded beach ridges implies that their ages vary. It was suggested above that they represent an age sequence from older in the east to younger in the west, but further investigation is required on this matter.

However, if the ridges consist of relatively uniform deposits, it would be expected that soils residual on such deposits might show some variation from ridge to ridge corresponding to age differences. All evidence indicates that the ridges have a core of Diapur Sandstone. Hand specimens from the deeper layers of this rock are relatively uniform even at widely separated points, but there are slight variations in clay content which may be significant for soil development. Apart from this problem of uniformity of parent material there is the difficulty of determining what is the residual soil on the Diapur Sandstone. It may be represented either by hard upper layers of the sandstone or by the lateritic podzolic soil.

No evidence was found of major variations in profiles of lateritic podzolic soils in the Little Desert, although they occur there on many different ridges from the district south of Kaniva to the margin of the Lowan Salt Lake Valley. No distinctive variation was seen from east to west n the upper layers of Diapur Sandstone, but in fact the present number of exposures is inadequate for detailed studies. Whether or not the secondary deposits of calcareous clay all occurred simultaneously, the obvious variations in their thickness and composition from ridge to ridge discouraged any attention to the relative ages of grey soils of heavy texture on different ridges.

(d) Soil Variation on Inter-ridge Corridors

The podzols and podzolic soils on inter-ridge corridors in the Little Desert are developed in extensive deposits of Lowan Sand. The grey soils of heavy texture immediately north and south of this desert are developed in lowland clays apparently deposited in estuaries or lakes associated with earlier drainage systems of the region. Further south, the inter-ridge corridors show a marked occurrence of solodized solonetz soils, apparently related to variations in the deposits on these corridors.

The local movement os the lowland deposits to form lunettes has led to the formation of soils quite distinct from the adjacent grey soils of heavy texture. Many lunettes show texture-differentiated soils, e.g. red-brown earths, in contrast to adjacent soils on flat land, yet both are developed in calcareous clay as indicated in Table 4 and 5. The reasons for this soil difference have not been established yet.

(e) Comparative Soil Age as indicated by Soil Profiles and Geomorphology

The soil and geomorphic data indicate that there are differences n the ages of soils. The lateritic podzolic soil is regarded as relatively old in view of its differentiated profile and high content of ironstone gravel apparently formed in situ. The grey soil of heavy texture on uplands shows little profile differentiation in the upper layers representing deposits of calcareous clay. This fact and the circumstances of its occurrence on stranded beach ridges indicate that it is a younger soil than the lateritic podzolic type. The solonized brown soil is regarded as young in view both of its lack of profile development, except with respect to carbonates, and its occurrence on lunettes most of which are in the Lowan Salt Lake Valley, a feature younger than the stranded beach ridges. The grey soils of heavy texture on lowlands show more profile development, e.g. with respect to percentages of clay and carbonates (Table 4), than those on uplands and consequently should be regarded as older than the latter. The red-brown earth and solodized solonetz cannot be ranked satisfactorily. The profile development of the former suggests a relatively old soil, yet its typical occurrence on lunettes suggests that it is younger than adjacent grey soils of heavy texture. The solodized solonetz also has a well-developed soil profile and compares with the lateritic podzolic soil, regarded above as comparatively old. However, some solodized solonetz soils occur on ridges and appear to be of similar age to adjacent grey soils of heavy texture, but other examples that occur on inter-ridge corridors, especially in the south, should be regarded, therefore, as younger.

IV. DISCUSSION AND CONCLUSIONS

The investigation showed that County Lowan contains a large number of parallel ridges passing through sandy and non-sandy areas alike. The soil patterns vary from the ridges to the adjacent corridors and also along the ridge and corridors. Soil differences along the corridors are related to sediments of different composition, either predominantly clay or sand, while variations along ridges are related to irregular occurrences of aeolian calcareous clay deposited on older soil material.

These findings account for many features of soil distribution in the county, but in order to explain the irregular distribution of sandy areas, particularly the Little Desert, it was necessary to establish reasons for the uneven distribution of the lowland clays. This was done by determining that the Lowan ridges were stranded beach ridges and that the lowland clay areas represented former drainage courses with a predominantly east-west direction rather than that suggested by Fenner (1918). The concentration of solonized brown soils and solonchakes in the Lowan Salt Lake Valley is another feature of this county that is not readily explained unless the strand-line origin of the ridges is accepted.

The Lowan ridges were identified particularly with this county by Hills (1939), but similar ridges are known to occur elsewhere in the Victorian part of the Murray Basin. Several aspects of the geomorphology and soils therefore require further attention to areas east and north-east of the county. Other aspects of these subjects require more attention to the west, where there is a problem concerning the transition from the calcareous stranded beach ridges of south-east Australia and their distinctive soils (Blackburn, Bond and Clarke 1965) to siliceous Lowan ridges and their soil suites. Other problems are the ages of the strand lines in this county, the order of their establishment, and the identification of their residual soils. Some of the ridges may correspond with Pleistocene glacial-eustatic strand lines at altitudes as claimed elsewhere in southern Australia by Ward and Jessup (1965). Such sea-level changes would not account for the number of ridges found in County Lowan, so diastrophism is indicated as one agency in their development. The establishment of the order of ridge formation would give a foundation for chronological studies of soil development on ridges, provided that residual soils on the Diapur Sandstone can be identified.

The indications of laterite on the ridges both in the soils named lateritic podzolic and in the underlying hard layers of Diapur Sandstone invite further attention, partly because of the possibility that this may be Pleistocene laterite, younger than many other Australian laterites (Stephens 1961).

One of the most interesting aspects of soil development in this county is the contribution of aeolian calcareous clay (parna – see Butler 1956) deposited in limited areas close to their sources. The aeolian movement indicated in the present paper is comparable with the restricted deposition involved in lunettes (Hills 1940) or that referred to by Bettenay (1962) as sheet deposits or lake parna.

The main conclusions are as follows:

(1) The distinctive ridges of County Lowan are stranded beach ridges composed relatively of uniform siliceous deposits yet covered with highly variable soils.
(2) The superficial deposits between the ridges consist either of relatively fine sands, probably deposited soon after the formation of each ridge, and calcareous clays, apparently deposited along predominantly east-west drainage lines before tilting down of the whole area to the north.
(3) Dissected areas are represented in the south by the Glenelg River valley mainly formed since the tilting of the area, and in the east by that defined as the Lowan Salt Valley representing dissection before this tilting.
(4) The characteristic soils of ridges in the Little Desert appear to be derived substantially from Diapur Sandstone and are probably the oldest soils of the area, but it is not clear that non-calcareous clays immediately underlying calcareous clays on ridges outside this desert are derived from these old soils by truncation. Further investigations are required to establish the origin of the non-calcareous clays of this county.
(5) Aeolian movement of siliceous sands has been a localized feature of sandy areas and does not appear to have involved extensive migration of sands from the west.
(6) It should be possible to establish and age sequence for the characteristic soils. Some indications of such a sequence are shown using soil and geomorphic data, but further investigations are necessary.
(7) The peculiar distribution of sandy and non-sandy soils in the county can be explained by reference to (I) the existence of stranded beach ridges with predominantly siliceous deposits, (ii) the irregular occurrence of calcareous clays related to early drainage of the littoral areas, and (iii) localized aeolian movement of siliceous sands and calcareous clays.

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