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A Soil Survey of the Red Cliffs Irrigation District, Victoria

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SUMMARY.

A soil survey has been made of approximately 12,000 acres of the Red Cliffs Irrigation District which is located on the River Murray in the north-west of Victoria. This settlement was established in the years following the Great War, and is devoted chiefly to the production of dried vine fruits, in particular, sultanas.

The soils all belong to the Mallee Zonal Group and are predominantly light textured, being associated with an undulating topography of which parallel sand ridges form the outstanding feature, They have been mapped in 16 types included in 12 soil series, and with the exception of Type 8 and its heavy phase, and the light deep subsoil phase of the Coomealla sandy loam, nave all been previously named and described in other irrigation settlements along the Murray River in South Australia, New South Wales, and Victoria.

The relation between the soil types, vegetation, and topography is discussed, and detailed descriptions of the types are given.

The laboratory analyses of over 100 soil samples have been made, and indicate that these soils conform very closely to the characteristics of other irrigated mallee soils. They have a much lower salt content than the soils of the neighbouring settlements, and, as at Mildura and Merbein, chlorides contribute a relatively small proportion of the total soluble salts. Although no determinations of sulphates were made it is likely that they are relatively important among the salts present.

Profiting by experience gained in the adjoining Mildura and Merbein settlements, the Red Cliffs Settlement was well designed, the channels were concrete lined, and tried cultural and irrigation practices have been employed from the beginning. These facts, together with the low salinity of the soils and the introduction, at an early stage in the development, of a conservative policy of drainage, have prevented the development of any serious salt and waterlogging troubles. In comparison with other settlements, the crops at Red Cliffs are in excellent condition, and productivity is high. At the same time improvement should follow the extension of drainage which has taken place since the installation of the comprehensive drainage scheme.

War time economy requires reduction in the Council's expenditure on publication. It is hoped that the adoption of the photo-lithographic process will be for a brief period only.

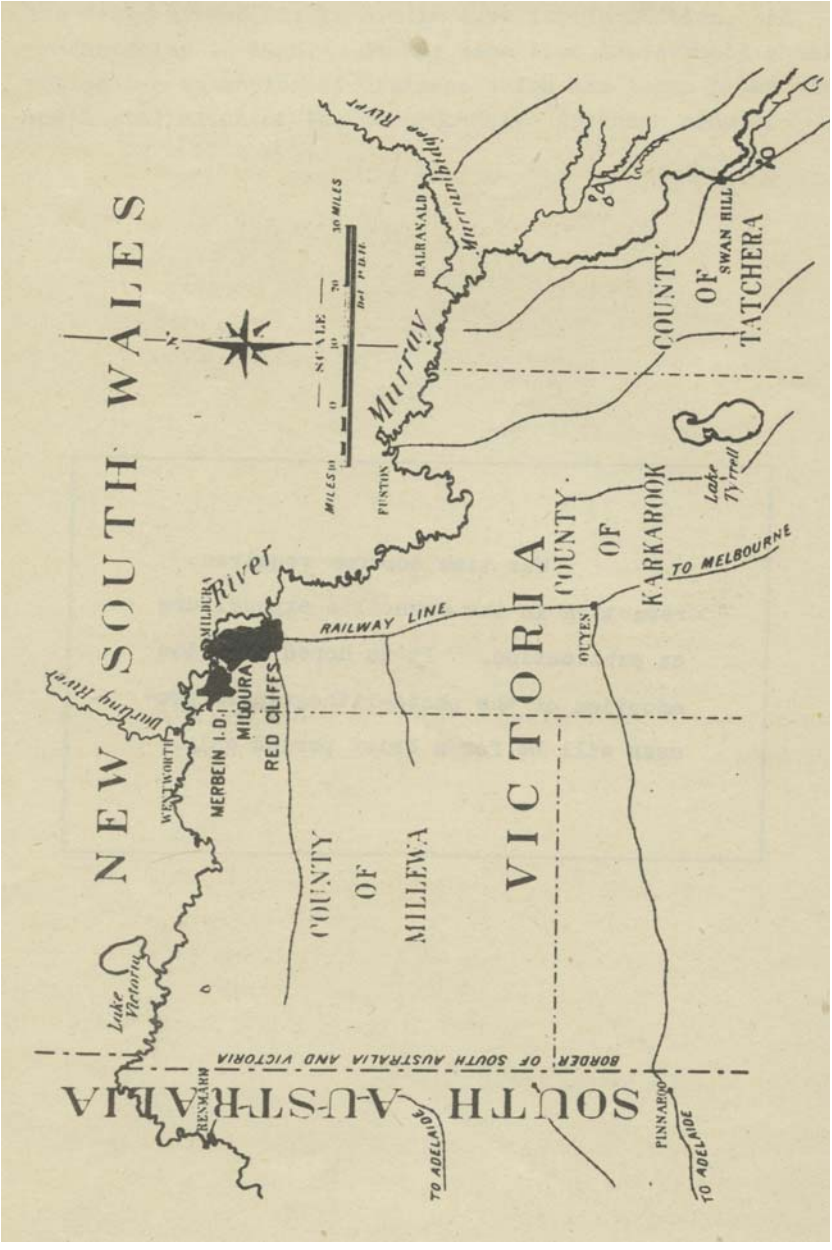

Fig 1 – Locality plan, showing position of soil survey

A Soil Survey of the Red Cliffs Irrigation District, Victoria

Note: The issue of this report brings to completion the survey of the soils of the irrigation settlements which lie round Mildura in the far north-west of Victoria. The Red Cliffs Irrigation District is the most recently established of the settlements in this area. The soils of the Merbein and Mildura settlements have already been discussed in bulletins of the Council for Scientific and Industrial Research (Aust.) Nos. 123 (1938) and 133 (1940) respectively. Since the majority of the soils of Red Cliffs are also found in one or other of these two settlements much of the information given in the bulletins mentioned above may be applied in this case.

The work reported in this publication was carried out by the Division of Soils, Council for Scientific and Industrial Research.[*]

I. INTRODUCTION.

1. The Red Cliffs Settlement.

The Red Cliffs Irrigation District is situated on the River Murray in the Parish of Mildura, County of Karkarooc, in the north-west mallee country of Victoria. Its position in relation to the older settlements of Mildura and Merbein, which lie a few miles downstream, is shown on the locality plan, Fig. 1.

The settlement was established under control of the State Rivers and Water Supply Commission of Victoria in the years following the Great War of 1914-18, as a result of the necessity of settling on the land large numbers of discharged soldiers. The large Red Cliffs Estate of 33,000 acres was one of the areas acquired by the State for this purpose.

The irrigation Settlement itself comprises 18,000 acres. Of this area approximately 11,300 acres, subdivided into 706 blocks, are at present under irrigation. There are 628 growers in the settlement, and approximately 500 of

[*] The field work was shared by Messrs. G. D. Hubble and R. L. Crocker. Of the laboratory work, the mechanical analyses were done by R. G. Downes and the remainder of the analyses by G. D. Hubble. The cartography is due to P. D. Hooper.

the holdings are occupied by discharged soldiers.

The experiences of the older adjoining settlements of Mildura and Merbein in horticultural and irrigation practices and in type of crop, as well as in the marketing of produce, have been of considerable value to the settlement.

The early development was carried out on sound lines, and was very rapid. Clearing and construction works were commenced in 1919/1920, the first plantings being made in the spring of 1921, and the first harvest, taken off in 1924, yielded 570 tons of dried fruit in addition to a certain amount sold fresh for table purposes. Production increased rapidly, reaching 17,000 tone of dried fruit in the 1928/29 season, and in the record 1937/38 season 18,000 tons of dried fruit were harvested as well as large quantities of citrus fruit and some grapes sold fresh for dessert and distillation.

Details of the acreages of the various crops for that year, given in Table 1, show the importance of the sultana in the district, 73 per cent of the land then irrigated being under this crop.

Table 1 - Areas of Crops under Irrigation in the Red Cliffs District.

(In acres)
Season 1937-38

Sultanas	Currants	Gordos	Other Vines	Citrus	Other Fruits	Lucerne	Pasture Land	Total
8266	1021	822	264	501	76	120	185	11, 255

At the present time the settlement supports a permanent population of approximately 3,150 persons, and in addition, about 1500 persons are required each year for the harvest.

2. Irrigation and Drainage Works.

The pumping plant at Red Cliffs with a capacity of 500 acre feet of water per day, the highest for any pumping system in Australia, is driven by electric power, generated at the station. The irrigation water is drawn from the Murray River and is distributed to the holdings through 125 miles of channels, 120 miles of which are concrete lined, thus minimizing seepage losses which would be excessive from earth channels in such light textured soils. Most of the few miles of unlined channels are away from irrigated holdings.

Three pumping lifts are necessary to water the area. The largest part of the settlement is watered from the 1st lift, the water being raised 90 feet through a reinforced concrete rising main. Water for the 2nd lift of 21 feet is pumped by electric power from the let lift channels, and two further substations pump water from the 2nd lift channels to serve smaller areas of 3rd lift country. The crests of the sand-rises in many parts of the settlement are above the present irrigation levels and are not watered. The water right is for 2½ acre feet per annum delivered in 6 waterings, and the annual charge of 70/- per acre, the highest in Victoria, is rendered necessary by the cost of such a high pumping lift. Water in excess of the water right is supplied at the rate of 10/- per acre per irrigation.

Early drainage in the settlement was into shafts sunk to "drift" sand, or, in the case of settlers favourably situated on the fringe of the settlement, on to unoccupied river flat or mallee land. However, the recognition of the importance of drainage to the maintenance of the productivity of these soils led to the construction of a comprehensive subsurface drainage scheme discharging into the river, on to river flats, and into natural depressions in the unoccupied mallee country behind the settlement. This work, which was commenced in 1934 and completed in 1938, was financed largely by the State Government, the growers contributing £5 per acre of their holdings. A total length of 85 miles of pipe drains and 5 miles of channels have been constructed, and 9,700 acres of holdings are now provided with gravitational outfalls for drainage waters by this scheme. Allotments not included are on the fringes of the settlement and have satisfactory outfalls on unoccupied crown lands or river flats.

3. Climate.

Accurate meteorological records are not available for a sufficient number of years for Red Cliffs to give a true indication of the climate. It is essentially the same as that of Mildura, which lies 11 miles to the north-west and has been fully discussed in Bulletin 133 of the Council for Scientific and Industrial Research. The data shown in Table 2, which have been reproduced from that bulletin, were compiled from figures made available by the Commonwealth Meteorologist (rainfall, humidity, and temperature) and the Officer-in-Charge of the Commonwealth Research Station, Merbein (wind-velocity, evaporation, and frost records).

Table 2 - Meteorological Data for Mildura.

	Rainfall (in.)	Mean Max. Temp. F.	Mean Min. Temp. ^{o}F	Relative Humidity	Wind Velocity (m.p.h.)	Evaporation (in.)	No. of Frosts
No. of years	49	44	44	26	12	12	12
January	0.70	91.0	61.5	51	2.3	9.40	..
February	0.70	91.3	61.8	56	1.9	7.17	-
March	0.77	84.8	56.5	61	2.0	6.31	-
April	0.65	75.5	49.8	68	1.9	3.88	0.1
May	1.03	67.3	45.2	75	1.4	2.61	2.0
June	1.26	60.7	41.3	82	1.4	1.81	5.6
July	0.88	59.7	40.0	83	1.4	1.91	6.5
August	1.09	64.0	42.1	73	2.0	2.52	4.3
September	0.95	70.0	45.8	65	2.4	3.91	2.0
October	1.05	77.1	50.2	58	2.6	5.25	0.3
November	0.74	84.7	55.4	51	2.2	7.66	-
December	0.81	89.0	59.1	50	2.2	8.61	-
Year	10.63	-	-	-	-	60.96	-

Rainfall records for Red Cliffs are as follows:-

No. of Years	Monthly Averages.												Year
	Jan.	Feb.	Mar.	Apl.	May	June	July	Aug.	Sept.	Oct.	Nov	Dec.	
13	0.71	1.09	0.87	0.69	0.84	0.84	1.06	1.11	0.57	0.96	0.77	0.78	10.47

Briefly, the climate is ideally suited to the production, under irrigation, of dried vine fruits; the rainfall is low with a winter maximum, the spring and summer are dry with high temperatures and a high evaporation rate, and the incidence of frost is low in the critical months of September and October.

Frosts causing appreciable commercial damage have been recorded for Red Cliffs, on seven occasions as follows:-* 1927, September 24th; 1930, September 24th; 1932, October 9th; 1934Cardrosser 22nd and October 5th; 1939, September 22nd and 23rd.

However, damage is negligible in most years over the greater part of the settlement, although the low area round Cardross is particularly liable to spring frosts. In 1936, following a succession of seasons in which damage had been severe in this area, an organisation known as the Cardross Frost Club† was formed. Frost alarm thermometers have been set up on selected properties and are in operation during the critical months. The landowner is

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* Information supplied by the State Rivers Year Water Supply Commission, Victoria.

† Information supplied by A. V. Lyon, Officer-in-Charge of the Commonwealth Research Station, Merbein.

awakened by a warning bell which rings when the temperature falls to 32^0 F. and, through an arrangement with the postal department, all members of the club are then warned by telephone. On each occasion approximately 40 to 50 growers then commence heating by lighting up a number of pails of crude oil, up to 60 per acre according to the severity of the frost. Brown coal briquettes are used by some growers, but are losing favour. This practice has been found effective in either preventing or considerably reducing damage to the vines. Over the last 5 seasons heating was found necessary 6 times in 1935, twice in 1936, twice in 1937, 3 times in 1938, and 9 times in 1939.

Occasionally damage is caused to the currant crop in late December and early January by monsoonal rains which may contribute considerably to the annual total in certain years. At other times much damage may be done by hail storms such as those which occurred in October, 1934, and December, 1936, and, as in the 1938-39 season, early rains before the fruit is harvested may cause considerable damage to the sultana crop.

II. THE SOILS.

1. General Features.

The soils of the Red Cliffs Irrigation Area all belong to the Mallee Zonal Group the general characters of which have been defined and discussed for Australia by Prescott,[*] and by Prescott and Piper[†] for South Australia.

At Red Cliffs many of the soils have developed on deep unconsolidated alluvial deposits. These sediments are exposed in a cliff face at the centre of the eastern edge of the settlement, where the river has cut through them to a depth of 50 to 60 feet. The succession of horizons is illustrated below:

0- 9 ft.	normal soil profile
9-20 ft.	bluish grey clay (sandier with depth)
20-30 ft.	mottled red and grey clay and sandy clay
30-50 ft.	red coarse sandy clay loam with grey inclusions and manganiferous and ferruginous concretions
50 ft.	river level - coarse cemented quartz grit.

Thomas[§] has mentioned very similar layers underlying Merbein soils where the bluish grey clay resembles recently deposited river alluvial clays in mechanical composition and reaction. In the Mildura settlement also a heavy bluish grey clay having an acid reaction underlies many of the soil types at shallow depth. This layer is practically impervious when wet and probably holds up much of the water which frequently accumulates in the sandy soil types at Merbein, Mildura, and Red Cliffs. In the latter settlement it is frequently exposed in hollows by excavations for silt boxes and main drains.

The country is gently undulating. It is made up of long and narrow sand rises, which are roughly parallel and generally run in an east-west direction. They are seldom more than 30 feet and frequently only 15 to 20 feet high, separated by hollows with heavier soils. The sand rises have been formed either by the re-sorting of the uppermost layers of the alluvial deposits by wind action, or by the deposition of material transported to the area from the surrounding country by wind. The chief topographical feature of the area is a long, more or less continuous ridge of sandy country which extends some miles, from a little west of Red Cliffs township, in a north-south direction. Hills[*] (1939) has studied the physiography of North-Western Victoria in great detail and considers that these major ridges, like the 'Red Cliffs Ridge', are due to faulting and warping in the basement complex, and probably connected with positive movements of elevation in Pleistocene and Recent times. Although

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[*] Prescott, J. A. Coun. Sci. Ind. Res. (Aust.) Bull. 52, 1951.

[†] Prescott, J. A., and Piper, C.S. Trans. Roy. Soc. S. Aust. LVI:118,1932.

[§] Themes, J. E. Corm. Sci. Ind. Res, (Aust.) Bull. 128, 1959.

[*] Hills, E. S. Proc. Roy. Soc. Vict. 51(N.S.). Pt. I : 297,. 1939.

his observations are based on examinations of the more southerly of these ridges it seems safe to assume that they are all underlain by the Miocene and Lower Pliocene series.

In general the soils are brown to red brown in surface colour, and light in texture, with occasional areas of the grey-brown types which originally carried a vegetation dominated by the mallees. The subsoils are light brown in colour, usually containing much lime and some limestone rubble. The maximum concentration of calcium carbonate, including rubble, occurs at a depth of 2 to 3 feet, and frequently continues to a considerable depth even in the red brown clay subsoils of the heavier types. As a general rule calcium carbonate content decreases with increasing clay content in the deep subsoil.

The rubble is frequently very sharp and angular, rather than in the form of rounded nodules as in most mallee soils, and in some parts of the settlement it is present in such quantity as to be impenetrable with the post-hole type soil auger. Occurrences are most common in the soils of the lower slopes and hollows, very little being found in the sandy rises. In the Loveday and Moorook sandy loams,[*] soils which originally carried mallee, stone and rubble are present in considerable amounts, usually quite close to the surface.

A certain amount of lime-cemented pan is also frequently found in the lime horizons of the Red Cliffs soils, particularly in the sand types and in the Berri, Barmera, and Coomealla (light phase) sandy loams. This material is of varying hardness, and, after having been broken up by the soil auger, is often mistaken for rubble. Its presence has been observed in open drainage cuts, and it is likely that it retards the penetration of irrigation water over small areas in some parts of the settlement.

The deep subsoils are generally light brown to reddish brown in colour; only in odd holes was greyish clay met within the 6 ft. depth of the borings. In the main they are light in texture, and even the heavier types with clay subsoil - the Nookamka sandy loam and loam and the Belar clay loam in particular - frequently show a tendency to become lighter in texture below 5 feet. Below the lime horizon, which continues as deep as 12 feet in some of the light types and may go even deeper, the soil is usually light red-brown or brown to red-brown in colour and often contains black inclusions of manganiferous material.

Gypsum is seldom found in these soils. Its occurrence is limited to the small amounts which are occasionally met at a depth of 3 to 4 feet in the subsoil of the Belar clay loam.

[*] For descriptions of these and other soil types see text below.

2. The Classification. Distribution and Extent of the Soil Types.

(i) Classification.

The soils of the Red Cliffs Irrigation Area are very similar to those of the Merbein settlement in Victoria, the Coomealla settlement across the river in N.S.W., and the Berri-Cobdogla district in South Australia. In the north-west corner or the settlement there are limited occurrences of some of the heavy, grey subsoil, types which characterise the Mildura district. With the exception of a small area of a new unnamed type, and an area of soils which have not been classified because of their extreme variability and the con- sequent difficulty of mapping them satisfactorily, it was possible to include all the soils mapped in types which have been previously named and described in these settlements. Some modification of the original definitions was necessary ***in*** certain instances.

Altogether 16 types and 5 phases - including the unnamed type and a phase - were mapped in 12 soil series. Because of the importance of the occurrence of a clay horizon in the deep subsoil of the light types, and the tendency to become lighter in texture in the deep horizons of the heavier types, the majority of the borings on which the soils were classified were to a depth of 6 ft.

The soil boundaries shown on the map should not be interpreted rigidly. Despite the detail with which the survey was made it was difficult to map as definite soil types the more or less continuously variable slope from the top of a sand-rise to the bottom of the neighboring hollow, more particularly as many of the types have surface soils of the same colour and texture. Ideally the lightest textured soils of the crests of the sand rises - Murray and Winkle sands - are surrounded by concentric bands of the heavier sand types - Berri and Barmera sands. On gentle slopes it is usually possible to draw these boundaries with reasonable accuracy, but on steep slopes the same variation in profile may occur over a much shorter distance, and preclude delineation on practical grounds. In all cases a transition zone should be understood to exist between adjacent type areas.

Variation within the soil type is often considerable, particularly in the depth of the different horizons of the profile. It is of most importance in the depth of the surface soil, and the depth to the clay horizon of the heavier types.

The separation of the soils into types is mainly on the basis of the colour, texture, and depth of the horizons, and the amount of lime and rubble present in the profile. In the separation of the Winkle and Murray sands, Vegetation is important; the Murray sand usually had a vegetation dominated by pine and belar, whereas the Winkle sand carried a vegetation of small mallee and porcupine grass. In addition the Winkle sand had a brown, incoherent sand surface.

(ii) Distribution and extent of the soil types.[*]

The distribution of the soil types in the area is shown in detail on the soil map.[†] In general, most of the light types are well distributed throughout the settlement. A notable exception is the Winkle sand, occurrences of which are limited to the south-western corner and the southern edge of the irrigated area. Of the heavier soils, the grey clay subsoil types - Mildura loam and Irymple clay loam - are practically limited to a small area just inside the northern boundary of the settlement where it joins with the Mildura irrigation area west of the Melbourne-Mildura railway line. The Belar clay loam, also, is of restricted distribution and limited extent, the largest individual areas of this type occurring in the wider hollows of the northwest and southeast sections. The brown to grey-brown soil types - Moorook, Coomealla, and Loveday sandy loams, and the Sandilong loam -are found mainly in the north west and to a lesser extent in the south-east of the area, with occurrences of the light deep subsoil phase of the Coomealla sandy loam almost confined to the area east of the railway line.

3. Relations between Topography, Soil Type, and Vegetation.

Brief reference has already been made to certain relations which have been observed between soil type, native vegetation, and topography.

The most obvious relation exists between topography and the texture of the soils. The crests of the long narrow sand rises are nearly always Murray or Winkle sands, occasionally Berri or Barmera sands, while the hollows are made up of soils of the Nookamka and Belar series. At the same time, on certain sand rises where one might expect to find the very light Murray sand, Barmera sand occurs instead, and Murray sand may be met on the slope. From an examination of these occurrences it is apparent that the relation between soil type and contour is a relative one only, and that degree of slope has a much more important relationship with soil type than absolute elevation. Heavy and light soils may both be found at all levels throughout the settlement, but where slope is steep the soils are usually light, and where there is little or no slope the heavier types are found. The same relation between soil type and topography has been noted by Marshall and Walkley[*] for the Coomealla soils.

Murray and Winkle sands are found, then, on the crests of the narrow sand ridges or on the steep slopes, Berri and Barmera sands on the less steep slopes, or on the flattish tops of the broader sand ridges, while on the lower, gentle slopes the Barmera, Coomealla, Loveday, and Nookamka sandy loam commonly occur. The Nookamka loam and Belar clay loam are always found in flat areas, and are best developed in the bottom of broad hollows. Type 8 and sometimes Nookamka sandy loam occur most frequently either in the

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[*] For summary of soil type descriptions see Table 3.

[†] See folder at back of bulletin.

[*] Marshall, T.J., and Walkley, Allan.-Coun. Sci. Ind. Res. (Aust.) Bull. 107, 1937.

narrow, shallow depressions, or else round the Nookamka loam and Belar clay loam in the Wider hollows. These relationships are well illustrated in Fig. 2.

In the absence of the native vegetation over the planted area, and with the incompleteness of the isolated remnants remaining along roads and on highland, it is impossible to get more than a sketchy idea of the original vegetation. It appears, however, that the relationship between soil type and vegetation is less definite than that between soil type and topography.

The most important trees over the greater part of the settlement were pine,[†] belar, and sandalwood, with mallee more important on certain smaller areas. As mentioned previously, evidence of the occurrence of a vegetation of small mallee and porcupine grass was used in the separation of the Winkie sand which always occurs on the crests of the rises. Occasionally this vegetation extends down the slope over soils which have been mapped as Berri sand. The other sand types - Murray, Berri and Barmera sands - usually carried a mixed vegetation of pine, belar, and sandalwood, often associated with hopbush, *Cassia* spp., *Acacia* app., and other shrubs. Pine is usually dominant on the Murray sand, both when it occurs on the top of the ridges and on the steep slopes off the crest of the rise, and often occurs as an almost pure stand. Medium to large belar is usually dominant on the Barmera sand, particularly when it occurs on the top of the broad sand rises where the vegetation is usually larger belar with odd trees of pine and sandalwood and a few shrubs. There is evidence that some pine has been cut from unplanted areas of this nature. In the south-east of the settlement some areas of Berri sand appear to have been covered mainly by *Cassia* spp., *Acacia* spp., and other shrubs. Elsewhere, the vegetation occurring on this type seems to have been pine, belar, and sandalwood, with many small shrubs, and sometimes with pine the dominant tree.

There is very little evidence of the vegetation which grew on the brown to red-brown soils of the slopes - mainly the Barmera sandy loam. From the vegetation which has been left standing along roads, belar and sandalwood seem to have been the most important trees, though odd pines and mallees etc. are present at times. Associated with these trees, which are much more widely spaced here-than on the sand rises, is a lower canopy of small trees and shrubs. Species of the genera *Hakea*, *Heterodendron*, *Eremophila*, *Acacia*, *Cassia*, *Dodonaea* and others are common.

[†] Botanical names of these and other common plants occurring at Red Cliffs and referred to in the following pages are:-
Callitris robusta (Murray Pine); *Casuarina lepidophloia* (Belar); *Myoporum platycarpum* (Sandalwood); *Fusanus acumi atus* (Quondong); *Hakea vittata* (Needlewood); *Heterodendron oleifolium* (Bullock Bush); *Eucalyptus dumosa*, *E. gracilis, E. oleosa* and *E. viridis* (Mallees); *Dodonaea attenuata* (Hopbush), and *Triodia irritans* (Porcupine Grass).

The brown to grey-brown soils of the slopes and some flatter areas in the hollows - the Moorook, Coomealla, and Loveday sandy loams, and the Sandilong loam - all apparently carried a vegetation dominated by the mallees. With them occurred many other small trees and shrubs, chiefly of the genera *Hakea*, *Fusanus*, *Pittosporum*, *Myoporum*, *Acacia*, and *Eremophila*. The soils supporting this vegetation usually contain a certain amount of lime rubble, often large amounts, occurring quite close to the surface.

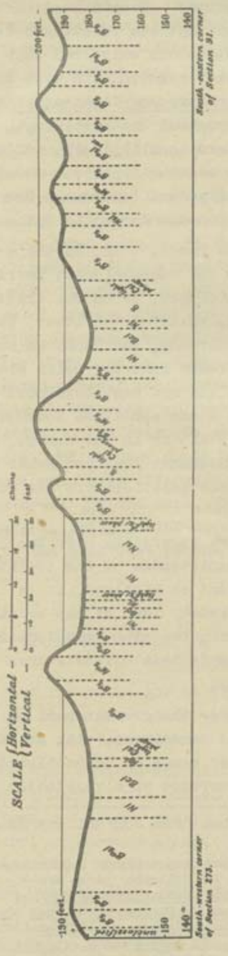

Fig.2 - A cross section of Red Cliffs soils showing the topographic relation of some of the soil types.

N.B. The section runs in a roughly north-south direction from the south-western corner of Block 273 to the south-eastern corner of Block 91 and is approximately at right angles to the long axis of the sand rises.

Key to the Soil Types:

Murray sand	M^us	Barmera sandy loam	B^asl	Nookamka sandy loam	Nsl
Berri sand	B^es	Coomealla sandy loam	Csl	Nookamka loam	Nl
Barmera sand	B^as	Type 8	8	Belar clay loam	Bcl

Table 3 - Summary of Soil Descriptions.

Soil Type	Profile			Topographic position and vegetation
	Subsurface soil	Subsoil	Deep subsoil	
Murray sand	Red-brown to brown sand 0"-18".	Brown to light red-brown sand 18"-30"	Light brown sandy loam or sand with some lime and pan 30"-72"	Crests of sand rises and steep slopes, carrying pine.
Winkie sand	Pale brown to brown - red-brown sand, usually of poor coherence 0"-16"	Brown to light red-brown sand 16"-27"	Light brown sandy loam or sand with variable slight to medium lime and some pan or rubble 27r-72"	Crests of Sand rises carrying small mallee and porcupine grass.
Berri sand	Red-brown to brown sand 0"-16"	Brown to light brown sand 16"-21", increasing to sandy loam with some lime and pan 21"-36"	Light brown sandy loam to sandy clay loam with variable slight to moderate lime, and some pan or rubble 36"-72"	Upper slopes of the rises usually carry mixed pine and belar sometimes some mallee.
Berri sandy loam	Red-brown to brown sandy loam 0"-12"	Brown to light brown sandy loam 12"-21".	Light brown sandy loam to sandy clay loam with lime and some lime pan or slight rubble 21"-72"	On long gentle slopes, or small saddles between two rises, carrying pine, belar, and shrubs.
Barmera sand	Red-brown sand 0"-12"	Light brown sand 12"-18" becoming sandy loam to sandy clay loam with some lime 18"-30".	Light brown sandy clay loam with moderate lime and some pan or slight rubble 30"-72"	On gentle slopes, or the gently sloping crests of the broad rises, carrying mainly belar and shrubs.
Barmera sand - Stony phase	As for Barmera sand.	As for Barmera sand but with a band of medium or heavier stony rubble somewhere between 18"-48"	As for Barmera sand, but may be somewhat heavier with depth.	On gentle slopes, usually carrying some mallee with the belar and shrubs.
Barmera sand - Shallow phase	As for Barmera sand.	As for Barmera sand.	Light brown clay loam or sandy clay with moderate lime, texture becoming heavier with depth 45"-72".	On lower gentle slopes carrying belar and shrubs.
Barmera sandy loam.	Brown to red-brown sandy loan.	Light brown sandy loam to loam or sandy clay loam with some lime 12"-21"	Light brown sandy clay loam with moderate lime and some slight rubble 21"-72".	On the lower gentle slopes carrying belar and shrubs.

Soil Type	Profile			Topographic position and vegetation
	Subsurface soil	Subsoil	Deep subsoil	
Barmera sandy loam - shall. phase.	As for Barmera sandy *loam.*	*As* for Barmera sandy loam.	Light brown clay loam or sandy clay with lime and slight pan or rubble, texture increasing 45"-72".	On lower gentle slopes carrying belar and shrubs.
Moorook sandy loam.	Brown to grey-brown sandy loam 0"-12".	Light brown sandy loam to sandy clay loam with medium stony rubble and light lime 12"-21"	Light brown sandy loam to sandy clay loam with medium lime and sane rubble 21"-72".	On the upper stony slopes carrying mallee,
Coomealla sandy loam.	Brown to grey-brown sandy loam 0"-12".	Light brown sandy clay loam with lime and slight to light rubble 12"-52".	Light brown to red-brown sandy clay or light clay with some lime and slight rubble de-creasing 52"-70".	On lower gentle slopes and in hollows, carrying mallee.
Coomealla sandy loam - light deep subsoil phase	As for Coomealla sandy loam.	As for Coomealla sandy loam.	Light red-brown sandy clay loam or lighter with some slight lime and pan 48"-72".	On upper slopes carrying mallee.
Loveday sandy loam.	Brown to grey-brown sandy loam 0"-12".	Light grey-brown sandy loam increasing to sandy clay loam, with medium stony rubble and lime 12"-30" light rubble and medium lime 30"-54".	Light brown to red-brown sandy clay or light clay with pockets of lime and slight rubble 54"- 64" becoming heavier with less lime 64"-72".	On stony lower gentle slopes or hollows, carrying mallee.
Sandilong loam.	Brown to grey-brown sandy loam or loam 0"-12".	Brown to light brown sandy clay loam with light lime and rubble 12"-50", becoming clay loam with lime 30"-50".	Light brown to brown light clay with some lime 50"-80", some-times with black and grey inclusions 60"-72".	On gently sloping ground usually in the bottoms of hollows, carrying mallee.
Nookamka sandy loam	Red-brown to brown sandy loam 0"-14".	Brown to light brown sandy clay loam with slight lime 14"-26", clay loam or sandy clay with light lime and rubble 26"-40".	Light brown sandy clay to light clay with medium lime and possibly some rubble 40"-60", becoming red brown with less lime 60"-72".	On lower slopes and in small hollows, carrying belar and shrubs.
Nookamka loam.	Red brown to brown loam or sandy loan. 0"-12".	Brown sandy clay loam with slight lime 12"- 16" clay loam with alight lime and rubble 16"-27", light clay with moderate lime and variable rubble 27"-48".	Light brown to red-brown light or medium clay with some lime 48"-60", medium clay with variable slight lime 60"-72".	In the flatter areas and hollows, carrying belar and some pine as scattered trees.

Soil Type	Profile			Topographic position and vegetation
	Subsurface soil	Subsoil	Deep subsoil	
Belar clay loam.	Brown to red-brown loam or clay loam 0"-12".	Brown or light brown light clay with slight lime 12"-18", medium clay with slight lime 18"-40".	Brown or light brown medium or heavy clay with slight lime and rubble, or some gypsum 40"-72".	In broad flat-bottomed hollows or open flat areas, carrying large belar and open grassy areas.
Type 8	Brown to red-brown sandy loam or loam 0"-16".	Light brown clay loam or sandy clay with slight to light lime and slight rubble 16"-40".	Light brown sandy clay loam with medium or heavier lime and variable rubble 40"-72".	Usually in narrow small depressions carrying belar and some pine.
Type 8 heavy phase.	Brown to red-brown sandy loam or loam 0"-9".	Light red-brown clay loam 9"-15", becoming light brown light to medium clay with same lime 15"- 30", texture becoming lighter with medium lime 30"-40".	As for Type 8 above	Usually in narrow depressions or round heavier soils in larger hollows, carrying belar.
Mildura loam.	Grey or grey-brown loam 0"-6".	Light brown sandy clay loam with light to moderate lime and rubble 6"-20", becoming heavier to light grey-brown and grey light clay with light lime 30"-40".	Mottled grey medium clay with gypsum 40"-60", becoming heavy clay with gypsum 60-72".	On flats between sand rises in some parts, carrying mixed mallee and bluebush.
Irymple clay loam.	Grey or grey-brown loam to clay loam 0"-9".	Light brown or grey-brown with slight lime 9"-12", becoming heavier to mottled light grey-brown and grey light clay with light lime 20"-27".	Mottled light grey-brown. grey, etc. medium clay 27"-36" and medium or heavy clay frequently with gypsum 36"-50". Grey or blue-grey heavy clay 50"-72".	Usually on broad flats between sand rises, and carrying mainly bluebush, with odd mallees.

The heavier soils of the hollows support a still more open vegetation with fewer trees and shrubs. The belar clay loam, the heaviest type of any importance, carried large belar trees separated by open more or less grassy areas. In some parts cabbage trees also occur. On the Nookamka types, pine and belar, though widely spaced, frequently occur in about equal numbers with an undergrowth of *Cassia* spp., *Acacia* spp. *Hakes* spp., and others.

4. Description of Soil Types.

The profile diagrams included below illustrate only this more important changes of colour, texture, etc., with depth, and, for each type, represent the average of a number of observations made during the survey.

(a) <u>Murray sand.</u> See also Coun. Sci. Ind. Res. (Aust.) Bulls. 86, 107, 123, and 133.

In the areas in which Murray sand was first named and described its occurrence was limited to the high rises close to the river valley. At Red Cliffs, however, as at Mildura, Merbein and Coomealla, the very light sands of the crests of the narrow parallel sand ridges and the steep slopes, on the plain well away from the river, have been mapped as this type. Many of the occurrences on the tops of the sand rises are above present irrigation level. As shown in Fig. 3, the soil is sandy to a depth of 6 feet and contains very little lime and less, if any, rubble, though a certain amount of lime-cemented sand pan occurs in the lime horizon at times. Occasionally also, there is a slight increase in texture to a sandy loam to sandy clay loam for a few inches only in this horizon, or at a depth of 5 feet 6 inches to 6 feet. In some of the third irrigation lift country east of the railway line, where the sand rises are much less pronounced than in the rest of the settlement, a few occurrences of Murray sand have been mapped with a shallow surface horizon, 12" to 18" deep, of sand to sandy loam texture overlying the normal deeper horizons. These areas have been marked "shallow surface" on the map.

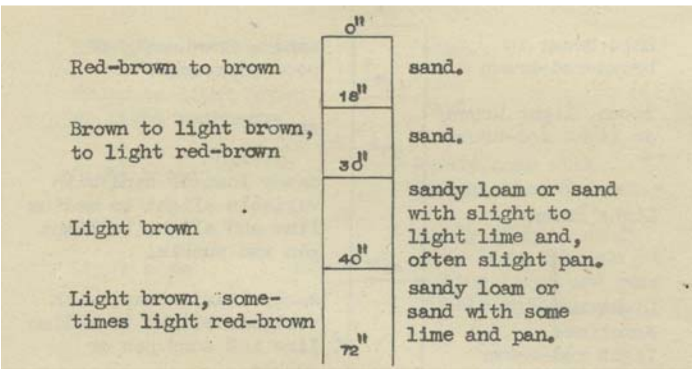

Fig. 3 - Murray sand.

(b) Winkie sand. See also Coun. Sci. Ind. Res. (Aust.) Bull. 86.

The soils of the crests of the sandy rises which carry a vegetation association of small mallee and porcupine grass; and which occur along the southern and south-western boundary of the planted area, have been mapped as Winkie sand. Occurrences at Red Cliffs differ from those at Berri, South Australia, where the type was first described, mainly in the depth of sand to the lime horizon where the texture is also somewhat heavier, and in the amount of lime and rubble in the deep subsoil. At Berri the lime horizon usually occurs below 40", whilst at Red Cliffs the average depth is 27". The surface soil is brown in colour rather than red-brown, and of poor coherence, this feature being associated with a low clay + silt content (See Appendix Table VII). The deep subsoil varies between sand and sandy loam in texture and often contains much lime and lime cemented pan. A considerable amount of rubble is also occasionally present. Whereas at Berri coarse and fine sand are present in approximately equal amounts, at Red Cliffs fine sand predominates throughout the profile, the ratio of coarse to fine sand for the surface horizon being 0.6.

The vegetation of small mallee and porcupine grass indicative of low fertility is the most important single feature distinguishing the Winkie from the Murray Sand; a description of an average profile is given in Fig. 4.

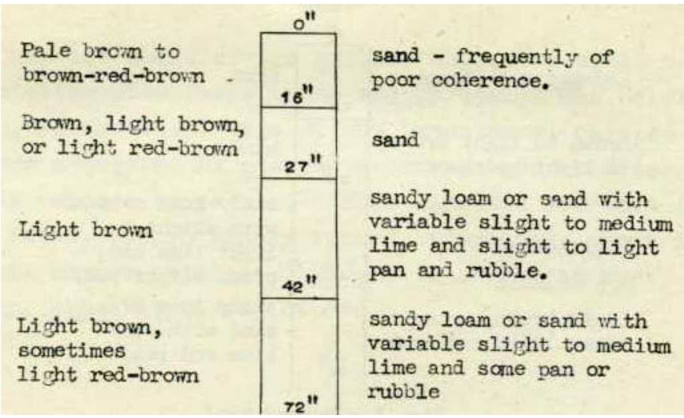

Fig. 4 – Winkie sand

Berri Sands. See also Coun. Sci. Ind. Res. (Aust.) Bulls. 86, 107, 123 and 133.

Average profiles of the Berri sand and sandy loam for the Red Cliffs Irrigation area are shown in Fig. 5 (a) and (b).

(a) **Berri sand**

Occurrences of this type at Red Cliffs conform fairly closely to previous descriptions. They are usually on steep slopes below the Murray or Winkie sand, and occasionally on the crests of lower rises. When associated with the Winkie sand the surface of the Berri sand is rather dull in colour, and loose in texture. The type covers a fairly wide variation in the texture of the subsoil, and includes those soils too heavy for the Murray or Winkie sand, and yet too light for the Barmera sands. The texture of the subsoil often rises to a sandy clay loam somewhere below 50". Sometimes the profile has a very light deep surface similar to the Murray sand, increasing to sandy loam to sandy clay loam at approximately 40", then to a sandy clay loam below 54". Lime and rubble are variable, often as much as medium, and some pan is frequently present.

(b) Berri sandy loam

There is little difference between the Berri sandy loam mapped at Red Cliffs and other occurrences of the type. Only a small area occurs in this settlement either on long gentle slopes, or on the saddle between two rises. The texture of the subsoil is very variable, usually between sandy loam and sandy clay loam, but the deep subsoil is sometimes as light as a clayey sand, light red-brown in colour.

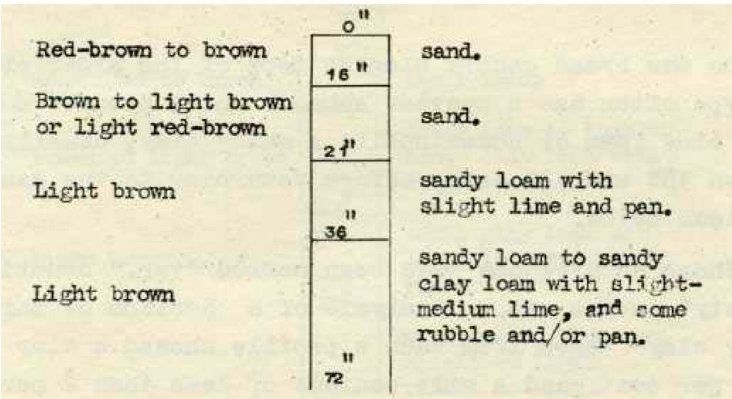

Fig. 5 – (a) Berri sand

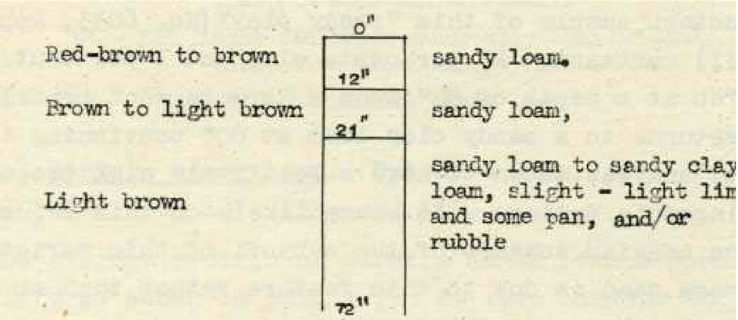

Fig.5 – (b) Berri sandy loam

Barmera series

(a) Barmera sand. See also Counc. Sci. Ind. Res. (Aust.) Bulls. 107,123 and 133.

An extensive area of the normal form, and small areas of both the shallow and stony phases of the Barmera sand are found at Red Cliffs. They agree very closely with the original descriptions, though the stony layer, which occurs between 18" and 48" deep (average 33") in the stony phase, shows very little evidence of cementation as at Mildura. This layers is not always penetrable with the soil auger, but as far as can be determined the deep subsoil is the normal sandy clay loam. The average depth to the clay loam or sandy clay horizon of the shallow phase at Red Cliffs is 48", and the texture may increase below to a medium clay at approximately 6 feet. The normal form is shown in Fig. 6 (a).

On the broad gently sloping tops of the wider rises the type often has a heavier subsoil which becomes a heavy sandy clay loam or occasionally a sandy clay, usually between 30" and 48" deep, before returning to the sandy clay loam below.

These occurrences have been marked "var." denoting "variety" on the map. Analysis of a horizon of this "sandy clay" taken from such a profile showed a clay content of 20 per cent and a silt content of less than 2 per cent, figures which are normal for a sandy clay loam and indicate a dispersed condition of the clay.

Another sample of this "sandy clay" (No. 6033, Appendix Table II) containing 17 per cent clay and 1 per cent silt was taken at a depth of 54" from a Barmera sand profile which returns to a sandy clay loam at 80" continuing to 12 feet, and was shown to have a relatively high proportion of replaceable sodium. It seems likely on this evidence that the heavier texture of the subsoil of this variety of Barmera sand is due to this feature rather than to any increase in clay and silt content.

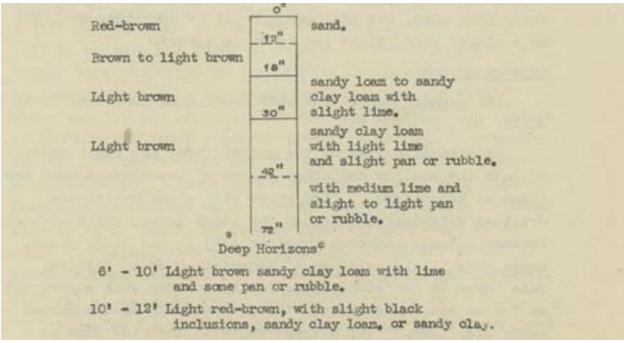

Fig. 6 - (a) Barmera sand.

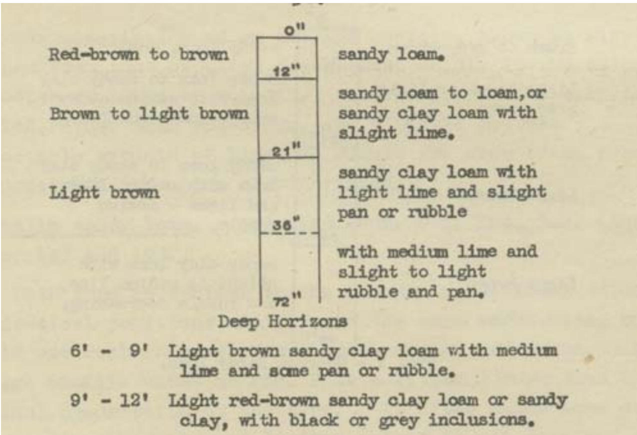

Fig. 6 - (b) Barmera sandy loam.

(b) **Barmera sandy loam**. See also Coun. Sci. Ind. Res. (Ault.) Bulls. 86, 107, 123, and 133.

The average profile of Barmera sandy loam mapped at Red Cliffs as shown in Fig. 6 (b) is very similar to previous descriptions of the type. Abnormally large amounts of rubble are found in the subsoil of this type in certain parts of the

* Descriptions of the deep horizons, where given, are based on no more than one or two deep borings in each case, and are only intended to give an approximate idea of deeper soil conditions

settlement. As at Merbein and Mildura a shallow phase has been separated with a clay loam or sandy clay horizon between 45" and 60" deep, and some areas, in which there is a temporary increase in texture in the subsoil to a heavy sandy clay loam or sandy clay, have been marked "var." on the map.

<u>Moorook sandy loam.</u> See also Coun. Sci. Ind. Res. (Ault.) Bulls. 86, 107 and 133.

The soils mapped as this type are very variable in profile but are always light throughout. They occur fairly high on the slopes of the sand rises and are characterised by a dull brown to grey-brown surface colour and the presence of considerable amounts of limestone rubble and lime in the subsoil, although these latter features are more variable at Red Cliffs than at Berri and Coomealla where the type has been described previously. In most of the occurrences in this settlement, lime and rubble are present in moderate amounts only. An average profile is shown in Fig. 7. Only a small area has been mapped.

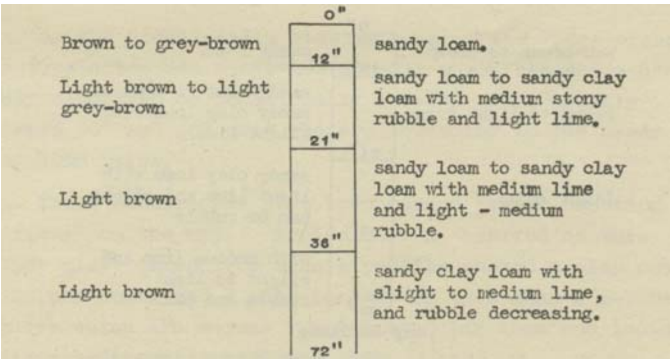

Fig. 7 - Moorook sandy lam.

<u>Loveday sandy loam.</u> See also Coun. Sol. Ind. Res. (Aust.) Bulls. 86 and 107.

Occurrences of Loveday sandy loam are of limited extent and are confined to the gently sloping ground, which originally carried mallee, toward the bottoms of the hollows. It is probably the most saline type found in this district.

As in the Moorook sandy loam, notable amounts of rubble and stone are present in the subsoil, often so close to the surface that it is exposed by cultivation.

The description of an average profile, shown in Fig. 8, differs from that of other occurrences mainly in the colour and depth of the clay subsoil. At Red Cliffs the clay is mottled rather than red-brown, and a little deeper.

Appreciable amounts of lime and rubble are also often present in pockets in the upper clay horizons.

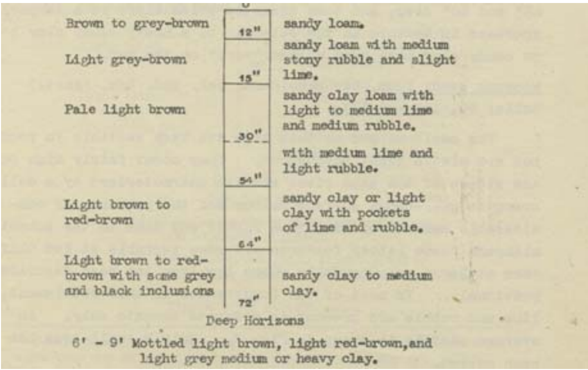

Fig. 8 - Loveday sandy loam.

<u>Coomealla sandy loam</u>. See also Coun. Sci. Ind. Res, (Aust.) Bulls. 107 and 123.

This type is similar to the Loveday sandy loam. It occurs in identical positions and carries the same vegetation, but should not contain more than a small amount of rubble. The average profile shown in Fig. 9 is a little lighter than the original description of the type. It often shows some evidence of salinity, but being of limited extent is not very important. A larger area of very similar soils but differing in the texture of the deep subsoil have been mapped as a "light deep subsoil phase" of the Coomealla sandy loam. They are to be found mainly east of the railway line in positions fairly high on the slopes of the sand rises, and in the natural state carried mallee and belar. The surface and subsoil are essentially the same as for the normal type, but the deep subsoil, below 48", instead of becoming heavy, continues as a light red-brown to light brown sandy clay loam to more than 10 feet with some lime and pan. Vines growing on these soils also show some evidence of salt damage, but are seldom seriously affected.

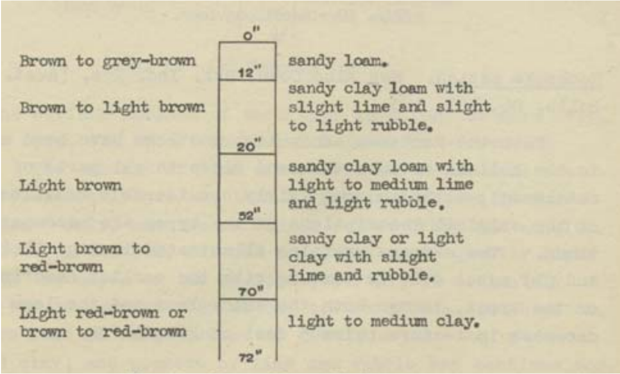

Fig 9 – Coomealla sandy loam

Sandilong loam. See also Coun. Sol. Ind. Res. (Aust.) Bulls.123 and 133.

This type has been fully described at Mildura where extensive areas occur on the mallee plain. At Red Cliffs the occurrences are practically confined to the north-west corner of the settlement. The soil is found on the lower slopes of the rises or in shallow hollows which originally carried mallee, and the surface texture is more often sand loam than loam. An average profile is shown in Fig. 10. One small area of the shallow phase in which the light clay horizon occurs less than 40" from the surface, has also been mapped. There is much less evidence of salt damage to vines growing on this type at Red Cliffs than at Mildura.

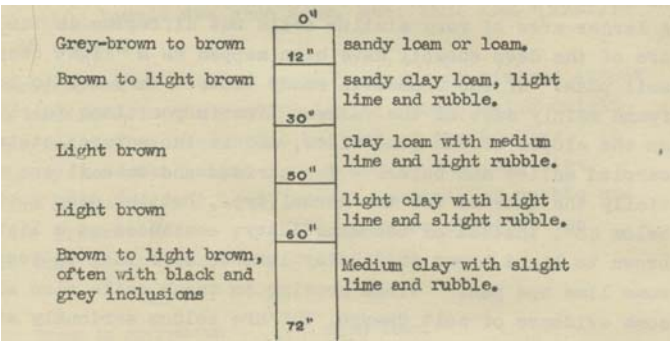

Fig. 10 - Sandilong loam.

Nookamka series. See also Coun. Sci. Ind. Res. (Aust.) Bulls. 86, 107, 123.

Both the Nookamka sandy loam and loam have been mapped in the hollows between the sand rises in all parts of the settlement, although some fairly considerable modification of the original descriptions of the types was necessary at times. The average profiles illustrated in Fig. 11 (a) and (b) agree well in texture with the earlier descriptions of the types, though both the sandy loam and the loam often decrease in texture below 5 feet at Red Cliffs.

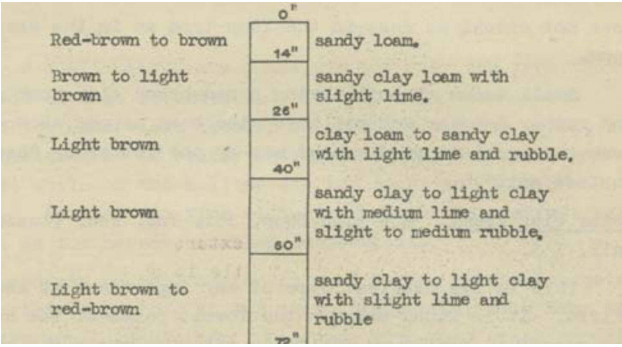

Fig. 11 - (a) Nookamka sandy loam.

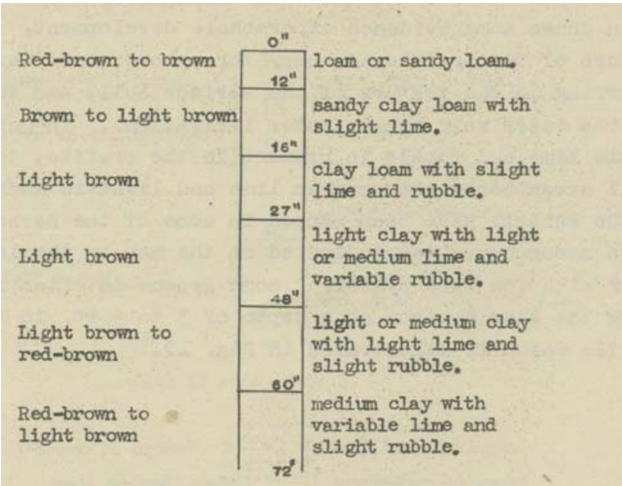

Fig. 11 - (b) Nookamka loam.

The surface horizon of each type is a foot or more deep, is lime free, and varies in colour between red-brown and brown. The amounts of lime and rubble in the subsoil are often considerably greater than have been recorded in these types previously, and the rubble is rather sharp and angular. The colour of the deep subsoil is variable, frequently light brown to the depth of the borings (6 ft.) but ultimately giving way to reddish clay at the bottom of the lime horizon. A narrow band of dark inclusions occurs at the top of the reddish clay, and pockets of lime and rubble may continue for some depth into this horizon. The lime and rubble horizon does not extend as deep in the loam type as in the sandy loam.

Small areas of soil having a red-brown clay loam surface and rather heavier subsoil have also been mapped as Nookamka loam and are indicated on the map by the lettering "heavy surface soil".

Belar clay loam. See also Coun. Sci. Ind. Res. (Aust.) Bull. 133.

This is the heaviest type of any importance at Red Cliffs. It is found only in the lowest parts of the hollows, and occurs typically on the flats which separate the rises in some parts of the settlement. In this position the type often shows some evidence of crabhole development. The texture of the profile is heavy throughout, most variation occurring in the texture of the surface soil, and the soil absorbs water very slowly under irrigation. In general, little lime and rubble is present in the profile, though small areas containing medium lime and light to medium rubble in the subsoil have been mapped in some of the narrow hollows. These areas have been indicated on the map by the lettering "var." with the type symbol. Some gypsum is often found below the lime horizon at a depth of 3 to 5 ft. in the normal profile which is illustrated in Fig. 12.

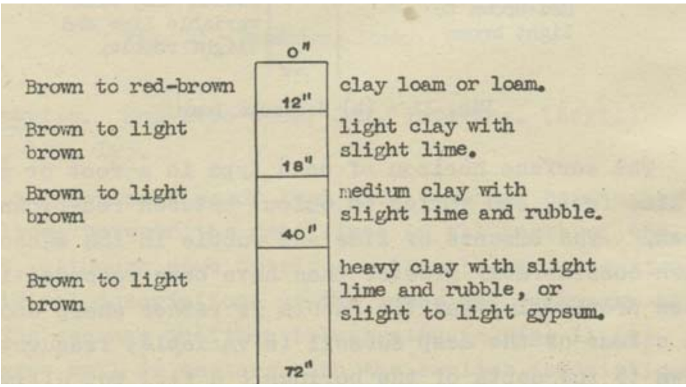

Fig. 12 - Belar clay loam.

Type 8.

Type .8 with its heavy phase, is the only new type described in this settlement. It occurs in the hollows between the sand rises usually surrounding heavier soils, in which position it is really a transition type between the heaviest soils of the hollows and the light soils of the slopes. At the same time it is frequently the heaviest soil present in the narrow, shallow, depressions.

There was no opportunity to observe the original vegetation on this type, but it was most likely belar with many of the *Hakes* spp., *Acacia* app., *Dodonaea* app., and other shrubs common in the district.

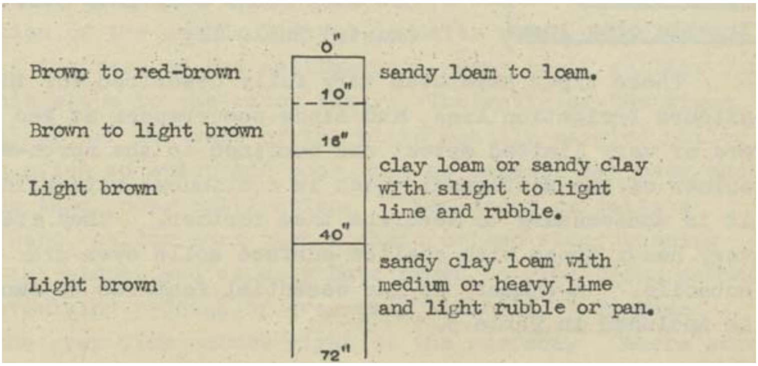

Fig. 13 - (a) Type 8.

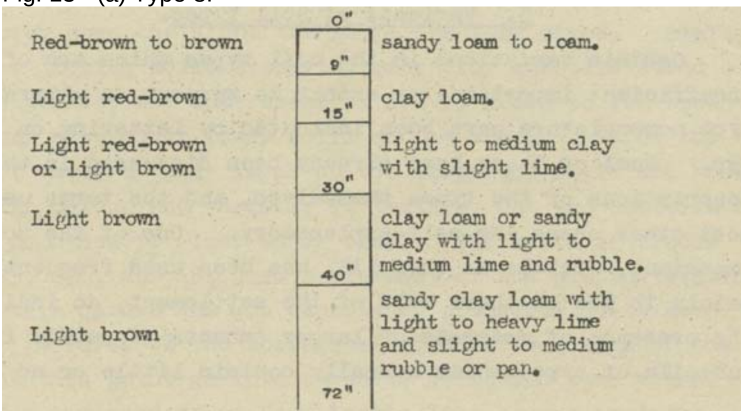

Fig. 13 - (b) Type 8 - Heavy phase.

The main features of the type are the brown to red-brown surface soil of very variable texture and the sandy clay loam deep subsoil, containing much lime and rubble, which underlies heavier textured horizons. The sandy clay loam deep subsoil should not commence deeper than 54 inches. Average profiles of both the normal and the heavy phase are shown in Fig. 13 (a) and (b).

The chief difference between the type and its heavy phase is in the subsoil, the heavy phase usually having a relatively lime-free light to medium clay subsoil, whereas the subsoil for the normal type is a clay loam or sandy clay often containing a fair amount of lime and rubble.

<u>Mildura loam</u>	)	See also Coun. Sci. Ind. Res.
<u>Irymple clay loam</u>	)	(Aust.) Bull. 113

These types have been very fully described for the Mildura Irrigation Area, and since occurrences at Red Cliffs are of very limited extent and confined to the north-west corner of the settlement which is continuous with Mildura, it is unnecessary to describe them further. They are both very heavy types with shallow surface soils over grey clay subsoils. A *summary* of the essential features of each type is included in Table 3.

5. Variants of Soil Tues.

Certain variations in the soil types which are of insufficient importance or extent to warrant an alteration of type nomenclature have been indicated by lettering on the soil map. Some of these have already been discussed in the descriptions of the types themselves, and the terms used in most other cases are self-explanatory. One of the more important, "rubble in subsoil", has been used frequently, mainly in the southern half of the settlement, to indicate the presence of moderate or larger amounts of rubble in the subsoils of types which normally contain little or no rubble.

6. Unclassified Soils.

Several areas of soil along the eastern and southern edges of the settlement though surveyed have been left unclassified on the soil map. The total area involved is not large. Although it would have been possible to map some of these soils by making a number of new types, others are **so** extremely variable that it was practically impossible to separate them into types even after doubling the number of borings made per acre.

Along that part of the eastern boundary which lies between the pumping station and the north edge of the settlement, the soils of the slope from the plain down to the drainage basin and river flat have been formed by the dissection of the unconsolidated deposits which underlie the soils of the rest of the settlement. Many small gullies run down this slope to the river flat. The soils of the first steep slope off the edge of the plain usually carried mallee, and are often so steep and poor that no attempt has been made to bring them under cultivation. They occur as quite a narrow band, seldom more than a chain or two wide, running across the slope, and usually have brown to grey-brown surface soils overlying reddish or grey clay subsoils. In some parts the grey clay occurs right at the surface. Where some planting has been carried out on the less steep areas of these soils the vines are in very poor condition.

Lower down the slope the soils are very mixed. Small knobs of greyish soils overlying grey clay subsoils stand out at some points, and some areas of heavy, brown to red-brown soils may also occur lower still on the slope. Below the level of the grey clay layer on the slope the soils are brown to red in colour and variable in texture, but the subsoils are seldom much heavier than sandy clay. The soils of blocks 274, 275, 276, and L5, just north-west of the pumping station, are of this nature and are capable of producing quite good crops. Several of the borings along the lower edge of the slope at this point go into a coarse yellowish sand within 6 feet of the surface. Very little lime occurs in these slope soils.

Again, south of the pumping station on the eastern edge of the settlement many small areas of soil associated with the fringe of the plain and the steep slope down to the river flat have been left unclassified. They are mainly brown to grey-brown in colour, of variable texture though seldom heavy, and carried mallee originally. Many of them contain large amounts of rubble, and where they are planted and cultivated the vines are frequently in poor condition and patchy.

On the south edge of the settlement east of the railway line the areas left unclassified occur in the bottoms of the hollows between the rises. Some of these soils are very similar to the Coomealla and Loveday sandy loams, and the Sandilong loam, but are very variable, and it was not possible to separate them into types. Most of them are rubbly mallee soils and they are among the less productive soils of this irrigation area.

III. LABORATORY EXAMINATION OF THE SOILS.

Standard methods of analysis were used for the determinations described below. Caustic soda was used as the dispersing agent in mechanical analysis which followed closely the International "A" pipette method. Reaction values were determined with the glass electrode in 1:5 soil - water suspension which had been previously shaken for 1 hour. An aliquot of this suspension was also used for the estimation of total soluble salts by conductivity, and for chlorides determined by Best's electrometric titration method.[*] The percentage of total salts was calculated from resistance figures using a factor[†] previously worked out for this relation for other mallee soils of the Murray River Irrigation settlements.

Phosphoric acid and potash figures were obtained by extraction with hydrochloric acid using the methods set out by Prescott and Piper.[§] All samples analysed for replaceable bases were first leached with 40 per cent, alcohol to remove soluble salts. The replaceable bases were extracted by leaching with normal ammonium chloride and sodium chloride. Sodium was determined by the magnesium uranyl acetate method,[*] potassium by the cobalt-nitrite method,[†] calcium by precipitation as the oxalate, and magnesium by the 8-hydroxyquinoline method.

The results of analyses set out in the following tables and in the Appendix are of normal character for soils of the mallee group, and are in close agreement with those for soils of neighbouring irrigation settlements.

1. Mechanical Analysis.

The soils of the Red Cliffs Irrigation area, although predominantly light textured, range from the sands of the crests of the rises to the comparatively heavy Belar clay loam type of the broad hollows. This range of texture is very well reflected by the mechanical composition of the soils (see Appendix). In Table **4** the clay contents of the surface soils and of a significant horizon of both the subsoil and deep subsoil of most of the types occurring at Red Cliffs are given to demonstrate the trends of the textural profiles.

Of the Red Cliffs soils, the sample profiles of the Coomealla sandy loam, its light deep subsoil phase, Type 8, and the Loveday sandy loam have lower clay contents than field impressions would indicate. However, the physical properties of the soil which are expressed as texture are determined not by

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[*] Best, R. J.,J. Agric. Sci., 19:535, 1939.
[†] Correlation (unpublished) by Allan Walkley, Division of Soils, Coun. Sci. Ind. Res. (Aust.).
[§] Prescott, J. A., and Piper, C. S., Coun. Sci. Ind. Res. (Aust.) Pamph. No. 8, 1928.
[*] Piper, C. Agric. Sci., 22:676, 1932.
[†] Piper, C. S.,J. Soc. Chem. Ind. 51: 392T, 1934.

clay content alone, but by the interrelation of the calcium carbonate, sand, silt, and clay content, and the nature of the latter. In the case of the Loveday sandy loam sample as with the sandy clay horizons, mentioned previously, which occur occasionally in soils of the Barmera series, the lower clay content is offset by its more dispersed condition. The replaceable base contents of samples of Loveday sandy loam, as seen in Table 10, show a much higher proportion of replaceable sodium than the majority of Red Cliffs soils. Other discrepancies in clay content and field texture may similarly be related to a high proportion of sodium in the replaceable bases.

Table 4 - A Comparison of Clay and Calcium Carbonate Contents of some of the Red Cliffs Soil Types.

(Clay percentages on the basis of coarse sand + fine sand + silt + clay = 100%. Figure for calcium carbonate (CaCO3) as a percentage of air-dry soil.)

Soil Type	Surface Soil			Subsoil			Deep Subsoil		
	Depth	Clay	$CaCO_3$	Depth	Clay	$CaCO_3$	Depth	Clay	$CaCO_3$
	%	%	in.	%	%	in.	%	%	in.
Murray sand	0-8	8	0	8-35	11	1	41-72	9	6
Winkie sand	0-6	6	0	20-41	16	12	54-72	12	6
Berri sand	0-8	10	0	24-36	18	9	62-80	14	7
Barmera sand	0-6	9	0	10-24	20	0	43-68	19	9
Barmera s. loam	0-8	14	0	18-39	23	18	39-70	23	25
Coomealla s. loam	0-6	13	7	12-27	22	34*	48-66	26	22
Coomealla s. loam- (lt. subsoil phase)	0-8	16	10	14-38	20	31	50-72	16	9
Loveday s. loam	0-6	17	8	18-48	26	44*	48-63	37	22*
Type 8	0-6	16	3	16-34	23	24	40-78	12	24
Type 8(heavy pH)	0-8	16	0	12-23	35	0	58-78	18	20
Nookamka loam	0-10	20	0	20-48	32	12	48-72	28	6
Belar clay loam	0-5	27	0	5-15	55	3	42-61	39	3

* Limestone rubble is an important feature in these horizons representing more than 10 per cent, of the field sample of soil.

Calcium carbonate, in the form of both soft lime and limestone rubble, occurs in considerable quantity in Red Cliffs soils, more particularly in the light to medium textured types, and plays an important part in determining their physical properties. The figures for rubble calculated as a percentage of the field sample are tabulated in the Appendix and reach the high level of 73 per cent in the subsoil of the Loveday sandy loam, in which type some limestone in pieces measuring up to 6" in length may occur. Large amounts of rubble are typical of the subsoil of the Moorook sandy loam also, and, in general, its presence in moderate or larger amount is a feature of all the brown to grey-brown soils which carried mallee in the original state. Appreciable quantities may be found at times in the brown to red-brown types, but with the exception of the stony phase of the Barmera sand it is not necessary to these types.

Where it does occur it is at greater depth than in the brown to grey-brown types, and is more commonly found in the medium textured soils than in the sands and the Belar clay loam.

Soft lime is present in all types ranging up to 44% in the subsoil of Loveday sandy loam, and 42% in one sample of Nookamka loam. The relations between this constituent and the coarse sand, fine sand, silt, and clay fractions for four representative Red Cliffs profiles to a depth of 6 ft. are illustrated in Fig. 14. As seen in the profiles of Murray sand, Barmera sandy loam, and Nookamka loam, lime is seldom present in the surface horizons of the brown to red-brown types, but is present in appreciable quantity in the surface of the grey-brown mallee types.

There is usually a well defined zone of maximum accumulation in the 3rd and 4th feet of the profile, but often deeper in the light types in which lime may continue to 12 feet or more in depth. However, in the deep subsoil of the heavier types, lime content generally decreases with increasing clay content, ultimately disappearing altogether in the clay horizons. At the same time larger amounts of lime may persist for some depth in the clay horizons of the deep subsoil of these heavier types (see profile 6057-6061).

The silt content is of normal order for the mallee group of soils, being seldom above 7 per cent- usually below 5 per cent - and ranging between 0.4 per cent, in the surface of the Winkie sand and 10 per cent in the clay loam surface of a heavy Nookamka loam profile. It decreases with depth in most profiles and apparently plays a very small part in determining the texture of these soils.

The sand fractions are important in most soil types at Red Cliffs. Fine sand generally predominates over coarse sand, values as coarse to fine sand ratio for all samples analysed ranging from 0.5 to 1.1. In the Winkie sand profile, despite the incoherence of the soil, fine sand dominance is outstanding, the ratio decreasing from 0.6 in the surface soil to 0.5 in the subsoil. These values contrast with those obtained for this type at Berri in South Australia, where coarse and fine sand were present in approximately equal amounts and the relatively large coarse sand fraction seemed to be characteristic of the type.

Furthermore, a detailed separation of some of the sands revealed that whereas most types at Red Cliffs contained a small amount of very coarse sand particles, this was not so of the Winkie sand. In all other respects the occurrences of this type at Red Cliffs agree with those at Berri.

The mean value for the coarse to fine sand ratios for all types at Red Cliffs is 0.8, and for similar mallee soil types at Coomealla,[*] Barmera, and Merbein, is 1.2, 0.7, and 0.7 respectively, Only in the surface horizons of the Coomealla sandy loam and Type 8 at Red Cliffs, does the ratio equal or exceed 1.

Frequency distribution curves drawn from detailed fractionation of the sands of the surface horizons of certain soil types at Red Cliffs had the following maxima:-

[*] Marshall, T. J., and Walkley, Allan, C.S.I.R. (Aust.) Bull. 107,1937.

Soil Types	Frequency percentage of total sand fraction	Particle size in mm.
Murray sand	31	0.16
Berri sand	30	0.15
Barmera sand	30	0.15
Barmera sand	29	0.14
Winkie sand	41	0.14
Barmera sandy loam	27	0.14

In accordance with the lightness of texture of the majority of the soils, the clay content of all samples analysed, with the exception of those of the Belar clay loam, is less than 30 per cent. The surface soil of a profile of Barmera sand selected as representative of soils of this type having a surface texture of loamy sand, surprisingly contained only 5 per cent of clay. This figure is the same as that obtained for the incoherent surface of the Winkie sand. though the silt content is slightly lower in the latter type. In general, however, the relationship between field texture and mechanical composition was satisfactory.

2. Reaction.

The distribution of reaction pH with depth for Red Cliffs soils is shown in Table 5, the values for each horizon of all types examined being set out in the Appendix.

The approximate depths for surface soils, subsoils, and deep subsoils in Table 5 are respectively, 0 - 9 inches, 9 - 45 inches, and 45 - 75 inches.

<u>Table 5 - Frequency Distribution of Reaction (pH).</u>

pH	8.1-8.3	8.4-8.6	8.7-8.9	9.0-9.2	9.3-9.5	9.6-9.8	9.9-10.1	No. of Samples
Surface	5	2	9	2	-	1	-	19
Subsoil	3	2	13	15	7	10	1	51
Deep subsoil	-	-	1	1	4	18	8	32

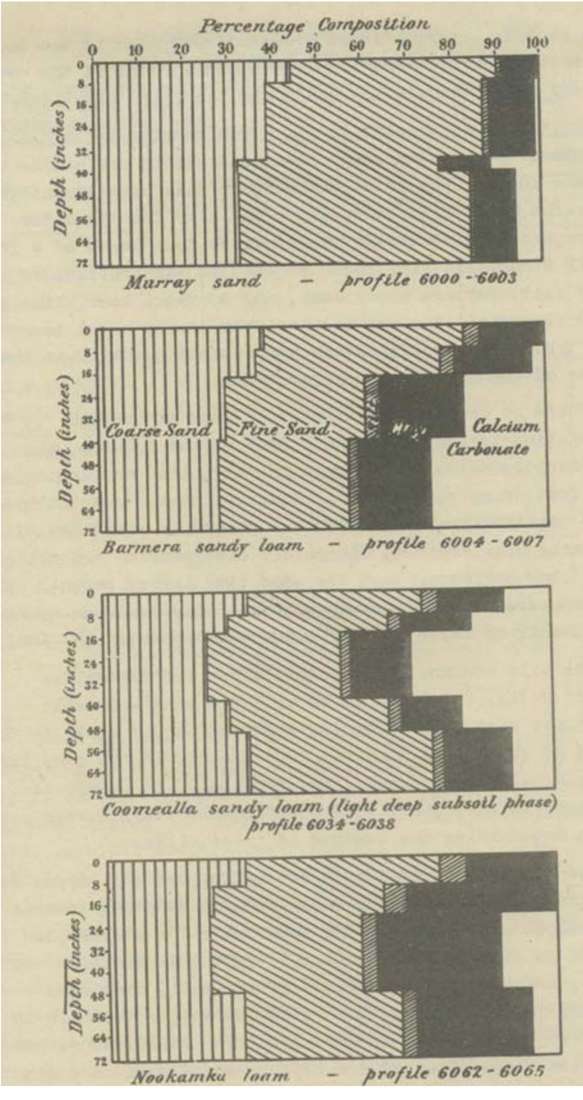

Fig 14. - Showing physical composition of the soil horizons to 6 feet depth for four representative Red Cliffs profiles. The diagrams are based on recalculations for the five constituents shown to 100 per cent.

All the soils examined are alkaline, many of them highly so, the lowest value recorded, pH 8.1, being for the surface horizons of the Murray sand and heavy phase of Type 8, and the highest, pH 10.1, for the deep subsoil of Type 8. In general there is a steady increase in pH from the surface to the deep subsoil, a typical change for the 3 divisions mentioned above is pH 8.5 to 9.3 to 9.8. This change is very similar to that found in the neighbouring irrigation settlements, Mildura and Merbein. In many types there is a slight decrease in pH from the surface to the subsurface horizon. The profile of Loveday sandy loam is notable for its high alkalinity throughout, the high pH of the surface soil being associated with a high content of replaceable sodium as shown in Table 10, and a calcium carbonate content of 8 per cent.

3. Nitrogen.

Values for the total nitrogen content of surface soils shown in the Appendix and summarised in Tables 6 and 7 are of normal order for soils of the Mallee group. The mean for 19 surface soils examined is 0.048 per cent, of total nitrogen.

Table 6 - Frequency Distribution of Total Nitrogen in Surface Soils.

Nitrogen Percentage (of air-dry soil	**0.01-0.02**	**0.02-0.03**	**0.03-0.04**	**0.04-0.05**	**0.05-0.06**	**0.06-0.07**	**0.07-0.08**	
No. of samples	1	1	5	3	3	2	4	**Total** 19

The same correlation between texture and nitrogen content observed by other workers on these soils is evident at Red Cliffs and is shown in Table 7.

Table 7 - Total Nitrogen in Surface Soils,

Surface Texture	No. of Samples	Average Nitrogen Percentage
Sands	8	0.032
Sandy loams	7	0.057
Loams	2	0.060
Clay loams	2	0.071

The very low figure of 0.016 per cent recorded for the surface horizon of the Winkie sand is in agreement with analyses obtained for this type at Berri, South Australia. Nitrogen content decreases rapidly with depth. (See Appendix tables.)

4. Hydrochloric Acid Extracts.

Analyses of the hydrochloric acid extracts of 6 surface soils for phosphoric acid and potash are given in Table 8. As in the case of nitrogen, some correlation between the percentages of these constituents and texture is apparent, and is greatest with respect to potash.

Table 8 - Chemical Analysis of Soils.

(P_20_5 and K_20 as percentages of air-dry soil).

Soil Type	Sample No	Depth (inches)	Phosphoric Acid P^20^5	Potash K_20
Winkie sand	5833	0 - 6	0.01	0.15
Murray sand	6000	0 - 8	0.04	0.28
Barmera sand	5994	0 - 6	0.06	0.30
Barmera sandy loam	6004	0 - 8	0.05	0.48
Coomealla sandy loam (1t. deep subsoil phase)	6034	0 - 8	0.09	0.48
Belar clay loam	5838	0 - 5	0.08	0.73

Following 15 or more years of fairly heavy applications of phosphatic fertilizers, figures for phosphoric acid are rather higher than would be expected for these soils under virgin conditions. The figure of 0.01 per cent for the Winkie sand is still very low, however, and is indicative of the poor fertility of this soil relative to the other types. The Barmera sand sample No. 5994 was taken from a particularly well-managed property carrying excellent vines, and its 0.06 per cent, phosphoric acid content is almost certainly above average for this type.

Soils of the Mallee group usually contain considerable quantities of potash, but because it is directly related to clay content, the percentages recorded for the sand types are below average for mallee soils, particularly in the case of the Winkie sand.

5. Soluble Salts.

Soils of the Red Cliffs Irrigation Area have a much lower chloride and total soluble salt content than is usually encountered in irrigated mallee soils. Figures for chloride and total soluble salt contents for the type samples are listed in the Appendix, and these, with some additional data for similar profiles, are summarised in Table 9.

Table 9 - Changes in Mean Chloride and Total Soluble Salt Content with Depth for Red Cliffs Soils (mean of 19 profiles).

Soil Horizon	Parts per 100,000 of air dry soil	
	Chlorides(as Cl.)	Total Soluble Salts
Surface soil*	6	42
Subsoil	7	62
Deep subsoil	8	102

* Approximate depths of the divisions shown are, surface 0 - 9", subsoil 9" - 45", and deep subsoil 45" - 75".

No records of analyses of virgin soils in this area are available, but although the application of from 30" -36" of irrigation water annually over the last 15 or more years has undoubtedly effected a considerable leaching of salt from these light soils, it is almost certain that the majority of the soils in their natural state had a much lower total soluble salt and chloride content than those of the neighbouring irrigation settlements. The low average figure for chlorides and the relatively small proportion of the total soluble salts contributed by them are notable. This feature is probably due to some extent to the greater solubility of chlorides than sulphates in the alkaline soil-calcium carbonate - water system, facilitating drainage removal. Though no detailed analysis of the total soluble salts occurring in Red Cliffs soils was made, it is likely that here, as at Merbein and Mildura, sodium sulphate is an important constituent.

In most cases there is a steady increase in both chloride and total soluble salt content with depth to 6 feet or more, although this increase is very slight for chloride, which remains practically constant throughout the profile in some of the lighter soil types. For the reason that there is very little evidence of salt damage to the vines in this settlement, few determinations of chlorides were made during the survey. The figures obtained were of the same order as those included in the Appendix. The highest value recorded for chlorides is 0.02 per cent in the subsoil of the Belar clay loam, and the lowest, 0.002 per cent found in the surface horizons of some of the sand types.

The range of the total soluble salt content for all soils examined was from 0.018 to 0.138 per cent. in the surface soils, 0.012 to 0.176 per cent in the subsoils, and 0.028 to 0.166 per cent. in the deep subsoils.

Only in the case of one profile examined, the Loveday sandy loam, profile 6019 - 6022, was there any indication ' of the adverse effect of salt on the vines in the vicinity. Throughout the entire settlement there are very few areas showing indications of the surface accumulation of salt.

6. Replaceable Bases.

The results of analyses of the ten representative soil samples from Red Cliffs for replaceable bases, set out in Table 10, are of normal character for irrigated mallee soils.

Table 10 - Replaceable Bases in Soils.

Soil Type	Soil No.	Depth (inches)	pH	Clay %	Total Bases m.e./100 gm soil	Percentage of Total Bases			
						Ca	Mg	Na	K
Barmera sand	5997	24-43	9.2	18.6	11.7	44	45	3	8
	6033	54-82	10.0	16.6	9.6	27	31	28	14
Barmera s. loam	6004	0-8	8.7	13.9	14.9	75	18	2	5
	6006	18-59	9.6	18.0	11.3	45	38	12	5
	6007	39-70	9.6	16.2	9.1	33	40	19	8
Coomealla s. loam (lt. subsoil phase)	6036	14-38	9.6	13.4	9.4	32	54	8	6
Loveday s. loam	6019	0-6	9.6	14.5	13.8	49	22	21	8
Nookamka loam	6022	48-63	9.8	27.2	15.1	18	35	34	13
	6064	20-48	9.5	26.3	15.7	34	40	16	10
Belar clay loam	5840	15-27	9.6	37.0	22.1	29	44	21	6

Among other things they illustrate the relationship which exists between total replaceable bases and texture, variations in the former being dependent mainly on clay content. In the surface soil, however, organic matter contributes considerably to the total replaceable base content.

In general, the relative proportions of the bases are in agreement with those usually found in these soils. Calcium falls from the position of dominant base in the surface soil with proportions varying from 50 to 75 per cent to as low as 18 per cent, in the clay subsoil of the Loveday sandy loam. The surface horizon of the Barmera sandy loam profile (sample No. 60010 with a very good base status, calcium contributing 75 per cent of the total replaceable bases and sodium and potassium together only 7 per cent, is representative of the large area of brown to red-brown light surfaced soils in this district.

In the subsoils magnesium is the dominant base in all samples examined, rising as high as 54 per cent in sample No. 6036, and even in the surface soils it is frequently important.

The proportion of replaceable sodium is usually low in the surface and upper subsoils, but increases with depth. The surface horizon (No. 6019) of the Loveday candy loam profile, in which sodium contributes 21 per cent, of the total replaceable bases and calcium only 49 per cent, shows the worst base status likely to be encountered in the surface soils of the settlement. Fortunately soils similar to this are of very limited extent. In the deep subsoils, replaceable sodium rises as high as 28 per cent in one profile of Barmera sand, and 34 per cent in the Loveday sandy loam. Where a replaceable sodium content of this order is associated with a clay content of much more than 20 per cent, as in the latter ease, an impervious layer is formed which often results in the development of a water table and salinity. These figures for the clay horizon of the Loveday sandy loam at Red Cliffs are in close agreement with those recorded for the same type at Coomealla where it was particularly prone to the same troubles. Even when a high proportion of replaceable sodium is associated with a much lower clay content as in sample No. 6033, permeability is much restricted.

Replaceable potassium in the soils examined varies from 5 per cent of the total bases in the surface of the Barmera sandy loam profile to 14 per cent in the deep subsoil of the Barmera sand. Expressed as potash, K_20, this range is from 0.024 to 0.096 per cent. However, many of the light surface soils, in particular those of the Winkie and Murray sand types, would contain less than the lower of these values. It is presumable that this mount of replaceable potash affords an ample supply for normal plant growth.

If any type is likely to be deficient in available potash it will be the Winkie sand, in which soil other factors are much more likely to be limiting crop production.

IV. IRRIGATION. WATERLOGGING, SALINITY. AND DRAINAGE IN RELATION TO SOIL TYPE.

Much has already been written in bulletins dealing with soil surveys of similar irrigation settlements along the River Murray on the subject of the irrigation and drainage of mallee soils. It has been discussed in some detail in relation to the soils of the Merbein district* which include many of the types occurring at Red Cliffs. Further, an investigation of the problems of salt accumulation† in soils carried out at the Commonwealth Research Station, Merbein, during recent years has considerably increased our knowledge of the effects of these practices. Reference should be made to this work.

1. Irrigation and the Development of Water Accumulation.

The efficient application and use of irrigation water with a view to the prevention of serious waterlogging and the development of salinity, while yet meeting the water requirements of the crop, is a problem in most irrigation areas. The aim should be to water adequately only that zone of soil occupied by the roots of the crop, avoiding the formation of a water table. In practice this is very difficult when dealing with light soils irrigated on the furrow system. Even where layout of channelling, degree of slope, and head of water available are ideal, overwatering of headland areas may still occur. At Red Cliffs the layout of channelling frequently makes necessary the watering of the heavier soils of the hollows by running water over the light soils of the crests and upper slopes of the rises. On a large proportion of the holdings, the entire slope from the crest to the bottom of the hollow, covering as many as six soil types, is irrigated from a single channel along the top of the rise. Under such conditions the avoidance of waterlogging the light sand types at the top of the slope is practically impossible if the heavier hollow soils are properly watered.

For all that, however, proportionately little evidence of water accumulation was found in this area on the survey. At the same time it should be mentioned that the survey was made during the spring and summer months of the 1938-39 season, which followed an abnormally dry winter and during which prolonged periods of extreme temperature were experienced. Following the growth of heavy green manure crops in the winter and early spring, the soils were almost certainly much drier than usual at the beginning of the irrigation season. Despite the much heavier applications of irrigation water (approximately 3.9 ac. ft. per acre) in this summer as compared with those of previous years, the soils remained drier throughout the season, due no doubt, to the greatly increased crop requirement to meet the high temperature and also to some extent, to increased evaporation. In addition, a conservative

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* Penman, F., et al., A Soil Survey of the Merbein Irrigation Area, Victoria. Corm. Sci. Ind. Res. (Aust.). Bull. 123.

† Thomas, J. E. An Investigation of the Problems of Salt **Accumulation** on a Mallee Soil in the Murray Valley Irrigation **Area; Coun.** Sci. Ind. Res. (Aust.). Bull. 128.

policy of drainage was put into operation at an early stage in the development of the settlement, and this has been effective in preventing the accumulation of free water in the light soils so treated.
Most of that water accumulation which was evident occurred in the Murray, Winkle, and Berri sand types, as would be expected from their high permeability (Table 11) and their position relative to the irrigation channels.

Citrus trees which are very sensitive to excess water often showed poor growth on undrained areas of these types -more particularly on the Murray and Berri sand. Considerable areas of the sand types in the settlement are above present irrigation level or larger areas would be affected.

The design of the holding and the method of irrigation practised have also been responsible for some considerable erosion of these light soil types for the first half to one chain below the head ditch. As much as 2 ft. to 2 ft. 6 in. of soil has been removed at the top end of the rows in some parts, and the first 3 to 6 vines in each row are frequently in poor condition due to the removal of the surface soil and the exposure of the vine roots. On a number of properties upwards of a half acre of vines are affected in this way. Much of this could have been avoided by better layout of the blocks, running the vine rows across the slope where slope is excessive and by making provision for the watering of the heavier soils of the lower slopes and hollows from a pipeline or channel, situated on the slope about the transition zone between the lighter and the heavier soils. This would also make for more efficient use of irrigation water and would reduce the possibilities of waterlogging in the light types.

The concrete lining of the main distribution channels and their efficient maintenance have minimized the occurrence of seepage troubles from this cause, which would otherwise have been prevalent on these light soils.

Over the last 12 years the amount of irrigation water pumped in each season has varied from the low level of 2.2 feet per acre of irrigated land in the very wet 1930/31 season to the high level of 3.9 acre feet in the dry 1938/39 Beason, with an average seasonal pumping of 2.9 acre feet for the whole period. While there is no doubt that, on the average, much less water could be used with as good if not better results, this figure compares favourably over a similar period with the average amount per season of water pumped in the neighbouring settlements.

2. Soil Salinity.

As mentioned previously, the figures for total soluble salts and chlorides included in the Appendix indicate that the majority of the soils are, at present, very low in salt content, and even when the soils were in the virgin condition, they were probably of much lower salinity than the average for virgin mallee soils.

Under irrigation, salt has been leached from the surface and subsoils -

particularly in the light soil types - into the deeper layers, and, in the absence of any extensive development of water tables, due largely to the early drainage of many holdings, there has been little redistribution and consequent surface accumulation of salt.

In general, the brown to grey-brown mallee types - the Loveday, Coomealla, and Moorook sandy loams, and the Sandilong loam - are, of all the Red Cliffs soils, most liable to develop salinity troubles. This is due both to the higher salt content of these soils in their original state compared with the red brown to brown types, and to the underlying clay horizons permitting local development of water tables when these types are undrained. Fortunately the total area of these soils, in proportion to that of all soils in production in the settlement, is small.

A line of weakness in vine growth to 1 chain wide frequently occurs across the lower slopes of the sand rises where the light soil types join the heavier soils of the hollows. This is caused by the movement of subsoil water down the slope being held up by the less permeable subsoils of the heavier types below. A certain amount of salt concentration sometimes occurs in this position, but the damage is more often due to water accumulation alone.

3. Drainage.

A certain amount of drainage was carried out at an early stage in the development of the Red Cliffs settlement, as growers were able to observe the effects of irrigation on undrained mallee soils in the neighboring settlements of Merbein and Mildura and profited by experience gained there.

The results of work done by Thomas[*] at Merbein have confirmed the general opinion that in most cases drainage is essential to the maintenance of productivity of these light textured mallee soils when irrigated on the furrow system, and that it is the essential method of reclamation following the. development of waterlogging and salinity troubles. As set out by him, the general principles to be observed in the drainage of these soils are, firstly, that drainage should be undertaken as early as possible following the introduction of irrigation to prevent the redistribution of salts above a shallow water table, and secondly, that both the depth and spacing of the drains should be governed primarily by soil texture determined by the examination of the soil profile.

In light soils drains may be laid deep and at wide intervals, whereas in heavier soils, to be effective, they must be shallower and closer together. On very heavy soils drainage may be both unnecessary and ineffective.

The approximate depths for the laying of tile drains in relation to the texture of the average profiles of the soil types occurring at Red Cliffs are given in Table

[*] Thomas, J.E., Calm. Sci. Ina. Res. (Aust.) 31404128, 1939.

11. With the light sand types drains could be laid even deeper than shown and be still more effective, but the expense of deeper drainage is prohibitive, and in any Case good results can be obtained using these depths.

Table 11 - Approximate Drainage Depth and Water Absorption, Rates for Red Cliffs Soils.

Soil Type	Liability to salt damage	Rate water absorption	Approx. depth for drains(in feet)
Murray sand	Not liable	Very high	6
Winkie sand	Not liable	Very high	6
Berri sand	Very slight	Very high	6
Berri sandy loam	Very slight	Very high	6
Barmera sand	Very slight	Very high	6
Barmera sand (stony phase)	Slight	High	5
Barmera sand (shallow phase)	Slight	High	5
Barmera sandy loam	Slight	High	6
Barmera sandy loam (shallow phase)	Slight	High	5
Moorook sandy loam	Liable	High	6
Coomealla sandy loam	Liable	Moderate to high	5 - 4.5
Coomealla sandy loam (lt. deep subsoil phase)	Liable	High	6
Loveday sandy loam	Liable	Moderate	5 - 4.5
Sandilong loam	Liable	Moderate	5 - 4.5
Nookamka sandy loam	Slight	Moderate	5
Type 8 and heavy phase	Slight	Moderate to low	5
Nookamka loam	Slight	low	4
Belar clay loam	Not liable	Very low	-

From the results to date of the early drainage work done in this area, it is apparent that deep drainage (approximately 6 ft) at 66 or 88 feet intervals is sufficient to prevent the rise of free water and the resultant damage to crops in the light soils which comprise most of the area. Drainage at similar intervals on the same types is also probably sufficient to effect reclamation where damage to the crop is only slight. However deep the heavier soils and those small areas where more serious damage occurs, drainage at more frequent intervals, either 66 feet or 44 feet, and at the approximate depths given in Table 11 is necessary if improvement is to be obtained in reasonable time.

At Cardross, in the north-west corner of the area covered by this survey, waterlogging troubles were prevalent prior to the installation of a community drainage scheme. As shown on the soil map, light textured soils which are naturally low in salinity predominate in this locality and the main problem was simply the removal of excess water. During the four seasons 1935-36 to 1938-39 for which records are available for this area, the average run off per acre of the area drained has been 0.8 acre feet. The low salt content of the soils is reflected in the composition of the drainage waters which are now, after several years of drainage, reported by Thomas to be approximately 100 parts of total soluble salts per 100,000. Chlorine constitutes about 16 per cent of this amount. The improvement in condition of vines and trees in this area has been general, and the present good condition as a whole is undoubtedly largely due to the early introduction of drainage following the establishment of the settlement.

Attention has been drawn by Thomas to the possibility of a deleterious change in soil fertility as a result of the excessive leaching of these light textured soils of low salt content following drainage. Unnecessarily heavy and prolonged application of irrigation water to the light sand types on drained properties was observed in many parts of the settlement during the survey. In most cases this was due to the grower's lack of knowledge on which to base irrigation practice, and, in some instances, to the fear that the soils were drying out too much between irrigations. Toward the end of the extreme 1938-39 season some evidence was observed of the vines on certain light, drained soils suffering from lack of moisture. However, in normal years and with six waterings available in the growing season this should seldom happen if the waterings are suitably timed.

Following the completion of the comprehensive drainage system a few years ago, rapid extension of the internal drainage of holdings has taken place and is continuing at present. With drainage there is no reason why all areas affected by salt and water troubles in this settlement should not be brought back to a profitable level of production.

V. THE PRODUCTIVITY OF THE SOILS.

In the comparison with neighbouring irrigation settlements, the general condition of the crops at Red Cliffs is excellent, and is reflected in the average yield per acre of dried vine fruits. In Table 12 the average annual per acre production over periods of 5 years are given for Red Cliffs and Merbein.

Table 12 - Average Yield of Dried Vine Fruits for Merbein and Red Cliffs.

Year	Yield cwt./acre.					
	1933	1934	1935	1936	1937	1938
Red Cliffs	-	27.3	38.6	34.9	43.6	32.3
Merbein	35.8	30.9	32.9	26.8	33.1	-

These figures have been calculated from data supplied by the Government Statist, Victoria, and show the generally higher production for the Red Cliffs area. Of the dried fruit production over the periods stated, sultanas average 78 per cent and currants 11 per cent at Red Cliffs, and 70 per cent and 23 per cent respectively at Merbein, the remainder being largely lexias in each case. From observations of the vigor of the vines in relation to soil type in all parts of the settlement, it is apparent that all types are capable of producing good crops. At the same time, the effect of the lightness of texture and the lower fertility of the Winkie and Murray sands in the condition of the vines is very noticeable in some parts of the settlement, particularly in the case of the former type. Some of the highest yields obtained have been produced from soils of the Barmera series which, when drained and well-managed, also grow good citrus crops. The heavy Belar clay loam, and to a lesser extent the Nookamka loam and sandy loam, are reputed to be less productive than average, though this is probably due more to the effects of the unfavourable topographic positions usually occupied by these types and the troubles attendant thereto, than to any characteristic of the soils themselves.

Where any appreciable area of Belar clay loam is under cultivation, the beneficial effect on the physical condition of the soil of applications of gypsum will make this practice worth consideration. The burying of vine prunings and the ploughing in of heavy green manure crops in alternate rows each year, practices almost universally adopted in this settlement, assist in the maintenance of productivity and the improvement of the physical condition of all soil types.

The productivity of the brown to grey-brown mallee soils is rather lower than that of the red brown soils owing to the more general occurrence of salt and water troubles in these types, but they improve considerably with drainage and are capable of producing good crops.

Despite the generally higher levels of production at Red Cliffs than in neighbouring settlements, it is evident from the yields obtained over a period of years by some growers, and from quite average soils, that there is no reason why the total productivity of this area cannot be considerably increased. Average yields of dried vine fruits of 3 tons per acre over several years are frequently reported by growers.

VI. ACKNOWLEDGMENTS.

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APPENDIX.
Mechanical Analyses and Other Data for Red Cliffs Soils.

All figures shown are as percentages of fine earth except those for reaction, depth, and rubble, the latter being percentages of the field samples. As indications of field texture, S signifies sand; Cl. S, clayey sand; SL, sandy loam; L, loam, SCL, sandy clay loam; CL, clay loam; SC, sandy clay; LC, light clay; MC, medium clay; and HC, heavy clay.

Loss on acid treatment figures have been omitted from the tables.

TABLE I -MECHANICAL AND CHEMICAL ANALYSES OF WINKIE SAND AND MURRAY SAND.

Type	Winkie Sand					Murray Sand			
Soil No.	5833	5834	5835	5836	5837	6000	6001	6002	6003
Depth (in.)	0-6	6-12	12-20	20-41	54-72	0-8	8-35	35-41	41-72
Texture	S	S	S-SL	SL-	Cl.S	S	S	S-SL	S
Rubble	-	-	-	-	-	-	-	-	-
Coarse sand	34.7	34.4	28.8	23.2	25.7	42.5	37.3	40.0	31.4
Fine sand	58.0	59.0	52.5	48.5	54.8	45.8	48.0	44.4	51.7
Silt	0.4	1.0	1.1	1.2	0.7	1.4	1.3	0.3	0.4
Clay	5.5	5.0	13.8	13.5	10.8	8.0	10.1	10.9	8.7
Moisture	0.6	0.6	1.9	1.8	1.2	1.2	1.6	1.8	1.3
L. on Ignition	1.0	0.8	2.2	6.8	3.8	1.8	2.0	6.2	3.8
$CaCO_3$	0.0	0.0	1.3	11.5	6.0	0.0	1.4	11.1	5.8
Tot. Sol. Salts	0.02	0.01	0.04	0.04	0.04	0.02	0.03	0.03	0.03
Chlorides (Cl)	0.002	0.003	0.005	0.006	0.005	0.002	0.003	0.004	0.002
Nitrogen	0.016	-	-	-	-	0.042	0.017	-	-
Reaction pH	8.8	8.5	8.9	9.2	9.3	8.1	9.0	9.2	9.2

TABLE II - MECHANICAL AND CHEMICAL ANALYSES OF EERRI SAND.

Type	Berri Sand						
Soil No. Depth (in.) Texture Rubble	6039 0-8 S -	6060 8-16 S -	6041 16-24 S -	6042 24-36 SL-SCL -	6043 36-48 SCL -	6044 48-62 SCL-SL -	6045 62-80 Cl.S. -
Coarse sand Fine sand Silt Clay	36.6 49.7 2.1 9.4	36.5 47.0 2.2 11.8	34.0 46.3 1.4 12.5	31.1 39.3 1.4 15.6	27.1 36.2 1.6 17.0	30.8 40.6 1.2 14.8	30.7 46.0 1.9 12.6
Moisture L. on ignition	1.3 1.7	1.9 1.8	2.1 3.5	2.6 5.7	2.8 8.4	2.4 5.8	2.3 4.2
$CaCO_3$	0.0	0.2	3.3	9.3	15.2	10.0	6.9
Tot. Sol. Salts Chlorides (Cl)	0.02 0.002	0.03 0.003	0.03 0.005	0.03 0.003	0.04 0.004	0.04 0.005	0.05 0.003
Nitrogen	0.030	-	-	-	-	-	-
Reaction pH	8.4	8.8	9.0	9.1	9.2	9.2	9.5

TABLE III - MECHANICAL AND CHEMICAL ANALYSES OF BARMERA SERIES.

Type	Barmera Sand						Barmera Sandy Loam			
Soil No.	5994	5995	5996	5997	5998	5999	6004	6005	6006	6007
Depth (in.)	0-6	6-10	10-24	24-43	43-68	68-104	0-8	8-18	18-39	39-70
Texture	S	S	SL	SCL	SCL	SCL	SL	SL-L	SCL	SCL
Rubble	-	-	-	-	-	-	-	-	-	-
Coarse sand	34.9	37.0	30.9	26.3	28.6	27.3	35.3	33.9	26.9	25.5
Fine sand	51.8	51.3	43.1	34.0	41.0	38.9	43.4	40.6	30.2	28.1
Silt	2.5	2.2	2.0	1.8	1.8	1.8	3.3	3.2	2.8	1.8
Clay	8.5	7.9	19.5	18.6	17.2	17.7	13.9	16.6	18.0	16.2
Moisture	1.3	1.3	3.5	3.3	3.1	3.0	2.4	2.9	3.4	3.1
L. on ignition	2.0	1.4	2.2	9.1	5.5	6.5	2.3	3.2	10.3	13.0
$CaCO_3$	0.0	0.0	0.5	15.6	8.6	11.7	0.1	2.5	18.1	25.2
Tot.Sol.Salts	0.02	0.01	0.03	0.04	0.07	0.09	0.04	0.04	0.08	0.09
Chlorides (Cl)	0.002	0.001	0.002	0.002	0.005	0.004	0.003	0.004	0.007	0.008
Nitrogen	0.040	0.018	-	-	-	-	0.038	0.023	0.015	0.006
Reaction pH	8.3	8.1	8.9	9.2	9.6	9.8	8.9	8.9	9.6	9.6

TABLE IV - MECHANICAL AND CHEMICAL ANALYSES OF COOMEALLA SANDY LOAM.

Phase.	Light Deep Subsoil					Normal					
Soil No.	6034	6035	6036	6037	6038	6013	6014	6015	6016	6017	6018
Depth (in.)	0-8	8-14	14-38	38-50	50-72	0-6	6-12	12-27	27-48	48-66	66-84
Texture	SL	SL-SCL	SCL	SCL	SCL-SL	SL	SL-L	SCL	SCL	SC	SC-MC
Rubble	-	3.3	4.1	5.0	7.8	-	12.0	12.3	18.4	3.4	-
Coarse sand	30.0	26.1	22.1	27.5	31.4	38.7	33.0	22.5	20.7	24.1	27.5
Fine sand	37.3	34.6	28.9	35.8	41.1	35.0	32.2	25.2	23.6	28.9	32.2
Silt	3.2	3.3	2.6	2.3	2.2	2.3	2.0	1.5	1.5	2.2	4.2
Clay	13.7	13.8	13.4	13.2	14.8	11.8	13.6	13.7	15.2	19.2	29.6
Moisture	2.4	2.7	2.3	2.1	2.3	2.5	2.5	2.5	2.4	3.2	4.8
L. on Ignition	7.2	10.4	15.6	10.6	5.5	6.2	9.2	17.0	18.4	12.0	4.5
$CaCO_3$	10.3	17.8	30.7	20.4	9.1	6.5	15.4	33.8	37.2	22.2	0.4
Tot.Sol.Salts	0.04	0.04	0.05	0.07	0.09	0.09	0.09	0.12	0.10	0.12	0.13
Chlorides(Cl)	0.005	0.004	0.005	0.004	0.006	0.015	0.015	0.014	0.007	0.007	0.006
Nitrogen	0.072	0.034	0.015	-	-	0.072	-	-	-	-	-
Reaction pH	9.0	9.1	9.6	9.8	9.9	8.7	8.8	9.4	9.6	9.6	8.9

TABLE V - MECHANICAL AND CHEMICAL ANALYSES OF LOVEDAY SANDY LOAM AND MAR CLAY LOAM.

Type	Loveday Sandy Loam					Belar Clay loam					
Soil No.	6019	6020	6021	6022	6023	5838	5839	5840	5841	5842	5843
Depth (in.)	0-6	6-18	18-48	48-63	63-84	0-5	5-15	15-27	27-42	42-61	61-70
Texture	SL	SL-SCL	SCL	SC-LC	LC-MC	CL	MC-HC	MC-HC	MC-HC	MC-HC	MC
Rubble	-	72.8	32.2	12.6	10.2	-	-	-	1.7	-	-
Coarse sand	29.9	22.3	16.0	18.9	20.5	29.3	15.6	13.3	18.4	24.3	28.2
Fine sand	38.2	31.2	21.8	24.6	27.1	34.5	20.0	19.8	22.0	27.3	25.7
Silt	4.2	3.4	1.8	2.5	2.9	7.1	3.7	3.8	4.2	5.6	2.8
Clay	14.5	15.2	14.2	27.2	32.0	24.4	47.4	37.0	37.2	36.5	34.3
Moisture	2.4	3.0	2.8	4.8	5.2	3.2	6.9	5.2	4.5	4.7	4.2
L. on Ignition	6.4	12.6	21.0	12.2	7.7	3.8	6.5	12.3	9.4	4.6	5.1
$CaCO_3$	8.2	23.8	43.8	21.9	11.0	0.0	3.0	18.6	12.9	2.6	4.5
Tot.Sol.Salts	0.14	0.10	0.10	0.14	0.17	0.05	0.07	0.14	0.18	0.15	0.14
Chlorides(Cl)	0.018	0.013	0.009	0.006	0.009	0.008	0.010	0.018	0.020	0.010	0.012
Nitrogen	0.056	-	-	-	-	0.070	0.046	-	-	-	-
Reaction pH	9.6	9.5	9.7	9.8	9.7	8.1	8.8	9.6	9.7	9.7	9.7

TABLE VI - MECHANICAL AND CHEMICAL ANALYSES OF NOOKAMKA LOAM.

Type	Nookamka Loam									
Soil No.	6062	6063	6064	6065	6066	6057	6058	6059	6060	6061
Depth (in.)	0-10	10-20	20-48	48-72	72-84	0-7	7-17	17-45	45-63	63-84
Texture	L	CL	LC	LC	MC	CL	LC-MC	LC	LC	MC
Rubble	-	-	1.4	3.2	1.9	-	-	-	3.2	-
Coarse sand	28.7	22.0	21.3	27.2	31.8	22.6	19.9	16.9	15.3	14.4
Fine sand	41.0	34.7	31.9	34.2	31.4	33.5	31.6	24.6	20.7	23.0
Silt	6.1	4.6	2.9	3.4	2.3	9.8	9.0	4.4	2.2	3.0
Clay	18.8	31.0	26.3	25.3	24.2	27.2	28.7	22.4	18.0	24.6
Moisture	2.9	6.3	4.5	4.4	3.9	4.6	5.2	4.3	3.2	4.5
L. on Ignition	3.3	3.8	7.9	4.6	4.5	4.8	6.0	15.0	20.1	16.3
$CaCO_3$	0.1	0.1	11.8	6.0	5.1	1.3	5.7	27.7	41.7	31.3
Tot.Sol.Salts	0.03	0.06	0.14	0.13	0.15	0.04	0.04	0.08	0.11	0.14
Chlorides (Cl)	0.004	0.007	0.015	0.010	0.010	0.005	0.004	0.006	0.012	0.011
Nitrogen	0.052	-	-	-	-	0.072	0.040	0.017	0.008	-
Reaction pH	8.7	8.9	9.5	9.8	9.9	8.8	8.9	9.7	9.9	9.9

TABLE VII - IECHANICAL AND CHEMICAL ANALYSES OF TYPE 8 (UNNAMED).

Type	Type 8					Type 8 (Heavy Phase)					
Soil No.	6046	6047	6048	6049	6050	6051	6052	6053	6054	6055	6056
Depth (in.)	0-6	6-16	16-34	40-78	78-96	0-8	8-12	12-23	23-36	36-58	58-78
Texture	L-SL	CL	CL	SCL	SL-SCL	L	CL	LC-MC	LC	SCL	SCL
Rubble	-	-	4.9	-	-	-	-	-	5.8	11.4	2.3
Coarse sand	36.5	29.8	24.8	26.8	30.8	32.0	28.6	22.1	22.6	28.4	33.5
Fine sand	37.5	33.2	29.2	37.4	38.7	40.2	37.4	32.2	24.9	28.2	29.3
Silt	3.5	3.9	2.2	1.4	1.9	7.4	7.0	6.6	4.6	3.2	2.0
Clay	15.1	19.9	16.6	9.3	11.7	15.2	22.3	32.8	30.8	19.4	13.8
Moisture	2.2	3.3	2.5	1.7	2.1	2.7	3.8	5.9	5.7	3.2	2.6
L. on ignition	3.8	6.4	12.8	11.9	7.7	3.6	3.2	3.8	8.1	9.9	10.5
$CaCO_3$	2.9	8.0	24.0	23.7	14.8	0.0	0.0	0.0	11.0	17.3	19.9
Tot. Sol. Salts	0.05	0.06	0.07	0.09	0.13	0.03	0.02	0.04	0.11	0.11	0.11
Chlorides (Cl)	0.005	0.009	0.009	0.005	0.005	0.004	0.002	0.007	0.012	0.010	0.009
Nitrogen	0.043	-	-	-	-	0.069	-	-	-	-	-
Reaction pH	9.0	8.9	9.4	10.0	10.2	8.1	8.2	8.4	9.2	9.7	9.8