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A STUDY OF THE MAJOR GROUPS OF SOILS
AS ENCOUNTERED IN A PORTION OF
THE BAROSSA VALLEY,
SOUTH AUSTRALIA.

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A. KARIM.
Waite Agricultural Research Institute.
The University of Adelaide.
South Australia.

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Mineralogical examination

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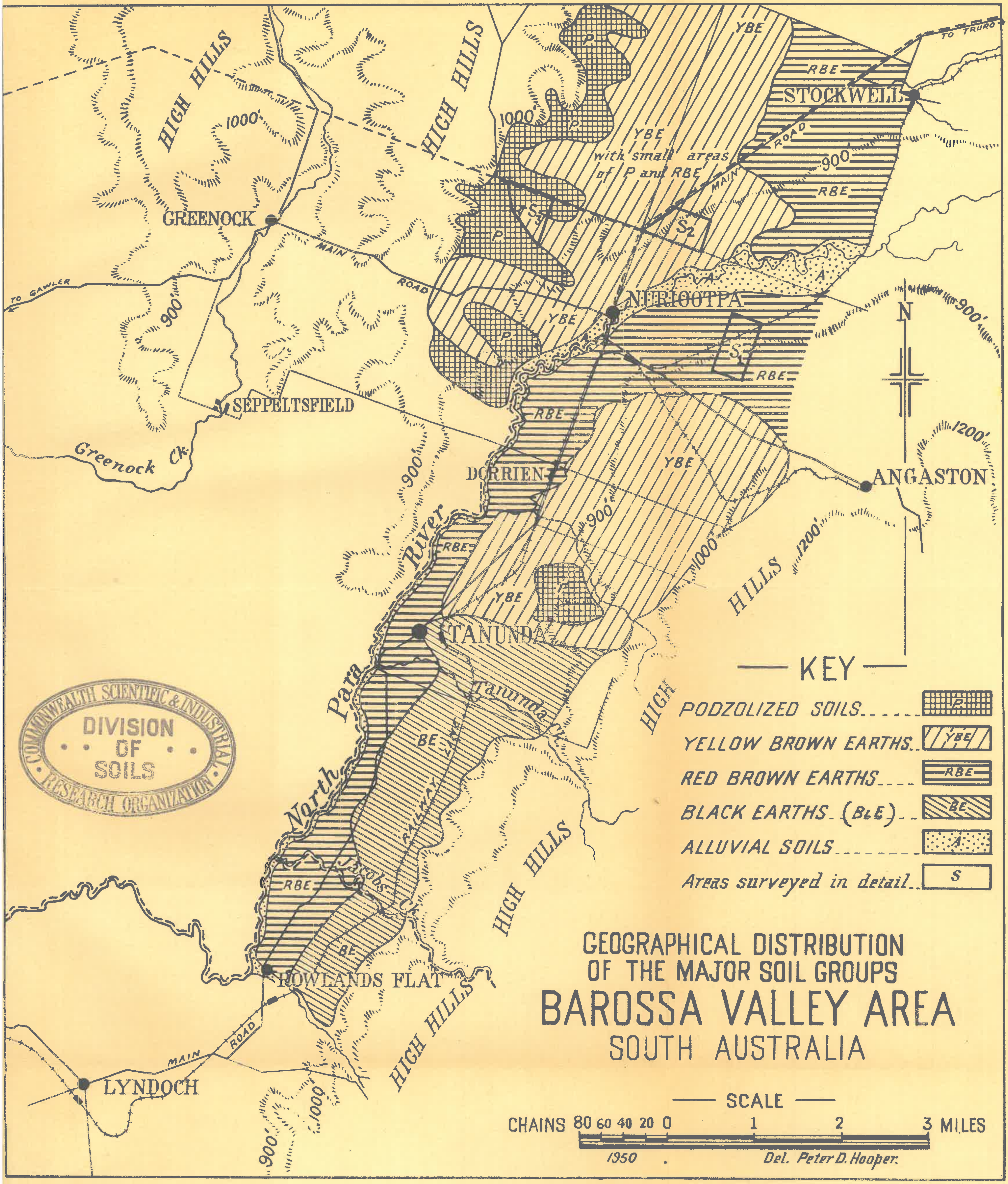
GEOGRAPHICAL DISTRIBUTION OF THE MAJOR SOIL GROUPS
BAROSSA VALLEY AREA
SOUTH AUSTRALIA
KEY
PODZOLIZED SOILS P
YELLOW BROWN EARTHS YBE
RED BROWN EARTHS RBE
BLACK EARTHS (BLE) BE
ALLUVIAL SOILS A
Areas surveyed in detail S
SCALE
CHAINS 80 60 40 20 0 1 2 3 MILES
1950
Del. Peter D. Hooper.
N
HIGH HILLS
HILLS
HIGH
GREENOCK
SEPPELTSFIELD
NURIOOTPA
STOCKWELL
TO TRURO
DORRIEN
ANGASTON
TANUNDA
ROWLANDS FLAT
LYNDOCH
TO GAWLER
MAIN ROAD
Greenock Ck.
North Para River
Tanunda Ck.
Jacobs Ck.
RAILWAY LINE
YBE with small areas of P and RBE
S1
S2
S3
1000'
900'
1200'

FIGURE 1.

SUMMARY.

The investigation deals with a Pedological study of the major soil groups of a portion of the Barossa Valley, which is one of the important wine producing areas of Australia. Pedological as was the investigation, the first job was obviously to carry out a detailed field work and this was done in conjunction with the C.S.I.R.O.Soil Survey party (through the kind courtesy of the C.S.I.R.O. Australia - Soils Division). As a result of the reconnaissance work done on the portion of the valley, diverse groups of soils - some well defined and some ill-defined - were recognised, and, for the subsequent laboratory studies, the reasonably well expressed groups and types thereof were sampled, keeping an eye on their trustworthiness as representative samples of the area surveyed within the time that could be spared for the extra-laboratory studies. The soil groups and types thereof sampled for laboratory studies were named after their colour and surface texture without attaching any pedological bias which might sound rather presumptuous. This had to be done for want of suitable locality names for all the types sampled to maintain a uniformity of nomenclature all throughout the text. However, the profiles sampled were named as follows:-

(1)	(a) R.B.E. 1/SL (b) R.B.E. 2/SL (c) R.B.E. 2/SCL	Comprising the group of Red Brown Earths.
(2)	Y.B.E. 1/S Y.B.E. 2/LS	Forming a group of Yellow Brown Earths.
(3)	P. 1/S	Representing a Podsolized soil group.
(4)	BL.E(A) BL.E(B)	Conforming a group of Black Earths.

The laboratory studies which were done on natural horizon basis comprised:

(a) Mechanical analyses.
(b) Chemical analyses.
(c) Mineralogical analyses of clay fractions.

The results of the mechanical analyses showed that :-

(i) The profiles studied irrespective of group or type are essentially genetic profiles, i.e. the eluvial and illuvial horizons are genetically correlated - and as such the investigation and the subsequent thesis should be pedologically valid;

(ii) The textures of the soil samples collected from the different horizons of the profiles under the investigation, as found by plotting the mechanical analyses data in Marshall's (1947) texture diagram, were in close agreement with the field texture.

The chemical analyses were performed to follow the distribution of pH, $CaCO_3$, Nitrogen, Phosphorus, Organic Carbon, Total Soluble Salts and Chloride, Free Iron Oxide, Exchangeable Bases and Capacity, with depth (of course on natural horizon basis). The data of the above analyses have been presented in mathematical and graphical figures.

The inter-relationship between the different constituents, particularly between nitrogen and carbon, nitrogen and phosphorus, total soluble salts and sodium chloride, ignition loss and organic carbon, percentage base saturation and soil reaction, has been brought to focus by discussion and illustration as well.

The contributions due to organic and clay colloids towards the total exchange capacity in soils of the different groups studied were statistically analysed and presented. The correlation between the total exchange capacity as determined analytically and the total exchange capacity calculated from statistical data has been illustrated graphically. It has also been brought to focus that whether or not the value, i.e. contribution due to organic matter, is statistically significant, it is simply impossible to disregard the contribution of organic matter towards the total exchange capacity of soils whatever the genetic group may be.

The distribution of free iron oxide has been studied both in soils and the corresponding clay fractions on horizon basis, and the movement of free iron oxide in the soils studied has been fully discussed. It was found that the free iron oxide particularly in the A horizon is also significantly associated with some fraction other than clay - especially so in the case of Black Earths, and as a possible suggestion it has been sought to be allocated to the humic matter as well.

A search into the reasons for the colour of the soils, particularly the very dark colour of the Black Earths, was made. It has been found that the blackening and darkening are all due to organic matter, and neither due to Titanium nor due to any clay mineral. It has also been shown that the intensity of red brown and yellow brown colours is in close agreement with the abundance of free iron oxide in soils. The red toning has been suggested to be due to better aeration and ageing and the yellow toning due to the prevalence of reducing condition imposed by impeded drainage and also high water table.

The distribution of Titanium in the clay fractions has been specially discussed with reference to its pedological implication, and it has been argued that accumulation of TiO_2 in the A horizon clay and gradual fall in the B horizon clay is an indication of a podsolic process of soil formation.

The clay fractions have been fully studied for the SiO_2: (Fe_2O_3 + Al_2O_3), SiO_2: Al_2O_3 and Al_2O_3: Fe_2O_3 ratios. The implications of the distribution of the above mentioned ratios with depth (on horizon basis of course) have been fully discussed, at different stages, to account for their pedological significance and also the mineralogical make-up of the clay fractions.

The grouping or classification of the soils studied was attempted on the strength of the morphological and chemical characteristics (particularly of the clay fractions of different horizons).

The Red Brown Earths studied were grouped as such following Prescott (1947) particularly because of their close agreement with the Red Brown Earths studied by Piper (1938) both in morphology and chemistry, and especially the clay-chemistry.

The Black Earths were allocated to the rendzina group particularly because of their morphology in harmony with chemistry.

The Yellow Brown Earths were regarded as Solodized-Solonetz Soils - the Y.B.E. 2/LS being weakly solodized and Y.B.E. 1/S being strongly solodized as evidenced by both morphology and chemistry (particularly of the clay fraction).

The P. 1/S, although looking like a Podsolised soil, had ultimately to be considered as a Solod mainly because of the presence of a cracky B_1 horizon indicating a columnar tendency in that horizon.

An attempt has been made to trace the history of the evolution of the soils studied and it was found that the geological and climatological history of the area under investigation seems to be mainly responsible for the development of the diverse groups of soils encountered in the present study. It has been shown that the valley had two forces, or rather two elements working together from the start, the elements being a calcimorphic one and a halomorphic-cum-halogenic one, and, with the improvement in the mid-recent period (Browne 1945) in climatic condition from the previous arid cycle, the interplay of lime and alkali, subsequently modified by the intrusion of a hydrologic element coupled with micro-topography and also by the intervention of phytosphere i.e. vegetation and human elements, brought about the diversity of the soil pattern as encountered in the area under study.

The last attempt was taken to study systematically the clay minerals, their qualitative and quantitative nature, their distribution with depth, their pedological significance and so on - the clay fractions being isolated from natural horizons of the soils studied.

It was found that the clay minerals of the soils studied are composed mainly of Illite and Kaolinite, in varying relative proportions. The Rendzina clays were found to be mainly Illitic, whereas the Solod is dominantly Kaolinitic - the Red Brown Earths and the Solodized-Solonetz being dominantly Illitic.

The relationship between the chemical nature and the mineralogical makeup of the clay fractions has been discussed and it was found that the SiO_2: R_2O_3 ratio is a fairly good indication of the relative abundance of the Bi-layer and Tri-layer minerals in the clay fractions excepting the clays of the hydro-halogenic soil in transitional stage particularly in the eluvial horizon.

As a test of reliability of the X-ray studies, some selected clay fractions were analysed for their K_2O content and also MgO content. It was found that the K_2O data coupled with the SiO_2: R_2O_3 ratio support the qualitative and quantitative report of X-ray analysis, especially as far as the Illites are concerned.

An attempt was also made to discuss the possibility of assigning a value of total exchange capacity to the Illites under the present study and it has been sought to prefer a value of 50 m.e.% as total exchange capacity for the Illites studied hereunder, thereby showing an inclination to the view of Endell and assoc. (1935).

Items of Interest.

1. Study on the movement of free iron oxide in soils and clays on natural horizon basis.

2. Fusion analyses of the clay fractions and the distribution of the $SiO_2 : R_2O_3$ and associated ratios with depth on natural horizon basis.

3. Studies on the clay minerals - qualitative and quantitative - on natural horizon basis.

4. Characterisation of Illite occurring in soil horizons.

Without making any direct comment, it might be said that most of the above studies, as far as available literature shows, seem to be new on Australian Soils of similar groups as studied hereunder and as has been pointed out from time to time; some of the studies may even be regarded as an opening attempt in soil science in general.

INTRODUCTION.

Situated at a distance of about 50 miles north of Adelaide, the capital city of South Australia, the BAROSSA VALLEY is regarded as one of the most productive horticultural areas of the State. The Valley, according to L. W. Jervis (Dept. of Information, C/A) is one of the biggest and best wine producing areas in Australia. As such the valley is an important factor in the Australian economy.

The geography and geomorphology of the valley can be considered in terms of two separate blocks formed by the east-west run of the north Para river - Fig. 1; which eventually follows a southwesterly direction. On the bank of the east-west run of the river is situated Nuriootpa, a small township.

The level flats surrounding Nuriootpa extend eastwards to the foot of the Angaston Hills which are an extension of the Barossa Ranges - Hossfeld (1925). These culminate in Mount Kaiserstuhl, 1980 ft., - Tepper (1888), now known as Mount Kitchener - Hossfeld (1935). In this direction the width of the flat plain is about three miles. The Greenock and Moppa Hills bound it at a distance of about two miles to the west. Towards the north, it extends to Stockwell and further runs on northeastwards for some six or seven miles to be finally blocked by the Kapunda and Truro Hills (not shown on the map).

To the south, it gently rises to a low ridge, at the western end of which Tanunda is situated, and descends rapidly to a lower flat through which flows the Tanunda Creek in an east-west direction. From here the same formation of the ground is repeated stretching in a curve from north to south and being traversed by Jacobs Creek (east-west) extending to Rowlands Flat to the south and finally narrowing to about one-sixth of a mile to join the Lyndoch Valley flat to the south-west.

Backed by the northern Mount Lofty ranges, and having a practically uniform climate, the Barossa Valley has a very complex and puzzling soil-distribution pattern presenting significant problems of pedological interest.

The decline of the fertility of the Barossa soils - due probably to continuous cultivation since settlement - as evidenced by the frequent patchy and poor growth of the fruit trees, and the occurrence of diseases in the fruit trees (which will be referred to in the Survey report) calls for immediate attention and amelioration.

To achieve this, the necessary prerequisite is obviously an intimate knowledge of the soils and the conditions prevailing therein which would be the guiding steps for the Pathologists and Agriculturists.

The importance and necessity of a detailed study of the Barossa Soils, which can thus hardly be over-emphasised, was one of the factors leading to the present investigation.

CHAPTER I.

FIELD AND ASSOCIATED STUDIES.

SOIL SURVEY REPORT OF THE PORTION OF THE BAROSSA VALLEY UNDER THE PRESENT INVESTIGATION.

As the main object of the investigation was pedological, the first and foremost move was to do some field traversing in order to study the soils under natural conditions. This was possible through the courtesy of the C.S.I.R.O. (Soils Division). Reconnaissance work was undertaken in conjunction with the C.S.I.R.O. Survey Party, keeping an eye on the maximum possible time that could be devoted to field studies.

However, within the part of the Valley that could be covered in the time available, diverse groups of soils were identified to be expressing themselves in a complex pattern within the area which Hossfeld (1949) has termed the "Barossa Sekungsfeld". The major soil groups recorded as shown on the accompanying sketch map - Figure 1 - are:-

(1) Red Brown Earths.
(2) Black Earths.
(3) Podsolized Soils.
(4) Yellow Brown Earths.

Red Brown Earths.

The Red Brown Earths occur on the eastern side of the Valley below the Angaston Hills and are divided into two distinct areas by the North Para River. It is interesting to note that the more southern of these two areas extends south and west in a broad band in close proximity to this river. A zone of alluvial soils occurs in the valley floor itself, varying greatly in width.

The Light Pass area provides a good expression of Red Brown Earths. The soil type dominant in the area surveyed was named for the field purposes as R.B.E. 1/SL and might be tentatively named as Light Pass sandy loam. But for want of suitable locality names for all the other Red Brown Earths and other soil groups as well, all the soil groups and types thereof were named after their colour and texture and will be referred to hereinafter as R.B.E. 1/SL, R.B.E. 2/SL, R.B.E. 2/SCL and so on.

The R.B.E. 1/SL has a grey-brown fine sandy loam surface becoming lighter in colour with depth. A definite bleached A_2 horizon is encountered in undisturbed sites at about 6 inches in depth. The B_1 horizon of red-brown to dark red-brown clay occurs at about 12 inches and at 30-33 inches the B_2 horizon appears. It is a brown clay containing lime. Below 4½ feet, a mottled reddish brown and brown sandy clay to light clay with some lime occurs. Abundant mica grains and occasional stones and gravels largely of a quartzitic nature occur throughout the profiles. A stony and gravelly phase of the type was recognised. It was found associated with very local rises and/or slopes of rises. Some minor variations of the type, such as depth of the surface (A) horizons, and some slight mottling of the B_1 horizon were also noticed, but they were of minor significance in the area surveyed.

The topography is very gently undulating with a slope of 0-2% and the drainage both internal and external is good.

The native vegetation is represented by occasional red gums (<u>Eucalyptus camaldulensis</u>).

Some wind erosion probably occurs. Gully erosion occurs in the vicinity of creeks but is stabilised for the most part.

Trees and vines are in fair to good condition, although apricots are patchy, largely due to the prevalence of a pathogenic disease - Gummosis - and some vines seem to be past their economic life.

The other types of Red Brown Earths express themselves in association with the Yellow Brown Earths mainly and will be referred to accordingly.

<u>Yellow Brown Earths</u>.

For convenience in the field the name Yellow Brown Earths was given on account of the general yellow and brown colours encountered in the subsoil, particularly in the auger samples. They differ from the Red Brown Earths in the fact that: (1) the subsoil colours are mottled in yellows and browns as against red brown in the Red Brown Earths; (2) the structure of the B_1 horizon is coarsely columnar as against prismatic and nutty in the Red Brown Earths.

The Yellow Brown Earths occur in two distinct areas:-

(A) the area south of the North Para River is bordered on the west and north by Red Brown Earths, on the east by the southern part of the Angaston Hills, and on the south by the black earths:

(B) the area north of the river occupies a somewhat central position in the lower lying portions of the Valley. This zone of Yellow Brown Earths is characterised by the occurrence of many small areas of both Red Brown Earths and Podsolized Soils and by the diversity of the morphology shown by the profiles of the individual soil types.

The two most important Yellow Brown Earths identified in the area locally known as "dirty corner" are denoted as Y.B.E. 1/S and Y.B.E. 2/LS. Very small areas of a Red Brown Earth - R.B.E. 2/ with two subtypes R.B.E. 2/SL and R.B.E. 2/SCL occur also.

Y.B.E. 1/S occurs on very low and sprawling rises throughout the area and supports a vegetation association dominated by <u>Callitris propinqua</u> (native pine), <u>Eucalyptus leucoxylon</u> (blue gum), <u>Banksia marginata</u> (honeysuckle), <u>Casuarina stricta</u> (oak). <u>Acacia</u> spp. are also pr~~i~~minent in the association. The surface horizon is a light grey brown fine sand. A distinct bleached horizon of a pale brownish white fine sand containing some buckshot and quartz gravel occurs at about 6 inches in depth. The B_1 horizon appears at about 12 inches and is grey, yellow-brown and brown mottled clay with an irregularly developed columnar structure. At 26 inches the subsoil becomes a yellow-grey and brown mottled clay with an intimate network of red-brown sandy clay. Lime, both in amorphous and concretionary forms, occurs at about 36 inches and persists to beyond 6 feet.

Hel o/

Y.B.E. 2/LS has a grey brown loamy sand surface with a thin bleached A_2 horizon containing a small amount of buckshot gravel. A drab mottled brownish grey and yellow brown, coarsely columnar clay occurs at 5-6 inches in depth. Below 15 inches the colour of the clay becomes brighter and lime occurs at about 22 inches. At 30 inches there is a "marly" horizon containing pockets of clay. Below 38 inches the lime content decreases slightly but persists to beyond 6 feet.

This type supports a vegetation association dominated by _Eucalyptus odorata_ (peppermint). An interesting feature is the occurrence of small local depressions or "clay pans" within the type. Under natural conditions the surface soil of the clay pan is often no more than ½ inch in thickness. It is a brownish grey clayey sand. The clay pans which are waterlogged in winter and spring support a community of cyperaceous plants.

Transition zones between Y.B.E. 1/S and Y.B.E. 2/LS are often broad and the tracing of the boundary is correspondingly difficult.

In this area also occurs the R.B.E. 2/ . The more important type was found to be R.B.E. 2/SL. It has a grey brown sandy loam surface horizon, underlain by a thinly developed blotchy grey-brown and brown sandy clay loam horizon. The B_1 horizon of a dark brown to red-brown clay occurs between 5 and 6 inches in depth. Lime appears at about 12-13 inches. A "marly" horizon of about 10 inches thickness starts between 18 and 19 inches in depth. Below 29-30 inches the soil material consists of a greenish yellow-brown clay with large pockets of lime both in the amorphous and concretionary forms. Small amounts of buckshot gravel were also observed throughout the profiles.

A shallow phase of the R.B.E. 2/ having a sandy clayey loam surface was also sufficiently important to merit sampling. This was named R.B.E. 2/SCL.

The topography of the area is flat to very gently undulating with slopes from 0-2%. The drainage is impeded, probably with a perched watertable during winter and early spring. Waterlogging in winter and spring months is a major problem in the area. Trees, notably apricots show particularly patchy growth on this account. Some quite fair areas of vines were noted where they are not waterlogged, but on the whole vine growth tends to be patchy. It is definitely poor in the clay pan phase of the Y.B.E. 2/LS.

The distribution of the Red Brown Earths in relation to the Yellow Brown Earths in the area of impeded drainage is such that the Y.B.E. 1/S and R.B.E. 2/ occur in local low rises encircling the relatively low lying flats wherein occurs the Y.B.E. 2/LS to receive all the surface runnings of Y.B.E. 1/S and R.B.E. 2/ .

Podsolized Soils. Two areas of Podsolized soils are shown on the accompanying map (Fig. 1). The larger area occurs along the northwestern margin of the valley immediately below the Greenock Hills. Yellow Brown Earths also occur here in the lower lying situations.

Another and much smaller area of Podsolized Soils occurs south of the North Para River in the middle of the Yellow Brown Earths on a comparatively elevated spot.

Two types of Podsolized Soils were observed - one with the (A) horizon exceeding 20 inches in thickness and the other designated as P. 1/S with the (A) horizon of about 14 inches thickness. The latter type was more widespread in the areas surveyed. The P. 1/S has a light brownish grey sand surface passing to a distinct bleached (A_2) horizon of off-white sand at about 6-8 inches in depth. Some gravel occurs in these horizons. The B_1 horizon usually appears between 14 and 17 inches. On closer and more careful examination after the opening of the pit, the B_1 horizon revealed a columnar tendency in the structure. It is a mottled grey, yellow-brown, and red clay. A sandy clay mottled in red, reddish-brown, yellow, yellow-grey and light grey appears at about 22 inches. From about 39 inches in depth the texture changes to a clayey fine sand and light grey becomes the increasingly dominant colour with depth.

P. 1/S occurs on the slopes of the order of 4-6% with a fair-good drainage condition.

On the flat country below the slopes of the northwestern hill both Y.B.E. 2/LS and R.B.E. 2/SL occur. Another type of Red Brown Earth ~~R.B.E.~~ designated as R.B.E. 3/was also noticed with a more mottled subsoil than either of R.B.E. 1/ or R.B.E. 2/ . But the R.B.E. 3/ was found in areas too restricted for typing purposes.

Ital.

The vegetation association supported by P. 1/S is dominated by *Callitris propinqua*. *E. leucoxylon* is also prominent.

The growth of apricots and pears is fair to good, but apricots are often patchy due to 'Gummosis'. Apples and quinces are only just fair in this area. Vines tend to be somewhat patchy although some good areas were noted.

Wind erosion is a danger particularly on the upper slopes and where vines are planted. It usually results in local removal and deposition of the surface soil material and can be fairly serious for these local patches.

Black Earths. The Black Earths occur in the southern part of the valley from Tanunda to Rowlands Flat. The topography here is quite distinctive. It consists of numerous ridges stretched across the valley from east to west and dissected by creeks. The Black Earths occur on the crests and upper slopes of these ridges. Various unclassified soils occur along the small creek valleys.

Two phases of the Black Earths were noticed, one with a deep surface clay horizon and the other with a shallow one.

The Black Earths start right from the surface with a very dark grey to black clay which is quite friable with granular to nutty structure. No visible lime was found in this horizon - deep or shallow. At about 20 inches in the deeper phase - BL.E(A), and about 7-8 inches in the shallow one - BL.E(B), the clay becomes variously mottled in brownish-grey, brown, grey, reddish-brown, etc. and lime makes its appearance. The lime all throughout the profiles down to 9 feet was characteristically amorphous and soft and at about 38 inches in the case of the BL.E(A) and 30 inches in the case of the BL.E(B), the texture of the clay was noted as clay with lime. Unlike the other groups, there was no sign of decrease in lime content down the profiles. The clay was found to be friable all throughout the profiles and the structure maintained a granular and nutty structure excepting in the case of BL.E(A) where the clay showed a tendency to massiveness at depths between 20 and 35 inches. The profiles showed no indication of genetic horizon development. The clay underlying the surface dark grey-black horizon showed randomly distributed brownish-white specks of lime on the exposed surface of the pits.

These Black Earths have been particularly esteemed for their productivity and all of them were brought under the plough thereby leaving no trace of any native vegetation. The thin strips along the fence lines exhibit a network of surface cracking and the crackings are quite deep too.

The micro relief of the area is flat with a moderately good internal and external drainage.

THE SOIL PROFILES FOR LABORATORY STUDIES.

Having covered the area representing the four main groups of soils by auger boring and general traversing, some spot areas were selected for detailed morphological study and for collecting samples for laboratory study from reasonably well expressed and representative soil types.

The samples collected for the laboratory investigation comprised three types of Red Brown Earths - R.B.E. 1/SL, R.B.E. 2/SL and R.B.E. 2/SCL; two types of Yellow Brown Earths - Y.B.E. 1/S and Y.B.E. 2/LS; one type of Podsolized Soils - P 1/S, and two types of Black Earths - BL.E(A), BL.E(B) - the descriptions of which are in Table 1. The notations SL, SCL, S and LS used to designate the soil types indicate the surface textures which are sandy loam, sandy clay loam, sand and loamy sand respectively.

/Table 1.

TABLE 1.

DESCRIPTION OF THE SOIL PROFILES.

Soil Type.	Soil Number.	Horizon.	Depth in inches.	Morphology.	Relief.	Culture.
R.B.E. 1/SL	15144	A_1	0 - 4½	Grey brown fine sandy loam with a trace of gravel, loose when dry and cloddy when moist.	Flat to very gently undulating. Both internal and external drainage - good. Slope - 2%.	Horticulture.
	15145	A_{2a}	6 - 9	Light grey brown fine sandy loam with light brown streaks, small amounts of gravel and stone - Compact.		
	15146	A_{2b}	9 - 11	Mottled grey-brown, reddish-brown fine sandy loam with a trace of gravel.		
	15147	B_1	12 - 27	Red brown - dark red brown hard and compact clay with trace of quartz grit, lime appearing structure tending to prismatic.		
	15148	B_2	31 - 48	Brown clay with lime and lime coated quartzitic gravel.		
	15149	-	54 - 66	Mottled reddish-brown and brown sandy to loamy clay with a trace of lime and some stone and quartzitic gravel.		

TABLE 1 (Ctd.)

DESCRIPTION OF THE SOIL PROFILES.

Soil Type.	Soil Number.	Horizon.	Depth in inches.	Morphology.	Relief.	Culture.
R.B.E. 2/SL	15150	A_1	? ¼ - 3	Grey brown sandy loam with a trade of buck-shot gravel, loose when dry and tendency to cloddy when moist.	Very gently undulating, occurs on local very low rises. Both internal and external drainage - fair to good - the external being on the good side and internal on the fair side.	Horticulture.
	15151	A_2	3½ - 4½	Blotchy grey brown and brown sandy clayey loam with a trace of buck-shot gravel - Compact.		
	15152	B_1	5½ - 13	Dark brown, red brown clay with a trace of buck-shot gravel, nutty-cubic structure, hard and knobby when dry, plastic-sticky when moist.		
	15153	B_{2a}	13 - 17	Dark brown, red brown clay with trace of buck-shot gravel, lime appearing, prismatic structure, hard and knobby when dry, plastic-sticky when moist.		
	15154	B_{2b}	19 - 27	Brown-dark brown marl with pockets of clay in highly calcareous (amorphous and indurated)matrix and traces of buck-shot.		
	15155	BC? B	29 - 39	Greenish yellow-brown clay with pockets of lime, cubic in structure, hard when dry, plastic to sticky when moist.		
	-	C? -	39 - 60	Same as above - below 60" not penetrable, hard indurated lime material.		

TABLE 1 (Ctd.)

DESCRIPTION OF THE SOIL PROFILES.

Soil Type.	Soil Number.	Horizon.	Depth in inches.	Morphology.	Relief.	Culture.
R.B.E. 2/SCL	15156	A_1	0 - 3	Grey brown sandy clayey loam with a trace of buck-shot gravel; compact both when dry and moist.	Same as R.B.E. 2/SL.	Virgin.
	15157	B_1	5 - 9½	Brown, red brown clay with trace of buck-shot; prismatic structure breaking down to nutty and cubic; hard when dry, plastic-sticky when moist.		
	15158	B_{2a}	12 - 14	Dark brown clay (highly calcareous) with trace of buck-shot; hard when dry, plastic-sticky when moist.		
	15159	B_{2b}	15 - 19	Marl with pockets of dark brown clay; trace of buck-shot.		
	15160	C? -	21 - 35	Greenish brown with black inclusions clay with pockets of amorphous and indurated lime; trace of buck-shot gravel; hard while dry, plastic-sticky while moist.		

TABLE 1 (Ctd.)

DESCRIPTION OF THE SOIL PROFILES.

Soil Type.	Soil Number.	Horizon.	Depth in inches.	Morphology.	Relief.	Culture.
Y.B.E. 1/S	15161	A_{1a}	0 - 1½	Light grey brown fine sand; single grain structure; loose when dry, coherent when moist.	Flat to gently undulating. Occurs on low sprawling rises. External drainage good, but internally impeded (probably perched water table during winter and early spring).	Virgin.
	15162	A_{1b}	1½ - 5	Light grey brown fine sand; structure and consistence as above.		
	15163	A_2	6 - 12	Faint brownish-white fine sand, a slight trace of buck-shot and quartz gravels; single grain structure; compact.		
	15164	(B_1	12 - 13	Grey with brown, yellow-brown mottling, off-white sand-clay capping (domed); very compact.		
	15165	(	13 - 22	Grey with yellow-brown, brown mottlings and black concret. and incl. clay; irregular columnar structure, hard and tough when dry, sticky when moist. The columns interspersed with deep vertical converging cracks.		
	15166	B_2	26 - 38	Mottled yellow grey, brown clay with an intimate network of red brown with black incl. sandy clay; massive; hard when dry.		
	15167	B_3C ? B_3	44 - 54	As above; lime (amorphous and indurated); massive.		
	15168	C ? -	63 - 69	Brown, yellow grey mottled clay with black inclusions, and a yellow brown network of sandy clay; lime continuing.		
		C ? -	69 - 78	Same as above (discarded and max. cont.)		

TABLE 1 (Contd.)

DESCRIPTION OF THE SOIL PROFILES.

Soil Type.	Soil Number.	Horizon.	Depth in inches.	Morphology.	Relief.	Culture.
Y.B.E. 2/LS	15169	A_1	0 - 3	Grey brown loamy sand; single grain structure; loose when dry, cloddy (weak) when moist.	Flat, relatively low lying. Drainage - internally impeded, externally nil. Liable to waterlogging during winter and early spring.	Horticulture
	15170	A_2	4 - 5	Light grey brown loamy sand, trace of buck-shot gravel; single grain structure; compact.		
	15171	B_1	5 - 15	Mottled drab brownish-grey, yellow brown clay with trace of quartz grit; coarsely columnar structure; hard and tough when dry - the domed columns intervened by deep vertical converging grooves filled with sandy material.		
	15172	B_2	15 - 20	Mottled brown, yellow brown, yellow grey clay; tendency to massive; hard when dry.		
	15173	B_2	22 - 30	Mottled reddish-brown, yellow grey with yellow brown incl. clay; lime appearing in pockets; massive; hard when dry.		
	15174	C? -	30 - 38	Marl - highly calcareous material with pockets of mottled reddish-brown, yellow grey with yellow-brown incl. clay.		
	15175	C -	38 - 48	Variously mottled brown, reddish-brown, greenish-grey, yellow grey clay with pockets of lime.		
	15176	C or D	57 - 68	Variously mottled dark brown, yellow brown, yellow grey with red and black incl. clay; small amount of lime and lime rubble.		

TABLE 1 (Ctd.)

DESCRIPTION OF THE SOIL PROFILES.

Soil Type.	Soil Number.	Horizon.	Depth in inches.	Morphology.	Relief.	Culture.
P. 1/S	15177	A_1	0 - 6	Light brownish-grey sand with some gravel (quartzitic); single grain structure; loose consistence.	Gently sloping with a slope of 5-6%. Good external drainage and a fair internal drainage. The internal drainage has a tendency to impedance as was evidenced by the moist A_2-horizon sand.	Horticulture.
	15178	A_2	8½ - 14	Off-white sand, slight gravel; single grain; cemented (slightly).		
	15179	B_1	16 - 21	Mottled grey, yellow brown and red clay; tendency to columnar structure; hard and tough when dry, probably sticky when moist.		
	15180	B_2	22 - 39	Mottled red, reddish-brown, yellow, yellow grey, light grey sandy clay; massive; hard and tough when dry.		
	15181	-	39 - 51	Mottled pale yellow grey, light grey, yellow clayey fine sand.		
	15182	-	52 - 72	Light grey with yellow brown streaked clayey fine sand.		

TABLE 1 (Ctd.)

DESCRIPTION OF THE SOIL PROFILES.

Soil Type.	Soil Number.	Horizon.	Depth in inches.	Morphology.	Relief.	Culture.
BL.E(A)	15758	? -	0 - 7	Brownish very dark grey clay; granular; friable when dry.	Undulating - broad flat ridges dissected by creeks. Drainage both external and internal moderately good.	Hay-cropping.
	15759	? -	9½ - 15½	Black with brownish streaked clay; nutty; friable when moist.		
?	15760	? -	20 - 29	Light brownish grey with light brown and black spectrys and large black streaked clay; lime in pockets; nutty-massive; friable when moist.		
	15761	? -	30 - 35	Mottled brownish-grey, light brown and black streaked clay; lime in pockets; nutty-massive; friable when moist.		
	15762	? -	38 - 60	Light brown with grey mottled '<u>clay-with-lime</u>'; highly calcareous (amorphous); granular; friable when dry.		

TABLE 1 (Ctd.)

DESCRIPTION OF THE SOIL PROFILES.

Soil Type.	Soil Number.	Horizon.	Depth in inches.	Morphology.	Relief.	Culture.
BL.E(B)	15763	? -	0 - 3½	Brownish very dark grey clay; granular; friable when dry.	Same as BL.E(A).	Same as BL.E(A).
	15764	? -	3½ - 6½	Same as above.		
	15765	? -	7½ - 14	Mottled dark grey, brown, yellowish grey, intermingled with mottled dark grey, light brown and reddish brown clay; lime in pockets; granular; friable when moist.		
	15766	? -	15 - 28	Mottled light yellow grey, grey, yellow brown, and reddish brown clay; lime in pockets; granular; friable when moist.		
	15767	? -	31 - 54	Mottled light brown, reddish brown, greyish yellow '<u>clay-with-lime</u>'; lime (soft) highly calcareous; granular; friable when dry.		
	Discarded	? -	54 - 90	As above (discarded).		
	15768	? -	90 - 108	Mottled greenish brown, yellowish grey, brown, yellowish brown clay; with lime and lime rubble; granular, friable when dry.		

THE PEDOGENIC FACTORS.

5/

A study of the factors contributing to the formation of soils, as is well known, is undoubtedly an essential necessity in elucidating the results of any Pedological work, and as such information available regarding climate, geology etc. of the area under investigation has been traced as follow:

(A) Climate.

The climate of South Australia as a whole is somewhat similar to that of Mediterranean countries, Cape region of South Africa, Chile, and California - Trumble (1948) - having a rainfall period concentrated between Autumn and Spring and a dry Summer. The Barossa Valley represents an area of practically uniform climatic conditions with a mean annual rainfall of 21-23 inches and a mean annual air temperature of 48°F. The mean effective rainfall period comprises 7-8 months commencing in March-April and concluding in October-November - the effective rainfall being maximum during the Winter months.

The available information on the climatological data of the area is given in Table 2(a) to show the monthly distribution of rainfall and evaporation. The data for evaporation were calculated with reference to the Waite Institute evaporimeter records and as such the evaporation data for the Waite Institute are also included in the Table for comparison.

The monthly values of Prescott ratio (P.R.) for rainfall efficiency - Prescott & Thomas (1948) - for the area are given in Table 2(b). Because of the fact that the monthly P.R. values of the areas surrounding the Valley show a good constancy, the means of the monthly P.R. values of the surrounding areas were taken to represent the monthly P.R. values for the valley as a whole.

By plotting the average P.R. values against the corresponding months the curve (Fig. 2) obtained presents a sinusoidal nature with its gradually rising peak at 2.42 in June and a minimum of 0.16 in February. The curve shows that the number of months with climatic index equal to or greater than:-

(a) 0.4 is 7.2
(b) 0.8 " 5.3
(c) 1.2 " 4.0
(d) 1.6 " 3.0
(e) 2.0 " 1.7,

which signifies that the break of season or the mean rainfall season continues for 7.2 months and the rainfall is sufficient to effect leaching for 5.3 months. The nature of the curve further shows that the mean rainfall season is well backed by a steadily rising index to facilitate seepage and possibly also storage that could be brought forward to meet the following dry period to some extent.

The Index (on annual basis) for the leaching factor $P/_{E}0.7$ and $^{P}/_{S.D.}0.7$ - Prescott (1950) - were found to be 1.313 and 64.1 respectively, Table 2(c), by taking the average of the mean annual rainfall values of the surrounding areas to represent 'P' for the valley and the average of the mean

TABLE 2(a). CLIMATOLOGICAL DATA - MONTHLY DISTRIBUTION OF RAINFALL AND EVAPORATION.

Recording Station.	Years of record.	Mean rainfall season (months).	Mean rainfall and evaporation in inches.																							
			Jan.		Feb.		Mar.		Apr.		May		June		July		Aug.		Sep.		Oct.		Nov.		Dec.	
			R	E	R	E	R	E	R	E	R	E	R	E	R	E	R	E	R	E	R	E	R	E	R	E
Angaston	62	7.6	0.90	8.7	0.77	7.1	0.94	6.0	1.73	3.7	2.39	2.0	3.03	1.5	2.68	1.4	2.99	2.0	2.57	3.0	1.89	4.8	1.30	6.8	1.08	8.3
Greenock	62	7.4	0.89	8.9	0.76	7.5	0.91	6.2	1.69	3.7	2.27	2.1	2.74	1.3	2.46	1.4	2.86	2.0	2.50	3.0	1.92	5.1	1.26	7.7	1.06	8.7
Lyndoch	56	7.7	0.86	8.9	0.71	6.8	0.83	5.5	1.76	3.5	2.42	2.0	3.36	1.3	2.93	1.4	3.16	2.0	2.78	3.1	2.04	4.4	1.22	6.6	1.03	8.6
Nuriootpa	60	7.2	0.90	9.1	0.71	7.5	0.90	6.1	1.62	3.7	2.17	2.1	2.83	1.3	2.46	1.4	2.76	2.0	2.37	3.0	1.79	5.1	1.19	7.5	1.12	8.8
Tanunda	75	7.6	0.91	8.9	0.67	7.2	1.00	5.9	1.75	3.5	2.39	2.0	3.08	1.3	2.61	1.4	2.85	2.0	2.50	3.0	1.89	4.6	1.22	6.6	1.00	8.5
Waite Institute	?			8.6		7.0		6.4		4.0		2.8		1.8		1.8		2.3		3.2		4.6		6.2		7.8

R ⟶ denotes rainfall and stands for P (precipitation which includes snow in colder regions).

E ⟶ evaporation.

TABLE 2(b).

INDEX OF RAINFALL EFFICIENCY (PRESCOTT RATIO - $P/_{E^{0.75}}$) ON MONTHLY BASIS.

Locality.	Months.											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
Angaston	0.178	0.177	0.245	0.648	1.421	2.237	2.082	1.778	1.128	0.583	0.309	0.221
Greenock	0.173	0.168	0.232	0.633	1.301	2.252	1.911	1.700	1.097	0.566	0.273	0.209
Lyndoch	0.167	0.169	0.231	0.688	1.439	2.761	2.277	1.879	1.188	0.672	0.296	0.205
Nuriootpa	0.172	0.157	0.232	0.607	1.244	2.326	1.911	1.641	1.040	0.527	0.263	0.219
Tanunda	0.177	0.152	0.264	0.684	1.421	2.531	2.028	1.694	1.097	0.602	0.296	0.201
Average P.R. for the Valley.	0.173	0.164	0.251	0.652	1.365	2.421	2.042	1.738	1.110	0.590	0.287	0.211

TABLE 2(c). ANNUAL CLIMATOLOGICAL DATA AND PRESCOTT RATIO FOR LEACHING FACTOR.

Station.	Mean air Temperature °F.	Mean Rainfall in inches (R).	Average R for the Valley.	Mean Evaporation in inches 'E'.	Average E for the Valley.	E for Waite Institute.	Prescott ratio for the Valley		Calculated S.D. for the Valley.	Observed S. D. Waite Institute.
							$P/E^{0.7}$ on annual basis.	$P/S.D.^{0.7}$ on annual basis.		
Angaston	47	22.27	21.87	55.3	55.7	56.4	1.313	64.1	0.216	0.213
Greenock	48	21.32		57.6						
Lyndoch	48	23.10		53.1						
Nuriootpa	48	20.82		57.6						
Tanunda	48	21.87		54.9						

annual evaporation values to represent 'E' for the valley. The saturation deficit (S.D.) was calculated by assuming that annual evaporation from free water surface is equal to 258 S.D. - Prescott (loc.cit.). The observed values of 'S.D.' and 'E' from Waite Institute evaporimeter records are also shown in Table 2(c) for comparison.

By taking the above mentioned average values of mean annual rainfall and evaporation, the Prescott ratio for rainfall efficiency $P/_{E}0.75$ comes to 1.073 and the corresponding value for $P/_{S.D.}0.75$ equals 67.7 or this may as well be presented as in Table 3.

TABLE 3.

(A) P.R. for leaching factor.		(B) P.R. for rainfall efficiency.	
$P/_{E}0.7$	$P/_{S.D.}0.7$	$P/_{E}0.75$	$P/_{S.D.}0.75$
1.313	64.1	1.073	67.7

(A) and (B) are essentially the same - (A) refers to data which have been used to mark the boundaries of great soil groups in Australia - Prescott (loc.cit.) - and (B) refers to data of more elaborate nature concerning the length of growing season and takes into full account all the monthly data for rainfall and evaporation as pointed out previously.

(B) Geology.

Genetically and structurally the Barossa Valley constitutes a portion of the Northern Mount Lofty Range, which is one of the chief assets and the most highly appreciated beauties of the gulf region of South Australia, nay, of the whole State - Fenner (1931). To quote Sir Samuel Way (unveiling of Light memorial, June 1905), who has given an eloquent appreciation of the area - "One of the finest plains in the world, under the shelter of beautiful hills which have moderated the climate. They have secured us from drought, have furnished us with a beautiful water supply and with a glorious picture ....".

The geology of the Mount Lofty Ranges was one of the most baffling problems that South Australian geology has ever faced. In fact, some of the earlier workers have gone so far as to say that "The complexity of the area renders it not only difficult to come to any precise conclusion, but also hopelessly unattractive for a detailed study".

The first geological study in the Mount Lofty area dates back to 1859 due to Selwyn. Following him a number of geologists,notably Tate (1879), Ulrich (1872), Brown (1884), Woodward (1884) and Tepper (1888) came into the picture. The works of Tepper (loc. cit) are of particular significance to the Barossa Valley itself and as such do deserve occasional reference in the present text.

It was not until the first decade of the current century that a systematic study of the geology of a part of the ranges was presented by

Howchin (1904). Since then Sprigg (1942, 45), Hossfeld (1925, 35, 49), Howchin (1906, 26, 35) and others produced quite a wealth of information on the ranges under reference - the contributions due to Hossfeld (loc.cit.) seem to be of great significance to the Pedology of the Barossa Valley.

However, the significant facts emerging out of the geological findings on the ranges under reference to date can be summarised as follow:

The area appears to have formed a part of the extensive Australian pre-miocene peneplain. Warping and block faulting, commencing probably in the early Miocene in some areas and continuing episodically until recent times, have dismembered the region and destroyed much of the pre-existing drainage.

The fracturing of the peneplain probably began with its submergence in Miocene times and continued at the close of the period of deposition, resulting in the breaking up of the area into numerous sections at different levels and emergence of the present Mount Lofty Ranges from beneath the tertiary sea. The emergence of the various blocks was accompanied by tilting and produced the present superimposed streams which are grafted on the pre-existing consequent drainage.

The trough faulting of this area has eventually resulted in the formation of a number of fault basins.

A further elevation of the area consequent to a further period of movement took place resulting in the entrenchment of the consequent streams, revealing their superimposed character, and in the draining of the fault basins. A final period of movement but of less intensity is believed to have closed the series of earth movements which the area was subjected to since the Tertiary period.

The fertile Barossa Valley of today represents one of the above-mentioned fault basins, the valley being formed by the filling up of a fault basin chiefly by deposits from the adjoining hills.

From what has been said above, it seems pretty clear that as the sea receded the fault basin (now Barossa Valley) assumed the form of an enormous Lake carrying brackish water.

Hossfeld (Priv. comm.) holds that the irregular stretch of sandy soils at the foot of Moppa Hills, extending to the sandhills towards west and north-west, and another band of sandy soils lying within a mile of Tanunda running south and south-eastwards of Nuriootpa, represent portions of the shore of the pre-existing "Lake Barossa" - Hossfeld (unpublished). It is interesting to note in this connection that as early as 1888 Tepper gave a definite hint of the above theory.

Hossfeld (loc.cit.) contends that as the draining of the lake, or, in other words, filling of the basin proceeded the heretofore submerged, comparatively lower elevations (due to differential tectonic movement) were exposed and eventually led to the reticulation of the lake forming smaller lakes bounded by the subsequently exposed ridges or elevations. With the march of time as the Lakes drained out, the brackish water - which as heir to the pre-existing sea was maintaining the lakes - laid down the salts preferentially over the central portions of the valley floor and also to some extent/inkled spr// all over the valley - sufficient to cause trouble in the succeeding generation, i.e. the soils to be developed in the valley.

Sedimentary Petrology.

It has been claimed that, with the exception of deposits belonging to the Tertiary or Quarternary eras, all the Sedimentary rocks of the Mount Lofty Ranges are of Prepalaeozoic age. These prepalaeozoic rocks have been regarded as consisting of at least three unconformable series, the oldest, the Barossa Series, everywhere exhibiting intense metamorphism and extensive Igneous activity; the sediments above the Barossa Series have been identified with those of the Adelaide Series. It has been shown, however, that they belong to two unconformable series, to which the names "Para" and "Marcoota" series have been given. They correspond respectively to the 'lower' and 'upper' beds of the Adelaide Series.

To be more precise the bed rocks can be briefly described as:-

(1) Overmass - Tertiary rocks.
(2) Undermass - Cambrian and Precambrian rocks.

(1) Tertiaries - These are relatively weakly resistant to erosion and level bedded and consist of limestones with interbedded clays and gravels, etc.

(2) Cambrian and Precambrian - The younger of these two ancient series lies largely along the inner curve of the Mount Lofty arc, with the more complex older rocks to the east. The rocks themselves consist of grits, conglomerates, quartzites, slates, limestones, tillites, schists, gneisses and plutonic rocks, all highly indurated; with silicification and recrystallisation, they are extremely resistant to erosion.

All beds are not, of course, of the same order of resistance; thus in the scarp front that faces Adelaide the less resistant Argillaceous limestones, calcareous slates, and mudstones gave rise to rounded hills and smooth sided valleys, such as Green Hill—the vantage point from which Light surveyed Adelaide plain in 1837 - Fenner (loc.cit.). The quartzites gave bold, high scrub covered hills such as Black Hill and precipitous valleys and waterfalls as at Slapes Gully and Morialta.

In addition to this, mention may be made of the Permo-carboniferous glacial deposits, readily eroded, and thus presenting once more to the air large areas of later Palaeozoic landscape features.

Now coming to the Barossa Valley proper, the information available to date can be briefly outlined as follow:

The older rocks in the eastern as well as the western hill ranges consist of micaceous and hornblendic schists, gneiss, quartzites and near Greenock granite. The last is intrusive and only outcrops near the base of depressions round about the north-east corner of Greenock (Fig. 1).

Magnesian Limestone and a seam of very hard Kaolin were noticed near Moppa and a vein of Baryta on the road near Greenock.

At Tanunda the river has broken through quartzites, sandstones and micaceous slates. Above the clay slates and intercalated with them occur thicker or thinner seams of crystallised limestone, mostly of a bluish or grey tint. Iron spar was also seen.

To the east and south-east of Tanunda, Miocene limestone deposits assumed enormous magnitude, forming the Angaston Hills which finally run on to the Truro Hills towards the north.

The strip from Tanunda to Rowlands Flat, bordering the North Para River, is underlain by conglomerates, grits, sandstones and slates, although the more easterly part is associated with a host of basic igneous rocks and marble.

(C) Vegetation Association.

As the country has been put under extensive as well as intensive horticultural practices, the native vegetation was destroyed to a great extent and as a matter of fact there is no trace of native vegetation left to identify the association of one of the soil groups (Black Earths) encountered in the valley. But none-the-less the existing native vegetation clearly indicates that the valley has an association dominantly of EUCALYPTS - such as *E. Odorata*, *E. Leucoxylon*, *E. Camaldulensis*, interspersed with *Callitris propinqua* (native pine), *Banksia marginata* (honeysuckle), *Casuarina stricta* (oak) and some *acacia* spp. such as *A. armata*. b/ Ital.

DISCUSSION ON PEDOGENIC FACTORS.

With the impact of Dokuchaiev school of thought on the western world, the Science of Pedology gained its foothold as an independent branch of scientific discipline in countries outside Russia. It was not until the first decade of the current century that the creation of the master mind of Dokuchaiev appeared with its far-reaching significance in German literature, principally due to Glinka (1914). Since then the devotees of Science from diverse directions contributed a wealth of information wherein lies buried the foundation of modern Soil Science.

The recognition of the very great but non-exclusive role of climate in the genesis and distribution of the soil groups and types thereof has been the stepping stone to the identification of the geographical and geomorphological distribution patterns of soils. The works of, among others, Glinka in Germany, Marbut in U.S.A., Robinson in U.K., Prescott in Australia, certainly accredit to themselves a treasury worth falling back on.

Inspired by the Russian outlook and the fast advancing frontier of Pedological Science, Jenny (1941) has adapted and developed the original equation suggested by Dokuchaiev and enunciated that: $S = f\ (cl, o, r, p, t)$, indicating thereby that the soil is the finished product of the interaction among climate, organisms including vegetation, relief including hydrology, parent material and time. Jenny (loc.cit.) attempted to present the relationships between the pedogenic factors and the soil properties whenever possible in quantitative terms. His perseverance in applying his mathematical outlook to Pedology has certainly been a great contribution towards the attempt of raising the status of Pedology to the level of PURE SCIENCE, which was so fervently hoped for by Dokuchaiev, who said - "Nevertheless, we may hope that all these difficulties will be overcome with time, and then Soil Science will truly become a Pure Science".

Stephens (1947), however, has further examined and developed this outlook pointing out that in nature the variables in Dokuchaiev's equation as adapted by Jenny (loc. cit.) are not completely independent.. He gives a complete list of all possible relationships in the form of partial differentials, e.g. $\delta S/_{\delta c}$, $\delta S/_{\delta o}$ etc. He contends that the relationship between a soil and its factors is best expressed as:-

$$S = \int f\ (c, o, r, w, p)\ dt.$$

in which t (time) is independent and c(climate), o(organisms including vegetation), r (relief), w (hydrology), p (parent material) have both dependent or independent status.

Evidently, therefore, the development of soils is a function of some factors, which are very faithful allies of nature, and which still today have refused to yield to the laboratory control. Notwithstanding the challenge of nature, the scientists, determined to master the mystery of nature, have taken an indirect course - the course of observation and inference relating to the cause and effect - the cause being the factors of soil formation and effect being the soils. And as a result of the untiring efforts of the scientists the information available to date is reasonably enough to enable one to apply the fundamental principles of deductive and inductive logic, or, in other words, if the cause - an invariable and unconditional antecedent - be known, the effect could be reasonably accounted for and vice versa, on the strength of the already available information, pending verification by laboratory studies. It is with this object in view that the present discussion was felt desirable to trace how far a general correlation of the soils and the soil formers could be traced with regard to the Barossa Valley Soils under investigation, pending the subsequent laboratory studies thereof. To do this, frequent references will necessarily be made to the works of Prescott, whose contributions, Pedological and climatological, are undoubtedly the guiding stars to Australian Pedology.

As is evident from the survey report outlined before and the accompanying soil map (Fig. 1), the Barossa Valley has presented diverse groups of soils such as Red Brown Earths, Black Earths, Yellow Brown Earths and Podsolised Soils.

From the climatological data furnished in Tables 2(a), 2(b) and 2(c), it is pretty clear that the area has a distinctly long wet period and a short dry summer period. The Prescott ratios for rainfall efficiency plotted against the corresponding months (Fig. 2) show that the duration of the pastoral season is 7.2 months, which is made up of periods having a -

Prescott ratio $P/E^{0.75}$ of	0.4	for	1.9	months	(for start of pastoral season)
" " " "	0.8	"	1.3	"	(for start of drainage)
" " " "	1.2	"	1.0	"	
" " " "	1.6	"	1.3	"	
" " " "	2.0-2.4	"	1.7	"	
	Total		7.2		

which indicates that drainage through the soil can take place for 5.3 months/year at varying degrees and the soil profiles would be expected to show differentiation of horizons depending of course on the other associated factors.

From a consideration of the Prescott ratio of leaching factor $P/E^{0.70}$ and/or $P/S.D.^{0.70}$ for soil-group boundaries, which (on an annual basis) are 1.313 and 64.1 respectively - Table 2(c) for the valley - the area lies within the zone of Red Brown Earths and Black Earths (vide Prescott's (1950) map of Australia with isologs of the climatic index projected against the boundaries of the major soil zones)..

Thirdly, the data for the saturation deficit and precipitation, which are 0.216" and 21.87" for the area, when plotted in Prescott's (loc. cit.) rainfall-saturation deficit diagram in relation to dominant soil zones of Australia, fall in the zone of Red Brown Earths and Black Earths. In Fig. 3, which is a reproduction of Prescott's (loc. cit) above-mentioned diagram, was plotted the point to show the precipitation and saturation deficit of the valley and the asterisk marks the position of the Barossa Valley with respect to rainfall and saturation deficit, showing clearly that the area is marginally but distinctly on the Red Brown Earths' side, the Black Earths being situated on the relatively slightly wetter side.

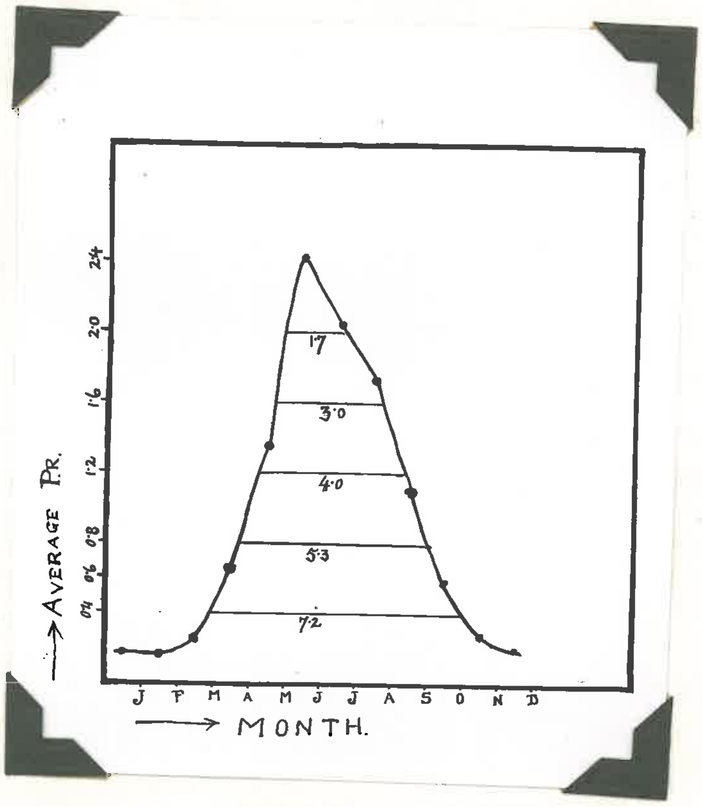

FIG. 2.

Curve illustrating the monthly distribution of average "Prescott Ratio" of rainfall efficiency $(P/E^{0.75})$ in the Barossa Valley.

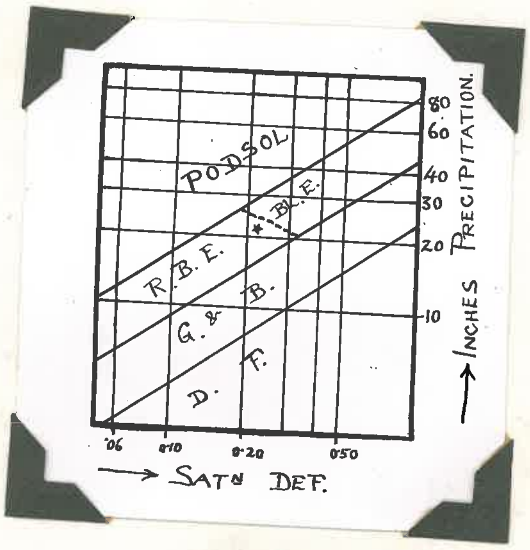

FIG. 3.

An outline reproduction of Prescott's (1949) 'Precipitation-Saturation Deficit' diagram in relation to soil boundaries in Australia wherein the asterisk shows the situation of the Barossa Valley with regard to Precipitation and Saturation Deficit. R.B.E. indicates Red Brown Earths, BL.E. - Black Earths, G & B - Grey and Brown Soils, and D.F. - desert formations.

Thus of the soil groups encountered in the Barossa Valley, climate quite satisfactorily accounts for the Red Brown Earths and possibly to some extent for the Black Earths which express themselves in the slightly wetter part of the valley, although the occurrence of the Red Brown Earths alongside the Black Earths seems to speak against this microclimatic contention. For the other two groups, climate by itself does not apparently seem to be very helpful. And in fact one would not expect either to cast all the die on climatic alone, particularly in a practically homoclimatic area, as otherwise it would be tantamount to the outright denial of the very concept of Pedology which does envisage that soil is a formation of the corporate and co-operative activities of different factors of which climate is one - very significantly important though. It is, thus, just but fair that the other factors should be given the chance to show themselves up to make their presence and activities felt.

It is in the fitness of things that Geology, with all its significance, should be dealt with next, but bearing in mind that this does not necessarily mean even by implication that Geology is of a lower order of importance than that of climate and in fact the matter would be the other way round, particularly where soils of a limited area are considered.

The geological history of the Barossa Valley as outlined before leads to some very significant implications of profound Pedological interest:-

(a) The emergence of the valley from a "Pre-existing lake" maintained by the brackish water or saline water (an heir to the Miocene sea), which hints at a distinct possibility of the occurrence of salt affected soils, i.e. halogenic soils, wherever local conditions make it possible and reasonably free from opposing forces such as excess lime, extra good drainage.

(b) The filling up of the valley by colluvial materials brought down to the valley floor from the adjoining hills and also by materials laid down from the sea water, indicate that the initial state of the soils, in addition to being saline, was also highly heterogeneous in nature - comprising quartzites, sandstones, micaceous and hornblendic schists, gneisses, micaceous slates, conglomerates and above all lime (hard and soft), and possibly also granites from Moppa Hills (Fig.1).

Recalling that the Yellow Brown Earths - both types - have shown distinct evidence of salt influence in their morphology, i.e. the characteristic Solonetzitic column in the B_1 horizon, even though the presence of lime was noticed in the B_2 horizon, it may be said that it was quite to be expected from what has been said in the paragraph (a) and (b) as well. And in fact everywhere in the world Solonetz morphology appears to develop commonly on marine and lacustrine sediments.

The paragraph (b) quite well explains the presence of lime in the Red Brown Earths and the Yellow Brown Earths as well.

In the case of the Black Earths, it is to be remembered that (i) the sub-soil horizons showed no tendency of decrease in the lime content with depth unlike the nearby Red Brown Earths, indicating thereby their more highly calcareous initial state amongst all the others; (ii) while estimating the texture of the subsoil clay in the field the clay down at 30-38 inches was recorded as clay with lime, indicating thereby that the lime is so soft and finely divided that it seemed to have formed an integral part of the clay; (iii) down to 90 inches the lime was all soft and marly with no sign of concretion or induration; only at a depth of 9 ft. some traces of lime rubble were observed in the general soft and marly matrix.

In the light of the above three observations, it may not be too much to say that the initial state of the Black Earths was a soft and very highly calcareous material and as such the occurrence of the Black Earths was quite up to expectation from what appears to be frequently reported in soil literature.

The P. 1/S, which apparently looks like a Podsolised soil, seems to be quite deceptive as the B_1 horizon has shown a columnar tendency, hinting thereby that the soil is probably a Solod, but prior to further investigation it may sound too presumptuous to regard the soil as a solod right from the start. But the morphology of the B_1 horizon suggests so. And in fact an invasion of salt, particularly when no lime was found anywhere in the profile, is quite an easy affair. And possibly because of a much lighter textured initial state - brought about by wave action of the pre-existing "Lake Barossa" and of the topographic advantage - the soil was fast moving towards the freedom from salt invasion. But at any rate the invasion of salt seems quite likely, particularly in the absence of a major opposition, i.e. lime, and hence is the presence of a mark of a supposedly previous solonisation on the body.

Thus it seems that the geological history, in conjunction with the sediments and also the climate, are quite in agreement with the occurrence of the diverse groups of soils under investigation. The whole affair will, however, be taken up at a later stage for a detailed discussion.

As for the native vegetation, although by virtue of being a reflection of local climate and the conditions prevailing in its habitat it can hardly merit the status of an independent soil former, it nevertheless furnishes some very useful information of Pedological and also geological significance. And in a country like Australia, native vegetation is quite expected to work as a first-class index of Pedological development.

From what has been said under vegetation before, it is pretty clear that the vegetation association of the valley is a Savannah Woodland (Wood 1937). Soils associated with Savannah Woodland as shown by Prescott (1931, 1947) and Piper (1938) are typically Red Brown Earths with the distinct possibility of some Black Earths too. And hence the occurrence of Red Brown Earths and Black Earths in the valley is not unexpected from the native vegetation. Secondly, referring to the observation of Ellis & Caldwell (1935), the presence of open woodland in an area of halogenic soils speaks for the distinct possibility of encountering Solodised and Solodic and even Podsolic Soils. Thus vegetation seems to speak for all the groups under investigation.

CHAPTER II.

LABORATORY INVESTIGATIONS (CHEMICAL & MECHANICAL).

TABLE 4(a)
RESULTS OF MECHANICAL AND CHEMICAL ANALYSES ON OVEN DRY BASIS.

Soil Type R.B.E 1/SL **Location:-** County - Light; Hd. - Moorooroo; Section - 151.

Soil No.		15144		15145		15146		15147		15148		15149	
Depth (in inches)		0 - 4½"		6 - 9"		9 - 11"		12 - 27"		31 - 48"		54 - 66"	
Horizon		A_1		A_{2a}		A_{2b}		B_1		B_2		-	
Texture		FSL(Light)		FSL		FSL		C		C		SC - LC	
Reaction	pH	6.51		6.30		6.78		6.84		8.81		8.91	
		%		%		%		%		%		%	
Analysis of Fine Earth (< 2 mm.)													
Calcium Carbonate	$CaCO_3$	.015		.028		.044		.074		6.305		1.516	
Mechanical Analysis													
Coarse Sand		5.7		5.4		5.6		2.3		5.0		5.0	
Fine Sand		73.4		69.5		64.6		26.1		44.1		54.0	
Silt		10.4		11.6		10.8		3.1		3.2		5.6	
Clay		8.4		11.5		17.3		59.7		34.5		29.3	
Loss on Acid Treatment		1.5		1.5		1.8		10.7		13.3		4.9	
Loss on Ignition		2.3		2.2		2.5		7.2		7.3		4.1	
Organic Carbon	C	.672		.452		.428		.501		.151		.082	
Nitrogen	N	.059		.041		.039		.061		.022		.014	
Phosphoric Acid	P_2O_5	.033		.024		.020		.039		.022		.019	
Total Soluble Salts		.027		.032		.032		.038		.077		.076	
Chlorides	as NaCl	.011		.015		.015		.015		.019		.018	
Exchangeable Cations		m.e.%	*	m.e.%	*	m.e.%	*	m.e.%	*	m.e.%	*	m.e.%	*
Calcium	Ca	3.52	77.0	3.13	73.5			15.33	64.3	12.40	65.6		
Magnesium	Mg	.45	9.9	.55	12.9			6.13	25.7	4.83	25.6		
Potassium	K	.45	9.9	.42	9.9			1.32	5.5	.79	4.2		
Sodium	Na	.15	3.2	.16	3.7			1.05	4.4	.88	4.6		
Total Metal Ions		4.57	100	4.26	100			23.83	100	18.90	100		
Exchangeable Hydrogen	H	2.30		2.46		2.69		6.60		-			
Percentage saturation		66.52		63.40				78.30		100			
Free Fe_2O_3		0.883				1.186		3.170		1.920			
Moisture in Air-Dry Sample		1.0		0.8		1.1		8.5		4.8		2.6	

m.e.% = milligram equivalents per 100 g. of soil. * = percentage composition of the exchangeable metal ions.

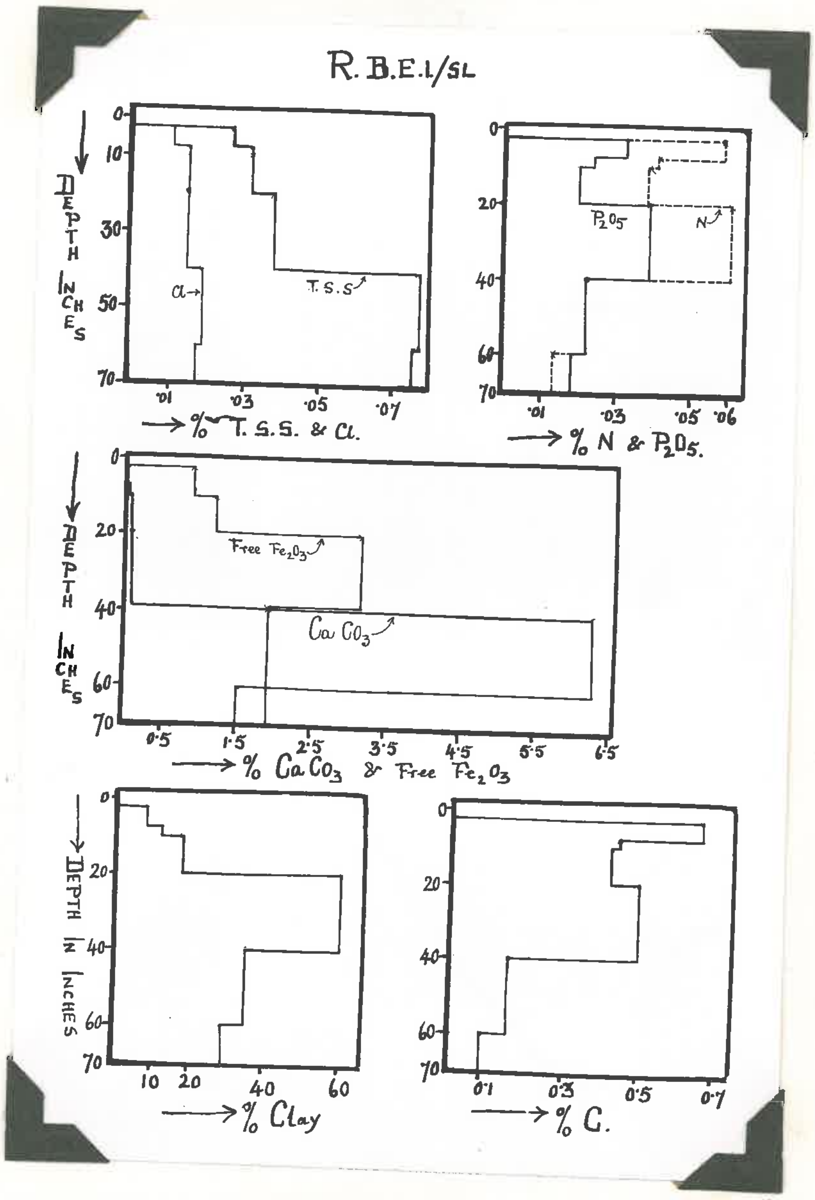

FIG. 4.

Illustrating the distribution of different constituents with depth - on natural horizon basis - in the profile.

C, N, T.S.S. and Cl represent respectively organic carbon, nitrogen, total soluble salts and chloride (as NaCl).

TABLE 4(b)

RESULTS OF MECHANICAL AND CHEMICAL ANALYSES ON OVEN DRY BASIS.

Soil Type R.B.E 2/SL Location:- County - Light; Hd. Moorooroo; Section - 174.

Soil No.		15150		15151		15152		15153		15154		15155	
Depth (in inches)		¼ - 3		3½ - 4½		5½ - 13		13 - 17		19 - 27		29 - 39	
Horizon		A_1		A_2		B_1		B_{2a}		B_{2b}		B	
Texture		SL		SCL		C		C		C		C	
Reaction	pH	7.01		7.15		7.71		8.31		8.67		8.74	
		%		%		%		%		%		%	
Analysis of Fine Earth (< 2mm.)													
Calcium Carbonate	$CaCO_3$	.019		.039		.207		7.436		44.235		35.967	
Mechanical Analysis													
Coarse Sand		22.3		21.6		7.7		5.4		1.1		2.1	
Fine Sand		53.2		50.8		19.1		14.9		8.5		15.8	
Silt		6.4		7.0		1.6		2.2		1.9		3.9	
Clay		13.1		16.3		64.7		58.0		35.2		37.1	
Loss on Acid Treatment		2.4		2.4		8.5		17.7		51.0		42.9	
Loss on Ignition		4.3		3.5		8.6		11.9		25.8		22.9	
Organic Carbon	C	1.393		.923		.970		.758		.399		.256	
Nitrogen	N	.102		.065		.088		.079		.043		.028	
Phosphoric Acid	P_2O_5	.023		.016		.032		.032		.023		.017	
Total Soluble Salts		.042		.044		.064		.084		.076		.077	
Chlorides	as NaCl	.016		.021		.017		.022		.020		.020	
Exchangeable Cations		m.e.%	*	m.e.%	*	m.e.%	*	m.e.%	*	m.e.%	*	m.e.%	*
Calcium	Ca	8.36	79.0	8.67	78.1			27.06	82.1	16.35	79.8		
Magnesium	Mg	1.39	13.1	1.49	13.4			3.24	9.8	2.24	10.9		
Potassium	K	.61	5.8	.54	4.9			1.95	5.9	1.34	6.5		
Sodium	Na	.22	2.1	.40	3.6			.70	2.1	.55	2.7		
Total Metal Ions		10.58	100	11.10	100			32.95	100	20.48	100		
Exchangeable Hydrogen	H	2.56		2.56		4.66							
Percentage saturation		80.51		81.26									
Free Fe_2C_3		0.850		0.913		2.60		2.185					
Moisture in Air-Dry Sample		1.6		1.6		6.2		6.2		3.9		4.4	

m.e.% = milligram equivalents per 100 g. of soil. * = percentage composition of the exchangeable metal ions.

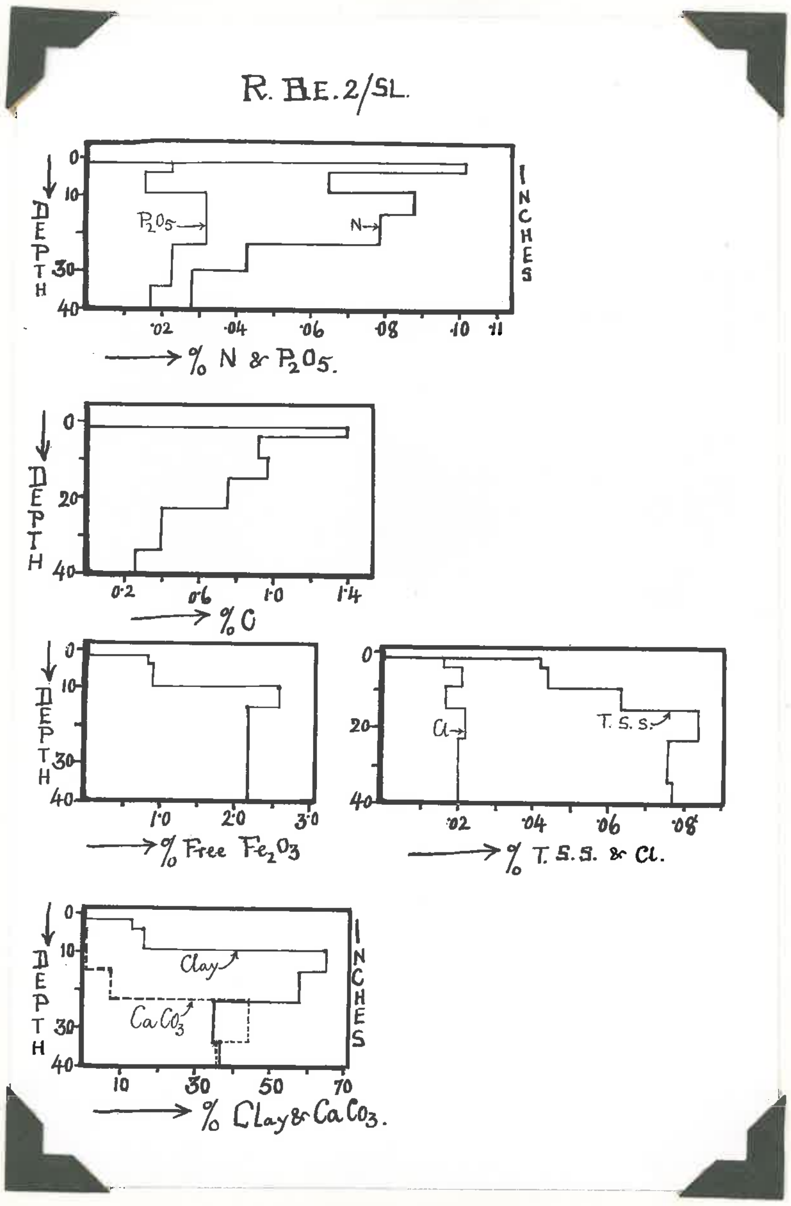

FIG. 5.

Illustrating the distribution of different constituents with depth - on natural horizon basis - in the profile.

C, N, T.S.S. and Cl represent respectively organic carbon, nitrogen, total soluble salts and chloride (as NaCl).

TABLE 4(c)
RESULTS OF CHEMICAL AND MECHANICAL ANALYSES ON OVEN DRY BASIS.

Soil Type R.B.E 2/SCL Location:- County - Light; Hd. - Moorooroo; Section - 174.

Soil No.		15156		15157		15158		15159		15160	
Depth (in inches)		0 - 3		5 - 9½		12 - 14		15 - 19		21 - 35	
Horizon		A_1		B_1		B_{2a}		B_{2b}		-	
Texture		SCL		C		C		C		C	
Reaction	pH	7.23		7.37		8.58		8.75		8.76	
		%		%		%		%		%	
Analysis of Fine Earth (< 2mm.)											
Calcium Carbonate	$CaCO_3$	.025		.044		42.782		56.240		39.284	
Mechanical Analysis											
Coarse Sand		23.7		9.9		2.4		2.3		1.7	
Fine Sand		47.0		22.9		8.6		12.4		12.8	
Silt		5.6		1.5		2.6		1.6		5.2	
Clay		21.4		57.4		35.2		22.7		34.3	
Loss on Acid Treatment		3.8		8.3		50.6		59.8		43.6	
Loss on Ignition		5.2		7.9		25.7		30.2		22.7	
Organic Carbon	C	1.423		.988		.806		.410		.269	
Nitrogen	N	.110		.096		.083		.042		.028	
Phosphoric Acid	P_2O_5	.042		.034		.027		.020		.017	
Total Soluble Salts		.038		.043		.066		.059		.063	
Chlorides	as NaCl	.015		.016		.017		.013		.017	
Exchangeable Cations		m.e.%	*	m.e.%	*	m.e.%	*	m.e.%	*	m.e.%	*
Calcium	Ca	12.19	76.6	24.42	78.8			13.09	78.2		
Magnesium	Mg	2.21	13.9	4.21	13.6			2.09	12.5		
Potassium	K	1.00	6.3	1.96	6.3			1.25	7.5		
Sodium	Na	.51	3.2	.39	1.3			.30	1.8		
Total Metal Ions		15.91	100	30.98	100			16.73	100		
Exchangeable Hydrogen	H	2.86		4.09							
Percentage saturation		84.76		88.33							
Free Fe_2O_3		1.140		2.20		1.455					
Moisture in Air-Dry Sample		2.6		6.5		5.2		3.3		4.6	

m.e.% = milligram equivalents per 100 g. of soil. * = percentage composition of the exchangeable metal ions.

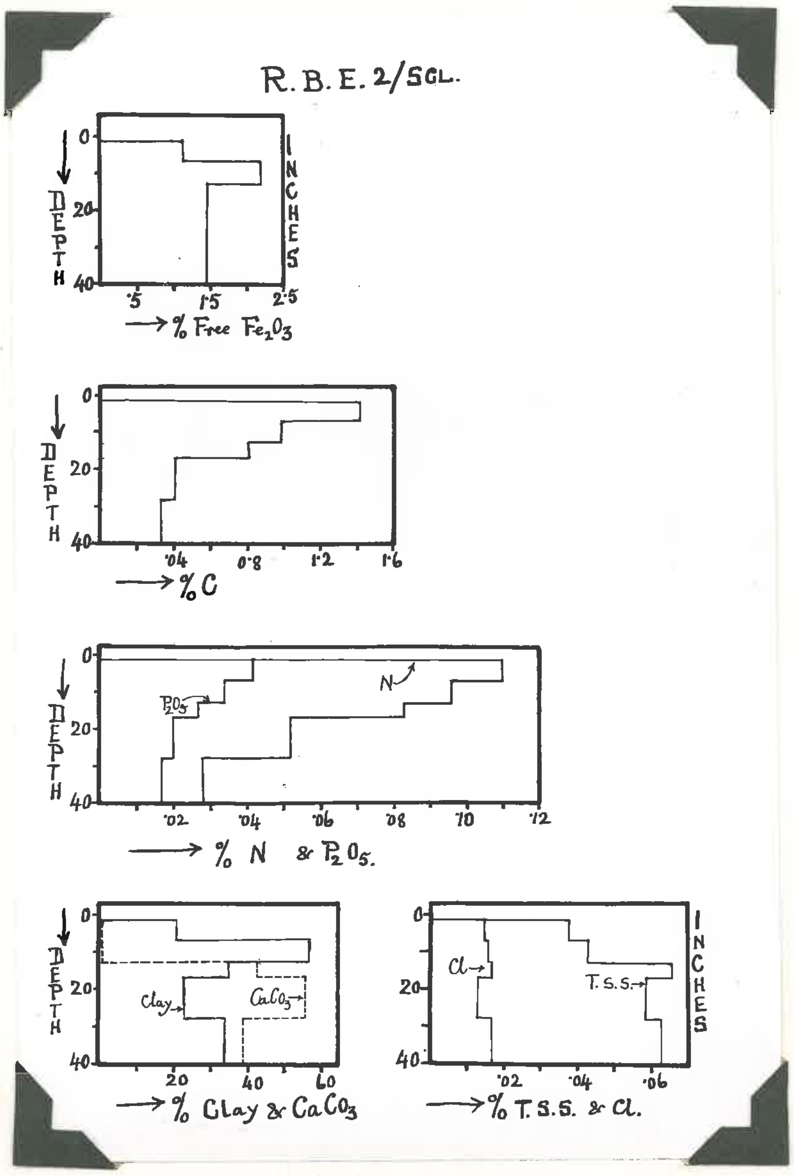

FIG. 6.

Illustrating the distribution of different constituents with depth - on natural horizon basis - in the profile.

C, N, T.S.S. and Cl represent respectively organic carbon, nitrogen, total soluble salts and chloride (as NaCl).

TABLE 5(a)

RESULTS OF CHEMICAL AND MECHANICAL ANALYSES ON OVEN DRY BASIS.

Soil Type Y. B. E 1/8 Location:- County - Light; Hd. - Moorooroo; Section - 174.

Soil No.		15161		15162		15163		15164		15165		15166		15167		15168	
Depth (in inches)		0 - 1½		1½ - 5		6 - 12		12 - 13		13 - 22		26 - 38		44 - 54		63 - 69	
Horizon		A_{1a}		A_{1b}		A_2		B_1		B_1		B_2		B_3		-	
Texture		F. Sand		F. Sand		F. Sand		Clay Sand Cap		C		C		C		C	
Reaction	pH	6.61		6.33		6.75		7.02		7.09		7.96		9.15		9.05	
		%		%		%		%		%		%		%		%	
Analysis of Fine Earth (< 2 mm.)																	
Calcium Carbonate	$CaCO_3$	.018		.030		.038		.035		.065		.069		2.56		1.95	
Mechanical Analysis																	
Coarse Sand		38.4		43.5		38.9		25.5		7.1		4.1		18.9		12.0	
Fine Sand		52.0		50.4		55.8		44.9		27.8		55.0		41.6		37.4	
Silt		3.8		3.3		2.8		8.0		4.1		4.1		6.2		6.3	
Clay		2.8		1.8		1.0		18.6		52.9		32.3		27.0		36.4	
Loss on Acid Treatment		0.7		0.5		2.0		1.6		6.5		4.5		5.5		6.5	
Loss on Ignition		1.6		1.0		0.4		2.4		6.6		4.0		3.9		4.2	
Organic Carbon	C	.507		.249		.064		.164		.174		.091		.079		.057	
Nitrogen	N	.043		.021		.007		.021		.031		.016		.011		.011	
Phosphoric Acid	P_2O_5	.011		.006		.004		.013		.023		.019		.019		.019	
Total Soluble Salts		.025		.021		.022		.027		.053		.077		.166		.270	
Chlorides	as NaCl	.012		.013		.009		.012		.022		.042		.076		.128	
Exchangeable Cations		m.e.%	*	m.e.%	*	m.e.%	*	m.e.%	*	m.e.%	*	m.e.%	*	m.e.%	*	m.e.%	*
Calcium	Ca	2.00	69.4			.40	59.7	2.07	44.8	7.28	40.7			6.03	42.5		
Magnesium	Mg	.57	17.8			.15	22.4	1.76	38.1	7.44	41.6			4.88	34.4		
Potassium	K	.23	8.0			.03	4.5	.31	6.7	1.28	7.2			.94	6.6		
Sodium	Na	.08	2.8			.09	13.4	.48	10.4	1.38	10.5			2.35	16.5		
Total Metal Ions		2.88	100			.67	100	4.62	100	17.38	100			14.20	100		
Exchangeable Hydrogen	H	1.59		1.39		.20		2.01		5.88		2.22					
Percentage saturation		64.42				77.0		69.68		75.25							
Free Fe_2O_3				0.112		0.060		1.063		2.018		1.681					
Moisture in Air-Dry Sample		0.4		0.3		0.1		1.3		5.4		3.6		3.5		4.9	

m.e.% = milligram equivalent per 100 g. of soil. * = percentage composition of the exchangeable metal ions.

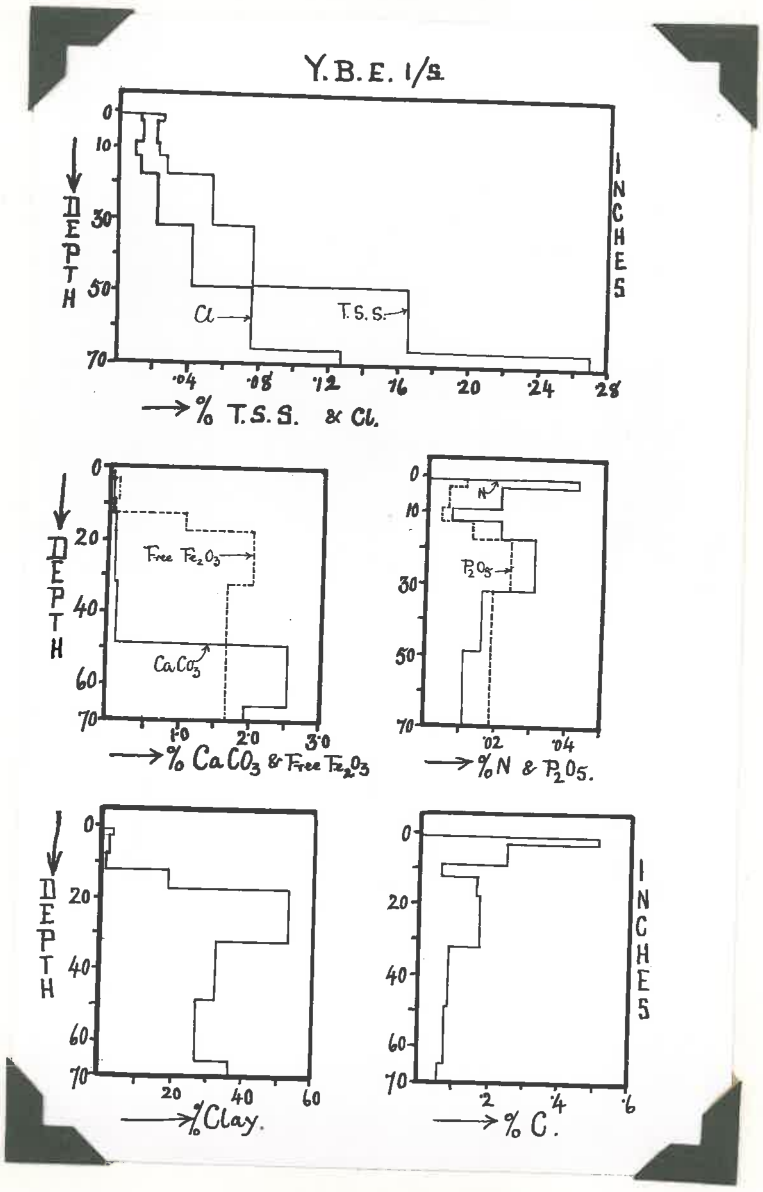

FIG. 7.

Illustrating the distribution of different constituents with depth - on natural horizon basis - in the profile.

C, N, T.S.S. and Cl represent respectively organic carbon, nitrogen, total soluble salts and chloride (as NaCl).

TABLE 5(b)

RESULTS OF CHEMICAL AND MECHANICAL ANALYSES ON OVEN DRY BASIS.

Soil Type Y. B. E 2/LS Location:- County - Light; Hd. - Moorocroo; Section - 174.

Soil No.		15169		15170		15171		15172		15173		15174		15175		15176	
Depth (in inches)		0 - 3		4 - 5		5 - 15		15 - 20		22 - 30		30 - 38		38 - 48		57 - 68	
Horizon		A_1		A_2		B_1		B_2		B_2						C or D	
Texture		LS		LS		C		C		C		Marl with C pockets		C		C	
Reaction	pH	6.89		7.00		7.78		8.76		9.40		9.63		9.61		9.42	
		%		%		%		%		%		%		%		%	
Analysis of Fine Earth (<2mm.)																	
Calcium Carbonate	$CaCO_3$	.067		.088		.091		.219		15.127		46.308		23.915		5.306	
Mechanical Analysis																	
Coarse Sand		25.8		29.1		19.1		18.6		9.4		1.4		1.6		1.2	
Fine Sand		53.0		50.7		30.4		32.6		24.3		14.4		23.5		23.5	
Silt		6.9		6.8		4.9		5.1		5.5		6.7		8.3		16.6	
Clay		10.5		9.9		39.0		39.6		41.1		29.9		38.2		46.9	
Loss on Acid Treatment		2.4		2.1		5.9		6.0		19.8		46.7		29.3		12.0	
Loss on Ignition		3.2		2.7		5.0		4.8		10.7		22.2		15.1		8.4	
Organic Carbon	C	.987		.869		.369		.190		.196		.151		.116		.080	
Nitrogen	N	.072		.063		.039		.031		.025		.015		.016		.012	
Phosphoric Acid	P_2O_5	.068		.049		.021		.019		.020		.017		.022		.033	
Total Soluble Salts		.038		.046		.052		.081		.158		.166		.181		.212	
Chlorides	as NaCl	.014		.013		.016		.020		.027		.027		.029		.040	
Exchangeable Cations		m.e.%	*	m.e.%	*	m.e.%	*	m.e.%	*	m.e.%	*	m.e.%	*	m.e.%	*	m.e.%	*
Calcium	Ca	5.36	64.9			6.18	34.0			6.97	30.8	4.31	22.6			5.40	20.1
Magnesium	Mg	1.79	21.7			8.13	44.8			10.57	46.7	8.87	46.6			11.78	43.9
Potassium	K	.92	11.7			2.07	11.4			1.04	4.6	1.44	7.6			1.85	6.9
Sodium	Na	.18	2.2			1.78	9.8			4.07	18.0	4.42	23.2			7.82	29.1
Total Metal Ions		8.25	100			18.16	100			22.65	100	19.04	100			26.85	100
Exchangeable Hydrogen	H	2.77		2.29		3.02											
Percentage saturation		74.86				85.75											
Free Fe_2O_3		0.763		0.711		1.796		1.591									
Moisture in Air-Dry Sample		1.5		1.3		4.5		4.6		5.3		4.8		5.5		5.4	

m.e.% = milligram equivalent per 100 g. of soil. * = percentage composition of the exchangeable metal ions.

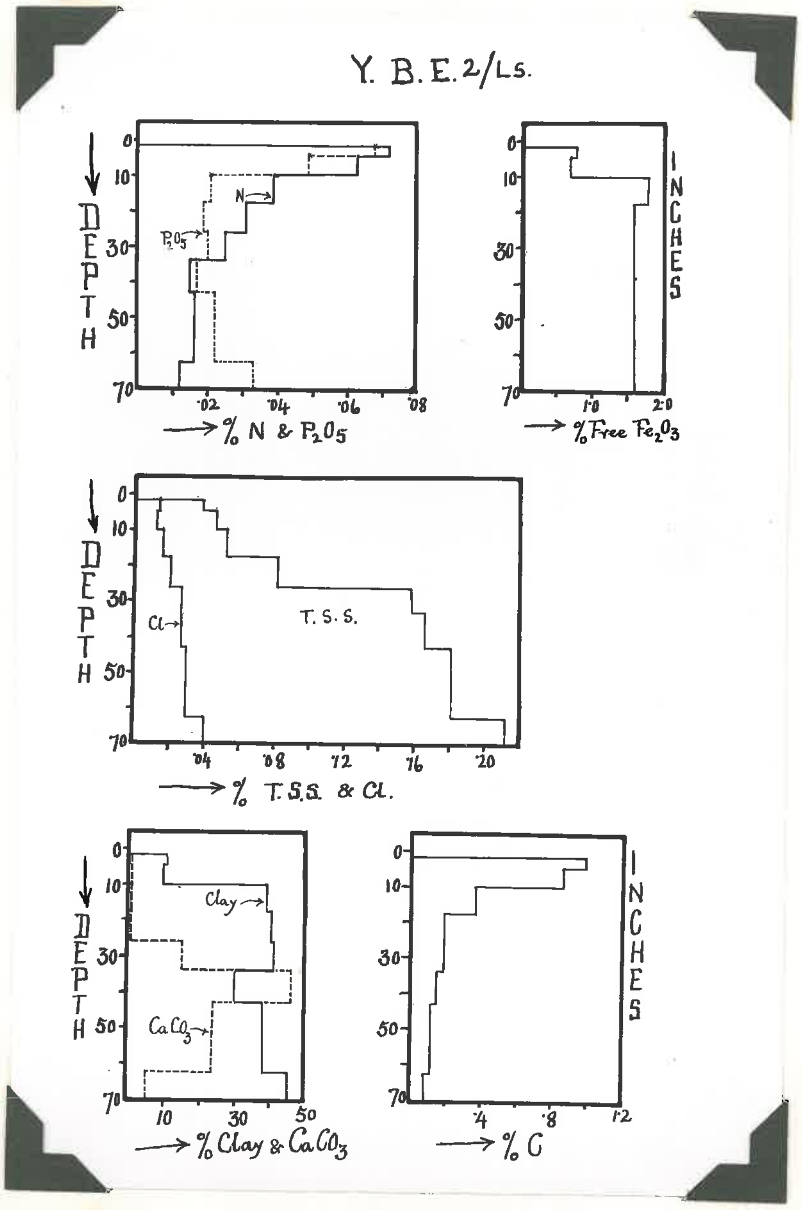

FIG. 8.

Illustrating the distribution of different constituents with depth - on natural horizon basis - in the profile.

C, N, T.S.S. and Cl represent respectively organic carbon, nitrogen, total soluble salts and chloride (as NaCl).

TABLE 6.
RESULTS OF CHEMICAL AND MECHANICAL ANALYSES ON OVEN DRY BASIS.

Soil Type P 1/S Location:- County - Light; Hd. - Nuriootpa; Section - Pt.754.

Soil No		15177		15178		15179		15180		15181		15182	
Depth (in inches)		0 - 6		8½ - 14		16 - 21		22 - 39		39 - 51		57 - 72	
Horizon		A_1		A_2		B_1		B_2					
Texture		S		S		C		SC		Clayey F.S		Clayey S	
Reaction	pH	7.09		7.14		7.21		7.02		8.17		8.52	
		%		%		%		%		%		%	
Analysis of Fine Earth (<2mm.)													
Calcium Carbonate	$CaCO_3$	.005		.005		.025		.022		1.129		1.408	
Mechanical Analysis													
Coarse Sand		42.8		20.9		7.1		5.6		6.1		5.0	
Fine Sand		50.3		66.7		46.2		59.5		71.3		73.2	
Silt		3.1		9.5		3.7		5.5		7.9		10.9	
Clay		1.1		1.1		37.0		27.3		9.7		7.9	
Loss on Acid Treatment		.05		.03		3.8		2.5		2.8		2.6	
Loss on Ignition		1.0		0.4		5.1		3.5		2.5		2.2	
Organic Carbon	C	.311		.054		.283		.137		.061		.020	
Nitrogen	N	.022		.007		.021		.017		.009		.004	
Phosphoric Acid	P_2O_5	.018		.005		.013		.009		.006		.005	
Total Soluble Salts		.029		.027		.035		.038		.048		.048	
Chlorides	as NaCl	.008		.008		.010		.012		.011		.013	
Exchangeable Cations		m.e.%	*	m.e.%	*	m.e.%	*	m.e.%	*	m.e.%	*	m.e.%	*
Calcium	Ca	1.67	76.3	.42	67.7	6.22	55.3			3.31	70.9		
Magnesium	Mg	.29	13.2	.08	12.9	3.44	30.6			0.97	20.8		
Potassium	K	.15	6.9	.03	4.8	1.08	9.6			.15	3.2		
Sodium	Na	.08	3.6	.09	14.5	.50	4.5			.24	5.1		
Total Metal Ions		2.19	100	.62	100	11.24	100			4.67	100		
Exchangeable Hydrogen		.48		.20		3.33							
Percentage saturation		82.02		75.61		77.12							
Free Fe_2O_3		0.048		0.040		1.382		0.726					
Moisture in Air-Dry Sample		0.2		0.1		3.0		2.1		0.6		0.2	

m.e.% = milligram equivalent per 100 g. of soil. * = percentage composition of the exchangeable metal ions.

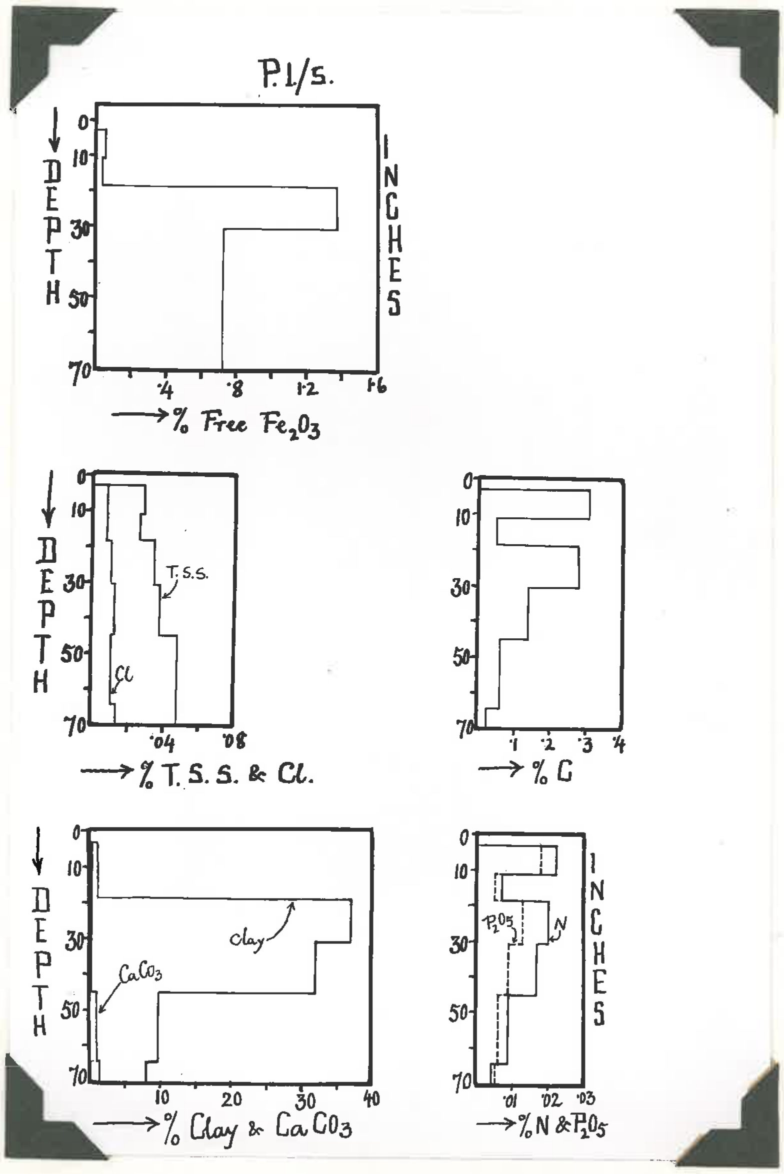

FIG. 9.

Illustrating the distribution of different constituents with depth - on natural horizon basis - in the profile.

C, N, T.S.S. and Cl represent respectively organic carbon, nitrogen, total soluble salts and chloride (as NaCl).

TABLE 7(a).
RESULTS OF CHEMICAL AND MECHANICAL ANALYSES ON OVEN DRY BASIS.

Soil Type		BL.E(A). Location:- County - Light; Hd. - Moorooroo; Section - 648.									
Soil No.		15758		15759		15760		15761		15762	
Depth (in inches)		0 - 7		9½-15½		20 - 29		30 - 35		38 - 60	
Horizon											
Texture		C		C		C		C		C with Lime	
Reaction	pH	8.58		8.69		9.07		9.11		9.34	
		%		%		%		%		%	
Analysis of Fine Earth (< 2mm.)											
Calcium Carbonate	$CaCO_3$	4.041		1.145		18.535		22.860		67.260	
Mechanical Analysis											
Coarse Sand		4.9		5.5		3.5		2.4		1.0	
Fine Sand		32.4		41.3		29.5		26.7		9.6	
Silt		7.9		9.4		8.4		8.4		2.7	
Clay		41.4		38.0		37.2		37.4		21.8	
Loss on Acid Treatment		14.9		8.6		24.3		27.4		67.5	
Loss on Ignition		8.2		4.8		10.4		12.0		28.9	
Organic Carbon	C	1.528		.677		.325		.299		.166	
Nitrogen	N	.136		.057		.029		.023		.013	
Phosphoric Acid	P_2O_5	.043		.020		.016		.017		.012	
Total Soluble Salts		.040		.038		.058		.071		.061	
Chlorides	as NaCl	.012		.007		.008		.009		.006	
Exchangeable Cations		m.e.%	*	m.e.%	*	m.e.%	*	m.e.%	*	m.e.%	*
Calcium	Ca	32.83	84.7	22.97	74.0	15.07	50.4			7.49	37.4
Magnesium	Mg	3.83	9.9	6.10	19.7	12.87	43.0			11.17	55.8
Potassium	K	1.72	4.4	1.45	4.7	.98	3.3			.33	1.6
Sodium	Na	.39	1.0	.50	1.6	.99	3.3			1.04	5.2
Total Metal Ions		38.77	100	31.02	100	29.91	100			20.03	100
Exchangeable Hydrogen											
Percentage saturation											
Free Fe_2O_3		1.059		0.712		0.735				0.427	
Moisture in Air-Dry Sample		7.7		5.8		7.2		7.0		5.6	

m.e.% = milligram equivalent per 100 g. of soil. * = percentage composition of the exchangeable metal ions.

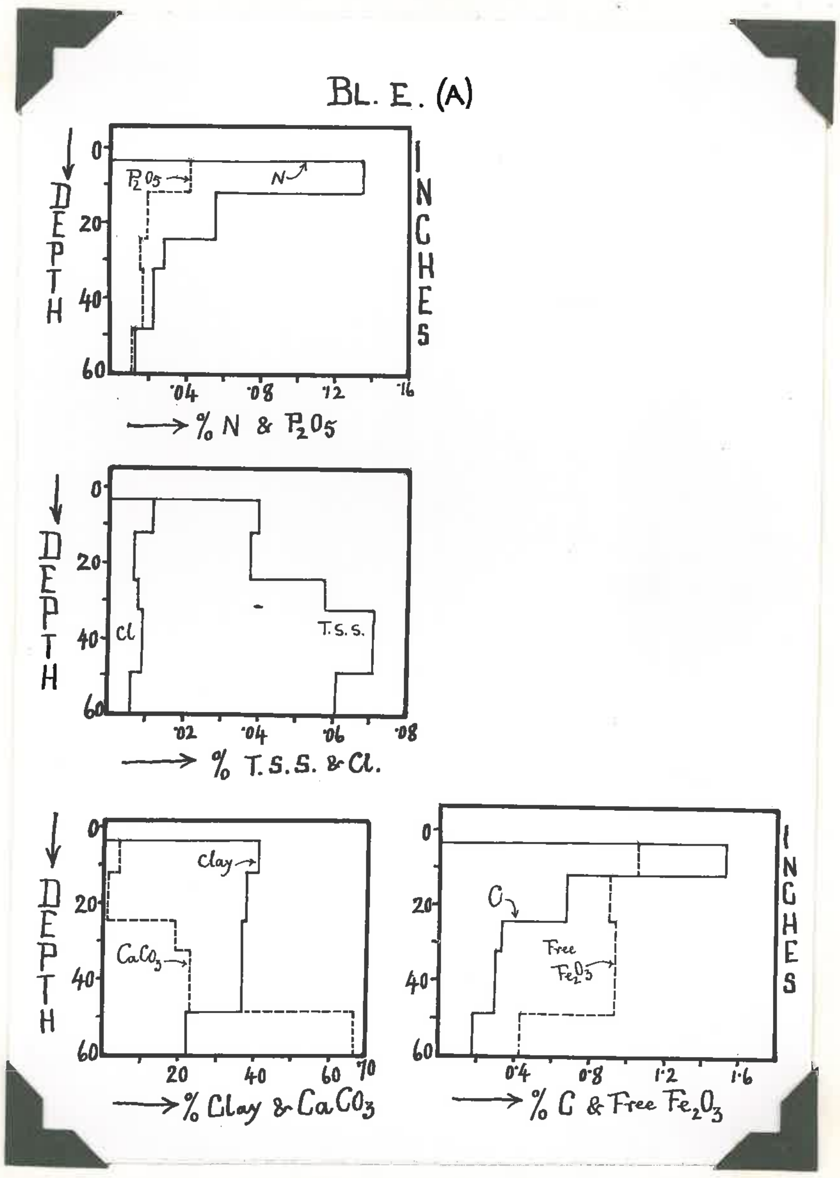

FIG. 10.

Illustrating the distribution of different constituents with depth - on natural horizon basis - in the profile.

C, N, T.S.S. and Cl represent respectively organic carbon, nitrogen, total soluble salts and chloride (as NaCl).

TABLE 7(b).

RESULTS OF CHEMICAL AND MECHANICAL ANALYSES ON OVEN DRY BASIS.

Soil Type		BL.E(B) Location:- County - Light; Hd. - Moorooroo; Section - 648.											
Soil No.		15763		15764		15765		15766		15767		15768	
Depth (in inches)		0 - 3½		3½ - 6½		7½ - 14		15 - 28		31 - 54		90 - 108	
Horizon													
Texture		C		C		C		C		C with Lime		C	
Reaction	pH	8.49		8.53		8.52		8.83		9.13		9.68	
		%		%		%		%		%		%	
Analysis of Fine Earth (< 2mm.)													
Calcium carbonate	$CaCO_3$	3.757		3.870		10.119		48.410		69.860		58.600	
Mechanical Analysis													
Coarse Sand		4.7		4.4		2.7		1.5		0.8		2.1	
Fine Sand		33.1		32.6		24.1		13.7		7.8		11.8	
Silt		8.7		9.0		6.3		2.9		2.1		4.1	
Clay		39.9		41.6		49.6		33.2		18.5		25.1	
Loss on Acid Treatment		13.5		14.2		20.2		49.4		73.0		59.1	
Loss on Ignition		8.7		8.3		10.3		17.9		28.7		18.6	
Organic Carbon	C	1.620		1.333		.813		.348		.193		.134	
Nitrogen	N	.141		.116		.079		.036		.014		.008	
Phosphoric Acid	P_2O_5	.052		.042		.031		.024		.015		.012	
Total Soluble Salts		.041		.042		.047		.049		.051		.080	
Chlorides	as NaCl	.005		.005		.005		.005		.007		.007	
Exchangeable Cations		m.e.%	*	m.e.%	*	m.e.%	*	m.e.%	*	m.e.%	*	m.e.%	*
Calcium	Ca	33.28	84.7	33.47	85.0	34.38	82.4	20.67	73.9			7.17	34.8
Magnesium	Mg	3.71	9.4	3.58	9.1	5.08	12.2	5.75	20.6			10.30	49.9
Potassium	K	1.95	5.0	1.96	5.0	1.81	4.4	1.11	4.0			.80	3.9
Sodium	Na	.35	0.9	.35	0.9	.43	1.0	.42	1.5			2.34	11.3
Total Metal Ions		39.29	100	39.36	100	41.70	100	27.95	100			20.61	100
Exchangeable Hydrogen													
Percentage saturation													
Free Fe_2O_3		1.047				1.361		0.757				0.548	
Moisture in Air-Dry Sample		6.2		6.7		8.0		5.1		4.7		5.2	

m.e.% = milligram equivalent per 100 g. of soil. * = percentage composition of the exchangeable metal ions.

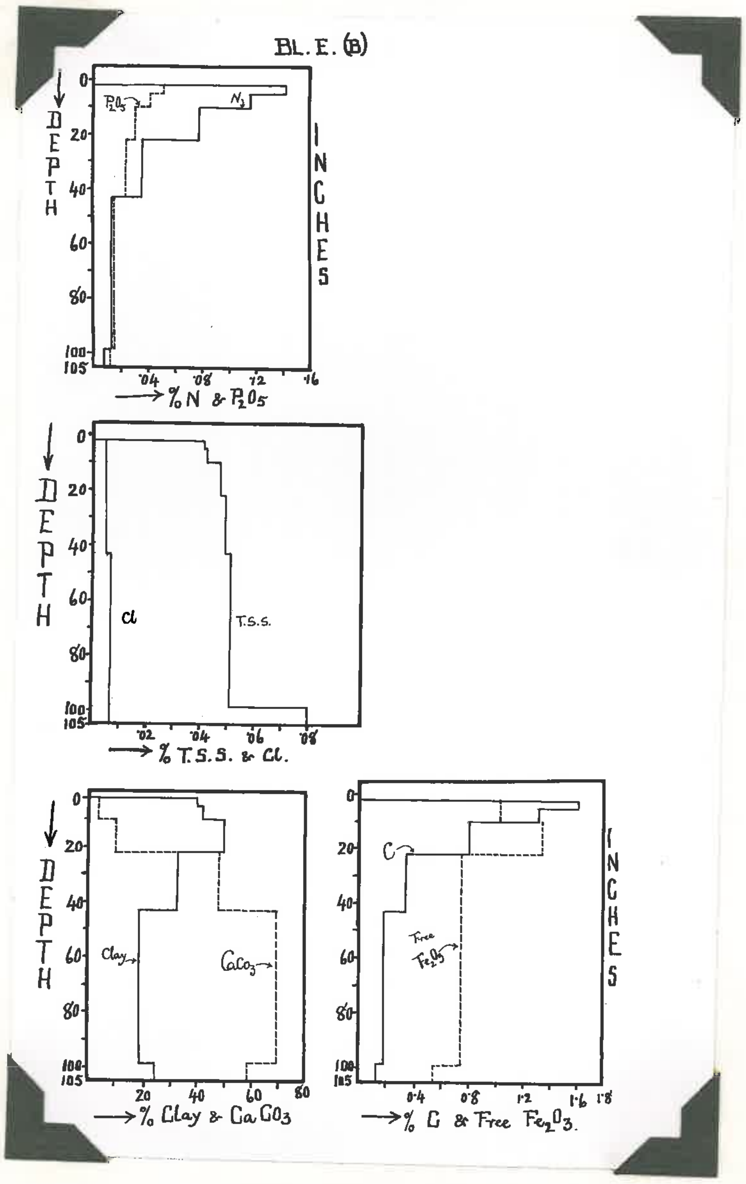

FIG. 11.

Illustrating the distribution of different constituents with depth - on natural horizon basis - in the profile.

C, N, T.S.S. and Cl represent respectively organic carbon, nitrogen, total soluble salts and chlorides (as NaCl).

CHEMICAL AND MECHANICAL ANALYSES.

Having had a preliminary appraisal of the state of the affairs with the soils of the Barossa Valley under investigation, particularly with reference to their distribution, morphology, and the factors of their formation, the next step was obviously to carry out a complete laboratory analysis, which comprised (1) Chemical and Mechanical analyses, and (2) Mineralogical analyses.

The results of the Chemical and Mechanical analyses of the soils are presented in Tables 4 to 7 on oven dry basis. The results are also illustrated graphically in Figs. 4 to 11.

(A) Mechanical Separates.

(1) The non-colloid fraction.

The fine sand is dominant in all the coarse fractions, i.e. the non-colloid portion, invariably and irrespective of group or type.

Since the fine sand : coarse sand ratio may be regarded as an index of uniformity of parent material throughout a profile, the ratios have been computed and presented in Table 8(a). An inspection of Table 8(a) shows that:-

(a) The ratio in the Red Brown Earths is distinctively highest of all amongst those of the different groups and types, the ratio in the Black Earths stands second in numerical order and those in the P. 1/S, Yellow Brown Earths and R.B.E. 2/ are the lowest - they themselves being more or less of the same numerical order, indicating thereby the heterogeneous nature of the valley deposit or in other words the initial states of the different soil groups - as the textural properties of a soil profile formed on homogeneous parent material are similar for any soil in a particular climatic belt (Joffe 1949).

(b) The heterogeneous nature of original materials laid down in the valley is also shown by the disconcerting ratio in the Black Earths as the ratios down the profiles could neither be regarded as exhibiting a good constancy nor could they possibly be regarded as a reflection of a pseudo profile, since the ratios down the profiles do not seem to be very contrastingly different from one another at successive depths. The R.B.E. 2/SCL also seems to present a similar picture.

(c) In the cases of R.B.E. 2/SL, P 1/S and more especially in Yellow Brown Earths, the ratios down the profiles are telling a seemingly significant story - as in the B_{2b} horizon of R.B.E. 2/SL, B_2 of P 1/S, there is a sharp rise in the ratio and particularly contrastingly so in the B_2 of Y.B.E. 1/S and B_2 (30-38") of Y.B.E. 2/LS - casting thereby a shadow of doubt as to whether the samples below the B_1 horizon of the P 1/S, below the B_{2a} horizon of the R.B.E. 2/SL, and below the B_2 horizon (22-30") of the Y.B.E. 2/LS should be regarded as parts of the genetic profiles. It seems quite reasonable to disregard them from the genetic profiles and take them as geological strata underlying the true profiles, which would be no wonder while dealing with soils having marine and/or lacustrine sediments and deposits as initial states - Joffe (loc.cit.). But in any case this does not affect the object of the

TABLE 8(a).

THE FINE SAND : COARSE SAND RATIO.

Soil Type.	Depth in inches.	Horizon.	Fine Sand/Coarse Sand.
R.B.E. 1/SL	0 - 4½	A_1	12.8
	6 - 9	A_{2a}	12.8
	9 - 11	A_{2b}	11.5
	12 - 27	B_1	11.4
	31 - 48	B_2	9.0
	54 - 66	-	10.9
R.B.E. 2/SL	½ - 3	A_1	2.3
	3½ - 4½	A_2	2.3
	5½ - 13	B_1	2.6
	13 - 17	B_{2a}	2.7
	19 - 27	B_{2b}	7.7
	29 - 39	-	7.5
R.B.E. 2/SCL	0 - 3	A_1	1.9
	5 - 9½	B_1	2.3
	12 - 14	B_{2a}	3.1
	15 - 19	B_{2b}	5.4
	21 - 35	-	7.5
Y.B.E. 1/S	0 - 1½	A_{1a}	1.3
	1½ - 5	A_{1b}	1.1
	6 - 12	A_2	1.4
	12 - 13	(B_1	1.8
	13 - 22	(B_1	3.9
	26 - 38	B_2	13.4
	44 - 54	B_3	2.2
	63 - 69	-	3.1
Y.B.E. 2/LS	0 - 3	A_1	2.0
	4 - 5	A_2	1.7
	5 - 15	B_1	1.5
	15 - 20	B_2	1.7
	22 - 30	B_2	2.5
	30 - 38	-	10.2
	38 - 48	-	12.2
	57 - 68	-	19.5
P 1/S	0 - 6	A_1	1.2
	8½ - 14	A_2	3.1
	16 - 21	B_1	6.5
	22 - 39	B_2	10.6
	39 - 51	-	11.6
	57 - 72	-	14.6
BL.E(A)	0 - 7	-	6.6
	9½ - 15½	-	7.5
	20 - 29	-	8.4
	30 - 35	-	11.1
	38 - 60	-	9.6
BL.E(B)	0 - 3½	-	7.0
	3½ - 6½	-	7.4
	7½ - 14	-	9.0
	15 - 28	-	9.0
	31 - 54	-	9.7
	90 - 108	-	5.6

investigation since as long as the horizons of eluviation and illuviation (even if it be the B_1 horizon only) are within the genetic profiles, the investigation and the subsequent thesis is beyond criticism as far as the genuine character of a genetic profile is concerned.

The silt content in all cases irrespective of group or type seems characteristically low and hardly exceeds 10 per cent. in the carbonate free mineral fraction and certainly so in the horizons belonging to the genetic profiles (as traced above) anyway.

(ii) The colloid fraction.

The distribution of the clay fraction with depth in the different profiles shows a very characteristic heavy accumulation of clay leading to the formation of an almost impervious B_1 horizon in the Yellow Brown Earths and also to some extent in the P 1/S. The heavy clay accumulative B_1 horizon has also been formed in the Red Brown Earths. This accumulation of clay down in the B_1 horizon has eventually lead to the development of a light textured A horizon - the texture being sandy loam to sandy clay loam in the well drained to ill drained soils of the Red Brown Earths and Yellow Brown Earths. The surface texture has risen even up to sand in the P 1/S and Y.B.E. 1/S probably because of a comparatively lighter textured initial state. That this is so is shown in Table 9 by computing the weighted average of the clay content down to 35 inches of all the profiles, which shows that (Table 9) the P 1/S has developed from the lightest material with an average clay content of 18% and Y.B.E. 1/S has developed on a material of an average clay content of 28% and all others have developed on materials having mean clay contents of 34-42%. This observation further shows the heterogeneous nature of the valley deposit, thereby lending support to the contention as suggested from the fine sand : coarse ratio previously.

The sandy A horizon with a definitely bleached off-white sandy A_2 horizon in the P 1/S and Y.B.E. 1/S might also have been developed due to more advanced stage of maturity, which of course remains to be seen.

The contrast in the clay contents of the A horizon and B_1 horizon may be well appreciated from the following data:-

in R.B.E. 1/SL	the clay content of the A_1 and B_1 horizons are respectively	...	... 8% and 60%
in R.B.E. 2/SL	"	"	13% and 65%
in R.B.E. 2/SCL	"	"	21% and 57%
in Y.B.E. 1/S	"	"	3% and 53%
in Y.B.E. 2/S	"	"	17% and 39%
in P 1/S	"	"	1% and 37%.

In the case of Black Earths the story is entirely different. There is no development of genetic horizons and the texture from surface downwards is a medium clay with no appreciable accumulation in the profiles excepting the BL.E(B) wherein at a depth of $3\frac{1}{2}$-$6\frac{1}{2}$ inches the subsurface soil has shown a rise of 2% in clay and at a depth of $7\frac{1}{2}$-14 inches a further rise of 8% in clay.

With a view to checking up the field textures, the mechanical analysis data were plotted in Marshall's (1947) triangular texture diagram (based on international fractions with effective diameters of 0.002, 0.02 and 2 mm. for the upper limits of clay, silt and sand fractions respectively), and it is interesting to note that there is a reasonably good agreement between the field textures and the textures obtained from the diagrams, as illustrated by the Figs. 12(a), (b), (c) and (d). This relationship has been shown in Table 8(b).

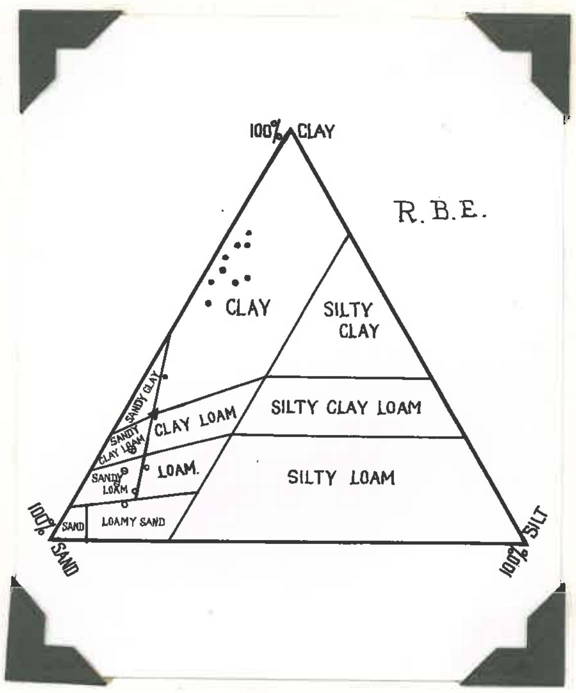

FIG. 12(a)

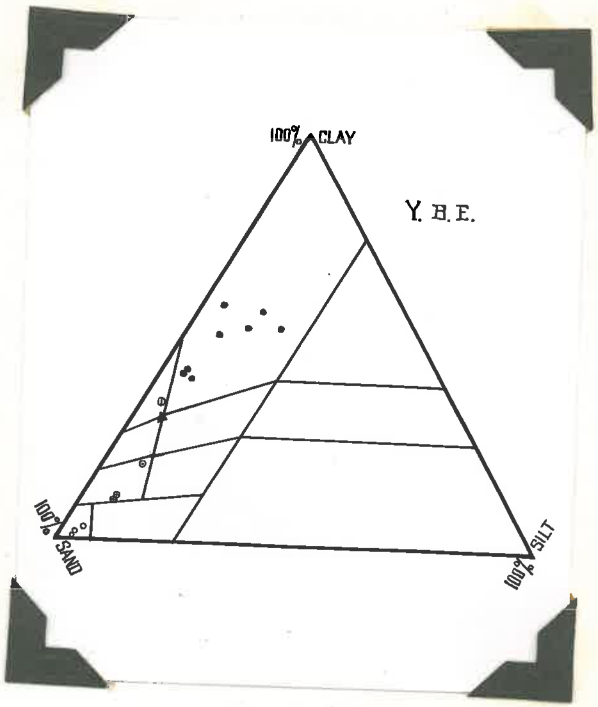

FIG. 12(b)

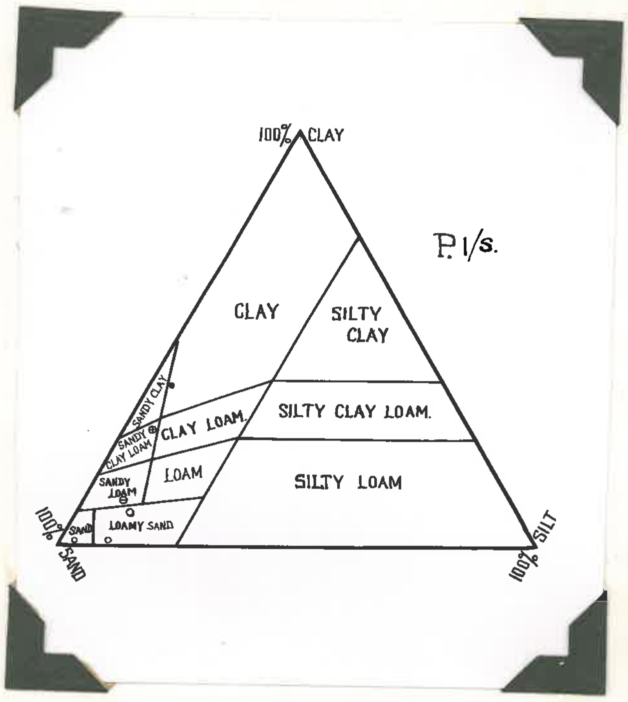

FIG. 12(c)

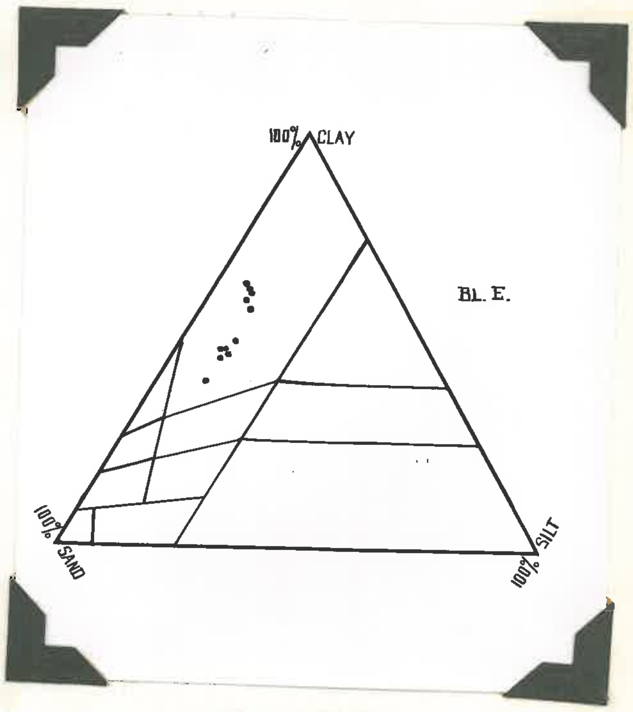

FIG. 12(d)

Distribution triangle illustrating the mechanical composition of the different groups of soils. The legend for the different points is given in Table 8(b). In the diagrams R.B.E., Y.B.E. and BL.E. represent respectively Red Brown Earths, Yellow Brown Earths and Black Earths.

TABLE 8(b).

RELATIONSHIP BETWEEN FIELD TEXTURE AND TEXTURE DETERMINED BY PLOTTING MECHANICAL ANALYSIS DATA IN MARSHALL'S TEXTURE DIAGRAM.

Figure Number.	Soil Type.	Horizon.	Notation in the texture diagram.	Texture observed from the diagram.	Field Texture.
12(a)	R.B.E.1/SL	A_1	◎	LS-SL (marginal)	FSL
		A_{2a}	0	SL	"
		A_{2b}	0	L-SL (marginal)	"
		B_1	●	Clay	Clay
		B_2	●	"	"
		-	▲	SC-CL (marginal)	SC-LC
	R.B.E. 2/SL	A_1	⊖	SL	SL
		A_2	⊖	SL	SCL
		B_1	●	Clay	Clay
		B_{2a}	"	"	"
		B_{2b}	"	"	"
		B	"	"	"
	R.B.E.2/SCL	A_1	⬤	SCL	SCL
		B_1	●	Clay	Clay
		B_{2a}	"	"	"
		B_{2b}	"	"	"
		-	"	"	"
12(b)	Y.B.E.1/S	A_{1a}	◎	Sand	Fine Sand
		A_{1b}	"	"	"
		A_2	"	"	"
		B_1	◎	SL	-
		B_1	●	Clay	Clay
		B_2	⊕	SC	"
		B_3	▲	SCL-CL-SC (Junction)	"
		-	●	Clay	"
	Y.B.E.2/LS	A_1	◉	SL	LS
		A_2	"	"	"
		B_1	●	Clay	Clay
		B_2	"	"	"
		B_2	"	"	"
		-	"	"	"
		-	"	"	"
		C or D	"	"	"
12(c)	P 1/S	A_1	0	Sand	Sand
		A_2	"	LS	Sand
		B_1	●	Clay	Clay
		B_2	⬤	SCL	SC
		-	⊖	SL	Clayey fine sand
		-	0	LS	Clayey sand.

The abbreviations SL, LS, SCL, FSL, SC & L denote Sandy loam, Loamy sand, Sandy clay loam, Fine sandy loam, Sandy clay and Loam respectively.

TABLE 8(b) (Ctd.)

Figure Number.	Soil Type.	Horizon.	Notation in the texture diagram.	Texture observed from the diagram.	Field Texture.
12(d)	BL.E(A)	-	●	Clay	Clay
		-	"	"	"
		-	"	"	"
		-	"	"	"
		-	"	"	"
	BL.E(B)	-	●	Clay	Clay
		-	"	"	"
		-	"	"	"
		-	"	"	"
		-	"	"	"
		-	"	"	"

(B) Calcium Carbonate.

An inspection of Tables 4, 5, 6 and 7 and the relevant graphs clearly reveals that the carbonate has been leached out of the surface horizons and accumulated in the lower horizons in all cases, irrespective of group or type. In all the groups excepting the Black Earths the calcium carbonate content is almost nil in the A horizon and the accumulation has occurred in the B_2 horizon below the zone of clay accumulation. In the case of the Black Earths, however, the surface horizon contains a comparatively fair amount of $CaCO_3$ although not exceeding 4%. In the subsoils, however, there is a very heavy accumulation of $CaCO_3$ increasing with depth. In the cases of the groups other than Black Earths, the condition is just to the contrary as, below the zone of maximum carbonate concentration, the $CaCO_3$ content shows a definite fall. In the case of BL.E(B) however a decrease of $CaCO_3$ will be noticed only at a depth below 90 inches.

Curiously enough the P 1/S has shown a little amount of carbonate accumulation (1.4%) in the deepest horizon, although no visible lime was detected during the field work. This may be partly due to presence of a small amount of $CaCO_3$ naturally present in the deeper horizons of the P 1/S, which were disregarded from the reach of the genetic horizon previously, or may even be partly due to the small amount of calcareous material in the initial state of the P 1/S which has eventually cleared out of the genetic horizons as indicated previously.

In this connection it is interesting to note that the weighted mean of $CaCO_3$ down to 35 inches for all the groups and types thereof (Table 9) show that the P 1/S and the Y.B.E. 1/S have developed on materials with practically no $CaCO_3$ content - the amounts being .02% and .05% respectively; next in order of increasing values come R.B.E. 1/SL (1.1%), Y.B.E. 2/LS (10.6%), R.B.E. 2/SL (20.7%), R.B.E. 2/SCL (29.4%), BL.E(B) (34.8%). Although the BL.E(A) shows a value of only 11.2%, it is by no means representative as it was just unfortunate that the calculations had to be restricted to 35 inches depth because of the shallowest profile collected, and also to guard against too liberal an access of the samples which do not appear to belong to the overlying genetic profile in some of the types as pointed out previously.

However, by taking into account the depths below 35 inches in BL.E(A), the mean $CaCO_3$ value far exceeds any of those of the Red Brown Earths, Yellow Brown Earths and P 1/S.

The most salient facts emerging from the above observations are that -

(a) the Black Earths developed on parent materials much more calcareous than any of the other groups, thereby lending support to the suggestion made before from field studies;

(b) the more calcareous the initial state of the soils the less is the tendency for eluviation-illuviation process or, in other words, the less pronounced is the expression of the A_2 (bleached) horizon. This can be very clearly seen from the fact that, considering in order of decreasing mean $CaCO_3$ content (Table 9), the Black Earths show no A_2 horizon, R.B.E. 2/SCL practically none (and certainly not sampleable), R.B.E. 2/SL - 1 inch thick A_2 horizon,

TABLE 9.

WEIGHTED MEAN OF $CaCO_3$ AND CLAY DOWN TO 35 INCHES.

Soil Type.	% Mean Clay.	% Mean $CaCO_3$.	Surface pH.
R.B.E. 1/SL	40	1.1	6.5
R.B.E. 2/SL	42	20.7	7.0
R.B.E. 2/SCL	35	29.4	7.2
Y.B.E. 1/S	28	0.05	6.6
Y.B.E. 2/LS	34	10.6	6.9
P 1/S	18	0.02	7.0
BL.E(A)	38	11.2	8.6
BL.E(B)	36	34.8	8.5

Y.B.E. 2/LS - 1 inch thick A_2, R.B.E. 1/SL - 5 inches thick A_2, Y.B.E. 1/S - 6 inches and P 1/S - 6 inches (another type of Podsolised soil encountered during field work, but not sampled due to too restricted an occurrence, showed about 12 inches A_2 horizon).

Thus the above observation, coupled with the texture of the initial states of the different soil groups and types thereof as discussed before, suggests that the soil pattern of the Barossa Valley is to a very great extent a reflection of the parent materials.- a state of affairs which is to be expected in any homoclimatic belt.

In this connection, referring back to Table 8(a), it seems worth mentioning that the carbonate in the P 1/S at a depth of 39-51 inches and downwards which may be Ca and/or Mg carbonate amounting to $< 2\%$ may also be totally disregarded from the true profile from a consideration of fine : sand ratio as pointed out before, or in other words the carbonate may be taken to be outside the genetic profile which may thus be accepted as carbonate free.

In the case of Y.B.E. 1/S, arguing in the same way, it may be said with much more confidence that the lime ($< 3\%$) accumulative horizon at a depth of 44-54 inches does not seem to belong to the genetic Y.B.E. 1/S profile which, therefore, is possibly carbonate free.

Following the same line of argument, the marly horizon at a depth of 30-38 inches in the Y.B.E. 2/LS, wherein the lime concentration is 46%, may also be disregarded from the reach of the genetic profile.

(C) Soil Reaction (pH).

The surface soils of the Red Brown Earths are acid to very slightly alkaline, whereas those of Yellow Brown Earths are on the acid side. The Black Earths, as was to be expected, show definitely alkaline surface (pH 8.5 - 8.6), the alkalinity increasing steadily with depth, attaining a maximum value of pH > 9 - the rise in pH being associated with the relative rise in the exchangeable Mg content (Table 12). In the Red Brown Earths and Yellow Brown Earths too the pH rises with depth assuming a value of greater than 8 in the horizon of $CaCO_3$ accumulation. The steady rise of the pH values with depth may also be a reflection of increasing exchangeable Na in the clay fractions, particularly in the Yellow Brown Earths. This will however be referred to later on.

It may be said that there seems to be a general correlation between the amount of $CaCO_3$ in the initial state of the soils and the pH of the surface soils amongst the different types of the Red Brown Earths and Yellow Brown Earths because of the fact that the order of pH of the surface soils is just in line with the order of the $CaCO_3$ content in the initial state as represented by the mean $CaCO_3$% in Table 9.

Apparently contrary to expectation the pH of the P 1/S starts with 7.09 right from the surface. This could however be visualised by considering that the soil had to be sampled from an area under horticulture, and as such the human and vegetation elements are probably responsible for the neutral pH of the P 1/S - which is associated with dominantly high Ca status of the exchange complex.

In this case also the pH of subsoils show steady rise, attaining a value of 8.5 where the $CaCO_3$ concentration is the maximum - only 1.4% though.

(D) Total Soluble Salts and Chlorides (as NaCl).

Looking back to the Tables 4 to 7 and the relevant graphs, it will be seen that the general trend of the salts and chloride is a downward movement and hence an increase with depth, the maximum concentrations being generally at depths where carbonate concentration is on the decline. This was to be expected as the salts and chloride are the first soil constituents to be affected by downward mobilisation on the initiation of Pedogenesis.

The analytical data on the salts and chlorides have been brought forward and presented in Table 10. An inspection of Table 10 clearly shows that all values are relatively low and in fact excepting in the deeper horizons of the Yellow Brown Earths, the salt and chloride contents have very little significance of pedological interest.

The relationship between the salt and chloride contents is illustrated graphically in Fig. 12(e) which shows that there is very little, if any, correlation between these two constituents in the Red Brown Earths, P 1/S and the Black Earths. Only in the case of Y.B.E. 1/S and also to some extent in the Y.B.E. 2/LS there is a significant correlation between these two constituents.

The above observation clearly demonstrates that the salts are mainly composed of constituents other than chlorides in all the soils excepting the Yellow Brown Earths. Secondly, the chlorides content is so low, particularly in the Black Earths and the P 1/S that bicarbonates could quite easily play a relatively increasing part in the conductivity of the soil suspensions to show a rather significant salt value, without any regard to the chloride content. This is what has happened in the Black Earths, P 1/S and also in the Red Brown Earths.

TABLE 10.

THE TOTAL SOLUBLE SALTS AND CHLORIDE (AS NaCl).

Soil Type.	Depth in inches.	Horizon.	% T.S.S.	% Cl.
R.B.E. 1/SL	0 - 4½	A_1	.027	.011
	6 - 9	A_{2a}	.032	.015
	9 - 11	A_{2b}	.032	.015
	12 - 27	B_1	.038	.015
	31 - 48	B_2	.077	.019
	54 - 66	-	.076	.018
R.B.E. 2/SL	¼ - 3	A_1	.042	.016
	3½ - 4½	A_2	.044	.021
	5½ - 13	B_1	.064	.017
	13 - 17	B_{2a}	.084	.022
	19 - 27	B_{2b}	.076	.020
	29 - 39	-	.077	.020
R.B.E. 2/SCL	0 - 3	A_1	.038	.015
	5 - 9½	B_1	.043	.016
	12 - 14	B_{2a}	.066	.017
	15 - 19	B_{2b}	.059	.013
	21 - 35	-	.063	.017
Y.B.E. 1/S	0 - 1½	A_{1a}	.025	.012
	1½ - 5	A_{1b}	.021	.013
	6 - 12	A_2	.022	.009
	12 - 13	(B_1	.027	.012
	13 - 22	(B_1	.053	.022
	26 - 38	B_2	.077	.042
	44 - 54	B_3	.166	.076
	63 - 69	-	.270	.128
Y.B.E. 2/LS	0 - 3	A_1	.038	.014
	4 - 5	A_2	.046	.013
	5 - 15	B_1	.052	.016
	15 - 20	B_2	.081	.020
	22 - 30	B_2	.158	.027
	30 - 38	-	.166	.027
	38 - 48	-	.181	.029
	57 - 68	-	.212	.040
P 1/S	0 - 6	A_1	.029	.008
	8½ - 14	A_2	.027	.008
	16 - 21	B_1	.035	.010
	22 - 39	B_2	.038	.012
	39 - 51	-	.048	.011
	57 - 72	-	.048	.013
BL.E(A)	0 - 7	-	.040	.012
	9½ - 15½	-	.038	.007
	20 - 29	-	.058	.008
	30 - 35	-	.071	.009
	38 - 60	-	.061	.006
BL.E(B)	0 - 3½	-	.041	.005
	3½ - 6½	-	.042	.005
	7½ - 14	-	.047	.005
	15 - 28	-	.049	.005
	31 - 54	-	.051	.007
	90 - 108	-	.080	.007

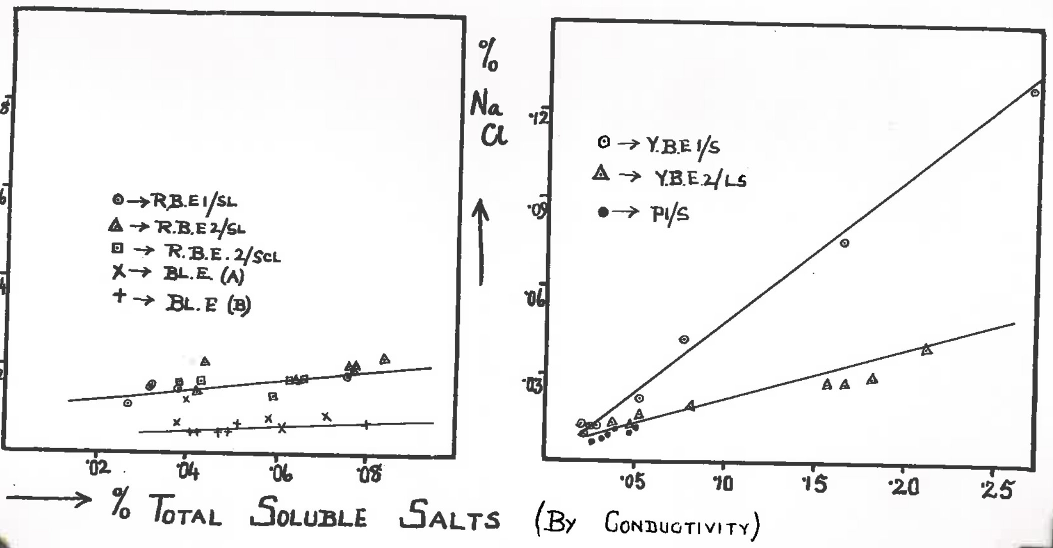

FIG. 12(e).

Illustrating the relationship between soluble salts and chloride (as NaCl) in the different soil groups studied.

(E) Organic Carbon and Nitrogen, P_2O_5 and Loss on Ignition.

Organic Carbon and Nitrogen.

As will be seen from Tables 4-7 and the corresponding graphs, the Organic Carbon and Nitrogen have followed precisely the same trend in their movement in the soil profiles, irrespective of group or type, indicating thereby a close relationship between them - although the C/N ratio varies amongst the different groups and types, and also with depth. The ratio narrows with depth, showing thereby a relative enrichment of Nitrogen with respect to Carbon. This relationship between carbon and nitrogen in the different soil types is presented graphically in Fig. 13 (a, b, c, d).

The amounts of organic matter and nitrogen in the surface 7 inches computed for the different groups and types (Table 11) show that the C/N ratio for the P_1/S is the highest and next in order is the Y.B.E. 1/S, showing thereby the poverty of nitrogen in the sandy soils which themselves are reflections of their parentage.

The Black Earths however are distinctively highest of all in nitrogen and organic matter, showing thereby their physiological superiority for plant growth. This comparatively high organic matter content coupled with free lime would probably account for the black colour of the Black Earth.

It might be argued that, although the absolute amounts of nitrogen and organic carbon are different, the C/N ratio of the Black Earths and R.B.E. 1/SL and R.B.E. 2/SCL are practically the same and as such why should the farmer make a sweeping statement in favour of Black Earths. Pending a fuller discussion, it might at this moment be pointed out that as will be seen shortly, there is a general but distinct relationship of P_2O_5 content with nitrogen build up and hence the absolute value of nitrogen content is quite significant.

The striking difference in the organic matter content of the R.B.E. 2/SL and SCL from that of R.B.E. 1/SL is probably due to the drainage condition of the types. The R.B.E. 1/SL being well drained command a much better oxidising condition, thereby bringing about a reduced value in the organic matter content. This however suggests that R.B.E. 2/SL and SCL being under restricted drainage the organic matter of the latter type would be higher than that of the former - as was actually found. Piper (1938) observed high values of organic carbon in some Red Brown Earths of South Australia. He sought to explain this occasional high value by increased growth of vegetation, favoured by an increased water supply brought about either by underground sources or by the microtopography diverting the surface run off to the lower lying areas. Whatever be the real explanation, there is no doubt that the difference in the local hydrological and consequent aeration condition has reflected itself in the organic matter content of the different soils.

However, referring back to the distribution of carbon and nitrogen with depth, in the R.B.E. 1/SL, R.B.E. 2/SL, P 1/S and Y.B.E. 1/S, both carbon and nitrogen showed a drop in the A_2 (bleached) horizon and then a rise in the B_1 (accumulative) horizon followed by steady drop downwards quite in concert with the clay distribution. In the case of R.B.E. 2/SCL, Y.B.E. 2/LS and Black Earths, the organic carbon and nitrogen contents showed no fluctuation -

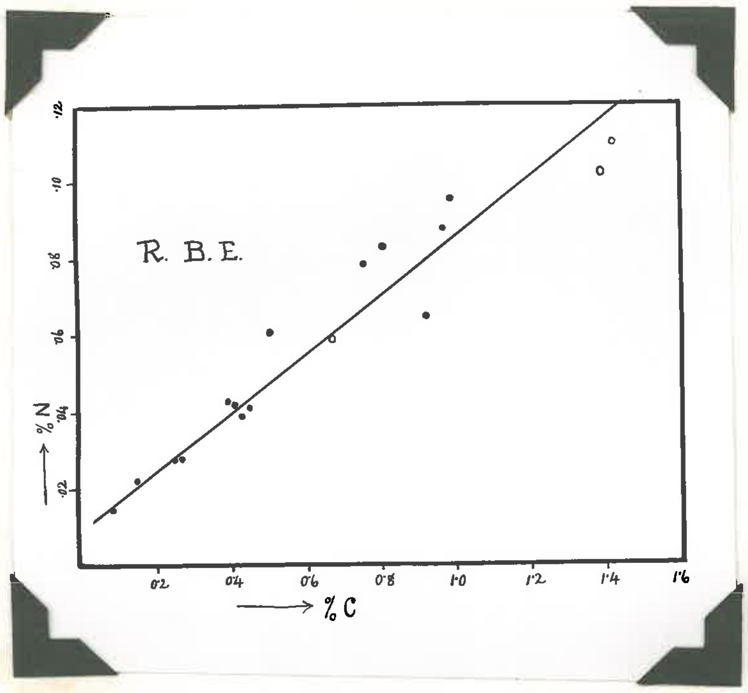

FIG. 13(a).

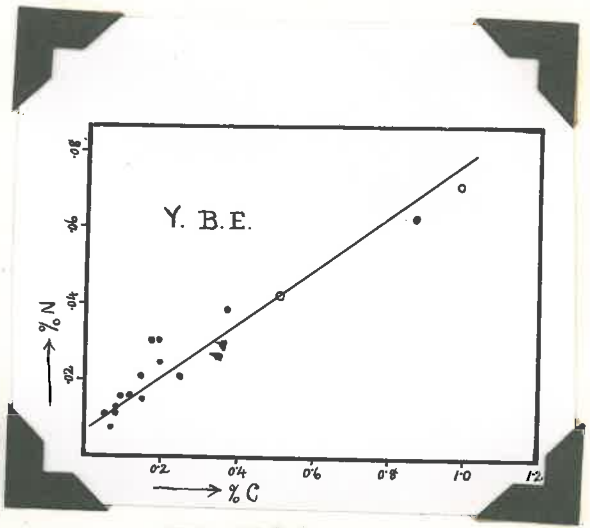

FIG. 13(b).

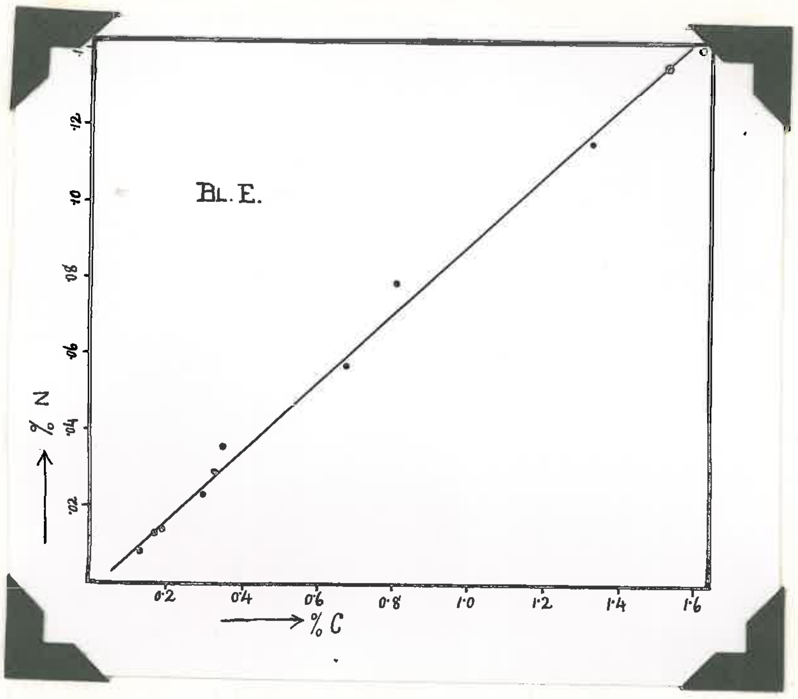

FIG. 13(c).

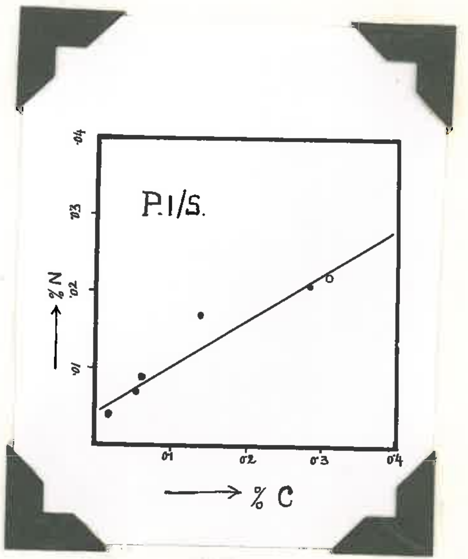

FIG. 13(d).

Illustrating the relationship between organic carbon (C) and nitrogen (N) contents in the different groups of the soils under investigation. (Open circles represent surface soils and black circles represent sub-soils).

R.B.E., Y.B.E. and BL.E. represent respectively Red Brown Earths, Yellow Brown Earths and Black Earths.

TABLE 11.

PER CENT. ORGANIC CARBON, NITROGEN AND P_2O_5 IN THE SURFACE 7 INCHES.

Soil Type.	% Carbon.	% Nitrogen.	C/N.	P_2O_5.
R.B.E. 1/SL	0.624	.055	11.3	.026
R.B.E. 2/SL	1.144	.090	12.7	.025
R.B.E. 2/SCL	1.174	.102	11.5	.033
Y.B.E. 1/S	0.304	.024	12.7	.006
Y.B.E. 2/LS	0.785	.060	13.0	.050
P 1/S	0.292	.020	14.6	.016
BL.E(A)	1.528	.136	11.2	.043
BL.E(B)	1.456	.126	11.5	.046

steadily dropping down with depth. This was quite to be expected for the R.B.E. 2/SCL as it presented no A_2 horizon at all. But in the case of Y.B.E. 2/LS, although it looked like having a one-inch thick lighter coloured horizon recorded in the field as A_2 horizon, the carbon-nitrogen distribution speaks against this record. The lighter colour noticed in the field is probably due to the lower amount of organic matter in contrast to that in the surface horizon. Or it may also be that the A_2 horizon in Y.B.E. 2/LS is just starting and as such there has been no detectable change yet, although a drop of clay content by 1% compared to the surface horizon should not be overlooked.

In the Black Earths the steady and smart drop of carbon and nitrogen down the profiles was quite expected and in this connection it is to be mentioned that, although in Bl.E(B) there has been a slight rise of clay content (a rise of 8%), down at the depth of 7½-14 inches, the distribution of the carbon and nitrogen showed no alliance to the clay movement.

P_2O_5.

By virtue of its being an essential element for plant growth, phosphorus generally limiting in South Australian soils, may be considered as occupying a characteristic position as a typical plant nutrient actively circulating through the profile. Plants gather the phosphorus through their roots from the soil body and redeposit it on the surface after their death. Because of the insolubility of most of its compounds, the mobility of phosphorus is restricted enough to bring about a surface enrichment. The phosphorus reserve of soils, particularly in South Australia, is certainly a subject deserving special attention.

An inspection of Table 11 will reveal that of the soil groups under investigation the Black Earths have the highest P_2O_5 status in the surface seven inches. The sandy soils P 1/S and Y.B.E. 1/S have the lowest status as was to be expected. The P_2O_5 content of P 1/S (.016%) looks comparatively higher than that of Y.B.E. 1/S (.006%) - this is possibly due to the superphosphate dressing of the P 1/S. The P_2O_5 value for the Y.B.E. 1/S is quite representative as it is still in its virgin state. The P_2O_5 content for Y.B.E. 2/LS (.05%) looks very encouraging but unfortunately this is not a virgin soil; the relatively high amount is just a result of the farmer's hand. In the case of the Red Brown Earths the values of P_2O_5 content are round about .03% which are quite in agreement with Piper's (1938) report on South Australian Red Brown Earths.

However, regarding the movement of P_2O_5 down the profiles of the different groups and types, it is, with reference to Tables 4-7 and the relevant graphs, quite evident that just like nitrogen and organic carbon the P_2O_5 content of the Black Earths showed steady drop with depth, giving no indication of any intermediary relatively rich horizon even if in BL.E(B) there was a distinct downward mobilisation of clay from the surface downwards up to a depth of 7½-14 inches, following which however the clay content dropped with depth.

In R.B.E. 1/SL, R.B.E. 2/SL, Y.B.E. 1/S, P 1/S, the bleached A_2 horizon marked a drop of P_2O_5 content being preceded and succeeded by higher P_2O_5 contents, indicating thereby the reality of the A_2 horizon. The values below B_1 horizon (accumulative) however, as was to be expected, showed decrease with depth.

The R.B.E. 2/SCL and Y.B.E. 2/LS, regardless of any horizon, showed a steady fall in P_2O_5 content with depth, as was the case with nitrogen and organic carbon.

Referring back to the figures (4-11) representing the movement of the different constituents with depth, it is quite interesting to note that in the N and P_2O_5 Vs depth curves there is distinct correlation between N and P_2O_5 themselves as evidenced by the to and fro movement of the N and P_2O_5 curves relative to each other, particularly in the surface soils. This relationship, although disturbed by the cultural practices, is presented in Fig. 14 by plotting the nitrogen contents against P_2O_5 contents of the surface soils, and from the linear relationship, it may be said that the nitrogen content can be fairly generally regarded as an index of P_2O_5 status for comparative purposes. And as such the importance of the absolute value of the nitrogen content in different soils is no less than that of its relative value with respect of carbon. The N - P_2O_5 relationship as presented by Prescott (1938) also showed a similar correlation.

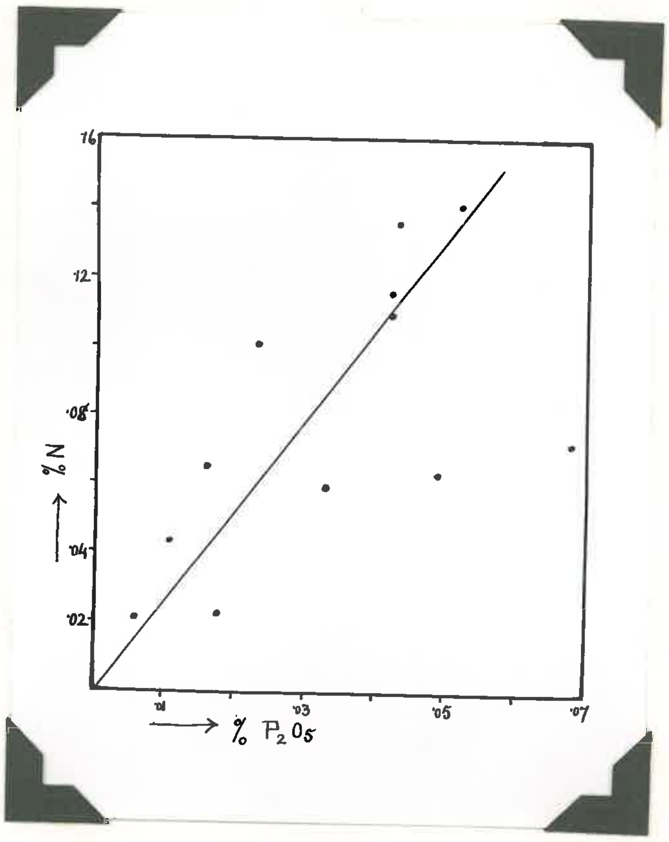

FIG. 14.

Illustrating the general correlation of nitrogen (N) and phosphorus ((P_2O_5)) contents in the surface horizons down to seven inches.

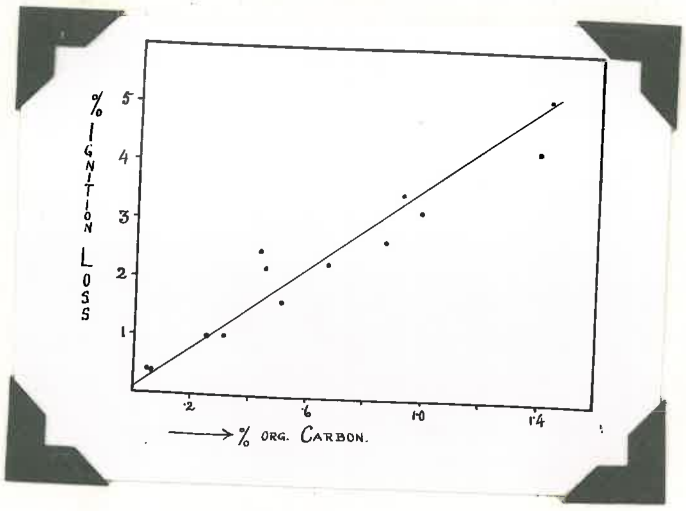

FIG. 15.

Illustrating the relationship between organic carbon and loss on ignition in the light textured and carbonate-free horizons.

Loss on Ignition.

Although a careful examination of the Tables 4-7 will clearly show that loss on ignition can hardly lead to any significant statement, it can however be regarded as a rough measure of organic carbon in absence of any combustion data provided the considerations are restricted to lime free ($< 0.1\%$) and light textured soils. Fig. 15 shows the reasonable validity of the above statement.

It is however to be remembered that the ignition loss is dependent on a number of factors such as organic matter, $CaCO_3$, the clay content and also the hydration condition of the clay minerals. And as such the ignition losses in the clay subsoils and calcareous soils do not lend themselves to any precise statement except that wherever the clay content is high the ignition loss is high and the loss varies along with $CaCO_3$ content too as will be seen in the Tables 4-7, thereby completely masking any correlation with the organic matter content.

It is therefore absolutely undesirable to accept the ignition loss as a measure of organic matter content without due reservation even by implication.

(F) The Exchangeable Cations.

The percentage composition of the exchangeable metal ions and the per cent. base saturation of the different soil groups and types thereof are brought forward from Tables 4-7 and shown in Table 12. It seems the implications of Table 12 are going to give a decisive verdict on the classification of the soils under investigation.

It will be seen that calcium, in the surface horizons of all the soils irrespective of group or type, is the dominant of the exchangeable cations, although appreciable amounts of Mg occur too, as is characteristic for Australian soils.

The proportion of Mg in the R.B.E. 1/SL increases with depth attended by corresponding fall in calcium. The R.B.E. 2/SL and R.B.E. 2/SCL however show a fair constancy with depth not only with regard to Ca and Mg but also with regard to Na and K.

In the Yellow Brown Earths, the story is absolutely different and seems significant. The proportion of Ca has shown a steady decrease with depth and a corresponding increase in Mg which has eventually exceeded Ca at a depth of 13-22" in the Y.B.E. 1/S and at 5-15" in the Y.B.E. 2/LS. In the Y.B.E. 2/LS the ratio of Ca : Mg has reached a value of less than 1 : 2 from 30-38" downwards. In the P 1/S the story is just the same as the R.B.E. 1/SL, i.e. decrease of Ca with depth with a corresponding increase of Mg but maintaining the dominance of Ca.

In the Black Earths the trend is more or less the same as in Yellow Brown Earths with the difference that the Ca : Mg ratio at the deepest horizon of both the Black Earths has come down to approximately 1 : 1.5.

The exchangeable Potassium in all the groups has generally shown relatively higher values in the surface exchange complex, possibly due to the enrichment by plant residues. It is however interesting to note that the Black Earths have shown distinctly lower values all throughout the profiles in comparison with the other groups. This is possibly because the release of K through the breakdown of the clay minerals has proceeded further in the case of Red Brown Earths, Yellow Brown Earths and P 1/S than in the Black Earths - suggesting thereby a higher K_2O reserve in the Black Earth clay than in the clays of other groups; which further suggests that the Black Earths are in a comparatively less advanced stage of profile formation. The relatively undifferentiated morphological features of Black Earths in contrast to the other groups as observed previously lends support to the above contention.

The exchangeable sodium in the Red Brown Earths is not noteworthy, although for the A horizon a value of 3-4% is to be taken note of as a possible explanation of the biscuity and compacted nature of the A_2 horizon of the Red Brown Earths. So also in the case of P 1/S where the A_2 horizon was noted as slightly compacted, the A_2 horizon has shown a significantly high amount of Na, although whether or not such a high value (14.5%) is truly representative is open to question, because of the fact that the total metal

TABLE 12.

PERCENTAGE COMPOSITION OF THE EXCHANGEABLE METAL IONS.

Soil Type.	Horizon.	Depth in inches.	pH.	% Composition.				% Saturation.
				Ca	Mg	K	Na	
R.B.E. 1/SL	A_1	0 - 4½	6.51	77.0	9.9	9.9	3.2	66.52
	A_{2a}	6 - 9	6.30	73.5	12.9	9.9	3.7	63.40
	B_1	12 - 27	6.84	64.3	25.7	5.5	4.4	78.30
	B_2	31 - 48	8.81	65.6	25.6	4.2	4.6	100
R.B.E. 2/SL	A_1	¼ - 3	7.01	79.0	13.1	5.8	2.1	80.51
	A_2	3½ - 4½	7.15	78.1	13.4	4.9	3.6	81.26
	B_{2a}	13 - 17	8.31	82.1	9.8	5.9	2.1	100
	B_{2b}	19 - 27	8.67	79.8	10.9	6.5	2.7	100
R.B.E. 2/SCL	A_1	0 - 3	7.23	76.6	13.9	6.3	3.2	84.76
	B_1	5 - 9½	7.37	78.8	13.6	6.3	1.3	88.33
	B_{2b}	15 - 19	8.75	78.2	12.5	7.5	1.8	100
Y.B.E. 1/S	A_{1a}	0 - 1½	6.61	69.4	17.8	8.0	2.8	64.42
	A_2	6 - 12	6.75	59.7	22.4	4.5	13.8	77.0
	B_1	12 - 13	7.02	44.8	38.1	6.7	10.4	69.68
	"	13 - 22	7.09	40.7	41.6	7.2	10.5	75.25
	B_3	44 - 54	9.15	42.5	34.4	6.6	16.5	100
Y.B.E. 2/LS	A_1	0 - 3	6.89	64.9	21.7	11.7	2.2	74.86
	B_1	5 - 15	7.78	34.0	44.8	11.4	9.8	85.75
	B_2	22 - 30	9.40	30.8	46.7	4.6	18.0	100
	-	30 - 38	9.63	22.6	46.6	7.6	23.2	100
	C or D	57 - 68	9.42	20.1	43.9	6.9	29.1	100
P 1/S	A_1	0 - 6	7.09	76.3	13.2	6.9	3.6	82.02
	A_2	8½ - 14	7.14	67.7	12.9	4.8	14.5	75.61
	B_1	16 - 21	7.21	55.3	30.6	9.6	4.6	77.12
	-	39 - 51	8.17	70.9	20.8	3.2	3.1	100
BL.E(A)	-	0 - 7	8.58	84.7	9.9	4.4	1.0	100
	-	9½ - 15½	8.69	74.0	19.7	4.7	1.6	"
	-	20 - 29	9.07	50.4	43.0	3.3	3.3	"
	-	38 - 60	9.34	37.4	55.8	1.6	5.2	"
BL.E(B)	-	0 - 3½	8.49	84.7	9.4	5.0	0.9	100
	-	3½ - 6½	8.53	85.0	9.1	5.0	0.9	"
	-	7½ - 14	8.52	82.4	12.2	4.4	1.0	"
	-	15 - 28	8.82	73.9	20.6	4.0	1.5	"
	-	90 - 108	9.68	34.8	49.9	3.9	11.3	"

ions amounted to only 0.62 m.e.% out of which Na was found to be .09 m.e.% and hence a definite possibility of misleading indication.

In the Black Earths the relative proportion of Na in the ex-complex seems too small to take note of except in the Bl.E(B) where at a depth of 90-108 the Na assumed a value of 11.3%. But this value at such a great depth could possibly be ignored without any serious reflection on Agro-Pedology.

The Yellow Brown Earths have shown significant amounts of Na in the ex-complex, enough to speak for solonisation. The Y.B.E. 1/S has started with a value of 13.8% right from the A_2 horizon, rising up to 16.5% in the B_3 at a depth of 44-54. Although the same note of caution may be applicable in the A_2 horizon as was sounded for the P 1/S - A_2 horizon, the significantly high values of Na all throughout the profile, excepting in the surface A_1 horizon, speak for themselves. In Y.B.E. 2/LS the Na content in the exchange complex has attained a value of 9.8% of the total metal ions in the B_1 horizon, at a depth of 5-15 inches and 18% at a depth of 22-30 inches (B_2 horizon), finally rising up to 29% at a depth of 57-68 inches.

Exchangeable Hydrogen was also determined in all the soils of pH less than 8, in order to obtain a measure of their base exchange capacity and percentage base saturation. The data for per cent. base saturation as shown in Table 12 indicate a more or less podsolised nature of the surface soils - the subsoil horizons moving towards full base saturation. The Black Earths of course start with full saturation, as was to be expected from their pH and the presence of free lime, right from the surface horizons. The general relationship between soil reaction and the corresponding percentage base saturation is presented graphically in Fig. 16. The same relationship of pH Vs per cent. base saturation was also observed by Piper (1938) in Red Brown Earths of South Australia.

As there can be no two opinions regarding the contribution of the soil organic matter towards the cation exchange capacity of any soil, the contributions of clay and organic matter towards the total exchange capacity was calculated by statistical regression for each group of the soils under investigation. Unfortunately a sufficient number of samples was not always available to give significant coefficients, but the results of the statistical analyses as presented in Table 13 show that - (i) for the Red Brown Earths the total exchange capacity is 0.495 mg. equiv. per grm. of clay and 4.20 m.e. per grm. of organic carbon - both the values are significant; (ii) for the Yellow Brown Earths the corresponding values are 0.499 and 5.36 respectively - the latter value being not significant; (iii) for the P 1/S the values are 0.342 and 4.89 m.e. per grm. of clay and organic carbon respectively - neither of the values being significant; (iv) for the Black Earths the values are 0.52 and 4.86 m.e. per grm. of clay and organic carbon - the latter value being not significant.

By substituting the above values of b_1 and b_2 in the regression equation ~~shown previously~~, the total exchange capacities corresponding to those actually determined were calculated and subsequently represented graphically

TABLE 13.

REPORT ON THE STATISTICAL ANALYSES REGARDING THE CONTRIBUTION OF CLAY AND ORGANIC MATTER TOWARDS TOTAL EXCHANGE CAPACITY.

The regression equation:- $y - \bar{y} = b_1(x_1 - \bar{x}_1) + b_2(x_2 - \bar{x}_2)$

where y = total exchange capacity in m.e. %

$\bar{y}$ = mean y

x_1 = % clay

$\bar{x}_1$ = mean x_1

b_1 = coefficient of x_1

x_2 = % organic carbon (as a measure of organic matter)

$\bar{x}_2$ = mean x_2

b_2 = coefficient of x_2

Soil Group/type.	No. of Samples.	b_1.	b_2.	Standard deviation. for b_1.	for b_2.
Red Brown Earths	11	$.495^{***}$	4.20^{*}	$\pm.0307$	±1.342
Yellow Brown Earths	10	$.499^{***}$	5.36^{x}	$\pm.0456$	±2.893
P 1/S	4	$.342^{x}$	4.89^{x}	$\pm.0185$	±2.262
Black Earths	9	$.52^{*}$	4.86^{x}	$\pm.1682$	±2.607

$*$ denotes significance at 0.05, i.e. $.05 > P > 0.01$

$***$ " " " 0.001, i.e. $P < 0.001$

x " " " $P > 0.05$

(P denotes probability of zero correlation).

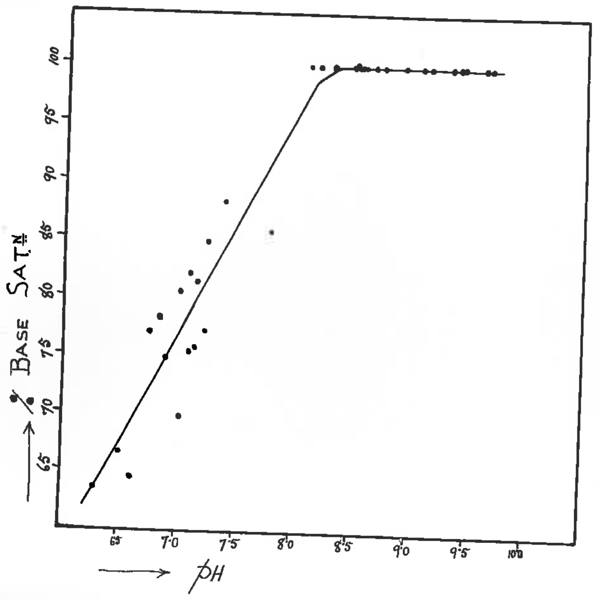

FIG. 16.

Illustrating the relationship between soil reaction (pH) and percentage base saturation in the soils under the investigation.

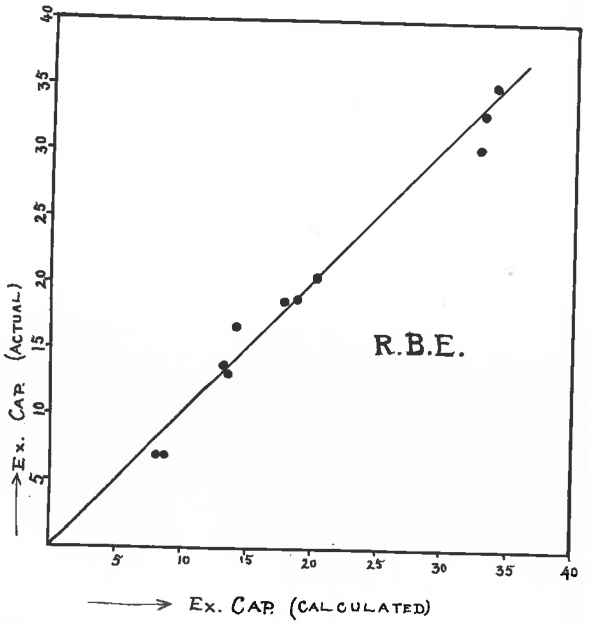

FIG. 17.

Illustrating the relationship between base exchange capacity (in m.e.%) actually determined and that calculated considering separately the exchange capacities due to clay and organic matter, using the appropriate values given in Table 13. The values for clay and organic matter are both significant in this case. R.B.E. indicates Red Brown Earths.

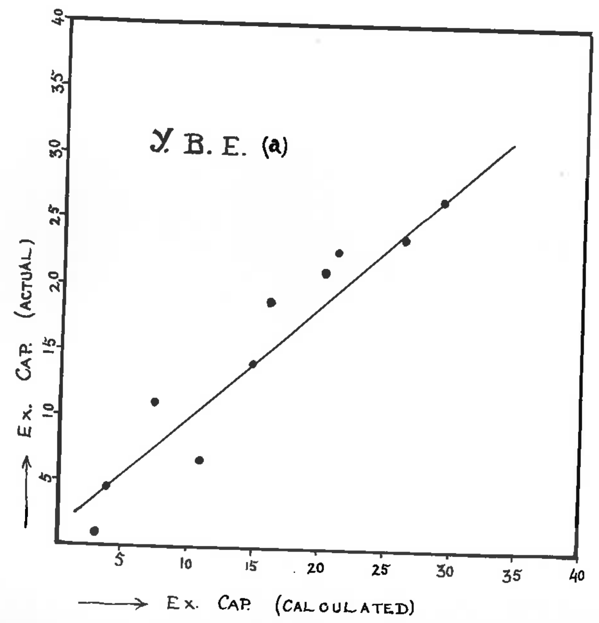

FIG. 18(a).

Illustrating the same as in Fig. 17 but the calculated capacity being due to clay only as the contribution due to organic matter is not within statistical significance. Y.B.E. indicates Yellow Brown Earths.

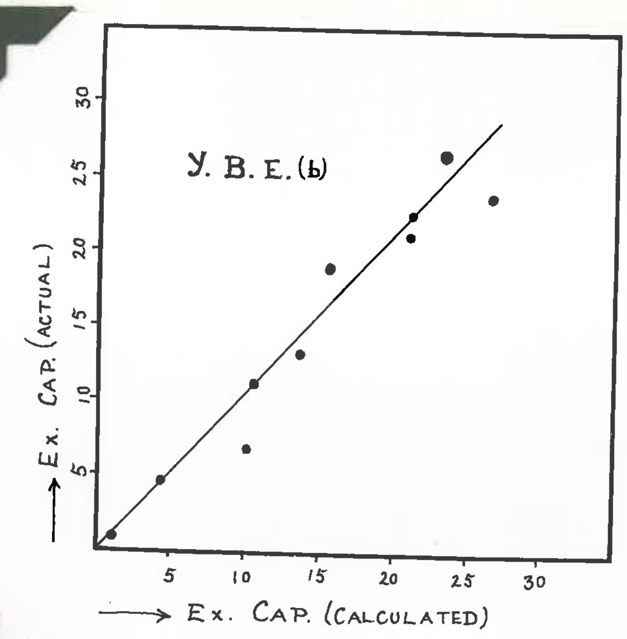

FIG. 18(b).

Illustrating the relationship as in Fig. 17 but taking into consideration both the significant and non-significant values in the calculated capacity. Y.B.E. indicates Yellow Brown Earths.

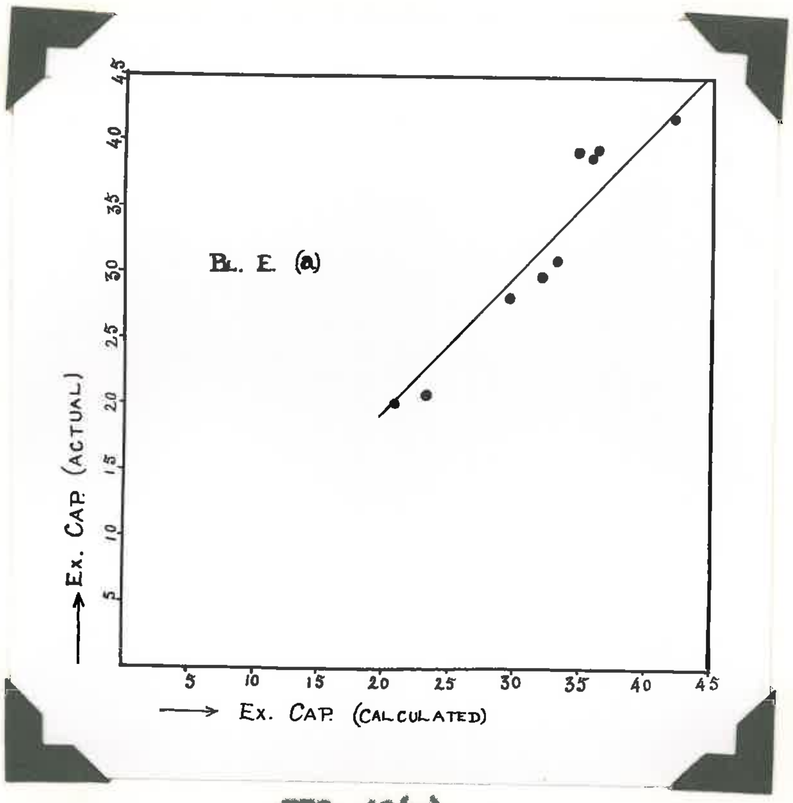

FIG. 19(a).
Illustrating the same as in Fig. 18(a).

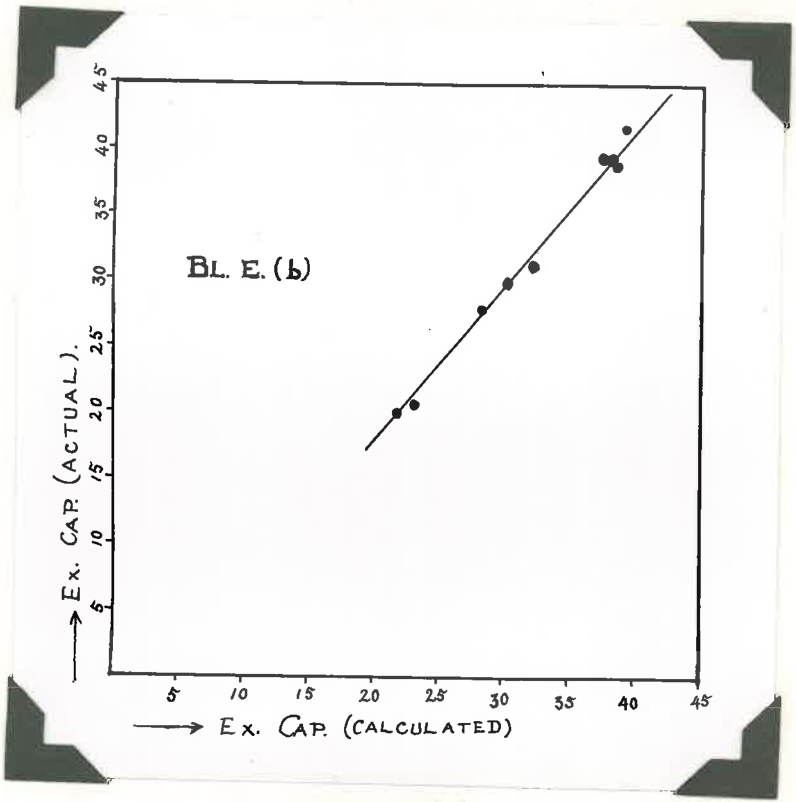

FIG. 19(b).
Illustrating the same as in Fig. 18(b).

(BL.E indicates Black Earths).

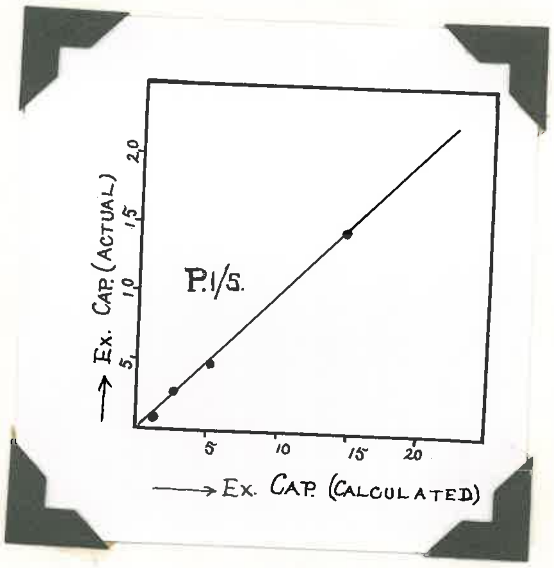

FIG. 20.

Illustrating the same relationship as in Fig. 17 but none of the values for clay and organic matter are statistically significant.

plotting against each other as in Figs. 17-20 to show the validity of the calculations as evidenced by the linear fitting of the curves. It is however to be noted that in the case of P 1/S, although neither of b_1 or b_2 was significant, the curve representing the relationship between the actual exchange capacity and the exchange capacity calculated with the above b_1 and b_2 values, shows an extraordinarily good linear fitting. In the cases of Black Earths and Yellow Brown Earths where b_2 values were not significant, the organic carbon was left out of consideration and the new values for b_1 were determined from a new regression equation which gave the values of b_1 for Yellow Brown Earths and Black Earths as 0.447 and 0.766 - both the values being highly significant. But the curves drawn by calculating the exchange capacity from the above values, disregarding the organic carbon, and plotting against the actual exchange capacity - Figs. 18(a) and 19(a) - showed no better fit, rather a worse fit than those when both b_1 and b_2 (even though not significant) values were taken into calculation. This shows that it is just impossible to neglect or disregard the contribution due to organic matter towards the exchange capacity of any soil.

(C) Composition of the Clay Fractions.

Clay fractions with a maximum settling velocity of 0.0001 cm. per sec. (corresponding to the former British clay) were separated on horizon basis from all the groups and types thereof to carry out chemical and mineralogical analyses. The chemical analysis was aimed at determining the silica : sesquioxide, silica : alumina and alumina : iron oxide ratios, and also to determine the distribution of TiO_2. The results of the analyses comprising the aforesaid ratios (grm. molar.) are shown in Table 14.

The tendency of the SiO_2/R_2O_3 ratio in all the groups excepting the Black Earths has shown a decrease in the B_1 horizon (clay accumulative) with respect to the A horizon. The ratio again widens in the B_2 horizon (calcareous horizon), of the Red Brown Earths and Y.B.E. 2/LS. The drop of SiO_2/R_2O_3 from A horizon to the B_1 horizon has been the most marked in the Y.B.E. 1/S and P 1/S with no sign of widening in the B_2 horizon. This clearly demonstrates that: (a) the eluviation of sesquioxides from the A horizon and their illuviation in the B horizon proceeded with a greater rate than that of silica, thereby leaving the A horizon comparatively richer in Silica, which is characteristically a Podsolic feature.

(b) the refusal of the Y.B.E. 1/S and P 1/S, unlike the Red Brown Earths and Y.B.E. 2/LS, to widen the SiO_2/R_2O_3 ratio in the B_2 horizon may be explained by recalling the position of the calcareous horizon in each of them. The widening occurred as soon as the calcareous horizon was reached in the Red Brown Earths and the Y.B.E. 2/LS but in the Y.B.E. 1/S and P 1/S the clay fractions were collected from the horizon above the calcareous zone, which, for reasons stated before, did not seem to be safe to include in the true profile. Following Robinson's (1949) contention that desilicification accompanies decalcification, it may be said that in the Y.B.E. 1/S and P 1/S the movement of lime, if it belonged to the true profile at all, at a deeper zone than the horizon of clay-collection has indirectly induced a downward movement of some silica, leaving ultimately a horizon with a relatively higher amount of sesquioxides which eventually reflected itself in the lower SiO_2/R_2O_3 ratio in the B_2 horizon than that in the B_1 horizon. The converse may be said in favour of a widening SiO_2/R_2O_3 in the B_2 horizon (calcareous) of the Red Brown Earths.

The distinctively high SiO_2/R_2O_3 ratio ~ 3 in the Black Earths - gives support to the contention laid down above, i.e. silicification and calcification move hand in hand, although the mobilisation of R_2O_3 from the A horizon has always to be taken note of before drawing any conclusion.

The SiO_2/Al_2O_3 ratio too shows practically the same trend as SiO_2/R_2O_3 ratio - i.e. in the Red Brown Earths the SiO_2 : Al_2O_3 ratio narrows down in the B_1 horizon, but widens in the B_2 horizon - showing thereby a comparatively aluminous B_1 horizon clay sandwiched by comparatively siliceous clay in the $A_{2 \text{ or } 1}$ and B_2 horizons. The ratio in the Yellow Brown Earths and P 1/S narrows down/depth with no sign of widening in the B_2 horizon. The item of interest in the Y.B.E. 1/S and P 1/S is that the contrast in the Silica : Alumina ratios of the A_2 and B horizons is more marked than that in any other group or type showing thereby a more advanced nature of the degradation of the clay complex in the Y.B.E. 1/S and P 1/S.

TABLE 14.

* FUSION ANALYSES OF THE CLAY FRACTIONS.

Soil Type.	Soil Number.	Depth in inches.	Horizon.	$\frac{SiO_2}{R_2O_3}$ ≠	$\frac{SiO_2}{Al_2O_3}$	$\frac{Al_2O_3}{Fe_2O_3}$
R.B.E. 1/SL	15146	9 - 11	A_{2b}	2.26	2.94	3.33
	47	12 - 27	B_1	2.13	2.78	3.24
	48	31 - 48	B_2	2.22	2.90	3.30
R.B.E. 2/SL	15151	3½ - 4½	A_2	2.30	2.86	4.14
	52	5½ - 13	B_1	2.17	2.69	4.13
	53	13 - 17	B_{2a}	2.20	2.75	4.04
R.B.E. 2/SCL	15156	0 - 3	A_1	2.21	2.84	3.52
	57	5 - 9½	B_1	2.19	2.78	3.85
	58	12 - 14	B_{2a}	2.24	2.82	3.83
BL.E(A)	15758	0 - 7	-	3.05	3.91	3.53
	59	9½ - 15½	-	3.00	3.84	3.57
	60	20 - 29	-	3.15	4.04	3.55
BL.E(B)	15763	0 - 3½	-	3.02	3.86	3.59
	66	15 - 28	-	3.16	4.02	3.66
	68	90 - 108	-	3.07	3.98	3.34

* The ratios are expressed as gm. molar ratios on ignited clay.

≠ R_2O_3 stands for (Fe_2O_3 + Al_2O_3).

TABLE 14 (Ctd.)

* FUSION ANALYSES OF THE CLAY FRACTIONS.

Soil Type.	Soil Number.	Depth in inches.	Horizon.	$\frac{SiO_2}{R_2O_3}$ ≠	$\frac{SiO_2}{Al_2O_3}$	$\frac{Al_2O_3}{Fe_2O_3}$
Y.B.E. 1/S	15163	6 - 12	A_2	2.65	3.26	4.40
	65	13 - 22	B_1	1.95	2.49	3.61
	66	26 - 38	B_2	1.90	2.48	3.27
Y.B.E. 2/LS	15170	4 - 5	A_2	2.24	2.85	3.68
	71	5 - 15	B_1	2.16	2.74	3.76
	73	22 - 30	B_2	2.17	2.73	3.89
P 1/S	15178	8½ - 14	A_2	2.78	3.09	8.92
	79	16 - 21	B_1	1.95	2.26	6.25
	80	22 - 39	B_2	1.93	2.17	7.82

* The ratios are expressed as gm. molar ratios on ignited clay.

≠ R_2O_3 stands for (Fe_2O_3 + Al_2O_3).

The Al_2O_3 : Fe_2O_3 ratio however tells an interesting story, i.e. a good constancy in all the horizons in the Red Brown Earths and the Y.B.E. 2/LS; but a comparatively higher value in the A_2 horizon than that in the B horizon in the case of P 1/S and Y.B.E. 1/S, indicating thereby that there has been a preferential mobilisation of iron oxide from the A_2 horizon with respect to Al_2O_3 in the Y.B.E. 1/S and P 1/S while it does not seem to be so in Red Brown Earths and Y.B.E. 2/LS.

In the case of the Black Earths, the analyses have shown a good constancy in all the ratios from surface downwards, although the BL.E(B) has indicated some differentiation in the profile in that the SiO_2/R_2O_3 and the associated ratios have shown a little rise at the depth of 15-28 inches, but, since the surface sample was taken at 0-3½ inches as against 0-7 inches of BL.E(A), this variation in the BL.E(B) profile might be overlooked, thus finally saying that the ratios in the Black Earths group are constant all throughout the profile.

The items of interest from the clay composition might however be pointed out as follow:-

(i) The unfailing trend of differentiation of SiO_2 : R_2O_3 ratio and the associated ratios in the clay fractions of the different horizons of the Red Brown Earths, however small it may be, does suggest a chemical mobilisation of the constituents from the upper to the lower, i.e. B horizon, particularly with regard to the Fe_2O_3 and Al_2O_3.

(ii) In the Black Earths, the trend of the ratios indicates no disintegration of the clay complex anywhere in the profile, as was quite to be expected due to their full base saturation consequent on the presence of free lime in all depths, as noted previously - precluding thereby any possibility of a chemical mobilisation of Fe_2O_3 from surface downwards, provided of course the iron oxide mobilisation is a function of disintegration of the clay complex. The highest SiO_2 : R_2O_3 and SiO_2 : Al_2O_3 ratio of the Black Earths clay amongst all those of the other groups suggests their least advanced stage of genesis amongst the soils under the present investigation, and a SiO_2 : R_2O_3 ratio of 3 and slightly over 3 of the Black Earth clays further suggests a very high dominance of trilayer minerals, i.e. Illite or Montmorillonite in the clay and that this is so will be seen later. The most highly siliceous nature of Black Earth clays, as evidenced by the highest SiO_2/R_2O_3 and SiO_2 : Al_2O_3 ratios amongst all the groups under the study seems to be the distinctive feature of the Black Earths - as also was observed by Robinson (1949).

(iii) In the Y.B.E. 2/LS the ratios suggest just a slight but appreciable silicification of the A_2 horizon, the more sesquioxidic nature being well perceptible in the B horizon, suggesting the initiation of the disintegration of the clay, whereas, in the Y.B.E. 1/S, all the ratios show a really and truly podsolic nature of differentiation of the clay complex in different horizons - which suggests that the Y.B.E. 1/S has undergone a good degree of degradation on its way to a true solod, while it is still maintaining the solonetz column in the B_1 horizon.

(iv) In the P 1/S the ratios no doubt have presented an indisputable podsolic character, while the morphology of the B_1 horizon seems to be a solodic one.

(v) The Al_2O_3 : Fe_2O_3 ratio smartly narrowing down with depth does suggest a marked mobilisation of Fe_2O_3 for the A horizon to the B horizon of Y.B.E. 1/S and P 1/S - that this is so will be seen later on.

(H) Free Iron Oxide.

The significant facts arising out of the iron oxide data as brought forward in Table 15 and graphically represented in Figs. 4 to 11 are:-

(i) A definite eluviation of iron from the A horizon and enrichment in the B horizon, the accumulation being maximum in the B_1 horizon (the horizon of maximum clay accumulation), in the Red Brown Earths, Yellow Brown Earths and P 1/S.

(ii) The movement of iron seems to have faithfully followed that of clay as evidenced by the similar trend of clay and iron oxide eluviation-illuviation, i.e. the maximum clay is accompanied by the maximum of iron oxide, the narrowing of clay content in the B_2 horizon is also repeated by iron oxide, and the minimum of clay in A_2 horizon is also accompanied by a minimum of iron oxide, suggesting thereby a very intimate relation between clay and free iron oxide.

(iii) The Black Earths, although standing separate from the above groups in consideration of genetic horizon formation, the BL.E(B) has shown a little increase in iron oxide at a depth of 15-28" along with a little increase of clay, while the BL.E(A) has shown no rise in free iron oxide anywhere with depth, just like the clay content.

From the observations noted above on the whole soil, one would possibly be inclined to think that the iron oxide is just a puppet of clay content and has no movement of its own - it has moved down just because clay has moved down - which would probably suggest that the free iron oxide is mostly associated with the clay fraction. As an answer to the above dubiousness, the free iron oxide in the clay fractions too was determined and the data (Table 15) show that the free iron oxide is by no means exclusively associated with the clay fraction of the horizon of eluviation.

The free iron oxide data on clay fractions further show that:

(i) In the B_1 horizon the clay accounts for 90-98% of the total iron oxide of the soil in the Red Brown Earths, Y.B.E. 1/S and P 1/S - this is probably due to the concomitant precipitation of iron oxide in the B_1 horizon with clay.

(ii) In the A horizon of the Red Brown Earths, Yellow Brown Earths and P 1/S, the clay has accounted for 50 to 89% of the total free iron oxide in the soil, and, in the surface horizon of the Black Earths, the clay hardly accounts for 50% of the free iron oxide present in the soil. This does suggest that the free iron oxide must be located somewhere else, which may be the humic matter of the soil. The possible combination of iron with humic matter to give a dark colouration was actually suggested by Harrison & Sivan (1912) in an attempt to explain the black colour of black soils of India.

However the above statements clearly suggest that free iron oxide is not just a slave of clay - it could move of its own accord. And the trend of the iron oxide mobilisation, i.e. depletion of the A horizon and enrichment in the

B horizon is an indisputable podzolic character, excepting of course in the BL.E(A). The BL.E(B) however has shown a mobilisation of Fe_2O_3; whether or not this is to be attended to with great care seems quite open to question. But, anyway, knowing apparently that free iron oxide has more or less moved by itself, it is to be answered as to how it has moved.

It is interesting to note in the present investigation that the mobilisation of iron oxide has taken place regardless of the soil reaction, which does demand a careful consideration and explanation.

Although the movement of iron oxide has been regarded as one of the most outstanding indices in soil classification, as is evidenced by the use of the terms, 'Ferrallite' - Robinson (1949): 'Ferromorphic' - Stephens (1950): and above all 'Pedalfer' - Marbut (1935), the mechanism of the peptisation and precipitation of this constituent in soil profiles is still delimited by obscurity in spite of the crowded literature on the subject. But nevertheless torn between hope and despair the soil chemists at different times have furnished quite valuable information, to wit a reasonable explanation of the movement of iron oxide under different conditions.

Iron can cross the frontiers of soil horizons in two distinct states:-

(a) in ionic state;
(b) in colloidal state.

(a) The ionic state comprises:-

    (1) a trivalent inorganic cation
    (2) a divalent inorganic cation
    (3) a complex organic ion.

(b) The colloidal state embraces:-

    (4) a positively charged iron-oxide sol.
    (5) a negatively charged SiO_2 protected iron oxide sol.
    (6) an iron-oxide sol with a negative charge under humus protection.

(1) The very fact that solubility of Fe^{+++} above pH 3.5 is very small, the Barossa Soils in consideration of their pH (none being less than 6.3) could not possibly expect to see the movement of iron in the Fe^{+++} state.

(2) As pointed out by Deb (1949) the solubility of Fe^{++} ion is quite appreciable over the pH range of soils in absence of air and can move in this state by percolation in soil solution provided the soil is saturated with water. From the observations of Winters (1940) too it is evident that iron as Fe^{++} ion can move in soils under reducing condition by surface diffusion.

Remembering that the Yellow Brown Earths in the Barossa Valley are under impeded drainage and the Y.B.E. 2/LS is particularly prone to waterlogging during the effective rainy season, the mobilisation of iron in the Yellow Brown Earths could find an explanation from the present paragraph, and particularly from Winters' (loc. cit) diffusion theory. During the dry period however, with the cessation of waterlogging, the Fe^{++} ion would be quickly oxidised to Fe^{+++} and irreversibly precipitated in the lower horizons. But due to the impeded drainage the Yellow Brown Earths would not get absolute aerobic condition for efficient ageing of the iron oxide which eventually reflected itself in the yellow tone of the subsoils.

Winters' (loc. cit.) diffusion theory may also be regarded as a probable mechanism of iron mobilisation in the P 1/S because of the facts that -

(a) the P 1/S, as will be seen later, is a solod and as such during solodisation process the prevailing reducing condition brought about the solution and the mobilisation.

(b) during sampling of the P 1/S, the sandy horizon was actually found to be quite moist, which would naturally be expected to speak for the mobilisation in the light of Winters' (loc. cit.) diffusion theory.

(3) The third possible ionic movement of iron is as a complex organic ion with a negative charge formed by simple organic acids produced during decomposition of organic matter. According to Jones and Wilcox (1929) the subsequent precipitation of iron in the B horizon takes place through the formation of basic salts, whereas Gallagher (1942) contends that the precipitation takes place as a result of the decomposition of the organic part of the complex, indicating thereby that the organic partnership is only just a temporary one. The additional information presented by Deb (loc. cit.) that the deposition of iron from salt solutions is independent of pH and also of the divalent cations of soil exchange complex, seems to be quite encouraging from the present purpose, especially because in the soils under investigation as was mentioned before the movement and deposition of iron oxide have not shown any regard to pH.

In the Red Brown Earths, however, the possibility of deposition in the light of Gallagher's (loc. cit.) view may be well worth considering as far as the B_1 horizon is concerned, but in the B_2 horizon, the zone of $CaCO_3$ accumulation, the deposition might have taken place by calcium salt formation, which indicates that the free calcium rather than the exchangeable calcium deserves the credit - supporting thereby the view of Deb (loc. cit.).

(4) Now coming to the colloidal movement of iron oxide, the suggestion of Mattson and Koutler-Anderson (1942) regarding the movement of iron as a positively charged iron oxide sol in association with alumina and humus may be considered specially in the case of the BL.E(B), where the soils are definitely of positive charge. The subsequent stabilisation has possibly occurred by $SO_4^=$ or Cl^- ions of the soil solution. The possibility of such a state of affairs in the P 1/S and also the R.B.E. 2/SL and SCL having slightly but distinctly alkaline reaction may also be considered.

(5) The next possible mechanism of the movement of iron, as suggested by Reifenberg (1938), is the peptizing action of SiO_2 on iron-oxide sols under slightly acid to alkaline reaction and the consequent mobilisation as negatively charged silica protected iron oxide sol. The subsequent deposition of the mobilised iron-oxide may take place by interaction with the electrolytes in the B horizon. This mechanism seems to be quite satisfactory for the Red Brown Earths and possibly the soils of the valley as a whole. But the observation of Barbier (1938) that thirteen parts of SiO_2 are required to peptize one part of ferric-oxide sol makes the situation rather difficult. Because, if Barbier's (loc. cit.) view is to be accepted, it would mean an enormously high amount of SiO_2 removal with respect to iron from the A horizon,

TABLE 15.

* DISTRIBUTION OF FREE Fe_2O_3 IN SOIL AND IN CLAY.

Soil Type.	Soil No.	Depth in inches.	Horizon.	% Clay.	% Fe_2O_3 in soil.	% Fe_2O_3 in clay fraction.	% Relative concentration in clay fraction.
R.B.E. 1/SL	15144	0 - 4½	A_1	8.4	0.88	-	-
	46	9 - 11	A_{2b}	17.3	1.19	4.00	58.34
	47	12 - 27	B_1	59.7	3.17	4.79	90.18
	48	31 - 48	B_2	34.5	1.92	4.74	85.27
R.B.E. 2/SL	15150	¼ - 3	A_1	13.1	0.85	-	-
	51	3½ - 4½	A_2	16.3	0.91	3.83	68.42
	52	5½ - 13	B_1	64.7	2.60	3.72	92.72
	53	13 - 17	B_{2a}	58.0	2.19	3.18	88.49
R.B.E. 2/SCL	15156	0 - 3	A_1	21.4	1.14	3.79	89.73
	57	5 - 9½	B_1	57.4	2.20	3.59	93.78
	58	12 - 14	B_{2a}	35.2	1.46	3.52	87.16
Y.B.E. 1/S	15162	1½ - 5	A_{1b}	1.8	0.11	-	-
	63	6 - 12	A_2	1.0	0.06	3.05	50.0
	64	12 - 13	B_1 (clay-sand cap)	18.6	1.06	-	-
	65	13 - 22	B_1	52.9	2.02	3.76	98.63
	66	26 - 38	B_2	32.3	1.68	4.33	83.16

* The results are reported on oven dry basis.

TABLE 15 (Ctd.)

* DISTRIBUTION OF FREE Fe_2O_3 IN SOIL AND IN CLAY.

Soil Type.	Soil No.	Depth in inches.	Horizon.	% Clay.	% Fe_2O_3 in soil.	% Fe_2O_3 in clay fraction.	% Relative concentration in clay fraction.
Y.B.E. 2/LS	15169	0 - 3	A_1	10.5	0.76	-	-
	70	4 - 5	A_2	9.9	0.71	3.63	50.55
	71	5 - 15	B_1	39.0	1.80	3.55	77.13
	72	15 - 20	B_2	39.6	1.59	-	-
	73	22 - 30	B_2	41.1	-	3.58	-
P 1/S	15177	0 - 6	A_1	1.1	0.05	-	-
	78	8½ - 14	A_2	1.1	0.04	2.97	80.39
	79	16 - 21	B_1	37.0	1.38	3.62	96.99
	80	22 - 39	B_2	27.3	0.73	2.55	95.94
BL.E(A)	15758	0 - 7	-	41.4	1.06	1.23	48.03
	59	9½ - 15½	-	38.0	0.71	1.10	58.80
	60	20 - 29	-	37.2	0.74	0.94	41.12
	62	38 - 60	-	21.8	0.43	-	-
BL.E(B)	15763	0 - 3½	-	39.9	1.05	1.29	49.28
	65	7½ - 14	-	41.6	1.36	-	-
	66	15 - 28	-	49.6	0.76	1.56	68.84
	68	90 - 108	-	25.1	0.55	1.18	54.28

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* The results are reported on oven dry basis.

which might obviously preclude the possibility of any iron accumulation in the B horizon leaving a comparatively SiO_2 rich A horizon. But Barbier (loc. cit.) presented no discussion on the effect of changing concentration and reaction to substantiate his thesis and as such it seems hardly reasonable to attach much importance to his view, and to disregard the mechanism as set out in the present paragraph as a possible one for the movement of iron in the Red Brown Earths and P 1/S studied.

(6) The last possible mechanism of iron movement as negatively charged iron-oxide sol under humus protection pioneered by Aarnio (1913, 15) and subsequently championed by his followers Udulft (1924), Simakov (1929) and Winters (1940), seems to be quite promising. Although some workers, such as Gallagher and Walsh (1943), Winters (loc. cit.), have questioned as to whether the amount of humus in the soil solution would be enough to peptize the iron oxide relying on the data of Aarnio (1913) and Winters (loc. cit.) that the amount of humus required for peptization may exceed 2.5 times the amount of ferric oxide, the evidence furnished recently by Deb (loc. cit.) has definitely given something to regard the potentiality of the mechanism under discussion. According to Deb (loc. cit.), the amount of humus necessary to peptize an iron oxide sol will not be more than about one-third of the amount of iron oxide even at a pH value near 4, and, with the increase of pH, the amount of humus necessary follows a decreasing order. But, whether or not the peptization can take place in alkaline medium has not yet been investigated.

The mechanism of precipitation, in general, is still a matter of guesswork and remains to be solved. The general trend of thought on this issue today is however swinging on to a microbiological process rather than any chemical process - Harder (1919), Albrecht (1941), Deb (loc. cit.).

Regny (1904), - as pointed out by Joffe (1949) - discussing the movement of Fe_2O_3 in the formation of terra rossa suggests that the Fe_2O_3 may be precipitated from ionic solution or even from colloidal state in contact with finely divided limestone, dolomite and clay. "Because of this precipitation", Regny (loc. cit.) holds, "cracks in limestone are enriched with iron. A small amount of iron would under such conditions, impart to the finely divided particles a red colour".

Thus to sum up - the mobilisation of iron oxide from A horizon to B horizon in the Barossa Soils under different pH conditions finds a reasonable explanation as traced out above, but the process of redeposition, although partly accountable, cannot fully be explained till such time as some definite hypothesis on this problem comes forward. The deposition in B horizon seems all the more problematic because of the preferential enrichment in the B_1 horizon and relatively lower concentration in the B_2 horizon.

THE COLOUR PROBLEM.

In the search for reasons for the colour of the soils of the tropics and subtropics, particularly the dark coloured soils, various theories have been put forward by many investigators at different times.

The dark colour was at first thought to be a reflection of organic matter but the observations that many of the dark soils do not contain particularly high organic matter called for some other explanation.

As early as 1898 Leather made an attempt to explain the colour of black soils on a mineralogical basis.

Annett (1909) from a study of similar soils from the Deccan Trap area (India) voiced his opinion that the black colour of the regur is particularly due to the presence of Titaniferous magnetite, although organic matter may play some part. But his investigations dealt with surface soil only and no comparative study of the titanium content of the soils from surface downwards was presented and as such this view seems difficult to accept unquestioningly.

Harrison and Sivan (1912) discredited Annett's (loc. cit.) theory, working on the regur soils of Madras (India), and suggested that the black colour is due to "presence of organic matter either in the form of humus or in peculiar combination with iron".

Hosking (1935) however has shown that the heavily alkaline soils require a pretreatment with acid to make the peroxide treatment effective and, treated in this way, the black colour changes to light grey to brown. Hosking (1935) states, "It is now possible to show that organic matter alone satisfactorily accounts for the colour".

Vageler (1935) from a study of some east african black soils suggests that the black colour is not due to humus but to the presence of iron oxide at a low stage of oxidation.

Raychaudhuri and associates (1943), failing to remove the black colour by H_2O_2 treatment, disregarded organic matter as a reason for the colour without however making any search for organic substances in the H_2O_2 treated residue. They have corroborated the views of Nagelschmidt and associates (1940) in that the main contrast between red clay and black clay is due to the fact that the former is predominantly kaolinitic or halloysitic and the latter is mainly beidellitic.

Villar (1944) believes that Fe_3O_4 is largely responsible for the dark colour of the "tirs" of Morocco.

Joffe (1949) observed that some dark coloured soils collected from Algeria and Palestine did not lose the dark colour after H_2O_2 treatment but lost the colour and turned red upon ignition at 400-500°C. He is of the opinion that the dark coloured substances that persist after H_2O_2 treatment consist of humins and perhaps some type of bitumens. He further contends that these high organic carbon constituents may form under the conditions of the high temperatures and periods of lowering of water table when the dark coloured soils are subjected to a change from anaerobic to aerobic state.

Under these circumstances, it was felt desirable to make a study of the colour enigma as typified by these soils from the Barossa Valley.

Both the soil and clay fractions were brought under investigation.

The clay fractions, which were practically of the same colour as the whole soil, were ignited at a dull red heat in the muffle furnace, as a result of which all dark colour vanished, giving way to bright red colour. This gave a lead to thinking that the dark colour is possibly due to organic matter. But the brightening of the colour might also be due to the existence of titanium as ilmenite ($FeTiO_3$), which might have been brightened up on ignition. The presence of ferrous compounds if any in the clay may also on ignition brighten up.

The next step thus was to determine the titanium content of the clays of all sorts of colour, i.e. yellow-yellow brown, red-brown and very dark grey to see whether there is any difference in the distribution of titanium on the basis of colour, and also to see whether titanium content varies from surface downwards in the Black Earths. The results of the analysis, as presented in Table 16, show that the titanium content in the Black Earths from surface downwards is quite constant, indicating thereby that the black colour of the surface clay is by no means related to the amount of titanium. Secondly, when compared with clay fractions of the other types, the titanium content of the black-earths' clay stands the lowest and, as a matter of fact, the titanium content of a brown clay collected from the A_2 horizon of P 1/S is the highest of all. This very clearly demonstrates that the black colour has nothing to do with the titanium and as such with titaniferrous magnetite as far as the clay is concerned. And hence the brightening of the colour on ignition of dark clay samples collected from the Black Earths, as mentioned before, is in all probability due to loss of organic matter.

The next step was however to deal with the soil as a whole and this was
I done by grinding the soil samples and sieving through 120 (I.M.M.) mesh sieve, and subsequently subjecting the selected samples to a drastic H_2O_2 (30%) treatment.

After the H_2O_2 treatment, the samples were filtered and washed with aq. alcohol, followed by absolute alcohol and, after drying, the residual colour was noted as reported in Table 17. It is interesting to note that after the H_2O_2 treatment all the soils unfailingly presented a bright shiny brown colour, depending of course on their original yellow or red toning. And the brownish very dark grey surface soils of the Black Earths gave way to a creamy or light yellowish brown colour. This very decisively shows that the very dark grey colour of the Black Earths as well as the dull nature of the colour of other soils of Red Brown Earths and Yellow Brown Earths is just due to organic matter.

The H_2O_2 treated soils were then subjected to the removal of free iron oxide to test whether the brown or red or yellow tonings are due to free iron oxide and if so whether the colour intensity as perceptible to the naked eye is related to the amount of free iron oxide.

TABLE 16.

DISTRIBUTION OF TITANIUM IN THE CLAY FRACTIONS.

Soil Type.	Soil Number.	Depth in inches.	Horizon.	% TiO_2
R.B.E. 1/SL	15146	9 - 11	A_{2b}	1.77
	47	12 - 27	B_1	1.19
	48	31 - 48	B_2	1.17
R.B.E. 2/SL	15151	3½ - 4½	A_2	1.49
	52	5½ - 13	B_1	1.11
	53	13 - 17	B_{2a}	1.13
R.B.E. 2/SCL	15156	0 - 3	A_1	1.41
	57	5 - 9½	B_1	1.09
	58	12 - 14	B_{2a}	1.02
Y.B.E. 1/S	15163	6 - 12	A_2	1.95
	65	13 - 22	B_1	1.25
	66	26 - 38	B_2	1.19
Y.B.E. 2/LS	15170	4 - 5	A_2	1.55
	71	5 - 15	B_1	1.23
	73	22 - 30	B_2	1.11
Podsolised (sand) P 1/S	15178	8½ - 14	A_2	2.79
	79	16 - 21	B_1	1.35
	80	22 - 39	B_2	1.19
Black Earth BL.E(A)	15758	0 - 7	-	1.11
	59	9½ - 15½	-	1.10
	60	20 - 29	-	1.09
Black Earth BL.E(B)	15763	0 - 3½	-	1.13
	66	15 - 28	-	1.00
	68	90 - 108	-	1.06

TABLE 17.

EFFECT OF H_2O_2 (30%) TREATMENT AND SUBSEQUENT REMOVAL OF FREE Fe_2O_3 ON THE COLOUR OF SOILS.

Soil Type.	Soil No.	Colour observed at the time of field sampling.	Overall colour after grinding and sieving through 120 mesh sieve.	% Free Fe_2O_3.	Colour after H_2O_2 treatment.	Residual Colour afte subsequent removal of free iron oxide.
Black Earth	15758	Brownish very dark grey.	brownish dark grey.	1.059	Creamy or light yellowish brown.	Very light greyish tinge.
	15763	Brownish very dark grey.	brownish dark grey.	1.047	Same as above.	Same as above.
	15765	Mottled dark grey, brown, yellow grey, intermingled with mottled dark grey, light brown and reddish brown.	brownish grey.	1.361	Yellowish brown.	Off-white.
Red Brown Earths.	15147	Red brown - Dark red brown.	red brown.	3.170	Bright red brown.	Off-white.
	15152	Dark brown, red brown.	Same as above but distinctly lighter.	2.600	Bright reddish brown.	Off-white.
	15153	Dark brown, red brown.	Distinctly lighter than 15152.	2.185	Bright reddish brown but lighter than 15152.	Off-white.
Yellow Brown Earths.	15165	Grey with yellow brown, brown mottled, red inclusions; black concretions & inclusions.	Yellow brown.	2.018	Bright yellow brown.	Off-white.
	15166	Yellow grey, brown mottled with an intimate network of red brown and black inclusions.	Yellowish brown.	1.681	Bright yellowish brown.	Off-white.
	15171	Mottled drab brownish grey, yellow brown.	Yellow brown, lighter than 15165.	1.796	Bright yellow brown - lighter than 15165.	Off-white.

The observations as noted in Table 17 very clearly show that the colourings, i.e. yellow or brown tonings of red, are all due to the presence of free iron oxide: Because after the removal of free iron oxide and the filtering and drying the ultimate colour of the Red Brown Earths' and Yellow Brown Earths' samples assumed an off-white colour. The very dark grey horizons of the two Black Earths have, on removal of the free iron oxide subsequent to H_2O_2 treatment, presented a very faint greyish tinge - certainly nothing like brownish or darkish.

An inspection of Table 17 further shows that the colour intensity is quite appreciably related to the free iron oxide content. Robinson and Holmes (1924) also made a similar observation. It is however to be noted that the difference in colour intensity would be easily detectable if the free iron oxide contents of the soils are significantly different. But, when the amounts of free iron between two samples are not significantly different, it is rather difficult to draw a line of demarcation by visual method, i.e. by simple naked-eye observation.

Speaking of the colour of black and red soils, Raychaudhuri and associates (1943), although not directly committing themselves, indirectly hinted at the mineralogical composition of the clay fractions as an explanation of colour.

In the present investigation, the free iron oxide of variously coloured clays (Table 15) - dark grey, brown, yellow, red brown and so on - were determined and as soon as the free iron oxides were removed the residual colour of the clay fractions was just devoid of any yellow or brown or red toning, which does mean that the clay minerals have nothing to do with the redness or blackness of soils or clays, thereby throwing a doubt on the contention, direct or indirect, of Raychaudhuri and associates (loc. cit.).

To sum up, it may be said that in the present investigation the black surface colour of the Black Earths and also the darkening of the soils in the other groups is due to the presence of organic matter. The black colour in particular may be due to the Ca-saturated organic colloids and may even be partly due to a combination of free iron oxide with the organic colloids - the likelihood of the presence of which has been suggested previously.

The intensity of the red-brown or yellow-brown tonings in the soils and clays seems to be generally functional to the amount of free iron oxide.

THE PEDOLOGICAL SIGNIFICANCE OF THE DISTRIBUTION OF TiO_2.

Referring back to Table 16, relating to the vertical distribution of Titanium in the clay fractions of the different types and groups, it will be seen that -

(a) in the Black Earths the TiO_2 content is quite constant from surface downwards;

(b) in the Red Brown Earths, Yellow Brown Earths and P 1/S, the titanium in the A_2 horizon is much higher than in the B horizon, and the trend of this distribution is remarkably unfailing;

(c) the contrast between the A_2 horizon and B horizon in relation to Ti content is most marked in the P 1/S, followed by Y.B.E. 1/S;

(d) amongst the types in the Red Brown Earths' group, the R.B.E. 1/SL shows the highest difference in the Ti content between A_2 horizon and B horizon - the difference in the R.B.E. 2/LS and R.B.E. 2/SCL is however practically the same;

(e) between the two types of Yellow Brown Earths the Y.B.E. 1/S certainly shows the difference or contrast more pronounced than that in the Y.B.E. 2/LS.

Before saying anything regarding the pedological significance of the distribution of Ti, it might be well worth looking back to the previous works in this line, if any, worth taking note of.

The available literature on "Titanium" content of soils dates back to 1891 due to Dunnington who collected soil samples from many parts of the world and analysed 80 specimens.

Following Dunnington (loc. cit.), Pellet and Freibourg (1905) reported on the TiO_2 content of an Egyptian soil under sugar cane; and Mc.George (1912) reported on the TiO_2 content of some normal Hawaiian soils.

Robinson in 1914 presented Ti data on 13 soils - both surface soils and subsoils - from the southern and north-eastern States, America, but with no reference to natural horizon.

Joffe and Pugh (1934) presented a compilation of data on titanium and other constituents of some soils of various parts of the world from the reports of Blanck, Benett & Allison, Harassowitz, Niggli, Stremme, Lundblad and Marbut.

An examination of the data presented by the aforesaid workers reveals that - (1) the Ti content within the various soil zones differs from as low as 0.27% to as high as 4.04%. According to Joffe & Pugh (loc. cit.) such variations must be attributed to the Ti-content of the parent material.

(2) the titanium content of soils especially the lateritic and laterites in the tropics, with a few exceptions, is higher than in the soils of temperate climate.

But any attempt to evaluate the distribution of the TiO_2 in the profile is very difficult indeed, as very few of the analyses deal with the distribution in the profile and the few that show the distribution at various depths do not clearly refer to any natural horizon. As they are, some depths might possibly have included portions of the bordering horizons, thereby overshadowing any precise elucidation of the movement and translocation of the soil constituents in the profile. On top of that, total analysis hardly gives any significant and complete picture without the composition of colloid fraction side by side.

Unfortunately, very few systematic studies have been made on the colloids of soils of various zones by profile method. The only work worth referring to seems to be that of Robinson and Holmes (loc. cit.) who made a pretty extensive study on the colloid fractions of various soils of the United States but there again at arbitrary depths - the soil and subsoil business in the presentation.

Steinkoenig, as early as 1914, did some work on the distribution of TiO_2 in various fractions of a number of soils, and showed that TiO_2 concentration is highest in the clay and fine silt fractions.

However, in spite of these limitations, considering side by side the distribution of SiO_2 and R_2O_3 even at the arbitrary depths, the data compiled by Joffe and Pugh (loc. cit.) do give some indications of pedological significance which may be stated as -

(1) Under podzolic process of soil formation TiO_2 seems to accumulate in the B horizon;

(2) Under lateritic process of soil formation the accumulation seems to be in the A horizon.

This was also observed by Joffe and Pugh (loc. cit.) and Joffe (loc. cit.) But this is all about the soil in total.

Regarding the TiO_2 status of clay fractions under varying pedogenic processes, nobody has made any direct comment yet. But just a comparison of the vertical distribution of TiO_2 content of the soils and the corresponding clays of some podsolic and lateritic soils of the United States as presented by Robinson & Holmes (loc. cit.) shows that the distribution of TiO_2 in clay follows in general (even if the analyses were done at arbitrary depths) just the opposite trend to that in soil. This has been shown in Table 18. In other words under a podsolic process the TiO_2 content seems to be higher in the A horizon clay than that in the B horizon clay and under lateritic process the reverse would be the case.

From what has been said above, it seems an accumulation of TiO_2 in the A horizon clay might be regarded as an index of a podsolic process. And thus all the soils under the present investigation, excepting of course the Black Earths, might be regarded to be undergoing a process of podsolisation to varying degrees, as is revealed by the unfailing accumulation of TiO_2 in the A_2 or A_1 horizon clay varying in degrees from type to type and group to group.

That a podsolic process of eluviation-illuviation is operating in varying degrees in the soils under the present investigation (excepting the Black Earths) is quite evident from the chemical data as has been referred to from time to time and will be referred to in the succeeding discussions and conclusion.

TABLE 18.

% TITANIUM OXIDE IN SOIL AND CORRESPONDING CLAY FRACTION. (QUOTED FROM ROBINSON AND HOLMES' ANALYSES OF VARIOUS SOILS OF THE UNITED STATES).

Soil Type.	Depth in inches.	% TiO_2 in clay.	% TiO_2 in Soil.
Cecil clay loam, Georgia.	0 - 9	0.62	0.80
	9 - 18	0.52	0.87
Norfolk fine sandy loam, North Carolina.	0 - 8	0.79	0.94
	12 - 36	0.71	1.06
Orangeburg fine sandy loam, Mississippi.	0 - 10	0.54	0.50
	10 - 36	0.44	0.52
Clarksville silt loam, Kentucky.	0 - 10	0.81	1.37
	10 - 36	0.63	0.92
Sassafras silt loam, Maryland.	0 - 8	0.63	1.09
	8 - 22	0.70	1.05
Huntington loam, Maryland.	0 - 8	0.40	0.78
	8 - 30	0.47	1.20
Chester loam, Maryland.	0 - 8	0.58	0.98
	8 - 32	0.70	0.80
Ontario loam, N.Y.	0 - 12	0.38	0.72
	12 - 22	0.56	0.71
Carrington loam, Iowa.	0 - 12	0.47	0.53
	15 - 36	0.65	0.40
Marshall silt loam, Nebraska.	0 - 14	0.48	0.67
	14 - 36	0.50	0.71
Miami silty clay loam, Indiana.	0 - 10	0.70	0.91
	10 - 30	0.79	0.82
Wabash silt loam, Nebraska.	0 - 15	0.49	0.58
	15 - 36	0.56	0.62

Hence, on the strength of the above discussion, and particularly the present investigation, it might not be too much to say that an accumulation of TiO_2 in the A horizon clay may be regarded as an index of a Podsolic process in operation - while the reverse would be the case in a lateritic process.

NOTES ON ANALYTICAL METHODS.

The analytical methods used were those published by Piper (1947); some recent and unpublished improvements have been adopted for the determination of free iron oxide and P_2O_5.

The mechanical analyses were carried out by pipette sampling method and the fractions separated were those recommended internationally.

Calcium carbonate was determined by Hutchinson & MacLennan's method (1914).

pH measurements were all made by the glass electrode using calomel half cell.

Organic carbon was determined gravimetrically by dry combustion; carbonates when present were removed by pre-treatment with sulphurous acid.

Total nitrogen was determined by the routine Kjeldahl method.

Phosphate determinations were made by developing the blue colour of the phospho-molybdate-complex-in-butyl alcohol on the concentrated HCl extract of the soils and finally comparing the colour with those of known standards.

Chlorides were determined by electrometric titration (Best 1929).

Total soluble salt determinations were done by conductivity measurements of 1 : 5 (Soil : Water) suspensions at 20°C - the specific conductivity being multiplied by a known factor found experimentally for Australian soils.

The exchangeable cations were determined by leaching the soils with ammonium chloride. Calcium was precipitated as oxalate, magnesium as 8-hydroxyquinolate, sodium as complex uranyl magnesium acetate and potassium as cobaltinitrite. Calcium and potassium determinations were done volumetrically by titration with $KMnO_4$ as usual. In the cases of calcareous soils ($CaCO_3$ amounting to 0.3 per cent. upwards) exchangeable calcium and magnesium were determined in sodium chloride leachates, by a slight modification of Hissink's (1923) method.

Exchangeable hydrogen was determined by Piper's (1936) meta-nitrophenol method.

Free iron oxide was determined by *Haldane's (1950), modification of Jeffries' (1941) method as will be outlined below.

The adoption of a method for the determination of free iron oxide in soils and clays is a difficult problem because of the fact that comparatively little work has been published on the possibilities and efficiency of the methods proposed.

With the exception of Tamm's (1920) original method, all the other methods proposed are based on the reduction of the ferric iron to ferrous state in the presence of a reagent that forms a stable complex with the ferrous iron.

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* An Officer of the C.S.I.R.O. (Aust.) - Soils Division, stationed at Waite Institute, Adelaide.

One of the major difficulties is to obtain a sufficient degree of dispersion of both the soil and coarser particles of iron oxides (iron oxide gravel, haematite, magnetite) to accomplish complete reduction of the iron oxides - as, for obvious reasons, the reduction reaction will be a function of the surface area. In this respect, the method of Truog et al (1937) seems better than others. But this method suffers from the defect that (a) it brings in considerable amounts of iron from the clay minerals, (b) frequently more than one extraction is necessary to remove the red or brown colour from the soil, (c) the nature of iron oxide too limits the efficiency of the method.

The method of Drosdoff & Truog (1935), although much less drastic in the chemical reaction, does not effect complete removal of iron oxide in all cases. Beck (1939) found that it was necessary to increase the time of the reaction with H_2S and that repeated extractions were necessary in almost all cases. Even then the complete removal of iron oxides was not effected as shown by Williams (1950).

The microbiological reduction method of Allison & Scarseth (1942) is not yet sufficiently well established to merit confidence for critical work. Further there is no positive evidence that this method has any outstanding advantages.

t/ The hydrosulphide method recently re-examined by Deb (1950), although seemingly promising, has not yet been well tried. Deb (loc. cit.) worked with clay fractions of four soils only.

n/ Methods employing nascent-hydrogen-reduction proposed by Dion (1944) and Jeffries (1941, 1945), have been thoroughly studied in the Waite Institute by several workers, particularly the method of Jeffries (loc. cit.). But they have been found unsuitable for an indiscriminate application.

The latest proposition of Haldane (1950), as a modification of Jeffries' (loc. cit.) method, was tried on varieties of soil types and groups and was found to be quite successful as long as the samples to be analysed are finely ground and passed through 120 mesh (I M.M.) sieve and do not contain more than 7% iron as Fe_2O_3.

The method employs zinc dust and a potassium oxalate-oxalic acid buffer (pH - 3.5) for reduction of the iron oxide at room temperature. The reduction reaction takes only one hour. The final estimation of the iron oxide is carried out by titration with potassium dichromate solution in the usual way.

The special merits of the method are:-

(1) Very little, if any, attack on clay minerals.

(2) Practically complete removal of free iron oxide in one hour by single treatment.

(3) No application of heat necessary.

(4) Fairly easy to manipulate.

(5) No deposition of the iron during the reaction, provided the iron oxide content does not exceed 7% as Fe_2O_3.

The clay fractions separated for silicate analysis as well as for X-ray photographs corresponded to the former British clay fraction and had a settling velocity of 10^{-4} cm. per second. Silica was determined in the separate by the standard methods of rock analysis, involving Na_2CO_3 fusion, double evaporation and dehydration, ignition and purification by hydrofloric acid.

Titanium was determined colorimetrically in an aliquot of the filtrate, iron and titanium in another aliquot by precipitation with cupferron (Welcher 1947), while iron, aluminium and titanium in a third portion by precipitation with ammonia.

DISCUSSION AND CLASSIFICATION.

Having had a reasonably comprehensive picture regarding the state of affairs in the soils of the area under the investigation, the next step is obviously an attempt to classify the soils studied.

(A) The Red Brown Earths.

The occurrence of the Red Brown Earths under a mediterranean-like climate in Australia, and a general similarity in the morphology of the Red Brown Earths and Terra rossa soils, led to some confusion regarding the classification of the Australian Red Brown Earths in the thirties of the present century - due to the absence of sufficient systematic information on these soils of the Continent. The first comprehensive study on Australian Red Brown Earths was made by Piper (1938) and it was a very intensive study indeed. Later studies of Stephens and assoc. (1945), Smith and assoc. (1943), Smith (1945), Butler and assoc. (1945), have added quite a good amount of information, principally to the morphological side and also to the general chemistry and geography of the Red Brown Earths. In consideration of their genesis, particularly their parentage, Prescott (1947) grouped them as such, i.e. as Red Brown Earths, pointing out clearly the obscurity of the genesis of terra rossa. And in fact the very concept of terra rossa has been so earnestly debated both by pedologists and geologists and yet so little is known about it.

Smith (1949) however, discussing the Australian Red Brown Earths from climatic and morphological considerations, sought to indicate their parallelism with the reddish chestnut soils of America, awaiting with interest the reaction of the American colleagues. The visit of C. G. Stephens to North America and his presentation, (Stephens - 1950), and the inspection of C. E. Kellogg of the Urrbrae loam (a typical South Australian Red Brown Earth) in 1949, have stimulated the idea of parallelism between the Australian Red Brown Earths and the American reddish chestnut soils from the morphological standpoint.

As a generalised statement of the morphology of the Australian Red Brown Earths, they may be described as follow:-

(i) The A horizon - brown to reddish brown in colour, medium texture, 2 to 15 inches thick, practically lime-free, weakly acid to neutral in reaction, often slightly laminated structure, without a well-developed A_2 horizon.

(ii) The B_1 horizon - about 15 inches thick, reddish brown to red in colour, of clay texture, generally friable, non-calcareous, faintly alkaline.

(iii) The B_2 horizon of variable thickness - brown to yellow brown in colour, sandy clay texture (clay less than that in the B_1 horizon), calcareous-(the lime being partly soft and partly nodular in a clay matrix); the presence of $CaCO_3$ however, according to Prescott (1947), is not invariable, particularly if the parent materials are deficient in lime.

It may at this stage be well worth bringing forward the important features of the Red Brown Earths studied in the present investigation - as follow:-

(1) A loamy (sandy loam to sandy clay loam) A horizon with slightly acid to slightly alkaline reaction, grey brown to light grey brown in colour, 3 to 11 inches thick and lime-free.

(2) A heavy clay accumulation in the B_1 horizon which is lime-free, neutral to slightly alkaline, red brown to dark red brown in colour, 5 to 15 inches thick.

(3) A B_2 horizon of brown to red brown light clay, (the clay content much less than that in the B_1 horizon), calcareous (lime being both amorphous and indurated) and as such distinctly alkaline. The above three clauses, in the light of the preceding discussion, do suggest that the Red Brown Earths under the present study should be classed along with the other red brown earths of Australia.

The presence of varying amounts of lime - from 1.2% to 29% - in the heterogeneous initial states of the Red Brown Earths studied, and also the climate of the Barossa Valley as discussed previously in the light of Prescott ratios (1950, 48) clearly support the above grouping.

Again, apart from all the above observations, which are essentially in agreement with those of Piper (1938) on the Red Brown Earths of South Australia, the nature of the clay fractions too is quite in agreement with Piper's (1938) findings. To come to more prosaic details however it may be pointed out that the above-mentioned agreement lies in:-

(i) a slight degree of unsaturation in the A horizon clay - the base saturation increasing with depth and attaining 100% saturation in the calcareous horizon;

(ii) the contribution due to the clay fraction towards the total exchange capacity - the average value observed in the present investigation is 0.49 m.e. per grm. of clay and the average value observed by Piper (loc.cit.) was 0.48 m.e. per grm. of clay;

(iii) the silica : sesquioxide and silica : alumina ratios of the clay fractions of different horizons, as the values found in the present investigation are well within the range of the frequency distribution of the ratios presented by Piper (loc. cit.);

(iv) the distribution trend of the above-mentioned ratios with depth on horizon basis, as the silica : sesquioxide and silica : alumina ratios slightly but appreciably narrow down on passing from the A horizon to the B_1 horizon and again widening up in the B_2 horizon even to exceed the value in the A horizon.

Thus, from the morphological and chemical characteristics, as set out in the discussion, it can be safely said that the Red Brown Earths of the present investigation join hands with those of Piper (loc. cit.) and as such following Prescott (1947) they may be classified as such, i.e. as Red Brown Earths.

(B) The Black Earths.

The facts that the Black Earths under the present investigation have occurred -

(a) in association with a group of Red Brown Earths under a mediterranean-like climate;

(b) having had a very highly calcareous and soft and marly initial state;

(c) with a texturally undifferentiated character of the profile;

(d) with a very heavy accumulation of lime below the almost-black surface horizon, showing a network of deep cracks during summer;

strongly suggest the inclusion of the Black Earths studied amongst the Rendzina.

Rendzinas, which are frequently referred to as lime-humus soils - Stephens (1950), Robinson (1949) - were originally identified and named in Poland and Western Russia. The term Rendzina is of a Polish peasant origin - Prescott (1947). In Poland the name which is of doubtful meaning, as pointed out by Prescott (loc. cit.), is given to soils derived from calcareous or gypseous parent materials and may be derived from a Polish word meaning "to tremble", indicative of the sounds heard when cultivating. Since then they have been recognised almost all over the world - they were studied in Western Europe, Africa, to some extent in North America, India and Australia. These soils, the so-called humus-carbonate soils, have been according to Robinson (loc. cit.) most widely studied in Central Europe.

As pointed out by Robinson (loc. cit.), in Glinka's system of classification they are considered to be typical endodynamomorphic soils, which have not yet reached mature development and in which the profile character is mainly determined by the nature of the parent material.

The profile characteristic of a Rendzina is, as is universally accepted, a very simple one:

(a) a dark grey to almost black medium to heavy textured surface of varying thickness with a friable granular structure, although Miklaszewski in Poland, as pointed out by Robinson (loc. cit.), noted white or even brown varieties of calcareous Rendzina; white Rendzinas were also noted in England, but in the Mediterranean region no report of white Rendzina has yet come forward.

(b) a greyish brown to brown subsoil immediately below the black or dark grey surface soil more highly calcareous than the black surface.

(c) no textural differentiation in the profile, and generally no break of alkalinity anywhere in the profile.

(d) the organic matter on the surface varying from 3-12%.

(e) fully base-saturated clay complex.

(f) the clay fraction more siliceous than the accompanying groups of soils.

The Rendzinas and Black Earths constitute 4% of the soils surveyed in Australia till 1948 (Prescott and Taylor, 1949).

According to Prescott (loc. cit.), the soils are black in colour and remain well supplied with lime even under reasonably wet conditions - they may be recognised on limestones in many parts of Australia.

The Rendzina soils have been fairly well studied in Australia by Stephens and associates (1941); Stephens and associates (1945), Stephens (1941); and also by Hosking (1935), who presented a comparative study of the black soils of Australia and regur of India.

While the morphology of the Australian rendzina has been quite thoroughly studied, the chemical characteristics especially of clay fraction has not received proper attention before now.

However, the features which seem especially applicable to Australian Rendzina, as evidenced by the presentations, referred to above, are that -

(a) the exchange complex, although dominantly maintained by Ca in the surface soil, Mg in some cases steadily increases with depth at the expense of Ca and sometimes even exceeds the Ca content in the exchange positions of the clay - and in some cases even Na assumes significant amount to bring about the formation of a columnar clay in the subsoil horizon, thereby leading to solonisation.

(b) the organic matter in the surface ranges from 2-5%, although values as low as 1% and as high as 10% were observed in Queensland - Hosking (loc. cit.).

Without proceeding any further in reviewing, it seems worth while to bring forward the distinctive features of the Black Earths under the present investigation as follow:-

(a) Very dark grey medium clayey surface cracking during summer - the clay is of a friable granular-nutty structure.

(b) No development of any texture profile.

(c) Presence of free lime right from the surface downwards - with a very distinct heavy accumulation of lime in the subsoil, the colour of which has changed from dark to greyish brown-brown.

(d) Highly calcareous initial state - the lime being soft and marly.

(e) Distinctly alkaline reaction of the soils right from the surface downwards, the pH reaching as high as 9.68 at the deepest sample, starting from 8.5 from the surface.

(f) Organic matter, nitrogen, P_2O_5 steadily narrowing down with depth with no sign of any accumulation anywhere below the surface.

(g) The exchange complex is fully saturated - the dominant cation being Ca in the surface - Mg increasing with depth and eventually exceeding Ca at the deepest horizons (particularly applicable to Australia - Hosking (loc. cit))

Considering the above facts with respect to what has been said before, it can safely be said that the Black Earths studied belong to RENDZINA.

An additional evidence to the aforesaid grouping has been provided by the composition of the clay fractions at the different depths, which may be mentioned as follow:

(1) the $SiO_2 : R_2O_3$ and the associated ratios from surface downwards are fairly constant.

(2) the $SiO_2 : R_2O_3$ and $SiO_2 : Al_2O_3$ ratios are higher than that of the associated soil groups, which, according to Robinson (loc. cit.), is a distinctive feature of Rendzinas.

An inspection of the analytical data on clay fractions collected from European Rendzina, as presented by Robinson, shows that the $SiO_2 : R_2O_3$ ratio varies from 3 to 4, $SiO_2 : Al_2O_3$ ratio from 4 to 5 and $Al_2O_3 : Fe_2O_3$ from 3 to 4, the individual ratio in the individual profiles being fairly constant at different depths. The data for the soils studied under the present investigation show that the $SiO_2 : R_2O_3$ is 3 to 3.16, the SiO_2/Al_2O_3 ratio is 3.84 to 4.04 and the $Al_2O_3 : Fe_2O_3$ is round about 3.5, whilst the corresponding values for the Red Brown Earths are round about 2.2, 2.8, 3.3-4.14 respectively, very clearly demonstrating the comparatively more siliceous nature of the Rendzina clay.

In this connection, it may be pointed out that in BL.E(B) a tendency of the clay moving downward was noticed. But from the data presented by various workers on Rendzina it seems nothing to worry about from the point of view of classification.

(C) The Podsolised Soil.

The morphology of the P 1/S studied, which is as follow:-

(a) an off-white or ashy grey bleached sandy single grained A_2 horizon of six inches thickness underlying a light brownish grey sandy A_1 horizon (6 inches):

(b) an illuvial B_1 horizon of mottled grey, yellowish brown and red with an overall effect of yellow grey coloured clay:

(c) no visible lime anywhere in the profile:

gives a definite indication of grouping the soil under the Podsol or Podsolic class.

The Podsols by reason of their wide extent in Russia and northern Europe, have received more detailed attention than any other group of soils - excepting of course the chernozems, which in the history of Pedology have played as important a role as frogs have in Physiology, calcium in Crystallography and benzol in Organic Chemistry.

The Podsolic Soils were also extensively studied in North America and Australia. In Australia podsols constitute 8.3 per cent. of the total area surveyed till 1948 - Prescott and Taylor (1949). The study of podsols and podsolised soils in Australia has been mainly due to Stephens (1933, 41) and Stephens and Hosking (1932). While the morphology and the general chemical characteristics of these soils have been pretty thoroughly studied in Australia - information on the clay fractions is still wanting.

However, it hardly needs emphasis to say that -

(a) an accumulation of humus and free Fe_2O_3 in the B_1 horizon along with clay;

(b) a chemical degradation of the clay fraction leading to a remarkably sesquioxidic clay in the B horizon as compared to that in the A horizon;

(c) dominance of kaolinite in the clay minerals;

are the indisputable characteristics of Podsolisation - Joffe (1949), Robinson (1949), Rode (1933), Zavalishin (1935).

Thus the aforesaid features of the P 1/S studied coupled with the following chemical characteristics:-

(a) a distinct removal of nitrogen, organic carbon and P_2O_5 from the A_2 horizon and accumulation in the B_1 horizon;

(b) remarkably high accumulation of free iron oxide in the B_1 horizon as compared to that in the A_2 horizon;

(c) a heavy drop of $SiO_2 : R_2O_3$ and $SiO_2 : Al_2O_3$ ratios in the B horizon as compared to that in the A_2 horizon, indicating a degradation of the clay complex and downward eluviation of the R_2O_3,- the $SiO_2 : R_2O_3$ and $SiO_2 : Al_2O_3$ ratios in the A_2 and B_1 horizon being 2.78 and 3.09; and 1.95 and 2.26 respectively;

do suggest the inclusion of P 1/S studied under the Podsol or Podsolic group.

To this may be added the dominantly kaolinitic nature of the clay in the P 1/S (as will be seen later) - the kaolinite content relative to illite in the clay increasing with depth, as a supposedly diagnostic mark in favour of a

Podsolic thesis for the P 1/S.

But, before saying anything finally, there are certain points to be taken note of as follow:-

(1) The reaction of the soil is neutral, which is associated with high Ca-saturation:

(2) The absence of an organic A_0 horizon in the morphology - unlike the Podsols or Podsolics of northern hemisphere. The reason is probably the cultivation and also the existing climate neither of which could favour an organic A_0 horizon in the P 1/S. Even if the soil was a virgin one, in consideration of the vegetation and climate, the presence of an organic A_0 horizon identical with those of northern hemisphere, would in the language of Stephens (1950) be "Surprising":

(3) The climatic condition, although maintaining a downwards leaching, is not possibly characteristic of Podsolic Soils. This however has possibly been, to some extent, compensated by the very light texture of the initial state as shown previously and does not preclude the possibility of a Podsolic genesis:

(4) The exhibition of a columnar tendency in the B_1 horizon, as evidenced by the presence of vertical cracks in the B_1 horizon clay- showing a solonising activity in the profile:

(5) High exchangeable Mg content, i.e. 30.6% of the total metal ions in the B_1 horizon clay complex - which normally wouldn't possibly be a cause of anxiety in Australian Pedology. But, coupled with observation (4), it is certainly standing as a serious and unscaleable barrier for the P 1/S to reach the Podsolic contention.

The observations 4 and 5 jointly cast a very definite reflection of some hydro-halomorphic activity, past or present, in the P 1/S. And in fact, the "Lake Theory" of the origin of the Barossa Valley as discussed in the earlier chapter and also the complex association of the Podsolized Soils (Fig. 1), with a group of Solonetzitic Soils, would hint at the probability of the P 1/S to represent a Solod.

The matter however will again be taken up in the next section relating to the Yellow Brown Earths.

(D) The Yellow Brown Earths.

The items of interest in the Yellow Brown Earths significantly pertinent to the discussion are:-

(1) the columnar structure of the B_1 horizon clay - the columns varying in diameter and well domed - overlying a massive B_2 horizon and underlying;

(a) in the case of the Y.B.E. 1/S a 12 inch thick sandy A horizon having a distinct brownish white sandy A_2 horizon of 6 inches thickness;

(b) in the case of the Y.B.E. 2/LS a five inch thick A horizon of loamy sand with an indication of an A_2 horizon development:

(2) the columns in the B_1 horizon interspersed with deep converging grooves and/or cracks - grooves in the case of the Y.B.E. 2/LS and cracks in the case of Y.B.E. 1/S;

(3) significant relative amounts of Na and also Mg in the exchange complex - particularly in the B horizon (Table 12).

The above observations clearly suggest a solonisation process in the Yellow Brown Earths of the present investigation.

Before proceeding any further with the soils studied, it seems worth while to trace a short pen picture of solonising activities in soils or, in other words, halogenesis of soils.

Soils reflecting the characteristics and properties brought about by the reactions due to the circulation of soluble salts in the profile are grouped under the type-name saline soils (Joffe 1949), which Vilenskii (1927) designated as "Hydro-halogenic" Soils.

Literature on "halogenic" soils is very extensive indeed - as works on these have been carried out in almost all parts of the world, some dating back to the 18th century, as was pointed out by Joffe (loc. cit.), who also observed - "It has been estimated that 39 per cent. of the world's dry land area is covered by these soils".

It was, however, not until 1912, when Gedroiz, stimulated by the physical, chemical and morphological investigations of his Russian predecessors on the specificity of Solonchak and Solonetz Soils, presented his classical researches on the colloidal properties of soils in relation to exchangeable cations and the implications of these reactions in the process of soil formation with special reference to Saline Soils, that the mechanism of the reactions responsible for the typical features of halogenic soils was brought into clear sight.

Hilgard (1892, 1921) in the United States did pioneering works on Halogenic soils. But, although his theories were acclaimed and accepted throughout the world, as pointed out by Joffe (loc. cit.), neither Hilgard nor his contemporaries and followers up to 1920 have appreciated the genetic relationship of the different types of halogenic soils.

Stimulated by the views of 'Hilgard' (loc. cit.) and Theories of 'Gedroiz' (loc. cit.), Sigmond (1928, 29) made a substantial contribution on the subject in his report on the Hungarian alkali soils to the First International Congress of Soil Science and in the "Transactions of the Alkali Sub-Commission of the International Society of Soil Science.

The First International Congress of Soil Science met with a direct conflict between the Schools of Chemistry and Morphology of Saline Soils, led by K. K. Gedroiz and K. D. Glinka respectively, who gave entirely different verdicts on the same soil.

However, researches on the hydro-halogenic soils due to, among others, Shaw & Kelley (1935), Ellis & Candwell (1935), Kelley (1934), Storie (1939), Nikiforoff (1937), Kellogg (1934), Sokolovskii (1941), Rost (1936) and also Prescott (1922), have thrown sufficient light on the understanding of the soils under reference, particularly in creating a happy compromise between the chemists and morphologists.

In Australia, halogenic soils constitute 6.1% of the total area surveyed till 1948 - Prescott & Taylor (1949). Teakle's (1937, 1938) contributions on the halogenic soils of Western Australia, and particularly on the accession of salt through rain water, are of great significance in the understanding of Australian halogenesis. Contributions due to Burvill and Teakle (1938) and Smith (1950) on West Australian halogenic soils are also of special interest from the point of view of halogenesis. To this may also be added the work of Prescott & Piper (1932) on the South Australian mallee soils, which Prescott (1947) termed as solonized brown soils. The edition of Taylor (1933) also presents solonised soils, particularly in the Monkoora sand.

Without unduly lengthening the review any further, it may be, on the strength of information available from the different parts of the world, safely said that there is a general agreement amongst the soil workers in that the evolution of hydrohalogenic soils conform to three distinct stages, at least theoretically, each one representing a well defined soil forming process resulting in a soil type.

The first stage represents a process of salinisation, i.e. the accumulation of soluble salts at the surface or at some point below the surface of the soil profile. Usually some portion of the divalent cations are replaced by monovalent cations, especially Na. The presence of excess salts prevents the hydrolysis of the Na from the exchange and keeps the colloid flocculated. The soil normally is not highly alkaline. Soils formed under this process are known as "Solonchak".

The second stage represents a process of desalinization, whereby the soluble salts are removed from the surface or pushed down to the bottom of the B or into the C horizon and the exchange complex is subjected to a considerable saturation with respect to Na-ion and/or Mg ion. In the order of their removal from the profile, the chlorides and nitrates come first, followed by the sulphates and carbonates (as HCO_3 ion). As the electrolytes are removed, the soil colloids become peptized depending on the type of cations and their quantitative relationship in the exchange-complex. In general the cation effect on dispersion, which is an expression of peptisation and can be measured qualitatively, decreases in descending order following the "Hofmeister series" - Li, Na, K, Mg, Ca, Ba. As the electrolytes are pushed downwards and the carbonate effects of Na become more prominent, the degree of alkalinity increases and the silicate complexes become highly dispersed and hydrolyzed in part. At this point, the soil is, technically speaking, a Solonetz, with the bases in the complex intact. Since Na salts are usually present in the Solonchak and the complex therefore contains some absorbed Na-ions, by virtue of its presence the solonetz takes up its characteristic morphology especially the columnar structure of the B_1 horizon - which of course may also be due to the presence of Mg - Ellis & Caldwell (loc. cit.) - directly or indirectly.

The process outlined above is called solonization and may be regarded as desalinisation plus alkalinisation.

As regards the morphology of a solonetz profile, it is too well known to require elaborate description at this time. In brief, it may be said that the most striking feature of a solonetz morphology is in the B horizon which may be described as follows:-

B_1 horizon - an extremely dense/ clay, impervious sticky when wet, and almost stone-like when dry. The colour is usually darker than any horizon, varying from black to brown. The texture is usually very heavy - with firm angular clods which in the top section appear as rough angular prisms whose vertical axis is three or four times the horizontal, exhibiting the characteristic cracky columnar structure. The columns are generally rounded at top although flat tops were also observed by Nikiforoff as pointed out by Joffe (1949).

The B_2 horizon - generally lighter in colour than the B_1 horizon - has generally a cubic-nutty structure and fairly stratified.

The A horizon as a whole is however of a loose light texture due to mobilisation of clay to the B horizon. Usually the lower portion of this horizon is of a lighter shade than the upper portion, giving an impression of A_2 horizon development. The lowest portion of the A horizon, sometimes designated as A_3, is quite greyish to off-white, forming a thin coating on the caps and moving deep down into the grooves and sides of cracks in between the columns of B_1 horizon. The A_2 horizon is quite often slightly compact and foliated.

Soon after the solonetz profile is formed, begins the third stage in the evolution of saline or hydro-halogenic soils. This is the stage of degradation of the exchange complex, consequent to the removal of soluble salts, i.e. the electrolytes, leading to some distinct changes in the profile - chemically and morphologically. This process of degradation is known as solodisation and the resulting profile is termed as a SOLODI or SOLOD or SOLOTI or SOLOTH.

The evolution of this stage is associated with the hydrologic conditions of the landscape. As more water becomes available for percolation (downward) either because of a change of climate or when the same rainfall becomes more effective because of a change in the movement of salt or improved drainage or gradual seepage through the cracks of the solonetz columns, the hydrolytic action of H_2O sets in after the almost complete removal of the soluble salts. The specificity of the hydrolysis in the Solonetz medium deprived of soluble salts is: (1) high alkalinity resulting from the replacement of Na by H, (2) the increased reactivity of the constituents resulting from the dispersion of the colloids.

As a consequence of the dispersion, the impeded percolation results in a waterlogged condition, with the solid phase changing to the dispersed phase in water as the dispersion medium. Under these conditions, large quantities of organic and mineral constituent go into solution. During wet seasons reducing reactions are conducive to the mobilisation of iron in the ferrous state from the A horizon. The dispersed condition brings about a movement of fine particles into the B horizon.

Soon after the Na-ions are out of exchange complex, and carried downwards, i.e. removed from the A horizon, the pH of the A horizon drops to acidity, and in extreme cases the pH may be below 6, but the reaction of B horizon is maintained on more or less the alkaline side. This marks the onset of solodisation.

Along with the mobilisation of free iron oxide, humus and clay from the A horizon, a breakdown of the clay colloids ensues bringing about a differentiation of SiO_2 and R_2O_3 and subsequent mobilisation of the R_2O_3 from the A to the B horizon, thereby giving a Podsolic appearance to the solod both chemically and partly physically.

It is to be noted that the dispersion of the clay by hydrogen ultimately breaks the caps of columns and as such in a solod the relics of solonetz-columnar structures can only be identified by careful examination.

In solod formation, Mg is released from the surface horizon and accumulates in the lower horizons, particularly with respect to the exchange complex. According to Joffe (1949) Mg content of the exchange complex may also serve as an index of the state of solodisation, being highest in the early stages and diminishing towards the stage of true solodi. The total exchange capacity in the A horizon decreases due to the breakdown of the colloids - inorganic and organic - the capacity increasing with depth.

The morphology of a solod profile can thus be shortly recorded as :-

(a) a darkish A_1 horizon with low organic matter content, granular when dry, occasional rusty spots in A_1 but more frequent in B_1 horizon;

(b) a light grey to ashy grey sandy A_2 horizon, resembling A_2 horizon of Podsols;

(c) a compact B horizon devoid of caps although the columns are retained to an appreciable extent.

It is to be noted that the individual stages as such , as outlined above, in the evolution of hydrohalogenic soils, are very rarely met with. There is always an overlapping of the immediate successor and predecessor stages.

Kellogg (1934), from a study of the solonetz soils of N. Dakota, observes:- "As a matter of fact, one rarely, if ever, finds a solonetz which is not tending either somewhat towards solonchalk or towards soloth. As soon as a solonetz forms it immediately begins to solotise with the development of a profile approaching the soloth".

Joffe (loc. cit.) from a comparative study of the Russian, Hungarian and American reports, concludes - "As a rule, solodi is associated with areas of solonetz and solonetzic-solonchak types".

Kellogg (1947) proposed to classify areas having the evolutionary overlapping as a <u>complex</u>. Thus areas of saline soils showing the marginal overlapping of the different stages of evolution may be regarded as "Hydro-halogenic complex" - which may be a solonchalk-solonetz complex or a solonetz-solodi complex (or may even be a solod-normal climatogenetic complex, because as soon as the vegetation is established after the removal of Na in the solod , the biosphere comes into action again and the solod is eventually transformed into the climatogenetic soil which may be termed as the stage of regeneration or freedom from subdued phase).

Smith (1950) reported an occurrence of a solodized-solonetz soil in W. Australia, following Kellogg's (loc. cit.) definition of such-like soils.

In the light of the above discussion, the Yellow Brown Earths studied under the present investigation may very well be classed as Solodized-Solonetz soils for the following reasons:-

(1) The maintenance of the capped cracky columnar structure in the B_1 horizon of both Y.B.E. 2/LS and Y.B.E. 1/S, the columns being discretely separated from each other by deep converging grooves and cracks filled with sandy materials (a Solonetz character):

(2) Acidic reaction of A horizon, the pH rising with depth attaining alkalinity in the B horizon (a Solod character):

(3) Mobilisation of free iron oxide from A horizon to B horizon (Solodisation):

(4) The exchange complex getting more and more dominated by Mg and Na ions and Ca-ions progressively dropping down with depth and the Mg ions eventually over-running the Ca ions in the exchange complex (Table 12).

The Y.B.E. 1/S however presents a more advanced degree of solodisation than Y.B.E. 2/LS for the following reasons:-

(1) The Y.B.E. 1/S is more acidic than Y.B.E. 2/LS, the pH of the Y.B.E. 1/S being 6.61, 6.33, 6.75 in the A_{1a}, A_{1b} and A_2 horizon respectively as against 6.89 and 7.00 of the A_1 and A_2 horizon of Y.B.E. 2/LS. So also the case with the B_1 and B_2 horizons, in which the pH of the Y.B.E. 1/S is just on thealkaline side (7.02 and 7.96), whereas those in the Y.B.E. 2/LS are (7.78 and 8.76):

(2) The A horizon contains less colloidal material in the Y.B.E. 1/S than in the Y.B.E. 2/LS:

(3) The bleached A_2 horizon is very well developed both morphologically and chemically in the Y.B.E. 1/S, presenting a real Podsolic appearance, whereas in Y.B.E. 2/LS there is just a lightening of colour in the 1 inch thick A_2 horizon and, unlike Y.B.E. 1/S, nitrogen, organic matter and P_2O_5, have not been leached out of the A_2 horizon, i.e. unlike Y.B.E. 1/S no chemical eluviation-illuviation process has taken place in Y.B.E. 2/LS.

(4) Total soluble salts in the A horizon are much higher in the Y.B.E. 2/LS than in Y.B.E. 1/S and in fact about double the amount in the Y.B.E. 1/S.

(5) The exchange complex of Y.B.E. 1/S in the A horizon is more unsaturated than that of the Y.B.E. 2/LS, the figures being 64.42 m.e.% and 74.86 m.e.% respectively.

(6) In Y.B.E. 1/S the free iron oxide in the B_1 horizon is enormously high in comparison to that in the A_2 horizon - the figures being 0.112, 0.060 and (1.063 - 2.018) % in the A_{1b}, A_2 and B_1 (clay-sand-cap - clay) horizon respectively, whereas in the Y.B.E. 2/LS the amounts are 0.763, 0.711 and 1.796% in the A_1, A_2 and B_1 horizon respectively.

(7) The Mg ion in the exchange complex, particularly in the B horizons (B_1, B_2) of the Y.B.E. 1/S, is much lower than the corresponding values of Y.B.E. 2/LS, the Mg ion amounting to 38 and 34% of total metal ions in the B_1 and B_2 horizon respectively in the Y.B.E. 1/S as against 44.8 and 46.7% in the corresponding horizons of Y.B.E. 2/LS. Na-ions also have shown the same trend and may be regarded as an additional information.

To this may be added the results of the chemical analysis of the clay colloids. Owing to scarcity of any systematic published report on the fusion analysis of the saline-soil-clay fractions, a comparison of the results obtained does not seem to be possible at present.

Referring back to Table 14 and the relevant discussion, it may be pointed out that the Y.B.E. 1/S far exceeded Y.B.E. 2/LS in the degradation of the clay colloid, and, as a matter of fact, the trend of the SiO_2/R_2O_3 ratio from A_2 to B horizon of the Y.B.E. 1/S is clearly podsolic, whereas in the Y.B.E. 2/LS the degradation seems to have just started as the SiO_2/R_2O_3 ratios from A_2 to B_2 horizons are 2.24, 2.16 and 2.17 respectively. That the degradation is on the move is indicated by the higher SiO_2/Al_2O_3 ratio of the A_2 horizon than that of the B_1 or B_2 horizon; this is also more pronounced in the Y.B.E. 1/S than in the Y.B.E. 2/LS.

The Al_2O_3/Fe_2O_3 of the A_2 horizon in the Y.B.E. 1/S is greater than that in the Y.B.E. 2/LS, showing a greater mobilisation of Fe_2O_3 in the former than in the latter, indicating the more advanced stage of solodisation in the former than in the latter.

Thus the weight of evidence strongly suggests both from chemical and morphological considerations that the Yellow Brown Earths studied hereunder may be regarded, following Kellogg (1947) and Smith (1950), as solodized-solonetz soils. The Y.B.E. 1/S is in a more advanced stage of solodisation, i.e. a more advanced stage than the Y.B.E. 2/LS in the way of getting onto the Solod state.

At this moment it seems desirable to recall the P 1/S which has been sought to be provisionally classified as a podsolised soil with particular reference to the chemical and mineralogical composition of the clay fraction - of course keeping an eye on the morphology too. But nonetheless a doubt was cast on its genesis because of the presence of a rudimentary columnar tendency exhibited by vertical cracks in the B_1 horizon.

The capless vertical cracks, in the light of the preceding discussion on the hydrohalogenic soils, suggests that the P 1/S is possibly a solod, which can very well exhibit a podsolic character chemically and morphologically (excepting of course the structure of the B_1 horizon). And in fact there is no essential difference between the Y.B.E. 1/S and the P 1/S excepting that the P 1/S has ~~got~~ not a capped column in its morphology. The chemical analyses too show exactly the same trend in the eluviation-illuviation process with the difference that the trend is a bit more pronounced in the P 1/S than that in the Y.B.E. 1/S. This was certainly to be expected because a solod is a step further in the course of degradation than a solodised-solonetz soil. Thus it seems safer to call the P 1/S as a solod rather than as a podsolic soil.

EVOLUTION OF THE SOIL GROUPS STUDIED.

Summing up the discussion, it may be said that -

(a) the Red Brown Earths studied in the present investigation, by virtue of their parentage and their agreement - morphological and chemical - with the Red Brown Earths studied by Piper (1938), have been, following Prescott (1947) and Stephens (1950), classed as Red Brown Earths;

(b) the Black Earths studied from morphological and chemical properties proceed on to the RENDZINA group without any trouble;

(c) the Yellow Brown Earths, by virtue of mainly the morphological features and also the ex-change complex in relation to the cations, have chosen to be within the solodised-solonetz grouping;

(d) the P 1/S, although by virtue of its ashy grey A_2 horizon and freedom from lime and also all the chemical characteristics excepting of course the pH, gave the impression of a podsolic soil, but the structure of the B_1 horizon called for a second consideration and the P 1/S eventually preferred the call of a SOLOD.

Having had the above grouping, it is now to be seen as to how these groups have originated, as such, in the valley as described in Chapter I.

The very co-occurrence of a group of calcimorphic soils with the halogenic soils and more especially the presence of lime in the halogenic profiles (especially the Y.B.E. 2/LS) in the portion of the Barossa Valley under investigation, hardly leaves any room to overemphasize the complexity of the origin and development of the Barossa soils. The presence of the sequence of hydrohalogenesis in the Yellow Brown Earths and P 1/S, i.e. a sequence from weakly solodised solonetz to solod does clearly speak for a previous invasion of salt in these soils, which could only be possible by the accumulation of salt at some previous date. And the accumulation must have been enough to bring about the solonisation. The questions naturally arise from where is the salt ~~is~~ to originate and how is it to accumulate. The salt may originate geologically or it may gain access through the agency of rain (Teakle 1937). Whatever might be the origin, the salt has to accumulate, i.e. stay for some time to invade the clay fractions. While the accumulation of cyclic salt may be possible under favourable microtopographic and drainage conditions, the occurrence of halogenic soils, irrespective of drainage and topographic variability in the valley, certainly calls for some other explanation. In other words, one has to visualize two things - (1) indiscriminate presence of salt in the initial state of all the soils of the valley, (2) climatic conditions favourable for accumulation of salt to initiate the invasion wherever free from opposing force, i.e. lime.

As regards class (1), the very history of the development of the Barossa Valley as outlined in the earlier chapter, i.e. emergence from beneath the tertiary sea as a fault basin holding in the brackish sea water, i.e. assuming the form of a 'Lake' maintained by the ancestral salt water and eventual draining off and drying of the lake, very clearly accounts for an indiscriminate general distribution of salt all over the valley, although preferentially higher accumulation could reasonably be expected towards the central flat area and also in local depressions.

Now the salt has come, the next question is how is it going to accumulate. Because, if it drains away, it could not possibly initiate halogenesis, particularly when lime too is there in the initial states. This suggests that there must have been an arid or semiarid climate at some time past, i.e. a climate certainly drier than what it is now, as the present climate, as discussed previously, is in no case in favour of salt accumulation. That there has been an intervention of an arid cycle in some recent past seems quite an accepted theory, not only for South Australia, but also for the Continent as a whole. The works and discussion of Crocker (1946), Crocker & Wood (1947), Browne (1945), Whitehouse (1940), amply speak for the above remark. However, to quote a few lines from the aforesaid authors: " .... nevertheless it accords best with the known facts to postulate that the cold, moist climate of the pleistocene gave place after the melting of the glaciers to an extreme and almost continent-wide aridity, from which Australia has not yet recovered." — Browne (Presidential address, Linnean Soc., N.S.W. 1945) who further observed: "It is to this arid interval that we must assign the drying up of the great lakes and rivers of the interior." Crocker (1946), discussing the post-miocene climate, observes: "The most important paleopedological influences have been, ...(3) a severe post-glacial arid period." Crocker & Wood (1947) observe: "There is strong evidence therefore to indicate that higher temperatures than those prevailing at present occurred in South Australia a very short time ago, and these were probably coincident with the lower rainfall of the period." The authors further observe: " (1) Preceding the onset of aridity climatic conditions were much more humid than at present; (2) Subsequent to the maximum aridity there was an increase in rainfall, though not of a high order and indeed very small by comparison with the preceding decrease - otherwise gypsum and lime accumulations of the drier period would have been entirely removed in solution." Whitehouse (1940) in Queensland has also made an exactly similar comment and indeed the works of Whitehouse (1940) seem to be pioneering in the understanding of post-miocene climate in Australia.

It has been suggested that the arid period occurred: "probably much less than 9000 years ago" - Crocker (loc. cit.) - in South Australia; and later studies of Crocker & Wood (loc. cit.) on paleo-ecological evidence too suggest a very recent age for the effects of maximum aridity. Browne (loc. cit.) in his scheme of the tentative post-tertiary chronology of the Commonwealth of Australia suggested the Recent Period to be divided as follows:-

Recent → Earlier recent (5000 years). → Climate-hot and dry, general desiccation, arid conditions except in narrow coastal belts.
Recent → Mid-recent Interval. → Onset of cooler and wetter conditions.
Recent → Later recent (4000 years). → More or less as at present, minor oscillations of temperature and rainfall.

However, whatever be the age of the period of maximum aridity - a more detailed discussion of which is obviously beyond the scope of the present work - it can be safely said that there has been an arid period in the recent past which has eventually brought about the deposition and accumulation of salt all over the valley in varying degree depending on the topography.

Now begins the main story of the Barossa soils studied. Referring to Table 9 and the relevant interpretation, it is to be noted that all the soils studied had lime in their initial state, as was to be expected in the light of the geological discussion given in Chapter I. But it is interesting in that the P 1/S (Solod) and the Y.B.E. 1/S (Solodised-solonetz) had practically negligible quantity of lime in the initial states - the amounts being roughly .02% and .05% respectively. Thus these soils would be expected to fall easy prey to the attack of Na and Mg and start salinisation straight away. Then on the history of their evolution might be depicted as follows:-

With the onset of the wetter conditions in the mid-recent period - Browne (loc. cit.)-the salts were brought into circulation to bring about an effective modelling of the exchange complex, depending on the nature and composition of the salts present. In other words, the exchange complex was charged with dominantly Na and probably also with notable amounts of Mg, as the analytical data on total soluble salts and chlorides of the Barossa Soils studied invariably show dominance of salts other than NaCl (Table 10), particularly in deeper horizons, signifying thereby the presence of Mg-salts too in appreciable amount in the initial state. But as long as the soluble salts, i.e. electrolytes, were in circulation, the soils were still a solonchak.

chloride
only
determined
not NaCl

With the further gradual advance of wet conditions - so as to be sufficient for removing the soluble salts from the soil horizons - the electrolytes started leaving the A horizon, without however affecting the exchange complex in any way. As soon as the excess soluble salts were pushed down to the lower horizons, the colloids started peptisation, due to hydrolysis of Na (which of course later forms Na_2CO_3), and mobilisation from the upper to the lower horizons - the theoretically solonetzitic stage, i.e. the stage of desalinisation and alkalinisation. At this stage came the full fledged expression of the solonetz with its columns in the B_1 horizon, only to restrict the free percolation of soil solution. With ageing however the development of cracks on the prisms of the B_1 horizon brought about a slow seepage of the soil solution to effect further removal of the electrolytes and especially the Na_2CO_3 formed during solonisation - finally to start the degradation of the clay complex as a result of hydrolytic action of H_2O - the stage of solodisation.

As soon as the solodisation started with all its degrading effects as discussed earlier, the Y.B.E. 1/S and P 1/S gradually took up a podzolic appearance particularly in the A_2 horizon and also in the chemical characteristics.

Now the question is - why the P 1/S reveals a rather true solod morphology as against the solodised-solonetz morphology of Y.B.E. 1/S.

This is possibly due to a difference in the local hydrological conditions, induced by proximity of the water table in the Y.B.E. 1/S and the texture of the initial states of the two soils.

That the texture of the parent material of the P 1/S (Solod) was much lighter than that of the Y.B.E. 1/S parent has been shown in Table 9 as the mean clay contents of the P 1/S and Y.B.E. 1/S down to 35 inches are respectively 18% and 28%. This would certainly have afforded a better internal drainage to P 1/S, thereby hastening the solodisation in P 1/S. The much lower amount of soluble salts and chloride (Table 10) in the lower horizons of P 1/S than that of Y.B.E. 1/S offers evidence to the much superior internal drainage of the P 1/S.

That the Y.B.E. 1/S has a high water table, to permit of a free upward reach of the saline water to oppose a steady and unimpaired degradation of the solonetz structure, could be visualised from the variously mottled - particularly in greys, blues with black inclusions - clay in the B_2 horizon to downwards. The higher amounts of chlorides and soluble salts in the B horizon of Y.B.E. 1/S, in comparison with that in the P 1/S (Table 10), may also speak for a high water table in Y.B.E. 1/S so as to retard the quick degradation of the solonetz structure by maintaining an intermittent saline washing on the degrading solonetz.

To this may also be added the geomorphic situation; the P 1/S (solod), being situated on the shore line of the pre-existing lake - Hossfeld (priv. comm.), might reasonably have had much lower amounts of salt deposition and as such got rid of the salt much quicker than those lying lower in the valley.

Fourthly, the rainwater is continuously supplying NaCl - Teakle (1937) -; the Y.B.E. 1/S having the column still retained, the distinct possibility of of reintroduction of Na on the colloids is there, because of the impeded drainage and all the more so because of the possible existence of a perched water table during the wet seasons.

Thus the hydrological condition induced by the internal drainage and water table,coupled with the possible higher amount of salt in the initial state of the Y.B.E. 1/S, has brought about the retardation in the degradation of the solonetz feature, whereas,due to the conditions all being favourable to the P 1/S, it got the chance of going on to the solod stage quickly.

Now about the Y.B.E. 2/S, which seems to be just a weakly solodised solonetz. The characteristic features of this soil are:-

(a) occurrence in a relatively <u>lower lying flat</u> or <u>rather in local depressions</u>, surrounded by Y.B.E. 1/S (solodized-solonetz) and R.B.E. 2/ on the higher level or rather on the edge. The whole area of this complex association has a high water table and especially so for Y.B.E. 2/S as evidenced by the greenish mottlings of the B_2 horizon clay (Joffe 1949);

(b) presence of CO_3 as high as 10.6% in the initial state - a fact which is apparently throwing much troubled water as the R.B.E. 1/SL seems to have had only 1.1% CO_3 in the initial state (Table 9).

However, by virtue of the microtopography of the Y.B.E. 2/LS, it no doubt has been receiving all the surface drainage from the adjoining areas and hence has been having a constant saline wash internally. Secondly, because of the depression, the Y.B.E. 2/LS spot could be reasonably expected to have had a higher amount of salt in the initial state, particularly when the Y.B.E. 2/LS occurrence has taken place in the central portion of the valley.

It might be suggested that the Y.B.E. 2/LS had started halogenesis much later than its co-geners and hence is the delaying of the subsequent stages of genesis in the Y.B.E. 2/LS. It seems reasonable to hold that the Y.B.E. 2/LS had to wait till such time as lime cleared out but the trouble arises in that by the time lime cleared out the soluble salts too should have cleared out. While the counter-argument is quite logical, this should not necessarily mean that lime will not move down at all till such time as all the soluble salts, however great the amount might be, have moved down. And in fact, from microtopographic considerations, a very high salt deposit could possibly be expected in the spots of Y.B.E. 2/LS occurrence, and hence an ultimate balance, however little, of salts in these spots could possibly be expected.

Even if the salts completely moved down before the lime, there is another factor still in operation, and that is the accession of cyclic salt (Teakle 1937) continuously by rain in the soil body. By reason of its Topographic Situation, it has been getting saline run down from the adjoining areas, in addition to what it received itself through rain, and all the accessions of salt had to trickle through its body which has eventually brought about the solonisation. This delay in start is possibly the reason of its relative youthfulness amongst its co-geners.

The high water table, maintaining an almost permenant saline washing in the B horizon, is possibly another opposition to a fast advancement of degradation.

Thus it seems that the halogenesis in the Barossa Valley exhibiting different stages from weakly solodized solonets to solod quite reasonably lends itself to the interplay of an halomorphic and calcimorphic element started probably about 5000 years ago, and subsequently modified by local hydrological and topographical elements and also the initial textural elements.

Before closing up the discussion of the halogenic activities, it might not be out of place to mention that the Biosphere element also seems to have started to play its part. This is seen in the P 1/S, particularly, wherein, due to intervention of the human element and also due to establishment of savannah woodland, a process of regeneration seems to have started in the solod as evidenced by its neutral reaction, restitution of Ca in the exchange complex of all the horizons at the expense of Na and also Mg (Table 12). And it might not be too much to say that in course of time the P 1/S will probably get rid of halogenic relics and will seek for a podsolic status - a view also held by Ellis and Caldwell (1935) - and in fact, but for the solodic structure of B_1 horizon, the P 1/S could be safely disposed of to the podsolic group - from chemical, physical and also mineralogical considerations (as will be seen later).

The Red Brown Earths have gained their distinctiveness possibly due to the drainage condition as a result of high Ca-saturation and very low amount of Na-ion in the exchange complex, probably due to the relatively dominating amount of calcium in the initial state.

Judging individually, the R.B.E. 1/SL has a good external and internal drainage, thereby precluding the possibility of any accumulation of salt anywhere in the profile to bring about solonisation. The presence of very little amount of lime 1.1% in the initial state suggests that the soil to start with possibly did not have much of salt to seriously interfere with the subsequent development.

The R.B.E. 2/ have good surface drainage but fair internal drainage, but, due to the high amount of lime in the initial state, the quantities being 20.7% and 29.4% for the R.B.E. 2/SL and R.B.E. 2/SCL respectively, the salt invasion could not interfere with their normal development. And, once the salt was out of effect, it was away for good as the chance of accumulation was and is practically nil under the advancing wetness and the present wetness, respectively.

The characteristic red toning on the brown colouring of the clay seems to be due to good aeration condition to facilitate oxidation and ageing (Joffe 1949) of iron; whereas the yellow toning in the Yellow Brown Earths is probably due to the prevalence of a reduced condition of the iron held in an ~~inhibited~~ imbibed state in the soil moisture. That the yellowing is due to the lower state of oxidation of iron could be visualised from the fact that the yellow toning is met with as soon as the impervious, and occasionally waterlogged, clay horizon of the Yellow Brown Earths is reached but not before that.

Thus it seems the presence of lime in the initial state, coupled with good drainage condition, has brought about the distinctive genesis and morphology of the Red Brown Earths.

In this connection, it may not be too much to say that, had the Y.B.E. 2/LS been situated as the surrounding R.B.E. 2/ in microtopographic consideration, the Y.B.E. 2/LS would probably express itself as a Red Brown Earth. And in fact, excepting the solonetzitic structure and the relative proportions of the exchangeable ions, which are seemingly induced by the microtopography, there is hardly any significant difference between the R.B.E. 2/ and Y.B.E. 2/LS.

As far as the Black Earths (Rendzina) are concerned, the governing force seems to be the nature and abundance of lime in the initial state -

wherein the lime content as shown (Table 9) and discussed previously is decidedly the highest amongst those of all the groups studied. Secondly, the nature of the lime was shown to be very soft as against the hard nature of lime in the cases of other soils studied.

The drainage condition too is moderately good, both internally and externally, to preclude any salt accumulation anywhere.

Thus the nature and abundance of lime in the initial state, coupled with the moderately good drainage, are the responsible factors of Rendzina formation.

The dark grey to black colour of the surface is due to the presence of humus as shown before, either as a Ca-saturated organic colloid or possibly in combination with free iron oxide as suggested before, or both, in conjunction with humic acid.

The 100% (Table 12) base saturation of the colloids has been exerting a buffering action against any textural differentiation of the profiles and hence is the distinctive morphology.

Thus in the light of the preceding discussion, it may be said that the soils of the Barossa Valley under the investigation seem to clearly tie themselves up with the geologic history and deposits, climatic history and evolution, micro and macro relief (including hydrology), and also human interference and phytosphere of the Valley.

CHAPTER III.

LABORATORY INVESTIGATIONS (MINERALOGICAL).

STUDY OF THE CLAY MINERALS.

(A) Review and general discussion.

The term clay, by virtue of its wide usage amongst the workers of various branches of scientific discipline, has assumed several shades of implication. The chemists, mineralogists, ceramists and soils men have taken up the study of clay to meet their individual diverse problems, but nonetheless the fundamental properties of the clay minerals are practically of the same order of importance to all the scientists whatever their branch of study may be.

Clay, as designated by the Committee on Sedimentation of the National Research Council and by a Committee of the American Ceramic Society, carries with it three meanings (Joffe 1949):-

(1) a natural material with plastic properties;

(2) an essential composition of particles of very fine size grades;

(3) an essential composition of crystalline fragments of minerals that are mainly hydrous aluminium silicates or occasionally hydrous magnesium silicates.

To a mineralogist, clay connotes a group of minerals, and, according to Grim (1942) clay minerals are hydrous aluminium silicates frequently with some replacement of the aluminium by iron and magnesium and with small amounts of alkalies and alkaline-earths. In rare instances Mg and Fe completely replace Al.

A soils man however uses the term to designate a mechanical separate of 0.002 mm. or less in diameter, i.e. a colloidal material, which is mainly responsible for practically all the chemical, physico-chemical and morphological properties of a soil body.

The earlier writers on soils, in discussing the nature of the clay, generally assumed it to be an amorphous gel. It was in 1928 when Powell, as pointed out by Robinson (1949), questioned the validity of the above assumption and gave a definite hint to the crystalline nature of clay.

Ross (1928) by X-ray studies on clays demonstrated the crystalline structure of certain clays and also identified some definite minerals as common constituents of clays.

Hendricks and Fry (1930) by the application of the X-ray method confirmed the crystalline nature of the clay colloids. A very significant fact that emerged out of the works of Hendricks and Fry (loc. cit.) was that the primary soil minerals such as felspars and micas were not found among the crystalline material of the colloid fraction, which suggests that the lower limit of their physical subdivision lies above the limit (0.001 mm.) which demarcates the colloidal material for this work.

Marshall (1930) from a study of the double-refraction properties of certain clays gave further evidence to the crystalline nature of clays. He further showed that the monovalent and divalent positive ions can occupy definite positions within the crystal structure too. From ultra-microscopic studies he concluded that for a given clay each cationic clay has a characteristic degree of dispersion.

Kelley and associates (1931), by comparing the X-ray patterns of potash bentonites and of some clay colloids, added to the evidence of crystalline nature of clay.

With the advancement of X-ray and other associated techniques for soil colloid studies, the crystalline nature of clay gained unquestioning acceptance.

But until recently the complexity and heterogeneity of the clay minerals was not fully appreciated. If the X-ray or other evidence indicated the presence of montmorillonitic clay, the conclusion was that the soil was a montmorillonitic one, and if the evidence was strong enough for kaolinite the soil was noted as kaolinitic. During the last twelve years, the problem was recognised in its true perspective and weight of later evidence shows that the matter is not just as simple as to designate the soils as kaolinitic or montmorillonitic. Evidence that mixtures of different clay are common in soils has now become convincing. It is now well established that two or more kinds of clay minerals are present in the vast majority of soils. In certain soil types one type of clay may greatly predominate over other types, but just a simple single type of clay has rarely been found yet in a soil. In this connection, mention may be made of the contribution of, among others, Alexander and associates (1939), Kelley and associates (1939), Russell and Haddock (1940), Nagelschmidt and associates (1940), Coleman and Jackson (1945), Jackson and Hellman (1941). As pointed out by Kelley (1948), evidence that mixtures of different types of clay are common in clays has now become convincing. Special reference to this contention may be made to Joffe's (1949) compilation regarding the paragenetic association of the minerals of the principal soil types (after Sedletskii).

During recent years, a good amount of work has been carried out on the actual crystal structure and associated properties of clay minerals. Following the ideas of Pauling (1930, 1940), Goldschmidt (1937) and others based on the Theories of Bragg (1937), it may be said that the clay minerals have crystal lattices built of successive layers of linked atoms. Two such types of layer have been recognised:- (1) the silica layer and (2) the gibbsite layer.

The units of clay minerals are formed by the condensation of the aforesaid layers to give rise to two types of minerals -

(a) the Bi-layer or two-layer or Si-Al type;
(b) the Tri-layer or three-layer or Si-Al-Si type.

The clay minerals falling under the two-layer type or "Si-Al" type embrace the kaolin group with the general formula Al_2O_3 SiO_2 x H_2O. Within this group are distinguished three sub-groups:- (I) the kaolinites, corresponding to Al_2O_3 2 SiO_2 2 H_2O; (II) the anauxites, which are similar to kaolinites but with SiO_2/Al_2O_3 ratio > 2; (III) the hydrated halloysite of the formula Al_2O_3 2 SiO_2 4 H_2O. To soils men kaolinite is of the greatest importance amongst the kaolin sub-groups. The Si/Al ratio varies from 1.8 to 2.1 in different members, owing to limited isomorphous replacement of Al^{+++} by Fe^{+++} and $Si^{++++}$by Al^{+++}. The lattice structure of kaolinite does not expand with varying amounts of H_2O and as such it has a low cation exchange capacity (10 - 15 m.e. %: Kelley (loc. cit.)).

Under the three-layer type or Si-Al-Si type of lattice come the -

(a) pyrophyllite-montmorillonite group;
(b) hydrous mica or illite group;
(c) palygorskite group.

(a) Amongst the three-layer minerals, those under group (a) have been studied most extensively indeed by various workers such as Hofmann and associates (1933), who suggested its probable composition as $(OH)_4Al_4Si_8O_{20}$ x H_2O; Caldwell and Marshall (1942), who studied the Mg substituted mineral (saponite) and Fe substituted mineral (notronite); Hendricks and associates (1940), who studied the swelling properties and interlayer spacings of montmorillonite; Ross & Hendricks (1945), who gave a very thorough discussion of the minerals of the montmorillonite group, their origin, relation to soils and clays; Ross & Kerr (1931) made a particular study of beidellite with special reference to $SiO_2 : Al_2O_3$ ratio; Grim (1942) presented a comprehensive discussion of montmorillonite and also all other clay minerals with reference to their various properties. In a nutshell, it may be indicated that SiO_2/R_2O_3 ratio in this group varies from 3 to slightly less than 4 and a cation exchange capacity of 90-110 m.e. %. This high exchange capacity, and in fact the highest known amongst clay minerals, of this group and particularly of montmorillonite, is said to be due to its expanding lattice. However, for the present investigation, the minerals under group (b), i.e. the "Illite" group, deserves more attention, as this is the one which was found, in combination with kaolinite, as will be seen later, by X-ray analysis in the clays examined in the present study.

(b) The term "Illite" is due to Grim and associates (1937), who, after discussing the various synonymous terms of hydrous mica and their implications, finally proposed this term after the name of the State (Illinois) where the mineral was studied by them. According to Grim and associates (loc. cit.), the illite structure is similar to that of montmorillonite except that 15% of Si^{++++} positions are replaced by Al^{+++} and the resulting deficiency in positive ions is satisfied by K^+ ions between the SiO_2 sheets of two successive unit cells.

Computing on the basis of the analyses of the purest available samples, Grim and associates (loc. cit.) proposed the formula for 'Illite' as 2 K_2O, 3 MO. 8 R_2O_3. 24 SiO_2, 12 H_2O - although they have left the formula open to modification from future additional analyses.

The SiO_2/R_2O_3 of Illite is about 3 and the cation exchange capacity, as suggested by Grim and associates (loc. cit.), is 20-40 m.e. %, but Endell and associates (1935) assigned a value of 50 m.e. % to Glimmerton, which is admitted by Grim and associates (loc. cit.) to be similar to Illite. And a cation exchange capacity of 50 m.e. % would be no wonder for Illite if the particle size is small enough as was hinted at by Grim and associates (loc. cit.).

An inspection of the K_2O content of Illite from the chemical data presented by various workers including Grim and associates (loc. cit.) seems quite a reliable index of Illite. The K_2O content of pure Illite as is evidenced by the available data swings round about 6.5% (on ignited samples).

By whom carried out?

(B) Report on the X-ray Analyses.

While the clay minerals as such have been quite considerably studied, very little work has been done on the mode of weathering of minerals in different soil types and in the soil profile. Most of the studies have been made on minerals isolated from native rocks with no direct reference to the soil. The information at present available is only of a preliminary character, and, to reproduce the words of Robinson (1949) - "One of the principal tasks in the future is the survey of clay minerals of the principal world groups and subgroups of soils". It was only in 1945 that an attempt in this line was made by Sedelstkii, whose mineralogical work on profile basis covering almost all the major groups of Russian soils - as compiled by Joffe (1949) - is well worth referring to. But the results of his investigation do not show the relative proportions of the different minerals and the distribution thereof on natural horizon basis (excepting the podsols and yellow earths which were studied on horizon basis).

The present investigation, under the circumstances, was aimed at making a systematic study of the nature, composition, relative proportion and distribution of the clay minerals in the types and groups of soils covered by the present study.

The results of the X-ray analysis on the clay minerals as presented in Table 19 show that -

(a) As was to be expected the clay minerals in the soils, irrespective of horizon, type or group, are present as combinations mainly of illite and kaolinite in varying proportions, except in one sample in the BL.E(B) where in the deepest sample (90-108") montmorillonite also made its appearance.

(b) The A horizon clay of all the soils excepting the Black Earths (which have been grouped under the Rendzina) has, in addition to the clay minerals (illite and kaolinite), shown some quartz too (varying from $< 10\% - 20\%$).

(c) The relative proportion of illite to kaolin in the Black Earth clay is the highest of all the groups studied, and lowest in the P 1/S which was regarded as a Solod, and intermediary in the Red Brown Earths and Yellow Brown Earths (solodized-solonetz).

(d) In the Black Earths or Rendzina soils, the vertical distribution of the relative proportion of illite to kaolinite is constant and the most noteworthy feature is the presence of a very little amount of kaolin and hence the clay minerals might possibly be regarded as rather pure samples of illite allowing for occurrence-under-field-conditions.

(e) In the P 1/S (Solod) clay fractions the illite : kaolin ratio in the A_2 horizon is 50 : 50; in B_1 horizon, 40 : 60; and in the B_2, 30 : 70, i.e. the kaolin starts as equal to illite in A_2 horizon and over-runs the illite content in the B horizon, thereby presenting the whole profile as dominantly kaolinitic as against the Rendzina profiles which are mainly illitic.

(f) In the Red Brown Earths the clay minerals, although dominantly illitic all through the profiles, have shown kaolin constituting a substantial amount. In the A horizon the illite : kaolin ratio is 70 : 30 in all the types with the distinct tendency of a comparative rise in the kaolin content and a corresponding fall in illite content with depth, as in the B horizon illite : kaolin ratio assumes 60 : 40.

(g) In the Yellow Brown Earths (Solodised-Solonetz) the illite : kaolin ratio trend with depth follows the same line as in the Red Brown Earths with the difference that in the Y.B.E. 1/S, which have shown a more advanced stage on the way to Solod (as indicated previously), the illite : kaolin ratio in the A_2 horizon has assumed 60 : 40, showing more kaolinisation than that in the Y.B.E. 2/LS (illite : kaolin = 70 : 30) which was previously shown to be just stepping towards a Solod, indicating thereby that the more the degradation of the clay complex, the more is the kaolinisation - which may be due to the formation of new minerals or may be just due to the breakdown of tri-layer ones giving way to the comparative rise in the bi-layer ones.

(h) The Illite in almost all cases is hydrated to a more or less extent - what it is due to seems rather hard to say, as the hydration of illite does not seem to correlate with the field hydrological conditions very well.

TABLE 19.

X-RAY CRYSTALLOGRAPHIC REPORT ON CLAY MINERALS.

Soil Type.	Clay Number.	Depth in Inches.	Horizon.	The minerals and their relative proportions.
R.B.E. 1/SL	15146	9 - 11	A_{2b}	Illite + Kaolin (70 : 30), Quartz 10% approx. Illite partly hydrated.
	47	12 - 27	B_1	Illite + Kaolin + Goethite. Illite partly hydrated, more than that in 15146.
	48	31 - 48	B_2	Illite + Kaolin + little Goethite (Illite more hydrated than 15147).
R.B.E. 2/SL	15151	3½ - 4½	A_2	Illite + Kaolin (70 : 30), possibly another mineral with line 10 Å, Quartz 10%.
	52	5½ - 13	B_1	Illite + Kaolin (2 : 1), small amounts of Goethite.
	53	13 - 17	B_{2a}	Illite + Kaolin (70 : 30). Illite hydrated.
R.B.E. 2/SCL.	15156	0 - 3	A_1	Illite + Kaolin (70 : 30), several % quartz.
	57	5 - 9½	B_1	Illite + Kaolinite (60 : 40) + a little Goethite. Illite partly hydrated.
	58	12 - 14	B_{2a}	Illite + Kaolin (60 : 40) + Goethite (more than in 15157). Illite partly hydrated.

TABLE 19 (Ctd.)

X-RAY CRYSTALLOGRAPHIC REPORT ON CLAY MINERALS.

Soil Type.	Clay Number.	Depth in Inches.	Horizon.	The minerals and their relative proportions.
Y.B.E. 1/S	15163	6 - 12	A_2	Illite + Kaolin (60 : 40), Quartz 20%. Illite a little hydrated.
	65	13 - 22	B_1	Illite + Kaolin + Goethite (15%) + very little Quartz. Illite hydrated.
	66	26 - 38	B_2	Illite + Kaolin (60 : 40), + Calcite. Illite hydrated.
Y.B.E. 2/LS	15170	4 - 5	A_2	Illite + Kaolin (70 : 30) + Quartz several per cent. Illite hydrated.
	71	5 - 15	B_1	Illite + Kaolin (60 : 40). Illite hydrated.
	73	22 - 30	B_2	Illite + Kaolin (60 : 40) + a little Goethite. Illite hydrated.
P 1/S	15178	$8\frac{1}{2}$ - 14	A_2	Illite + Kaolin (50 : 50). Quartz (20%).
	79	16 - 21	B_1	Illite + Kaolin (40 : 60). Illite partly hydrated.
	80	22 - 39	B_2	Illite + Kaolin (30 : 70). Illite hydrated.

TABLE 19 (Ctd.)

X-RAY CRYSTALLOGRAPHIC REPORT ON CLAY MINERALS.

Soil Type.	Clay Number.	Depth in Inches.	Horizon.	The minerals and their relative proportions.
Black Earth BL.E(A).	15758	0 - 7	-	Mainly hydrated Illite (highly hydrated - about 0.5) a little Kaolin and a little Illite.
	59	9½ - 15½	-	Same as above.
	60	20 - 29	-	Same as above + Calcite.
	61	38 - 60	-	Same as 15760.
Black Earth BL.E(B).	15763	0 - 3½	-	Same as 15758.
	64	3½ - 6½	-	Same as above.
	65	7½ - 14	-	Same as above.
	66	15 - 28	-	Same as above + Calcite.
	68	90 - 108	-	Montmorillonite + little Illite + little Kaolin + Dolomite.

Analyses conducted by Mr. K. Norrish (an Officer of the C.S.I.R.O. Soils Division, stationed at the Waite Institute, Adelaide).

(C) Pedological Significance.

Regarding the pedological significance of clay mineral studies, although the information available heretofore hardly permits any critical discussion, nonetheless it does allow certain general statements to be made particularly in keeping with the chemical data on the clay minerals and the works of Sedeltskii as compiled by Joffe (1949) and also some American works which will be referred to in due course.

Because of the fact that the cation-exchange material of soil is not merely a finely comminuted igneous rock material but is one or another of a few products which are bearing the brunt of geologic and pedogenic processes which came into play for its formation, the SiO_2/R_2O_3 ratio should afford a significant distinction between the relative abundance of the two-layer and three-layer minerals so as to throw some light on the pedogenic significance of the clay minerals especially in soil classification and also in plant and animal nutrition.

In consideration of $SiO_2 : R_2O_3$ ratio, the clay minerals can be divided into two classes:-

(1) The Si-Al-Si or three-layer minerals, i.e. the illites and montmorillonites, with a SiO_2/R_2O_3 ratio of about 3 to 4.

(2) The Si-Al or two-layer minerals, i.e. the kaolins with SiO_2/R_2O_3 ratio of round about 2.

But in actual practice in the clay separates of different soils, it is hardly possible to get a clear-cut demarcation because as pointed out before the bi-layer and tri-layer minerals occur together in the same sample. We can nevertheless conceive of the facts that - (a) the more siliceous the clay the more would be the dominance of the tri-layer mineral; (b) the more sesquioxidic the clay the more would be the dominance of the bi-layer minerals. The index of siliceousness however is to be assumed to be a value of 2 (although provisional) for $SiO_2 : R_2O_3$ ratio of the clays.

The present investigation clearly justifies the above conception as the clay minerals of the Black Earths (Rendzina) which are of the highest $SiO_2 : R_2O_3$ ratio and highest SiO_2/Al_2O_3 ratio are also mainly illitic.

Again considering the vertical distribution in the P 1/S, the deeper the horizon the less is the siliceous nature, i.e. the more is the sesquioxidic nature, and this is accompanied by a gradual and sharp dominance of kaolinite with depth. Secondly, looking group by group as the relative proportion of illite comes down, the clay also becomes less siliceous and more sesquioxidic. This has been brought forward in Table 20.

An examination of Table 20 further shows that, while the Rendzina and Red Brown Earths show a pretty good relationship between the $SiO_2 : R_2O_3$ ratio and the relative abundance of bi-layer and tri-layer minerals in the clay, i.e. the more the clay is relatively rich in the tri-layer mineral (illite) the higher is the $SiO_2 : R_2O_3$ ratio, the halogenic soils with the advent of solodisation seem to disobey the above principle, thereby sounding

TABLE 20.

RELATIONSHIP BETWEEN THE NATURE OF CLAY MINERALS AND SiO_2/R_2O_3* RATIO OF THE CLAY.

Genetic type.	Soil type.	Horizon.	Illite : Kaolin.	$SiO_2/Fe_2O_3+Al_2O_3$
Red Brown Earths	R.B.E. 1/SL	(A_{2b}	(70 : 30	2.26)
		(B_1	(not certain	2.13)
		(B_2	(not certain	2.22)
	R.B.E. 2/SL	(A_2	(70 : 30	2.30)
		(B_1	(2 : 1	2.17)
		(B_{2a}	(70 : 30	2.20)
	R.B.E. 2/SCL	(A_1	(70 : 30	2.21)
		(B_1	(60 : 40	2.19)
		(B_{2a}	(60 : 40	2.24)
Rendzina	BL.E(A)	(0 - 7"	(Mainly illite, a little kaolin.	3.05)
		(9½ - 15½"	(" "	3.00)
		(20 - 29"	(" "	3.15)
		(38 - 60"	(" "	-)
	BL.E(B)	(0 - 3½"	(Mainly illite, a little kaolin.	3.02)
		(3½ - 6½"	(" "	-)
		(7½ - 14"	(" "	-)
		(15 - 28"	(" "	3.16)
		(90 - 108"	(Montmorillonite, little illite + little kaolin.	3.07)
Solonetz-Solodi Complex.	Y.B.E. 2/LS	(A_2	(70 : 30	2.24)
		(B_1	(60 : 40	2.16)
		(B_2	(60 : 40	2.17)
	Y.B.E. 1/S	(A_2	(60 : 40	2.65)
		(B_1	(not certain	1.95)
		(B_2	(60 : 40	1.90)
Solodi	P 1/S	(A_2	(50 : 50	2.78)
		(B_1	(40 : 60	1.95)
		(B_2	(30 : 70	1.93)

* R_2O_3 - Stands for $Fe_2O_3 + Al_2O_3$.

a note of warning against too liberal an application of the $SiO_2 : R_2O_3$ ratio as an index of the mineralogical nature of the clay. Because in the Y.B.E. 2/LS which is just stepping to solodisation there is a $SiO_2 : R_2O_3$ ratio of 2.24 with an illite : kaolinite ratio of 70 : 30 (in the A_2 horizon), a seemingly reasonable ratio with reference to the Red Brown Earths, whereas in the corresponding horizon of Y.B.E. 1/S and P 1/S the clays with illite : kaolinite ratios of 60 : 40 and 50 : 50 respectively have the $SiO_2 : R_2O_3$ ratios of 2.65 and 2.78 respectively, which is contrary to all expectations in the light of the present discussion.

An explanation of the above discrepancy may not be far to seek. As suggested by Robinson (1949) - "There may be an actual liberation of SiO_2 under Solotisation". According to this suggestion, it seems quite reasonable to expect that the liberation of SiO_2 in the A_2 horizon accompanied by removal of R_2O_3 would widen the $SiO_2 : R_2O_3$ in the A_2-horizon-clay of an appreciably solodised soil and more so in a solod, without any reference to the mineralogical composition. This is exactly what has happened in the Solodised-Solonetz (Y.B.E. 1/S) and in the Solod (P 1/S). Thus it seems quite logical to say that it is due to the liberation of SiO_2 that the $SiO_2 : R_2O_3$ ratio of the A_2-horizon-clay has assumed high value in the Y.B.E. 1/S and P 1/S disregarding the relative proportion of illite to kaolinite.

It is also quite interesting to note that as the solodisation in the soils of the present investigation has proceeded onwards to form the solod - the $SiO_2 : R_2O_3$ ratio in the A_2 horizon clay has gone up and up, whereas the illite : kaolin ratio has gone down and down. This clearly demonstrates two things:-

(1) with the advance of solodization more and more SiO_2 is liberated from the degradation of the clay complex;

(2) the advance of degradation of the clay complex along with the advance of solodisation breaks down the Tri-layer mineral part of the clay (illite in the present case) preferentially, thereby showing up the kaolinite portion more and more.

Thus in a complex association of the different stages of solodised soils to solod, the relative maturity may be traced from a study of the chemistry in conjunction with mineralogy of the clay fraction from A_2 horizon.

Regarding the mode of formation, it may be said that the more siliceous type of clays generally betokening a dominance of tri-layer minerals to greater or less extent may be formed:-

(I) by primary weathering from crystalline rocks under conditions which stand in the way of SiO_2 removal which may happen due to -

(a) restricted leaching owing to an excess of evaporation over rainfall as in arid and semi-arid climates;

(b) impeded drainage as in ground water soils or in soils developed from parent materials with impervious strata;

(c) prevalence of high base status:

(II) by the concomitant precipitation of dissolved silicic acid with suspended matter in eustarine, lacustrine and marine sediments, as in clays of soils of secondary weathering and in clays of immature soils derived from calcareous sediments -as observed by Robinson (1949);

(III) by the removal of R_2O_3 by leaching as in -

(a) Podsolization under acid humus;

(b) Solotization - consequent on the hydrolysis of Na-clay, and removal of NaOH and eventual loss of R_2O_3 due to unstability of the clay complex, consequent to the ingress of H on the exchange complex. In this process however there may be an actual liberation of silica - Robinson (loc. cit.).

In consideration of the above-outlined processes, it might be said that a dominance of Tri-layer minerals would be no wonder in the soils associated with calcareous parent material and also in the soils of hydro-halogenic origin. Joffe's (1949) compilation of Sedeltskii's contribution in this line amply justifies the above hypothesis, at least qualitatively.

The present investigation too, wherein the Rendzina soils are mainly of illitic (tri-layer mineral) clay, the Red Brown Earths and the Solodised-Solonetz soils are of dominantly illitic clay, adds to the evidence of the hypothesis.

In the aforesaid outline of the processes, it was said that podsolic or solodic process of R_2O_3 mobilisation may also bring about the formation of a siliceous type of clay to hint at the presence of a substantial if not dominant amount of tri-layer mineral in the eluviated horizon. This indirectly suggested that, due to illuviation of R_2O_3 in the B horizon, the SiO_2/R_2O_3 ratio must narrow down with depth as is found under a podsolisation or solodisation process. In that case one would expect a relative predominance of highly sesquioxidic clay minerals or bi-layer minerals in the B horizon, provided of course the formation of new bi-layer minerals takes place in the B horizon. Definite evidence of the formation of bi-layer minerals in the B horizon of podsols is heretofore not available, not to speak of Solods. Peterson (1944), working with some Iowa soils to examine the influence of bi-layer (kaolinite) and tri-layer (montmorillonite) minerals on soil structure, made some clay mineral study (thermographic) of podsol profiles. It appears from his statements, as he did not mention the quantitative relative proportions, that the younger podzols showed a relatively higher amount of tri-layer mineral in the B-horizon clay than in the A horizon clay, but the older ones presented just the reverse case, i.e. in the older one the kaolinite content is relatively higher in the B horizon clay than that in the A horizon. Nikiforoff and Alexander (1942) observed an increase in kaolinite in the B horizon clay of podzols. The works of Sedletskii on the clay minerals of podsol profiles as compiled by Joffe (loc. cit.) unfortunately do not indicate the relative proportions of the hydrous muscovite (which is just a synonym of illite) and kaolinite in the different horizons.

But, depending on the few available reports and from theoretical consideration, it may be said that in a mature podsolic profile, the kaolin content should be expected to be comparatively dominant in the B horizon or, in other words, the relative proportion of kaolinite would be higher in the B horizon than in the A horizon.

Under the pretext it might also be assumed that in the podsolization process new minerals are formed in the B horizon as the soils attain maturity. Peterson's (loc. cit.) observation that the older podzols show a higher kaolin content in the B horizon clay than in the A horizon clay, and reverse is the case in the younger podsols or podsolic soils, is an evidence to the above supposition. In this connection, the contribution due to Jackson and associates (1948) on the weathering sequence of clay minerals seems very significant. The authors, philosophising on their "successive parent material principle" and "simple residue principle in soil horizons", very clearly hinted at the possibility of "Secondary kaolinisation" in the illuvial horizons due to the reunion of Gibbsite and Silica colloids demobilised from the eluvial horizons - wherein however the kaolinisation takes place by the degradation of the tri-layer minerals of the colloids and non-colloids as well. Another very important observation was made by Alexander and associates (1942) who advanced that the gibbsite, formed as a result of primary weathering, may normally be resilicated to kaolinite in the zone near the parent material. Harrison (1933), as pointed out by Jackson and associates (loc. cit.), postulated resilication of gibbsite through rise of SiO_2 through the ground water from freshly decomposing silicates. It seems therefore with the advance of pedogenesis that the clay silicates in the A horizon gradually proceed on to the formation of bi-layer minerals by the rupture of the tri-layer ones and the bi-layer ones on further break give rise to the appearance of free SiO_2 and Al_2O_3, which move down under varying conditions and eventually start rebuilding the bi-layer minerals in the deeper horizons. The rebuilding according to Jackson and associates (loc. cit.) may even proceed on to the formation of secondary tri-layer minerals in the illuvial horizons in course of time.

Thus, under the circumstances, it might be assumed that a mature podsol would be expected to show a relatively higher kaolinite content in the B horizon clay than in the A horizon clay. And, as a general case, it would be expected that the podsols and also the laterite soils, i.e. all the strongly leached soils, tend to be of an overall kaolinitic nature - Kelley (1948) - as against the illitic nature of the Rendzinas as discussed previously. But it has to be presumed that new formation of kaolin takes place during the podsolisation or laterisation process at the expense of tri-layer minerals. As far as the surface horizons are concerned, the possibility is there - as discussed before.

Before proceeding with the discussion any further, it might be well worth quoting a few lines from Robinson (1949) - "It would be of particular interest to ascertain if the removal of sesquioxides in podsolisation and solotization leads to the formation of new minerals or merely to liberation of silica".

As far as the podsols are concerned, the evidence presented before, however little it may be, does indicate the possibility of new mineral formation with maturity, leading to the relatively greater dominance of kaolinite in the B horizon clay than in the A horizon clay.

Now the point is what happens in a solodisation process is hard to say. But since solodic process of soil formation can be regarded as a parallel to the podsolic process, it might not be too much to expect new kaolin formation in a mature solod. The observations of Alexander and associates (loc. cit.) and Harrison (1933) seem to be quite in harmony with this analogical assumption.

It does not seem very safe to speak any more on this at this stage of development of clay mineralogy, particularly because ~~a~~ report on the clay mineralogy of solods does not seem to be available in soil literature.

But the present study, which has shown (1) an overall dominance of kaolin in the solod clay fractions, (2) a relative increase in kaolin content of clay with depth, although it may not be safe to rely on more than simple statements, nonetheless has afforded something to think about ~~in~~ the new kaolin formation in the deeper horizons of the solod studied. The overall dominance of kaolin may or may not have any definite pedological significance but the distribution with depth is not to be ignored.

To sum up, it may be said that -

(1) The clay minerals of the Barossa soils studied are composed mainly of Illite and Kaolinite in varying proportions in different groups; some minor appearances of such as Quartz and Goethite have also been noted - Quartz in the Red Brown Earths and halogenic soils and Goethite in the Red Brown Earths and the Solodized-Solonetz soils. In no case was Goethite found in the A horizon. The Rendzina clay however has shown no accessories such as Quartz or Goethite, showing thereby a more youthful stage in pedogenesis - Jackson and associates (1948).

(2) The Rendzina soils have presented mainly illitic clay with no sign of any variation in the relative proportion of illite to kaolin with depth, whereas the solod (P 1/S) presented a dominantly kaolinitic clay - the relativeamount of kaolinite to illite is increasing with depth - the illite : kaolin ratio in the A_2, B_1 and B_2 horizons being respectively 50 : 50, 40 : 60 and 30 : 70; the Red Brown Earths and the solodised-solonetz (Yellow Brown Earths) clays are dominantly illitic with a tendency to get comparatively richer in kaolin with depth (Table 20).

(3) The $SiO_2 : R_2O_3$ ($Al_2O_3 + Fe_2O_3$) ratio seems to have a reasonably good correlation with the mineralogical composition of the clay, excepting the halogenic soils, particularly in the A_2 horizon, wherein, due to liberation of free SiO_2, the ratio has gone up, indicating a high siliceous nature of the clay although the mineralogy has followed just the opposite direction as far as the relative proportion of illite : kaolinite in the clay is concerned. Because of the fact that the SiO_2/R_2O_3 ratios in the A_2 horizon

clay of Y.B.E. 2/LS, Y.B.E. 1/S and P 1/S respectively are 2.24, 2.65, 2.78, normally one would expect a gradual dominance of illite over kaolin accordingly as one passes from the weakly solodised to the solod, but in practice the present case has shown just the reverse as the relative proportions of the minerals in the A_2 horizon are respectively 70 : 30, 60 : 40, 50 : 50 - (Illite : Kaolin).

(4) The vertical distribution of the $SiO_2 : R_2O_3$ ratio, in the Solod (P 1/S), however, shows a good correlation with the illite : kaolin ratio, as the ratio has narrowed down with depth along with the relative widening of the kaolin portion at the expense of the illite portion.

(5) The gradual advance of kaolinisation with the advance of solodisation seems quite significant and may be regarded as a good index in the absence of other data.

(6) The overall dominance of kaolin in the clay fractions of the Solod (P 1/S) profile holds it as a parallel to a podsol and the possibility of new kaolin formation in the B horizon seems reasonable in the solodi profile, although the influence of parent material is also to be considered.

(D) Characterisation of Illite.

Having ascertained that the clay minerals of the soils under the present investigation are combinations of Illites and Kaolinites, the next step was to examine how far the illites studied conform to the illites of Grim and associates (1937) - the originator of the name Illite. As was mentioned previously, K_2O content is quite a critical index of illites. MgO may also be taken into consideration, but with definite reservation because of the distinct possibility of isomorphous substitution in the octahedral position of the lattice structure.

Chemical analyses for K_2O and MgO were undertaken on some selected samples of the clay fractions, the selection being made such that -

(1) the samples contain no adventitious minerals such as goethite or dolomite or montmorillonite or even montmorillonite intermediate;

(2) the samples represent a gradual sequence in the proportion of illite (such as I : K = 30 : 70, 40 : 60, 50 : 50, 60 : 40, 70 : 30) so as to enable a final calculation on the basis of 100% illite for K_2O and MgO.

The results of the chemical analyses are presented in Table 21 and are also illustrated graphically (Fig. 21) to show the variation of K_2O content with that of the illite content of the samples analysed. The results of the analysis show that percentages of K_2O when computed on 100% illite basis swing round about 6.4, which is just about the same value as reported by Grim and associates (loc. cit.). As far as the MgO content is concerned, it has not shown agreement with those given by Grim and associates (loc. cit.), probably because of the isomorphous substitutions taking place during the pedogenesis in the octahedral position. And in fact it would be rather surprising if the MgO data were in agreement with those of Grim and associates (loc. cit.), particularly because their reports are based on the analyses of specimens taken from native rocks and not from clay fractions of soil horizons. The data presented by them show a K_2O content of 6.09 - 6.93% and a MgO content 2.69 - 3.93% in illite.

The above mentioned authors have assigned a $SiO_2 : R_2O_3$ ratio of about 3 to illite. Looking back to Table 20, it will be seen that the clay fractions of the Rendzinas which contain mainly illite with a little kaolin have a $SiO_2 : R_2O_3$ of 3 - 3.15, thereby agreeing with the assignment referred to.

As far as the cation exchange capacity is concerned, the above-mentioned authors proposed a capacity of 20-40 m.e. % for illite, whereas Endell and associates (1935) assigned a value of 50 m.e. % to Glimmerton which is similar to illite (admitted by Grim and associates (loc. cit.)). Although it is rather a great risk to venture to say much to relate the cation exchange capacity of soils with the mineralogical composition of the clay fractions, it may not be too much to indicate that the cation exchange capacity of the inorganic colloid of the Rendzina soils was by statistical calculation found to be 52 m.e. %. This value is obtained by assuming that the clay fraction is the only inorganic fraction responsible for exchange

TABLE 21.

* K_2O AND MgO CONTENT OF ILLITE.

Free F_2O_3
%
3.18

Clay Number.	Minerals present.	% K_2O in the combination.	% MgO in the combination.	% K_2O in 100 % Illite.	% MgO in 100 % Illite.
15153	Illite + Kaolin (70 : 30)	4.54	1.41	6.48	2.01
15171	Illite + Kaolin (60 : 40)	3.67	1.22	6.11	2.03
15178	Illite + Kaolin) (50 : 50)) Quartz - 20%)	2.56	0.49	6.40	1.22
15179	Illite + Kaolin (40 : 60)	2.55	0.61	6.37	1.52
15180	Illite + Kaolin (30 : 70)	1.98	0.45	6.60	1.50

* Expressed on Ignited clay.

K_2O - was determined by precipitating as Cobaltinitrite and titrating with $KMnO_4$ as usual.

MgO - was determined gravimetrically precipitating as 8-hydroxyquinolate.

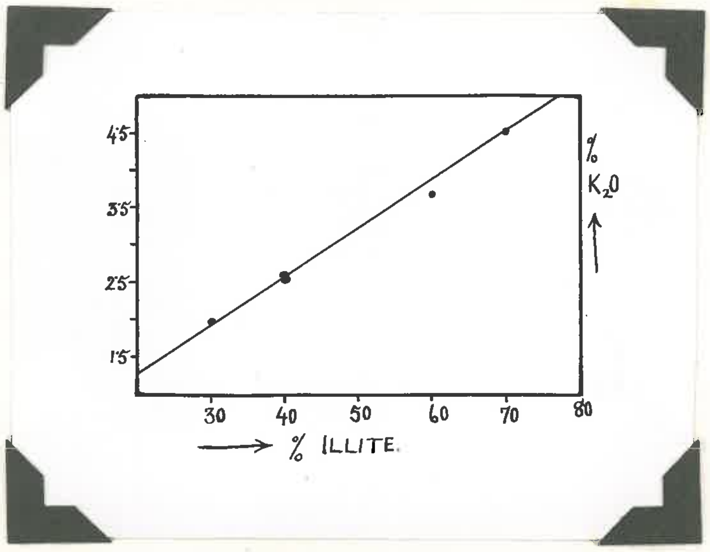

FIG. 21.

Illustrating the realtionship between the K_2O content and Illite content in the selected clay samples.

reaction which certainly is open to question. To quote Kelley (1948 pp.26), "When examined more closely, it becomes apparent that cation exchange is a property not peculiar to the colloidal state as such, but to certain kinds of surfaces. Surfaces showing this property may or may not be ultramicroscopic or microscopic in dimensions, in fact particle size as such is no indication of cation-exchange property". Kelley (loc. cit. pp.67) further writes - "The silt and fine sand fractions of certain soils possess notable cation-exchange power". Thus in the face of all these arguments it certainly is a far cry to assign the exchange capacity of the inorganic fraction to the clay alone. And as such the computed capacity for the clay fraction would present a bit too high a datum for the relevant mineral.

But in spite of all these limitations, a capacity of 52 m.e. % for the clay fraction of the Rendzina soils studied seems quite a significant value to speak something about the illites of soil horizons, because the clay fractions of the Rendzina soils (Black Earths) are composed mainly of illite with a little kaolinite. The presence of a little kaolin in the clay under reference would tend to reduce the value and depress it a bit below 50 (assigning a value of 50 m.e. % to illite), but the supposed contribution due to the arbitrarily-earmarked coarser fractions, which have entered into the computations to give a higher value both for the clay and organic matter (because the total exchange capacity which is supposed to be due to organic matter + clay + silt and fine sand to some extent, has been allotted to clay and organic matter only, depriving the coarser fractions although their contribution is supposed to be there, however little or great it may be), would be expected to eventually make up the depression due to the little kaolin. Thus, as far as the exchange capacity of illite from soil horizon in the present study is concerned, it seems reasonable to contribute to Endell and associates (loc. cit.) who assigned a value of 50 m.e. % rather than ~~a~~ to the value of 20-40 m.e. % due to Grim and associates (loc. cit.). Here again the assumption is that the contribution due to the coarser fractions of soil in the exchange capacity is not very great - not greater than 10 m.e. % anyway, because the kaolin content, even if it amounts to 10% in the clay, would not drop the capacity below 46 m.e. % (assuming of course a value of 50 m.e. % to 100% illite), and hence the reinforcement due to the coarser fractions would not be expected to be very high to nullify the depression due to the kaolin.

If however, the capacity of the illite under reference be not 50 m.e. %, the other alternative is 20-40 m.e. % due to Grim and associates (loc. cit.). Considering the maximum value, i.e. 40 m.e. % due to the above authors, the coarser fractions will have to make up for (12 + the depression due to the kaolin and consequent fall in illite content), i.e. about 15 m.e. % to raise the capacity to 52. Although a forecast is impossible to make, it nonetheless seems very doubtful that the coarser fractions would contribute that much to the capacity. Secondly, the organic matter also has to receive some part of the supposed contribution due to the silt and fine sand fractions as demanded by calculation. That would mean that the actual contribution due to the coarser fraction would be a value much higher than 15 m.e. % which is very hard to reconcile, at least in the absence of any evidence anyway.

Again considering the case of P 1/S (The Solod), wherein the overall composition of the clay minerals may be roughly regarded as Illite : Kaolinite = 40 : 60 (Table 19), the cation exchange capacity which is also an overall computation was found to be 34 m.e. % (Table 13). Arguing exactly in the same way as above, it seems reasonable to assign a value of 50 m.e. % as cation exchange capacity to illites under the present study, thereby contributing to Endell and associates (loc. cit.).

Thus it may be said that the illite in the present investigation seems to hint at a value of 50 m.e. % to be assigned to her and thereby contributing to the proposition of Endell and associates (loc. cit.). Nothing more definite could possibly be said about illite present in clay minerals of soil horizons till such time as some more reports dealing with clay minerals of soil horizons get into publication.

The graphical illustration of the K_2O content Vs Illite content (Fig.21) shows a pretty good linear fitting, indicating thereby the reliability of X-ray analysis from quantitative point of view also.

To sum up it may be said that:

(a) The Illites under the present study quite satisfactorily conform to the illites of Grim and associates (loc. cit.) in so far as their chemical composition, i.e. the K_2O content (which is distinctively critical for illite) and $SiO_2 : R_2O_3$ ratio, which is a value of about three, are concerned.

(b) The cation-exchange-capacity value of Illites as far as the present study is concerned seems to agree with that due to Endell and associates (loc. cit.) (50 m.e. %) more favourably than that due to Grim and associates (loc. cit.) (20-40 m.e. %), although based on conservative arguments.

(c) The observation under (b) is quite subject to criticism because of the fact that (i) nothing is as yet known regarding the quantitative contribution towards exchange capacity of soils due to silt and fine sand, and as such the arguments are rather presumptuous;

(ii) the X-ray studies on the quantitative proportions of illite and kaolinite may or may not be exactly correct although the K_2O data do show that as far as illites are concerned the reports are quite reliable within reasonable limits of error.

(d) The present study is just a pebble in an attempt to bridge the gap relating to systematic studies on the clay minerals of soil horizons and no more definite a statement, especially with regard to exchange capacity, is thus possible in this line till such time as further works are carried out with clay fractions from soil horizons as such.

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