SOUTH AUSTRALIA

Department of Mines

GEOLOGICAL SURVEY OF SOUTH AUSTRALIA

Bulletin No. 32

The Soils and Geology of Adelaide and Suburbs

BY

G. D. AITCHISON, M.E., Senior Research Officer, Soil Physics and Mechanics Section, Division of Soils, C.S.I.R.O.

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Issued under the authority of
The Hon. A. Lyell McEwin, M.L.C., Minister of Mines

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LETTER OF TRANSMITTAL

Geological Survey Office, Department of Mines,
Adelaide, 2nd June, 1952.

Sir,

This publication is the result of a joint investigation, by the Department of Mines and the Division of Soils of the C.S.I.R.O., of the soils of the Adelaide metropolitan area. The object of the work was to obtain information on the distribution of the different types of soils in order that engineers, architects, builders and other interested persons would be able to have guidance on the type of foundation construction best suited to the sites on which building is contemplated.

The Bulletin contains the basic data for determining the nature of the soil type and sets out their characteristics and seasonal behaviour in relation to the foundations of houses. A feature of the Bulletin is the colour illustrations of the various soil types.

The officers of the Department of Mines have dealt primarily with the geological and hydrological aspects, whilst C.S.I.R.O. officers have covered the examination and testing of the soils.

The information should be extremely useful to persons interested in building or contemplating building in the metropolitan area. The Department has also established an advisory service to supply information and deal with specific applications.

S. B. DICKINSON,
Government Geologist.

The Hon. A. Lyell McEwin, M.L.C., Minister of Mines.

Submitted for approval to print as a Bulletin of the Geological Survey of South Australia.

Approved,

A. LYELL McEWIN, Minister of Mines.

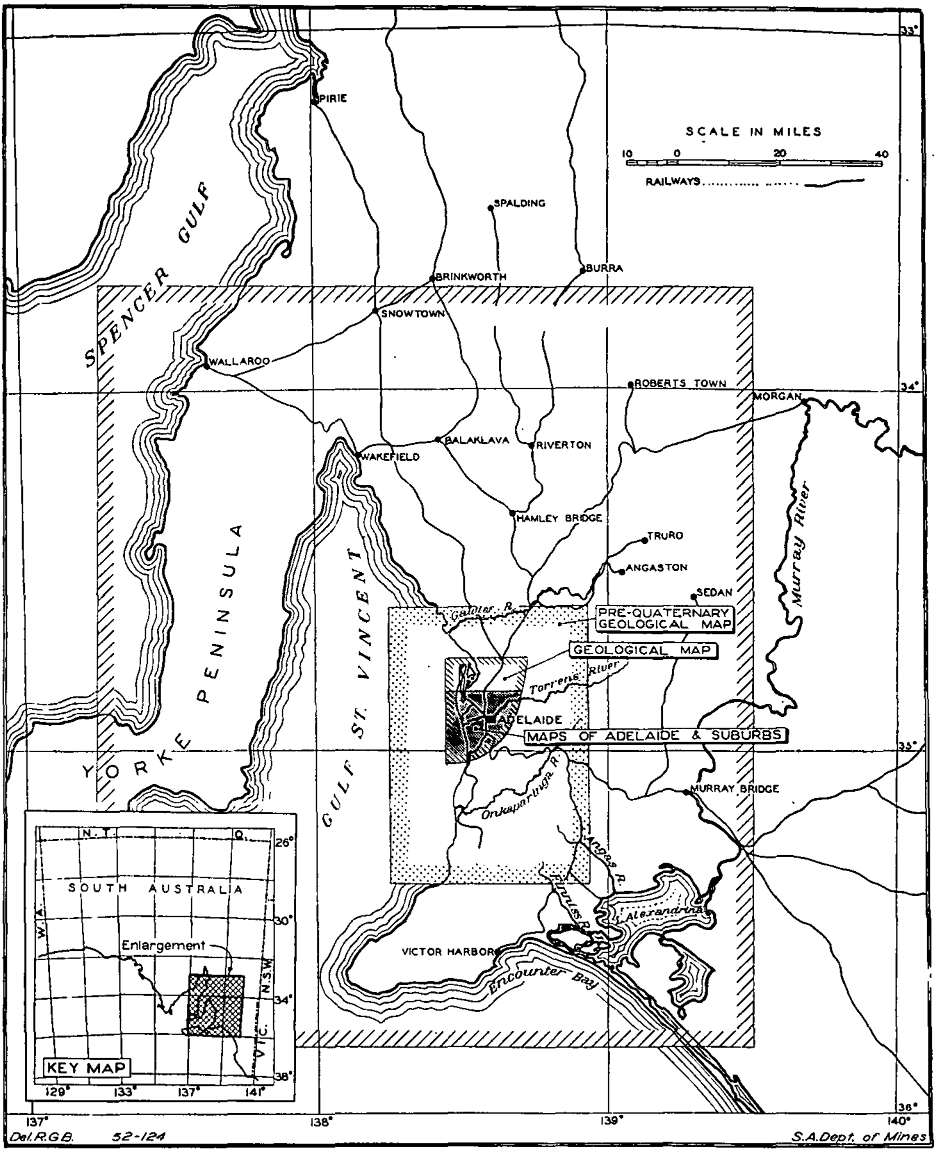

Fig. 1—MAP OF PORTION OF SOUTH AUSTRALIA
Showing areas referred to in *Bulletin* 32

Frontispiece]

PREFACE

This *Bulletin* is the outcome of work carried out in collaboration by the South Australian Department of Mines and the Commonwealth Scientific and Industrial Research Organization, Division of Soils. For the past 12 years investigations in soil mechanics have been carried on by the Division of Soils and these more recently have been directed to the problems of soils in relation to building foundations especially smaller structures such as houses. These are matters which have a place and value in the work of architects and engineers and the study was aimed at classifying the soils of Adelaide and identifying their specific characteristics as an aid to the practice of building.

The idea of mapping the Adelaide region developed from the considerable number of soil surveys made of lands resumed by the South Australian Housing Trust for the mass building of small homes. It was clear that geological factors required parallel investigation and the Director of Mines made available officers for the examination of the geology and hydrology of the surburban area between the Mount Lofty Range and the Gulf coast.

The *Bulletin* is a summation of the field investigations of both the South Australian Department of Mines and the Commonwealth Scientific and Industrial Research Organization, Division of Soils, together with the characterization, by the latter, of the soil groups in regard to their qualities for foundation purposes.

J. K. Taylor, Chief, Division of Soils,
Commonwealth Scientific and Industrial Research Organization.

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Chapter 1

INTRODUCTION

Adelaide, the capital city of South Australia, is now in its second century of development. Founded in 1836, the city with its suburbs has grown to cover an area of more than 100 square miles with a population of 400,000. The city proper is located at latitude 34deg. 56min. South and longitude 138deg. 35min. East. It occupies a central position on an alluvial plain which extends from the hills of the Mount Lofty Range to the seaboard of Gulf St. Vincent.

HISTORICAL BACKGROUND

From a comparatively early stage in the history of Adelaide's suburbs, progress has been dependent to at least a minor degree on the soils of the various areas. Some of the first settlements appeared in the form of suburban villages in which could be found the natural advantages of water supply and fertile well-drained soils. Along the coastline, townships became established on the elevated sand ridges which were free from the danger of flooding. Subsequently, with progress in transportation and the provision of facilities for drainage of surface water, development became more widespread. As the population increased and agriculture gave way to industry an expansion of building activity was inevitable. Here too, the control exerted by the nature of the soil is discernible, for while certain areas made rapid headway as industrial or residential districts, other adjacent zones fell into disfavour as reputedly containing inferior building soils.

As the trend towards more intense settlement of Adelaide's suburban areas is continued into the future, the need for knowledge of the underlying strata will doubtless arise on many occasions. This *Bulletin* represents an attempt to outline the present state of this knowledge. It is hoped that such a preliminary presentation of geological and pedological data may serve as a background to the definition of certain problems and as the basis for recognition of the deficiencies in our local knowledge.

Discussion of the soils and geology of Adelaide and suburbs is given jointly since, in the authors' opinions, there is in this area no evidence to support the creation of any artificial line of demarcation between the two subjects. The study of soils of the Adelaide Plains is virtually an investigation into Quaternary sedimentation and the modification of the last alluvial increments by soil-forming processes. During this period most of the constituent soil material was deposited by stream action although there were minor or restricted accessions of aeolian, marine, and other materials. The cumulative soils so formed may be regarded as successions of old soil-profiles (mature or otherwise) which have been continuously buried by periodic accessions of new material so that pre-existing dynamic equilibria have been destroyed and new sets of conditions brought into play tending to produce uniformity in the old profile.

The study of such soils requires first a knowledge of the parent source-materials, the processes by which these eroded and decomposed materials were transported to their present position, the climatic environment, and finally the nature of the operating and oscillating pedogenetic processes. The historical geology of the area, including the whole drainage basin, is obviously of fundamental importance as also are the climatic history and the hydrology.

SCOPE OF INVESTIGATIONS

The geological work is based upon investigations carried out over an extended period, culminating in the recent production of the geological map of the area contained in the Adelaide military sheet. These investigations have been supported by much new hydrological and palaeogeographic data obtained during the extensive drilling undertaken to supplement Adelaide's inadequate reservoir water-supply.

The soils work is based upon a general reconnaissance survey of the Adelaide suburban area, which was initiated primarily to obtain an insight into the factors associated with foundation failures in domestic buildings. Most attention has therefore been focussed on those soils which constitute the major engineering problems. No deliberate attempt has been made in the field to study the soils from the purely pedological aspect, although, as a result of some detailed surveys of housing estates supplemented by random observations over a period of years, sufficient information now exists to permit some comment on pedogenetic subjects. The soil map arising from this work is intended to be of a generalized rather than a detailed character. It is presented principally to permit the soils problems to be viewed in their proper perspective, and is not suitable for direct interpretation as a land-use map.

Chapter 2
PHYSIOGRAPHY

Adelaide is situated on an uplifted coastal plain at the eastern margin of the Gulf St. Vincent senkungsfelder (sunken valley). To the east the major horst blocks of the Mt. Lofty Range rise sharply in stepped fault blocks to plateau levels culminating in the monadnock of Mt. Lofty at 2,234ft. Late Cainozoic block faulting has provided a major control on local topography and the development of drainage patterns, and the Eden, Burnside, and Para Faults (fig. 2) are of greatest significance.

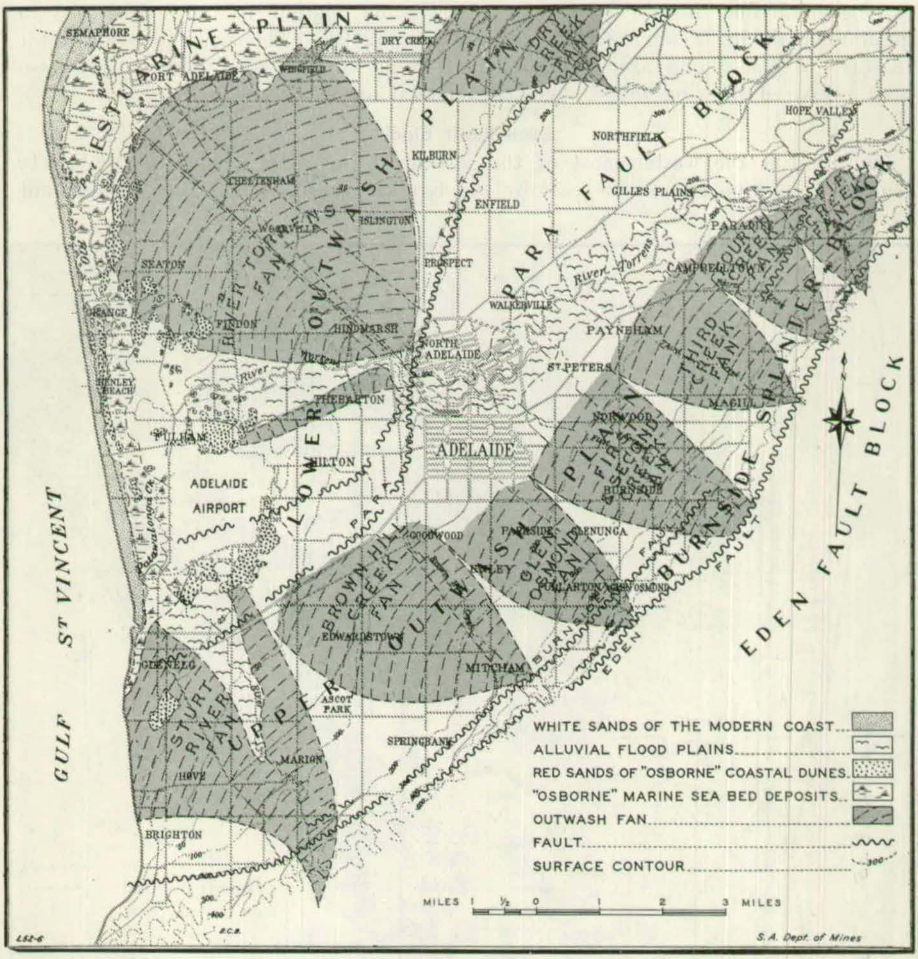

Fig. 2—MAP OF ADELAIDE AND SUBURBS
Showing physiography

The Mt. Lofty Range in the western escarpment region presents a youthful appearance with the development of deep narrow valleys containing waterfalls and high gradient streams. The various escarpment consequent streams have produced a series of outwash fans bordering the plains, but to the west the stream gradients flatten and the stream channels may fade almost into insignificance. Practically without exception they discharge on to swamp and estuarine plains bordering the sea-coast between Glenelg and Outer Harbour. Due to the large seasonal variation in rainfall, the creeks typically come down in flood during a wet winter, but flows practically cease as summer progresses. Until settlement by white man was well advanced the Adelaide Plains were being continuously built up by the seasonal deposition of flood material by these creeks, but the diversion of most of the headwaters of the Torrens River to reservoirs, the construction of the Torrens outlet channel, and the confinement of some of the smaller creeks to artificial channels has substantially modified the natural cycle.

THE TOPOGRAPHIC UNITS

Fenner (1930) made a major investigation of the physiography of the region, while Sprigg (1945) carried out a detailed analytical study of the range. The plains region and its immediate environment, for the purpose of the *Bulletin,* can be subdivided into seven topographical units, similar to those described in greater detail by Fenner (1927) and Miles (1952). The main physiographic features of the region are illustrated on fig. 2, while a plan (fig. 3) has also been prepared showing the changes of gradient across the plains.

Eden Fault Block

This unit is the westernmost of the several blocks constituting the Mt. Lofty Horst. It is bounded on the east by the Kitchener and Ochre Cove Faults and

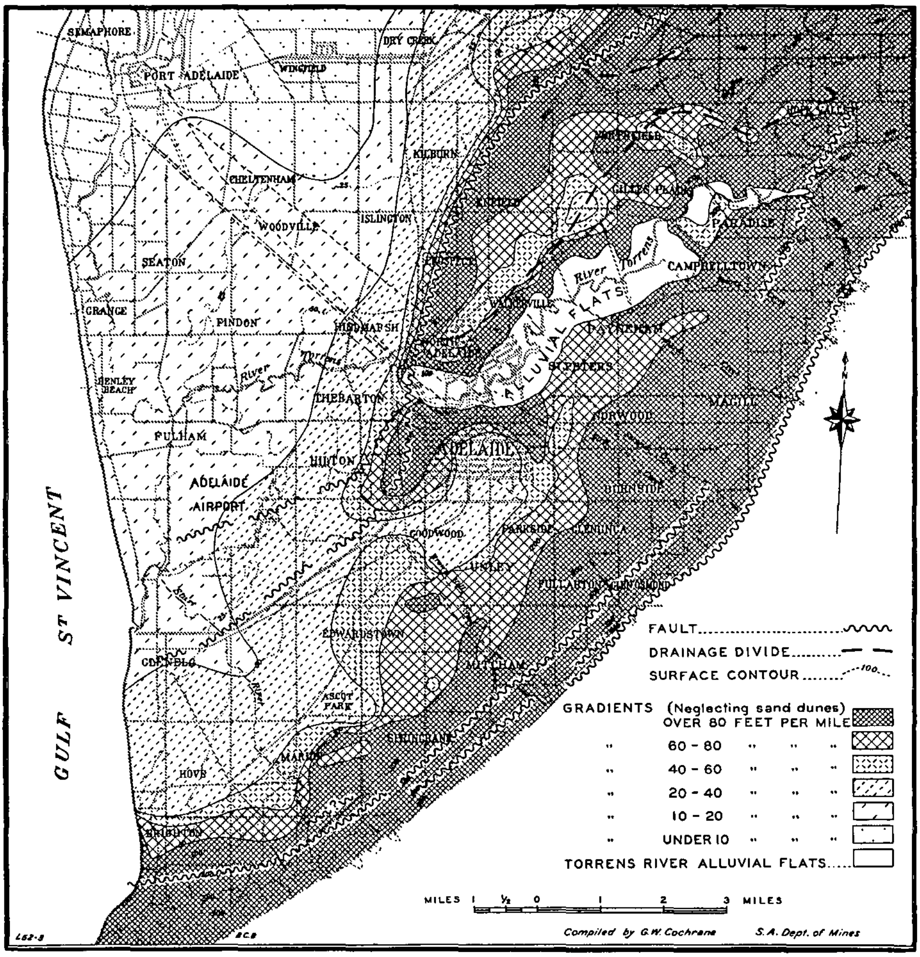

Fig. 3—MAP OF ADELAIDE AND SUBURBS
Showing drainage divides and topographic gradients

on the west by the Eden Fault. The major range escarpment in the region forming a background to the city and suburbs is developed along the Eden Fault. The scarp at its edge rises rapidly to 1,000 or more feet above sea-level in the central region, but to the north and south falls slightly. The lowest development is along the southern hills where frontal slopes are more gentle and the plateau is only some 450-500ft. above the plains. This is a result of a tilt to the south which accompanied fault movement, together with the existence of more resistant rocks in outcrop north of the Sturt River. Such prominences as Black Hill, Rocky Hill, and Norton Summit all attain heights of over 1,400ft. above sea-level, but to the south the highest point is O'Halloran Hill with an elevation of only 658ft. The Eden block harbours the source of most of the shorter escarpment creeks, and the larger streams such as the Rivers Torrens and Sturt have cut deep narrow gorges through it.

Burnside Splinter Block

This narrow block occurs at intermediate levels between the Eden and Para blocks and near Clapham is only 500yds. broad, but to the north at Thorndon Park is approximately 1 mile wide. Its surface usually lies at 400-500ft. above sea-level, and it appears that in the north it has a general southerly tilt, while at the southern end it dips to the north. It is largely obscured by outwash from higher levels, but a low scarp is recognizable at intervals between Fourth Creek and the River Torrens, and from First Creek to beyond Clapham where it coalesces with the Eden Fault and follows an arcuate course to the sea at Marino. East of Hope Valley Reservoir its extension has been traced from bore information, but in the central portion its position has not yet been determined.

Para Fault Block

As a physiographic unit this term is confined to the country north of the River Torrens, although structurally the plains to the south were also affected by the same fault movement. As a result of a southerly to southeasterly tilt associated with faulting, the height of the scarp decreases from north to south. Across the western city parklands the fault can be traced as a low escarpment which rises to the north to a height of several hundred feet near the Little Para River, where it forms the main front-of-range fault scarp. South of the city area all surface manifestation of the Para Fault is lost, but it is known from bore records and geophysical measurements that it splits near the River Torrens into two branches which swing round towards the west and gradually diverge approaching the Gulf near Glenelg.

A local drainage divide is formed across the block trending northeast from the city area, and the crestal region is mainly rather flat. Dry Creek, which rises towards the eastern side of the block near Golden Grove, is the main watercourse traversing the block in the area under investigation. Fenner (1927) concluded that this creek originally flowed southward into the Torrens but was later captured by an escarpment consequent creek from the west.

Movement along the Para and Eden Faults occurred contemporaneously, but the greater magnitude of the latter movement meant that it was possible for alluvial deposition to occur over the Para block from fans of creeks emanating in the hills north of the River Torrens, despite the normal tendency for the block to be eroded as it was uplifted relative to the plains to the west. During some periods of the Pleistocene to Recent times however, activity along the Para Fault was probably the greater, resulting in a general erosional cycle over the block. Main drainage was probably into a creek running southward towards the River Torrens down the eastern side of the block. During such occasions erosion of previously deposited outwash material on the Para block would have taken place. The net result is that alluvial cover over this block is much less than that over the plains to the south. Pre-Cambrian bedrock or Early Tertiary sediments are generally encountered at quite shallow depths.

Upper Outwash Plain*

This area is bounded by the River Torrens in the north, the Burnside Fault to the east and south, and approximately by the Anzac Highway on the west. It is the zone which includes the foothills outwash aprons as well as adjacent alluvial areas and descends from elevations of 500-600ft. to less than 100ft. above sea-level. Above the 300-ft. contour the slopes mainly exceed 80ft. to the mile. The locus of the 40ft. to the mile transition slope runs along the Para Fault north of the city and then across the Upper Outwash Plain, roughly corresponding with the 180-ft. contour as far as the Sturt River, whence it swings westward to the coast. The Adelaide city area provides an exception where gradients under the influence of the buried Para block are much lower. The locus of the 20ft. per mile slope extends diagonally from Torrensville to Somerton on the coast. The general picture is therefore one of gentler changes of slopes in the northern part of this unit than in the south.

Local seaward displacements of surface contours in this area demarcate alluvial fans of small creeks emerging from the hills particularly in the southern part of the area. There is a general tendency for the contours to be diverted upstream nearer the hills but downstream lower on the plains, indicating the change from excessive near-channel erosion to deposition in these two zones.

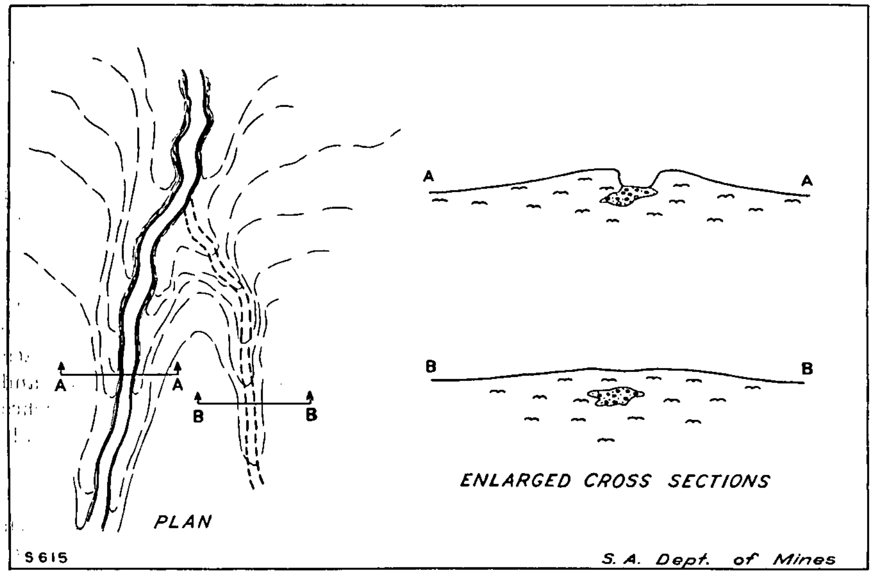

Fig. 4.—LEVEE DEVELOPMENT ON LOWER OUTWASH PLAIN

Lower Outwash Plain

This zone extends landward from the subcoastal marshes to the Para Fault block in the east, and to the south is bounded by the Upper Outwash Plain. Surface gradients over the whole area are very low (10-20ft. per mile) and the topography is dominated by the outwash fan deposits of the larger creeks from the range (viz. Little Para River, Dry Creek, River Torrens, Brownhill Creek and Sturt River). These rivers and creeks normally build levees in this zone (fig. 4). Other escarpment streams mostly lose their identities within the Upper Outwash Plain. The most important of these larger streams is the River Torrens which has found outlets as far south as Glenelg (Miles 1952), but from which the major recent flood-plain accretion has been in the Findon-Woodville-Cheltenham district. The area is low lying and less than 60ft. above sea-level.

* The term "Outwash Plain" is preferred in lieu of "Deltaic Plain" as used by Fenner (1927) and Miles (1952) as the deposits are not truly deltaic.

Estuarine Plain

This swampy area is approximately bounded on the east by the 20-ft. contour and sporadic red sand-dunes. As the site of Recent period "Osborne" high sea-level inundations it is estuarine, flat, and subject to periodic creek-flooding. It extends north from Glenelg and widens rapidly near Port Adelaide to include wide intertidal flats.*

Sand Dunes

A series of modern white siliceous sands mark the coastline from Seacliff to Outer Harbour, while east of the Estuarine Plain from Glenelg to Port Adelaide there are a number of older light-red sand-dunes.

Fenner (1927) and Miles (1952) have both described the formation of these dunes and indicated the tendency for the coastal dunes to extend northward as spits until the construction of the Outer Harbour. These bay-bar hook and dune structures have continuously obstructed stream outlets in Recent times and influenced local stream sedimentation in their lee.

* Prior to the construction of the Torrens outlet channel at West Beach, seasonal flooding occurred in the Reedbeds-Patawalonga Creek area. This in turn periodically led to flooding upstream over the Lower Outwash Plain, as a result of which the Torrens built up silty levee banks.

Chapter 3

HYDROLOGY

The surface drainage pattern of the area is typical for an escarpment region. Without doubt the pattern has not changed significantly within the Recent period although individual streams may have changed position markedly on the plains during floods. It is in this manner that the plains have been built up so evenly, and buried gravels of older deserted stream-courses are consequently distributed liberally and erratically throughout the outwash deposits. These gravels figure prominently as shallow aquifers.

The composition of surface and underground waters varies greatly in the area, depending upon many factors. Their nature is as follows:

SURFACE WATERS

These are subject to considerable seasonal variation in composition due to the summer increment being minor by comparison with the winter portion. The salinity of the River Torrens waters may vary from 15 to 32 gr. per gall., and the location of these and other samples are shown on fig. 5. The compositions of some of the surface waters are given in table I. It can be seen that there are quite wide variations in quality between waters of the different creeks due in part to differences in the geological nature of the country drained by each stream. In the case of Brownhill and First Creeks, the relatively high proportions of calcium and magnesium present are probably due to the occurrence of Beaumont Dolomite within the drainage basins of these two creeks. The high salinity for waters of Third Creek may partly be caused by the headwaters eroding the Montacute Dolomite beds.

In general, salinities of surface waters increase with the distance travelled across the plains (*vide* analyses of River Torrens waters, table I), but the change in composition at the Estuarine Plain junction is rapid. These latter waters are highly saline and grade laterally into marine waters to the north and into shallow groundwaters to the east. Variation is great, depending largely on seasonal and flooding factors.

UNDERGROUND WATERS

Underground waters of the Adelaide Plains Basin have been investigated extensively by Miles (1952). Available waters group naturally into two categories; groundwaters and pressure (artesian or subartesian) waters. Both have extensive application agriculturally and horticulturally, and more recently the pressure waters have been drawn upon increasingly heavily to supplement city and suburban supplies. The shallower (non-pressure) aquifer, in a limited capacity, also serves for storm-water and other waste-water disposal. During the winter months of 1951, artificial recharge of the artesian aquifers was undertaken for the first time to combat overdraft from the deeper aquifers.

By and large, groundwaters are restricted to Quaternary formations wherein buried creek-sands and gravels, usually only a few feet in thickness and frequently lenticular in places, form the principal aquifers. No plan of the groundwater table is available, but it is known to be rather irregular with "high areas" generally occurring where streams debouche on to the plains.

The movement of ground waters in general is from areas of high altitude to areas of lower elevation, *i.e.*, from intake areas towards Gulf St. Vincent, the shallow waters probably emerging in gravel beds in the swamps and below sea-level close to the present shore-line. Intake is partly provided by local rainfall but is mainly derived from rains falling in the high lands and entering the aquifers along the front of the scarp and through the fan deltas of the various drainage channels.

The largest supplies of these waters are obtained from gravel beds flanking the present channels of the Sturt, Torrens, and Little Para Rivers. Yields vary seasonally according to the flow along these rivers. Thus in the Marion district good supplies are available in sands and gravels of the Sturt River flood-plains at depths from 35ft. to 70ft. below surface. Along the River Torrens valley and outwash fan, three particularly good areas exist, viz., (*a*) west of Torrensville to Fulham where the principal groups of aquifers occur at 35ft. to 60ft. and 95ft. to 120ft.; (*b*) Findon "basin", in the Welland-Beverley-Woodville

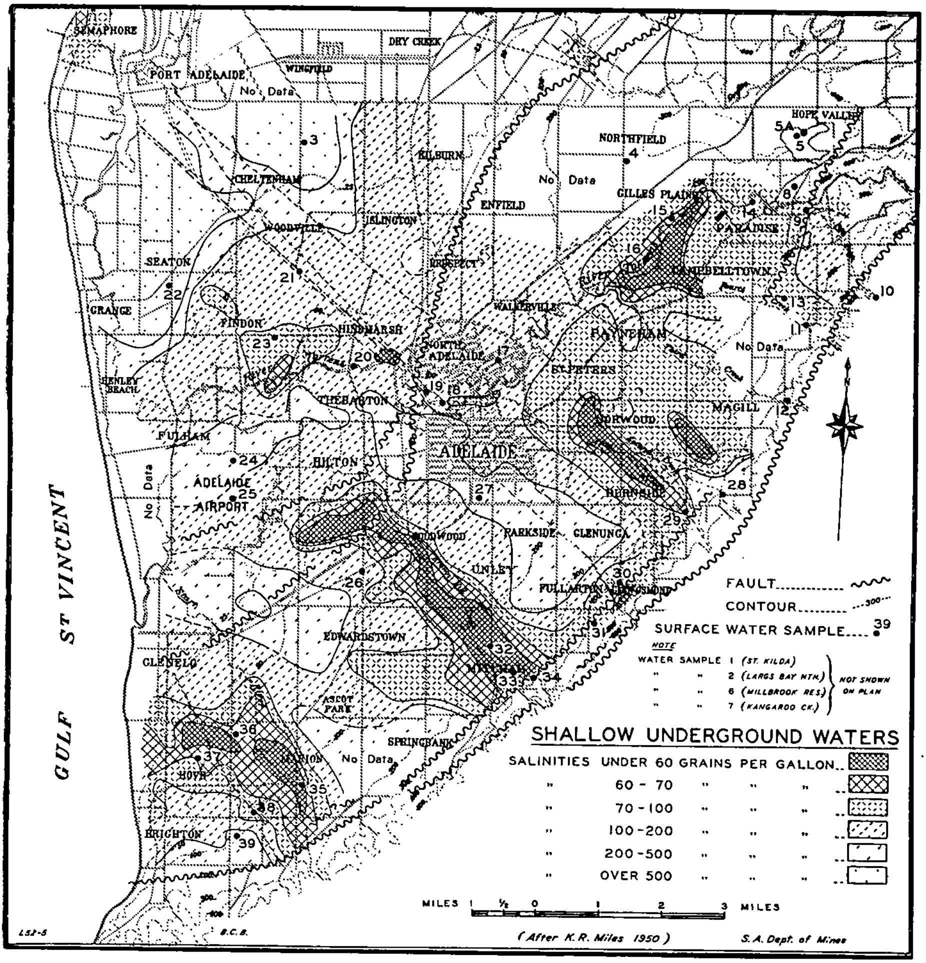

Fig. 5.—MAP OF ADELAIDE AND SUBURBS
Showing salinities, surface waters, and underground waters cut from the surface to 100 feet

area on the lower outwash plain at depths of from 25ft. to 60ft.; and (*c*) Payneham-Marden-Paradise area where the waters occur in gravel beds overlying Tertiary beds or Pre-Cambrian basement at 30ft. to 70 feet.

In the southern and southeastern foothills region water is generally available adjacent to escarpment tributaries, but supplies are mostly small due to the poor definition of the old stream-beds and the high clay-content of many of the gravels.

Groundwaters also occur in Tertiary beds where they approach the surface. They are rarely shallower than 80ft. below surface, however, except in the Gaza-Marden district where mid-Tertiary marine sediments occur at 30ft. to 50 ft. Early Tertiary freshwater sediments on the Burnside block, because of their high argillaceous-content, rarely contain useful waters. Pre-Cambrian beds on the other hand may contain reasonable supplies, and are frequently utilized along the Torrens valley upstream from Marden. Along the foothills fault zone, waters have been encountered in bedrock under considerable pressure, *e.g.*, artesian bores occur at Highbury East near the Eden Fault, and along the Burnside Fault at Glen Osmond and near the Waite Agricultural Research Institute where water was struck at depths of 100ft. and 150ft. respectively. Springs also occur in this zone.

K. R. Miles has also indicated the following generalities regarding the behaviour of the water-table.

(1) Eastern and Southeastern Areas—Water-table stands at 5ft. to 30ft. in the intermediate suburbs, *e.g.*, Goodwood to Edwardstown-Mitcham, Unley to Kingswood-Fullarton, Kent Town to Norwood and Kensington, etc.

(2) Towards the foothills the depth to water increases to 50-70 feet.

(3) Water-level rises along the courses of the tributary creeks—Brownhill, First, Second, Third, Fourth, and Fifth Creeks.

(4) West of Adelaide in the Lower Outwash Plain water stands at from 10ft. to 20ft. in River Torrens gravels.

(5) Estuarine Plain—Water at surface or within 6 feet.

Fluctuations in groundwater level occur continuously, reflecting changes in the quantity of water in storage in the underground aquifer. This is dependent upon a number of factors, including recharge by rainfall, transpiration and evaporation, atmospheric pressure, and, since the advent of man, by withdrawal in bores and irrigation.

SALINITIES OF GROUNDWATERS

The groundwaters are essentially chloride waters with sodium chloride—received as cyclic salt—being the main constituent. Calcium and magnesium carbonates are low and sodium carbonate rare. The carbonates are largely derived from rocks in the range, but also from cyclic-salt sources. Occasionally there is a high percentage of sulphate as calcium or magnesium sulphate. Traces of nitrate ion, which sometimes occur, are often due to human agency. Great variations in the salinity of the shallow waters have been recorded—total soluble-salt figures varying from 26 gr. to 5,507 gr. per gall. having been analyzed.

The distribution of the salinities of the groundwaters between 0 and 100ft. is shown on fig. 5 prepared by Miles and Eley. This shows a general increase in salinity going away from the intake areas. Salinities are also comparatively lower in more permeable media-sands or gravels. It appears that areas of waters containing less than 60 gr. per gall. are limited to strips adjacent to the scarp consequent creeks. In the southern suburbs—south of a line between Oaklands and Somerton—which are influenced by intake from the Sturt River, and in the eastern suburbs between the River Torrens and First Creek, salinities up to 100 gr. per gallon are normal. Over the suburbs between the Brownhill Creek and First Creek intake areas, *i.e.*, the Adelaide City-Parkside-Glenunga districts, groundwater salinities may range over 200 gr. per gall. Salinities continue to rise in the northwestern suburbs, and very saline waters are not uncommon approaching the coast. Some waters with less than 100 gr. per gall., however, have been obtained from the sand dunes between Semaphore and Largs. Some representative chemical analyses for groundwaters and waters within Pre-Cambrian bedrock are given in table I.

TABLE I

Detailed Chemical Analyses of Surface Waters on Adelaide Plains and Hills

Bore No.	Physiographic unit	Chlorine (Cl)	Sulphuric acid radicle (SO_4)	Carbonic acid radicle (CO_3)	Nitric acid radicle (NO_3)	Sodium (Na)	Potassium (K)	Calcium (Ca)	Magnesium (Mg)	Sesquioxides	Silica (SiO_2)	Total saline matter	Total saline matter	Assumed Composition of Salts: Calcium carbonate	Calcium sulphate	Calcium chloride	Magnesium carbonate	Magnesium sulphate	Magnesium chloride	Sodium carbonate	Sodium sulphate	Sodium chloride	Sodium nitrate	Silica	Depth at which water cut	Depth to water level	Date	Locality	D. of M. Analysis No.
		gr/gall	gr/gall	gr/gall	gr/gall	gr/gall	gr/gall	gr/gall	gr/gall	gr/gall	gr/gall	gr/gall	oz/gall	gr/gall	gr/gall	gr/gall	gr/gall	gr/gall	gr/gall	gr/gall	gr/gall	gr/gall	gr/gall	gr/gall	ft.	ft.			
	Torrens River—																												
7	(*a*) Kangaroo Creek dam site	8·61	0·99	8·55	nil	7·36	—	3·00	0·96	—	—	29·47	0·07	7·49	—	—	3·33	—	—	2·99	1·46	14·20	nil.	—	—	—	9/9/49	—	9794
18	(*b*) Weir when reservoirs overflowing	7·65	1·23	3·90	nil	5·07	—	1·14	1·14	—	—	20·13	0·05	2·85	—	—	3·08	1·29	—	—	0·35	12·61	nil	—	—	—	17/11/49	—	10231
19	(*c*) Below lake (after drought)	22·0	16·17	12·15	pres.	12·93	—	4·50	4·46	—	—	62·21	0·14	11·24	—	—	7·60	7·73	2·78	—	—	32·86	pres.	—	—	—	22/7/49	—	9404
20	(*d*) At Welland	32·13	9·96	11·72	trace	16·89	—	4·93	6·36	—	—	81·99	0·19	12·33	—	—	6·07	12·48	8·18	—	—	42·93	trace	—	—	—	23/3/37	—	1819
6	Millbrook Reservoir	8·71	1·54	3·18	0·09	4·65	—	1·48	1·43	0·16	0·01	21·23	0·05	3·7	—	—	1·4	1·7	2·6	—	—	11·3	0·12	0·01	—	—	21/11/28	—	902d
5	Hope Valley Reservoir	5·88	1·63	5·99	0·14	3·65	—	3·04	1·82	0·24	0·02	21·35	0·05	5·1	—	—	4·1	2·0	0·9	—	—	8·76	0·19	0·02	—	—	21/11/28	—	902b
5A	Hope Valley Reservoir	8·61	1·32	11·40	—	6·17	—	3·14	2·73	—	—	33·37	0·07	7·85	—	—	9·40	0·10	—	—	1·83	14·19	—	—	—	—	25/10/34	—	—
35	Sturt River	19·65	2·96	9·00	nil	—	—	2·29	3·76	—	—	48·99	0·11	5·72	—	—	7·83	3·71	2·94	—	—	28·79	nil	—	—	—	14/9/49	10 chains upstream from South Road.	9850
10	Fifth Creek	6·40	2·59	5·85	pres.	3·79	—	1·57	2·27	—	—	22·47	0·05	3·92	—	—	4·92	3·25	0·74	—	—	9·64	pres.	—	—	—	28/9/51	Near quarry	W2099/51
11	Fourth Creek	6·45	1·48	3·90	nil	4·14	—	1·07	1·33	—	—	18·37	0·04	2·67	—	—	3·23	1·86	0·08	—	—	10·53	nil	—	—	—	28/9/51	Stradbroke Terrace bridge	W2098/51
12	Third Creek	8·75	2·88	9·45	trace	4·73	—	2·36	3·02	—	—	32·19	0·07	8·29	—	—	6·21	3·61	1·96	—	—	12·02	trace	—	—	—	28/9/51	Near Magill Road	W2097/51
28	Second Creek	6·90	1·55	3·45	nil	4·49	—	0·79	1·38	—	—	18·16	0·04	1·97	—	—	3·19	2·28	—	—	0·04	11·38	nil	—	—	—	28/9/51	Near Hallett Road crossing	W2095/51
29	First Creek	7·25	2·26	8·40	trace	3·92	—	3·00	2·56	—	—	27·39	0·06	7·49	—	—	5·49	2·83	1·61	—	—	9·97	trace	—	—	—	28/9/51	Beaumont Road bridge	W2095/51
33	Brownhill Creek	10·25	3·74	10·05	trace	5·61	—	3·79	3·28	—	—	36·72	0·08	9·46	—	—	6·16	4·69	2·15	—	—	14·26	trace	—	—	—	28/9/51	Near Mitcham Cemetery	W2094/51
	Detailed Chemical Analyses of Groundwaters on Adelaide Plains																												
2	Newer sand dunes	26·72	5·14	9·60	trace	14·42	—	4·86	3·78	—	—	64·52	0·15	12·15	—	—	3·25	6·44	6·03	—	—	36·65	trace	—	40	20	—	—	958
		1319·20	115·86	30·90	—	787·05	—	24·08	63·29	—	—	6340·38	5·35	51·20	12·84	—	—	133·84	—	—	—	2000·55	—	—	110	28	—	—	959
1	Lower Outwash Plain	2221·62	521·86	8·57	—	1269·69	—	56·67	191·76	—	—	4270·17	9·76	14·28	173·11	—	—	500·92	354·59	—	—	3227·27	—	—	10	—	—	—	2158
3	Lower Outwash Plain	697·16	81·93	8·25	—	299·61	—	39·73	80·63	—	—	1207·31	2·76	13·75	116·10	0·17	—	—	315·75	—	—	761·54	—	—	11	8	—	—	1906
21	Lower Outwash Plain	34·42	10·20	14·42	trace	18·53	—	8·58	4·54	—	—	88·69	0·20	21·42	—	—	2·22	12·78	5·17	—	—	47·10	trace	—	25	25	—	—	4762
23	Lower Outwash Plain	430·5	77·7	31·2	—	264·5	—	14·8	31·0	—	2·0	852·2	1·95	37·0	—	—	12·6	97·3	30·3	—	—	672·8	—	2·0	17	17	—	—	E.W.S.
24	Lower Outwash Plain	31·11	5·51	14·40	trace	14·37	—	7·65	5·66	—	—	78·70	0·18	19·12	—	—	4·12	6·91	12·02	—	—	36·53	trace	—	34	26½	—	—	4819
25	Lower Outwash Plain	35·81	6·38	13·35	—	26·53	—	2·72	3·62	—	—	88·41	0·20	6·80	—	—	12·55	—	—	0·60	9·43	59·03	—	—	14	12	—	—	913
26	Lower Outwash Plain	170·80	23·17	17·55	—	94·84	—	8·15	16·45	—	—	330·96	0·75	20·37	—	—	7·49	29·03	33·01	—	—	241·06	—	—	18	3	—	—	1014
		32·31	7·69	24·30	—	30·40	—	3·43	4·72	—	—	102·85	0·24	8·57	—	—	16·36	—	—	13·28	11·37	55·27	—	—	20	10	—	—	907
17	Para Fault block	46·98	11·89	18·15	24·28	22·34	—	15·79	9·87	—	—	149·50	0·34	30·25	12·53	—	—	3·82	35·64	—	—	33·70	33·56	—	40	40	—	—	1657
27	Upper Outwash Plain	135·4	30·9	40·2	—	95·3	—	9·2	17·5	—	2·0	341·7	0·78	23·0	—	—	37·8	32·6	—	—	6·1	223·4	—	2·0	23	—	—	—	1252
14	Upper Outwash Plain	21·51	5·56	13·53	—	12·89	—	4·86	4·50	—	—	62·85	0·14	12·15	—	—	8·77	6·97	2·19	—	—	32·77	—	—	30	14	—	—	1688
32	Brownhill Creek gravels	9·27	4·07	7·80	trace	6·07	—	3·21	2·21	—	—	32·63	0·07	8·03	—	—	4·19	4·95	—	—	0·18	15·28	trace	—	5	—	—	—	989
34	Near Brownhill Creek	11·34	3·91	9·30	—	6·71	—	3·07	3·23	—	—	37·56	0·08	7·67	—	—	6·60	4·90	1·33	—	—	17·06	—	—	5	surface	—	—	1001
36	On Sturt River floodplain	29·06	4·81	12·45	trace	12·48	—	7·22	5·24	—	—	71·26	0·16	18·05	—	—	2·28	6·03	13·16	—	—	31·74	trace	—	33	26	—	—	1024
37	On Sturt River floodplain	37·98	4·20	9·15	trace	10·23	—	10·65	5·92	—	—	78·13	0·18	15·26	5·95	7·73	—	—	23·18	—	—	26·01	trace	—	30	30	—	—	8969
38	Upper Outwash Plain	27·44	6·91	13·65	trace	15·34	—	5·79	5·07	—	—	74·20	0·17	14·46	—	—	7·00	8·66	5·09	—	—	38·99	trace	—	60	30	—	—	8995
39	Upper Outwash Plain	90·65	29·01	13·20	trace	48·93	—	12·86	10·11	—	—	204·76	0·47	22·02	13·72	—	—	24·22	20·44	—	—	124·36	trace	—	64	64½	—	—	5425

TABLE I.—*continued*

DETAILED CHEMICAL ANALYSES OF UNDERGROUND WATERS WITHIN PRE-CAMBRIAN ROCKS

Bore No.	Physiographic unit	Chlorine (Cl)	Sulphuric acid radicle (SO_4)	Carbonic acid radicle (CO_3)	Nitric acid radicle (NO_3)	Sodium (Na)	Potassium (K)	Calcium (Ca)	Magnesium (Mg)	Iron (Fe)	Silica (SiO_2)	Total saline matter	Total saline matter	Assumed Composition of Salts: Calcium carbonate	Calcium sulphate	Calcium chloride	Magnesium carbonate	Magnesium sulphate	Magnesium chloride	Sodium carbonate	Sodium sulphate	Sodium chloride	Sodium nitrate	Depth at which water cut	Depth to water level	Log of Strata Intersected	D. of M. Analysis No.
		gr/gall	gr/gall	gr/gall	gr/gall	gr/gall	gr/gall	gr/gall	gr/gall	gr/gall	gr/gall	gr/gall	oz/gall	gr/gall	gr/gall	gr/gall	gr/gall	gr/gall	gr/gall	gr/gall	gr/gall	gr/gall	gr/gall	ft.	ft.		
	Artesian Waters																										
8	Para Fault block	32·59	4·65	14·48	—	22·79	—	3·57	4·00	—	—	82·08	0·19	8·92	—	—	12·83	1·49	—	—	5·12	53·72	—	375	Flows	0-103ft. clays, sand, and gravel; 103-126ft. yellow shaly slate; 126-602ft. blue slate; 602-640ft. quartzite	1683
																								602-640			
30	Burnside Fault block	11·41	3·04	16·65	—	8·29	—	4·57	4·26	—	—	48·22	0·11	11·43	—	—	13·75	1·48	—	—	2·75	18·81	—	146-152	Flows	Clays bottoming on bedrock	1462
31	Burnside Fault block	12·46	1·97	15·75	—	11·16	—	3·43	3·45	—	—	48·22	0·11	8·58	—	—	11·97	—	—	4·22	2·91	20·54	—	4,090	—	0-105ft. clays and slate gravel; 105-150ft. slates	1465
																								120-145	Flows		
	Groundwaters																										
4	Para Fault block	134·35	23·21	23·26	trace	92·35	—	6·72	8·47	—	—	288·36	0·66	16·78	—	—	18·55	15·44	—	—	16·10	221·49	trace	120	112	0-1½ft. brown clay; 1½-5ft. travertine; 5-115ft. clays and sandy clays; 115-135ft. sandstone; 135-175ft. grey quartzite; 175-206ft. slates	4578
		143·41	29·17	20·58	trace	96·32	—	8·15	9·05	—	—	306·67	0·70	20·35	—	—	11·78	27·92	—	—	10·19	236·13	trace	181	—		4582
15	Para Fault block	70·97	13·74	13·95	—	54·28	—	2·50	3·25	—	—	158·69	0·36	6·25	—	—	11·27	—	—	3·85	20·32	117·00	—	120	60	0-25ft. clays; 25-135ft. decomposed slate; 135-310ft. blue slate	1441
																								200-300	—		
16	Para Fault block	27·49	9·38	12·75	—	19·37	—	4·36	4·08	—	—	77·43	0·17	10·90	—	—	8·73	7·72	—	—	4·76	45·32	—	50-110	50	0-35ft. clays; 35-50ft. gravels; 50-90ft. limestone and glauconitic sandy clay; 90-200ft. decomposed slates (quartz reef at 110ft.); 200-220ft. blue slate	1425
																								205	—		
14	Upper Outwash Plain	21·51	5·56	13·53	—	12·89	—	4·86	4·50	—	—	62·85	0·14	12·15	—	—	8·77	6·97	2·19	—	—	32·77	—	30	14	0-35ft. sand, gravel, and clay; 35-189ft. slate, merging to quartzite	—
		35·63	6·42	13·83	—	23·80	—	4·22	4·30	—	—	88·20	0·20	10·55	—	—	10·54	6·24	—	—	2·13	58·74	—	180	12		
9	Burnside Fault block	42·98	13·49	17·10	—	28·35	—	6·43	6·18	—	—	114·53	0·26	16·07	—	—	10·48	15·64	—	—	1·49	70·85	—	112-138	40	0-55ft. sands and gravels; 55-112ft. slate; 112-138ft. quartzite; 138-160ft. slate	1673
13	Burnside Fault block	35·42	42·10	13·65	—	29·76	—	9·36	6·92	—	—	137·21	0·31	22·77	0·82	—	—	34·26	—	—	20·97	58·39	—	400-442	140	0-131ft. shaft; 131-206ft. yellow sand; 206-280ft. lignitic sand and lignite; 280-290ft. white sandy clay; 290-293ft. gravel and sand; 293-305ft. decomposed quartzite with lignite; 305-442ft. quartzite	—

Chapter 4

GEOLOGY

The geological formations of the Adelaide Plains and the adjacent range have now been mapped in detail. The results of the greater part of the area are embodied in the Adelaide geological map sheet (scale 1 mile to the inch), issued by the Department of Mines (1952). The Brighton-Belair-O'Halloran Hill area has been covered by Sprigg (1942) and the relevant portion of his plan is included in fig. 6.

Broadly speaking, the Mount Lofty Horst east and south of the Eden Fault is composed of rocks of Pre-Cambrian age, while on the downfaulted block to the west, younger Tertiary to Recent sediments have been preserved. The Pre-Cambrian bedrock outcrops also become increasingly prominent on the Para block going north from the River Torrens and appear intermittently along the Burnside splinter block.

THE STRATIGRAPHIC SUCCESSION

The subdivision of the Pleistocene-Recent strata has been elucidated, but the absolute geological age of the various Tertiary deposits is still a matter of considerable controversy. Ages from Eocene to Pliocene have been assigned to different beds in the past, the most recent age-determinations having been carried out by Crespin and Cotton (Miles, 1952, Appendix III). In this *Bulletin* the unambiguous terms early, mid, and upper Tertiary have been preferred to describe respectively lacustrine sandy beds and the two marine sequences which carry pressure waters.

Nomenclature of the formations constituting the Adelaide System has also been confusing at times, but it is hoped that the subdivision presented recently by Mawson and Sprigg (1950) will find general usage.

The full stratigraphic succession encountered in the Adelaide region is as follows:

Cainozoic Era

Quaternary

	Maximum thickness ft.
Recent	
(1) White sands of the modern coastal dunes	50
(2) Re-sorted sands, clays, and gravels of the Hope Valley-Golden Grove area	± 50
(3) Alluvial flood-plains and terraces	—
(4) Red sands of Osborne high sea-level coastal dunes	50
(5) Marine sands and clays of Osborne high sea-level	10
(6) Alluvial clays and sands	20
(7) Marine sands and clays of Anadara high sea-level	15
Pleistocene	
Mottled terrestrial clays, sands, and gravel; argillaceous sandstones	400
Tertiary	
Upper	
Fossiliferous calcareous sandstones, clayey sands, and sandy limestones; slight angular unconformity in part	200-220
Middle	
Fossiliferous limestones, marls, and sands	1,155
Early	
Lacustrine mottled sands, clay, and minor lignites	645 +

Unconformity

Proterozoic Era (Adelaide System)

Marinoan Series

(1)	Grey and flaggy quartzites, with or without interbedded slates	1,150 +
(2)	Chocolate quartzites and slates, in part regularly alternating	2,250
(3)	Massive grey quartzites, with slate bands	300
(4)	Chocolate slates, in part calcareous and dolomitic	140
(5)	Grey and purple quartzites, flaggy quartzites, and slates ..	270
(6)	Chocolate and grey slates, with a little calcareous arkose and thin bands of quartzite	300
(7)	Hallett Arkose (pebbly in part), and associated quartzites and sandy limestone	180
(8)	Flaggy quartzites	200
(9)	Chocolate and grey flaggy quartzite and slate	500
(10)	Chocolate siliceous slates passing down into calcareous slates	630

Sturtian Series

(1)	Brighton limestone, in part oolitic	100
(2)	Tapley Hill calcareous laminated slates and siliceous banded limestones, with many intraformational breccias	10,500
(3)	Sturtian Tillite, with interbedded glaciofluvial slates and quartzites	1,000
(4)	Belair slates and quartzites group including Mitcham Arkosic Quartzite	1,000

Torrensian Series

(1)	Brighton limestone, in part oolitic	100
(2)	Beaumont Dolomites and interbedded slates	450
(3)	Upper phyllites, with minor quartzites; a few thin dolomites	1,000
(4)	Stonyfell Quartzite, in part argillaceous and arkosic	1,000
(5)	Lower phyllites and slates, with minor quartzites	1,100
(6)	Montacute Dolomite, blue and grey dolomites, limestones, and sedimentary magnesites, with chert bands and minor quartzites	430
(7)	Phyllites, with minor quartzites	680
(8)	Castambul Dolomite—light coloured cryptocrystalline dolomite	150 +
(9)	Phyllites and slates	100
(10)	Aldgate Sandstones—mainly argillaceous and in part ilmenitic, with interbedded slates and minor conglomerates (very variable in thickness)	1,000-3,000

Unconformity

Archaeozoic Era

Schists and gneisses, diorites and pegmatites.

GEOGRAPHY OF THE PRINCIPAL FORMATIONS

The Adelaide System is folded into a major regional anticline over a core of Archaeozoic rocks and the whole has been extensively dislocated by Palaeozoic faults. Some of these have been reopened in later Cainozoic times to produce the horst range and graben system. The Palaeozoic faulting has resulted in a complicated pattern of fault blocks causing much repetition of rock types along the range escarpment and a complication of rock types exposed in particular escarpment stream head-waters. Along the Para block a synclinal axis runs NNE. from near Modbury parallel to the main anticlinal axis of the range.

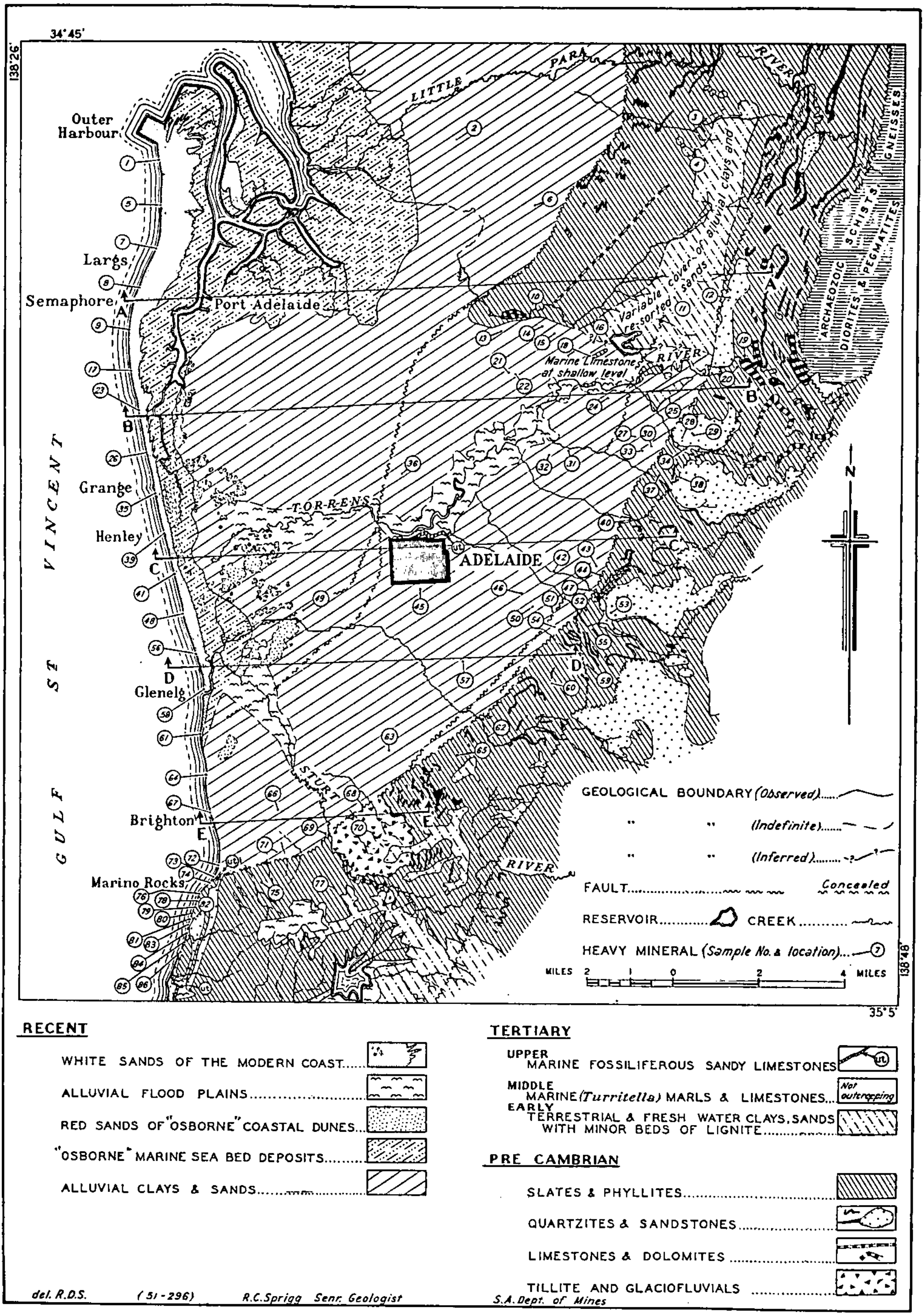

Fig. 6—GEOLOGICAL MAP OF THE ADELAIDE PLAINS AND THE WESTERN ESCARPMENT OF THE MOUNT LOFTY RANGE

Most of the individual formations have been the subject of detailed petrographic, chemical, and palaeontological investigations by different workers, and reference should be made to the relevant papers where cited. Discussion will be limited here to a broad discussion of the more important formations and an indication of their geographic distributions.

Archaeozoic

The older Pre-Cambrian complex forms the core of the range and consists of a variety of metasediments—schists and gneisses—which have in part been metasomatized to syenites and diorites and intruded by pegmatite dykes. The metamorphic complex is generally referred to as Barossian in age, a term introduced by Woolnough (1904) for similar rocks in the Barossa Valley and extended to the Houghton district by Benson (1909). An inlier of these rocks occurs between Filsell Hill and Crafers, but the main belt, which has influenced soil formation on the Adelaide Plains extends northward from the River Torrens, near Castambul, and is 3-5 miles wide. There is also a small inlier northwest of Aldgate.

Benson carried out a petrographic study of rocks in the Houghton district and showed the commonest minerals present in the diorite to be sodic plagioclase and uralitic diopside. Ilmenite is a common constituent of all rocks, and epidote is common. Quartz-tourmaline veins frequently occur. A general petrographic description of the Barossian rocks, with particular reference to the Houghton Diorite is included in a recent report by Whittle and Webb (in the press).

Proterozoic

Torrensian Series

The lowermost series of sedimentary rocks within the Adelaide System forms the greater proportion of the country on the Para block and on the Eden-Moana block north of Sleeps Hill. The earliest attempt to systematize the classification of the beds was by Howchin (1906), and the succession was finally elucidated by Sprigg (1946). Both authors give petrological descriptions of individual rock types.

The landscape south of Mount Lofty, and between Waterfall Gully and the River Torrens, is dominated by a single thick rugged formation—the Stonyfell Quartzite—which forms the prominent landmarks of Black Hill, Rocky Hill, Rockdale Hill, and Mount Lofty. However, in the formation of the outwash alluvials of the plains, the greatest contributions have been made by the more easily eroded calcareo-argillaceous rocks (slates and phyllites), for while the sandstones and quartzites are not normally eroded deeply, the slates have been extensively denuded. Much of the area of quartzites represents little more than an exposure of the formation by removal of some overlying more argillaceous bed (*e.g.*. along the Greenhill branch of the Waterfall Gully Creek and the Morialta Creek). However, a gorge has been developed by Second Creek (Slape Gully) in resistant quartzite, producing a massive outwash apron of quartzite boulders and siliceous sand at the base of the escarpment.

The Beaumont Dolomites form an important group of beds locally in the valleys behind Brown Hill and again immediately to the north and south of Mt. Osmond. These beds have been studied in detail at Beaumont and the Devil's Elbow by Barnes and Kleeman (1934) and chemical analyses by them indicate that some 13 bands of true dolomite are present. Their occurrence probably accounts for the relatively high percentage of calcium and magnesium in the waters of Brownhill Creek.

The Montacute and Castambul Dolomites are quite thick dolomitic horizons, but their relative influence on the formation of alluvial soils is small because of the large area of country drained by the River Torrens and its tributaries. Sprigg (1945) quotes analyses for these rocks and Howchin (1906) discusses them at length.

North of the River Torrens, the forefront of the range consists predominantly of quartzite with slates and thin dolomite farther east. Bedrock on the Para block consists largely of slates and phyllites (in part calcareous) with interbedded thin quartzites. One prominent dolomite band can be traced along the block in a northeasterly direction from just east of Yatala Stockade.

Torrensian sediments also appear along the Torrens valley as far downstream as Windsor.

Sturtian Series

This group of glacial and glaciofluvial beds extends along the ranges from the Brighton limestone quarry to Glen Osmond. Howchin (1901, 1904, 1906, 1927) and Sprigg (1942, 1946) have discussed the beds at length. The Belair group of slates and interbedded quartzites is found between Shepherd Hill Creek and the Princes Highway and extends back from the main scarp for distances varying from 1 mile to 3 miles. The sediments have been described recently in detail by Solomon (unpublished). Woolnough (1904) studied the mineralogy of the 100ft. thick Mitcham Arkosic Quartzite, and showed that it consists of largely quartz and up to 40 per cent felspar (albite, microcline, and kaolinized orthoclase). Sericite is also common.

The Sturtian Tillite extends for 1-1½ miles north from the Sturt River in the Shepherd Hill area. The tillites introduce into the succession a great variety of erratic rock types set in a slaty matrix and complicate the mineralogical composition markedly.

The overlying Tapley Hill laminated calcareous slates and limestones provide the predominating calcareo-argillaceous influence for the soil-forming sediments between Darlington and Seaview. The uppermost siliceous limestones may contain from 40-80 per cent lime with magnesia usually about 3-5 per cent. In normal laminated slates, lime can vary from zero to 10 per cent, and there is usually 2-5 per cent magnesia present.

The Brighton Limestone (in part dolomitic) is a well-known horizon because of its economic importance, but from the point of view of soil formation it is too thin to be more than of very local importance.

Marinoan Series

This series represents a change from glacial to red-bed conditions and has been generally referred to as Purple Slates Series (Howchin 1904 etc.). It consists of quartzites and slates with minor limestones and one notable arkose horizon. The slate influence is most pronounced in that part of the series which forms the southern hills immediately to the west of Marino. The lime content of the slates is much lower than that in the underlying Sturtian Series.

The contribution of this series to the development of the soils of the plains has been very small because of its limited outcrop extent in the area drained by the escarpment creeks.

Cainozoic

Tertiary

K. R. Miles (1952) gives a comprehensive summary of available data on the Tertiary sediments. Because of their very restricted occurrence in outcrop and their slight influence on the development of present-day soils, these formations are only discussed very briefly here.

Early Tertiary

Lacustrine mottled sands, argillaceous sandstones, and clays of this formation occur sub-horizontally on a pre-Tertiary erosion surface. Most of the sands evidence prolonged erosive activity and many grains are poly-cyclic products. Lignitic clays, thin seams of brown coals, and occasional gravel beds occur sporadically through the succession.

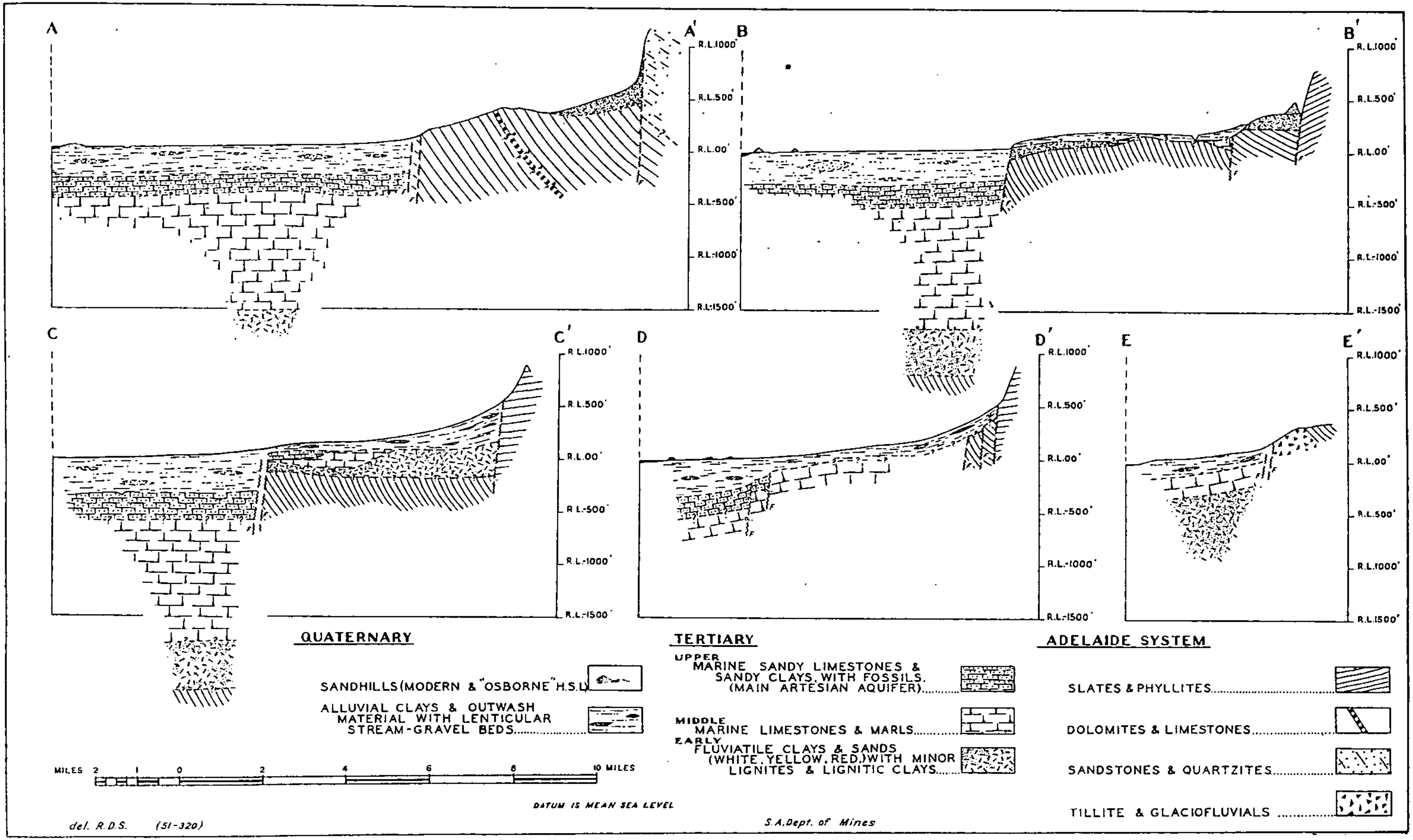

Fig. 7—GEOLOGICAL SECTIONS OF THE ADELAIDE PLAINS AND THE WESTERN MOUNT LOFTY RANGE AREA

Between Paradise and Golden Grove, outcrops of mottled sandstone—and rarely, white clay—occur, which may be referable in part to the early Tertiary, but it is difficult to differentiate such sediments from the post-block faulting re-sorted sands and gravel which are distributed liberally throughout the area. Similar mottled argillaceous sandstones are found in the Athelstone-Thorndon Park area and at isolated points on the Burnside Fault block at least as far south as Waterfall Gully.

The southerly tilting movement associated with the Para block has brought the early Tertiary sediments close to the surface towards the western side of the Para block. For example, bores at Northfield have encountered sands below a shallow (less than 10ft.) alluvial clay cover.

There still remain a few outliers of lateritized early Tertiary sediments in the Mt. Lofty Range and the southern hills, but, except in the Sturt River area, they are beyond the limits of the creeks draining out on the plains.

Middle Tertiary

In the downfaulted areas the early Tertiary formations are disconformably overlain by marine sandy limestones, sandstones, limestones, and marls, which are frequently highly fossiliferous. The mid-Tertiary beds consist principally of bryozoal limestones and *Turritella* marls, but towards the base green glauconitic sandstones became prominent. The formation underlies the greater part of the plains with gentle west-southwesterly dips, except where dragged up against the Eden Fault. Near Gaza and Klemzig the limestones occur at shallow depth and are being eroded by the River Torrens.

Upper Tertiary

Fossiliferous blue-grey calcareous sandstones, sandy limestones, and clayey sands of upper Tertiary age attain a maximum known thickness of 200-220ft. in the Lockleys district, but erosion has thinned the beds considerably inland from the Para Fault. Shelly limestones formerly outcropped in quarries along the southern bank of the River Torrens immediately north of Government House, and can still be seen at the coast at Marino where a small outlier occurs against the main escarpment fault. Under the Adelaide city area, the formation has been encountered in excavating deep building foundations and is sometimes utilized in drainage bores.

Quaternary

Pleistocene

Overlying the Tertiary limestones and sandstones, with minor unconformity, are up to 400ft. of terrestrial mottled clays with minor discontinuous beds of creek sands and gravels. They represent the products of erosion of overmass and undermass beds from the upfaulted range regions. The clays generally exhibit marked mottling, the most common colours being red-brown, yellow-brown, and light grey. The calcareous content is very variable and is present as calcium carbonate, either as nodules or as diffuse matter. Manganese staining is sometimes prevalent, and, rarely, horizons of small laterite nodules are found.

Recent

Sands and clays of Recent marine, fluviatile, and aeolian origin form the uppermost deposits over the greater part of the plains and most soils have developed on these materials. The deposition of mottled terrestrial clays and creek sands and gravels has proceeded continuously throughout Pleistocene into Recent times. There is evidence of at least two periods of still-stand along the Torrens valley between the hills and the city area, with the development of minor meanders and the deposition of fertile gravelly silt flats, so prized by market gardeners and orchardists. The Sturt River and the River Torrens west of the Para Fault are flanked by zones of dark silty flood material which broaden out approaching the sea. Levee banks are charactertisic of both streams. The smaller creeks do not have similar dark flats, but gravel beds often underlie or are adjacent to them.

Exploratory boring for brown coal near Hope Valley Reservoir has indicated that the uppermost more-or-less consolidated accumulations of sands, clays, and gravels are post-Burnside Fault movement in age. In the Golden Grove-Hope Valley area the sands are extensively quarried for use as building sands. They are difficult in the field to distinguish from the underlying early Tertiary sandstones, and probably represent re-sorting of the latter beds by stream action.

Deposits in the subcoastal districts include the two series of sand dunes previously described, marine marls formed during two periods of high sea-level and some 10-20ft. of alluvial clays and sands formed in between these two periods. The older marine incursion has been called the Anadara high sea-level because of the large development of the pelecypod, *Anadara trapezia,* within the sands and clays. Over the present estuarine plain, varying successions of fluviatile silts and clays, aeolian sands, and marine deposits are encountered. Fauna characteristic of the younger Osborne high sea-level in the Port Adelaide-Outer Harbour area, and remaining there to the present day, include *Katelysia peroni, K. scalarina, Bullaria termissima, Macoma deltoidalis, Zeacumantus diemenensis, and* many other forms. In some areas, *e.g.,* Wingfield, muds typical of subcoastal swamps are found, while about 1 mile south of Glenelg red clays over blue-grey clays containing mangrove roots are exposed on the beach under exceptional tidal conditions (Cotton 1949). Locally, in some of the seaside suburbs, solid travertine is encountered at shallow depth.

Some of the major geological features illustrative of the pre-going discussions are given in the geological sections (fig. 7). The progressive south plunge of the surface of the Para block is well shown by comparison of the serial cross-sections.

THE SEQUENCE OF EVENTS LEADING TO THE DEVELOPMENT OF THE ADELAIDE PLAINS

The formation of the Adelaide Plains is intimately concerned with late Cainozoic block faulting. Differential block movements formed the Gulf St. Vincent sunken valley or graben on the west, and a step-faulted but well-defined "horst" range flanking to the east, while oscillatory movements of Quaternary sea-level and the changing elevations of the fault blocks in the graben area complicated the history considerably.

Prior to the reopening of the ancient faults to accentuate the horst-graben structure, the undermass (Adelaide System) sediments were peneplained and blanketed extensively in low-lying areas (Glaessner 1953) by up to several hundred feet of light-coloured early Tertiary fluviatile clays and sands. The depressed areas were subsequently inundated by mid- and late-Tertiary seas.

With the renewed activity of block faulting, particularly during the Plio-Pleistocene Period, and following a further (late Miocene-early Pliocene) period of peneplanation (Fenner 1930) the pre-existing positive and negative areas were accentuated into the well-developed horst-graben area of the present day. Remnants of the dismembered pre-Tertiary erosion surface came to lie at elevations separated by as much as 4,000ft. Upper Tertiary seas merely lapped at the foot of the developing mountain range (fig. 8).

Faulting reached its zenith during the Quaternary Period and by differential block movements and by eustatic sea-level changes the sea was again excluded from much of the Gulf region. The extensive removal of Tertiary "overmass" sediments which had commenced during the upper Tertiary now became greatly accelerated. The stripping proceeded rapidly as differential block elevation and the associated relative lowering of base level became more extreme. Pluviality of

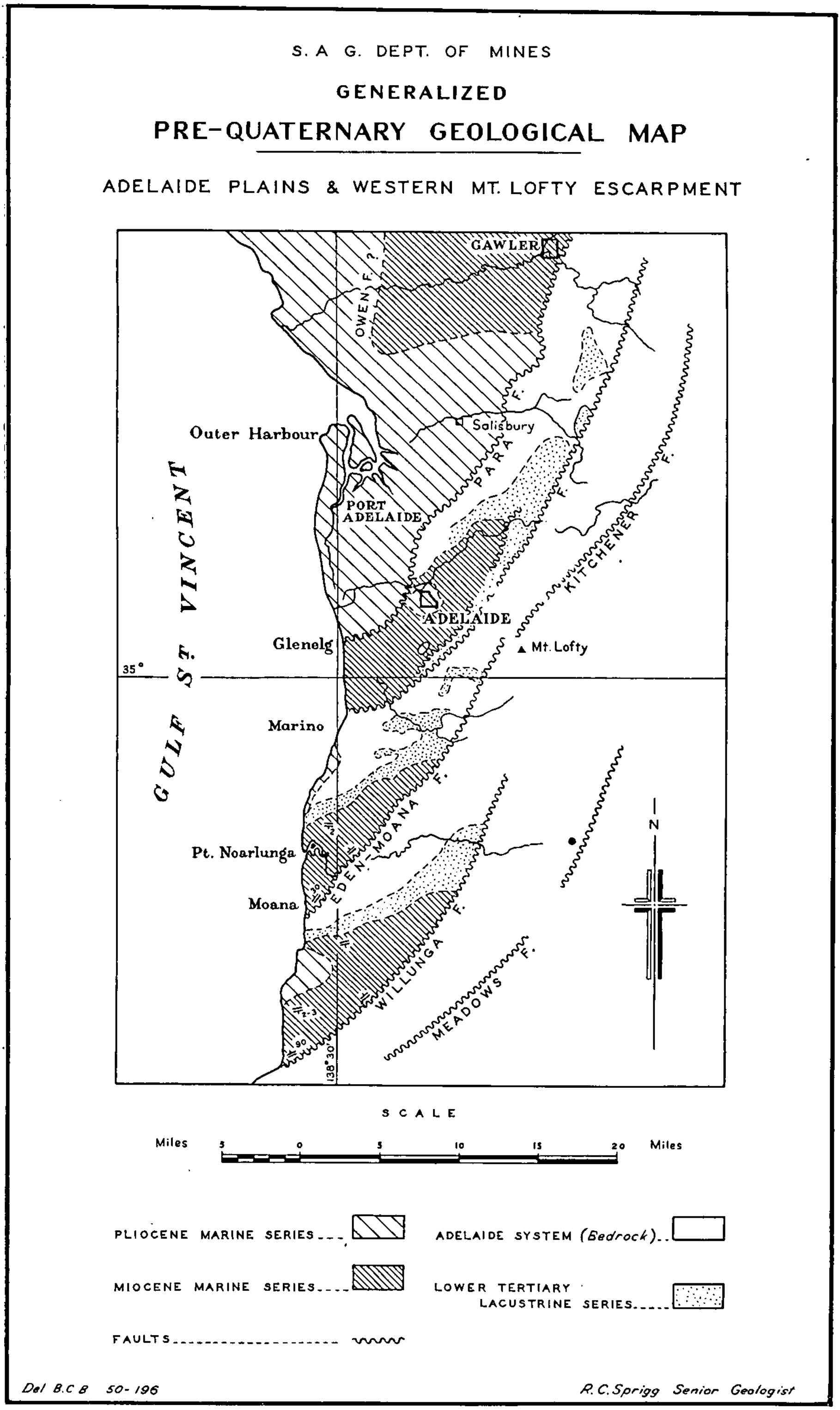
S. A G. DEPT. OF MINES
GENERALIZED
PRE-QUATERNARY GEOLOGICAL MAP
ADELAIDE PLAINS & WESTERN MT. LOFTY ESCARPMENT
GAWLER
OWEN F. ?
Salisbury
PARA F.
KITCHENER F.
Outer Harbour
PORT ADELAIDE
GULF ST VINCENT
ADELAIDE
Glenelg
Mt. Lofty
35°
Marino
EDEN-MOANA F.
Pt. Noarlunga
Moana
WILLUNGA F.
MEADOWS F.
138°30'
N
SCALE
Miles 5 0 5 10 15 20 Miles
PLIOCENE MARINE SERIES
MIOCENE MARINE SERIES
FAULTS
ADELAIDE SYSTEM (Bedrock)
LOWER TERTIARY LACUSTRINE SERIES
Del B.C.B 50-196
R.C.Sprigg Senior Geologist

Fig. 8

the Pleistocene glacial phases aided erosion still further. Eroded material from the horst region was transported to the sunklands and there spread on the collapsing block surfaces as massive outwash accumulations (dominated by variegated clays) exceeding 300ft. in thickness. These comprised the developing Adelaide Plains. Source materials of these outwash alluvials were at first largely Tertiary overmass sediments but bedrock was probably extensively exposed by early Pleistocene times.

During practically the whole of the Pleistocene Period the sea was excluded from much of the sunklands area. In Recent times, by continued graben sinking, the sea was again admitted extensively. Maximum encroachment corresponded with the climatic optimum (mid-Recent warm stage) and left a fossil fauna characteristic of sub-tropical seas (*e.g.,* the dominant pelecypod *Anadara trapezia*). This was the Great Australian Arid Period of Crocker (1946) and in its interval the deserts of Australia were at peak development. Desert (sief) sand dunes and clay pans were present on the Adelaide Plains at least as far south as Roseworthy.

A pronounced marine recession followed the Anadara high sea-level permitting extensive travertinization of the exposed shell-beds seaward far beyond the present coast-line. In the Port Adelaide area, as on the western side of the Gulf St. Vincent, the travertinized *Anadara* beds may lie 20ft. or more below modern low water and indicate at least an equivalent sea-level decline.

In this post-Anadara terrestrial phase, alluvials were deposited over the shell beds to depths of 15ft. or more. They were followed in turn by another high sea-level phase in Holocene times which again inundated the low-lying plains only slightly less than the Anadara high-sea level. It left huge shell-banks extending just above modern high-water level in the Osborne, Dry Creek, and St. Kilda areas (Marshall and Walkley 1934). A minor warm period to be correlated with this last, or Osborne (Sprigg 1952) high sea-level probably gave the local desert areas their latest peak activity.

Both the Anadara and Osborne high sea-levels transgressed the line of the modern sea-coast in the vicinity of Patawalonga Creek. Both produced mangrove swamps, the remains of which can be traced north from Somerton (Cotton 1949) through Lockleys, Port Adelaide, and north along the eastern margin of the Gulf. Maximum landward overlap by the Osborne high sea-level occurred in the vicinity of Dry Creek, and its deposits have since been blanketed in the extreme landward extension by a foot or more of black swampy alluvial clays. Coastal sand dunes were formed along the irregular "Osborne" sea-coast from Somerton to Port Adelaide, but latterly, with a minor retreat of the sea, these have been stranded. The dunes were fixed and varyingly ferruginized, and soil horizons have developed within them. In the Marino vicinity the "Osborne" coast was marked by steep cliffs in outwash clays and gravels. These are also now clearly stranded.

A new coastal dune now lines the modern coast, and until recently, with the erection of harbour structures at Outer Harbour, the dunes continued to grow northward by the formation of a succession of bay-bar hooks. Sand is transported northwards along the coastal shallows under existing wind, wave, and tidal regimes, and much of it comes to rest in subaerial dunes and, until recently (before harbour construction), also at the finger-like extremities of LeFevre Peninsula in the hook complexes. Now, with the erection of the Outer Harbour breakwaters, siltation of the foreshore shallows is occurring rapidly and extensive areas are already stranded above tidal level. A correspondingly rapid retreat of the 5-fathom and other contours is also notable.

Chapter 5

CLIMATE

The present-day climatic environment of the Adelaide Plains is essentially that of a warm temperate zone. In general terms the climate may be described as typically Mediterranean, having a pronounced seasonal cycle of winter rainfall summer drought. Winters are mild with a monthly mean minimum temperature approximating 45°F., while the summers are warm to hot with a monthly mean maximum exceeding 80° Fahrenheit.

METEOROLOGICAL DATA

Rainfall intensity is quite variable over the Adelaide Plains, and even within the metropolitan area there is a range of average annual rainfall from less than 16in. to more than 25in. The distribution of rainfall is shown in fig. 9. As the land surface rises gently from the seaboard the isohyets are widely spaced. On the steeper slopes adjacent to the fault-line escarpments, precipitation is more intense and rainfall continues to increase with increasing altitude beyond the mapped areas. To the north of the city there is a tendency for a decline in precipitation as compared to equivalent elevations in the southern suburbs. This decline is partially an effect of gentler slopes and greater distance from the seaboard, but is principally a consequence of the fact that most of the winter rains are borne by southwest winds.

Climatological data are recorded at only three stations within the mapped areas. These data are given in table II., for Adelaide, Waite Institute, and Dry Creek. In addition, the values for stations adjacent to the metropolitan area are given in table III—viz., for Roseworthy which is on the plains to the north of the city and for Stirling and Belair which are southeast of the city on the Eden-Moana fault block at elevations of more than 1,000 feet.

CLIMATIC INDICES

There is a general tendency for rainfall and humidity both to increase with altitude, and for temperature and evaporation to decrease with altitude. Thus the effectiveness of rainfall in promoting leaching of the soil is accentuated in the higher areas. Adopting Prescott's (1949) annual index $P/E^{0\cdot7}$ as the basis for differentiation of climatic zones it is evident that the soils of the Adelaide Plains area are affected appreciably by the variation in the leaching factor.

Table IV summarizes the range of the index $P/E^{0\cdot7}$ throughout the suburban and adjacent areas. Since it can be assumed that the isologs of this index will tend to follow isohyets (particularly where these are reasonably parallel to contours) it is not difficult to separate the Adelaide suburban area into appropriate climatic zones. For this purpose the values of the index corresponding to the principal boundaries between soil groups, as suggested by Prescott, are of interest.

Those elevated districts which correspond to the Eden-Moana escarpment area and the Burnside Fault block have climatic indices greater than 1·70 and thus may be considered as zones of podsolization. Most of the remainder of the suburban area, including the upper and the lower outwash plains, has a drier climate with annual indices within the range of 0·92 to 1·70. These limits are normally associated, in well-drained areas, with red-brown earths and black earths. Only to the north of the city is there a zone with an index below the value of 0·92, which is considered to be the boundary between the red-brown earths and the grey and brown soils.

TABLE II

CLIMATOLOGICAL DATA FOR STATIONS WITHIN THE SUBURBAN AREA

Location—	Waite Institute Lat. 34° 58′ S. : Long. 138° 38′ E. : Alt. 402ft.						Adelaide Lat. 34° 56′ S. : Long. 138° 35′ E. : Alt. 140ft.						Dry Creek Lat. 34° 50′ S. : Long. 138° 45′ E. : Alt. 20ft.					
	P	E	Temperature *			R.H.	P	E	Temperature			R.H.	P	E	Temperature			R.H.
			Max.	Min.	Mean				Max.	Min.	Mean				Max.	Min.	Mean	
	in.	in.	°F.	°F.	°F.	per cent	in.	in.	°F.	°F.	°F.	per cent	in.	in.	°F.	°F.	°F.	per cent
January	1·06	8·59	81·3	60·2	70·8	49	0·76	9·17	85·8	61·3	73·5	38	1·15	12·47	—	—	71·4	—
February	1·22	7·03	81·0	60·7	70·8	52	1·10	7·45	85·5	61·7	73·6	42	1·26	10·21	—	—	70·1	—
March	0·99	6·41	78·5	59·6	69·0	52	0·87	6·15	80·8	58·8	69·8	46	0·67	8·92	—	—	66·0	—
April	1·99	3·99	70·2	54·3	62·2	62	1·45	3·64	73·1	54·4	63·7	55	1·82	5·30	—	—	50·4	—
May	2·91	2·75	64·3	50·7	57·5	68	2·49	2·18	65·8	50·3	58·1	67	2·08	3·36	—	—	45·8	—
June	2·89	1·76	58·8	46·5	52·6	75	2·93	1·32	60·4	46·6	53·5	76	1·88	2·21	—	—	51·1	—
July	3·16	1·75	57·3	45·3	51·3	76	2·49	1·37	59·1	44·8	52·0	76	2·22	2·34	—	—	50·9	—
August	3·12	2·28	59·1	45·8	52·4	71	2·58	2·00	62·0	45·9	53·9	69	2·06	3·11	—	—	52·0	—
September	2·70	3·21	63·6	48·0	55·8	65	2·39	3·01	66·4	47·9	57·2	60	1·45	4·78	—	—	55·0	—
October	1·84	4·63	68·4	50·7	59·5	60	1·54	4·90	72·2	51·3	61·8	51	1·53	7·03	—	—	58·3	—
November	1·47	6·20	74·3	54·8	64·6	51	1·22	6·73	78·3	55·2	66·8	44	1·43	9·35	—	—	63·5	—
December	1·17	7·83	78·8	57·9	68·3	51	1·27	8·61	83·0	58·8	70·9	40	1·03	11·55	—	—	68·8	—
	24·52	56·43	69·6	52·9	61·3	61	21·09	56·45	72·7	53·1	62·9	53	18·58	80·63	—	—	58·6	—
	Total	Total	Mean	Mean	Mean	Mean	Total	Total	Mean	Mean	Mean	Mean	Total	Total	—	—	Mean	—

P—Precipation E—Evaporation R.H.—Relative humidity (9 a.m. readings).

* Temperatures are given as monthly mean maximum and minimum figures.

TABLE III

Climatological Data for Stations Adjacent to the Suburban Area

Location—	Roseworthy Lat. 34° 05′ S. : Long. 138° 45′ E. : Alt. 208ft.						Stirling West Lat. 35° 0′ S. : Long. 138° 43′ E. : Alt. 1,628ft.						Belair (Kalyra) Lat. 35° 0′ S. : Long. 138° 38′ E. : Alt. 1,010ft.					
	P	E *	Temperature			R.H.	P	E *	Temperature			R.H.	P	E *	Temperature			R.H.
			Max.	Min.	Mean				Max.	Min.	Mean				Max.	Min.	Mean	
	in.	in.	°F.	°F.	°F.	per cent	in.	in.	°F.	°F.	°F.	per cent	in.	in.	°F.	°F.	°F.	per cent
January	0·90	11·2	86·7	57·7	72·2	45	1·54	6·7	75·9	52·4	64·2	56	1·07	8·5	79·0	58·0	68·5	53
February	0·66	8·9	87·8	59·5	73·6	48	1·67	6·2	77·6	53·8	65·7	56	0·80	6·7	80·7	59·8	70·2	52
March	0·78	6·8	81·8	55·3	68·6	53	1·66	3·7	71·4	50·3	60·8	61	1·25	5·3	74·7	57·0	65·9	59
April	1·51	4·5	74·2	50·7	62·4	64	3·31	2·6	64·4	47·4	55·9	72	2·36	3·4	67·4	53·2	60·3	69
May	1·78	2·5	66·5	47·7	57·1	75	5·81	1·4	57·7	44·5	51·1	78	3·59	2·2	61·3	50·0	55·6	74
June	2·35	1·7	60·8	43·9	52·3	84	6·95	0·8	52·2	41·8	47·0	85	4·60	1·5	55·4	45·7	50·6	84
July	1·89	1·7	59·5	42·4	51·0	85	6·26	0·8	50·7	40·3	45·5	85	3·68	1·5	53·7	44·1	48·9	84
August	2·12	2·5	62·2	43·2	52·7	78	6·13	1·4	53·3	40·9	47·1	79	3·63	2·1	56·4	45·1	50·7	80
September	1·85	3·5	67·1	44·6	55·8	71	5·55	1·9	57·5	43·0	50·3	73	3·01	3·1	60·7	47·4	54·0	73
October	1·61	5·8	73·2	48·0	60·6	59	3·28	3·4	62·9	44·9	53·9	66	2·19	4·5	66·7	50·2	58·5	66
November	1·05	8·3	79·1	52·7	65·9	50	2·38	4·7	68·9	48·0	58·4	61	1·43	6·2	72·8	53·5	63·1	56
December	0·88	10·4	83·8	56·1	70·0	48	2·01	5·8	73·3	50·7	62·0	59	1·21	7·9	76·5	56·4	66·5	55
	17·38	67·8	73·6	50·2	61·9	63	46·55	39·4	63·8	46·5	55·1	67	28·82	52·9	67·1	51·7	59·4	67
	Total	Total	Mean	Mean	Mean	Mean	Total	Total	Mean	Mean	Mean	Mean	Total	Total	Mean	Mean	Mean	Mean

P—Precipitation E—Evaporation R.H.—Relative humidity (9 a.m. readings) * Evaporation is a calculated figure.

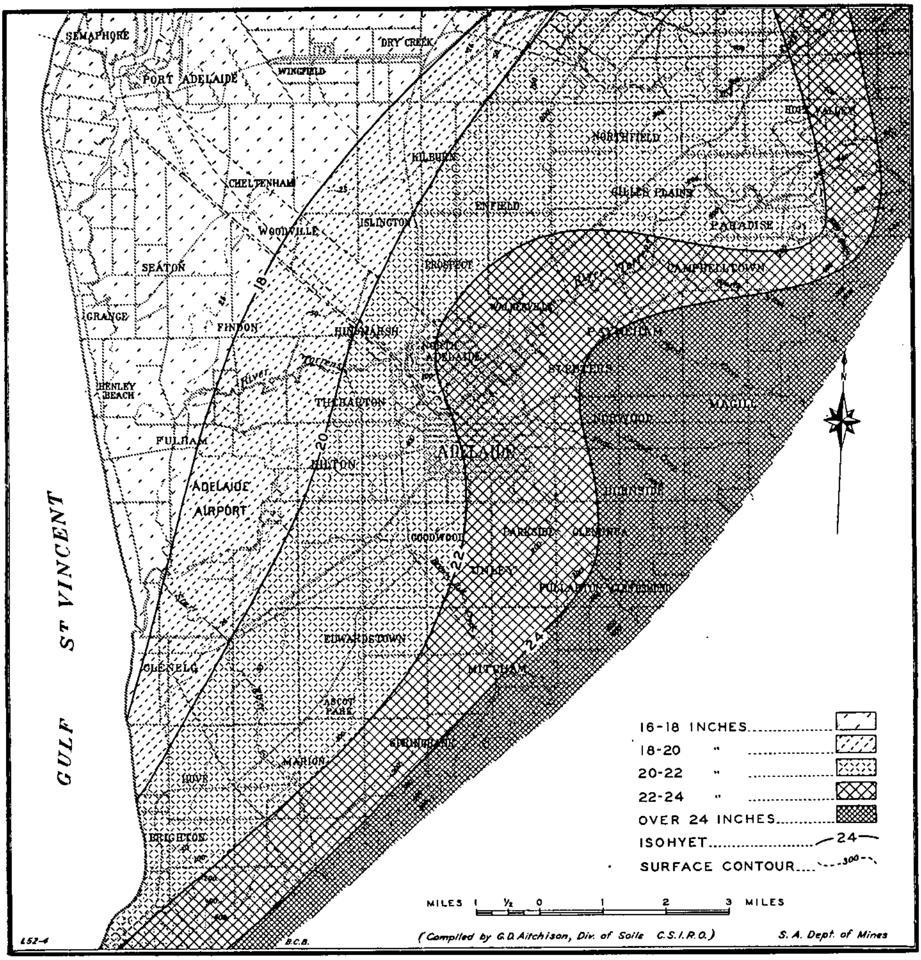

Fig. 9—MAP OF ADELAIDE AND SUBURBS
Showing average annual rainfall (compiled from Commonwealth Meteorological Bureau data)

Climatological data in the suburban areas is too scanty to support precise zoning. However, from the limited information available, the approximate location of the isologs of selected indices can be deduced to provide a background for some discussion of soil formation. Within reasonable limits of accuracy, the 25-in. and the 17-in. isohyets may be considered to represent also the $P/E^{0\cdot7}$ isologs of 1·70 and 0·92 respectively.

TABLE IV

VALUES OF THE ANNUAL CLIMATIC INDEX $P/E^{0\cdot7}$ FOR STATIONS ADJACENT TO ADELAIDE

Location	Altitude ft.	Precipitation P–in.	Evaporation E–in.	$P/E^{0\cdot7}$
Dry Creek	20	18·6	80·6	0·86
Roseworthy	208	17·4	67·8	0·91
Adelaide	140	21·1	56·4	1·26
Waite Institute	402	24·5	56·4	1·46
Belair	1010	28·8	52·9	2·37
Stirling West	1628	46·6	39·4	3·60

Chapter 6

CONTROLS IN SOIL DEVELOPMENT ON THE ADELAIDE PLAINS

A great variety of processes operate in the development of a soil. Within a restricted environment such as exists on the Adelaide Plains the principal non-biological controlling factors in soil formation are of a geological, physiographical, and to a lesser extent of a climatic nature. These controls may be grouped as follows:

(1) Parent or source material.
(2) The influence of antecedent aridity.
(3) The formation of calcareous loess.
(4) Contributions of cyclic salts.
(5) Topography and drainage.
(6) Climatic effects.

There is no suggestion that these are the only items of importance in soil formation in this area. All of the normal pedogenetic processes are operative, but those discussed have been observed to have some significance in one or more parts of the mapped area.

PARENT OR SOURCE MATERIAL

The nature of the parent material from which a soil is derived must have an important influence upon ultimate soil-type. A soil may be modified drastically by pedogenetic processes, but some imprint of its origin will generally remain. Texture, gravel content, soil structure, soluble salt content, fertility, and particularly mineralogical composition are all dependent to varying extents on the parent rock-type.

Subsequent to their initial formation, rock minerals are subject to modification by the processes of lithifaction and metamorphism. Once exposed to moisture and the atmosphere, decomposition of the more unstable minerals readily takes place. For example, felspars tend to break down to micas or kaolinite, and primary ferromagnesians into secondary minerals such as epidote, chlorite, etc. Quartz on the other hand remains unaltered. Erosion by creeks greatly accelerates these changes. Where jointing is prominent in quartzitic rocks, mechanical disintegration is marked, and an important source of gravels is provided. Generally speaking both sedimentary rocks and alluvial soils tend to contain a simple assemblage of minerals representing end-products after weathering and transport. Quartz, weathered felspars, clay minerals, and micas are most common, together with the more resistant accessory heavy minerals, *e.g.*, zircon, tourmaline, garnet, and iron oxides.

In considering soils of the Adelaide region in which the significance of the geological factor can be readily recognized, two major categories appear to be of importance. They are the sedentary or shallow *in situ* soils developed upon outcrop, and the deeper soils formed principally upon alluvial fan outwash. Also along much of the foothills area overlying the Burnside splinter block, are soils probably more of a colluvial origin, the material being derived from outcropping Pre-Cambrian rocks—at slightly higher elevations—by erosion and hillside creep. Angular talus and gravels are plentiful here.

Parent Material of Sedentary Soils

Although sedentary soils are common throughout the Mt. Lofty Range above the Eden Fault—they occur only infrequently within the areas discussed in this *Bulletin.*

Adelaide System rocks outcrop to an increasing extent to the north along the Para block and also intermittently along the Burnside block, but in both areas alluvial-outwash parent-material is normally present. Sedentary soils on the Para block should therefore reflect a strong calcareo-argillaceous influence due to the underlying slates (in part calcareous) and minor dolomites and quartzites of the Torrensian System.

In the Athelstone and Hope Valley-Golden Grove areas, early Tertiary sandstones, argillaceous sandstones, and clays and their re-sorted Pleistocene sand and gravel derivatives occur extensively. Where heavy black clay soils occur in these areas however, even though the Cainozoic sandstones exist at shallow depth, it is probable that the alluvial fraction is of greater significance.

Upgraded Alluvial Soils

The soils of the plains are predominantly alluvial in origin, receiving frequent sedimentary increments by repeated outwash flooding. The major source of parent sediment is the "undermass" Pre-Cambrian material of the range; the "overmass" semi-consolidated early and mid-Tertiary rocks are of lesser importance in this respect.

A well-developed system of escarpment "consequent" streams and several "antecedent" streams now erode the frontal range regions and amongst these the River Torrens is the major agent of alluviation in the upbuilding of the Adelaide Plains (fig. 10). It is eroding its valley across the Para Fault block in both overmass and undermass sediments while its extensive headwaters beyond Athelstone are practically wholly entrenched in bedrock. Its depositional fan beyond the Para Fault therefore has increments from a variety of sources in which the influence of the Adelaide System sediments and lesser Archaeozoic metasediments will dominate. The remaining streams north of the River Torrens are eroding almost wholly in Adelaide System bedrock with minor contributions from early Tertiary sediments. Local variations in the nature of outcropping Adelaide System rocks therefore have an important influence on the types of soil developed within the various alluvial fans confronting the range. The rocks within this system can be classified into three major categories, and a fourth is provided by the Archaeozoic complex of the Torrens Gorge.

(1) Arenaceous sediments (sandstones, felspathic sandstones, arkoses, and quartzites).
(2) Argillaceous sediments (slates, phyllites, and tillites).
(3) Calcareous and magnesic sediments (calcareous slates, limestones, and dolomites).
(4) Metamorphic rocks (gneisses, schists, and migmatites, etc.).

The arenaceous sediments (and also quartz veins) break down mainly into siliceous sands of varying coarseness, while contained felspars (usually partly weathered to sericite mica) decompose completely into clay minerals. Quartzites tend to produce gravels because of their hardness and normally well-developed jointing.

The argillaceous rocks on the other hand are composed principally of submicroscopic grains and in the resulting soils the proportion of sand tends to be very small with large amounts of silt and clay. Tillites usually have a predominantly clay-mineral base, but, as the content of "erratics" is extremely varied in nature and frequency, the proportion of sand-producing materials is also very variable.

Calcareous and magnesic rocks vary considerably in the amount of impurities. Pure limestones and dolomites go principally into solution whereas other less calcareous sediments contain varying amounts of insolubles, such as clay mineral and silica, which are freed as clays, silts, and sands.

The metamorphic rocks of the Torrens Gorge are highly felspathic, micaceous, and siliceous. The felspars decompose to clay minerals with the silica providing sand and the mica mostly suffering only mechanical disintegration. North of the River Torrens the Houghton metamorphic complex supplies a large proportion of uralitic diopside, which decomposes into secondary ferromagnesian minerals and ultimately breaks down to clays and iron oxides. Ilmenite is derived both from the Archaeozoic and basal Adelaide System rocks.

Early Tertiary argillaceous sandstones are also sources of sand and clay, while a small organic increment must at times have been derived from erosion of lignitic beds.

Some minerals within the alluvial succession might have originated from the coastal sand dunes being blown inland by prevailing westerly winds. This possibility is further discussed in Appendix C.

In any attempt to relate the pattern of soil distribution on the Adelaide Plains to the source of the alluvial parent material, there are complications of considerable magnitude due to the varied stratigraphic sequence and the repetition of outcropping rocks due to faulting. However there are some distinct tendencies between Marino and Dry Creek. From south to north they are as follows:

Marino to Sturt Creek: Calcareous slates and limestones (Tapley Hill beds) assume high dominance in this zone except near the coast where the lime factor is much less in evidence (purple slates and quartzites). Outwash alluvials must reflect the general calcareous influence of the Tapley Hill formations in some way and the detrital mineral suite may be restricted in variety. The clayey increment should be high. Remnant early Tertiary sediments remain on the Tapley Hill plateau and these may exercise minor complications on clay mineralogy and heavy mineral composition.

Sturt Creek to Glen Osmond: Escarpment rocks outcropping in this area are chiefly argillaceous and poorly or non-calcareous; slates and tillites take precedence, while sandstones and quartzites are generally minor features and limestones are mostly absent. Brownhill Creek introduces a local but important complication. Much of its headwaters have eroded deeply into calcareous slates and dolomitic limestones of the Beaumont stage.

Glen Osmond to Greenhill: The dominating source rock in this section (as in the restricted Brownhill Creek zone) is calcareous (dolomitic), but some of the creeks have eroded back into quartzites although the net contribution (by volume) of sandy material is not large.

Greenhill to the Torrens Gorge: Arenaceous rocks figure more prominently in this portion of the escarpment, although in bulk, the calcareo-argillaceous rocks have been eroded more extensively. Thus in estimating the influence of various escarpment rock-types on outwash alluvial soil developments calculation of the area of outcrop of specific rock-types within headwater basins is not sufficient in itself. Consequently the argillaceous sediments may be considered dominant in this zone, although in an area adjacent to Second Creek extensive erosion in the Stonyfell Quartzite has produced a massive outwash apron of quartzite boulders and siliceous sand at the base of the escarpment.

A minor amount of early Tertiary sediments outcropping on the low-lying Burnside Fault block adds its contribution to the creek outwash.

Torrens Gorge and River Torrens: The River Torrens is of special interest in that its catchment also includes the metamorphic Archaeozoic rocks and the basal ilmenitic sandstones of the Adelaide System. Where it crosses the plains west of Athelstone it erodes both overmass early Tertiary sandstones and mid-Tertiary limestones and undermass sediments of the Torrensian Series. Along its course, before emerging from the range, the latter strata are relatively dolomitic, with slates and phyllites and lesser quartzites. The complex nature of the catchment zone therefore provides an extremely involved parentage for the soils of the Torrens outwash areas. No single factor can be expected to be dominant in such a case.

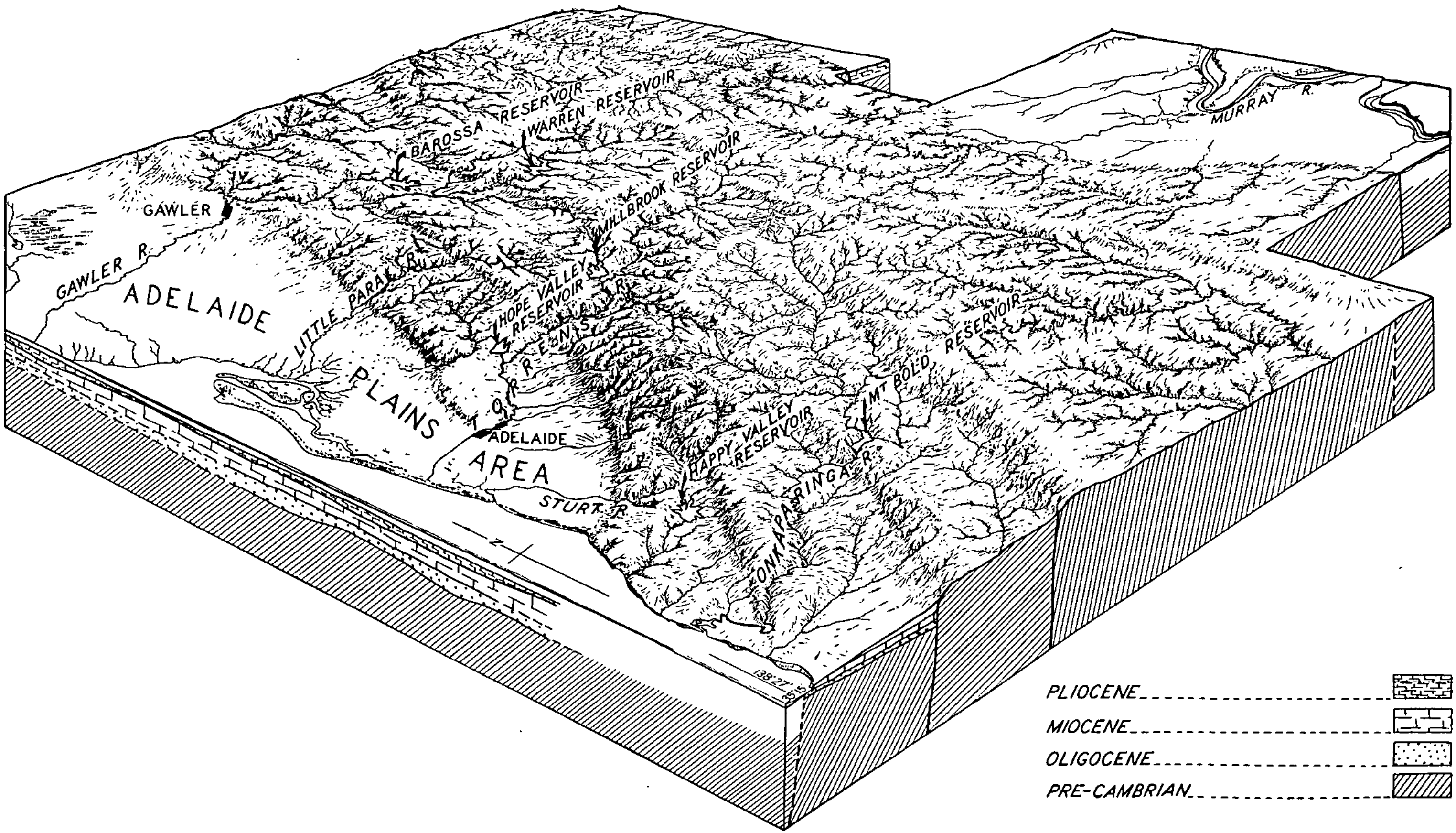

Fig. 10—BLOCK DIAGRAM OF THE ADELAIDE PLAINS AND MOUNT LOFTY RANGE
Showing the catchment areas of escarpment streams

[*After Sprigg*, 1945]

Para Fault Block: Torrensian Series phyllites, with minor quartzites and dolomites, outcrop along and north of Dry Creek and in a small area near Hope Valley Reservoir. Along the eastern side, Cainozoic sands become of importance. Moderately heavy-textured soils should predominate to the north with sandy soils in the southeast, except where outwash from the hills has deposited silty material. Some of the soils are residual on early Tertiary sandstones and clays or upon the re-sorted Pleistocene sands and sandstones.

The tilt of the Para block has led to a transition from dominantly sedentary soils on the north to alluvial soils in the south. Complicated movements of the block in the past have probably meant that erosional cycles have occurred as well as depositional periods. Hard rock can therefore be encountered under quite shallow soils of both types on the Para block.

THE INFLUENCE OF ANTECEDENT ARIDITY

Crocker (1946) has postulated that the Anadara high sea-level corresponded with maximum post-Pleistocene deglaciation, and with what he termed the Great Australian Arid Period. The phase is probably coincident with the Climatic Optimum of the Northern Hemisphere (Sprigg 1952) during which interval the climate of northern Europe and northern North America was more mild than at present. The peak of this phase is variously dated at 4,000 to 7,000 years ago and it may have lasted for about 1,000 years.

During this phase which was characterized by extreme aridity over much of Australia, the deserts attained maximum development (there is no evidence of *greater* aridity during any of the preceding Pleistocene interglacials). Top soils of the vast alluvial plain and peneplain areas were denuded of denser vegetation by prolonged drought, and sand drifting commenced. The medium sands were concentrated in sief dunes, while the finer silt and clay fractions were winnowed out as dust. Where the sand supply was plentiful, coarser material was frequently stabilized in sand sheets, but mostly the interdune areas presented typical clay-pan developments, the exposed clays being of the original soil "B" horizons.

Widespread sheet erosion and gullying under the influence of abnormal flood rains typical of drought conditions was an added consequence of vegetation depletion in creek headwater country. The eroded material mostly went to build up broad alluvial flood-plains and generally to enhance desert dune-formation.

This arid cycle was later temporarily halted by the return of a more equable climate, although yet another arid phase intervened before the present. This was the Osborne arid phase and, although less intense, its effect upon modern soils is more marked. Dunes which had been built up in the Anadara arid period were modified considerably in marginal areas during the subsequent climatic "improvement", and in the Adelaide area progressive alluviation and stream action buried or redistributed much of these sands. The Osborne phase has since favoured a repetition of desert formation, but the latest climatic amelioration has led to dune fixation within southern areas with erosional modifications and some dune soil profile developments.

Under arid conditons sand dunes form most readily where river flood-plains are amply supplied with silts and fine sands. Such conditions are satisfied on the Adelaide Plains and desert dunes were formed prominently at least as far south as Gawler. Related light-red sand dunes also occur in the subcoastal area west of Adelaide (Glenelg-Lockleys-Alberton area). The dunes are less regular and apparently represent an admixture of leached coastal sands of the Osborne phase with sediments of the River Torrens flood plains.

THE FORMATION OF CALCAREOUS LOESS

The distribution of heavily calcareous soils and soil travertines throughout southern Australia suggests a close genetic relation with the coast, and in particular with the continental platform. Their spread away from these supposed sources suggest that prevailing winds played the major role.

Crocker (1946) has postulated wide exposures of the continental platform during Pleistocene times when sea-level fell intermittently by several hundred feet. In the interval of these glacial low sea-levels, great quantities of sand were swept up from the exposed sea-floors to produce massive subcoastal shelly sand dunes, portions of which extend well inland at the present day. In South Australia they now cover much of western Eyre Peninsula, southern Yorke Peninsula, southern Kangaroo Island, and southeastern South Australia (fig. 11); massive remnants form islands in lower Spencer Gulf where aeolianite cliffs, *e.g.*, Wedge Island, tower up to 600ft. above sea-level.

Before consolidation, the sands of these dune systems endured prolonged abrasion of the softer shelly matter and enormous amounts of very fine material were winnowed out in the process, becoming airborne as a calcareous loessial dust. The tendency was probably assisted by the northern migration of the "Roaring Forties" wind belt during these glacial phases. Generally the "parent" sand became more siliceous by removal of calcareous matter as loess, but also by active soil leaching.

The "winnowed" lime was usually distributed widely beyond these coastal sources, but in general the heaviest deposits lay immediately to the lee of the particular dune accumulations and consequently much of it would have been swamped by later high sea-levels. In arid subcoastal areas, where alluvial deposition was restricted, the loessial dusts built up thick beds of soil travertine which by cyclical repetition (upon repeated glaciation) became layered or massive. However, in areas further removed from the continental platform the lime accretion fell off markedly, and in situations where soil upgrowth was rapid (as on the Adelaide Plains) the lime was diluted and, in effect, spread vertically. With higher rainfall the leaching action of soil and groundwaters continually reduces the lime content in the subsoils.

During the Quaternary Period there were at least four major interglacials and many more significant interstadials (minor warm phases within the glacial phases) during which the formation of calcareous loess was probably prodigious. In the fields the sedimentary record frequently displays a number of discrete nodular lime (travertine) layers suggesting several such distinct periods of activity.

Where dunes became stabilized by vegetation, soil illuviation also operated to provide strongly protective travertine crusts. Providing these lay beyond the reach of subsequent high sea-levels there has been little opportunity for their deeper, less indurated, sands ever to become exposed extensively to aeolian agencies again.

A final expression of the loessial travertinization process has been in association with the Anadara and Osborne fossil sea-beaches. Following the Anadara high sea-level phase the sea fell *at least* 30ft. below its present level allowing the development of soil travertines over the exposed sea-bed. The travertines frequently aggregated 12 or more inches in thickness to include much of the shell bed itself. Slightly calcareous clays were then deposited over this horizon in the Adelaide area followed by the Osborne high sea-level deposits which were again travertinized following subcoastal exposure. It seems that upon each fall in sea-level the exposed marine sediments were subject to wind-winnowing action during which notable amounts of calcium were distributed farther inland.

An assessment of the real significance of calcareous loess in the formation of the soils of the Adelaide Plains cannot be made with any certainty. The possible sources of lime in these soils are many and varied, since the majority of the parent rocks are more or less calcareous. However in certain locations, as upon the higher portions of the Para block and on some locally sheltered areas of the frontal escarpment of the Eden Fault block, the presence of lime can best be

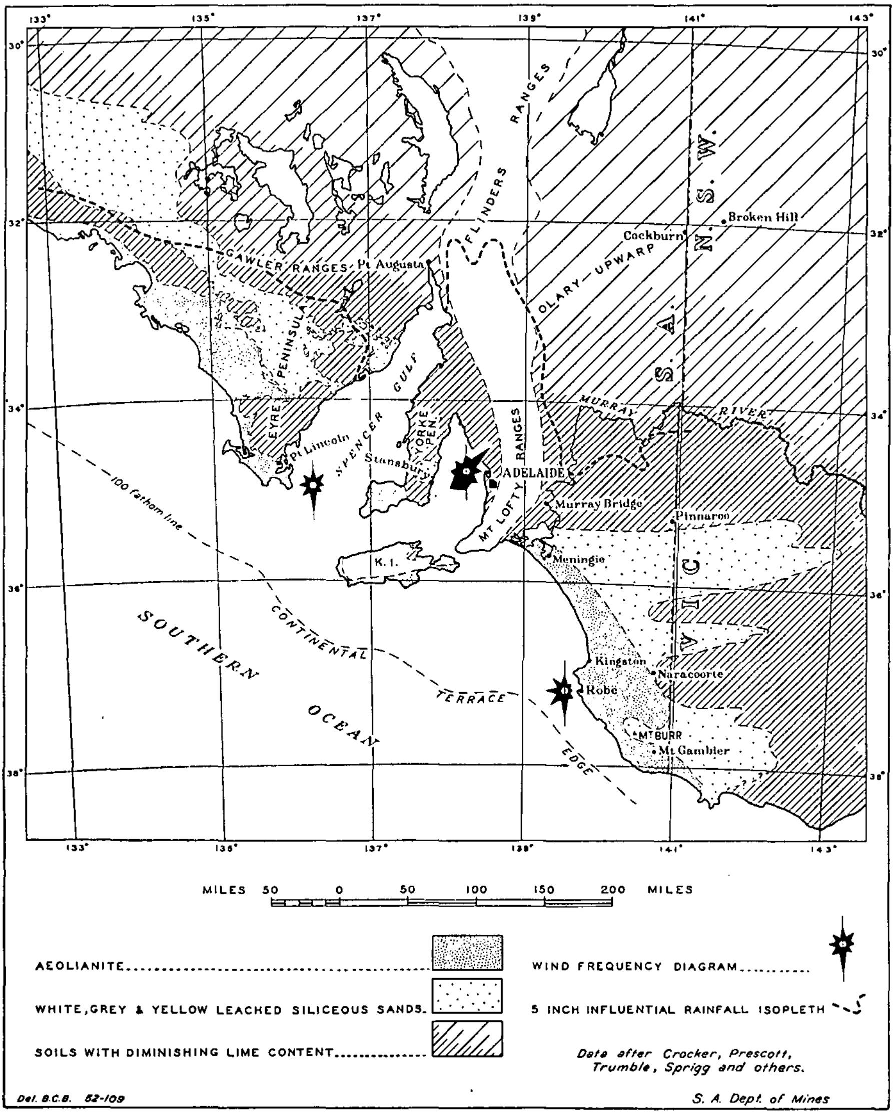

Fig. 11—MAP OF PORTIONS OF SOUTH AUSTRALIA, VICTORIA, AND NEW SOUTH WALES

Showing the distribution of aeolianite, siliceous sands, and loessial travertines in relation to the Continental Terrace

accounted for in terms of an aeolian or loessial origin. The Mallee soils of the Para block and the Rendzina and Terra Rossa soils of the foothills are in some instances obviously related to an "external" source of lime.

CONTRIBUTION OF CYCLIC SALTS

Analyses of rain-water normally indicate impurities which (in non-industrial areas) in order of abundance approximate the composition of the salts in sea-water. For example, rain-water analyzed from south of Perth (Simpson 1926) contained 1·5 parts per million calcium carbonate, 6·4 p.p.m. magnesium salts, and 24·6 p.p.m. sodium chloride.

Jack (1912, 1914) has suggested that the salts originate from sea spray carried inland by winds, subsequently to fall as rain. In South Australia the principal rains are seasonal and accession of cyclic soluble salts therefore varies throughout the year. The salts may be carried inland either in the form of minute droplets of water or as dry dust-like particles derived from the fine spray thrown up along the coast-line during rough weather. The theory has been accepted by most investigators and much supporting data has been accumulated, particularly by Teakle (1937) and Anderson (1941, 1945). Teakle concluded that "in coastal areas the mean salt content of rain water may be expected to range from 15 to 50 p.p.m. and in inland areas from 4 to 20 p.p.m. The annual precipitation of salt in rain-water generally ranges from 100 to 600 lb. per acre in coastal regions and from 10 to 60 lb. per acre in inland centres". Anderson (1945) gives figures of 5-22 lb. per acre of chloride radicle at distance over 100 miles from the coast, and often over 50 lb. nearer the sea. The more arid the climate in an area, the greater is the concentration by evaporation of these cyclic salts in surface waters.

Studies by these men have demonstrated very clearly the marked fall-off in salt content of rain-waters away from the coast, and that stronger winds directly off the sea introduce the most salt. The mechanism of cyclic salt generation therefore seems unassailable. Sea spray whipped up by high wind travels considerable distances inland, but in general the "salt" as dust and spray will be washed out from the atmosphere roughly proportionately to the distance travelled from the coast. Teakle also notes that the cyclic salt increment "is deemed adequate to account for the amount of salt observed in the soils and ground waters in Western Australia". The process is therefore of extreme importance to both the pedologist and the hydrologist.

In South Australia the wide variation in the composition of shallow groundwaters from point to point even in broad alluvial belts might not at first sight appear to support such a theory for, although sodium chloride is practically always dominant, the ratio of other salts is highly variable. This points to some change during the migration of salts through the soil profile. One of the most common of these changes is brought about by solonization whereby base exchange occurs between minerals in solution in the soil water and the soil clay mineral component. Sodium, magnesium, and calcium are the readily exchangeable ions and during the process the sodium-enriched clay complex becomes more mobile (peptized) and the leaching of the clay fraction may become possible under conditions which normally are not favourable.

The influence of cyclic salts upon soil formation in the Adelaide area is not dramatically evident. Most of the soils of the Para block and of the upper and lower outwash plain areas exhibit some signs of solonization. This effect is most marked in areas adjacent to the sea, where the cyclic salt increment is probably higher and where the lower rainfall provides less effective leaching. However, in almost any part of the area, whenever local drainage conditions favour an accumulation of percolating groundwaters, the soils tend to become noticeably saline. In limiting cases solonetz soils are formed.

TOPOGRAPHY AND DRAINAGE

Topography can influence soil formation in several ways. Control is exercised upon local drainage and, in steeply graded areas, upon the incidence of erosion in various forms. Adjacent to the steep escarpments rapid erosion tends to produce talus and the plentiful gravels which make a large contribution to the upper outwash fans. Old buried stream beds are an important feature in underground water movement and in soil drainage.

The drainage factor, under topographic influence, indirectly exerts a strong control on groundwater composition by affecting the rate of runoff, upon the range of oscillatory groundwater tables, upon soil salinity, and upon flood incidence. Saline conditions in turn may bring about marked changes in the physical state of the soil, as evidenced by structure and permeability effects. Frequent flooding may retard soil eluviation processes and mask profile development by the rapid addition of new increments of sediments.

In the Adelaide region most soils are moderately well-drained. True marsh conditions exist only in the subcoastal belt north from Patawalonga Creek where the Osborne high sea-level has flooded the lowlands extensively. In these areas the zone of saturation is at shallow depths and the water-table will oscillate markedly with the seasons. Developing soils will certainly vary markedly both structurally and in depth of profile from the better drained soils farther to the east.

Conditions satisfactory for spring development may be present under two sets of conditions. Firstly, where creek gravels occur shallowly in steep alluvial fans adjacent to the foothills, water may be confined with sufficient hydraulic head to permit surface leakage during wet seasons. Springs can also be anticipated along splinter and escarpment faults (*e.g.*, Eden and Burnside Faults) particularly where there has been recent fault movement. The spring on the Waite Institute property and one about a mile southwest of Clapham Railway Station are of this type. Black soils are associated with both examples and fossiliferous fresh-water limestone occurs at the Clapham site. In view of the steep escarpments on the intake side, escaping waters may be under considerable pressure, and it has been found that bores penetrating outwash alluvium to bedrock adjacent to the Waite Institute and near Portrush Road have tapped pressure waters with high hydraulic heads. Conditions along the foregoing faults are in direct contrast to those along the Para Fault where Ward (1946) and Miles (1952) have indicated that any movement of groundwater on these planes would be downward. There would therefore be no influence of these waters on local surface soil.

CLIMATIC EFFECTS

Adelaide's climate has been described as typically Mediterranean—with wet winters and summer droughts. Although there is no part of the suburban or adjacent areas for which this climatic definition is not valid, nevertheless there is at the same time a large range of climatic zones occurring within these areas. The climates vary, as discussed previously, from the cool humid conditions ($P/E^{0 \cdot 7} > 1 \cdot 7$) which favours podsolization, to the warm semi-arid zone ($P/E^{0 \cdot 7} < 0 \cdot 92$) in which "Mallee" type soils may be developed. The dominant climate however lies between these extremes (*i.e.*, $1 \cdot 7 > P/E^{0 \cdot 7} > 0 \cdot 92$) and thus provides the environment suitable for the formation of red-brown earths and black earths.

Recordings at the Waite Institute may be taken as indicative of this dominant climate. The climatological data of table II may be interpreted to provide information concerning the normal soil-moisture regime throughout the year. Prescott (1949) has shown that drainage through bare soil commences when the monthly climatic index $P/E^{0 \cdot 75}$ exceeds a value of 0·8 and that a balance between evapo-transpiration and rainfall is maintained in vegetated areas where the monthly climatic index is of the order of 1·2 to 1·5. The data of table II show that rainfall at the Waite Institute is more than adequate to cope with evapo-transpiration for a period of five winter months from May to September. For a further period of two months (April and October) the rainfall is sufficient to maintain growth ($P/E^{0.75} > 0.54$) but during the summer months (November to March inclusive) there is a deficiency of rainfall leading to desiccation of the soil where normal vegetation is established.

Thus the soil experiences approximately equal periods of abundance and lack of water with a consequent pronounced cycle of leaching and desiccation. At the same time there is a marked seasonal cycle of soil temperature (fig. 12) with appreciable differences between summer and winter periods. A range of more than 17°F. has been observed at Adelaide at a depth of 3ft. beneath the soil surface.

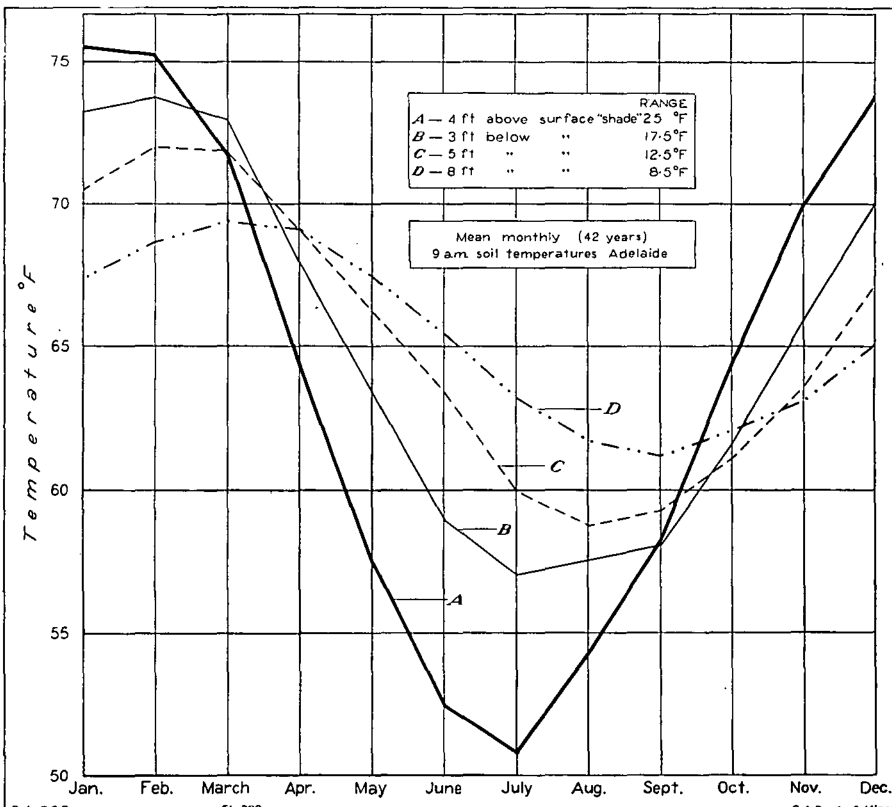

Fig. 12—ANNUAL VARIATIONS OF SOIL AND AIR TEMPERATURES AT ADELAIDE (Compiled from Commonwealth Meteorological Bureau data)

One result of this seasonal influence is the tendency for salts to accumulate in the lower parts of the soil profile. Lime frequently occurs in well-defined horizons underlying the "B" horizon whereas most of the more soluble salts have been concentrated in the groundwaters.

TIME SCALES AND THE DEVELOPMENT OF SOIL PROFILES

The Mt. Lofty Range rose continuously during the Pleistocene period and consequently on the adjoining lowlands outwash alluviation was practically unbroken. The sea had retreated completely from the horst region at about the end of the Pliocene period and the last few feet of marine sediments in the plains region were possibly earliest Pleistocene*.

* Personal communication from B. C. Cotton, Conchologist, South Australian Museum.

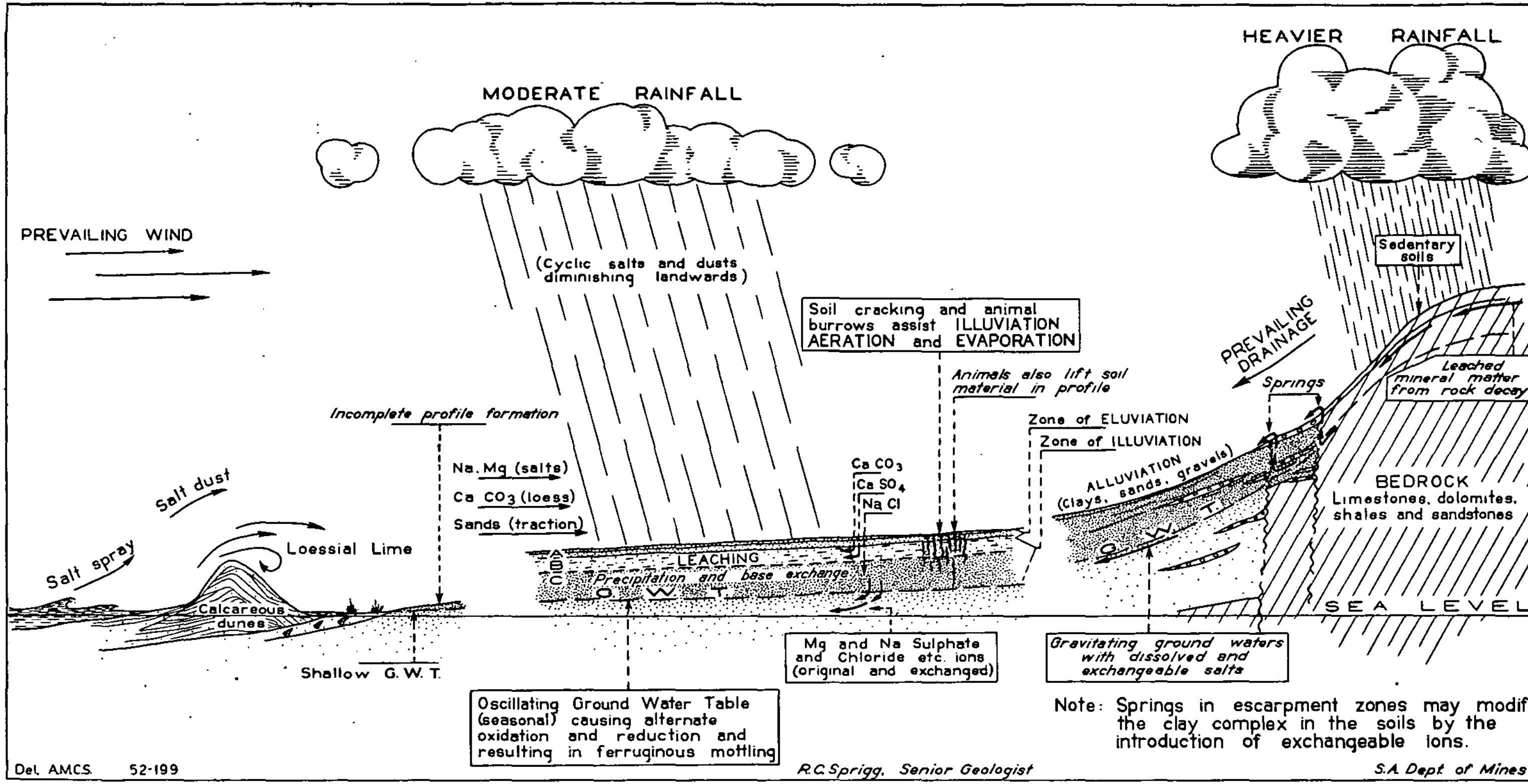

Fig. 13—IDEALIZED SECTION THROUGH THE ADELAIDE PLAINS

Illustrating the major geological processes active in soil formation

Soils of the alluvial outwash area are continuously "growing" vertically, mostly by additions from the escarpment zone, but also from the coastal zone. Downward migration of groundwaters temporarily concentrates the more insoluble materials (alumina, iron oxides, calcium carbonate, calcium sulphate, etc.) in the "B" soil horizon, but as the soil continues to upgrade, all but the most insoluble of these are reduced extensively in quantity by further downward leaching to produce a "C" horizon of more even composition.

The sediments were estuarine in character and the fossil fauna is thought to indicate a minor deterioration of climate such as might be expected with the onset of Gunz (Early) Glaciation. However the possibility must not be overlooked that this evidence of lowered temperature may be coincident with a late Pliocene climatic cold phase recorded in Europe and New Zealand. For the present the close of marine Tertiary sedimentation in this area can be equated approximately with the Plio-Pleistocene boundary.

The Pleistocene period is variously estimated to have begun about 600,000 to 1,000,000 years ago. During this period 300 to 350ft. of outwash alluvials were deposited on the plains to the west of Adelaide and an *average* rate of aggradation would therefore be about 4 to 6in. per 1,000 years. Any deviation from this average is unlikely to be excessive even in spite of accelerated uplift and climatic variation.

It is also obvious that soil developments in the plains areas involve continuous accretion from above, or, in other words, vertical "growth." The soils are not being developed from underlying parent material but rather the underlying clayey accumulations are the end products of continuous soil processes (the cumulative soils of Nikiferoff 1949). The "C" horizon is being developed aggradationally through "A" and "B" horizons and it is therefore the climax of the processes of pedogenesis.

In fig. 13 an idealized soil profile is represented in which most of the geological and pedological processes are illustrated graphically. Sands, silts, and clays (principally) are introduced intermittently and at frequent intervals *via* the normal erosive agencies. Flood waters distribute clays widely from creek lines at times of heavy rains whereas silts and sands are deposited nearer the actual channels to build levees along the creek banks in low situations (fig. 4). In piedmont areas, as near Adelaide, the creeks change their courses frequently maintaining a fairly even overall distribution of sediments.

At the same time, aeolian agencies also add their varying increments of sediment. Minor amounts of sand are blown along the surface—particularly during dry periods—while silts, clays, loessial lime, and cyclic salts are more truly windborne. The aeolian parent materials supplied in these ways will generally be much finer than the alluvial products and they will also contain more soluble mineral matter.

The net result of these processes is the relatively rapid soil upbuilding to produce a fairly generalized parent material approximating a slightly sandy silty clay with minor but varying amounts of calcium carbonate and cyclic salts. Once these materials are trapped in the soil they are immediately subject to redistribution within the soil profile by various pedological processes. These latter are in turn influenced considerably by the nature of the added material, by climate, topography, drainage, soil moisture, and permeability and by various biological factors.

In general there will be a downward movement (illuviation) of clay, lime, iron oxides, alumina, and soluble salts with the more soluble salts moving farthest down the profile and largely escaping *via* the medium of the groundwaters. As a result a relatively leached zone (A_2) usually develops just beneath the surface (except where soil profile formation is impeded, due to poor drainage conditions). This zone of eluviation is usually more silty and sandy in composition than the underlying ("B" and "C" horizon) zones and contains less soluble mineral matter or clays. In the "B" horizon the clay and lime content usually reaches maximum concentration.

By and large, soluble salts tend to migrate vertically through the soil profile to the zone of saturation. Under Adelaide's dry climate this results in fairly saline groundwaters. During the semi-arid phases of the Quaternary the salinities of the groundwaters were probably even higher.

In low-lying areas on the Adelaide Plains, in view of the considerable seasonal variation in rainfall, the groundwater table fluctuates considerably and the moisture content of the overlying alluvials also varies markedly. These variations cause a mottling of the "C" soil horizon clays, some of which mottling may be repressed subsequently upon deeper burial. However "incipient" mottling can be recognized practically throughout the complete section of the Pleistocene clays in the plains area.

In the geological sense the "A" horizon of a soil profile in aggrading situations is transient only. Although an essential part of the soil profile it will rarely be fossilized "unmodified" except under the more exceptional circumstance of rapid burial. Recognizable "B" horizons will occur slightly more often, but generally the buried clays will be an extended and slightly modified "C" horizon, *i.e.*, an ancestral "parent" horizon. It is obvious, therefore, that under such conditions of slow overall alluviation, well-defined fossil soil horizons will be the exceptions within the mass of the deep subsoil section and that the more spectacular short period climatic or geological effects will be spread vertically within the profile and their intensity minimized.

Chapter 7

THE SOILS OF THE ADELAIDE PLAINS

In proceeding from the generalized discussion of soil formation in the Adelaide area to an account of the particular soils occurring, it is desirable that some emphasis should be laid upon the scope and accuracy of this phase of the work.

Whereas the geology of Adelaide and its environs has been considered worthy of note on a number of occasions over a long period of years, this has not been the case with the soils. Most of the available data relating to soils has referred to areas where the geological factor has been of principal importance and pedogenetic factors scarcely operative. (Marshall and Walkley 1934.) The exception has been where a particular soil profile has been studied locally, largely as a matter of convenience to provide data representative of a widely occurring soil (Piper 1938).

Thus at the commencement of this soil study in 1946 there existed an excellent, though uncollated, background of geological information, with a dearth of data on any of the soils. The investigation into the nature and distribution of the soils of Adelaide was the outcome of an upsurge of interest in the engineering characteristics of soils. Over the last decade or two the science of soil mechanics has become established and it is now widely appreciated that some evaluation of the engineering behaviour of soils is possible. In any urban or suburban area, the greatest use of the soils is in some engineering sense, and is particularly associated with the foundations of buildings or the construction of roadways.

With such an engineering use in mind the attempt has been made to define the principal soils of Adelaide and their characteristics and distribution. It is as well that this engineering bias, during the course of the observation, should be stressed. Although a purely objective interpretation of soil morphology is clearly desirable, it is also evidently impracticable if the observations are to be related at any stage to land use.

Chapter 8

SOIL CLASSIFICATION AND MAPPING

In the development of a system of soil classification and mapping for any practical purpose it is obvious that some compromise must be made between that approach which is most desirable and that which, in the light of all of the circumstances, is achievable. The soil studies discussed in this *Bulletin* represent the outcome of an attempt to use pedological concepts of soil classification in the investigation of foundation characteristics of soils. Since this approach is, as far as is known, without precise precedent, there are no accepted principles to be followed in the adoption of a proper basis for soil classification and mapping within this area.

Undoubtedly the most desirable classification for the purposes of shallow foundation engineering is one which takes as its unit the whole depth of soil from the surface down to a level below which no surface loading will have significant effect, and below which no natural forces of a seasonal character will be operative; very frequently this may be synonymous with that depth of soil below which no current pedogenetic processes are operative. Thus the complete soil profile provides the basis for the classification while the soil type, comparable to that defined by the pedologist, may be taken as the unit of the classification.

Ideally a soil type is represented by a unique soil profile. In practice, however, since soils are continuously variable, a soil type must be defined in terms of a limited range of soil profiles. It is at this point that any bias in the eyes of the investigator becomes incorporated in the classification. Thus if a classification is developed for engineering purposes, it is permissible, from the viewpoint of the engineer, for all soils of appreciably similar morphology, and apparently identical engineering characteristics, to be lumped together to conform with a practicable definition of a soil type. But it must be stressed that the soil type so defined, with limits of variability extending only narrowly from the ideal unique soil profile, may in fact be significantly different from a soil type defined for the purposes of the agriculturalist.

There is no doubt that the standard classification of the pedologist, such as that described by Stephens (1951), if carried to its ultimate limit of accuracy can be regarded as almost completely objective. If soils are mapped in the greatest detail by the pedologist, with clear demarcation and description of series, type, and phase, then a land-use interpretation of such data can be made without difficulty by the engineer. However, soil mapping in such detail is a major undertaking under any circumstances, and in a partially built-up area is entirely impractical. Hence the approach adopted for this project has been one of deliberate engineering bias and of direct interpretation from soil morphology to a land-use soil classification.

For this reason it has seemed to be desirable to adopt a system of soil nomenclature which differs from that commonly used in soil surveys for agricultural purposes. The modified nomenclature is significant at only a relatively low level in the overall classification system, *i.e.*, at the soil-series and soil-type level, thus corresponding to the stage at which land use begins to dominate. At all higher levels of classification the taxonomic system of the pedologist is applicable as much for the purposes of the engineer as for the agriculturalist.

THE CLASSIFICATION SYSTEM

A symbolized notation has been adopted in lieu of the place-name notation used in agriculture. It has not been intended that any greater significance should be attached to the symbol than is associated with the use of a particular place-name to identify a soil. The symbol, for convenience usually a combination of two letters and a numeral, *e.g.*, RB3 is merely a name-tag for the soil.

The symbol is intended to denote a single soil-type. The tripartite concept of soil series, soil type, and soil phase—the worth of which is well proven in agriculture—is regarded as being somewhat artificial in this classification. In its place it is suggested that a soil type may be defined as including all of those occurrences of a soil which are in an engineering sense similar to an established modal soil profile. The emphasis in this case need not be laid upon detailed consideration of the "A" horizon of the soil as is common in agriculture. In many instances certain gross differences of surface texture may have less effect on the engineering behaviour of the whole profile than a minor difference in the "B" horizon.

Following the classification system discussed by Stephens (1951) it is possible to set down the principal features of the classification adopted for this work.

In table V, categories I, II, and III are identical with those used by Stephens, while an engineering bias is associated with categories IV, V, and VI. Since, within any great soil group, the physical properties of member soil-types will differ appreciably with change of parent material, this factor is rated high in the classification system. The engineering performance of the whole soil profile will also be affected by the total depth of solum, hence this too is regarded as an attribute of some significance. Thus parent material and depth of solum determine category IV.

It is, however, frequently convenient to by-pass this category and to proceed directly to the soil type. The term "soil type," used in the sense defined above, embraces all occurrences of soils of similar profile and relatively uniform physical characteristics. Since physical properties may well be dependent upon the nature of the clay fraction, it follows that the greatest attention in defining this soil type will be focussed upon the horizon of clay accumulation. Ample morphological evidence usually exists to permit field identification of soils containing similar clays, although inadequacies of terminology may set a limit to the soil definition on this basis. Because the soil type of category V is strongly dependent on "B" horizon characteristics of the soil and less dependent on "A" horizon features, it has much in common with the soil series (Stephens, *loc. cit.*) if the latter is defined in the strictest sense. However, everyday usage of the soil series concept has been such that an agricultural bias has crept in. Therefore it is felt that sufficient justification exists for discarding the soil series and adopting the term "soil type" to denote the primary unit of soil classification and mapping for the purposes of this *Bulletin*.

A unit of lesser importance is the sub-type of category VI. Almost any attribute of soil which can be related to engineering land-use may determine a sub-type. Principal among those used have been depth, texture, and drainage status of the surface horizon.

THE SOIL MAP

Ideally, a soil map should delineate separately all areas of occurrence of soils which differ significantly from one another. Thus the map should normally show all soil types and possibly sub-types. Such mapping is practicable on a small scale and has been accomplished on certain housing estates adjacent to Adelaide (Aitchison and Blackburn 1947; Aitchison 1947; and others). But on larger areas, and particularly when the soil pattern is complex as it normally is around Adelaide, soil-type mapping is impracticable—even on the basis of the extended soil-types adopted for this work.

SOIL ASSOCIATIONS

As an alternative, mapping can be carried out in terms of soil associations. A soil association may be defined as an aggregation of a number of soil types which normally occur together within a broad environment, and which differ one from another as a consequence of localized changes of genetic factors. Thus a simple association could consist of a repetitive pattern of red-brown earths and rendzinas

TABLE V

Adaptation of the Pedological Approach to Soil Classification for Engineering Land-use Interpretation

Category—	I Orders	II Sub-orders	III Great soil groups	IV Families	V Types	VI Sub-types
Number of classes in category—	2	7	40-50	Any number	Large number	Small number per type
Determinant morphological attributes of category	Presence or absence of lime or gypsum in " A " or " B " horizons	Position of horizons of organic matter, clay, sesquioxides, lime, and gypsum	Profile colour and presence or absence of halomorphic, calimorphic, or hydromorphic features	Parent material and depth of solum	Texture and structure of " A " and " B " horizons with emphasis on " B " horizon where well developed	Depth, texture, and drainage status of " A " horizons
Significance of category	Prerequisites in establishment of great soil-group category		Key to classification but rarely interpretable directly for land-use	Useful subdivision of great soil group where parent material has pronounced effect on physical properties, e.g., in podsolic group ; often unnecessary in other great soil groups	The basis of mapping and land-use interpretation	Related to detailed engineering land-use
Examples from Adelaide area	—	—	Black earths, red-brown earths, rendzinas, etc.	(Not used in relation to Adelaide soils)	RB9	RB9a RB9b RB9c

or terra rossas formed as sedentary soils on shales and limestones respectively. Usually the pattern is much more complicated than this simple example and the contributing environmental factors may not be well defined.

The advantage to be gained by mapping soil associations is that recognition can be given to all of the soils of an area. Although it may not be possible to demarcate accurately each particular occurrence of a soil type, it becomes practicable, by the use of association mapping, to define the limited number of soils which may be found within a prescribed area. Thus, when the characteristics of each soil-type have been determined, knowledge of the proper land-use at any location within a mapped zone will follow immediately upon the identification of the soil type at that point as being one of the previously described members of the soil association.

This approach is particularly useful in relation to foundation problems for domestic buildings. As an average house covers less than 1/20 acre, the accuracy required for normal soil-type mapping would be far beyond hopes of attainment. With association mapping though, information can be presented to describe possibly six soil types which may occur within any general locality. The further work required to complete the soil knowledge is merely that of recognizing the soil profile at the house site as being one of the six described. This involves no extensive skill or training in soil survey procedures or methods of classification.

Since soil-association mapping is applicable with equal facility to almost any land-use in the metropolitan area, it has been adopted for the purposes of this *Bulletin*. The soil associations, their areas of occurrence and component soil types are described in the following sections.

The soil map accompanying this *Bulletin* is based only on long-term reconnaissance information. It is certain that there will be an appreciable number of errors and omissions, partly as a result of the inaccessibility of some portions of the metropolitan area. An attempt has been made, however, to present most of the subsequent soils data in such a fashion that the need for a map of any description is minimized. (*See* fig. 14.)

Chapter 9

SOIL GEOGRAPHY

Consideration may first be given to the general character of the soils which occur within the various principal topographic zones described earlier.

SOILS OF THE ESCARPMENT REGION

For the purposes of this discussion those parts of the Eden Fault block and of the Burnside splinter block which occur within the mapped areas are considered jointly. Only those escarpment areas quite close to the fault lines are of significance in this *Bulletin.*

The soils of the adjacent Mount Lofty Range above the escarpment have been described by Specht and Perry (1948). However, these soils are characteristic of a climatic environment which is in the main wetter than that of the escarpment zone, and the parent material associations are not identical in the two areas. Consequently, although there is some overlap of soil occurrences, the two zones provide distinct pedogenetic features.

The soils of the escarpment zone include principally podsolized soils, black earths, red-brown earths, rendzinas, and terra rossas.

Podsolized Soils

Rainfall, within the mapped areas, is barely adequate to provide the degree of leaching normally associated with the formation of podsols or podsolized soils. However, in some limited areas—particularly adjacent to Stonyfell—there are some well-developed yellow podsolic soils which show the typical dark-grey loam "A_1" horizon with a light-grey sandy loam "A_2" horizon with gravel overlying a yellow clay "B" horizon. These soils occur only in peculiar environmental circumstances where dominantly arenaceous sediments are exposed on elevated areas of relatively gentle slopes. They are usually quite close to outcrops of quartzite. Specht and Perry (1948) have shown that in general throughout the western Mt. Lofty Range, podsolic soils are similarly developed, usually as sedentary soils on quartzites.

It is probable that some red podsolic soils also occur within the mapped areas (Litchfield 1951) but, in this description, no distinction has been drawn between red podsolic soils and red-brown earths. The mapped yellow podsolic soils are included within the Stonyfell Association.

Red-Brown Earths

On the relatively steep slopes of the escarpment zone, red-brown earths are the dominant group of soils. However, within this limited area, the environment is not favourable for the formation of the normal profile as it occurs at lower elevations on the plains. The red-brown earths of the escarpment zone are principally shallow to skeletal soils containing a high proportion of unweathered rock fragments. They may be formed as sedentary soils on outcropping argillaceous rocks or may be derived from alluvial or colluvial parent material.

Litchfield (1951) describes the Netherby series of sedentary red-brown earths as occurring over Pre-Cambrian slates on the Waite Institute property. These soils are invariably shallow and stony throughout the profile. As a general description, they may be considered as having a shallow brown silt-loam "A" horizon containing a moderate to large percentage of angular stone, overlying a red-brown clay "B" horizon which contains stone in increasing proportions with depth.

Two other distinct groups of red-brown earths occurring on the escarpment are the stony types of the Urrbrae Series (Litchfield *loc. cit*) and of the Knightsbridge Association. The Urrbrae soils are developed on alluvial or colluvial material derived principally from the weathering of argillaceous sediments. These are

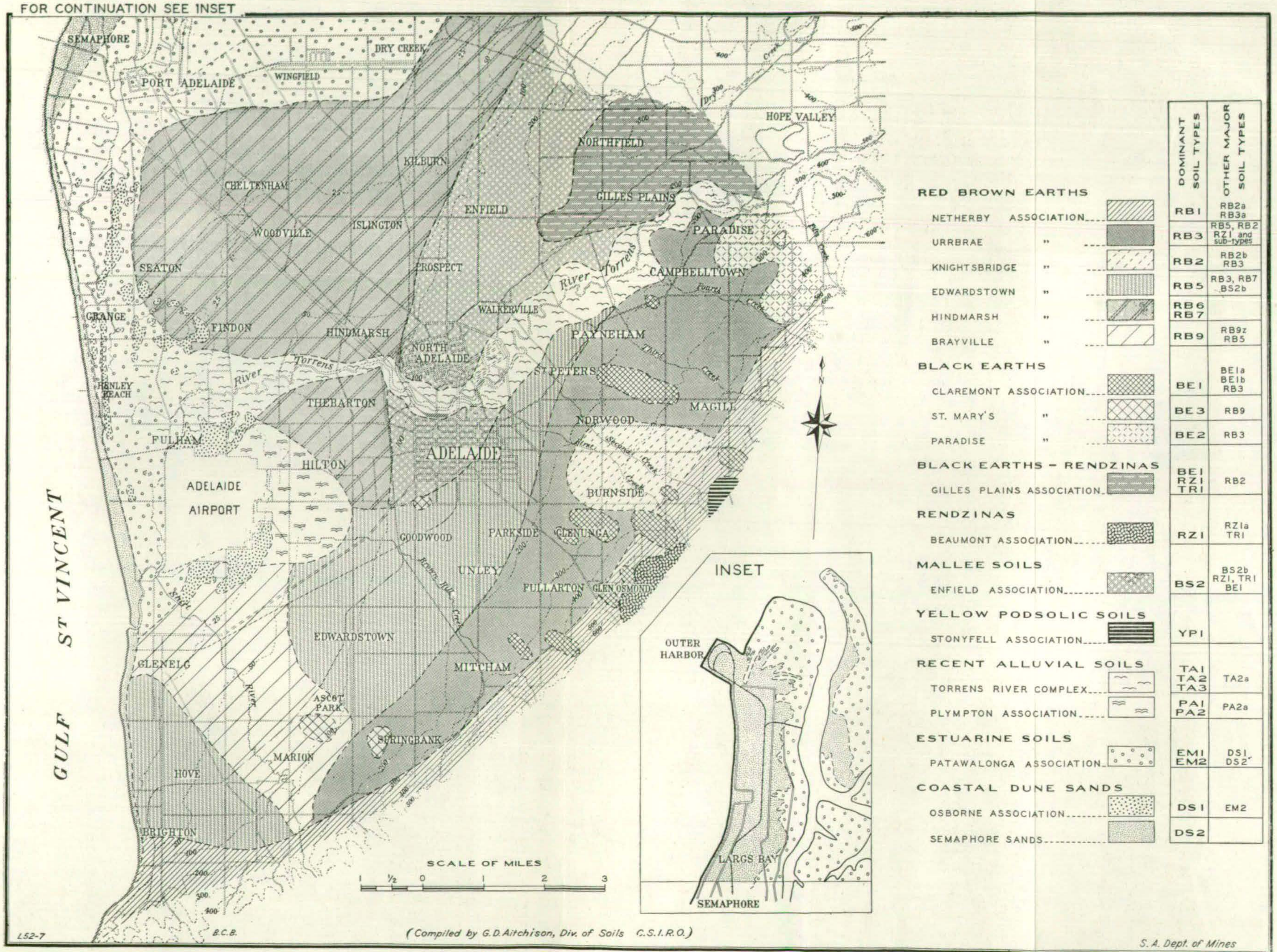

Fig. 14—MAP OF ADELAIDE AND SUBURBS
Showing the soil associations of the Adelaide Plains

the most common of the stony soils of the escarpment zone, and a typical soil consists of a brown loam "A" horizon with some water-worn gravel fragments overlying a red-brown prismatic clay containing moderate to large amounts of water-worn or sub-angular stone.

The stony types of the Knightsbridge soils are developed on alluvial or colluvial material associated with the weathering complex of the arenaceous rocks—principally the thick quartzites. A typical form of these soils would be a light reddish-brown sandy loam with large water-worn quartzitic stones overlying a red-brown sandy clay containing similar stone.

These groups of soils are all included within the Netherby Association.

Rendzinas and Terra Rossas

On many parts of the escarpment zone, where the parent material of the soil is rich in lime—whether in the form of an outcropping lime formation or in the form of an alluvial, colluvial, or aeolian deposit—soils of the rendzina and the terra rossa groups have been developed. These two soils, though pedologically distinct, occur in such intimate relationship within this area of interest that they must be regarded as inseparable.

Most important of these soils in the escarpment zone are those which occur on the outcropping Beaumont Dolomite. But basic similarities exist between the soils as developed on any of the lime-rich parent materials including Miocene marine limestones (as noted by Specht and Perry 1948), loessial limestone (Litchfield 1951) or weathered calcareous slates, or possibly colluvium which has been enriched by solution and redeposition of loessial lime. The general characteristic of these soils is that of a clay-loam surface overlying the calcareous parent material at shallow depths. The colour of the surface ranges from a grey-brown in the case of the rendzina to a bright red-brown for the terra rossa soils.

The whole of this group of soils has been included within the Beaumont Association.

Black Earths

Adjacent to the rendzinas and the red-brown earths along the fault lines of the escarpment are many small and large areas of black earths. If consideration is given only to the black earths of the escarpment zone there seems to be reason for describing them as hydro-calcimorphic soils (Litchfield 1951). However, a discussion of black earths properly belongs to the account of the soils of the upper outwash plain region. An exception is the case of the black-earth-like soil which occurs occasionally in a toposequential relationship with some rendzina soils. This is a deep dark-coloured clay soil which is formed at the lower topographic limit of some rendzinas, particularly along the base and verges of broad drainage lines associated with very short escarpment streams. These soils may in fact represent a colluvial or a hydromorphic variant of the adjacent rendzinas, but in morphology they are indistinguishable from black earths. Specht and Perry (1948) have observed the occurrence of such a soil which they have described as a degraded rendzina.

SOILS OF THE UPPER OUTWASH PLAIN

This area is principally a zone of alluvial soils—the up-graded alluvials discussed in previous chapters. Due to the complexity of factors involved in the deposition of the soil-forming materials, there is scarcely any possibility of uniformity of soils within this region. At the same time, this is an area of particular interest in the development of the suburbs of Adelaide. The favourable topographic situation provides an incentive for the expansion of domestic building in this zone, despite the fact that the soils which occur are particularly unfavourable for that purpose. Consequently this is an area in which soil studies have been concentrated to some degree in an endeavour to ascertain the soil factors of importance in domestic foundation-engineering.

The whole of the upper outwash plain is, in general, adequately drained. The moisture regime of the soil does not change markedly from point to point in this zone with the exception of limited areas adjacent to streams or springs or along disused watercourses or in closed depressions. These locally humid environments invariably produce soils which differ markedly from those formed in normal circumstances.

The principal soils of this zone are dominantly red-brown earths with numbers of occurrences of black earths and a limited extent of mallee soils.

Red-Brown Earths

The upper outwash plain represents the characteristic environment of red-brown earths (Piper 1938). However, the red-brown earths which do occur in this region of comparatively uniform climate and moderate to gentle slopes, are, in fact, extremely diversified in character. All are quite mature soils but nevertheless they possess physical properties extending over a very wide range.

The principal factor in controlling the formation of the soils of this zone is the nature of the original parent material from which the soils have developed. On alluvium derived principally from argillaceous material, and particularly from those shales and slates which are moderately calcareous, the soils of the Urrbrae Association have developed. The chief feature of dominant types among these soils is the "B" horizon which is a red-brown clay of prismatic or coarsely polyhedral structure which is subject to seasonal expansion and contraction movements of considerable magnitude.

By contrast there are the soils of the Knightsbridge Association which, though comparable in terms of depth of each horizon and of total profile, are dominantly sandy throughout. These soils are formed on alluvium derived principally from arenaceous material. Most of these deposits are transported by First Creek and Second Creek whose headwaters flow mainly through the soils sedentary on the thick quartzites. Only a limited area of these soils occurs, therefore, within the areas representing the present and past distributory zones of these two streams. General features of the Knightsbridge soils are the light reddish-brown sandy loam "A" horizon overlying a red-brown sandy clay "B" horizon. The sand component of the soil is medium to coarse in particle size.

The third important group of red-brown earths in this zone is the Edwardstown Association. These soils commonly occur at lower elevations than the Urrbrae soils with which they have many features in common. Texturally the two groups of soils are frequently almost indistinguishable, but there are recognizable differences of "A" horizon colour and "B" horizon structure which are associated with important differences of physical properties. The principal types among the Edwardstown soils exhibit a more pronounced development of an "A_2" horizon than the corresponding Urrbrae soils and the "B" horizon clay has a fine granular structure as compared to the prismatic to coarsely polyhedral structure of its counterpart. No entirely satisfactory explanation can be put forward at this stage of the genetic factors associated with the differing morphology of the soils—despite the fact that the characteristic morphological features can be adequately correlated with the engineering behaviour of the two soils thus providing sufficient justification for treating the Edwardstown and Urrbrae soils as distinct categories. It is probable that the Edwardstown soils are derived principally from the alluvium from distant sources deposited by the well-defined stream lines whereas the Urrbrae soils have received a major contribution of colluvial material in addition to similar alluvium. There is some morphological evidence of greater effective leaching of the Edwardstown soils. In view of their lower rainfall this could only come about as a result of a more susceptible parent material or possibly as a consequence of a mild process of solonization.

A further group of red-brown earths which occurs on the Upper Outwash Plain is mapped as the Brayville Association. In terms of their general morphology, however, these soils should rightfully be regarded as characteristic of the Lower Outwash Plain. They are formed on the flatter slopes where the outwash of the Sturt River has dominated topography and influenced the moisture relations of the soils. In over-simplified terms they may be regarded as hydromorphic variants of the adjacent Edwardstown soils. However, since the region of occurrence of these soils includes part of the Lower Outwash Plain they will be described further among the soils of that zone.

Black Earths

Throughout the whole of the Upper Outwash Plain, and in some adjacent areas, there are patches of black earths. These have been observed over areas of as little as ¼ acre and as large as about 400 acres. Since extreme variability seems to be one characteristic of black earths there has been considerable difficulty in attempting to define the typical black earths of this zone and in assessing the pedogenetic relationships of the soils. If, as a definition, it is accepted that a black earth is a dark-grey to black clay soil of granular to crumb structure with lime at almost any depth within the profile, then such black earths have been observed to grade continuously into red-brown earths, rendzinas, and occasionally mallee soils. They frequently occur in such an intimate relationship with red-brown earths that the soils cannot be mapped separately even on a micro scale.

Most of the mapped black earths of the Upper Outwash Plain occur immediately below the major fault lines. In areal extent they form a lenticular pattern with their greatest dimension transverse to the contours. There is thus the suggestion that there is an added pedogenetic factor arising from their peculiar location. This could be a hydromorphic factor due to the influence of the fault lines on groundwater distribution. Some, but not all, of the observed areas of black earths occur adjacent to spring lines or in locally humid environments provided by a typical topography. Alternatively it may be a halomorphic factor which is significant in their genesis. At the fault lines there will be a dramatic change in the nature of the colluvium produced. It is observable that the black earths occur in zones rich in calcium. Piper (1938) has commented on this tendency for black earths rather than red-brown earths to be formed in lime-rich alluvium where other factors remain constant. Litchfield (1951) regards the black earths of the Waite Institute as alkaline soils with hydro-calcimorphic affinities. The possibility of other less evident factors being of importance must not be ignored. It may be of significance that many of the groundwaters rising along the fault lines are somewhat magnesic. There is a tendency for a magnesium-rich environment to favour the development of montmorillonitic clay minerals, and the presence of such minerals must be suspected in view of the shrinkage and swelling properties of these soils.

Despite the uncertainties as to their genesis, there is no doubt about the general morphology and no difficulty in recognizing these black earths. Within the Upper Outwash Plain region three groups of black earths are recognized. Litchfield (1951) has described the Claremont series of black earths which occur on the Waite Institute property. The Claremont Association may be taken to include all soils of comparable morphology, *i.e.*, with a dark-grey clay-loam surface overlying a very dark-grey to brown or red-brown clay tending to become yellowish with depth, and with lime occurring almost at random throughout the profile. The Claremont soils are normally formed within a region of Urrbrae soils.

The second group of black earths is the St. Marys Association. These soils have been observed to occur contiguously with the Edwardstown and Brayville soils. In many instances they do not differ markedly from the Claremont soils, but there is a tendency for the development of a relatively impermeable mottled profile possibly associated with a slightly greater degree of solonization.

The third group of black earths is mapped as the Paradise Association. These soils appear to have been affected to a varying degree by an admixture of coarse sandy material, possibly from the erosion of early Tertiary sediments at higher elevations to the north and east. Otherwise these soils exhibit the normal morphological features of the black earths noted elsewhere near Adelaide.

Mallee Soils

Some of the soils overlying that part of the Para block which is buried shallowly beneath the city and adjacent parts can be considered to have affinities with the Mallee soils. These soils can properly be regarded as characteristic of the Para Fault block rather than of the Upper Outwash Plain. No separate account will be given of the limited extent of these soils which intrude into the latter region.

SOILS OF THE RIVER TORRENS VALLEY

Along the course of the River Torrens there is a broad band of soils in which profile development is not well advanced. The principal soils of this zone are, of course, composed of recent alluvium. Gravels and sands are common adjacent to the present or previous channels of the river with fine-textured soils in the areas which are subject only to periodic flooding.

On the river terraces a similar range of soils is encountered, from coarse gravels to silts. At all locations above the present-day flood-level of the river there is some evidence of profile formation, but usually only at an immature stage. Recognizable red-brown earths occur at intermediate levels but many of these are complicated by an overlying deposit of Recent alluvium.

At the highest limits of the river terraces, grading on the northern side to the Para block and on the southern side to the Upper Outwash Plain, red-brown earths commonly occur as well as scattered small zones of black earths.

All of these soils are mapped as the River Torrens Complex.

SOILS OF THE LOWER OUTWASH PLAIN

The principal factors operative in the formation of the Lower Outwash Plain have been the larger river and creek systems of the area, notably the Rivers Torrens and Sturt and the Brownhill Creek, and in the north, the Dry Creek. Climatic conditions are substantially uniform throughout the area and the major controls on soil development have been associated with parent material and efficiency of drainage. Topographic gradients in this region are quite small and natural drainage of considerable portions must have been inadequate.

The soils formed in this zone divide naturally into two systems. In the southern part of the area there are the heavy-textured soils of poor internal drainage, associated with the distributary systems of the Sturt River and the Brownhill Creek. These soils include degraded red-brown earths and immature alluvial soils which may be intermingled with some red-brown earths. To the north there are the lighter-textured soils, associated with the distributary pattern of the River Torrens and to a lesser extent, the Dry Creek. These soils are all red-brown earths or closely related types.

Red-Brown Earths

The most extensive groups of soils on the Lower Outwash Plain are the sandy saline red-brown earths associated with the River Torrens alluvial deposits. These soils have formed on parent materials of extremely complex derivation, which was, on the average, possibly dominantly arenaceous. During all stages of their development the groundwater table has been relatively close to the surface, and this fact, together with the limited rainfall has retarded the leaching of soluble salts from the soil.

The soils of this group range from the deep mature sandy red-brown earths of the higher portions of the area to the shallow more saline soils abutting the coastal plain.

All of these soils are mapped within the one group as the Hindmarsh Association.

Degraded Red-Brown Earths

Within the distributary zone of the Sturt River there has been developed a group of soils allied to the red-brown earths but exhibiting, in their general morphology, signs of inferior drainage. It is probable that the parent material from which these soils have been formed is not dissimilar to that of surrounding soils being derived principally from calcareous slates. However, the influence of the Sturt River waters has been sufficient to appreciably affect the moisture status of the nearby soil. Waterlogging of the soil has probably occurred for part of each year and the seasonal cycle of wetting and drying typical of the red-brown earths has been substantially modified. Under these conditions, a so-called degraded red-brown earth has formed, with the customary profile differentiation but with dull colours and mottling in the "B" horizon. In the lower portions of the area the soils become progressively more saline and some profiles exhibiting solonetz affinities have been observed. All of these soils have been mapped as the Brayville Association.

Heavy-textured Alluvial Soils

Most of the headwaters of the Brownhill Creek erode in argillaceous sediments which are also high in lime content. These eroded materials have been deposited as a result of periodic floodings over an extensive outwash area which includes part of the Lower Outwash Plain as well as the coastal plain. These sediments, the accession of which has been halted only by artificial drainage in recent years are thus heavy-textured soils, dark in colour and showing little or no regular profile development. Frequently fossil soil-horizons can be observed at various depths, but the overall characteristic is principally that of the alluvium. These soils are mapped as the Plympton Association.

SOILS OF THE PARA FAULT BLOCK

Lime may be regarded as the dominant constituent of the soils of the Para Fault block.* The three major soil groups of this zone, mallee soils, black earths, and rendzinas (and associated terra rossas) are highly calcareous. There can be no certainty in the postulate that there are possible influences of aeolian (loessial) lime as well as of lime-rich alluvium and/or underlying sediments.

Mallee Soils

In the areas immediately above the escarpment there is a widespread occurrence of mallee (or brown solonized) soils. The environment in which these soils are found is quite compatible with the mode of formation postulated by Crocker (1946). In the lee of the jutting escarpment, loessial lime was deposited in considerable thicknesses on the backward-tilting fault block. Due to its topographic isolation, and its relatively low rainfall since the time of deposition this near-escarpment zone has been comparatively free from the effects of erosion. The conditions of exposure, of accessions of cyclic salts, and of free drainage have thus been typical of these associated with the formation of mallee soils. These mallee soils are characteristically variable, but the general morphological features of a light-textured surface-soil overlying a highly calcareous (rubble or travertine) horizon apply over a considerable area of the Para block. Those soils mapped as the Enfield Association include all of the mallee-soil types noted in this zone.

Black Earths

Farther east on the Para block—where the aeolian lime is no longer evident—there occurs a zone of black earths. The parent material association of these soils is not entirely clear, but it is probable that contributions have been received from the weathering complex of the underlying argillaceous sediments, and from alluvium derived from the calcareo-argillaceous formations of higher elevations

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* Only a portion of the Para Fault block is considered in this discussion. The Grand Junction Road is taken as the northern limit and the Hope Valley Reservoir as the eastern limit.

on the Para block. Some lime enrichment of the soil parent-material has possibly occurred during the erosion of the original aeolianites. Morphologically the black earths formed on these deposits and mapped within the Gilles Plains Association appear to differ from the black earths mapped elsewhere around Adelaide principally in the structure of the lower horizon clays. The granular black clay top-soil gives way to a red, brown, yellow-grey or grey clay of prismatic structure with the well-defined polished cleavage faces which are often associated with highly expansive soils. Lime occurs almost invariably at random depths throughout the profile.

Rendzinas and Terra Rossas

At locations on the Para block adjacent to the areas of occurrence of the black earths there are certain soils which resemble the rendzinas and terra rossas. These soils have all been formed on calcareous parent-material which may have been derived from one or more of a number of possible sources. In some exposures a rendzina-like soil appears to have developed on a lime horizon of a dissected fossil mallee-soil. Nearby a similar surface horizon may be underlain by a marl, presumably derived from the weathering of the underlying or adjacent calcareo-argillaceous Pre-Cambrian formation.

In the light of the limited information available on these soils it is considered advisable to map them together with the black earth as one group—the Gilles Plains Association.

The soils of the Para block have not been thoroughly explored. However, present observations would indicate that most of the soils occurring, with the exception of the mallee soils, have their counterparts elsewhere in the Adelaide area. Further surveys are therefore unlikely to reveal any soils of a significantly different character from those already known.

SOILS OF THE ESTUARINE PLAIN AND OF THE COASTAL SAND DUNES

The formation of the Estuarine Plain has been discussed in preceding chapters. The soils of this zone are principally geological in character. They are simply assorted sands, silts, and clays with some shell beds—the typical estuarine muds. They are described and mapped as the Patawalonga Association.

The two systems of sand dunes—of the present and of the fossil coast-lines—have also been discussed in preceding pages. The white siliceous sand of the existing coast are mapped as the Semaphore Sands while the red sands of the stranded coast-line are mapped and described as the Osborne Association.

Chapter 10

OCCURRENCE AND MORPHOLOGY OF THE PRINCIPAL SOIL TYPES

Eighteen soil associations are mapped in fig. 14, including sedentary red-brown earths, rendzinas and terra rossas, and yellow podsolic soils; red-brown earths and black earths on alluvium; mallee soils; and immature soils of an alluvial, estuarine, or coastal nature. The associations mapped are as follows:

Red-Brown Earths:
- Netherby Association.
- Urrbrae Association.
- Knightsbridge Association.
- Edwardstown Association.
- Hindmarsh Association.
- Brayville Association.

Black Earths:
- Claremont Association.
- St. Marys Association.
- Paradise Association.

Black Earths-Rendzinas:
- Gilles Plains Association.

Rendzinas-Terra Rossas:
- Beaumont Association.

Mallee Soils:
- Enfield Association.

Yellow Podsolic Soils:
- Stonyfell Association.

Recent Alluvial Soils:
- River Torrens Complex.
- Plympton Association.

Estuarine Soils:
- Patawalonga Association.

Coastal Dune Sands:
- Osborne Association.
- Semaphore Sands.

RED-BROWN EARTHS

Of the above associations, those which are mapped within the red-brown earth group occupy about one-half of the total area. The red-brown earth associations are as follows:

The Netherby Association

These may be described as principally stony to skeletal red-brown earths of the escarpment outwash apron. They are the soils formed either upon the talus slopes fronting the escarpment, or as sedentary profiles upon shallow basement rock.

Dominant Soil Type—Type RB1

Principal among these soils is Type RB1, a shallow to skeletal red-brown earth formed directly upon Pre-Cambrian slates. Litchfield (*loc. cit.*) has mapped, within the Netherby series, soils comparable to this type. The chief morphological features of Type RB1 include:

(*a*) A surface horizon characteristically of brown loam containing moderate amounts of sub-angular stone principally slate with occasional quartzite.

(*b*) A "B" horizon of red-brown clay containing moderate to high proportions of stone.

(*c*) An horizon of lime accumulation overlying weathered parent rock (usually slate of low lime-content) at shallow depths—not more than 5 feet.

No great precision is attempted in defining soil Type RB1 since a considerable variation of horizon depths is to be expected in view of the relatively unstable environment in which it is formed. Breadth of definition is also permissible as a result of the overall similarity of physical properties of all such stony sedentary soils.

Sub-Dominant Soil Type—Type RB3a

Another important soil of this association is a stony variant of Type RB3 (*see* later). This soil (Type RB3a) occurs in those localities, on somewhat gentler slopes, where a stony parent-material, predominantly argillaceous and slightly calcareous, is provided to moderate depths. Such is frequently the case in zones intermediate between the areas of outcrop of the Pre-Cambrian slates and lower colluvial-alluvial accumulations which give rise to the normal Urrbrae soils. Litchfield (*loc. cit.*) has described as the Urrbrae stony fine sandy loam, a soil which is similar to Type RB3a. Apart from the general stony character of the soil, with some water-worn or sub-angular gravel concentrations particularly in the surface horizon and at random depths beneath, the general morphology is comparable to that of Type RB3.

Minor Soil Type—Type RB2a

A third member soil of this association is Type RB2a, which is a variant of the principal type of the Knightsbridge Association. The soil is developed on the moderate slopes, comparable to the environment of Type RB3a, but in those localities where the colluvial parent-material is predominantly arenaceous. In general this soil type is confined to an area adjacent to First and Second Creeks, which are eroding in the Stonyfell Quartzite. However, similar soils may occur in random locations along the escarpment outwash apron, wherever the conditions of arenaceous parent-material and well-drained sites are fulfilled. Morphologically these soils resemble Type RB2 (*see* later) with the additional feature of a moderate to high proportion of slightly rounded water-worn quartzite gravel and boulders concentrated in the lower part of the "A" horizon and scattered elsewhere in the profile.

Other Minor Soil Types

Also occurring within the Netherby Association are a number of less important soils. In situations where parent materials rich in calcium are provided there are patches of rendzina and terra rossa soils. The lime which determines the genesis of these soils may have originated from any one of a variety of sources—from the outcrops of calcium-rich slates; or from groundwater transfer of lime from outcrops at higher elevations; or from an occasional remnant of aeolianite where preserved by favourable topography. Morphologically the soils developed on such materials mostly have their counterparts in the principal local zone of rendzinas and terra rossas—the area mapped as the Beaumont Association (*see* later).

On the steeper slopes of the escarpment zone, within the mapped area of the Netherby Association, there are many occurrences of skeletal soils which may be only a few inches thick. Such soils are not given a place in the classification, due in part to their variability, but principally as a consequence of insignificance of the soil mantle in determining the overall physical behaviour of the complete sub-stratum.

The Urrbrae Association

This group of soils can be regarded as probably the most important of the Adelaide area—important because of their widespread occurrence and their favourable topographic location and because at the same time they possess physical characteristics which complicate building development in these areas.

The Urrbrae Association includes the principal types which represent the upgraded alluvial soils. These soils have all been formed on alluvial-colluvial material which has more or less steadily increased in thickness at an average rate of about 6in. per 1,000 years. In such soils the accretionary processes and the pedological processes are by no means distinct. One consequence is that the detailed classification of such soils is difficult, firstly because parent material differences cannot readily be observed (the parent material being the surface-deposited alluvium weathering as it proceeds down the profile) and secondly because in such soils the transition from type to type is extremely diffuse. A more fortunate consequence of the genetic history of these soils lies in the fact that the present soil profile is almost invariably a reflection of the sub-solum soil material. There is usually no sudden change in the physical nature of the soil as one proceeds downward from the surface for distances of up to 20ft. Thus, in this environment it is possible to use the soil profile of the pedologist as an indication of the nature of the soil material to greater depths. It so happens that within the environment of the Urrbrae Association soils this information is commonly of value in relation to domestic building foundations.

The parent material for the Urrbrae Association soil has been discussed earlier. It is composed principally of the erosion products of the escarpment rocks with argillaceous materials dominating and lime present in appreciable amount, and cyclic salts exerting a minor influence. The parent material may change abruptly adjacent to present or recent stream lines, but elsewhere within the area of these soils may be considered as reasonably uniform.

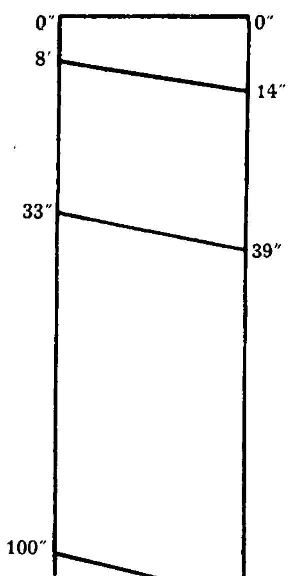
Dominant Soil Type—Type RB3

Dominant among the soils of the Urrbrae Association is Type RB3. This soil is comparable to the Urrbrae fine sandy loam (Litchfield 1951) and represents a near modal form of a red-brown earth. It has been studied in detail at a site at the Waite Agricultural Institute (Piper 1938), principally to define the agricultural potential of such soils. A similar soil to that analyzed by Piper has been selected for long-term observations of physical characteristics and seasonal behaviour (see Appendix A). Thus this soil is possibly the best known of all of the soils of the Adelaide area.

The chief morphological features of Type RB3 are the brown-loam surface-soil, the red-brown clay "B" horizon with characteristic prismatic or polished polyhedral structural aggregates, a lime-enriched horizon of brown clay passing to a firm fissured brown clay with some lime extending for a considerable depth.

The soil profile of Type RB3 is illustrated in colour plate I (fig. 1). The photograph depicts a soil which differs only slightly from the modal form. Gravel may or may not be presented in the "A" horizon, and the horizon of lime accumulation may often be more clearly and regularly defined than the example of plate I.

A typical profile of Type RB3 may be described as follows:



"A" Horizon—brown, greyish-brown, or light reddish-brown loam (or silt loam or fine sandy loam). Gravel may be present in limited quantities in the lower "A" horizon.

A lighter colour of the lower "A" horizon may be evident although not marked

"B" Horizon—Red-brown clay. Structure is variable at the top of the horizon, but is characteristically prismatic lower. The clay readily breaks into strong polyhedral structural units with a distinct surface sheen

"B-C" Horizon—Horizon of lime accumulation. A brown clay with lime usually visible but varying markedly in concentration at the top of the horizon where the structure is usually friable to granular.

Lime tends to decrease and become more uniformly distributed with depth giving a light-brown clay with pockets of lime. The clay is stiff and exhibits well-developed fissures or cleavage planes

When dry the whole profile of Type RB3 shows marked cracking. Wide vertical cracks are to be seen through the "B" horizon with an horizontal crack between "A" and "B" horizons.

Variants of Dominant Soil Type—Types RB3a and RB3b

Two principal variants of Type RB3 have been recognized. Type RB3a or stony variant of Type RB3, has been described above as occurring within the Netherby Association. To a lesser extent it also is found within the area mapped as the Urrbrae Association. Where grades are slightly steeper than normal there is a tendency for Type RB3a to develop.

On the other hand, where slopes are locally gentler than normal but with adequate drainage maintained, there is a tendency for a soil of Type RB3b to form. This soil is identical in general morphology with Type RB3, described above, except for an abnormally deep "A" horizon. Typically the "A" horizon of Type RB3b extends for at least 18in. from the surface although depths of almost 24in. have been noted.

Sub-Dominant Soil Type—Type RB5

Another major soil of the Urrbrae Association is Type RB5. This is in fact the dominant soil-type of the Edwardstown Association, but it also occurs in less prominent fashion among the Urrbrae soils.

Morphologically the RB5 soils may be distinguished from the rather similar RB3 soils on the basis of three features. Type RB5 soil possesses a shallower profile, exhibits a definite bleaching of the lower "A" horizon and has a granular structure of the "B" horizon (for detailed description see under Edwardstown Association). However a large number of soil profiles have been observed to have certain morphological affinities with both types—hence it would seem that within the Urrbrae soil association there is a range of soils transitional between Type RB5 and Type RB3. No attempt has been made to separate these soils into various sub-types.

Minor Soil Types—Types RB2 and RB2b

Another soil occurring to a minor extent within the Urrbrae Association is Type RB2, which is developed upon a parent material which is characteristically arenaceous. Although the major areas of Type RB2 are provided by the environment of the Knightsbridge Association—in which it is the dominant type—circumstances favourable for its formation are provided elsewhere, frequently in well-drained areas adjacent to present or recent creek channels. The chief morphological features of Type RB2 (which is described in detail under the heading of the Knightsbridge Association) are the light-brown sandy "A" horizon overlying a red-brown sandy clay "B" horizon.

A variant of Type RB2, associated with localities of somewhat impeded drainage close to creek lines, is also to be found at random among the Urrbrae Association soils. This soil, described (*see* later) as Type RB2b, has characteristic morphological features of a sandy surface soil overlying a mottled greyish heavy clay.

Minor Soil Type—Type BE1

Small areas of black earths occur widely as member types of the Urrbrae Association. Although quite morphologically distinct from the adjacent red-brown earths, these black soils are found on such limited areas, frequently intermingled with red-brown earths, as to make separate mapping impossible. The features of these soils, represented here by Type BE1, and their characteristic environment are discussed with the Claremont Association soils.

Minor Soil Type—Type RZ1

A further member of this soil association with distinctive morphology occurs to a limited extent in these localities which provide a lime-rich parent material. This soil has affinities with the rendzinas, particularly those of the Para block. The environment in which these soils have been noted is usually that of an elevated well-drained site, near the northernmost extent of the mapped zone. These areas may well represent some remnants of the old Para block surface. The soils are comparable in morphology to Type RZ1. (*See* Gilles Plains Association.)

Other Minor Soil Types

In transitional zones several other soils may be noted. Principal among these are the mallee soils, which are included within the Enfield Association. However, these soils are not properly regarded as member types within the Urrbrae Association, and any occurrences may best be considered within the appropriate association.

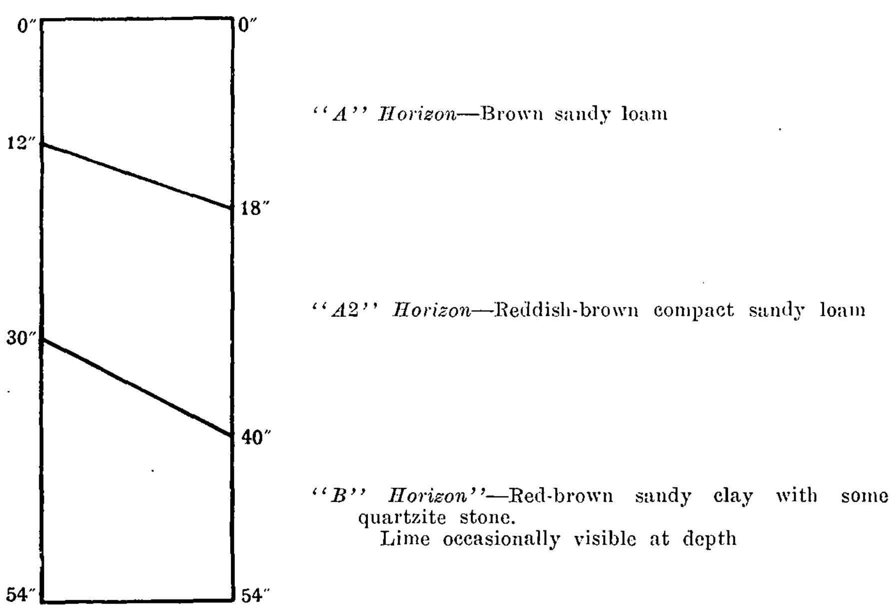
The Knightsbridge Association

This group of soils occupies a similar topographic position to the soils of the Urrbrae Association and is subject to similar climatic influences. Like the Urrbrae soils the Knightsbridge Association is comprised of the upgraded alluvial soils and differs only as a consequence of parent-material differences. The Knightsbridge soils are derived from alluvial-colluvial deposits laid down principally by First Creek and Second Creek, with a significantly arenaceous character reflecting the influence of the Stonyfell Quartzite as the probable source of the material.

Dominant Soil Type—Type RB2

The dominant soil of this Association is Type RB2. Its chief morphological features are a brown sandy loam surface of considerable depth, overlying a red-brown sandy clay "B" horizon. There is often very little evidence of a lime horizon, and there may be considerable proportions of rounded quartzite gravel at random depths.

A typical profile of Type RB2 might be:



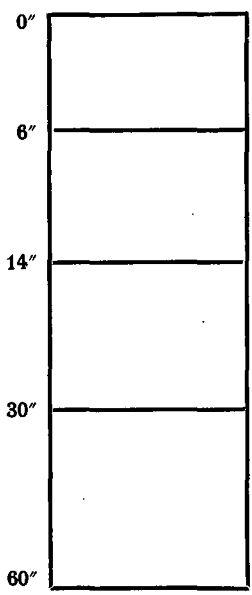
Sub-Dominant Soil. Type—Type RB3

Throughout the area mapped as the Knightsbridge Association, soil type RB3 also occurs to a moderate extent in a random manner. The formation of Type RB3 rather than Type RB2 is probably the consequence of a local enrichment of the argillaceous content of the parent material—due possibly to the influence of micro-relief on the distribution of the alluvial-colluvial complex.

Variant of Dominant Soil Type—Type RB2b

Of some importance also is a variant of Type RB2 which occurs in areas adjacent to First Creek and Second Creek. In these areas the internal drainage of the soil is affected by the temporary proximity of a groundwater table during the winter or in wet season. The resulting soil, defined as Type RB2b, exhibits the characteristic mottling associated with such temporarily impeded drainage. Other morphological features are the greyish colours of the upper parts of the profile and the relatively impervious nature of the lower horizons. This soil shows certain affinities also with Type RB3, but is classified as a variant of Type RB2 principally because of the continuous transitional relationship observed between the latter soil and Type RB2b.

A typical profile of Type RB2b might be:—



"*A*" *Horizon*—Grey sandy loam

"*A2*" *Horizon*—Brownish-grey loamy sand

"*B*" *Horizon*—Yellow-grey and red-brown mottled clay

"*B2*" *Horizon*—Red-brown clay with some mottling and heavy lime.
Mottling diminishes with depth

The Edwardstown Association

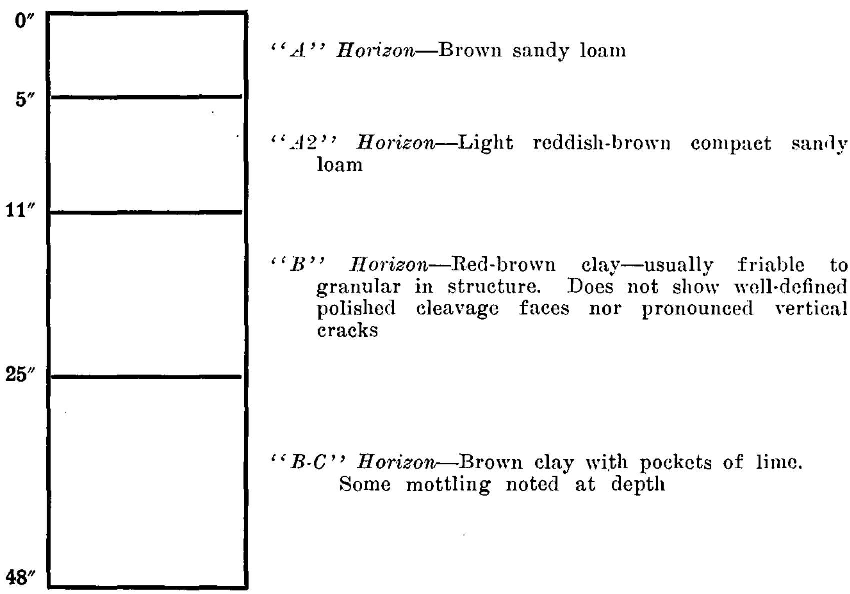
These are the soils of the lower portions of the Upper Outwash Plains. Like the Urrbrae soils they may be regarded as upgraded alluvial soils but with appreciable differences due to dissimilarity of environment. Over much of the area of these Edwardstown soils the processes of soil accretion have been more gradual than at higher elevations. Simultaneously the pedogenetic processes have operated in an environment markedly influenced by higher groundwater-table conditions than in the adjacent Urrbrae soils. Consequently there is a tendency for the resulting soils to be shallower and to exhibit some effects of hydromorphism. An additional factor is the influence of increased contributions of cyclic salts particularly nearer the sea.

The importance of the alluvial parent-material is not well established. It is obvious that most of the material must have been transported by the larger streams (including some of the escarpment consequent streams), but it is difficult to estimate the contribution of the various distributary systems or to adjudge the relative importance of the eroding outcrops in the catchment zones. Since the area is one of moderate slope with generally adequate surface drainage most of the alluvial material deposited by the larger streams was probably coarse in texture.

Dominant Soil Type—Type RB5

The soils of the Edwardstown Association are principally red-brown earths. The dominant soil of the area is Type RB5. This soil has the characteristic morphology of a near modal red-brown earth. Its particular features are a brown sandy loam surface over a light reddish-brown compact sandy loam "A2" horizon which in turn overlies a friable red-brown clay with a lime horizon just below a depth of 2ft. The profile does not exhibit any pronounced vertical cracking nor does it show, when dry, a horizontal shrinkage crack between "A" and "B" horizons. The basic differences between Type RB5 and Type RB3 are thus morphologically evident as the sum of a number of minor features which together are significant.

A typical profile of Type RB5 might be:



There is some evidence of a tendency towards solonization in these soils. In the profile described above, which represents a median location within the mapped areas, the partially bleached "A2" horizon, the structure of the "B" horizon and the high salinity of the lower portions of the profile may be significant. In localities nearer the coast with decreasing rainfall but increasing accession of cyclic salts, the soils become duller in colour with the lime horizon more strongly developed, sometimes to the verge of travertine.

Transitional Soils—Related to Types RB3 and RB5

Away from the coast-line and towards the areas of Urrbrae soils there is a tendency for transitional soils between Types RB3 and RB5 to be formed. In plate I (fig. 2) a soil profile defined as Type RB5, but with slight affinities with Type RB3, is illustrated.

No attempt has been made to classify all of the transitional sub-types which exist within this Association. Apart from Type RB5 there are frequent occurrences of Type RB3 soils in the mapped zone of Edwardstown soils. Since the environmental factors controlling the formation of these soils are not fully recognized, the soils can only be separately distinguished on the basis of their morphological features as described above. It should be stressed, though, that whereas Type RB3 is established as a widely occurring soil-type, the Type RB5 of the above description, and conforming in general to the illustration of plate I (fig. 2), is merely an arbitrarily chosen representative of a range of soils. Hence it will commonly be easier to recognize, in a transitional soil, some affinity with the clearcut Type RB3 rather than the diffuse Type RB5.

Sub-Dominant Soil Type—Type RB7

The Edwardstown Association also includes, in areas remote from the escarpment, some soils which have affinities with the adjacent Hindmarsh Association soils. These are the sandy, somewhat saline soils which are widespread on the Lower Outwash Plain. Soil Type RB7, which is a dominant member of the higher portion Hindmarsh Association, also occurs to a moderate extent as a member of the Edwardstown Association.

Minor Soil Types—Type BS2b and Variants

Another transitional range of soils is that which is developed between the RB5 soils and the Mallee soils of the shallowly buried Para block on the eastern side of the city proper. In this zone there is a mixed pedogenetical influence due possibly to quite minor physiographic features—with alluvial-colluvial soils of the newer land-surface mingled with the soils of the exposed remnants of the Para block surface. Within this portion of the mapped area of Edwardstown soils there are several transitional types which show some affinities with the soils of the Enfield Association. Soils resembling Type BS2b (*see* later) have been noted mainly in elevated locations (which are possibly remnants of the old Para block surface), but no continuous expanse of uniform soil-type occurs in this zone. Rather it is an area of progressive soil-change with all gradations of soils present from Type RB5 to Type BS2b.

The whole area of Edwardstown soils is in fact one of transition in which categorical definition is difficult. The proper elucidation of soil relationships is hampered considerably by the fact that a large proportion of the zone is already closely settled and therefore not readily accessible. It is unlikely that much further detail will be forthcoming.

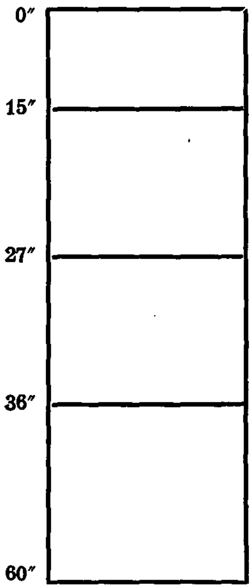
The Hindmarsh Association

These are the soils characteristic of the well-drained portions of the Lower Outwash Plain. They are formed on the alluvial deposits of the larger streams, principally the River Torrens. In general they may be described as sandy saline red-brown earths in the formation of which a moderately high groundwater-table has been of significance.

Broadly these soils divide into two distinct groups: those which occur in the higher portions of the area, are of considerable total thickness and may still be regarded as upgraded alluvial soils; and those of the lower flatter areas in which the total thickness of present and past soil-profiles is but a few feet. Naturally, the two types grade one into another.

Dominant Soil Type—Type RB7

The former soils, which have been of economic value as sources of brickmaking clays, are characteristically somewhat variable, but may be represented in terms of soil Type RB7. A typical profile of this type might be:



"A" *Horizon*—Brown to reddish-brown loamy sand

"B" *Horizon*—Reddish-brown sandy clay

"B-C" *Horizon*—Light-brown sandy clay with light to moderate lime.

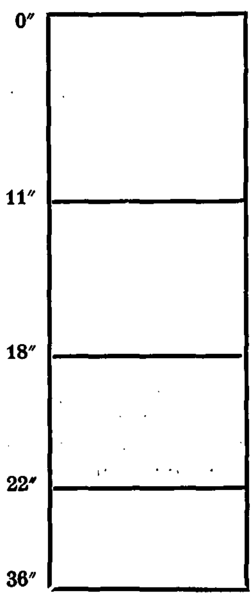
Light-brown sandy clay or clayey sand continues to considerable depth

Micaceous material is frequently found throughout the profile of Type RB7. Visible salt accumulations sometimes occur in the profile while pockets of gypsum crystals have been noted in the sub-strata. Water-table depths vary considerably but do not normally approach within 10ft. of the surface in this soil.

Sub-Dominant Soil Type—Type RB6

In the lower portions of the area mapped as the Hindmarsh Association, occur soils of shallow profile, high groundwater-table, and marked salinity. Although described as red-brown earths on the basis of overall profile characteristics, they show quite marked affinities, as a consequence of the salinity of their environment, with solonetz soils. The soils of this portion of the Hindmarsh Association naturally exhibit a wide range of degrees of development—from the exceedingly limited profile differentiation of the soils bordering the Estuarine Plain to the deeper soils extending into Type RB7.

Soil Type RB6 may be taken to represent a median condition in this lower portion of the Hindmarsh Association. Its profile is illustrated in plate II (fig. 1) and may be described as follows:



"*A*" *Horizon*—Brown loamy sand to sand

"*B*" *Horizon*—Reddish-brown sandy clay of coarse prismatic structure

"*B-C*" *Horizon*—Reddish-brown to light-brown sandy clay with moderate lime.

Reddish-brown sandy clay

In soil type RB6 the groundwater table will usually rise each season to within 6ft. of the surface and in wet years may be as close as 3 feet.

Minor Soil Types

The soils of the Hindmarsh Association also include a variety of transitional types. To the northeast of the mapped area, adjacent to the Para scarp, there is a zone in which the products of surface erosion of the escarpment area have influenced soil formation. Local enrichment of lime from this source has led to the development of soil types showing affinities with the Mallee soils of the Enfield Association. However, no well-defined Mallee soils occur within the area, and the transitional types are not sufficiently important to warrant separate classification.

Other transitional areas occur in zones abutting several of the mapped associations. Insufficient is known however of the overlap of soils in these areas to permit the inclusion of other soil-types within the Hindmarsh Association.

The Brayville Association

This is a zone of so-called degraded red-brown earths. It is an area dominantly influenced by the waters of the Sturt River and includes much of the old flood-plain of this river. All of the soils exhibit some signs of hydromorphism and in addition, in localities where the groundwater table is high, some halomorphic effects are evident.

In the better-drained areas, the environment is broadly comparable to that in which the adjacent Edwardstown soils have been formed. However, there is some evidence that under natural conditions the surface gradients of the soil were insufficient to provide adequate drainage throughout the winter months. Some seasonal waterlogging of the soil tended to occur, although this condition has been considerably modified by artificial drainage.

Dominant Soil Type—Type RB9

Under these circumstances there has been formed a range of soils grading continuously from Type RB5, as defined above, to a soil which tends to lose its affinities with the red-brown earth groups. But if consideration is given to a soil designated as Type RB9, and representing a mean stage in this transition, the basis of the description "degraded red-brown earth" may be more evident.

In plate II. (fig. 2) is illustrated a soil comparable with Type RB9. The dull-coloured heavy-textured surface overlying the normal lower-horizon sequence of a red-brown earth is visible.

The profile of Type RB9 might be described as follows:

0″–6″	Grey-brown silt-loam to clay-loam
6″–12″	Grey and light-grey mottled clay
12″–21″	Brown clay of coarse prismatic structure; becoming reddish in colour with depth
21″–24″	Light-brown friable clay with moderate lime
24″–36″	Reddish-brown friable clay

Variants of Dominant Soil Types—Types RB9a, RB9c, and RB9z

An extensive range of variants of Type RB9 occur within the area and some of these have been described. Typical of that stage of the transition between soil Type RB9 and RB5, *i.e.*, towards a better drained condition, is Type RB9a. The profile of this type may be described as follows:

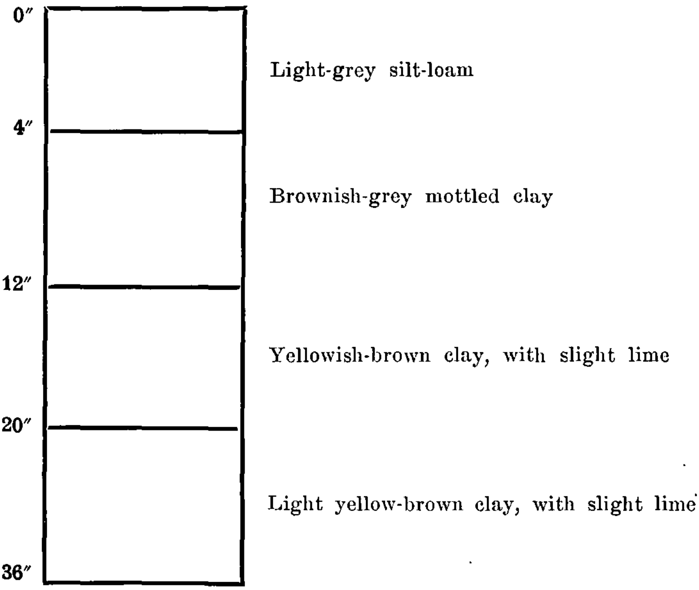
0″–12″	Grey-brown slightly mottled clay-loam
12″–24″	Reddish-brown friable clay with slight mottling
24″–30″	Reddish-brown friable clay with some lime
30″–42″	Light-brown to reddish-brown friable clay with some lime

Under poorer drainage circumstances, a heavier duller profile, designated as Type RB9c, is developed. A typical profile of this type might be:

0″–5″	Grey-brown silt-loam to silty clay-loam
5″–8″	Yellow-grey and grey mottled clay
8″–18″	Yellow-grey-brown mottled clay; tending to become friable with depth
18″–24″	Brown friable clay
24″–36″	Light-brown friable clay, with slight lime

There is a tendency for the soils of Type RB9c to be closely associated with the black earths of the St. Marys Association (*see* later).

In the flatter more low-lying portions of this area, in which the groundwater table rises close to the surface, a soil is developed which is a further (halomorphic) variant of Type RB9c. This soil, designated as Type RB9z, is illustrated in plate III (fig. 1). Under the influence of rather saline groundwaters the soil has been formed with strong solonetzic affinities. It does not properly belong within the category of red-brown earths but is retained for simplicity in the classification as the limiting case of so-called degradation within the environment of these Brayville soils. A typical profile of Type RB9z might be:



Transitional Soil Types

In addition to Type RB9 and variants, the Brayville Association as mapped includes some areas of Type RB5 soils as well as some occurrences of recent alluvium. No attempt has been made to classify these immature alluvial soils—recent deposits of the Sturt River—which are limited in extent. All transition zones between the Brayville soils and those of adjacent associations tend to be broad and diffuse. Consequently there may be considerable overlap in the occurrences of the types of the respective associations.

BLACK EARTHS

Throughout a considerable proportion of the Upper Outwash Plain area, there are occurrences of soils with black-earth affinities. Some aspects of the genesis of these soils have been discussed in previous chapters although somewhat inconclusively.

The principal feature of these soils can be set down as that of variability. They rarely occur over any considerable expanse of country. Within the Adelaide suburbs the greatest single extent of these soils is an area of about 400 acres. On the other hand there is a great number of minor occurrences, many of which are too small for mapping on any convenient scale.

Similarly, a black-earth profile is in itself characteristically variable to almost an extreme degree. It is frequently impossible to describe the nature of these soils in terms of a single soil-profile since major changes may occur and re-occur within a lateral space of only a few feet. It is common to encounter, in excavations in such soils, a change from a modal black earth to a red-brown earth and again to a black earth all within a distance of about 10 feet.

Under these circumstances it is obviously impractical to attempt any precision in defining soil-types within these associations. Attention is paid mainly to the broader features of the soils and the basis of recognition in the field. Despite their variability, the black earths of this area all have in common certain conspicuous characteristics which make them morphologically distinct from all other soils of the area. Thus while classification and identification within the black-soil associations is vague and difficult, the differentiation of a black earth from any other soil is simple, and for the purposes of this *Bulletin* it is also, fortunately, adequate.

The chief feature of the black earths are:

(1) The surface horizon of dark-grey to black clay which usually shows, when dry, an almost dramatic pattern of cracks.

(2) The micro-relief of the soil surface which is evident as a series of small mounds and depressions (gilgai or crab-holey formations). In areas in which the natural condition has been disturbed these gilgai effects may no longer be visible.

(3) A continuous extensive depth of clay soil which may vary in colour from black to almost white (where lime is present in large quantities), or with tinges of red, yellow, brown, or grey. There is usually evidence of cracking of the soil for some distance below the surface (except through the horizons of lime accumulation where the crack pattern is diffuse).

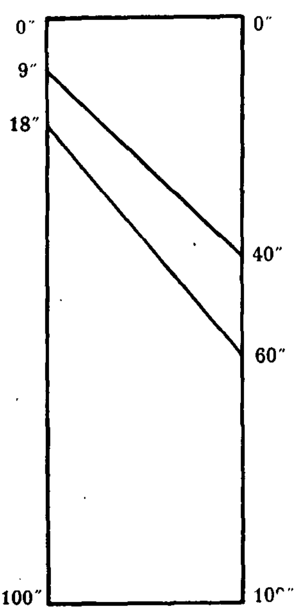
In the classification and mapping of the black-earth soils of Adelaide four separate associations have been recognized.

The Claremont Association

These soils are found typically on or close to the escarpment outwash apron. Like the adjacent Urrbrae Association soils they can be regarded as upgraded alluvial soils of considerable total depth.

Dominant Soil Type—Type BE1

The morphology of these soils is, as mentioned above, so variable that any profile description has its limitations. However, with due recognition of such variability, it can be said that the dominant soil of this Association is Type BE1. This soil-type occurs in regions representing the average drainage status of the environment. Soil Type BE1 may be defined as follows:



Dark-grey to black granular clay; extensively cracked when dry

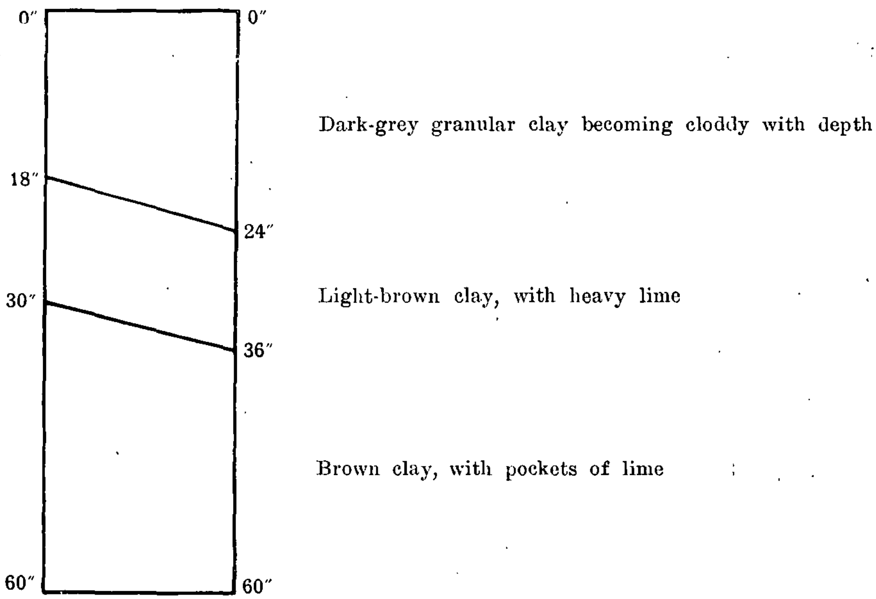
Dark-grey, brown, or red-brown clay, often coarsely structured

Light-brown clay, with lime in varying concentrations

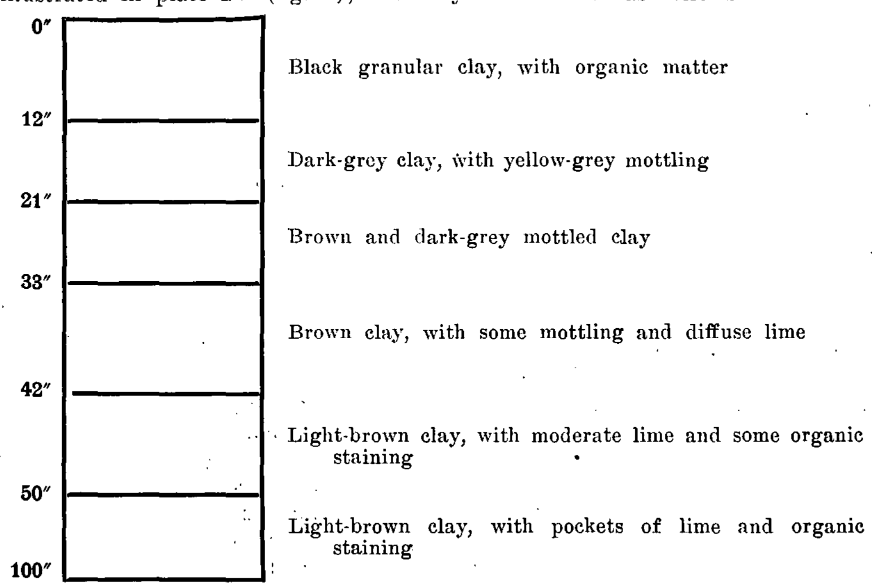
Soil Type BE1 is normally as inconstant in morphology as is indicated in the above discussion.

Sub-Dominant Soil Types—Types BE1a and BE1b

In better-drained localities there is a tendency for a slightly less variable soil type to be found. This soil, designated as Type BE1a occurs on the ridges and saddles of the near escarpment zone. Litchfield (1951) has mapped a soil similar to Type BE1a as the Claremont Clay-Loam. A typical profile of this soil is illustrated in plate IV (fig. 1) and may be described as follows:



In wetter zones, however, as adjacent to stream or spring lines within the same general environment, a soil of different character is developed. This soil which is designated as Type BE1b, and mapped by Litchfield as the Claremont Clay-Loam deep phase, may properly be regarded as a hydromorphic black earth or wiesenboden.* A soil profile representative of such an environment is illustrated in plate IV (fig. 2), and may be described as follows:



* Communicated by C. G. Stephens.

All gradations of soils between Types BE1a and BE1b may exist within quite a restricted locality. In addition it is frequently found that a soil comparable to Type RB3 occurs in an intimate relationship with the BE1 soils. The resulting pattern of soil distribution is, to say the least, rather confused.

Minor Soil Types

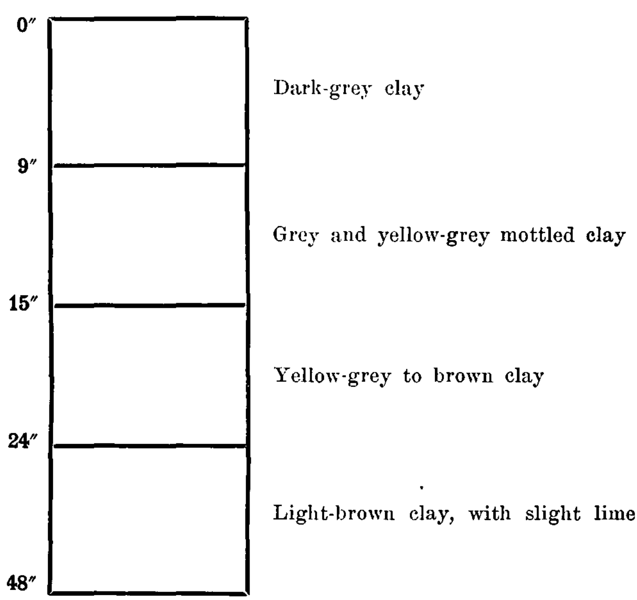
The mapped areas of Claremont Association soils may include as well (but in minor proportions) any member type of the adjacent Urrbrae, Netherby, or Knightsbridge Associations. These soils have been described above and will not be specified here.

The St. Marys Association

In overall morphology these soils do not differ extremely from the Claremont soils. However, due to the continuous relationship which exists between the St. Marys soils and the soils of the Brayville Association, the former soils have been recognized as a distinctive association.

Dominant Soil Type—Type BE3

The St. Marys soils are found in an environment of impeded surface-drainage and moderately high seasonal water-table. The soils tend consequently to exhibit some signs of hydromorphic and/or halomorphic variance from the adjacent red-brown earths. The profile described above in broad terms as representing Type BE1 could apply almost as well to the dominant soil of the St. Marys Association. This soil designated as Type BE3 may be further detailed as follows:



In addition to soil Type BE3, the only other soils which are important members of this Association are of Type RB9 and its variants—as described within the Brayville Association.

The Paradise Association

These are the soils formed in an environment directly comparable to the soils of the Claremont Association. However, to a minor degree at least, they are influenced by a modification of parent material. Throughout much of this area there has been an accession of small amounts of siliceous material probably from adjacent outcropping quartzites or from eroding early Tertiary sediments at higher elevations. The resulting soils appear as typical black earths with a more or less superficial addition of coarse sandy material.

Dominant Soil Type—Type BE2

The dominant type of this Association, Type BE2, has essentially similar morphology to Type BE1, described above, with the exception of the occasional presence of small to moderate amounts of coarse sand usually in the surface horizons and rarely at other depths in the profile. In most other respects the Paradise Association and the Claremont Association soils are rather similar.

The Gilles Plains Association

These are the soils formed on the Para block in areas where erosion has partially stripped the surface and where there is an influence of alluvium and colluvium from adjacent sources. They occupy a zone in which the parent-material factor—again dominant in soil formation—is extremely complex. Some of the soils may be formed on the lime-rich alluvial-colluvial deposits from the adjacent zone of Mallee soils (the Enfield Association); others are developed on dissected Mallee-soil profiles; others occur as sedentary soils on the underlying Tertiary clays; while others are found on alluvial-colluvial material from outcropping Pre-Cambrian rocks to the north.

Throughout the whole area there is a dominance of lime-rich material. Consequently most of the soils formed are either black earths or rendzinas—often with terra rossas. Due to the complexity of the soil-forming factors and to the absence of detailed soil-survey knowledge of this area, it has been found necessary to group a wide range of soils together within this Association.

Dominant Soil Types—Type BE1 and Variants

Perhaps the most important soil of the area is one of the black earths. As usual with such soils there is a marked variability from place to place with a consequent lack of distinctness in type morphology. However, certain of these soils show pronounced similarities with Type BE1 and its variants. In the absence of more detailed information it may be taken that the black-earth components of this Association have their counterparts within the Claremont Association, described above. Although some genetic differences may exist between the soils, the physical properties may be expected to be similar.

Sub-Dominant Soil Types—Types RZ1 and TR1

On outcropping limestone, whether this is of the form of a travertinized fossil soil-horizon or of a lime-enriched alluvium or possibly basement rock, there are soils with rendzina affinities. These soils are quite comparable with those of the Beaumont Association (*see* later). They are generally shallow soils with dark-grey clay-loam to clay surfaces overlying limestone. Type RZ1, as described in the subsequent section as a member of the Beaumont Association, may be regarded as typical of these soils within the Gilles Plains Association. Soils with terra rossa affinities also occur, frequently side by side with the rendzina soils. Type TR1 of the Beaumont Association may also be regarded as characteristic of this area.

Minor Soil Type—Type RB2

On the fringes of the River Torrens, within the area mapped as the Gilles Plains Association, there are limited occurrences of red-brown earths. Usually these are sandy soils showing affinities with some previously described types—principally Type RB2.

No attempt has been made to classify separately any of the soils of this Association. Most of the soils have their counterparts elsewhere within the mapped areas. Too little is known of the exceptional soils to warrant further description at this stage. A detailed survey would be required to reveal the full background to the development of all of the soils of this Association.

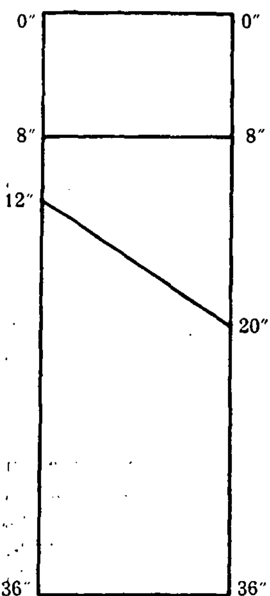
RENDZINAS AND TERRA ROSSAS

The Beaumont Association

These soils are formed principally on outcropping limestone or on lime-enriched material. Most of the member types within this Beaumont Association have affinities with the rendzina group of soils, although some terra rossas and red-brown earths are also quite common.

Dominant Soil Type—Type RZ1

The dominant soil-type of this Association is Type RZ1, which is formed on outcropping Beaumont Dolomite or on scree material contiguous with such outcrops. Morphologically these soils show a superficial resemblance to certain of the black earths, having a dark-grey friable clay-surface extending to a calcareous horizon beneath. However, the RZ1 soils are invariably shallow (not more than 1ft. to 2ft. to the underlying weathered limestone). A typical occurrence of a Type RZ1 soil is illustrated in plate V (fig. 1). The description of the profile might be as follows:



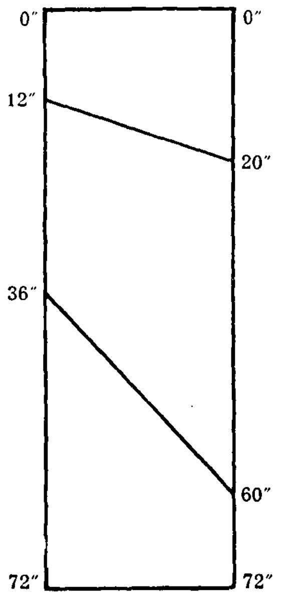
Dark-grey friable clay, with some fragments of limestone

Chocolate-brown friable clay, with some fragments of lime

Weathered limestone, with small proportions of clay

Variant of Dominant Soil Type—Type RZ1a

Some deeper sub-types of this soil may occur in localities which favour the accumulation of colluvial material. Such deep soils have been noted in and adjacent to valley bottoms within the mapped areas of Beaumont soils. Type RZ1a may be taken as typical of these, with a profile which may be described as follows:



Dark-grey to black granular clay

Dark grey-brown clay, granular on top, tending to be massive with depth. Some lime fragments

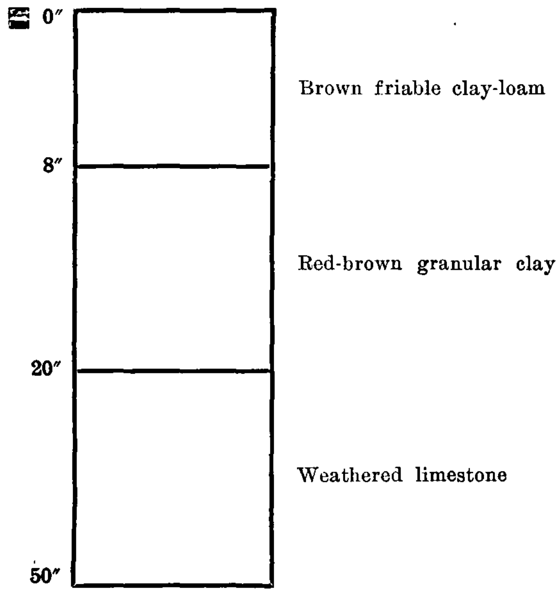
Weathered limestone, with some clay

Soils resembling Type RZ1 may grade continuously into the zones of black earths which occur at lower elevations. There is obviously some genetical relationship between the two soils.

Sub-Dominant Soil Type—Type TR1

Often in close proximity to rendzina soils—such as Type RZ1—there occur small areas of terra rossas or of soils closely allied to these. As with the rendzinas, the terra rossa soils are formed on limestone, but the exact derivation of the two types of soils is not well established. A typical example of the latter soils is illustrated in plate V (fig. 2) which shows a profile exposed only a few yards from the location of RZ1 soil of plate V (fig. 1).

This soil is designated as Type TR1 may be described as follows:



Some deeper variants of this type may also be noted, although the total extent of type and sub-types is quite limited.

Minor Soil Types

Within the area mapped as the Beaumont Association are minor occurrences of red-brown earths comparable with the Netherby Association soils. Some small areas of black earths, related to the Claremont Association, may also be found. No detailed listing is given of any of these lesser constituents of the Association since none are widespread and all have been described above.

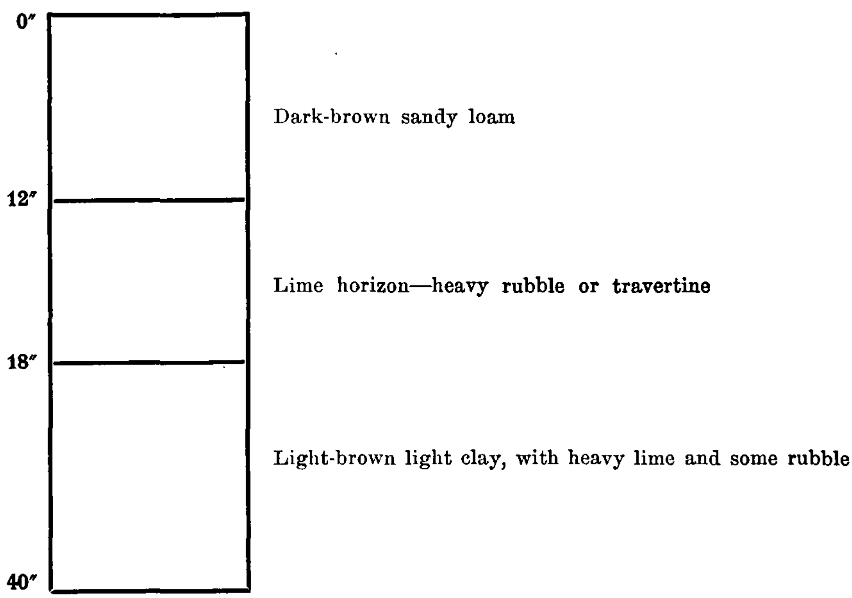
MALLEE SOILS

The Enfield Association

This group of soils is characterized principally by the dominance of lime as a pedological feature. The Enfield Association is comprised of the soils formed on the Para Fault block, adjacent to or in the lee of the escarpment. In such localities erosion has, in general, not been severe, and there has been no alluvial accretionary process as elsewhere in the Adelaide area. The soils formed are, in the main, closely related to the mallee or brown solonized great soil-groups. Parent material, in the normal sense, is not of such importance in these soils. There is, however, a pronounced influence of the accession of aeolian lime (as discussed earlier) and of the operations of a process of solonization in soil formation.

Dominant Soil Type—Type BS2

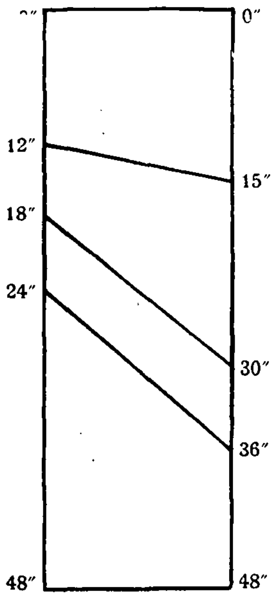
The major soil of this area is that designated as Type BS2. This is a typical mallee soil with a light-textured surface soil overlying a lime horizon (either in the form of rubble or travertine) which is also the horizon of some clay accumulation. The profile of Type BS2 may be described as follows:



This soil is characteristic of the elevated well-drained portions of the area.

Sub-Dominant Soil Type—Type BS2b

On lower slopes of the escarpment, and elsewhere in localities which favour the accumulation of colluvial material, there is a tendency for soils with deeper surface-horizons to be developed. Type BS2b may be taken as representative of these colluvial variants. A description of this type could be:



Brown sandy loam (or any texture from sand to sandy clay-loam)

Light-brown sandy clay-loam

Light-brown sandy clay, with moderate lime and lime rubble

Light reddish-brown sandy clay to clay, with some lime and lime rubble

A typical profile of Type BS2b is illustrated in plate VI (fig. 1).

Transitional Soils and Minor Soil Types

Along the western face of the escarpment there is a small expanse of outwash apron, part of which is mapped within the Enfield Association. In this area there is a variety of soils principally derived from colluvium from the adjacent high lands. Some of these soils resemble the deepest phases of Type BS2b and others grade into the sandy red-brown earths of the adjacent Hindmarsh Association. None of these transitional soils occupies any extensive area and consequently they are not listed separately in this discussion.

On the eastern fringes of the zone mapped as the Enfield Association the influences of profile dissection by erosion, and of the accession of alluvial material become noticeable. In this area the soils grade continuously into the complex pattern of the Gilles Plains Association. Thus some soils allied to Types RZ1, TR1, or BE1 may occur to a limited extent within the Enfield Association. No detailed discussion of their individual formation will be attempted here.

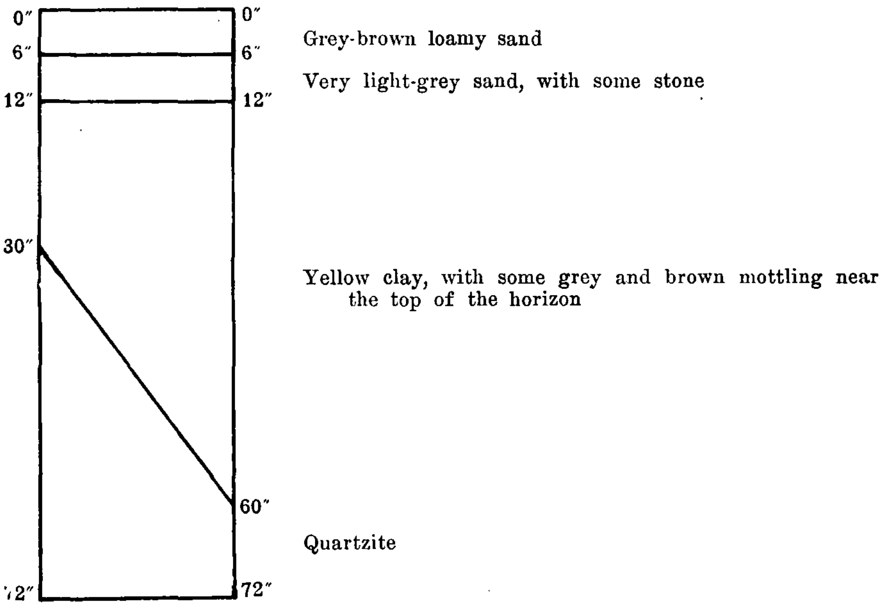
YELLOW PODSOLIC SOILS

The Stonyfell Association

These are the soils of a restricted area of the escarpment zone, adjacent to an outcrop of the Stonyfell Sandstone-Quartzite. They occur principally upon an exposed ridge near Second Creek at an elevation of approximately 600ft. On the relatively permeable parent-material, with good drainage and high rainfall, there is a tendency for podsolic soils to develop.

Dominant Soil Type—Type YP1

In the most elevated portion of the area, a yellow podsolic soil designated Type YP1 has developed. This soil exhibits the characteristic morphology of a grey sandy surface with a bleached subsurface horizon overlying a yellow clay, the whole being sedentary on quartzite. A typical profile might be:



A soil showing basic similarities to Type YP1 is illustrated in plate VI (fig. 2).

Variants and Minor Soil Types

Within the area mapped as the Stonyfell Association there are quite a few variants of the above soil-type. On the lower areas, where drainage is inferior and where some colluvial accumulation is possible, soils with slightly heavier surface-texture and dull-coloured "B" horizons are developed. In view of the insignificant areal extent of these soils no attempt has been made to classify them.

RECENT ALLUVIAL SOILS

Most of the above discussion is concerned with soils in which pedological processes play an important part. However, there is a small but significant proportion of the mapped area which contains immature soils as the results of relatively recent accretionary processes. These are soils, therefore, more in the geological rather than the pedological sense.

The River Torrens Complex

These are the soils laid down by the River Torrens in its present and past locations, and within the confined zone of its trans-escarpment channel as well as the broader reaches of its flood plain.

The pattern of distribution of alluvium along the course of an active stream is naturally a complex one. However, the soils formed in such an environment may be so grouped as to be radically different, one from another, with each distinguishable from the soils of the adjacent areas.

The soils of this zone fall naturally into several categories: the gravels and sands of the present or past river channels; the silty alluvial soils of the river flats; and the soils of the river terraces.

Dominant Soil Types—Types TA1 and TA2

Profile development in many of the recently deposited soils is not well advanced. These immature soils include Type TA1 and Type TA2 which may be described as follows:

Type TA1—This includes all of the river-bed deposits of gravel and sand. It exhibits no profile development although it may be layered in a random fashion with successive accumulations of coarse (gravelly) and fine (sandy) material. There is very little clay at any depth through this soil. Deposits of this type may be quite extensive both in terms of area and of depth. Some older deposits may be mantled by a more recent accumulation of finer material—as Type TA2 below. No Detailed description of Type TA1 will be attempted due to the absence of any order in the strata. All of the coarser fraction of the soil is water-worn while much of the sand fraction is sub-angular.

Type TA2—This type includes all of the finer alluvial deposits. These are usually spread on the higher river-flats during periods of heavy flooding and consist principally of silt and fine sand with a small proportion of clay. They show little or no profile development, although some layering due to differential effects during deposition may be evident. The colour of these soils is usually dark, ranging from a dark grey-brown to a chocolate loam on the surface.

As with Type TA1, no attempt is made at profile description of Type TA2, due to its random nature. The dark fine-textured alluvium of this type may extend without change for considerable depth and may overly sands, gravels, or older soil-profiles. A groundwater table is usually within a few feet of the soil surface, subject of course to some seasonal variation.

On the outer fringes of the area mapped as the River Torrens Complex there are frequent occurrences of buried soil-profiles.

Variant of Dominant Soil Type—Type TA2a

Adjacent to the zone of Urrbrae Association soils there are appreciable areas in which a soil material comparable to Type TA2 overlies a complete or dissected profile similar to Type RB3. Such a soil, designated as Type TA2a, is identical in all morphological features with Type RB3 except for an additional surface cover of up to 2ft. of dark-brown loam.

Minor Soil Types—Types RB2 and RB6

On the elevated old river-terraces, soils comparable to the newly forming soils of the present channel area may also be found. Type TA1 may occur commonly, with only a minor degree of surface cover above the gravels. However, on the residual sandy and silty alluvium in these raised areas there is a tendency for red-brown earths to develop as elsewhere in the Adelaide area. Consequently soils of a sandy red-brown earth nature, resembling Types RB2 or RB6 (as described previously) may be considered as characteristic also of this complex.

In the broad flood plains of the lower reaches of the River, the soils approximate Type TA2 with extensive deposits of dark-brown sandy or silty alluvium. On the fringes of this area these alluvial soils grade into the sandy red-brown earths of the Hindmarsh Association, or nearer the coast become involved in a complex pattern with the dune sands and the estuarine formations.

The Plympton Association

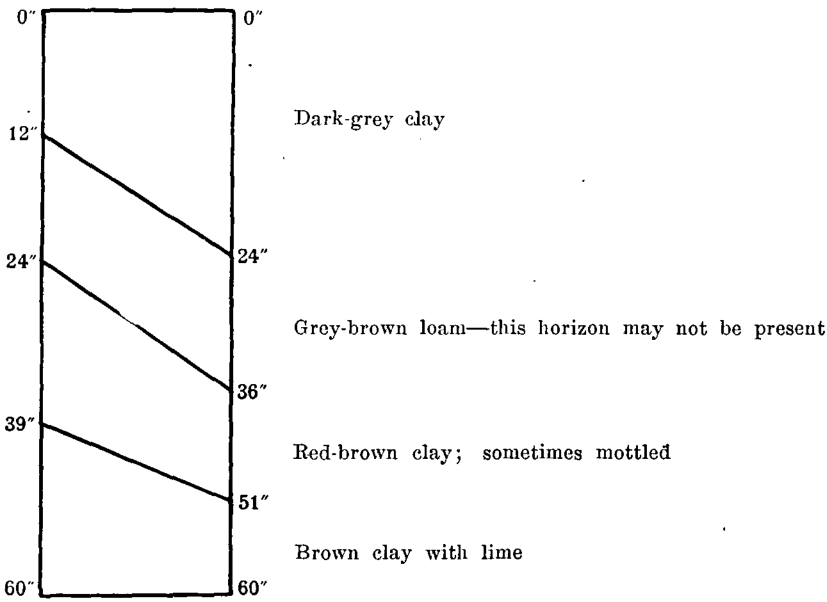
These are the soils of the old flood-plain of the Brownhill Creek. The waters of this stream were discharged in an area behind the bank of sand-hills of the old "Osborne" coast. Within this poorly drained zone, the finer-textured materials transported by the Creek were deposited in conditions which must seasonally have approached lacustrine. As a result there has been built up a relatively uniform dark-coloured fine-textured soil.

Dominant Soil Type—Type PA1

It is only within recent years that this area has been adequately drained by artificial means. Even with present drainage the groundwater table is relatively close to the surface. Profile development has not taken place to any marked extent and the soil may be described as an immature heavy alluvial type. The dominant soil of the area designated as Type PA1 is simply a grey to dark-grey clay or silty clay for its complete depth.

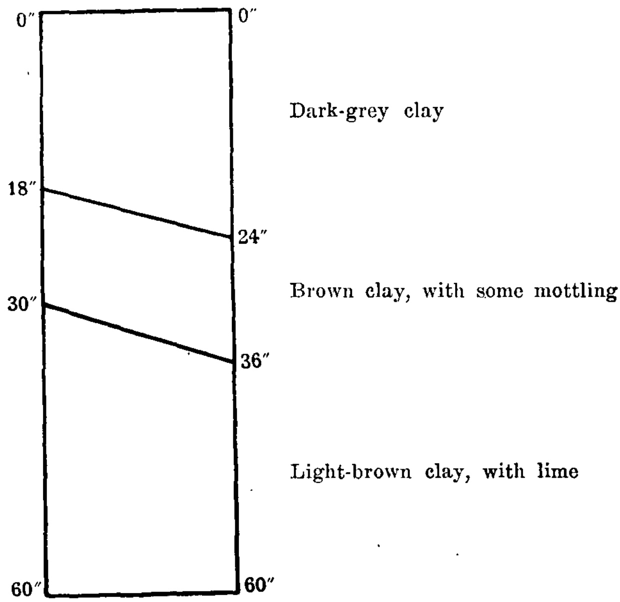
Sub-Dominant Soil Type—Type PA2

On the more elevated portions of the area mapped under the Plympton Association there have been developed soils with some black-earth affinities. In these localities the accession of alluvial material and the moisture status of the zone tended to be sufficient merely to modify the normal soil-forming processes of the adjacent better-drained areas. Thus, in lieu of the red-brown earths of the Hindmarsh Association, there have been developed soils either with red-brown earth-profiles overlain by recent heavy alluvium, or a hydromorphic variant of this soil, tending to a black earth. The former soil, designated as Type PA2 occupies a significant area. Its profile may be described as follows:



Variant of Sub-Dominant Soil Type—Type PA2a

The black earth-like soil (described as Type PA2a) which occurs as a variant of Type PA2, occupies only a limited area. Its profile might be:



ESTUARINE AND COASTAL SOILS

The Patawalonga Association

In an area which receives the discharge from all of the major streams (including the River Torrens and the Sturt River as well as the Brownhill Creek and Dry Creek) and which is contained behind the modern series of coastal sand dunes, there has been formed a series of swamp or estuarine soils. These are affected by tidal salt-waters as well as the fresh river-waters. The whole of the area is low-lying, being not more than 20ft. above sea-level with a groundwater table within a few feet of the surface.

Due to variations in sea-level, the sediments may have been in turn principally marine, estuarine, or fluviatile. Consequently a layered system has been built up with a random succession of sands, silts, clays, and shell beds.

The variability of these soils precludes any attempt at precise definition. However, as examples of the soils encountered, two types designated as EM1 and EM2 are described below.

Dominant Soil Type—Type EM1

Type EM1 is a soil in which river alluvium and littoral sands are evident. Its profile is as follows:

0″–8″	Dark-grey silty clay-loam
8″–14″	Dark grey-brown clay-loam
14″–24″	Dark grey-brown sandy clay loam, with limestone nodules
24″–30″	Light-grey sandy clay, with some lime
30″–72″	Light-grey sand, with variable yellow mottling and small pockets of clay

Sub-Dominant Soil Type—Type EM2

Type EM2 is a heavier soil, more typically estuarine. Its profile is as follows:

0″–8″	Dark-grey clay
8″–24″	Light-grey sandy clay
24″–36″	Grey clay, with yellow-brown mottling and some shells
36″–42″	Grey clay
42″–60″	Dark-grey clay, with blue sand

This soil is quite saline for its complete depth.

Throughout a considerable portion of the area mapped as the Patawalonga Association, soils of the above types EM1 or EM2 occur in intimate relationship with the dune sands of the modern or the "Osborne" series. Inevitably some of these sands will be found, therefore, within the mapped unit, as well as almost every conceivable combination of drifting sand and estuarine soil. No attempt is made to specify any of these overlapping soil occurrences.

The Osborne Association

These are the soils of the area which fringes the Osborne high sea-level. They include the relatively extensive chain of reddish-coloured sand ridges paralleling the modern coast between Grange and Glenelg, as well as some of the interdune swales.

Dominant Soil Type—Type DS1

The only soil of major importance is the red dune sand itself. This soil rarely shows appreciable signs of profile development although analyses may show some clay accumulation at depth. The profile consists simply of a great depth of a light reddish-brown fine sand, darkened often at the surface by a limited accumulation of organic matter and with occasional formation of a clay "pan" horizon several feet at least below the surface. This soil which is designated as Type DS1, is illustrated in plate III (fig. 2).

In the swale formations between the dunes there are often soils of heavier texture. These are related very commonly to the soils which are characteristic of the Patawalonga Association. They are quite variable in profile and may be affected to any degree by admixtures of dune sand. In view of their limited extent they are not classified separately.

The Semaphore Sands

These constitute the modern coast-line forming an almost continuous chain from Le Fevre Peninsula to as far south as Seacliff. The soil of these coastal sand-ridges, designated as Type DS2, is simply white siliceous fines and is of considerable depth. No profile development and little variability is noted within these sands.

Chapter 11

SUMMARY AND CONCLUSIONS

It can be said that at least some background knowledge now exists concerning the past and present stages of development of that portion of the Adelaide Plains within the metropolitan area.

On the geological side the available knowledge is sufficiently comprehensive for many purposes. The historical aspects of local geology and the stratigraphical successions have been fairly fully elucidated, while mapping of the principal geological features has reached a mature stage.

As far as the soils of the area are concerned, present knowledge is sufficient to give an appreciation on a broad basis of the factors of formation and distribution. But it must be admitted that there is still a lack of precision in the definition of some of the soils and in mapping the areal extent of even the best recognized types. Indeed the problems of complexity of soil patternation are such that it is difficult to visualize at any time in the near future the completion of a detailed soil-type map of the whole area.

By the adoption of a system of soil-association mapping the basis is provided for a semi-quantitative appreciation of soil distribution. Recognition can be given to the principal soils (and soil problems) of any zone. Identification of many of the more important soil-types should be possible in terms of profile descriptions and illustrations accompanying the text. The composition, characteristics, and engineering behaviour of these soils are described in the following appendices. From these data, admittedly incomplete, a first approach can be made to a sound engineering land-use within the mapped areas.

It should be reiterated that the authors have intended this *Bulletin* as an introductory discourse rather than as a handbook of established information. Although the latter is clearly the more desirable, it must be considered as a project of maturity and therefore should be set down as a task for the future.

ACKNOWLEDGMENTS

This *Bulletin* is a compilation of the work of a considerable number of geologists and soil scientists. Wherever possible acknowledgment of the source of material used has been given in the text. However, a certain amount of unpublished data has been available and for the use of this material and for other assistance acknowledgment is gratefully given to the following officers and former officers of the Division of Soils:

To Mr. J. H. Shepherd for introductory soil survey work in the Burnside area.

To Mr. J. S. Womersley and Mr. G. Blackburn, for soil survey data from housing areas.

To Mr. C. G. Gurr, Mr. N. W. Forrester, Mr. J. W. Holmes, and Mr. M. W. Hughes for assistance in field observations.

To Mr. J. T. Hutton, for the carrying out of all chemical analyses of the soils.

To Mr. E. W. Radoslovich for X-ray analyses of the clay mineral component of the soils.

The authors wish to acknowledge the assistance of Dr. K. R. Miles for information on groundwater compositions in the Adelaide Plains area and of the Petrological Section of the Department of Mines under the supervision of Mr. A. W. G. Whittle for the identification of soil and sand minerals. The greater bulk of the determinative work has been done by Mrs. I. Chebotarev.

Underground-water analyses have been carried out by the Assay Department of the School of Mines under the direction of Mr. T. W. Dalwood.

The coloured photographs of soil profiles were the accomplishment of Mr. K. P. Phillips.

The authors wish to acknowledge the encouragement received at all stages of this project from Mr. S. B. Dickinson, Director of Mines, and from Mr. J. K. Taylor, Chief, and Dr. T. J. Marshall, and Dr. C. G. Stephens, of the Division of Soils.

REFERENCES

AITCHISON, G. D., 1947: "Soil Survey and Foundation Report of an Area at Clovelly Park, South Australia, for the War Service Homes Commission," Unpub. Rept. 32/47 Div. Soils C.S.I.R.O.

AITCHISON, G. D., 1950 (*a*): "Soils and soil conditions in relation to the design of the foundations of domestic buildings," Unpub. Thesis, Univ. of Adelaide.

AITCHISON, G. D., 1950 (*b*): "Domestic building foundations on the shrinkable clay soils of the suburbs of Adelaide," Unpub. Rept., 10/50 Div. Soils, C.S.I.R.O.

AITCHISON, G. D., 1953: "The physical condition of the soil as a modifying factor in the measurement and interpretation of shear strength," Proc. 1st. Aust. N.Z. Conf. Soil Mech. and Found. Eng. (in press).

AITCHISON, G. D., AND BLACKBURN, G., 1947: "The Enfield North Estate of the South Australian Housing Trust," Unpub. Rept. 33/47 Div. Soils C.S.I.R.O.

AITCHISON, G. D., AND HOLMES, J. W., 1953 (*a*): "Seasonal changes of soil moisture in a Red Brown Earth and a Black Earth in Southern Australia," *Aust. Jour. Ap. Sci.* 4, 260/273.

AITCHISON, G. D., AND HOLMES, J. W., 1953 (*b*): "Aspects of swelling in the soil profile:" *Aust. Jour. Ap. Sci.* 4, 244-259.

AITCHISON, G. D., BUTLER, P. F., AND GURR, C. G., 1951: "Techniques associated with the use of gypsum block moisture meters," *Aust. Jour. Ap. Sci.* 2, 56.

ANDERSON, V. G., 1941: "The Origin of the Dissolved Inorganic Solids in Natural Waters with Special Reference to the O'Hannessey River Catchment, Victoria," *Jour. Aust. Chem. Inst.* 8: 6.

ANDERSON, V. G., 1945: "Some Effects of Atmospheric Evaporation and Transpiration on the Composition of Natural Waters in Australia," *Jour. Aust. Chem. Inst.* 12: 41.

BARNES, T. A., AND KLEEMAN, A. W., 1934: "The Blue Metal Limestone and its Associated Beds," *Trans. Roy. Soc. S. Aust.* 58, 80-85.

BENSON, W. N., 1909: "Petrographical notes on certain Pre-Cambrian Rocks of the Mount Lofty Ranges, with Special Reference to the Geology of the Houghton District," *Trans. Roy. Soc. S. Aust.* 33, 101-140.

COTTON, B. C., 1949: "An old mangrove mudflat exposed by wave scouring at Glenelg, South Australia," *Trans. Roy. Soc. S. Aust.* 73, 59-61.

CRESPIN, I., AND COTTON, B. C., 1952: "The Stratigraphy and Palaeontology of the Subsurface Deposits of the Adelaide Plains," Appendix III to K. R. Miles (1952).

CROCKER, R. L., 1946: "Post Miocene Climatic and Geologic history and its significance in relation to the genesis of the major soil types of South Australia," *Counc. Sci. Ind. Res. Aust. Bull.*, 193.

FENNER, C., 1927: "Adelaide South Australia: A study in Human Geography," *Trans. Roy. Soc. S. Aust.* 51, 193-256.

FENNER, C., 1930: "The Major Structural and Physiographic Features of South Australia," *Trans. Roy. Soc. S. Aust.* 54, 1-36.

GLAESSNER, M. F., 1953: "Problems of Tertiary Geology in Southern Australia," *Jour. and Proc. Roy. Soc. N.S.W.* 87 (1).

HOLMES, J. W., 1952: "Triaxial compression tests on a soil at the South Australian Railways Mile End depot," Unpub. Tech. Memo. 10/52 Div. Soils, C.S.I.R.O.

HOWCHIN, W., 1901: "Preliminary Note on the Existence of Glacial Beds of Cambrian Age in South Australia," *Trans. Roy. Soc. S. Aust.* 25, 10-13.

HOWCHIN, W., 1904: "The Geology of the Mount Lofty Ranges; Part I; The Coastal District," *Trans. Roy. Soc. S. Aust.* 28, 253-280.

HOWCHIN, W., 1906: "The Geology of the Mount Lofty Ranges; Part II," *Trans. Roy. Soc. S. Aust.* 30, 227-262.

HOWCHIN, W., 1927: "The Sturtian Tillite in the Neighbourhood of Eden, and in the Hundreds of Kapunda, Neales, and English, South Australia," *Trans. Roy. Soc. S. Aust.* 51, 330-349.

HOWCHIN, W., 1929: "On the probable occurrence of Sturtian Tillite near Nairne and Mount Barker," *Trans. Roy. Soc. S. Aust.* 53, 27-32.

HOWCHIN, W., 1929: "The Geology of South Australia," Gillingham and Co., Adelaide.

ISAACS, D. V., 1951: Appendix to Tasker, Russell, and Hodgson (1951).

JACK, R. L., 1912: "The Geology of Portions of the Counties of Le Hunte, Robinson, and Dufferin with Special Reference to Underground Water Supplies," *Geol. Survey S. Aust. Bull.* 1.

JACK, R. L., 1914: "The Geology of the County of Jervois and of Portions of the Counties of Buxton and York, with Special Reference to Underground Water Supplies," *Geol. Survey S. Aust. Bull.* 3.

LITCHFIELD, W. H., 1951: "Soil Survey of the Waite Agricultural Research Institute, Glen Osmond, S. Aust.," Unpub. Rept. 2/51 Div. Soils, C.S.I.R.O.

MARSHALL, T. J. AND WALKLEY, A., 1934: "Report on the Swamp Lands adjoining St. Kilda (Hundred of Adelaide). Rept. Parliamentary Standing Com. on Public Works. 1934, Govt. Printer, Adelaide.

MAWSON, D., AND SPRIGG, R. C., 1950: "Subdivision of the Adelaide System," *Aust. Jour. Sci.* 13.

MILES, K. R., 1952: "The Geology and Underground Water Resources of the Adelaide Plains Area," *Geol. Survey S. Aust. Bull.* 27.

NIKIFEROFF, C. C., 1949: "Weathering and Soil Evolution," *Soil. Sci.* 67, 219-230.

PIPER, C. S., 1938: "The Red-Brown Earths of South Australia," *Trans. Roy. Soc. S. Aust.* 62, 53-100.

PRESCOTT, J. A., 1949: "A climatic Index for the Leaching Factor in Soil Formation," *J. Soil Sci.* 1, 9-19.

SIMPSON, E. S., 1926: "Problems of Water Supply in Western Australia," *Aust. and N.Z. Assoc. Adv. Sci. Rept.*, 1926.

SKEMPTON, A. W., AND BISHOP, A. W., 1950: "The measurement of the shear strength of soils," *Geotechnique* 2, 90-107.

SOLOMON, M.: "The Structural Features of The Belair Quartzites and Slates," Unpub. Rept., S. Aust. Dept. of Mines.

SPECHT, R. L. AND PERRY, R. A., 1948: "The plant Ecology of Part of the Mount Lofty Ranges," *Trans. Roy. Soc. S. Aust.* 72, 91-132.

SPRIGG, R. C., 1942: "The Geology of the Eden-Moana Fault Block," *Trans. Roy. Soc. S. Aust.* 66, 185-214.

SPRIGG, R. C., 1945: "Some aspects of the Geomorphology of portion of the Mt. Lofty Ranges," *Trans. Roy. Soc. S. Aust.* 69, 277-302.

SPRIGG, R. C., 1946: "Reconnaissance Geological Survey of Portion of the Western Escarpment of the Mt. Lofty Ranges," *Trans. Roy. Soc. S. Aust.* 70, 313-347.

SPRIGG, R. C., 1952: "The Geology of the South-East Province, South Australia, with Special Reference to Quaternary Coast-line Migrations and Modern Beach Developments," *Geol. Surv. S. Aust. Bull.* 29.

STEPHENS, C. G., 1951: "The Present State of Soil Science," *Jour. Aust. Inst. Ag. Sci.* 17, 126-131.

TASKER, H. E., RUSSELL, F. A., AND HODGSON, J., 1951: "Failure of Footings of a Number of Houses at Burnside, Adelaide, South Australia," *Comm. Exp. Bldg. Sta. Spec. Rep.* 5 (unpub.).

TEAKLE, L. J. H., 1937: "The salt (sodium chloride) content of rain water," *J. Dept. Agr. W. Aust.* 14, 115-123.

WARD, L. K., 1946: "The Occurrence, Composition, Testing, and Utilisation of Underground Water in South Australia and the search for further supplies," *Geol. Survey S. Aust., Bull.* 23.

WHITTLE, A. W. G., AND WEBB, B. P.: "Uranium Investigations in the Adelaide Hills, *Geol. Survey S. Aust. Bull.* 30 (IV) (in the press).

WOOLNOUGH, W. G., 1904: "Petrographical Notes on some South Australian Quartzites, Sandstones and Related Rocks," *Trans. Roy. Soc. S. Aust.* 28, 193-211.

Appendix A

COMPOSITION AND CHARACTERISTICS OF THE SOILS

Soil Analyses

Soil type—	RB2				
Location of sample—	Kensington Gardens				
Soil No.	10,345	10,346	10,347	10,348	10,349
Depth, in.	0-6	6-18	18-32	32-40	40-48
Reaction, pH	7·3	7·5	7·4	7·3	7·5
Total soluble salts, per cent	0·017	0·043	0·038	0·055	0·041
Chlorides, as NaCl, per cent	0·005	0·020	0·017	0·024	0·019
Mechanical analysis—	A	A	A	A	A
Coarse sand, per cent	44	44	40	34	37
Fine sand, per cent	28	27	24	24	24
Silt, per cent	20	18	14	13	13
Clay, per cent	8	10	13	23	24
Consistence—					
Liquid limit	23	18	23	34	39
Plastic limit	19	4	14	14	13
Plasticity index	4	4	9	20	26
Total exchange capacity—					
(*a*) m.e. per cent	—	—	4	9	10
(*b*) m.e. per cent	—	—	31	38	41

Soil type—	RB2b					
Location of sample—	Hazelwood Park					
Soil No.	10,335	10,336	10,337	10,338	10,339	10,340
Depth, in.	0-2½	2½-6	6-14	14-30	30-47	47-72
Reaction, pH	6·0	5·9	6·2	6·5	8·9	9·0
Total soluble salts, per cent	0·026	0·010	0·006	0·033	0·070	0·152
Chlorides, as NaCl, per cent	0·005	0·002	0·002	0·008	0·014	0·063
Mechanical analysis—	A	A	A	A	A	A
Coarse sand, per cent	26	29	26	7	14	7
Fine sand, per cent	42	41	38	16	21	15
Silt, per cent	24	21	19	13	20	20
Clay, per cent	8	9	9	63	42	58
Consistence—						
Liquid limit	28	16	14	115	68	70
Plastic limit	20	16	14	27	20	20
Plasticity index	8	N.P.	N.P.	88	48	50
Total exchange capacity—						
(*a*) m.e., per cent	—	—	2	26	19	18
(*b*) m.e., per cent	—	—	22	41	44	30

Soil type—	Transition RB2-RB3			
Location of sample—	Linden Park			
Soil No.	10,341	10,342	10,343	10,344
Depth, in.	0-6	6-11	11-36	36-53
Reaction, pH	7·0	7·1	7·8	9·1
Total soluble salts, per cent	0·014	0·011	0·075	0·149
Chlorides, as NaCl, per cent	0·004	0·005	0·030	0·040
Mechanical analysis—	A	A	A	A
Coarse sand	11	11	5	1
Fine sand	36	34	14	22
Silt	37	33	20	24
Clay	16	22	61	52
Consistence—				
Liquid limit	20	25	80	70
Plastic limit	20	15	26	21
Plasticity index	N.P.	10	62	49
Total exchange capacity—				
(*a*) m.e., per cent	—	8	29	25
(*b*) m.e., per cent	—	35	48	47

Soil type—	RB3					
Location of sample—	Soil Pit-Arboretum—Waite Institute					
Soil No.	12,721	12,722	12,723	12,724	12,725	12,726
Depth, in.	0-7	7-13	13-30	30-35	35-45	45-69
Reaction, pH	5·7	6·0	6·6	7·2	8·6	8·5
Total soluble salts, per cent	0·062	0·080	0·070	0·079	0·096	0·132
Chlorides, as NaCl, per cent	0·023	0·043	0·033	0·039	0·040	0·059
Mechanical analysis—	B	B	B	B	B	B
Coarse sand	4	2	1	1	1	1
Fine sand	41	40	17	25	22	24
Silt	33	32	15	26	31	36
Clay	20	25	65	48	34	36
Consistence—						
Liquid limit	—	—	—	—	—	—
Plastic limit	—	—	—	—	—	—
Plasticity index	—	—	—	—	—	—
Total exchange capacity—						
(*a*) m.e., per cent	—	—	—	—	—	—
(*b*) m.e., per cent	—	—	—	—	—	—

Soil type—	RB3						
Location of sample—	Waite Institute (Arboretum)—Sec. 268, Hundred Adelaide						
Soil No.	17,184	17,185	17,186	17,187	17,189	17,190	17,191
Depth, in.	0-4	4-10	10-14	14-22	22-30	32-47	47-60
Reaction, pH	6·0	6·2	6·6	7·0	7·3	8·6	8·5
Total soluble salts, per cent	0·012	0·007	0·008	0·011	0·012	0·046	0·058
Chlorides, as NaCl, per cent	0·004	0·004	0·003	0·003	0·003	0·006	0·022
Calcium carbonate, per cent	0	0	0	0	0·01	9·6	3·7
Mechanical analysis—	C	C	C	C	C	C	C
Coarse sand	3	3	3	1	0	0	1
Fine sand	44	46	39	19	22	28	27
Silt	30	31	25	13	22	27	33
Clay	17	17	31	66	55	35	36
Loss on solution	4	2	2	3	3	10	5
Loss on ignition, per cent.	5	3	4	7	7	8	6
Organic carbon, per cent	1·9	0·8	—	0·7	—	—	—
Exchangeable cations—							
Calcium, m.e., per cent.	5·0	—	—	13·9	—	—	—
Magnesium	1·2	—	—	8·3	—	—	—
Potassium	0·7	—	—	2·0	—	—	—
Sodium	0·1	—	—	0·5	—	—	—
Total metal ions	7·0	—	—	24·7	—	—	—
Total exchange capacity—							
(*a*) m.e., per cent	10·6	—	—	24·6	—	—	—

Soil type—	RB3				
Location of sample—	Waite Institute (Field Station)				
Soil No.	F9S	F9	F10	F11	F12
Depth, in.	0-3	12	24	48	72
Reaction, pH	—	7·4	7·5	8·6	8·7
Total soluble salts, per cent	—	0·022	0·017	0·059	0·052
Chlorides, as NaCl, per cent	—	0·009	0·007	0·015	0·013
Mechanical analysis—	—	A	A	A	A
Coarse sand	—	3	1	1	1
Fine sand	—	37	8	22	32
Silt	—	33	39	29	28
Clay	—	27	52	48	39
Consistence—					
Liquid limit	—	26	75	51	49
Plastic limit	—	16	28	20	20
Plasticity index	—	10	46	31	30
Total exchange capacity—					
(*a*) m.e., per cent	—	9	26	22	21
(*b*) m.e., per cent	—	35	51	47	53

Soil type—	RB3b					
Location of sample—	Glenunga					
Soil No.	10,350	10,351	10,352	10,353	10,354	10,355
Depth, in.	0-6	6-13	13-18	18-30	30-57	57-72
Reaction, pH	7·3	7·1	7·5	8·7	9·6	9·8
Total soluble salts, per cent	0·025	0·033	0·043	0·129	0·304	0·282
Chlorides, as NaCl, per cent	0·004	0·012	0·022	0·052	0·105	0·088
Mechanical analysis—	A	A	A	A	A	A
Coarse sand	5	5	10	2	2	4
Fine sand	45	44	42	31	16	22
Silt	34	34	27	21	82 }	74 }
Clay	15	17	21	46	}	}
Consistence—						
Liquid limit	30	29	32	63	89	82
Plastic limit	23	20	18	20	23	22
Plasticity index	7	9	14	43	66	60
Total exchange capacity—						
(*a*) m.e., per cent	—	11	10	21	25	22
(*b*) m.e., per cent	—	62	48	45	—	—

Soil type—	RB5				
Location of sample—	Cudmore Park				
Soil No.	F17A	F17E	F18	F19	F20
Depth, in.	12	12	24	48	72
Reaction, pH	7·1	7·0	7·4	8·9	9·0
Total soluble salts, per cent	0·021	0·011	0·028	0·077	0·147
Chlorides, as NaCl, per cent	0·008	0·006	0·015	0·024	0·072
Mechanical analysis—	—	C	A	C	A
Coarse sand	—	3	1	1	2
Fine sand	—	32	5	12	20
Silt	—	29	9	27	41
Clay	—	36	85	45	37
Consistence—					
Liquid limit	40	31	81	54	49
Plastic limit	—	13	29	23	19
Plasticity index	—	17	52	31	30
Total exchange capacity—					
(*a*) m.e., per cent	15	11	31	20	20
(*b*) m.e., per cent	—	31	36	45	53

Soil type—	RB5 (transitional towards Type RB3)						
Location of sample—	Cudmore Park—Sec. 7, Hundred Adelaide						
Soil No.	17,192	17,193	17,194	17,195	17,196	17,197	17,198
Depth, in.	0-3	3-6	6-10	10-17	17-24	24-32	32-40
Reaction, pH	6·9	6·7	6·9	7·0	7·3	8·6	8·7
Total soluble salts, per cent	0·022	0·009	0·008	0·016	0·016	0·052	0·059
Chlorides, as NaCl, per cent	0·021	0·004	0·007	0·007	0·007	0·010	0·011
Calcium carbonate, per cent	0	0	0	0	0·01	17·6	13·2
Mechanical analysis—	C	C	C	C	C	C	C
Coarse sand	9	7	5	1	1	0	0
Fine sand	43	40	30	9	13	13	18
Silt	33	31	31	14	12	22	25
Clay	14	18	33	74	71	47	43
Loss on solution	3	2	2	3	3	20	13
Loss on ignition, per cent.	3	3	4	8	8	13	10
Organic carbon, per cent.	1·0	—	—	0·8	—	—	—
Exchangeable cations—							
Calcium, m.e., per cent.	5·6	—	—	18·0	—	—	—
Magnesium	1·2	—	—	9·3	—	—	—
Potassium	1·0	—	—	2·0	—	—	—
Sodium	0·1	—	—	0·8	—	—	—
Total metal ions	7·9	—	—	30·1	—	—	—
Total exchange capacity—							
(a) m.e., per cent	—	—	—	—	—	—	—

Soil type—	RB6				
Location of sample—	Woodville Gardens				
Soil No.	F29	F30C	F30E	F31	F32
Depth, in.	12	24	24	48	72
Reaction, pH	8·2	8·8	8·7	9·5	9·7
Total soluble salts, per cent	0·162	0·681	0·624	0·380	0·250
Chlorides, as NaCl, per cent	0·096	0·407	0·374	0·205	0·123
Mechanical analysis—	C	C	C	C	C
Coarse sand	19	12	21	6	8
Fine sand	51	30	34	43	55
Silt	16	9	8	18	16
Clay	11	38	35	18	14
Consistence—					
Liquid limit	20	—	37	33	31
Plastic limit	19	—	16	18	19
Plasticity index	1	—	21	16	12
Total exchange capacity—					
(a) m.e., per cent	9	15	15	8	7
(b) m.e., per cent	82	40	40	46	51

Soil type—	RB6			
Location of sample—	Woodvile Gardens—Sec.414, Hd. Yatala			
Soil No.	17,207	17,208	17,209	17,211
Depth, in.	0-6	6-11	11-16	22-30
Reaction, pH	7·3	7·8	9·2	9·6
Total soluble salts, per cent	0·025	0·011	0·075	0·199
Chlorides, as NaCl, per cent	0·012	0·005	0·015	0·051
Calcium carbonate, per cent	0·02	0·01	0·08	4·97
Mechanical analysis—	C	C	C	C
Coarse sand	20	16	11	7
Fine sand	62	61	38	60
Silt	10	13	9	12
Clay	6	9	40	16
Loss on solution	2	1	3	5
Loss on ignition, per cent	2	2	5	4
Organic carbon, per cent	0·6	—	0·5	—
Exchangeable cations—				
Calcium, m.e., per cent	3·1	—	3·9	—
Magnesium	0·8	—	6·6	—
Potassium	0·7	—	1·9	0·6
Sodium	0·1	—	3·2	1·6
Total metal ions	4·7	—	15·6	—
Total exchange capacity—				
(*a*) m.e., per cent	3·6	—	16·1	5·4

Soil type—	RB9			
Location of sample—	Brayville East			
Soil No.	F21	F22	F23	F24
Depth, in.	8	24	48	72
Reaction, pH	8·5	8·4	9·2	9·1
Total soluble salts, per cent	0·129	0·489	0·420	0·428
Chlorides, as NaCl, per cent	0·025	0·240	0·223	0·223
Mechanical analysis—	C	C	C	A
Course sand	13	1	4	6
Fine sand	31	9	17	14
Silt	25	19	31	26
Clay	32	47	46	54
Consistence—				
Liquid limit	36	54	60	61
Plastic limit	17	20	21	20
Plasticity index	19	34	40	40
Total exchange capacity—				
(*a*) m.e., per cent	17	17	21	23
(*b*) m.e., per cent	54	37	46	42

Soil type—	RB9z							
Location of sample—	Brayville West							
Soil No.	F37	F38	F39	F40	F25	F26	F27	F28
Depth, in.	12	24	48	72	9	24	48	72
Reaction, pH	—	—	—	—	9·4	9·9	9·6	9·3
Total soluble salts, per cent	—	—	—	—	0·172	0·398	0·498	0·382
Chlorides, as NaCl, per cent	—	—	—	—	0·073	0·180	0·242	0·203
Mechanical analysis—	C	C	C	C	C	C	C	—
Coarse sand	3	4	5	12	6	3	5	—
Fine sand	25	17	16	28	29	13	15	—
Silt	26	21	25	25	22	21	26	—
Clay	45	42	46	34	42	40	53	—
Consistence—								
Liquid limit	73	71	63	49	45	77	84	62
Plastic limit	20	18	18	19	16	16	21	—
Plasticity index	53	53	45	30	29	61	63	—
Total exchange capacity—								
(*a*) m.e., per cent	—	—	—	—	20	21	25	23
(*b*) m.e., per cent	—	—	—	—	48	57	46	23

Soil type—	RB9z (solonetz)				
Location of sample—	Brayville—Sec. 444, Hundred Adelaide				
Soil No.	17,200	17,201	17,202	17,203	17,205
Depth, in.	0-2	2-4	4-9	9-12	20-32
Reaction, pH	7·4	8·2	9·1	9·3	9·7
Total soluble salts, per cent	0·060	0·046	0·176	0·417	0·616
Chlorides, as NaCl, per cent	0·033	0·018	0·049	0·165	0·346
Calcium carbonate, per cent	0·05	0·01	0·54	12·9	32·2
Mechanical analysis—	C	C	C	C	—
Coarse sand	13	10	5	3	1
Fine sand	35	33	20	8	15
Silt	24	24	23	15	15
Clay	24	29	43	60	47
Loss on solution	4	3	10	15	21
Loss on ignition, per cent	5	4	3	11	19
Organic carbon, per cent	1·8	—	0·7	—	—
Exchangeable cations—					
Calcium, m.e., per cent	6·3	—	—	—	—
Magnesium	5·5	—	—	—	—
Potassium	1·1	—	1·7	—	—
Sodium	1·6	—	9·1	—	—
Total metal ions	14·5	—	—	—	—
Total exchange capacity—					
(*a*) m.e., per cent	14·3	—	20·4	—	—

Soil type—	BE1				
Location of sample—	Linden Park				
Soil No.	F13A	F13B	F14C	F15	F16
Depth, in.	12	12	24	48	72
Reaction, pH	8·3	7·7	8·8	9·6	9·6
Total soluble salts, per cent	0·068	0·026	0·069	0·164	0·259
Chlorides, as NaCl, per cent	0·016	0·015	0·010	0·036	0·081
Mechanical analysis—	B	C	C	A	A
Coarse sand	—	2	2	2	2
Fine sand	—	45	18	18	21
Silt	—	27	14	20	21
Clay	—	22	61	60	56
Consistence—					
Liquid limit	70	—	79	70	77
Plastic limit	28	—	30	19	20
Plasticity index	42	—	49	51	57
Total exchange capacity—					
(*a*) m.e., per cent	36	36	—	24	26
(*b*) m.e., per cent	—	62	—	40	46

Soil type—	BE1					
Location of sample—	Linden Park					
Soil No.	10,327	10,328	10,329	10,330	10,331	10,332
Depth, in.	0-8	8-22	24-40	40-54	54-61	61-78
Reaction, pH	7·8	8·4	8·6	8·8	9·0	9·1
Total soluble salts, per cent	0·042	0·071	0·046	0·070	0·080	0·093
Chlorides, as NaCl, per cent	0·005	0·018	0·006	0·012	0·015	0·017
Mechanical analysis—	A	A	A	A	A	A
Coarse sand	2	2	2	3	3	2
Fine sand	25	17	20	18	14	14
Silt	30	23	20	17	18	7
Clay	43	58	58	62	65	77
Consistence—						
Liquid limit	72	78	80	95	88	81
Plastic limit	26	26	25	27	24	20
Plasticity index	46	52	55	68	64	61
Total exchange capacity—						
(*a*) m.e., per cent	36	39	37	40	24	29
(*b*) m.e., per cent	83	66	64	64	52	38

Soil type—	BE1			
Location of sample—	Claremont			
Soil No.	10,356	10,357	10,358	10,359
Depth, in.	1½-5	5-15	16-26	26-42
Reaction, pH	6·8	7·0	7·8	8·7
Total soluble salts, per cent	0·048	0·033	0·042	0·040
Chlorides, as NaCl, per cent	0·008	0·003	0·008	0·006
Mechanical analysis—	A	A	A	A
Coarse sand	3	2	2	3
Fine sand	29	16	13	18
Silt	23	17	13	17
Clay	43	65	71	62
Consistence—				
Liquid limit	55	79	99	81
Plastic limit	26	30	33	25
Plasticity index	29	49	66	56
Total exchange capacity—				
(*a*) m.e., per cent	35	39	39	28
(*b*) m.e., per cent	91	60	56	46

Soil type—	BE1a				
Location of sample—	Claremont—Sec. 893, Hundred Adelaide				
Soil No.	17,177	17,178	17,180	17,181	17,183
Depth, in.	0-3	3-9	15-20	23-30	39-46
Reaction, pH	8·0	8·2	8·4	8·7	8·6
Total soluble salts, per cent	0·080	0·055	0·058	0·050	0·072
Chlorides, as NaCl, per cent	0·010	0·009	0·007	0·010	0·008
Calcium carbonate, per cent	5·8	2·3	1·3	39·0	33·6
Mechanical analysis—	C	C	C	C	C
Coarse sand	3	3	3	1	1
Fine sand	23	25	20	13	15
Silt	15	15	10	8	10
Clay	46	50	64	38	40
Loss on solution	13	8	5	43	36
Loss on ignition, per cent	13	10	8	22	19
Organic carbon, per cent	3·6	2·3	0·9	—	—
Exchangeable cations—					
Calcium, m.e., per cent	—	—	—	—	—
Magnesium	—	—	—	—	—
Potassium	5·8	2·4	1·4	—	—
Sodium	0·1	0·3	0·6	—	—
Total metal ions	—	—	—	—	—
Total exchange capacity—					
(*a*) m.e., per cent	37·4	41·1	44·9	—	24·9

Soil type—	BE1b						
Location of sample—	Claremont—Sec. 893, Hundred Adelaide						
Soil No.	17,167	17,168	17,169	17,171	17,172	17,174	17,176
Depth, in.	0-3	3-6	6-11	17-24	24-28	40-50	60-66
Reaction, pH	6·7	7·1	7·5	8·4	8·7	9·1	8·9
Total soluble salts, per cent	0·037	0·023	0·028	0·065	0·053	0·108	0·238
Chlorides, as NaCl, per cent	0·011	0·009	0·010	0·011	0·011	0·011	0·109
Calcium carbonate, per cent	0	0	0·03	0·07	0·08	39·9	40·0
Mechanical analysis—	C	C	C	C	C	C	C
Coarse sand	3	3	2	1	1	0	2
Fine sand	34	28	21	18	14	7	13
Silt	18	14	10	10	9	4	8
Clay	38	51	63	70	75	45	33
Loss on solution	6	5	3	3	3	44	44
Loss on ignition, per cent.	10	8	8	8	8	23	20
Organic carbon, per cent	4·2	2·3	—	—	1·0	—	—
Exchangeable cations—							
Calcium, m.e., per cent.	20·2	21·3	—	—	16·5	—	—
Magnesium	11·9	17·0	—	—	24·2	—	—
Potassium	1·4	1·6	—	—	2·1	—	—
Sodium	0·3	0·6	—	—	3·0	—	—
Total metal ions	33·8	40·5	—	—	45·8	—	—
Total exchange capacity—							
(*a*) m.e., per cent	36·8	40·5	—	—	41·2	—	21·6

Soil type—	BS2b			
Location of sample—	Enfield			
Soil No.	F33	F34	F35	F36
Depth, in.	12	24	48	72
Reaction, pH	—	—	—	—
Total soluble salts, per cent	—	—	—	—
Chlorides, as NaCl, per cent	—	—	—	—
Mechanical analysis—	C	C	C	C
Coarse sand	25	23	11	10
Fine sand	42	41	26	28
Silt	7	6	3	4
Clay	22	21	18	24
Consistence—				
Liquid limit	34	32	32	48
Plastic limit	15	14	14	15
Plasticity index	19	18	18	33
Total exchange capacity—				
(*a*) m.e., per cent	15	13	9	12
(*b*) m.e., per cent	68	64	51	51

Soil type—	RZ1	
Location of sample—	Beaumont	
Soil No.	10,333	10,334
Depth, in.	0-5	5-11
Reaction, pH	8·3	8·4
Total soluble salts, per cent	0·066	0·066
Chlorides, as NaCl, per cent	0·012	0·015
Mechanical analysis—	A	A
Coarse sand	4	3
Fine sand	34	20
Silt	26	18
Clay	29	29
Consistence—		
Liquid limit	46	51
Plastic limit	24	21
Plasticity index	22	30
Total exchange capacity—		
(*a*) m.e., per cent	—	21
(*b*) m.e., per cent	—	71

Soil type—	DS1			
Location of sample—	Graymore			
Soil No.	10,776	10,777	10,778	10,779
Depth, in.	6-8	8-30	30-48	50-72
Reaction, pH	7·2	8·0	7·8	8·2
Total soluble salts, per cent	0·009	0·009	0·012	0·013
Chlorides, as NaCl, per cent	0·001	0·001	0·002	0·003
Mechanical analysis—	A	A	A	A
Coarse sand	14	14	13	10
Fine sand	85	81	77	82
Silt } Clay }	1	5	10	1
Clay				7

Soil type—	EM1				
Location of sample—	Graymore				
Soil No.	10,780	10,781	10,782	10,783	10,784
Depth, in.	0-2	2-6	10-16	21-33	33-52
Reaction, pH	7·0	7·2	8·4	8·8	8·6
Total soluble salts, per cent	0·024	0.031	0·050	0·022	0·018
Chlorides, as NaCl, per cent	0·010	0·013	0·016	0·005	0·005
Mechanical analysis—	A	A	A	A	A
Coarse sand	6	7	1	14	22
Fine sand	38	31	70	81	73
Silt	56 }	19	29 }	1	1
Clay		43		4	4

Soil type—	EM2					
Location of sample—	Graymore					
Soil No.	10,785	10,786	10,787	10,788	10,789	10,790
Depth, in.	0-4	4-8	11-23	23-36	36-42	42-56
Reaction, pH	6·7	8·8	9·4	9·5	8·9	8·9
Total soluble salts, per cent	0·203	0·442	0·582	0·488	0·924	0·788
Chlorides, as NaCl, per cent	0·084	0·157	0·208	0·162	0·337	0·283
Mechanical analysis—	A	A	A	A	A	A
Coarse sand	2	1	3	5	4	10
Fine sand	66 }	28	44	66	18	29
Silt		21	53 }	10	78 }	19
Clay	32	50		19		42

NOTE—

(1) Mechanical Analysis—

A. = Hydrometer method (*vide* C. S. Piper: "Soils and Plant Analysis," 1942).

B. = Pipette method (*vide* C. S. Piper: "Soils and Plant Analysis," 1942).

C. = Plummet Method (*vide* J. T. Hutton: C.S.I.R.O., Division of Soils, Tech. Memo. 7/50).

(2) Total Exchange Capacity—

(*a*) m.e., per cent = Milligram equivalents per 100 grams of soil.

(*b*) m.e., per cent = Milligram equivalents per 100 grams of clay.

The Mineralogical Composition of the Clay Fraction (< 2 μ) of the Soils

Soil Type RB3

Location—Waite Institute (Arboretum)

Sample No.	< 2 μ	2-0·2 μ	0·2-0·05 μ	< 0·05 μ
12721	Illite (mod.) Kaolinite (mod.) } 7:3 Chlorite (l.) Quartz (< 10%)	Illite Kaolinite } 7:3 Chlorite (l.) Quartz (< 10%)	Illite Kaolinite } 7:3 Chlorite (l.) Quartz (l.) Mica-mont. intermediates (l.)	Illite Kaolinite Quartz (l.)
12722	As above + mica-mont. intermediates (?)	As above	Illite Kaolinite Quartz (l.) Mica-mont. intermediates (?)	Illite (l.) Kaolinite (l.) Chlorite (v.l.)
12723	Illite Kaolinite } 7:3 Quartz (10%) Chlorite (?)	Illite Kaolinite } 7:3 Quartz (5%) Chlorite (v.l.) Calcite (v.l.) Mica-mont. intermediates (l.)	As for 2 μ to 0·2 μ	Illite (l.) Kaolinite (l.) Chlorite (v.l.) Montmorillonite (v.l.)
12725	Illite Kaolinite } Chlorite (mod.) Quartz (10%) Calcite (l.) Montmorillonite (l.)	Illite Kaolinite } Chlorite (mod.) Quartz (l.) Calcite (l.)	As above	Kaolinite (l.) Illite (l.) Chlorite (v.l.) Montmorillonite (v.l.) Quartz (v.l.)
12726	Illite Kaolinite } 7:3 Chlorite (mod.) Quartz (l.) Mica-mont. intermediates (l.)	As above, but no calcite	As above	Kaolinite (l.) Illite (l.) Chlorite (v.l.)

SOIL TYPE RB3

Location—Waite Institute (Field Station)

Sample No.	< 2 μ	< 2 μ and > 0·2 μ	< 0·2 μ and > 0·05 μ	< 0·05 μ
F9S	Illite } 7:3 Kaolinite } Quartz (5-10%)			
F9	As for F9S			
F10	Illite } 7:3 Kaolinite } Quartz (l.) Mica-mont. intermediates (v.l.)			
F11	Illite } 7:3 Kaolinite } Chlorite (mod.) Quartz (l.) Calcite (l.) Montmorillonite (v.l.) Mica-mont. intermediates (l.)			
F12	Illite } 7:3 Kaolinite } Chlorite (mod.) Montmorillonite (l.) Mica-mont. intermediates (l.)	Illite } 7:3 Kaolinite } Chlorite (mod.)	Illite Kaolinite Montmorillonite (l.) Mica-mont. intermediates (l.)	Illite Kaolinite Montmorillonite (?) Mica-mont. intermediates (l.)

SOIL TYPE RB5

Location—Cudmore Park

Sample No.	< 2 μ	< 2 μ and > 0·2 μ	< 0·2 μ and > 0·05 μ	< 0·05 μ
F17A	Illite (mod.) } 7:3 Kaolinite (mod.) } Quartz (l.) Calcite (v.l.)	As for < 2 μ + Montmorillonite (?)	Illite Kaolinite Montmorillonite (?)	Illite Kaolinite
F18	Illite } 7:3 Kaolinite } Quartz (v.l.) Calcite (v.l.)	As for < 2 μ	As above	As above
F19	Illite } 7:3 Kaolinite } Quartz (v.l.) Calcite (l.) Montmorillonite (?) Chlorite (l.)	Illite Kaolinite Quartz (v.l.) Calcite (mod.) Chlorite (l.)	As above	Illite Kaolinite Montmorillonite (?)
F20	Illite } 7:3 Kaolinite } Quartz (l.) Calcite (trace) Goethite (l.) Chlorite (l.) Montmorillonite (l.)	Illite Kaolinite Quartz (l.) Calcite (v.l.) Chlorite (mod.) Montmorillonite (l.) Mica-mont. intermediates (l.)	As above	Illite Kaolinite Montmorillonite

SOIL TYPE BE1

Location—Linden Park

Sample No.	$< 2\ \mu$	$< 2\ \mu$ and $> 0{\cdot}2\ \mu$	$< 0{\cdot}2\ \mu$ and $> 0{\cdot}05\ \mu$	$< 0{\cdot}05\ \mu$
F13A	Illite (mod.), Kaolinite (mod.) } 7:3 Quartz (< 3 %) Chlorite (v.l.) Montmorillonite (v.l.)	As for $< 2\ \mu$	As for $< 2\ \mu$ + Mica-mont. intermediates (l.)	Illite Kaolinite Montmorillonite (l.)
F14C	Illite, Kaolinite } 7:3 Quartz (< 3 %) Chlorite (l.) Montmorillonite (?) Mica-mont. intermediates (l.)	As for $< 2\ \mu$	As for $< 2\ \mu$	As above
F15	Illite, Kaolinite } 7:3 Quartz (v.l.) Calcite (mod.) Chlorite (v.l.) Montmorillonite (v.l.)	Illite Kaolinite Montmorillonite (l.) Mica-mont. intermediates (l.)	Illite Kaolinite Chlorite (l.) Gibbsite (?) Mica-mont. intermediates (mod.)	Illite Kaolinite Chlorite (l.) Montmorillonite (l.)
F16	Illite, Kaolinite } 7:3 Quartz (l.) Calcite (mod.) Chlorite (l.) Montmorillonite (l.) Mica-mont. intermediates (mod.)	As for $< 2\ \mu$ but more Chlorite	Illite Kaolinite Montmorillonite Mica-mont. intermediates	As above with montmorillonite increasing
Deep Sample (95in.)	As for F16			

SOIL TYPE RB6

Location—Woodville Gardens

Sample No.	$< 2\ \mu$	$< 2\ \mu$ and $> 0{\cdot}2\ \mu$	$< 0{\cdot}2\ \mu$ and $> 0{\cdot}05\ \mu$	$< 0{\cdot}05\ \mu$
F29	Illite (mod.) } 9:1 Kaolinite } Quartz (< 10%) Calcite (v.l.) Chlorite (v.l.)	As for $< 2\ \mu$	Illite } 7:3? Kaolinite } Quartz (v.l.)	Illite Kaolinite
F30C	Illite } 8:2 Kaolinite } Quartz (l.) Calcite (mod.) Mica-mont. intermediates (l.)	As for $< 2\ \mu$ + Chlorite (v.l.)	Illite Kaolinite Quartz (v.l.) Calcite (v.l.) Chlorite (v.l.)	As above
F31	Illite (mod.) } Kaolinite (mod.) } 7:3 Quartz (v.l.) Calcite (v.l.) Dolomite (v.l.) Montmorillonite (?) Chlorite (v.l.) Mica-mont. intermediates (l.)	As for $< 2\ \mu$	As above	As above
F32	Illite } 7:3 Kaolinite } Quartz (v.l.) Montmorillonite (l.) Chlorite (l.) Mica-mont. intermediates (mod.)	Illite Kaolinite Chlorite (mod.) Quartz (v.l.)	Illite Kaolinite Chlorite Montmorillonite (?)	As above

NOTE—
mod. = Moderate amounts, probably between 15 per cent and 50 per cent.
l. = Little, probably between 5 per cent and 15 per cent.
v.l. = Very little, less than 5 per cent to 10 per cent.
(?) = Identification not certain.

Characteristics of the X-ray Diffraction Patterns

E. W. Radoslovich, in 1951, reported the following limitations and conclusions relating to the above tabulated data:

(1) The clay minerals which are recorded are those which were identified by an X-ray examination. The results of chemical analyses, and of thermal analysis of certain samples are not reported here. They do, however, support the X-ray work reasonably well.

(2) In certain cases it has been possible to give the *relative* proportions of two minerals, particularly of kaolinite and illite. This does not necessarily mean that these are the major constituents. Indeed, it is not certain that the minerals positively identified are the only components of the clay fractions of these soils.

(3) Particular features noted in relation to the respective profiles are:

(*a*) *Type RB3* (Samples 12721 to 12726)—The clay-mineral lines are very weak relative to the scattered radiation. Although the lines are reasonably sharp in the 2μ to 0·2μ fraction, they become rapidly more diffuse with decreasing particle-size. The clay minerals give patterns which are somewhat stronger, but also more diffuse in the case of the deeper horizons. The diffraction lines present probably only account for a moderate proportion of the sample analyzed, especially for the smaller particle sizes. The clay minerals are more poorly crystallized in these small particles.

(*b*) *Type RB*3 (Samples F9S to F12)—Clay lines are reasonably sharp, though rather weak, suggesting that a moderate proportion of the sample is well crystallized—more than in (*a*)—and the rest gives no pattern. The clay minerals appear to have quite well-formed lattice structures for the lower horizons.

(*c*) *Type RB*5 (Samples F17A to F20)—The clay minerals appear to be quite well crystallized except in the $< 0{\cdot}05\mu$ fraction, and the soil colloids identified probably comprise at least 80 per cent of the sample.

(*d*) *Type BE*1 (Samples F13A to F16)—The X-ray diffraction patterns for this profile indicate that the clay minerals identified are poorly crystalline in all particle sizes, and that the non-crystalline material could quite easily represent up to 50 per cent of the sample.

(*e*) Type RB6 (Samples F29 to F32)—The clay mineral lines for the fraction 2μ to $0{\cdot}2\mu$ are comparatively sharp and strong for the upper horizons in this profile. They become very weak for the smaller particle sizes, particularly $< 0{\cdot}05\mu$, and certainly do not seem to represent the whole of the sample analyzed. The clay lines become rather weak and broad (for all fractions) in the lower horizons.

Physical Characteristics of the Major Soil Types

Laboratory data—as in the preceding sections of this Appendix—cannot alone characterize the behaviour of a natural soil. The climatic environment of each and every soil dominates its physical behaviour in nature. Although climatic factors are reflected in the mature soil profile, it is not as yet possible to deduce quantitatively a pattern of soil behaviour from analyses of the soil profile and knowledge of the relevant climatic data.

The alternative approach is to study the seasonal behaviour of soils within their natural vegetative and climatic environments. Such studies have been made on several of the major soil types within the Adelaide area. Aitchison and Holmes (1953a) have reported data defining seasonal moisture changes in several soils; while the same authors (1953b) have observed the shrinkage and swelling movements which accompany these moisture changes.

A summary of these data is given below. It should be stressed that the pattern of physical behaviour so presented relates to the natural environment. Modification of this environment—as by domestic or industrial building, or by road construction or agricultural practice—may well modify the observed pattern of behaviour.

OBSERVED SEASONAL MOISTURE CHANGES AND CONSEQUENT VOLUME CHANGES

	Soil Type		
	RB3	RB5	RB6
1. Maximum depth (D) of significant seasonal wetting and drying in the profile........ ft.	7 < D < 9	6 < D < 8	1 < D < 2
*2. Maximum depth of significant shrinkage and swelling movements in the profile....... ft.	7†	—	0
‡3. Vertical movements within the soil profile—			
At surface.......................... in.	1·5	—	—
1ft. below surface .... in.	1·4	—	—
2ft. below surface .... in.	1·1	—	—
3ft. below surface .... in.	0·6	—	—
4ft. below surface .... in.	0·4	—	—

	Soil Type		
	RB9	BE1	BS2
1. Maximum depth (D) of significant seasonal wetting and drying in the profile........ ft.	3 < D < 4	6 < D < 8	4 < D < 6
*2. Maximum depth of significant shrinkage and swelling movements in the profile....... ft.	1·5	6†	0
‡3. Vertical movements within the soil profile—			
At surface.......................... in.	0·6	3·2	0·1
1ft. below surface .... in.	0·3	2·0	0·1
2ft. below surface .... in.	0	1·5	0·1
3ft. below surface .... in.	0	0·7	0
4ft. below surface .... in.	0	0·4	0

* Movements less than 0·1in. are not considered significant.
† Estimated depth—Based on extrapolated direct measurements.
‡ Measured relative to datum 6ft. below surface.

In the engineering sense, seasonal moisture changes are of considerable importance because of the dominating influence they exert upon the strength and volumetric stability of soils—clay soils in particular. Seasonal shrinkage and swelling movements have been reported above; while a parallel series of observations has been undertaken to measure soil strength and the influence thereon of seasonal moisture changes.

J. W. Holmes (1952 and priv. comm.) has collated some of these data which are tabulated below. All shear-strength measurements were made on small undisturbed samples (1½in. diam.) tested in triaxial compression under conditions representative of an "undrained" test (Skempton and Bishop 1950).

All triaxial compression test records have been examined statistically to determine the angle of shearing resistance (ϕ u) and the cohesion (Cu). In most cases it has been found that the angle of shearing resistance (ϕ u) did not suffer significantly from zero, although all of the soils examined were in the unsaturated moisture condition. Some instances of an effect of increasing lateral pressure were noted, but in most of the heavy clay soils this effect has been ascribed (Aitchison 1953) to an interaction of the structural condition of the soil and the testing technique.

In the following tables, the shear strength of the soil is quoted in terms of the compressive strength for all soils to which the conditions of ϕ u = 0 has been found applicable. For these soils:

Compressive strength = 2.Cu

COMPRESSION TESTS

SOIL TYPE—BE1

	Tests made at end of summer drying cycle					
	1950			1951		
Depth	Water content	Compressive strength	pF (approx.)	Water content	Compressive strength	pF (approx.)
in.	per cent	p.s.i.		per cent	p.s.i.	
0-24 ..	14·1 ± 0·9	45 ± 8*	4·2	19·0 ± 3·4	71 ± 12	4·2
24-48 ..	14·9 ± 0·2	88 ± 32	4·2	24·0 ± 1·5	44 ± 5	3·8
48-72 ..	15·9 ± 0·1	66 ± 15*	4·1	22·5 ± 0·8	51 ± 6	3·4
72-96 ..	22·0	90 ± 10*	3·1	23·4 ± 0·9	59 ± 4	2·9

	Tests made at end of winter wetting cycle		
	1950		
Depth	Water content	Compressive strength	pF (approx.)
in.	per cent	p.s.i.	
0- 24.	32·3 ± 4·6	21 ± 3	< 2·5
24- 48.	24·2 ± 1·7	35 ± 4	2·8
48- 72.	20·4 ± 0·9	56 ± 6	2·9
72- 96.	22·6 ± 0·1	42 ± 5	2·9
96-120.	25·7 ± 0·7	32 ± 2	—
120-144.	23·9 ± 0·4	37 ± 4	—

NOTE.—Values quoted are means and standard errors. * Two tests only.

SOIL TYPE—RB3

	Tests made at end of summer drying cycle					
	1950			1951		
Depth	Water content	Compressive strength	pF (approx.)	Water content	Compressive strength	pF (approx.)
in.	per cent	p.s.i.		per cent	p.s.i.	
0- 18.	6·9 ± 1·5	83 ± 50	4·2	6·8 ± 0·6	67 ± 11	4·2
18- 36.	17·8 ± 1·0	87 ± 18	4·2	22·9 ± 0·4	87 ± 12	4·2
36- 60.	14·3 ± 0·4	106 ± 25	4·2	15·5 ± 0·2	86 ± 11	4·2
60- 84.	13·5 ± 0·5	74 ± 18	4·2	13·7 ± 0·7	76 ± 7	4·2
84-108.	17·2 ± 0·7	122 ± 36	—	12·6 ± 0·7	73 ± 4	—
108-144.	20·4 ± 0·1	134 ± 10	—	18·6 ± 1·3	73 ± 25*	—

	Tests made at end of winter wetting cycle		
	1950		
Depth	Water content	Compressive strength	pF (approx.)
in.	per cent	p.s.i.	
0- 18.	18·0 ± 0·7	44 ± 33	< 2·5
18- 36.	31·7 ± 1·0	21 ± 3	< 2·5
36- 60.	22·7 ± 1·2	36 ± 5	2·5
60- 84.	15·8 ± 1·2	106 ± 21	2·5
84-108.	15·6 ± 1·5	87 ± 14	—
108-132.	19·3 ± 0·3	85 ± 14	—
132-150.	20·5 ± 0·2	49 ± 20*	—

NOTE.—Values quoted are means and standard errors. * Two tests only.

SOIL TYPE—RB9

Depth	Date of testing	Water content	pF (approx.)	Compressive strength
in.		per cent		p.s.i.
0-18	December, 1950..	20·7	3·7	91 *
18-36	December, 1950..	16·0 ± 0·2	2·7	85 ± 3 †
36-60	December, 1950..	20·1 ± 0·1	3·1	43 ± 10 †
60-84	December, 1950..	25·4 ± 1·3	2·9	30 ± 3
0-24	April, 1950	—	4·2	62 ± 10
24-48	April, 1950	—	—	80 ± 20
48-72	April, 1950	—	3·0	43 ± 6
72-86	April, 1950	—	3·0	34 ± 5

NOTE.—Values quoted are means and standard errors.
* Single value only. † Two tests only.

SOIL TYPE—BS2b

Depth	Date of testing	Water content	pF (approx.)	Compressive strength	
in.		per cent		p.s.i.	
0-18*	November, 1950 .	9·0 ± 0·3	4·1	22 ± 5 †	Lateral pressure in test = 20 p.s.i.
18-36*	November, 1950 .	9·4	3·9	30 ± 6 †	
36-60	November, 1950 .	9·1 ± 0·6	3·5	32 ± 9	
60-84	November, 1950 .	13·3 ± 1·8	3·9	66 ± 22	

NOTE.—Values quoted are means and standard errors.
* These horizons could be expected to behave as C, ϕ materials.
† Two tests only.

SUB-STRATA OF SOIL TYPE RB5 AT EDWARDSTOWN

Depth, in.	42-53	56-66	66-82	78-94	98-116
Water content, per cent	19·0 ± 0·8	16·8 ± 0·5	17·3 ± 0·8	18·0 ± 0·5	16·7 ± 0·5
Compressive strength, p.s.i.	46 ± 9	30 ± 2	30 ± 2	23 ± 2	21 ± 2

SUB-STRATA OF SOIL TYPE RB7 AT MILE END

Depth, in.	60-72	84-96
Water content, per cent	18·3 ± 2·5	18·6 ± 1·3
Compressive strength, p.s.i.	36 ± 6	31 ± 3
Apparent dry density, gm/cc.	1·67 ± 0·06	1·70 ± 0·03

MOTTLED (TERTIARY) CLAYS

Location	Hindley Street, Adelaide	Springfield (Burnside block)
Depth, in.	144-150	120-126
Water content, per cent	34·4 ± 0·4	29·6 ± 0·3
Compressive strength, p.s.i.	18 ± 3	30 ± 3

NOTE.—Values quoted are means and standard errors.

Notes on Seasonally Observed Soil Data

In the preceding tables, there is evidence—in the large magnitude of the standard errors—of some considerable variability within the observed data. However there are no grounds for assuming that these soils are excessively variable. Aitchison, Butler, and Gurr (1951) have examined the variability of the "B" horizon of an RB3 soil. Their data reveals a pattern by no means unusual in heavy clays.

It is well established that a very great number of samples must be taken for reliable representation of a natural clay soil. In many of the figures quoted in the above tables, it is possible that the number of samples was inadequate; and hence it must be borne in mind that the true error in some of the values of strength or water content may exceed the standard error quoted. Some of the lack of agreement from season to season may be simply the consequence of insufficient observations—a shortcoming possibly pardonable in view of the difficulty of extensive sub-surface sampling. The data of the above tables must therefore be regarded merely as the best available current information, which may, however, be modified by subsequent investigations.

Appendix B

THE SOILS IN RELATION TO THE FOUNDATIONS OF DOMESTIC BUILDINGS

The principal practical purpose of the soils investigations reported in this *Bulletin* has been that of obtaining a background to the elucidation of some problems associated with the design of adequate economical foundations for domestic-type buildings. It has been necessary first to become acquainted with the soils and then to observe empirically their foundation behaviour before any more detailed studies of soil properties could be undertaken.

In their preliminary stages it has become clearly established that each particular soil type is unique in its foundation behaviour; and that such behaviour is reproduced constantly wherever the soil type re-occurs. Thus in the simplest sense it is possible to make use of the soil classification described in previous chapters by regarding the soil type as the medium of transferring engineering experience from one location to another. The knowledge so far available is virtually adequate to permit the adoption of this qualitative approach to the selection of sound foundation practices for each home site.

However it has been shown (Aitchson 1950*a*; Isaacs 1951) that a quantitative design procedure based upon characteristics of the soil profile as a whole, *i.e.*, based upon soil type, is entirely practicable.

This *Bulletin* does not include data on the various design-constants for all soil types (although some are given in the Appendix A) nor does a discussion on design of foundations properly belong herein. It is sufficient to record the fact that there is no incompatibility between the simple use of the soil profile as the basis of transfer of engineering experience and the more elaborate procedures of detailed foundation design to suit the peculiarities of the soil type. In fact it is obvious that, in relation to domestic building, the latter process will normally serve to establish newer and sounder foundation-practices where necessary on troublesome soil-types; which practices will then be applied without further design-calculations wherever the same soil-type is again encountered and the same class of building is involved.

Foundation Characteristics of the Recognized Soil-Types

For the present all that will be attempted is the recording of the known foundation-behaviour of the soils with comments on these particular soil-characteristics which may contribute to peculiar performance. Some suggestions as to an appropriate foundation-practice for each soil will be made based upon observed satisfactory performances and/or upon design recommendations in previously published work. (Aitchison 1950*b*; Tasker *et al.* 1951.) These practices merely represent the limits of available knowledge and may be subject to later amendment when further designs, calculated from soils data at present incomplete, are forthcoming.

FOUNDATION CHARACTERISTICS OF THE SOILS

Soil type	Characteristics of the soil profile	Foundation experience on the soil *		Suggested appropriate foundation practice	Remarks
		Incidence of foundation failure	Soil-variable related to foundation failure		
RB1	Shallow stony red-brown earth formed *in situ* on slates of the escarpment zone. Dominant type of Netherby Association †	Rare	Soil creep, *i.e.*, movement of the soil mantle downhill over a rock surface may cause some trouble	Support-foundations (piers or beams) on basement rock	High bearing-capacity permissible at proposed foundation depth
	† Description in preceding text, page 59.				
RB2	Sandy compact red-brown earth. Dominant type of Knightsbridge Association † ‡	Rare to non-existent......	—	Standard strip-footing on soil surface	Bearing capacity high. Soil movement negligible. Drainage good
	† Description in preceding text, page 63. ‡ Analytical data in Appendix A., page 90.				
RB2a ...	Similar to Type RB2, but with water-worn gravel throughout the profile	As for Type RB2	—	Strip-footing on soil surface	As for Type RB2
RB2b ...	Sandy mottled red-brown earth, characteristic of drainage lines within the Knightsbridge Association †‡	Not observed—probably not high	Some shrinkage and swelling may occur in the " B " horizon and below	Strip-footing on the soil surface (Precautions should be taken to prevent abnormal drying—as by trees—of the subsoil)	This soil occurs over a limited area only. No reliable observations of foundation behaviour are available. These remarks on foundation practices are tentative only
	† Description in preceding text, page 64. ‡ Analytical data in Appendix A., page 90.				
RB3	Red-brown earth, with heavy-textured coarse-structure " B " horizon. Dominant type of the Urrbrae Association †‡§	Common—More than 50 per cent of houses show some cracking; many are seriously disfigured	Shrinkage and swelling movements of large magnitudes occur in the " B " horizon and below. Consequent vertical movement of surface of soil approximately 1½in. seasonally	" Pier and beam " with piers effectively supported at depths below zone of significant soil movement, *i.e.*, below 8ft. Beams to be clear of ground by at least amount of seasonal movement, *i.e.*, 1½in.	Bearing capacity high at foundation depth. Uplift force on the pier may be large enough to necessitate reinforcement in the pier shaft
	† Description in preceding text, page 61. ‡ Analytical data in Appendix A., pages 91-92. § Illustrated in Plate I., fig. 1.				

RB3a ...	Similar to RB3, but with medium to large amounts of water-worn or sub-angular stone throughout the profile	Infrequent to moderate (cracking rarely serious)	As in Type RB3 shrinkage and swelling movements tend to occur within the clay horizons. However if the profile is sufficiently stony actual soil movements may be diminished by this rigid skeleton	Surface strip-footings often successful. Practice as for Type RB3 recommended where soils are not pronouncedly stony	Bearing capacity moderately high. On steep slopes precautions against soil creep should be taken
RB3b ...	Similar to Type RB3, but with deep " A " horizon (18in. or more) ‡	Infrequent (failures rarely serious)	Total soil movements as well as differential movements may be reduced much below the values for Type RB3 as a result of the additional depth of non-swelling soil material	Strip-footings on the soil surface are often successful although not recommended except on the grounds of economy. Pier and beam practices as for Type RB3 are safer	If surface strip-footings are used, extra attention should be paid to surface and sub-surface drainage of the site to minimize the wetting and drying of the subsoil

‡ Analytical data in Appendix A., page 92.

RB5	Red-brown earth, with heavy-textured fine-structured " B " horizon. Dominant type of the Edwardstown Association †‡§	Infrequent (about 10 per cent of houses show mild cracks)	Probably some small shrinkage and swelling movements occur. Actual magnitude of seasonal movement of soil not known	Surface strip-footing of increased rigidity (deep beams or inverted T-beams have been successful)	Foundation conditions tend to improve in transitional types between RB5 and RB7 and also in the travertinized soils within the Edwardstown Association nearer the sea than the modal RB5. Foundation conditions deteriorate in the transitional soils between Types RB5 and RB3. In such cases the practice for Type RB3 must be adopted

† Description in preceding text, page 65. ‡ Analytical data in Appendix A., page 92. § Illustrated in Plate I., fig. 2.

* In houses of normal construction.

Soil type	Characteristics of the soil profile	Foundation experience on the soil *		Suggested appropriate foundation practice	Remarks
		Incidence of foundation failure	Soil-variable related to foundation failure		
RB6	Shallow sandy saline red-brown earth, with shallow water-table. The dominant member of lower portions of the Hindmarsh Association †‡§	Infrequent	Not established. Possibly differential settlement of soil due to uneven loading (only in areas of high water-table)	Strip-footing on soil surface	Bearing capacity of soil not high, but adequate for domestic building if normal conservative practices are followed. In industrial buildings problems of bearing capacity and settlement of the soil may arise
† Description in preceding text, page 68. ‡ Analytical data in Appendix A., pages 93-94. § Illustrated in Plate II., fig. 1.					
RB7	Deep sandy red-brown earth. Slightly saline with water-table at intermediate depths. A major member of the Hindmarsh Association †	Rare to infrequent	—	Strip-footing on soil surface	Bearing capacity inferior to that of Types RB3 and RB5, but adequate for domestic buildings
† Description in preceding text, page 67.					
RB9	Degraded red-brown earth, with dull mottled surface horizons. Water-table at shallow depth. Dominant member of the Brayville Association †‡§	Infrequent to moderate ...	Shrinkage and swelling movements of small magnitude	Strip-footing of moderate rigidity on soil surface (deep beam or inverted T-beam type)	Bearing capacity not high, but adequate for suggested foundation practices
† Description in preceding text., page 69. ‡ Analytical data in Appendix A., page 94. § Illustrated in Plate II., fig. 2.					
RB9a ...	Degraded red-brown earth. Transitional sub-type between Types RB5 and RB9 †	Moderate to infrequent ...	Shrinkage and swelling movements of small magnitude	As for Type RB9	As for Type RB9
† Description in preceding text, page 70.					

RB9c ...	Degraded red-brown earth with heavy-textured dull-coloured horizons †	Moderate to frequent	Shrinkage and swelling movements of small magnitude	Rigid strip-footing (deep beam or inverted T-beam) supported 1ft. to 2ft. below the soil surface	This soil presents a complicated foundation problem. The soil movements may be too high for strip-footings to be satisfactory, whereas the bearing capacity may be too low for the economical adoption of pier and beam practices. The suggested practice represents a compromise which could be satisfactory

† Description in preceding text, page 70.

RB9z ...	Degraded red-brown earth, with dull-coloured saline profile and shallow water-table. Occurs within the Brayville Association †‡§	Moderately frequent (cracking not severe)	Shrinkage and swelling movements of small magnitude	Rigid strip-footing (deep beam or inverted T-beam) supported 1ft to 2ft. below soil surface	Bearing capacity not high, but adequate for suggested foundation practices

† Description in preceding text, pages 70-71. ‡ Analytical data in Appendix A., page 95. § Illustrated in Plate III., fig. 1.

BE1 (also BE1a and BE1b)	Black earth, with considerable profile variability. Clay from surface down to considerable depth. Normally found in escarpment outwash apron. Dominant member of the Claremont Association †‡§	Common—Practically all houses erected on this soil with normal surface foundations fail badly	Shrinkage and swelling movements of considerable magnitude, (seasonal vertical movement of the soil surface is of the order of 3in.). Differential movements may occur due to soil variability	Pier and beam, with piers effectively supported at depths below zone of significant soil movement, *i.e.*, below 7ft. Beams to be clear of ground by amount of seasonal movement, *i.e*, 3in.	Bearing capacity moderate to high at foundation depth. Uplift forces in the pier may be large enough to warrant reinforcement of the pier shaft

† Description in preceding text, pages 72-73. ‡ Analytical data in Appendix A., pages 96-97. § Illustrated in Plate IV., figs. 1 and 2.

BE3	Black earth, with some mottling in the upper horizons. Dominant type of the St. Marys Association †	Common—But severity of cracking less than in Type BE1	Shrinkage and swelling movements of appreciable magnitude (not measured)	Pier and beam or particularly rigid deep-beam or inverted T-beam types	Bearing capacity not high, therefore pier and beam constructions may not be economical

† Description in preceding text, page 74.

* In houses of normal construction.

Soil type	Characteristics of the soil profile	Foundation experience on the soil *		Suggested appropriate foundation practice	Remarks
		Incidence of foundation failure	Soil-variable related to foundation failure		
BE2	Black earth, with some admixture of silicious sand. Dominant type of the Paradise Association	As for Type BE1	As for Type BE1	As for Type BE1	As for Type BE1
RZ1	Rendzina—Shallow dark-coloured clay soil overlying parent limestone. Dominant type of the Beaumont Association †‡§	Infrequent	Some shrinkage and swelling of the surface soil. Bearing capacity of the surface soil probably not high. Soil creep may be troublesome on steeper slopes	Support foundation (piers or beams) on basement rock (or solid zone within weathering rock)	Moderate to high bearing-capacity permissible at foundation depth
RZ1a ...	Deep dark-coloured clay soil overlying parent limestone †	Moderately frequent	Shrinkage and swelling movements may be quite significant. Soil creep also may occur	As for RZ1. Pier and beam foundation is usually adopted	As for RZ1
TR1	Terra Rossa—Shallow red-coloured clay soil over lying parent limestone. Occurs with Type RZ1 in the Beaumont Association †§	Infrequent	Some shrinkage and swelling of the soil horizons. Soil creep may occur	Support foundation (piers or beams) on basement rock or solid zone within weathering rock	Moderate to high bearing-capacity permissible at foundation depth
BS2	Mallee soil, with lime horizon at shallow to moderate depth. A major soil of the Enfield Association †	Rare to infrequent	As for Type BS2b	Strip-footings on the soil surface	As for Type BS2b

RZ1: † Description in preceding text page 76. ‡ Analytical data in Appendix A., page 98. § Illustrated in Plate V., fig. 1.

RZ1a: † Description in preceding text, page 77.

TR1: † Description in preceding text, page 78. § Illustrated in Plate V., fig. 2.

BS2: † Description in preceding text, page 79.

BS2b ...	Mallee Soil—Deep sandy surface soil overlying a rubbly lime horizon. A member soil of the Enfield Association †‡§	Infrequent	When subjected to flooding some settlement of the soil occurs. Differential soil movements may thus occur if part only of the foundation area is submerged. Damage is of a minor nature only	Strip-footings on the soil surface	All known foundation failures have been the result of mismanagement. Floodings due to inadequate surface drainage or to over-watering of gardens have contributed to these troubles

† Description in preceding text, page 80. ‡ Analytical data in Appendix A., page 98. § Illustrated in Plate VI., fig. 1.

YP1	Sandy surface soil overlying yellow clay above sandstone or quartzite. Dominant member of the Stonyfell Association †§	Rare	In winter the A_2 horizon of the soil—which is a sand with clay—becomes saturated. This horizon can become unstable if lateral support removed (as by trenching). On steeper slopes some soil creep may occur	The topographic environment of these soils may favour excavations to basement rock. On the flatter slopes the soils are sufficiently stable and free from seasonal effects to permit the use of surface strip-footings	These soils are unimportant within the mapped areas, but occur more widely in the hills districts

† Description in preceding text, page 81. § Illustrated in Plate VI., fig. 2.

TA1	Gravel and sand deposits of the River Torrens	None	—	Strip-footings on the soil surface	Few buildings will be erected on these soils except in old river terraces
TA2	Dark-coloured fine-textured alluvium of the River Torrens	Not observed	Soil probably subject to settlement under load	Rigid strip-footings (of inverted T-beam type)	Buildings are rarely erected on these soils
TA2a ...	Dark-coloured alluvium from River Torrens, overlying buried red-brown earth profile (Type RB3)	Not observed	Soils may behave in similar fashion to Type RB3 or to Type RB3b	Due to variability of deposition of the alluvium, strip-footings may be unreliable. Pier and beam foundations as for Type RB3 are advisable	—

* In houses of normal construction.

Soil type	Characteristics of the soil profile	Foundation experience on the soil *		Suggested appropriate foundation practice	Remarks
		Incidence of foundation failure	Soil-variable related to foundation failure		
PA1	Grey heavy-textured silty clay. (No profile development). A member soil of the Plympton Association	Moderate	Shrinkage and swelling and/or settlement under load	Rigid strip-footing of adequate bearing-area (inverted T-beam type) or pier and beam type with enlarged base to the piers	In some areas of these soils a foundation problem can be created by improvements to the drainage. As the water-table is lowered by drainage, shrinking of the soil may occur. Differential foundation movements may possibly result
PA2	Dark-grey heavy alluvium, overlying buried red-brown earth †	Frequent................	Shrinkage and swelling movements and/or some settlement under load	As for Type PA1	These soils have affinities with the black earths. Hence foundation practices for, say Type BE1 tend to be applicable with some modifications due to the less marked seasonal moisture-changes of Types PA1, PA2, and PA2a
	† Description in preceding text, page 83.				
PA2a ...	Dark-grey heavy alluvium overlying buried degraded red-brown earth †	Frequent................	As for Type PA2	As for Type PA1	
	† Description in preceding text, page 84.				
EM1	A soil composed of river alluvium overlying littoral sands. A member type of the variable Patawalonga Association † ‡	Infrequent	The soil may be sensitive to disturbance (as severe vibration) when the water-table is high ; otherwise quite stable in the lower layers	Strip-footings supported about 1ft. below the soil surface	This type represents about the best foundation condition within the Patawalonga Association

† Description in preceding text, page 85. ‡ Analytical data in Appendix A, page 99.

EM2	A soil composed of estuarine deposits. A common member of the variable Patawalonga Association † ‡	Moderate to frequent	This soil is quite soft and may settle under building loads	Strip-footings of adequate bearing-area with proper distribution of load to avoid tendencies for differential settlement	This type is quite normal within the Patawalonga Association. The foundation problem—that of settlement under small load—is common to all of the soft estuarine deposits
	† Description in preceding text, page 85. ‡ Analytical data in Appendix A, page 99.				
DS1	Reddish-coloured dune sands of the " Osborne " coast-line. Little or no profile development. Dominant member of the Osborne Association †‡§	Rare	Some of these sands are in a loose or unconsolidated condition. Severe vibration may cause settlement ; otherwise these soils are completely stable	Strip-footings on the soil surface	Where buildings are to be erected on any loose sands in an area subject to vibration, pre-consolidation of the foundation sub-strata can be achieved by flooding and vigorous stirring
	† Description in preceding text, page 86. ‡ Analytical data in Appendix A., page 98. § Illustrated in Plate III., fig. 2.				
DS2	White siliceous dune sands of the southern coast-line. The Semaphore Sands †	Rare	As for Type DS1	As for Type DS1	As for Type DS1
	† Description in preceding text, page 86.				

* In houses of normal construction.

Determinant Attributes of the Soils in Relation to Building Foundations

In the whole of the preceding discussion each soil-type has been considered as an entity recognizable in terms of its characteristic morphology. It has been postulated that the physical behaviour of the soil type is reproduced in each and every locality in which it may occur and hence that identification of a known soil-type permits the utilization of all previously accumulated performance data relevant to that type.

However, for the successful adoption of this approach there are certain basic prerequisites. Firstly, it is essential that in any area a soil classification must precede the study of foundation behaviour; and secondly, since the required performance data are dependent on seasonal effects, it is necessary for a lengthy period of observations to be undertaken.

In order to relieve the obvious tedium of these processes when applied to any completely new area, it would be helpful if some simple direct or indirect measure of foundation performance of a soil could be achieved. If some determinant attribute of the soil could be found which would serve in all cases as an index of foundation properties, the future assessment of any as yet unrecognized soil would become a simple matter. Consequently some consideration must be given to any observable or measurable feature of the soil which can be consistently related to foundation behaviour.

From the available data from the field and from the laboratory, there does not appear to be any immediate promise of success in this simplification process. In the broadest sense there is a definite significance in the texture of the soil—the sands, loams, and clays behave quite differently, as is to be expected. In this regard there can be no preference for the laboratory figures of mechanical analyses of the soil as distinct from field estimates of soil texture. Either will serve equally well.

In attempting to differentiate one clay soil from another, or one clay-soil horizon from another, little credence can be attached to any refinements of mechanical analysis or to any other laboratory measurement. For it must be appreciated that the foundation behaviour of a soil is a function not only of its composition, but also of its environment. Laboratory data can adequately express the former of these two contributory factors but overlooks the latter.

On the other hand, in the field the overall soil morphology permits a qualitative appreciation of both factors. From past pedological experience expressed in terms of accepted soil-classifications (Stephens 1951) an assessment can be made of soil composition and of its moisture or drainage status. But no single morphological feature (other than texture) is consistently related to foundation behaviour. Rather there is an interaction of a complexity of features which cannot be discussed separately here.

Laboratory examinations of the soils, in an effort to explain differences of behaviour, have not been entirely successful. Although it is highly probable that the nature and proportions of the clay minerals present in the soil exert a controlling influence, it has not proved to be a simple matter to assess these factors in any manner which can be correlated positively with observed foundation-characteristics. From direct interpretation of clay type with X-ray techniques, and from indirect measurements based upon consistence data or exchange capacities, the evidence, though suggestively in favour of the above postulate, is by no means significant. Hence it must be admitted that, at the present time, laboratory examination of the soil does not alone provide an adequate indication of foundation behaviour.

Identification of the soil type in the field, supported either by recorded experience on the soil or by field measurements pertaining specifically to that soil, must remain the basis for the assessment of the foundation potentialities of any site.

Appendix C

HEAVY-MINERAL INVESTIGATION

Limited heavy-mineral studies on various soils of the Adelaide Plains, of early Tertiary and Pre-Cambrian bedrock types in the local fault blocks, and of creek sands were undertaken with a view to tracing the soil parent-materials.

The greater part of the laboratory work was carried out by Mrs. I. Chebotarev under the supervision of A. W. G. Whittle (Petrologist) of the Department of Mines. The results of the investigation have been produced in tabular form, and the minerals are noted in order of assumed stability from left to right in the table. The data have been gained by studying only the fine-sand fraction of the various samples and the approximate proportions of the heavy minerals have been indicated by the terms flood, abundant, common, etc. The ranges of the proportions of the total heavy-mineral contents which these terms cover are indicated at the beginning of the table. The localities from which samples have been collected are shown in fig. 6.

Minerals of the Rock Formations

Adelaide System Rocks

Heavy minerals provide a very small contribution to these sedimentary rocks. While percentages are very variable, ranging as high as 50 per cent or more in certain basal sandstones, mostly they form less than half of one per cent by weight. Intermediate values were obtained for a calcareous shale from Rocky Hill which produced 9 per cent heavy minerals, and a dolomite from near the Torrens Weir which yielded 5 per cent.

By way of summary it is noted that besides the low content of heavy minerals the suites themselves contain few species. The following generalizations hold:

(1) Iron-ore minerals are ubiquitous and "common to abundant" in most assemblages. A phyllite specimen from near Hope Valley Reservoir forms an exception.

(2) Ferromagnesian minerals: One or more amphibole minerals occur in very small quantities in some rocks north of the River Torrens and south of Glen Osmond. They are most prominent in partially decomposed rocks, *e.g.,* calcareous slate from South Road, and Hope Valley Phyllite. The alteration minerals, epidote and zoisite, only occur in the decomposed calcareous slate and in a dolomite from Dry Creek.

(3) Chlorite: Apart from a trace in Sturtian Tillite samples, the occurrence of this mineral is largely restricted to the lower Adelaide System rocks north of Glen Osmond. North of Second Creek it assumes a relatively large portion of some rocks, forming 5 per cent of the total slate at Rocky Hill and several per cent of a dolomite near the Torrens Weir.

(4) Muscovite is practically ubiquitous in small amounts, and increases slightly to the north of Slape Gully.

(5) Hydromica occurs in samples taken between Slape Gully and the River Torrens, and in one specimen from near Hope Valley.

(6) Metamorphic minerals: Andalusite occurs in several samples, but kyanite is absent. Staurolite and sillimanite are present in small amounts between Glen Osmond and South Road. Sillimanite is also present in a somewhat decomposed slate at Hope Valley.

(7) Zircon and tourmaline are ubiquitous in small quantities.

(8) Garnet is absent in specimens taken between the River Torrens and Glen Osmond, and elsewhere is only present as a few grains.

(9) Rutile is scattered in small amounts, and between Third Creek and the River Torrens it has not been recorded at all. Brookite and anatase have not been observed.

(10) Corundum, spinel, sphene, and xenotime are absent, and monazite has been found only in the Brighton Limestone and a single grain in slate from the Devil's Elbow.

Early Tertiary Sediments

The several samples examined have only restricted suites of heavy minerals although the proportions ranged up to 7·5 per cent. A re-sorted sand from near Yatala Vale has a greater variety of minerals than the fresh rock.

(1) Iron-ore minerals are again ubiquitous and form the bulk of the heavy minerals.

(2) Ferromagnesian minerals: Apart from the re-sorted sand, these are absent from the samples except for small amounts of zoisite in one sample and hornblende in two.

(3) Chlorite and muscovite only occur in the re-sorted sand and from a locality on the Slape Gully road. Hydromica occurs in only one sample.

(4) Zircon and tourmaline are ubiquitous and most common north of the Torrens.

(5) Garnet is sometimes found in small amounts.

(6) Rutile is comparatively common. There is a trace of anatase in the Yatala Vale Sands and also in the re-sorted material.

(7) Metamorphic minerals such as staurolite, kyanite, and sillimanite are absent in the Athelstone and Penfold Reservoir samples, but elsewhere are present to form from 1 to 10 per cent of the total. Andalusite is absent from the "Gun Emplacement" beds at the base of Anstey Hill.

(8) Minor accessories: Xenotime is present north of the Torrens, in small amounts only. Sphene and spinel are practically lacking except as rare grains. Monazite is absent and corundum has been noted only in the Yatala Vale sample.

(9) Barite appears in quite large amounts at both Athelstone and near Penfold Reservoir.

Creek Sands

A fairly representative sampling of sediments from the main watercourses draining from the hills has been undertaken. In most cases these consist of sands, but in First Creek a red silt was taken, and a black silt was collected overlying normal creek-sands behind the Torrens spillway. In the latter case the heavy-mineral percentage in the sands is much greater, but the relative proportions are about the same.

Certain generalizations can be made as follows:

(1) Iron minerals are again ubiquitous and form a large proportion of the total.

(2) Ferromagnesians are also ubiquitous, with primary types in excess of the epidote group. The hornblende suite in particular is high in the Torrens samples—as the creek drains across Archaeozoic rocks—and comparatively higher north of Third Creek than to the south. Brownhill Creek sands are especially impoverished in these minerals.

(3) Chlorite is also present in practically every sample (except Second Creek) usually varying from 1 to 10 per cent of the total.

(4) Muscovite is present in all samples and is comparatively common north of Third Creek, constituting from 5 to 30 per cent of the total.

(5) Hydromica is absent from the Glen Osmond Creek suite, and is much higher in Fourth Creek and Fifth Creek samples than in others.

(6) Zircon and tourmaline are ubiquitous in small amounts.

(7) Garnet occurs sparsely in the Torrens sands and in very small amounts in Third Creek and to the south.

(8) Metamorphic minerals: Kyanite has not been detected in any creek samples and andalusite is present only in small amounts in First Creek and Brownhill Creek. Staurolite and sillimanite are present in minor amounts except in First Creek, and sillimanite is found only in one of the Torrens samples in spite of the fact that this river drains through the Archaeozoic metamorphic complex in the Houghton area.

(9) Titanium minerals: Rutile is usually present in small amounts whereas brookite and anatase are absent.

(10) Of the minor accessory minerals xenotime occurs in First, Second, and Third Creeks, corundum in First and Second Creeks, sphene in First Creek and the River Torrens, and spinel is found only in Glen Osmond Creek. Monazite is absent.

Minerals of the Soils

Residual Soils

(1) A skeletal black earth over limestone and calcareous slates near Brighton presents anachronous features. Rutile for instance is uniformly absent, while monazite which is very rare in the Adelaide region is present in both the clay and the calcareous slate. On the other hand the soil contains staurolite, sillimanite, kyanite, andalusite, and xenotime which are not present in the rock, while ferromagnesian minerals are very much more plentiful in the soil.

(2) A shallow red-brown earth with a brown sandy clay topsoil overlies a green shale near Hope Valley Reservoir. The heavy-mineral content of both parent-material and soil are about the same, but the proportions of tourmaline, zircon, rutile, and the ferromagnesian minerals are much higher in the soil. Moreover muscovite, corundum, and sphene are found in the soil but not the rock, although muscovite is present in a phyllite collected less than ¼ mile away.

(3) A red-brown earth topsoil, the clay subsoil at 5ft., and underlying early Tertiary sandstone have been studied from near Athelstone. The percentages of heavy minerals increase upwards from the rock, and barite is notable in that it is present both in the rock and clay but not in the topsoil. The metamorphic minerals of the sillimanite group occur only in the clay and topsoil although they have been found in early Tertiary rocks elsewhere. The ferromagnesian minerals also increase rapidly throughout this profile beginning with "rare" hornblende in the rock, followed by clay with three of the ferromagnesians present, and finally the subsoil where they all occur, with tremolite and actinolite in particular being common.

Colluvial Soils

(1) A clay-loam surface-sample has been collected overlying an accumulation of gravel in a heavy calcareous clay matrix. The gravel consists of dominantly angular fragments of dolomite, slate, and other rocks from the nearby escarpment fault-zone near Beaumont Terrace. The clay-loam and the underlying matrix have been studied and the proportions of heavy minerals proved to be similar in both cases. However, a number of minerals are present only in the surface soil, notably ferromagnesian minerals, the metamorphic suite, sphene and xenotime.

(2) A clay-loam surface sample has been taken on an outwash apron near the Boys' Reformatory, Magill, and compared with a calcareous slate typical for a considerable area, and collected about ½ mile up the nearby hill. The slate contains 9 per cent heavy minerals against less than 1 per cent in the soil. This striking difference is largely the result of the decreased amount of chlorite. The ferromagnesians and staurolite, kyanite, xenotime, garnet, and rutile are found in the soil only. Sillimanite and andalusite in this case are, however, absent from both soil and rocks.

Alluvial Soils

There is a general similarity between the assemblages of all alluvial soils studied irrespective of the major soil-group to which they belong. No differences in mineral suites or in individual minerals present have been noticed to suggest that any one of the red-brown earth, black earth, or mallee soil associations has been derived from any particular bedrock type. Neither does there appear to be any special areal distribution of mineral species. It has been noted that where black earths and red-brown earths are closely associated in the field, their heavy-mineral assemblages are quite similar, *e.g.*, in the Glynde area.

Where samples have been collected from more than one soil-horizon down to depths of 10ft. there are no appreciable changes in the minerals present or in their relative amounts. A possible exception appears to be that the proportion of ferromagnesian minerals in several cases decreases below 100ft. Also some minerals, notably chlorite and muscovite, are often scattered irregularly through profiles, being absent in some horizons and present in others—indicating the risks inherent in any random sampling.

The minerals present are:

(1) Ore minerals: Magnetite, ilmenite, hematite, and leucoxene are always present and form a major proportion of the total.

(2) Ferromagnesian minerals: The amphiboles (hornblende, actinolite, and tremolite) are present in all the soils although one or more of them is occasionally absent from the alluvium below 100ft. Generally they are present to 5 to 20 per cent of the total heavy minerals. Members of the epidote suite (epidote, zoisite and clinozoisite) are present in most samples.

(3) Staurolite and sillimanite are practically always present with sillimanite often in preponderance. They usually constitute from 1 to 5 per cent of the whole and the proportions tend to remain constant throughout the profile. Andalusite and kyanite are at times absent, but within a profile they are generally found in at least one horizon though rarer than sillimanite and staurolite.

(4) Tourmaline and zircon are ubiquitous and evenly distributed through the profile usually forming 5 to 30 per cent of the total heavy mineral.

(5) Garnet is also distributed evenly throughout most of the profile, but from 1 to 10 per cent.

(6) Chlorite sometimes occurs in small amounts, but tends to be more common in the red-brown earths and in the upper horizons. It is frequently absent in the black earths and only in one case was it found in a topsoil.

(7) Muscovite commonly occurs in small amounts without an obvious pattern of distribution.

(8) Hydromica occasionally occurs, and again without special distribution. Probably most of this mineral would be in the clay fraction.

(9) Of the titanium minerals, rutile is ubiquitous except that it is absent in a sample of residual black earth developed over non-rutile bearing limestones at Brighton. It often exceeds 10 per cent of the heavy fraction. Anatase and brookite are extremely rare.

(10) Minor accessories such as corundum, spinel, sphene, monazite, and xenotime occur sporadically over the whole area. Monazite is commoner north and northeast of the city area and also occurs in the residual black earth near Brighton. Sphene shows a preference for red-brown earths and possibly a tendency to occur more often in shallower horizons. Spinel and xenotime have a very limited and sporadic distribution, and traces of corundum are confined to the north and northeast of the city.

Distribution of Heavy Minerals

Though the investigations undertaken are in the nature of broad reconnaissance only, a few generalities on distribution of heavy minerals seem apparent.

(1) The tie-up of mineral assemblages in sediments of the plains region with source rocks of the range is generally not possible.

(2) No reliable marker minerals or suites have been found in plains soils which would differentiate sedimentary parentage from older or younger Adelaide System rocks or from the early Tertiary sediments.

(3) Iron-ore minerals are ubiquitous in the area and without further subdivision and study are of little diagnostic value.

(4) Tourmaline and zircon are also ubiquitous in smaller concentrations. They constitute a smaller percentage of the total "heavies" in the rocks than in the soils, indicating a concentration in the latter environment probably due to their relative stability.

(5) Rutile is ubiquitous in soils and is generally plentiful. It is common in early Tertiary sediments, and small amounts occur in the creek sands. Because it may be deuteric in origin it is not very useful in the present investigation. The same applies to anatase and brookite.

(6) Chlorite occurs sporadically in small amounts in the soils. It is rare in early Tertiary rocks, so is apparently derived from the Adelaide System rocks in which it is plentiful, particularly north of Second Creek and also in Tapley Hill Slates. The creeks carry large amounts of chlorite which evidently breaks down extensively in soils. There does not even appear to be any concentration of chlorite in soils close to rocks with a high content of the mineral.

(7) Muscovite is scarce in the early Tertiary sediments, but otherwise occurs plentifully in some soils and in the Adelaide System rocks. It is more concentrated in rocks and creek sands north of Second Creek, but there is no special distribution within the soils.

(8) Ferromagnesian minerals: The hornblende-tremolite-actinolite (original mineral) group are usually present in greater amount than the epidote, zoisite, and clinozoisite (secondary) group, and tremolite and actinolite are usually in approximately even proportions and slightly in excess of hornblende. In the soils, ferromagnesian minerals are practically ubiquitous, the secondary minerals being in smaller amount often with one or more absent. The creeks also carry the "original" ferromagnesians, the River Torrens in particular containing relatively high amounts. On the other hand Adelaide System and the early Tertiary sediments are low in ferromagnesians, and evidently they are commonest in re-sorted or partially decomposed rocks. Except for traces in the Athelstone early Tertiary Sandstones and in the Slape Gully Quartzite the minerals appear to be absent altogether in rocks between the River Torrens and Glen Osmond. In several

residual soils the percentages of ferromagnesian minerals are much higher in the soils than in the underlying rocks. Here is thus a problem as to how such a concentration came about in the soil. The hornblende and epidote suites in contrast with chlorite are much less plentiful in the rocks and creek than in the soils.

(9) Metamorphic minerals, namely, andalusite, sillimanite, kyanite, and staurolite: The distribution of metamorphic minerals, upon the restricted evidence, appears erratic and rather more occur in the soils than would be expected in view of their low concentration in rocks of the escarpment region. Their very low concentration in creeks sands, and particularly in those draining from the Houghton region of the Archaeozoic metamorphic complex, is even more puzzling. Staurolite and sillimanite are practically ubiquitous in the soils, whilst kyanite and andalusite are usually present in at least one horizon of a profile. The creeks supplying the alluvium mostly have small quantities of staurolite and/or sillimanite, but andalusite is absent north of First Creek, and kyanite has been found only in the Sturt River sands. Even the River Torrens—draining a large area of the Archaeozoic complex—contains only a small amount of sillimanite and none of the others. The Adelaide System locally has little of these minerals at all—kyanite being completely missing. Staurolite and sillimanite occur only sparsely between Glen Osmond and the South Road, and sillimanite is also in a slate at Hope Valley. Andalusite is present in four widely separated rocks. Even an apparently residual skeletal black earth near Brighton contains all these metamorphic minerals, when they are absent from two parent-rocks. A possible source of the minerals is the early Tertiary sedimentary rocks, which usually contain staurolite, sillimanite, and kyanite, and sometimes andalusite. However, it is doubtful whether the amount of early Tertiary material which has gone to form the upper alluvium is large enough to account for the comparatively high proportion of these minerals in the soils. They might also be expected to be concentrated in the northern and northeastern suburbs where the early Tertiary is most prominent in outcrop. Andalusite is thus the only one in the group whose origin may be satisfactorily accounted for, as it is sporadic in the Adelaide System, early Tertiary, and soils.

(10) Hydromica is more prominent in the rocks, but in any case it would be expected mainly in the clay fraction of the soils.

(11) Garnet is not very common in the rocks, there being little in the Adelaide System or in creeks between the River Torrens and Third Creek. North of the Torrens it is only found in the early Tertiary rocks. On the other hand, it is evenly distributed throughout most soils, regardless of locality, and often rises to over 5 per cent of the total heavies. It is a resistant mineral which would be concentrated during weathering, but even so it is not certain whether this fact alone explains its relative abundance in the soils especially in the eastern suburbs.

(12) Minor accessories, namely, monazite, sphene, spinel, corundum, and xenotime. The occurrences of these minerals in the rocks so far examined are inadequate to account for their distributions in the soils. Small amounts are found in the creeks draining the range, notably First Creek, but the distributions in the soils do not relate themselves to the creek courses in any obvious way. Monazite, for example, is absent from all the rocks and creek sands with the exception of the Brighton Limestone, yet it appears in a number of soils,

particularly in the northern and northeastern suburbs. Corundum is only found in the early Tertiary sandstone from Yatala Vale, yet it occurs in First Creek and Second Creek sands, while the soils in which it occurs are mainly north and northeast of the city area. Spinel is absent from all rocks and has been detected only in the sands of Glen Osmond Creek. Nevertheless, traces of it occur sporadically in the alluvium of the plains. Sphene likewise is not found in the rocks, but appears in the sands from First Creek and the River Torrens. It is also present in several soils. The only rocks with xenotime are early Tertiary in age and occur north of the River Torrens. It is found in First, Second, and Third Creeks though, and frequently occurs in small amounts in soils.

Observations

Only a very few samples have been examined, so deductions made from the results must be treated with caution. Nevertheless, certain points appear to stand out. The rocks of the hills behind Adelaide, from which the greater part of the materials constituting the alluvial deposits of the plains appear to have been derived, seem to contain a restricted suite of heavy minerals. The number of mineral species found within the soils is generally greater than in the rocks, and the origins of some of the soil minerals do not appear yet to have been satisfactorily explained. This applies particularly to the ferromagnesian minerals of the horneblende and epidote groups and some of the minor accessory minerals. The metamorphic minerals, especially kyanite, staurolite, and sillimanite, are also of doubtful origin, since although they occur in general throughout the early Tertiary sediments, they are very widespread in the soils, even in areas where accession of weathered early Tertiary material must have been quite small. Several other minerals appear to be more concentrated and widespread in the soils than would be expected; garnet is a notable example.

The study of heavy minerals has not provided any suggestion that different soil-types may be derived from different parent-rocks since for the most part their distribution appears remarkably even throughout the area. The work does suggest however, that certain minerals are found in the soils which have not been derived either from underlying rocks (in the case of residual soils) or from the parent rocks eroded by the streams dissecting the nearby hills (in the case of alluvial and colluvial soils). If these minerals are truly detrital, the only other obvious source seems to be *via* aeolian agencies (as loess), although since prevailing winds are and have been predominantly from the west and southwest, the minerals could not have come directly from the highlands but could only have been derived from sub-coastal deposits, such as the sand dune systems. Such sands could have been carried north by marine activity from the Hallett Cove (Permian) glacial area.

To test whether the accession of these minerals has occurred throughout Pleistocene to Recent time, several additional samples have been studied from material obtained from bores put down recently in the Northfield, Pooraka, and Parafield areas in search for clays suitable for brickmaking. Samples have been selected from depths ranging from 18ft. to 148ft. Results show that the metamorphic minerals (sillimanite, etc.) still occur at these depths and that the minor accessories still appear sporadically. Garnet maintains similar concentrations to those in the near-surface samples. The proportions of ferromagnesian minerals tend to be much lower however. This may be due to the tendency for these species to weather fairly easily in deep sub-soil environment.

On the whole it is probably reasonable to assume that whatever process has been introducing the minerals in question into the soils, has been operating throughout Pleistocene to Recent times.

An unpublished investigation by Mrs. I. Chebotarev and R. C. Sprigg into the heavy minerals of some of the beach and dune sands between Christies Beach and Port Adelaide reveals some interesting data, which may support a theory for a proposed loessial origin of the controversial minerals. The metamorphic minerals, the ferromagnesians, and garnet are all prominent in samples collected from the Old Red Sand dunes of the Seaton Park area. For instance, in different samples sillimanite has been found to constitute up to 19·2 per cent of the total heavies, garnet to be as high as 13 per cent, and hornblende rises to 10 per cent. It is thus conceivable that these minerals have been transported by wind action from the dunes and redeposited over the plains area or even on sedentary soils developed on bedrock in the hills.

HEAVY-MINERAL ANALYSES

Legend—F = Flood = 75% total heavies A = Abundant = 30-50% C = Common = 10-30% O = Occasional = 5-10% r = Rare = 1-5% V = Very Rare = 0·1-1% X = Trace Locations of samples are indicated on fig 6.

No.	Locality	Description	Depth	Heavy Minerals	Zircon	Rutile	Tourmaline	Spinel	Sphene	Brookite	Monazite	Xenotime	Garnet	Staurolite	Kyanite	Sillimanite	Andalusite	Hornblende	Actinolite	Tremolite	Epidote	Zoisite	Clinozoisite	Muscovite	Hydromica	Chlorite	Anatase	Ore Minerals	Corundum	Dolomite	Barite	Others
			in.	per cent																												
	Rocks	*Adelaide System*																														
10	Dry Creek	Dolomite		0·07	O	r	O										r	V	r		V	V		O		A		F				Topaz—r
16	Hope Valley	Phyllite		0·08	r	V	O						V					V	r	r				r		C						
18B	Hope Valley	Green shale		0·03	r	r	V						X			V		V		V			X		V			F				Azurite—r
20	Torrens Gorge	Dolomite		5·00	r		r																	O	r	F		C				
28	Fifth Creek	Quartzite		0·24	r		r										r							r		A		F				
34	Rocky Hill	Calcareous slate		9·00	r		V																	r	O	F		C				
37	Third Creek	Slate		0·20	r		r																	O	O	F		C				
53	Slape Gully	Quartzite		0·50	r	r	r																	r	O	F		A				
54B	Beaumont Terrace	Calcareous slate			r	V	V						O											V		X		A				Apatite and calcareous-argillaceous material—X
59A	The Elbow	Beaumont dolomite		1·00			X							V					V					r		r		A		X		
59B	The Elbow	Slate		0·4	r	X	V						X	X			X			X				V		r		F				
65	Windy Point	Slate		0·2	C		C						V	X		V								V				F				
68	South Road	Decomposed calcareous slate		0·3	C	O	O						r	r		r	r	r	O	O	r	r		r				F				
70	Shepherds Hill Road	Tillite		0·3	O	V	r									V			V					V		V	V	F				
75B	Brighton	Calcareous slate		1·4									X					X														
75C	Brighton	Limestone		0·25																								F				Calcareous-argillaceous material—F
77	Tapley Hill	Slate		1·9	r	V											V		V					r		C		A				
		Early Tertiary																														
3	North Yatala Vale	Re-sorted yellow sands		1·5	C	C	C		X				r	r	r	O	r	V	V	V	V		V	r		V	V	A				
4	Yatala Vale	White sandstone		1·1	C	C	C	X				V		O	r	O	r										X	F	V			
12	Gun Emplacement	Red and white sandstone		1·7	C	C	O					V	r	r	r	r												F				Topaz (?)—V
25C	Athelstone	Red and white sandstone		0·09	r	V	r						V					V							O?			A			C?	Azurite—V
44	Penfold Reservoir	Sandstone and conglomerate			r		r															V			V			F			A	
52	Summertown Road	Sandstone		0·5	O	O	O							r	V	r	V	r						O	r	O		F				
	Creek Alluvium																															
19A	Torrens River Spillway	Sands	0-60	1·7	r	r	O		r				V					C	C	C	r	r	r	C	r	O		C		r		Barkevikite—r
19B	Torrens River Spillway	Black silts	60-180	0·6	r	r	O		r							V		C	C	C	r	r		O	r	O		C				Biotite—r Azurite—r
29	Fifth Creek	Sands		0·9	O	r	O					X				r		r	r	O	r	r		C	C	O		A				
37	Fourth Creek	Sands		0·6	O	r	O							V		r		r	r	O	r	V	r	C	C	O		A		V		
40	Third Creek	Sands		0·6	O	O	O					r	r	r		r		r	O	O	r	r	r	O	r	r		A				
44	Second Creek	Sands and conglomerate outwash		0·14	C	O	C					r	r	r				r	r	r				r	O			A	V			Azurite—r
55	First Creek	Red silts		0·2	O		O		V			V	r				V	r	r	r	V	V		r	r	r		F	V			
60	Glen Osmond Creek	Sands		0·6	O	r	O	V					r	V		r		r	r	r		V		r		O		A			r	Pyrite—C
62	Brownhill Creek	Sands		1·2	O	V	r						V	V		V	V	V	V	V				r	r	A		A				
69	Sturt Creek	Sands		0·9	O	r	O					V	r	V	V	r		V	r	r	V		V	r	r	r		A				17·2% shell fragments
	Soils	*Black Earths, Etc.*																														
11A	Highbury	Black clay-loam	0-6	0·09	C	C	C		X				O			O	O	O	r	r	r	r	r	X	O	V		A	X			
11B	Highbury	Black clay	36-42	0·04	C	C	A		V			V	r	r	V	O	r	r	O	O	r	r	r	V				A	V			Azurite—X
14A	Northfield	Grey-brown clay-loam	0-6	0·02	C	C	C	V	r			V	r	r	r	O		O	C	C	r	O		r				A	r			
14B	Northfield	Grey clay	18-24	0·09	C	C	C	r	r	X	V	V	r	O	r	O	r	O	O	C	r	O			r		V	A	r			Chloritoid—V Basaltine—V
14C	Northfield	Drab yellow-grey clay, with light lime	39-45	0·06	O	C	C				X		r	r	r	O	r	O	O	O	r	r	r	r	r			A				

HEAVY-MINERAL ANALYSES—*continued*

No.	Locality	Description	Depth	Heavy Minerals	Zircon	Rutile	Tourmaline	Spinel	Sphene	Brookite	Monazite	Xenotime	Garnet	Staurolite	Kyanite	Sillimanite	Andalusite	Hornblende	Actinolite	Tremolite	Epidote	Zoisite	Clinozoisite	Muscovite	Hydromica	Chlorite	Anatase	Ore Minerals	Corundum	Dolomite	Barite	Others
			in.	per cent																												
		SOILS—*continued*																														
		Black Earths, etc.—continued																														
14D	Northfield	Yellow-grey clay with red-brown and light-grey mottling and light lime	78-84	0·06	C	C	A					V	r	O	r	O	r	r	C	C	r	r	r	r				A				Azurite—r Apatite—V
15A	Strathmont	Dark brown-grey clay, with sand	0-3	0·9	C	C	C					V	O	r		O	r	O	C	O	O	r	r	r				A				
15B	Strathmont	Yellow-grey clay, with trace lime	72-78	0·08	C	A	C				r	r	r	r	r	O		C	C	C	O	r	r					A				
27A	Newton Gardens .	Black clay, with trace sand, lime, and gravel	12-24	0·05	C	C	C						r	r	X	O		r	r	r	r	r						A				Azurite—X
27B	Newton Gardens .	Drab yellow clay	132-144	0·04	C	C	A						r	r		O	r	V								V		A	V			
33A	Stradbroke	Dark-grey clay-loam.........	0-6½	0·2	C	O	C		V		V		r	r		r	V	r	r	r	r	r	r	r	O			A				Rock—r
33E	Stradbroke	Yellowish-grey clay	35-42	0·7	C	r	C	V	V		V	V	r	r	V	r	V	r	r	r	r	r	r	r	V			A				
32A	Glynde	Black friable clay	0-6	0·12	C	O	C		r		V	r	O	r		O	r	O	C	C	O	r	V					A				
32B	Glynde	Dark grey-brown clay, with light lime	45-51	0·08	C	C	O	V	X	V		X	r	r	V	O		r	O	O	r	r		r	r	r		A	V			
32C	Glynde	Yellow-brown clay, with sand and lime rubble	105-110	0·05	C	C	A	V				V	r	r	r	O	r	O	O	O	O	r	r			r		A				
32D	Glynde	Mottled yellow-brown and light-grey clay, with sand	135-139	0·08	O	O	O						r	r	r	r	V		r		V			r				A				Calcareous-argillaceous material—O
43A	Wattle Park	Dark brown-grey clay-loam ..	0-6		C	C	C	V	V	V	V		r	r		r		O	C	C	r	O		r	O			F				Basaltine—V
43B	Wattle Park	Brown clay, with quartzite gravel	72-78		O	C	C		r				r	r		O	r	C	O	C	r	O	O	r			X	A				Chloritoid—r
45A	South Parklands .	Black heavy clay	0-3	0·3	O	O	C		r	V		V	r	r	r	O	r	O	O	O	r	r	r		r			C				Topaz—V
45F	South Parklands .	Yellowish-brown clay	29-37	0·6	r	r	C		V	V			r	r	V	r	r	r	C	C	r	V	r	r	O	V		C				
46A	Linden	Black clay	0-6	0·8	O	O	C		X				r	r		O	r	O	C	C	r	r	r					F				
46B	Linden	Yellowish-brown clay, with light lime	49-55	0·6	O	O	C		V			r	O	r	r	O	r	O	C	C	r	r	r	r			X	F				
46C	Linden	Yellow-brown clay	112-118	0·9	C	C	O					V	r	V		r		r	O	O	r	V				V		F				
49A	Richmond.......	Black clay	0-4	0·09	r	r	C	V				X	O	O	r	O	r	O	C	C	r	O	r	r	O			A				
49B	Richmond.......	Yellowish-brown clay, with trace lime	66-72	0·07	C	r	C		X				r	·r		r		r	C	C	r	r		r			X	A				
51	Linden Park Gardens	Brown clay, with slight lime..	60-66	0·05	C	C	O					r	O	r		O	r	r	O	O	r	r		O	r	O		A				Azurite—T Apatite—V
63A	Daws Road	Black clay	6-12	0·3	C	C	C						r	r	r	r	r	r	O	O	r	r		r				F				
63B	Daws Road	Yellowish-red-brown clay, with trace lime	60-66	0·2	C	C	r	X					r	r	V	r	r	r	O	O		r		r		V		F				
75A	Brighton	Black skeletal clay	0-6	0·25			O				V	r	O	r	V	O	V	r	C	C	V	r		r		r		A				
22	Northfield	Yellow-grey clay, with dark-red mottling	216-218	0·10	C	C	C	V					r	V		r	r	V	r	r	V			r	V	V		C	V	V		Azurite—V
21	Northfield	Yellow-grey clay		0·01	C	C	C						r	O	r	r	r							r		r		A				Biotite—r
		Red-Brown Earths, Etc.																														
2	Parafield	Mottled clay...............	140-148	0·2	r	O	O	V			V	V	O	O	V	C	r	V	r		r			r	O	r		C				Azurite—V
6	Pooraka	Brown clay................	40-43	0·3	C	C	C		V			V	r	A	V	r	r	V	r	r	r		r	r	r	r		C				
13A	Enfield Estate ..	Red-brown friable clay	9-15		C	C	O		V		r	r	r	r	r	O	r	O	C	C	O	O		r		r		A				
13B	Enfield Estate ..	Brown clay, with very heavy lime	51-57	0·2	C	C	C		V				r	r	r	O		O	C	C	r	r	V			r		A				Calcareous-argillaceous material—C
13C	Enfield Estate ..	Reddish-brown clay, with trace lime	78-84	0·2	C	C	C	V	r		r		r	O		O	r	O	C	C	r	O	r	O	r	r		A				
13D	Enfield Estate ..	Variegated clay	114-120	0·14	O	C	C	X			X			r		O		r	r	O	V	V		r	r			F				
18A	Hope Valley	Brown sandy clay-loam	9-12	0·03	C	C	C		V			X	O			r		O	O	C	V	V	V	r	O			A	V			
24A	Fifth Creek Fan .	Dark-brown loamy sand, with trace quartzite gravel	0-6	0·9	C	C	C		V	X		r	r	r	V	O	r	r	C	C	O	r		r	r	r		A				
24B	Fifth Creek Fan .	Red-brown clay	24-30	0·7	C	C	C	V			V		r	r	V	O	r	O	C	C	O	O	r		r			A				
24C	Fifth Creek Fan .	Mottled yellowish-brown and red-brown clay, with slight lime and gravel	63-69	0·2							X																	A				

HEAVY-MINERAL ANALYSES—*continued*

No.	Locality	Description	Depth	Heavy Minerals	Zircon	Rutile	Tourmaline	Spinel	Sphene	Brookite	Monazite	Xenotime	Garnet	Staurolite	Kyanite	Sillimanite	Andalusite	Hornblende	Actinolite	Tremolite	Epidote	Zoisite	Clinozoisite	Muscovite	Hydromica	Chlorite	Anatase	Ore Minerals	Corundum	Dolomite	Barite	Others
			in.	per cent																												
		Red-Brown Earths—continued																														
25A	Athelstone	Dark-brown clay-loam, with fine sand	0-3		C	C	C					r	r	r	r	O		r	C	C	O	r	r			r		F				
25B	Athelstone	Very light-grey clay, with trace sand and lime	60-66		C	C	C							r	r	r		V	r			V		r				F				
31A	Glynde	Dark-brown clay	15-18	0·9	r	O	C					V	r	r	V	O	r	r	O	O	r	r	V	r	V			F				
31B	Glynde	Yellow-brown friable clay ...	60-64		O	r	O	X				r	r	r		r		r	O	O		r		O				F	V			
36A	North Parklands	Dark-brown clay, with slight lime	24-33	0·1	C	C	O		V		r	r	r	r	r	O	r	O	C	C	O	O		r		r		A				
36B	North Parklands	Mottled yellow-brown and red-brown clay, with slight lime	77-81		C	C	O		V		V	r	r	r	V	r		r	C	C	O	r						A	V			
42	Leabrook	Red-brown clay, with yellow-brown mottling	15-21		C	C	C		V			r	r	r		r	r	r	C	C	O	r		r	O			F				
45I	South Parklands .	Grey-brown silty loam	0-3	0·5	O	O	C	V			V	V	V	r	V	O	r	r	O	O	r	r	r		O			A				
45L	South Parklands .	Mottled dark-brown and red-brown clay	24-32	0·7	r	r	C				r		r	V	r	r	V	r	O	O	r	r	r	r	O	V		C				Hypersthene—O
50A	Linden Park Gardens	Dark-brown loam, with slight slate and quartzite gravel	0-6	0·4	A	C	C		V		V	V	O	r		r	r	O	C	C	r	r	r	O		r		F				
50B	Linden Park Gardens	Light-brown clay, with slight gravel	18-24	0·16	C	C	O						r	r	V	O	r	O	O	C	r	r		O		r		F				
50C	Linden Park Gardens	Light-brown clay, with slight gravel	69-75	0·05	C	C	C		r				O	O		O		O	C	C	O	r	r			r		A				
57	Rosefield	Red-brown clay, with sand ..	15-21		C	C	C		V	V			r	r	r	r	r	O	O	O	r	r				V		F				
66A	Oaklands	Red-brown clay	18-24	0·5	C	C	O					V	O	r	V	r		r	O	O	r	r		r				A				
66B	Oaklands	Variegated yellow and brown clay	72-78	0·3	C	r	r						O	r	r	r	r	r	O	O	r	r						A	r			
71A	Seaview Downs .	Dark grey-brown clay to clay-loam	0-4	0·2	C	r	O	V					O	r	r	O	r	O	C	C	r	r				r		A				
71B	Seaview Downs .	Light-brown clay, with medium lime	36-45		C	C	C		r			r	O	O	V	r	r	O	C	C	r	r	r	r	r	r		A				
		Profiles																														
33A	Stradbroke—East end of trench (Slightly degraded)	Dark-grey clay-loam........	0-6½	0·2	C	O	C		V		V		r	r		r	V	r	r	r	r	r	r	r	O			A				Rock fragments—r
33B		Dark-grey clay	7½-11	0·5	O	O	C		r		V	V	V	r		r	r	r	O	r	r	V	r		r	V	V	A				Rock fragments—r
33C		Mottled dark-grey-brown and greyish-brown clay	11-18	0·6	O	O	C		V		V		V	V	V	r	r	O	O	O	r	V	V	r	r		V	A				Diopside—r
33D	Middle of trench (Solonized soil)	Yellow-grey clay	24-29	0·2	C		C	V	r	V	V	V	r	V		r	V	O	r	O	r	V	V	r	r	r		A	r			
33E		Yellowish-grey clay	35-42	0·7	C		C	V	V		V	V	r	r	V	r	V	r	r	r	r	r	r	r	V			A				
33F		Yellow-grey clay	46-58	0·7	C	O	O		V	V		V	r	V	V	r	V	r	r	r	r	r	V	r	r			A				
33G		Grey loam	0-6	0·3	C	C	C		V	V		V	V	V		r	r	r	r	O	r	r	V	r	r			A				
33H		Very light-grey fine sandy loam	7-12	0·3	C	C	C						V	V		r	V	r	r	r	V	V	r	r	r	V	V	A				
33I		Yellowish grey-brown clay ..	15-24	0·3	C	C	C		V	V	V		r	V	V	r	V	r	r	O	r	r		r	r	r		A				
33J		Mottled yellow-grey and brown clay	26-36	0·2	C	O	C				V		r	V		r	r	O	O	O	r	r	r	r	r			C				
33K		Yellow-grey clay, with reddish inclusions	45-53	0·2	C	O	C		V			r	r	V		r	r	r	r	r	r	V	r	r	r	r		A				
45A	South Parklands—West end of trench (Black earth)	Black heavy clay	0-3	0·3	O	O	C		r	V		V	r	r	r	O	r	O	O	O	r	r	r		r			C				Topaz—V
45B		Black heavy clay	3-6	0·5	O	O	O	V	V				r	r	V	O	V	r	O	O	r	r	V	r	r		V	A				
45C		Brown heavy clay	9-12	0·5	r	O	C		V			V	r	r		O	V	r	r	C	O	r	r		r		V	C				
45D		Brown clay...............	13-17	0·7	O	O	C		V				V	V	V	r	V	r	r	r	V	V		r	r			F				
45E		Light-brown clay	20-27	0·6	r	O	C						r	r	V	O		r	C	O	r	r	r		r	V	V	C				
45F		Yellowish-brown clay.......	29-37	0·6	r	r	C		V	V			r	r	V	r	r	r	C	C	r	V	r	r	O	V		C				
45G		Drab yellow-brown clay.....	41-55	0·8	r	r	O		V				r	r	r	O	V	r	C	C	r	r	r	r	O			C				
45H		Yellow-brown clay	100-103	0·7	C	O	r						V	V	V	r		r	r	O	r	r	r	r	O			A				
45I	East end of trench (Red-brown earth)	Grey-brown silty loam	0-3	0·5	O	O	C	V			V	V	V	r	V	O	r	r	O	O	r	r	r		r			A				
45J		Light-brown fine sandy loam	5-14	0·5	r	r	C	V			V	V	V	r	r	O	r	r	C	C	r	r	V	r	O			C				
45K		Dark-brown heavy clay	16-24	0·8	r	r	O	r			V		r	r		O		r	O	C	r	r	r	r	O	O		C				

HEAVY-MINERAL ANALYSES—*continued*

No.	Locality	Description	Depth	Heavy Minerals	Zircon	Rutile	Tourmaline	Spinel	Sphene	Brookite	Monazite	Xenotime	Garnet	Staurolite	Kyanite	Sillimanite	Andalusite	Hornblende	Actinolite	Tremolite	Epidote	Zoisite	Clinozoisite	Muscovite	Hydromica	Chlorite	Anatase	Ore Minerals	Corundum	Dolomite	Barite	Others
			in.	per cent																												
												Profiles—continued																				
45L	South Parklands *continued*—	Mottled dark-brown and red-brown heavy clay	24-32	0·7	r	r	C				r		r	V	r	r	V	r	O	O	r	r	r	r	O	V		C				Hypersthene—O
45M	East end of trench	Mottled red-brown and dark-brown heavy clay	32-38	0·5	O	O	O		V		V	V	r	r		O	V	r	O	O	r	r	r	r	r			A				Hypersthene—r; Topaz—V
45N	(Red-brown	Dark red-brown heavy clay .	44-49	0·7	r	O	C				r		r	r	r	O	r	r	O	O	r	r	r		O			C				Diopside—O
45O	earth)	Yellow-brown clay	50-57	0·5	O	r	O		V		V		r	r	O	O	r	r	O	C	r	r	r	r	V	V		C				
												Residual Soils																				
18A	Hope Valley	Brown sandy clay-loam	9-12	0·03	C	C	C		V			X	O			r		O	O	C	V	V	V	r	O		A	V				
18B	Hope Valley	Green shale	21+	0·03	r	r	r						V			r		r		r			V		r		F					Azurite—r
25A	Athelstone	Dark-brown clay-loam, with fine sand	0-3	0·9	C	C	C					r	r	r	r	O		r	C	C	O	r	r			r	F					
25B	Athelstone	Very light-grey clay, with sand and trace lime	60-66	0·3	C	C	C							r	r	r		V	r			V		r			A			O		
25C	Athelstone	Mottled early tertiary sandstone		0·09	r	V	r						V					V							O		F			C		Azurite—r
75A	Brighton	Black skeletal clay	0-6	0·25			O				V	r	O	r	V	O	V	V	C	C	V	r		r		r	A					
75B	Brighton	Limestone..................		1·4	V		V						V													V	F					
75C	Brighton	Calcareous shale		0·06	V		V				V		X							V				V			F					
												Colluvial Soils																				
54A	Magill Reformatory	Dark-brown clay-loam, with light slate and quartzite gravel	0-6	0·2	A	C	C					V	r	r	r			O	C	C	r	r	r	r	O	r	A					
54B	Magill Reformatory	Green calcareous shales		9·0	r		V																	r	O	F	C					
30	Beaumont Terrace	Dark-brown clay-loam	6-12	0·8	O	O	O		V			V	r	r	V	O	r	r	O	O	r	V		r		V	F					
34	Beaumont Terrace	Dolomite and calcareous shale	18+	0·4	r	V	V						O											V		X	A					Apatite—X; Calcareous-argillaceous material—C

PLATE I.

Fig. 1.

Soil Type RB3, dominant soil type of the Urrbrae Association.
Location: Waite Institute, Glen Osmond, S.A.

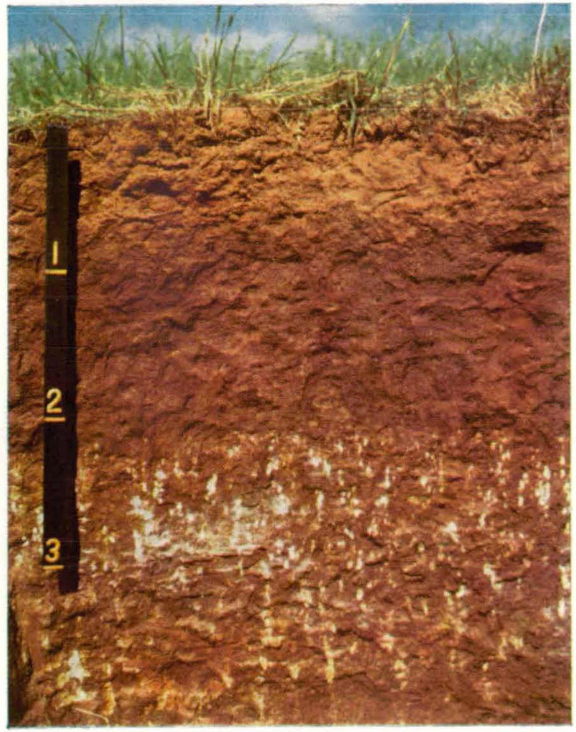


Fig. 2.

Soil Type RB5, dominant soil type of the Edwardstown Association.
Location: Ascot Park, S.A.

PLATE II.

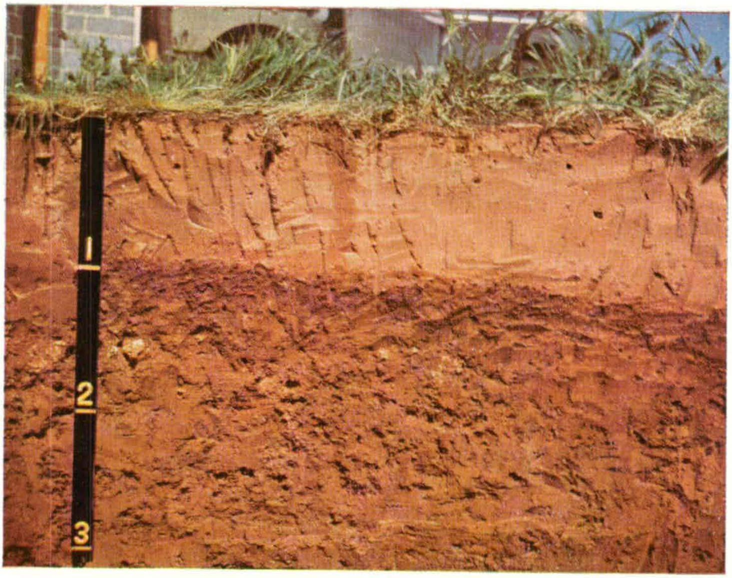


Fig. 1.

Soil Type RB6, a major soil type of the Hindmarsh Association.
Location: Woodville Gardens, S.A.

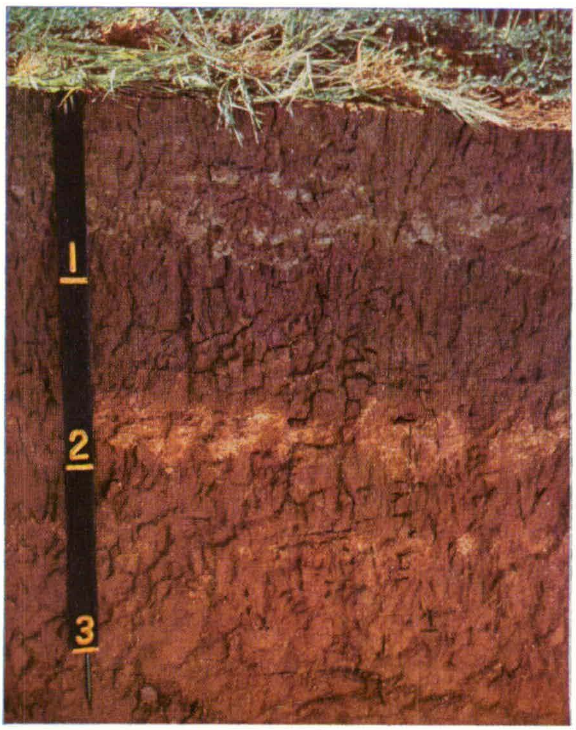


Fig. 2.

Soil Type RB9, a major soil type of the Brayville Association.
Location: Clovelly Park, S.A.

PLATE III.

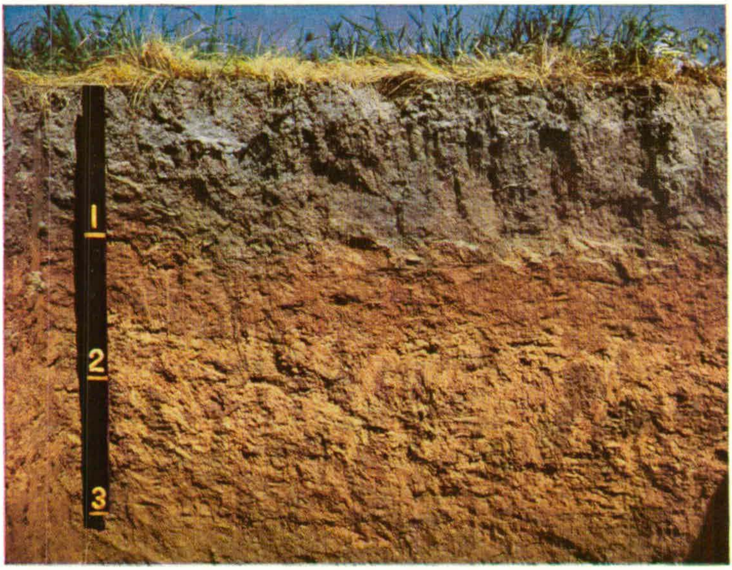


Fig. 1.

Soil Type RB9*z*, a minor soil type of the Brayville Association.
Location: Brayville West, S.A.

Fig. 2.

Soil Type DS1, a major soil type of the Osborne Association.
Location: Graymore, S.A.

PLATE IV.

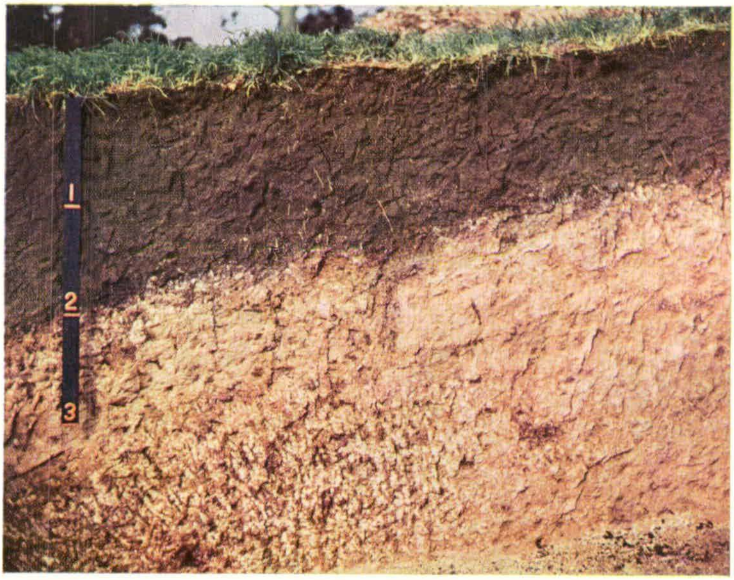


Fig. 1.

Soil Type BE1*a*, a major soil type of the Claremont Association.
Location: Waite Institute, Glen Osmond, S.A.

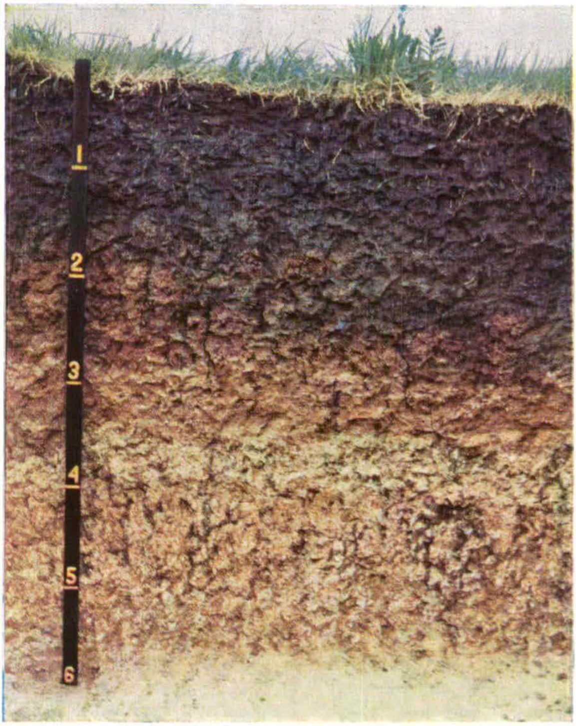


Fig. 2.

Soil Type BE1*b*, a major soil type of the Claremont Association.
Location: Waite Institute, Glen Osmond, S.A.

PLATE V.

Fig. 1.

Soil Type RZ1, a major soil type of the Beaumont Association.
Location: Beaumont, S.A.

Fig. 2.

Soil Type TR1, a minor soil type of the Beaumont Association.
Location: Beaumont, S.A.

PLATE VI.

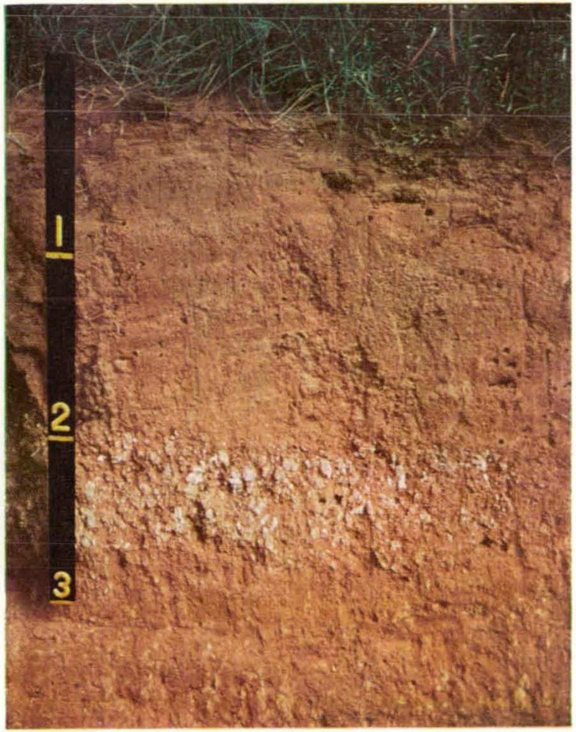


Fig. 1.

Soil Type BS2*b*, a major soil type of the Enfield Association.
Location: Enfield North, S.A.

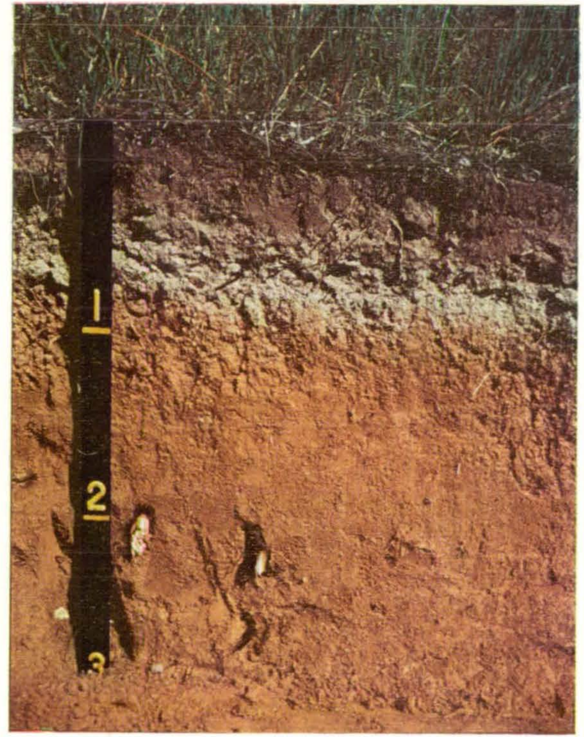


Fig. 2.

A soil type representing the typical form of the principal types of the Stonyfell Association (similar to Type YP1).
Location: Stirling, S.A.