DEPARTMENT OF MINES
GEOLOGICAL SURVEY OF SOUTH AUSTRALIA

THE SOILS AND GEOLOGY OF THE ADELAIDE AREA

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Geological Survey Office,
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12*th June,* 1974

Sir,

Bulletin 32, *which described the soils and geology of Adelaide and Suburbs, has been out of print for some ten years. It was published in* 1954 *to fill a long felt public need for guidance in house building on the less stable of Adelaide's various soil types. The Bulletin was well received, and became the basis of a soils advisory service available at moderate cost to home builders in the Metropolitan area. This service, originally conducted by officers of the Geological Survey, has now been taken over by industry, leaving Survey officers free to concentrate their efforts on major engineering projects of the Government.*

The lack of a standard reference work, together with the spread of housing activity to areas with relatively new soil types pointed to the need for a revised soils bulletin. The need was partly met by the issue of four small booklets in 1969 *and* 1970 *which, together with soil maps, dealt with problem soils in the eastern and northeastern suburbs. This was the Metropolitan Soil Map Series, based on the Adelaide and Environs* 10 *chain series of topographic maps.*

This soil map series was not continued, having served its purpose, but is now replaced by the present work, a new Bulletin on the Soils and Geology of the Adelaide area by J. K. Taylor, B. P. Thomson and R. G. Shepherd. Mr. Taylor has dealt with all sections concerned directly with soils, while Mr. Thomson has contributed the chapter on regional geology and Mr. Shepherd that on hydrological aspects of the area. The Bulletin is accompanied by a large new soil map in full colour, and includes coloured plates showing 12 *soil types.*

It is believed that the Bulletin will be welcomed by all sections of the building industry, especially those concerned with housing construction. Not least, it should be a very welcome reference work for the public in general.

Approval is sought to publish this report as a Bulletin of the Geological Survey.

B. P. Webb, Government Geologist

To the Honourable D. J. Hopgood, Minister of Development and Mines:
18*th June,* 1974.

Approved,

D. J. Hopgood, Minister of Development and Mines

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CHAPTER 1

INTRODUCTION

European settlement of South Australia commenced in 1836 with the establishment of what was to become the city of Adelaide on a slightly elevated plain about six miles inland from Gulf St. Vincent. The location was partly influenced by the presence of a low lying coastal plain, large portions of which were subject to flooding through the impeded drainage of rivers and creeks descending from the ranges to the east. At an early stage the settlement, from its place astride the River Torrens, reached out, with the essential farming development, over the plains which extend northward from Brighton on the coast in an arc along the foot of the Mount Lofty Ranges.

In the first 100 years Adelaide grew into a compact city with a population of over 300 000 spread over an area of about 300 to 350 square kilometres. Since World War II its fast growing population has carried urban building at an increasingly rapid rate over much wider territory, particularly northward on the plains and onto the hills of the Mount Lofty Ranges. The building of houses was concentrated on the better drained areas and on soils suited to low-cost foundations. Other parts, with drainage problems or difficult soils, were left to agricultural use until the recent expansion of industry in the metropolitan area created pressures which, assisted by the accompanying rise in population, demanded their use for housing. Up to about 1960, the environment and the soil pattern directly influenced the areas developed and the intensity of building.

The increase in population of metropolitan Adelaide from 313 000 in 1933 to 588 000 in 1961 and then to 728 000 in 1966,* together with the requirements of industry, resulted in three moves. First, reclamation of the poorly drained coastal area which progressively reduced the extent of market gardens as building began to close the gap with the coast; second, the conversion of farmland situated closely east of the city to housing, so making use of soils of inferior building quality; third, a remarkable spread of new suburbs, initially thinly built over, to the northeast following the plains, to the south into the Adelaide Hills, and all along the rising slopes of the foothills.

It is impossible to discuss soils without considering their geological history. This concerns the processes governing the creation of present landform and the nature and source of the surficial material from which the soils have developed. "The study of the soils in the Adelaide Plains is virtually an investigation into Quaternary sedimentation and the modification of the last alluvial increments by soil forming processes". (Aitchison, Sprigg and Cochrane, 1954). In the light of the extended boundaries of the present survey, the necessary association of geology and soils is all the more emphasized as for example, in the significance of parent material for the extensive residual soils encountered.

The soils and geology of the then metropolitan zone with particular regard to building foundations were discussed by Aitchison *et al.* (1954) in Bulletin 32 of the South Australian Department of Mines. The changes in urban development indicated above have now caused the situation to be reviewed. The earlier Bulletin was very valuable and, considering the soil evidence, remarkably good in setting out the data then available. Since then a large amount of information has accumulated,† so that the soil types may now be better defined, new ones created as necessary and the boundaries of their occurrence more precisely fixed. The area of the present study is about 460 square kilometres, much larger than the first survey, and embraces particularly some of the more recent building developments fringing the Adelaide Region.

The authors of Bulletin 32, (*op. cit.*) emphasized that it should be regarded as "an introductory discourse rather than a handbook of established information". The present bulletin carries that study some steps further through a more detailed examination of soil patterns and more precise delineation of their occurrence. The geology of the region is reasonably well known; the variety and approximate distribution of soil types likely to be encountered have been collated with considerable care and the hydrology, both surface and underground, has been examined closely. These data are incomplete from the engineering viewpoint without proper laboratory studies and the field correlation of them with the performance of building foundations.

The controlling features in the stability of foundations of small buildings are related to the nature of the soil as the uppermost layer of the land surface, but to much greater depths than are usually considered for agricultural purposes. In recent years geologists have paid more attention to the stratigraphy of surficial deposists, whether as the soil profile or as the more or less unaltered sediments beneath it. These stratigraphic layers are of great importance in affecting moisture regimes, the movement of underground water and, in some cases, the salinity of the soil materials.

Some contributions on the pedological side have presented a generalized picture of the soils from the agricultural and ecological aspect. Litchfield (1960) and Ward (1966) have given data on the classification and distribution of soils over the higher land of the Mount Lofty Ranges and foothills. All available pedological material was subsequently assembled by Wells (1966), who correlated the classifications of a number of surveyors as far as practicable. Although these studies have indicated a broad relationship of these soil types with certain engineering properties, the classifications used were based primarily on agricultural criteria and the units defined are not necessarily acceptable for engineering application.

It is presumed that there is a relation between the soil profile and its morphology and engineering response, so that certain relatively limited data on selected samples of soil types may be extended for application wherever those types are observed *in a comparable environment*. The infinite variability of soils makes an assumption necessary that, to a skilled observer at a particular site, the morphology of the soil profile may relate it to an established soil type. It may therefore be interpreted in terms of the probable response for building foundations.

The present publication is designed to assemble available information on the nature of the soils of the Adelaide region (Fig. 1), to classify them into identifiable soil types and to show their distribution broadly on a soil map. Since the proper background is geological, an account is first given of the geology, physiography, and hydrology which, with the influence of climate, have controlled the development of the soil pattern. Finally, the relation of soils to engineering response and the problems ancillary to stability of buildings are discussed‡.

* In 1966, the boundary of metropolitan Adelaide was extended to include the new areas of Elizabeth, Salisbury and Tea Tree Gully. (South Australian Year Book, 1972.)

† The records of the S. Aust. Dept. of Mines contain about 5 500 site examinations and the private engineering consultants have made many more.

‡ The available engineering data used in discussion of the soils and their classification, and in the preparation of the soil map were confined to those supplied previously in Aitchison, *et al.*, 1954.

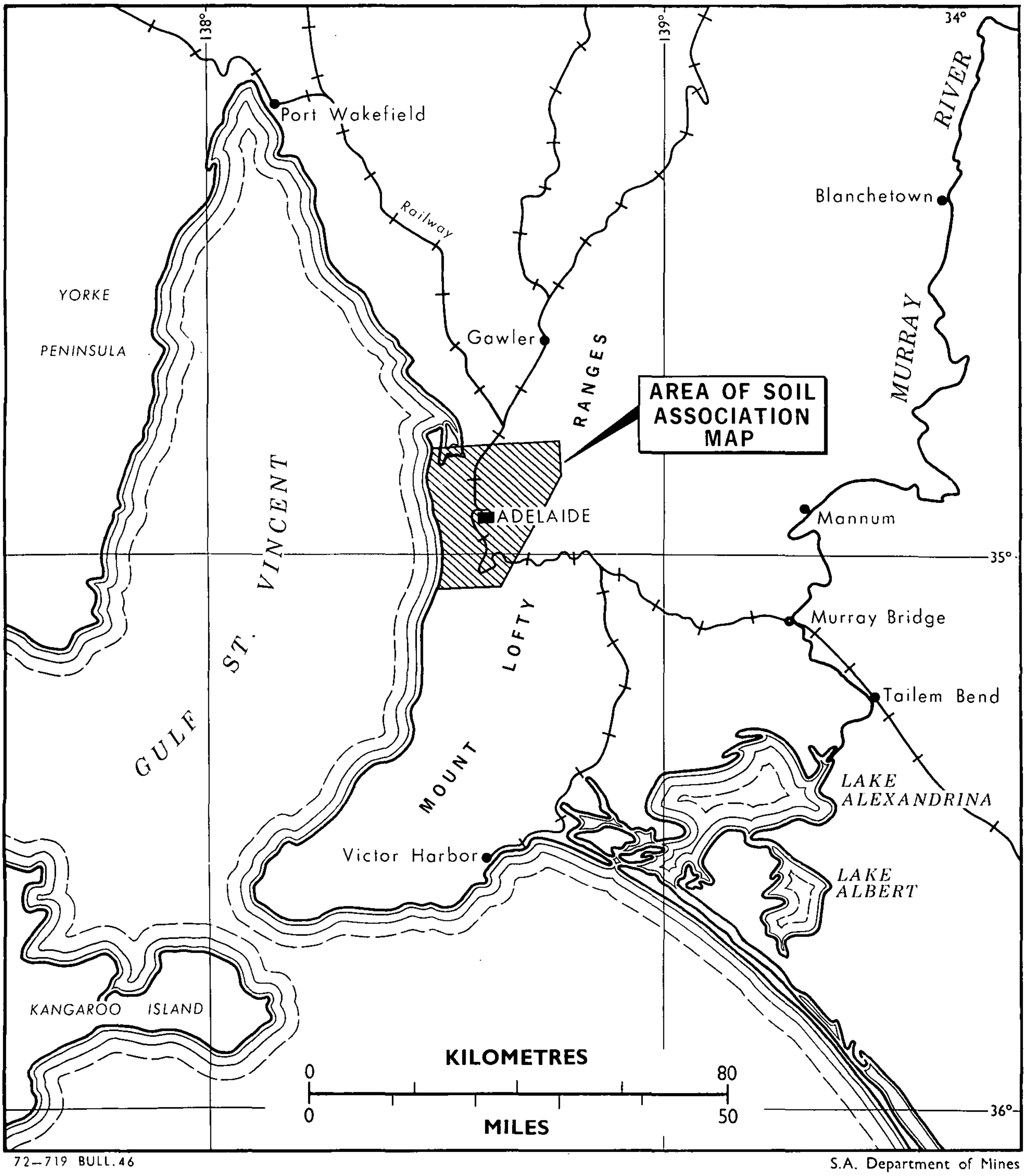

Fig. 1—Locality map showing area covered by Soil Association map of the Adelaide region.

CHAPTER 2

GEOLOGY

The geology of the Adelaide region was compiled by R. C. Sprigg on 1:63 360 scale, Geological Atlas Series, Sheets *Adelaide* and *Echunga*, and published by the Department of Mines in 1952 and 1954 respectively. Revisionary mapping of the area was made by B. P. Thomson and R. C. Horwitz and published on 1:250 000 scale, Geological Atlas Series, Sheets BARKER and ADELAIDE, by the Department of Mines in 1962 and 1969 respectively.

Studies of the Mount Lofty Ranges area were made by Sprigg (1942 and 1946). Miles (1952), presented a thoroughly documented study of the geology and hydrology of the Adelaide Plains area and Glaessner and Wade (1958) compiled a relevant chapter on the development and stratigraphy of the St. Vincent Basin. Campana (1958) similarly dealt with the Mount Lofty Ranges. Ludbrook, Firman and Thomson contributed chapters on Tertiary, Quaternary and Precambrian stratigraphy of the region in the Handbook of South Australian Geology, edited by Parkin (1969). Finally, an up-to-date account of the Cainozoic stratigraphy of the Adelaide Plains Sub-Basin was given by Lindsay (1969). Selby and Lindsay (1973) also describe the engineering geology of the Blanche Point Banded Marl formation beneath the Adelaide city area.

The boundary between the Adelaide Plains, underlain by young (Cainozoic) sediments and the Mount Lofty Ranges, formed by uplifted blocks of older (Precambrian) rocks, reflects the importance of geological structure in the setting of Adelaide and suburbs. The structures of the Mount Lofty Ranges and St. Vincent Basin region to the west are of ancient origin and have undergone movements (tectonism) beginning in the Precambrian and recurring intermittently up to the present day. The current tectonic event the "Kosciuskan Uplift" has probably been of major importance from the aspect of soil development and related sedimentation. The geological background of the region can be best understood by outlining its tectonic evolution as completely as possible.

TECTONIC EVOLUTION OF THE REGION

Development of Precambrian crystalline basement

The oldest rocks in the Mount Lofty Ranges are the cores of Precambrian crystalline basement (Barossa Complex), which have been steeply upthrust from the east in the Torrens Gorge and Crafers areas. These rock masses form anticlinal wedges which, although partly fault bounded, show undoubtedly that they are unconformably overlain by the younger Precambrian (Adelaidean) cover rocks and that the basement was folded prior to the oldest of these. At present it is uncertain whether the crystalline basement in the cores, which may be 860 million years or considerably older, is of the same age as the basement which is believed to underly the Adelaide Plains at between 3 km and 5 km depth.

Development of the Adelaide Geosyncline and subsequent Precambrian movements

The younger Precambrian (Adelaidean) cover rapidly decreases in thickness in the Mount Lofty Ranges to the south-southwest of Adelaide. The thick cover northwards, extending to the Flinders Ranges and Olary areas, marks the site of a former great basement downwarp feature known as the *Adelaide Geosyncline.*

The Delamerian Orogeny

Sedimentation in the Adelaide Geosyncline ceased in the Cambrian as a consequence of crustal movements, associated with an increase in temperature and pressure, which terminated in the early Ordovician, 470 million years ago. By then, the Cambrian and Precambrian rocks of the Mount Lofty Ranges region had been converted into a mobile fold belt and developed some of the fold and fault structures which still influence the modern topography.

The sediments of the western ranges area were converted during this event to phyllites, shales and quartzite which form the parent material for many old and modern soils. Further to the east, the metamorphism was more intense and granites were intruded. The regional metamorphism, because of its marked effect on the mineralogy and composition of the rocks, has indirectly influenced the character of the soils derived from them. The Delamerian event was also associated with widespread mineralization of the Precambrian rocks, *e.g.* quartz-carbonate, silver-lead sulphide veins in the Glen Osmond area and copper in the Montacute area.

The later Palaeozoic, Mesozoic and early Tertiary interval

The sedimentary record of this interval, apart from the Lower Permian glacial deposits seen in the Hallett Cove area and the Croydon bore

(Steel, 1962), is missing or unrecognized in the area. By Lower Permian time, about 270 million years ago, the Delamerian fold belt in this region had been elevated into a mountain range and was being eroded by glaciation with minor marine associations. During the Mesozoic Era there was further erosion of the Permian landscape into an area of lower relief which was deeply weathered. In the early Tertiary, about 50 million years ago, subsidence of basement blocks allowed the sea to advance over much of the Adelaide Plains area. Deep weathering of the exposed rocks continued further east where local lake deposits were formed.

Mid Tertiary and younger movements—the "Kosciuskan Uplift"

In the Middle Miocene about 17 million years ago, there was uplift of the basement accompanied by faulting and warping which produced slight folding in the Tertiary sediments. There was a retreat of the sea from the Plains area and some erosion of the Tertiary sediments. The sea returned to the coastal areas during the Pliocene and the land areas were deeply weathered; lateritic soil profiles were formed below the peneplained surface.

At the close of the Pliocene or early Pleistocene, about two million years ago, the "Kosciuskan Uplift" began with a renewal of upward movement on the fault blocks which led to a retreat of the sea. Old peneplain surfaces were displaced up to 180 metres in the Mount Lofty Ranges and the modern topography began to develop. The movements have continued until the present day.

The major land forms are controlled by two fault zones, one the Para Fault which extends from Gawler to the western side of the Adelaide parklands and continues below shallow cover to Glenelg, and the other, the Eden-Burnside Fault Zone, which forms the escarpment or fault-line scarp, east of the city and extends from the Golden Grove area to Marino. The two fault zones are part of a more extensive belt, of north-northeasterly trending faults arranged *en echelon* on the western side of the ranges; the surface traces of the faults are generally crescentic in plan and concave to the northwest. In detail they are complex; Lindsay (1969) for example has indicated that the Eden-Burnside Fault Zone comprises at least three faults along the range escarpment facing the Adelaide Plain. The Burnside Fault has been confirmed by Department of Mines gravimetric survey. The existence of the Eden Fault is based entirely on topographic evidence.

Within the ranges, a complex group of northeast trending faults, namely the Montacute, Stonyfell and Clarendon Faults, appear to split from the Eden-Burnside Fault Zone; these are reverse faults dipping steeply east and associated with Palaeozoic folding. The dips of the Eden-Burnside and Para Faults have not been established, and although drawn on many published cross-sections as west-dipping normal faults, they may in fact be steep east-dipping reverse faults related originally to the Delamerian folding.

The total difference in level between the floor of the Adelaide Plains Basin and Mount Lofty Summit is over 1 200 metres. A large proportion of this difference can be taken to be a measure of the relative movement of an early Tertiary or Mesozoic land surface. Movement was most active in the late Pleistocene and Cainozoic when the Para and Eden Blocks were uplifted, tilted and warped to the southeast. The movements, accompanied by seismic activity, continue to the present day. This tectonism has already been referred to as the "Kosciuskan Uplift". Vigorous erosion of the uplifted areas, which were covered with easily-stripped Tertiary sediments, followed. Coupled with this activity was a fall of Pleistocene sea level, associated with extensive glaciation elsewhere. The result was extensive deposition of a vast sheet of riverine sediments over the Gulf St. Vincent and Adelaide Plains areas. This process was interrupted by minor incursions of the sea in the late Pleistocene and Holocene.

A spectacular marginal feature during the Quaternary was the building of large coalescing outwash fans of sand, clays and gravels along the foot of the Eden-Burnside and Para escarpments. These fans form the Upper and Lower Outwash Plains and have played a major role in establishing the pattern of soil types, the clay component contributing largely to the character of many of the red-brown earth* soil types.

SEISMIC ACTIVITY

Records of past earthquakes in South Australia (Sutton and White, 1968) indicate that movement along fault zones resulting in seismic shocks is still occurring in the Adelaide area. Most earthquakes are minor, although one which occurred in 1st March 1954, had a maximum intensity of eight on the Modified Mercalli Scale (Kerr-Grant, 1956). Systematic recording of tremors in South Australia commenced in 1962, and since that time small shocks have been recorded at a rate of three to four per month: the frequency in the Adelaide area is much less than this.

* The full description of this and other pedological terms mentioned in Chapters 2 to 6 is given in Chapter 7.

The faults west of the foothills are covered by a sequence of soils and of relatively unconsolidated sediments up to several hundred metres thick. In the Adelaide Hills area, the faults are covered by a thinner layer of topsoil and slopewash on the hill slopes, or alluvium in the valley floors. The large thickness of cover in the plains area, and the fact that the faults are complex zones of some width, make it impossible to demarcate zones adjacent to fault lines, in which various degrees of seismic intensity could be predicted.

There is no method at present known for predicting the time and place of occurrence of earthquakes, or their intensity. Some authors have classified the earth into various regions, based only on observed earthquake activity in the past. The eastern part of Australia, including the Adelaide area, is generally classified as a "semi-stable" region. The difficulty in prediction is well shown by the example of the 1954 Adelaide earthquake. In 1953, the possibility of the movements along the Eden-Burnside Fault would have been based upon its then known past record of no activity and an earthquake would have been considered unlikely. Today the record of this fault certainly indicates that it should be considered active.

STRATIGRAPHY OF THE REGION

Older Precambrian crystalline basement—The Barossa Complex

A major anticlinal inlier of these rocks extends from the vicinity of Kangaroo Creek Reservoir in the Torrens Gorge, 25 km northwards to the Barossa Reservoir and has a maximum width of 8 km. Smaller inliers occur in the Crafers-Stirling-Aldgate area. The inlier mainly comprises a great variety of mica-quartz-feldspar schists and gneiss. Part of the Torrens, Onkaparinga and Sturt Rivers systems are entrenched in these basement rocks.

Younger Precambrian (Adelaidean) cover rocks

These rocks form the major part of the western Mount Lofty Ranges and the various sedimentary units contribute to the varying topography of the region because of the contrast between the resistant quartzites and relatively easily eroded siltstones and phyllites.

The range front from Torrens Gorge to Marino and south to Port Stanvac, south of Hallett Cove is the type area of the Adelaide System of Mawson and Sprigg (1950) revised by Thomson *et al.* (1964). Further modifications were subsequently made by Thomson (*in* Parkin, 1969; Chapter 2) and incorporated in the ADELAIDE 1:250 000 Geological Atlas sheet. Following are the revised Adelaidean rock units in order of decreasing age.

Burra Group

This sequence of coarse to fine grained clastics and carbonate rocks, associated with sedimentary magnesite, disconformably underlies the glacigene Sturt Tillite. It incorporates the Torrensian Series of Mawson and Sprigg (*op. cit.*) and the overlying Belair Sub-Group, which was formerly assigned to the Sturtian. The Group forms the main mass of the Para and other fault blocks east of Adelaide and has a total thickness of about 2 700 metres. It is important in that it forms the source beds for many of the alluvial sediments and associated soils of the Plains.

The basal formation is the *Aldgate Sandstone.* The thickness of this unit is variable and reaches a maximum of about 900 metres. The formation comprises dominantly feldspathic fine to coarse grained sandstone and arkose with local cross-bedding and heavy mineral banding. The unit also includes local conglomerate, siltstone and dolomite members. It is most extensively developed in the Uraidla area and south of the type area at Aldgate. The rock, because of its granular texture and high feldspar content, is relatively heavily weathered. In the area south-east of Norton Summit it has a marked association with the podzolic (P1) soil type.

The overlying *Castambul Dolomite* and *Montacute Dolomite Members* with sedimentary magnesite have, with associated siltstones, a thickness of about 400 metres. To the south and east the carbonate members give way to cherts and the unit grades upwards into the carbonaceous black slaty *Balhannah Shale Member.* This forms part of the phyllitic siltstone equivalent of the Woolshed Flat Shale, which, with minor quartzite members, has a total thickness of about 300 metres.

The sequence above the Aldgate Sandstone as a whole is characterized by the presence of carbonates in the areas adjacent to the Para and Eden Faults. The development of red-brown earth (Type RB1) soils within the ranges area along the Norton Summit and Montacute road appears related to calcareous bedrock which belongs to this sequence.

The next unit in the Group is the *Stonyfell Quartzite.* It extends from Stirling southwards to Mount Bold and northwards east of the Eden Fault to Anstey Hill. This formation, about 300 metres thick, is extensively quarried for construction aggregate. The quartzite is resistant to erosion and forms many of the topographic features of the ranges, including the regional syncline in which Tea Tree Gully is situated and the prominent features of Black Hill, Rocky Hill, Rockdale Hill, and Mount Lofty. The formation is associated closely with skeletal soils and, because it tended to have a relatively high relief in the Tertiary land surface, shows in places an association with leached podzolic soils (Type P2).

Overlying the Stonyfell Quartzite is a sequence of phyllitic siltstones, the *Saddleworth Formation*, the thickness of which exceeds 300 metres. The siltstones are developed in the syncline in the Tea Tree Gully area where they include the *Beaumont Dolomite* which extends intermittently southwards as a dark lenticular dolomite zone up to about 120 metres thick. In the Beaumont area, the calcareous rendzina and terra rossa soils appear to be derived from the underlying bedrock and upslope outcrops of Beaumont Dolomite and associated calcareous phyllites. The uppermost part of the phyllitic siltstones are laminated and calcareous and have been described as the *Glen Osmond Slates*. They are best seen on the main highway at Glen Osmond. The rock is weathered in places at the foot of the Eden Fault Scarp in the Glen Osmond area where it forms an economic clay deposit.

The *Belair Sub-Group* follows next in the succession and is characterized by sandstones and quartzites interbedded with siltstones. The Sub-Group exceeds 300 metres in thickness and extends from the Glen Osmond area in a folded and faulted belt to the Blackwood area. It also occurs as isolated outcrops in the south bank of the Torrens River, near the Thorndon Park Reservoir. The uppermost units display extensive ripple marks and mud cracks. The resistant members of the Sub-Group have been responsible for preserving part of the Tertiary weathering profile from erosional stripping after uplift. The relict weathering is expressed by the skeletal and podzolic soils of the Eden Hills-Belair-Coromandel Valley area occurring near the tilted old land surface preserved in places on the uplifted Eden Fault Block.

Umberatana Group

Defined by its associated rocks of glacial origin, the oldest representative of this group in the Adelaide region is the *Sturt Tillite*, a generally massive bouldery rock with a siltstone matrix. The boulders are glacial erratics of crystalline basement rocks and of sediments resembling some units of the Burra Group. The thickness of the formation is about 300 metres. Coats (1967) demonstrated that the contact with the underlying Belair Sub-Group probably is a disconformity marking a break in sedimentation. The tillite is succeeded by about 1 500 metres of calcareous carbonaceous shales and siltstones and limestones of the *Tapley Hill Formation* from which are derived the highly calcareous rendzina and terra rossa soils in the Bedford Park-Seaview Downs area.

The *Brighton Limestone*, about 30 metres thick, forms the next unit in the Group. The lower part of the formation is dark, dolomitic and oolitic and passes upwards to a buff coloured limestone with minor pink and red siltstones. The top of the Brighton Limestone was taken by Mawson and Sprigg (1950) as the top of the Sturtian Series. The formation has also contributed to the calcareous soil groups.

Above the Brighton Limestone the sequence is more sandy. The succeeding Marinoan unit, about 460 metres thick, is the equivalent of the *Angepena Formation* of the *Willochra Sub-Group* and comprises flaggy red siltstones with ripple marked shale partings and sandy lenticles. The overlying unit of the Willochra Sub-Group is the equivalent of the *Wilmington Formation*. It is about 460 metres thick in the Marinoan type area between Marino Rocks and Hallett Cove and comprises grey flaggy limestones, pebbly limestone and green siltstone. The formation ends with the red massive gritty *Reynella Siltstone Member* about 120 metres thick which may be the equivalent of Marinoan tillites to the northern and eastern parts of the Geosyncline. This member is the uppermost unit of the Umberatana Group in the Adelaide area.

These units and the Wilpena Group are the source for slope and outwash gravels in the Kingston Park and Marino areas on which are developed brown solonized soils to which they may have contributed some minor calcareous material.

Wilpena Group

The lower part of this Group is represented by the equivalent of the *Brachina Formation* in the Hallett Cove area, commencing with the red and grey feldspathic *Seacliff Sandstone Member* containing minor dolomite horizons and passing upwards into red and green siltstones, shales and flaggy sandstones. The uppermost unit of the Group represented is the white quartzite about 460 metres thick in the Port Stanvac area.

Palaeozoic Sediments

Although Cambrian sediments may be present in the subsurface of the Adelaide Plains, the only undoubted Palaeozoic sediments are the Lower Permian tills, sands and clays of the *Cape Jervois Beds* at Hallett Cove. These may be present in the subsurface in the Croydon Bore (Steel, 1962) in the Adelaide Plains and it is possible that they had overlain part of the Eden Fault Block south of Adelaide, subsequently being eroded, reworked and incorporated in the younger sequences of the Plains area.

Cainozoic Sedimentation

Important references are Miles (1952), Glaessner and Wade (1958), Ludbrook (Chapter 5 *in* Parkin, 1969) and Lindsay (1969).

During the early Tertiary and late Mesozoic the land surface in the Adelaide area had a low relief and was subjected to prolonged and deep weathering. Some lateritic iron horizons were probably formed in the old weathering profiles. Sedimentation in the St. Vincent Basin commenced in the Middle Eocene with the *North Maslin Sands* which include minor lignite members, indicating an association of abundant vegetation in a swamp and lake environment. Possible equivalents of these sands are associated with podzolic and solodic soils in the Tea Tree Gully-Athelstone area. These earlier sands were overlain after a minor erosional interval by the late Eocene marine *South Maslin Sands.* These sands are greenish grey in colour and comprise clay sands associated with the green iron-potash mineral, glauconite, which, on weathering, changes colour to brown due to development of iron oxides. Maximum thickness of the unit is about 40 metres and it grades upwards into the grey glauconitic and silty Upper Eocene *Blanche Point Marls,* which are about 20 metres thick in the Adelaide city area and thin out northwards. The *Port Willunga Beds* comprising bryozoal sands, limestones and marly limestones attain a maximum thickness of over 200 metres in the Croydon Bore in the western suburbs of Adelaide, (Lindsay, 1969), but the unit thins rapidly to the east across the Para Fault partly due to original restricted sedimentation and to erosion during the Pliocene and Quaternary. The age of the beds ranges from uppermost Eocene into the Miocene. In the Adelaide Plains basin the *Munno Para Clay Member* is an imporant aquiclude separating the two main basin aquifers. The deformational and erosional interval in the Miocene and early Pliocene was terminated by renewed marine transgression in the Upper Pliocene. While lateritic weathering continued inland, the *Hallett Cove Sandstone* was deposited as calcareous sandstone or sandy limestone over the western plains region including the Adelaide city area. Outcrops in the grounds of Adelaide University have now been largely concealed by new buildings. It was formerly exposed on the south side of the Torrens River in the vicinity of Government House. Erosional remnants of the formation also underlie much of the Adelaide city area and, because of the presence of deep solution channels and holes associated with the erosion of its surface, it is an important factor in influencing the design of foundations of city buildings.

The *Dry Creek Sands* are fine grey shelly sands and are part equivalent to the Hallett Cove Sandstone. The sequence passes upwards through the *Carisbrooke Sand* of Plio-Pleistocene age into the Pleistocene mottled red and grey *Hindmarsh Clay.* This clay is very widespread in the subsurface of the Plains and is exposed in the banks of some of the deeper creeks. The formation comprises widespread riverine deposits, the result of uplift of the fault blocks to the east of Adelaide. It contributes to some of the red-brown earth soil types and crops out in the coastal areas near Seacliff where it contains abundant sand and gravel lenses derived from the nearby hillslopes. The overlying green *Keswick Clay,* which apparently extended even further inland than the Hindmarsh Clay, is of major importance as it is thought to be associated with areas of black earth soils in the Bellevue Heights locality near Eden Hills and in the Modbury, Athelstone, Hope Valley areas (Firman, 1969).

The following period of Pleistocene low sea level was associated with the spread of a blanket of a wind blown carbonate which developed into a calcareous layer (calcrete) in the *Bakara Soil* (Firman, 1969). The calcareous soils in the Kingston Park-Seacliff area may be partly attributed to this event.

A restricted deposition of shelly sands and clays, the *Glanville Formation* in the coastal areas, contained the marine mollusc *Anadara,* which has been dated at more than 45 000 years by radioactive carbon measurement. Erosion of the earlier calcrete then followed and a strip of clayey fine sand and silt, the *Pooraka Formation,* was deposited as a widespread sheet, about six metres thick, over earlier outwash faults and plain deposits. This unit is associated with red-brown earths and has been carbon dated as older than 34 000 years (Williams, 1969).

The *Loveday Soil* occurs near the top of the formation and contains carbonate accretions derived in part from erosion of an earlier calcrete. In the coastal areas near Dry Creek and Port Adelaide, the Holocene shelly marine, estuarine and beach ridge deposits of the *St. Kilda Formation* were laid down over the Pooraka Formation. In places they are overlain by modern intertidal and swamp deposits. This complex of units has an association with saline groundwater and corresponds to the EMS soil unit. In the coastal region the red dunes of the *Fulham Sand,* associated with Type DS1 soil, mark an old shore line. West of these, and related to the modern coast are the white dunes and beach deposits of the *Semaphore Sand,* associated with Type DS2 soil which extend northward from Seacliff to Lefevre Peninsula. The modern drainage channels of the Sturt and Torrens Rivers contain grey silts and sands which are deposited in a channel cut into older valley fill deposits (see Allchurch, 1967). The younger river sediments formed local levees and swamp deposits overlying the St. Kilda Formation in the Lower Outwash Plain, where the drainage system is generally diverted northwards by the coastal dune system.

SUMMARY OF GEOLOGICAL HISTORY

(*a*) Development of Adelaidean and Lower Cambrian sedimentation in the Adelaide Geosyncline formed by downwarp of Precambrian crystalline basement, which includes the Barossa Complex in the ranges area.

(*b*) Delamerian folding, faulting and metamorphism in Lower Ordovician and development of fold belt on site of future Mount Lofty Ranges.

(*c*) Uplift of fold belt, glaciation of mountain range in Lower Permian followed by prolonged erosion and peneplanation in late Mesozoic and early Tertiary, deep weathering, some lake and swamp deposits.

(*d*) Eocene-Miocene, marine sedimentation in Adelaide Plains area, subsidence on fault blocks, then gentle faulting and erosion in Miocene-Pliocene interval.

(*e*) Pliocene to early Pleistocene marine sedimentation in plains area, lake deposits and laterite development in ranges area, followed by block uplift on revived Para and Eden-Burnside Faults establishing framework of modern topography.

(*f*) Pleistocene active block uplift of ranges area, high rainfall and rapid erosion of younger cover sediments, deposition of blanket of riverine fans of Hindmarsh Clay in plains area; followed by arid interval, low sea level and formation of mantle of calcrete.

(*g*) Continued uplift of fault blocks—erosion of calcrete and continued erosion of older sediments, blanket of Pooraka Formation as slope deposits extending on to Lower Outwash Plain.

(*h*) Change from arid to modern climate, Fulham and then coastal Semaphore dunes, and modern drainage regime fully established.

CHAPTER 3

PHYSIOGRAPHY*

Adelaide is situated on an uplifted coastal plain at the eastern margin of the Gulf St. Vincent graben (sunken valley). To the east the major horst blocks of the Mount Lofty Range rise sharply in stepped fault blocks to plateau levels culminating in the summit of Mount Lofty at 727 metres. 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 great significance.

The Mount 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 consequent streams from the escarpment have produced a series of outwash fans bordering the plains, but to the west the stream gradients flatten and the stream channels fade almost into insignificance. Practically without exception they discharge onto swamp and estuarine plains bordering the sea-coast between Glenelg and Outer Harbor. Due to the large variation in rainfall, the creeks typically come down in flood during a wet winter, but flows practically cease as summer progresses. Until European settlement 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 and other rivers 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, then Sprigg (1946) 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 and Fig. 3 shows the changes of gradient across the plains.

Eden Fault Block

This unit is the westernmost of the several blocks constituting the Mount Lofty Horst. It is bounded on the east by the Kitchener and Ochre Cove Faults and on the west by the Eden-Burnside Fault Zone. 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 300 metres or more 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 140-150 metres 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 outcrops north of the Sturt River. Such prominences as Black Hill, Rocky Hill and Norton Summit all attain heights of over 430 metres above sea level, but to the south the highest point is O'Halloran Hill with an elevation of only 200 metres. The Eden Fault Block is the source of most of the shorter escarpment creeks, and the larger streams such as the Torrens and Sturt Rivers have cut deep narrow gorges through it.

Burnside Splinter Block

This narrow zone interpreted as a splinter block occurs at intermediate levels between the Eden and Para Fault Blocks and near Clapham is only 460 metres broad; but a possible extension to the north at Thorndon Park is approximately 1·6 kilometres wide. Its surface usually lies at 120-150 metres 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 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 possible extension has been traced from bore information, but in the central portion its position has not yet been determined. It has been traced by gravimetric methods from Third Creek to Marino. (Coppin, 1967).

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

* Reprinted with minor amendments from Bull. 32, Geol. Surv. S. Aust. (Aitchison *et al.*, 1954, ch. 2).

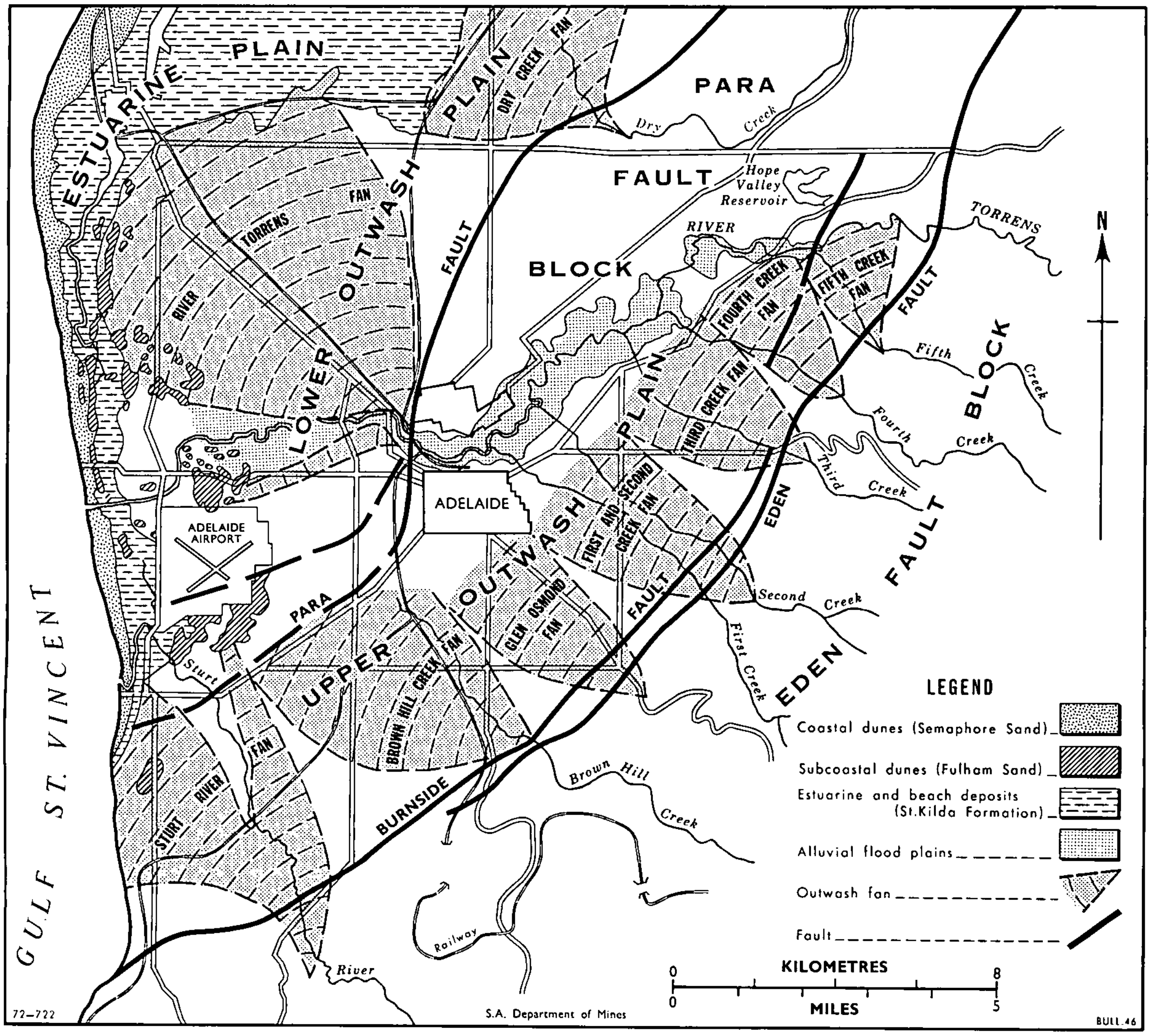

Fig. 2—Physiographic features of the Adelaide region with diagrammatic sketch of the pattern of outwash fans for the principal streams.

After Aitchison et al. (1954)

western city parklands the fault can be traced as a low escarpment which rises to the north to a height of over a hundred metres near the Little Para River, where it forms the main front of the 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 coast 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 (1930) 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 Eden Fault movement meant that it was possible for alluvial deposition to occur over the Para Fault 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 Holocene 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

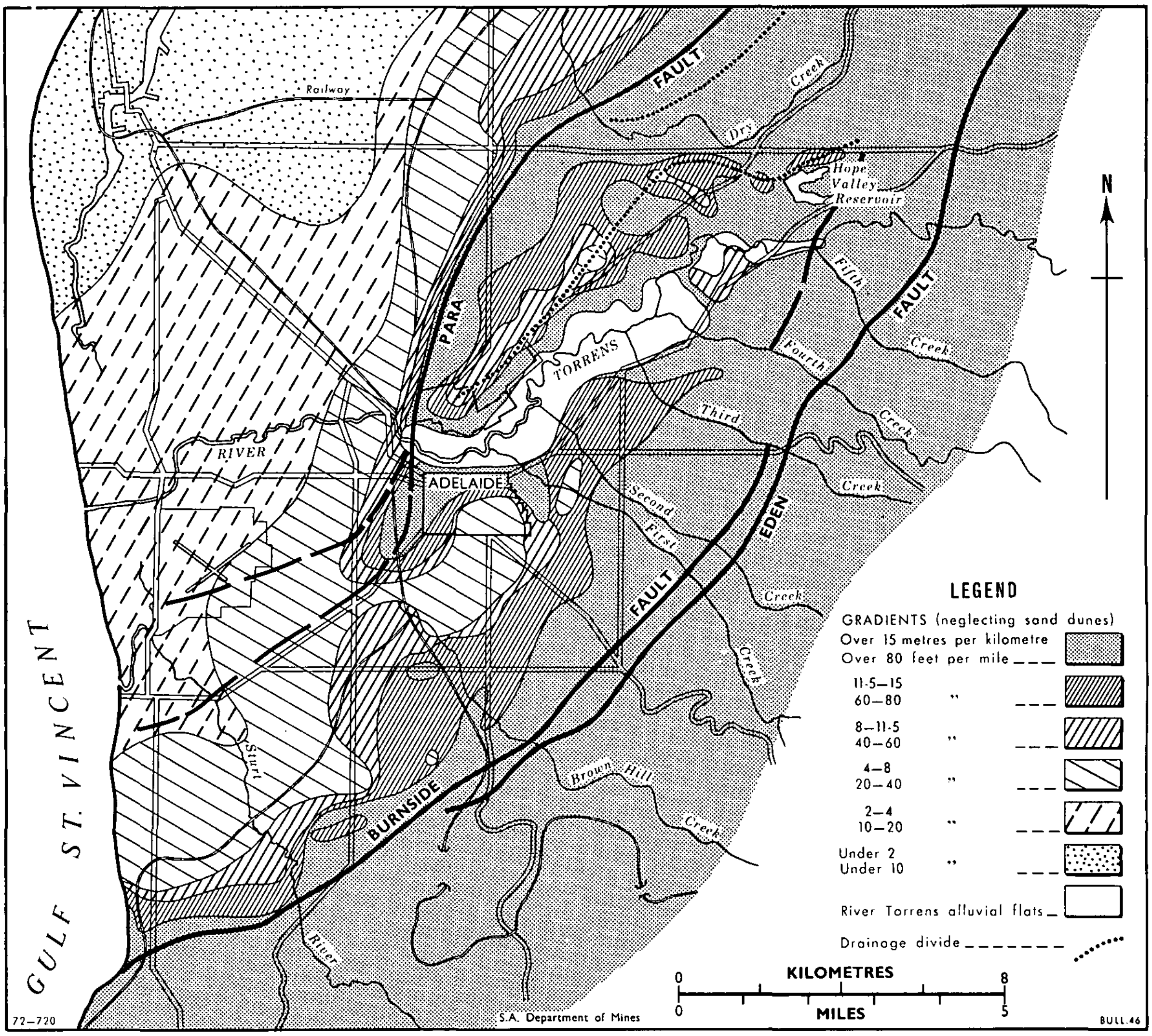

Fig. 3—Drainage divides and topographic gradients in the Adelaide region.

After Aitchison et al. (1954)

block. During such occasions erosion of previously deposited outwash material on the Para Fault 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. Precambrian 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 line of the Para Fault on the west. It is the zone which includes the foothills outwash aprons as well as adjacent alluvial areas, and descends from elevations of 150-180 metres to less than 30 metres above sea level. Above the 90 metre contour the slopes mainly exceed 15 metres per kilometre. The locus of the 8 metre per kilometre transition slope runs along the Para Fault north of the city and then across the Upper Outwash Plain, roughly corresponding with the 55 metre 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 Fault Block are much lower. The locus of the 4 metre per kilometre slope extends diagonally from west of the city to south of Glenelg 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 sourthern 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 erosiòn to deposition in these two zones.

Lower Outwash Plain

This zone extends landward from the sub-coastal marshes to the Para Fault Block in the east, and to the south it is bounded by the Upper Outwash Plain. Surface gradients over the whole area are very low, 2 to 4 metres per kilometre and the topography is dominated by the outwash fan deposits of the larger streams from the range—Little Para River, Dry Creek, River Torrens, Brownhill Creek and Sturt River. These rivers and creeks normally build levees in the 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) although the recent major flood plain accretion has been in the Findon-Woodville-Cheltenham district. The area is low lying and less than 18 metres above sea level.

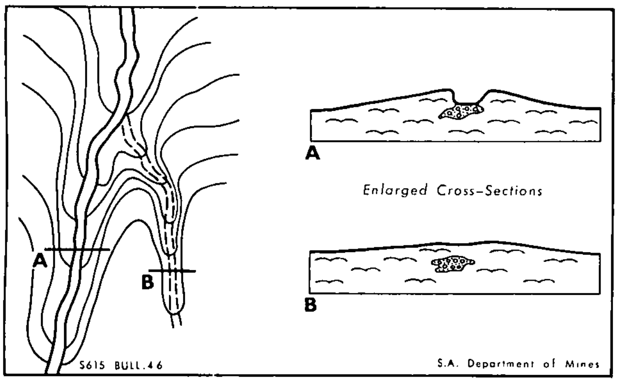

Fig. 4—Levee development in the Lower Outwash Plain.
After Aitchison et al. (1954)

Estuarine Plain

This area, originally swampy, lies immediately behind the present line of coastal dunes; its eastern limits are defined approximately by the six metre contour and by sporadic red sand dunes. 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. As the site of inundations in Holocene time by Flandrian high sea levels, it is marked by the shelly silts and sands of the St. Kilda Formation and associated younger sediments†.

Sand Dunes

A series of modern white siliceous sand dunes, the Semaphore Sand, mark the coast line from Seacliff to Outer Harbor, while east of the Estuarine Plain from Glenelg to Port Adelaide there are the sites of a number of older light red sand dunes of the Fulham Sand, now largely removed.

Fenner (1930) 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 Outer Harbor. These bay-bar hook and dune structures have continuously obstructed stream outlets in Holocene times and influenced local stream sedimentation in their lee.

* 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.

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

CHAPTER 4

HYDROLOGY

The following discussion of the hydrology of the Adelaide region is confined to the occurrence, availability and salinity of surface and underground water with particular reference to shallow groundwaters. Other phases of the hydrological cycle, including precipitation, are important aspects and are partly dealt with in Chapter 5 under Climate. As indicated in Chapter 3 on the physiography of the region, the drainage developed on the Eden Fault Block and its escarpment has determined the form and structure of the coastal plains which in their upper sediments provide storage in shallow aquifers for considerable bodies of water of low salinity. Three through-flowing streams occur and add a material annual quota, but, in addition, the intake from the short consequent streams in the vicinity of the Eden and Burnside Faults is undoubtedly large.

The drainage pattern and the distribution of groundwaters according to salinities is shown in Figure 5.

SURFACE WATERS OF THE PLAINS

Almost all streams entering the Adelaide Plains are ephemeral and even the larger ones, the Torrens and Sturt Rivers, have only very small summer flows and there is generally no flow at all in their lower courses. Flood flows in the Sturt River are controlled by a dam, designed to alleviate flooding in the southwestern suburbs. In the Torrens River a small flow is usually maintained during summer. Part of this water was used for irrigation of market gardens but the demand for this purpose is now minor, as those activities have practically ceased in the western suburbs of Adelaide. However, the waters of Torrens Lake in the Adelaide area are used for some of the city gardens and lawns and to fill and maintain the level of artificial lakes in the east parklands.

A number of the larger creek channels are now concrete lined and in these, most surface water flows to the sea or to the Torrens River, the only loss being through evaporation. Included in these are the Brownhill, First, Second, Third and Fourth Creeks, which have now been straightened and the channels lined.

All of the smaller consequent streams from the escarpment cease to flow shortly after rain and their waters are lost by recharge to shallow groundwater or by transpiration.

Salinity of Surface Waters

Generally, salinities of surface waters are low, less than 0·5 mg per litre, but there are a number of factors which may combine to cause its increase. Some of these are:—

Time of Sampling—Water collected during late spring and summer or from the first flows of winter are likely to have a higher salinity than in winter or early spring.

Place of Sampling—Salinity of surface streams generally increases in the direction of flow and those traversing the Adelaide Plains show such an increase from their hills catchment to the sea. However, the rate of increase varies widely from stream to stream and would depend to a large extent on their flow and the geology of the catchment area.

Origin of Water—At times, depending on local distribution of rainfall, a larger proportion of run-off may come from certain parts of the catchment area in the Adelaide Hills, possibly where weathering of the rocks is well advanced. Rocks which are strongly weathered or decomposed yield soluble products which may increase the salinity of streams traversing them.

TABLE 1

COMPOSITION OF SURFACE WATERS

Sample No.	Stream	Location	Total soluble salts mg/litre	Assumed sodium chloride mg/litre
1	Torrens River	Kangaroo Creek ...	421	203
2	Torrens River	Weir (overflowing) .	287	180
3	Torrens River	Below weir (drought)	888	490
4	Torrens River	Welland	1 171	613
5	Millbrook Reservoir	Chain of Ponds ...	303	161
6	Hope Valley	Hope Valley	305	125
	Reservoir	Hope Valley	477	203
7	Sturt River .	Sturt	700	411
8	Fifth Creek..	Lower gorge.......	321	138
9	Fourth Creek	Rostrevor	262	150
10	Third Creek..	Magill	460	172
11	Second Creek	Burnside	259	162
12	First Creek..	Burnside	391	142
13	Brown Hill Creek	Mitcham..........	524	204

Table 1 shows a selection of sampling sites and the salinity of free flowing water in the various streams at locations shown. Generally, salinity of surface water remains low until it reaches the low lying coastal fringe. In this area the waters are tidal and mingle with sea water, for example, where the Sturt River enters the Patawalonga Creek. The latter has a controlled outlet to the sea and salinity in the lower

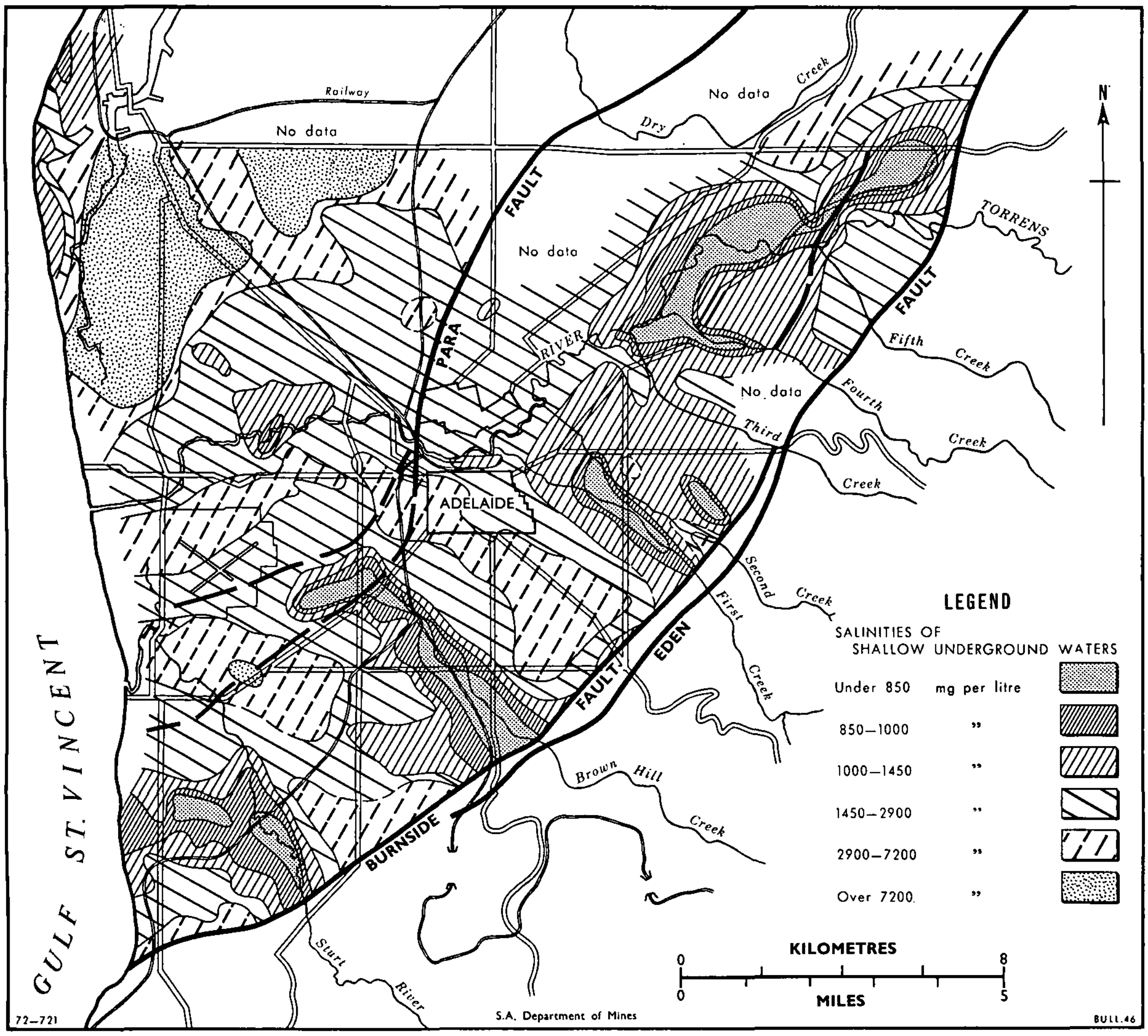

Fig. 5—Hydrological map of the Adelaide region showing surface waters and occurrence of groundwaters together with their salinities to a maximum depth of 30 metres.

After Miles (1952)

reaches normally approaches that of sea water, but may be considerably lower during periods of high winter flow in the Sturt River.

The dominant non-metallic ion in the surface waters is chlorine, usually in the range 40 to 60 per cent of the total ions. The carbonate ion (CO_3) usually as bicarbonate (HCO_3) seems to form constantly 15 to 25 per cent. Metallic ions present are mainly of sodium, calcium and magnesium. The surface waters, on the basis of salinity and composition, would be considered high quality.

UNDERGROUND WATERS OF THE ADELAIDE PLAINS BASIN

Groundwater occurs as both pressure and non-pressure water within Tertiary to Holocene sediments in the Adelaide Plains Basin. This basin, which is part of the much larger St. Vincent Basin, occupies the greater part of the metropolitan area. It extends northward from Marino over the surface of the Para Fault Block to the line of the Torrens River and is bounded on the east by the Burnside and Eden Faults. The basin continues north of the Torrens River between the coast and the Para Fault, and extends to beyond the Gawler River. Sediments forming the basin are essentially flat lying, although there is a dip of about one in 350 towards the south and the beds thicken in that direction. The maximum thickness of all beds occurs beneath the western suburbs of Adelaide in the vicinity of Adelaide Airport, to the north-west or downthrow side, of the Para Fault.

On the Para Fault Block the Tertiary sediments are much thinner. Northeast of the city, Tertiary marine sediments thin out and disappear, with lower Tertiary non-marine lignitic sediments occurring near Hope Valley.

Details of the stratigraphy and aquifers of the Adelaide Plains Basin are given in Table 2.

TABLE 2

STRATIGRAPHIC SUMMARY OF TERTIARY—QUATERNARY SUCCESSION, ADELAIDE PLAINS

Geological unit name	Age	Environment of deposition	Occurrence	Description	Maximum thickness	Remarks
St. Kilda Formation .	Recent........	Marine	Adjacent to present coast	Stranded shell beds	4 m	
Pooraka Clay	Pleistocene	Alluvial	Whole of plains..	Sand, silt and clay	3 m	
Glanville Formation .	Pleistocene	Marine	Adjacent to present coast	Shell beds	3 m	
Hindmarsh Clay.....	Pleistocene	Fluviatile alluvial	Whole of plains..	Clay, silt sand and gravel	107 m	Thin aquifers common
Carisbrooke Sand ...	Pliocene-Pleistocene	Fluviatile alluvial	Vicinity of rivers and Para Fault	Yellow silt and sand	52 m	Continuous with Aquifer *A* in some areas
Hallett Cove Sandstone and Dry Creek Sand	Pliocene	Marine	Mainly northwest of Para Fault. Restricted elsewhere	Calcareous sandstone, limestone and sand; fossiliferous	68 m	Aquifer *A*
Port Willunga Beds (upper)	Middle-Lower Miocene	Marine	Plains south of Gawler River	Fossiliferous sandy limestone	38 m	Aquifer *A*
Munno Para Clay ...	Middle-Lower Miocene	Marine	Plains south of Gawler River	Blue grey clay .	12 m	Semi-confining bed
Port Willunga Beds (Lower)	Lower Miocene-Oligocene	Marine	Whole of Plains	Fossiliferous sandy limestone	171 m	Aquifer *B*
Blanche Point Marls .	Upper Eocene .	Marine	Whole of plains..	Marl, siltstone limestone	119 m	Confining bed
South Maslin Sands..	Upper Eocene .	Restricted marine	Whole of plains..	Poorly fossiliferous sands	38 m	Aquifer *C*
Clinton Formation...	Middle-Upper Eocene	Restricted marine and non-marine	Missing in some areas. Penetrated in only 3 bores	Silty calcareous clay	40 m	Confining bed where present
North Maslin Sands .	Middle Eocene.	Fluviatile estuarine	Whole of plains. Penetrated in only 3 bores	Sand and gravel	31 m	Aquifer *C*

Pressure Aquifers

Within the Adelaide Plains there are three main pressure aquifers, which in their continuation northward into the Salisbury-Virginia area have been designated *A*, *B* and *C* in order of increasing depth from the surface. These aquifers are continuous throughout the Adelaide Plains west of the Para Fault. On the Para Fault Block all aquifers are thinner with Aquifers *A* and *B* wedging out northeast of the city.

Aquifer *A* consists of Pliocene Dry Creek Sands together with the upper part of the Port Willunga Beds above Munno Para Clay (see Table 2). The latter is a semi-confining bed within the Port Willunga Beds, with a maximum known thickness of 12 metres. Aquifer *B* underlies this in the lower Port Willunga Beds. These two deep pressure aquifers provide the irrigation supply for the extensive vegetable growing on the Northern Adelaide Plains. Aquifer *C*, comprising sands of lower Tertiary age, is not important west of the Para Fault because of its very considerable depth below the surface (488 metres at Grange). However on the Para Fault Block, particularly east and northeast of the city, water supplies have been developed from Aquifer *C*. This is in areas where Aquifers *A* and *B* are missing or are of negligible thickness.

Shallow Aquifers

These aquifers occur commonly in the Adelaide Plains, mainly within the Hindmarsh Clay formation and also, at higher stratigraphic levels, within the Pooraka Clay. The aquifers are usually non-pressure and the water they contain is derived from local sources.

West of the Para Fault, shallow aquifers are well developed, particularly over a broad strip in the vicinity of the Torrens River and following the courses of other main streams. They consist essentially of fine to course sand and occasional gravel beds. In other areas, such as the city of Adelaide, shallow aquifers are poorly developed and where sand beds occur they usually contain a considerable proportion of clay. This is because deposition of coarser materials normally occurred much closer to the Adelaide hills.

COMPOSITION OF GROUNDWATERS

Salinity of Pressure Aquifers

Salinity of waters in Aquifers *A* and *B* in the area south of a line joining the city of Adelaide and Port Adelaide and west of the Para Fault is less than 1 000 mg per litre. For this reason these aquifers have been pumped extensively in the past to augment the water supply for Adelaide.

The best quality groundwater of approximately 700 mg per litre occurs west of Adelaide where the Torrens River crosses the Para Fault. The Para Fault Zone is apparently the place where much of the intake to the Tertiary aquifers occurs. Salinity increases markedly proceeding north of Port Road; within 1·5 kilometres it rises to approximately 3 000 mg per litre, reflecting lower permeability of the sediments and greater distance from intake areas. A similar pattern has been observed in the Northern Adelaide Plains where water of less than 700 mg per litre occurs in the pressure aquifers in the vicinity of the Gawler and Little Para Rivers. Dry Creek, where it crosses the Para Fault apparently has not resulted in any material intake to the pressure aquifers.

On the Para Fault Block, salinity of pressure Aquifers *A* and *B* ranges from 1 000 to 1 500 mg per litre in the southern and southwestern suburbs while salinity of water of Aquifer *C* in the northeastern suburbs is generally less than 1 000 mg per litre. In part of the Adelaide Plains at North Adelaide, the salinity of water within the Tertiary aquifers is high, up to 3 000 mg per litre. This is because it is a relatively elevated area where recharge can only occur locally and not from water of the River Torrens. Similar quality water occurs in the Northfield

TABLE 3

COMPOSITION OF GROUNDWATERS

Sample No.	Physiographic Unit	Location	Total soluble salts mg/litre	Assumed sodium chloride mg/litre
		GROUNDWATERS (<20 metres depth)		
14	Coastal sand dunes	Taperoo	921	524
15	Coastal sand dunes	Taperoo	33 421	28 580
16	Lower Outwash Plain	St. Kilda (ICI)	60 978	46 100
17	Lower Outwash Plain	Woodville North	17 240	10 880
18	Lower Outwash Plain	Kilkenny	1 266	673
19	Lower Outwash Plain	Flinders Park	12 169	9 611
20	Lower Outwash Plain	Adelaide Airport	1 124	522
21	Lower Outwash Plain	Adelaide Airport	1 262	843
22	Lower Outwash Plain	Glandore	4 720	3 444
23	Lower Outwash Plain	Black Forest	1 469	789
24	Upper Outwash Plain	Unley	4 879	3 191
25	Upper Outwash Plain	Paradise	897	468
26	Upper Outwash Plain	Oaklands Park	1 060	557
27	Upper Outwash Plain	Seacombe Gardens	2 924	1 777
28	Brown Hill Creek	Mitcham	536	244
29	Brown Hill Creek floodplain	Lower Mitcham	466	215
30	Sturt River	Warradale	1 018	453
31	Sturt River floodplain	Warradale	1 116	372
32	Para Fault Block	Walkerville	2 135	481
		GROUNDWATERS WITHIN PRECAMBRIAN ROCKS (<45 metres depth)		
33	Para Fault Block	Dernancourt	1 172	767
34	Burnside Fault Block	Glen Osmond	689	269
35	Burnside Fault Block	Urrbrae	689	294
36	Burnside Fault Block	Paradise	1 635	1 012
37	Burnside Fault Block	Rostrevor	1 959	834
38	Upper Outwash Plain	Paradise	900	468
39	Para Fault Block	Northfield	4 118	3 164
40	Para Fault Block	Vale Park	2 266	1 671
41	Para Fault Block	Klemzig	1 106	647

area, which is also a relatively elevated area, where recharge of groundwater is from local rainfall.

Salinity of shallow aquifers

The pattern of salinity of waters in shallow aquifers at less than 30 metres is shown in Figure 5. Table 3 shows the composition of a number of representative samples of waters from shallow aquifers, and from groundwaters in Precambrian rocks.

As with surface waters of the Adelaide Plains, the dominant non-metallic ion in the groundwater of the sediments of the plains is chlorine. Under strong marine influence, as in the coastal dunes at Taperoo, chlorine ions form more than 55 per cent of the total ions. However, chlorine also exceeds 50 per cent of the ions in bores at Flinders Park and Glandore at a depth of about five metres. Otherwise, this ion varies from 30 to 50 per cent of the total ions, and is generally lower in proportion when the total saline content is lower.

The second ion of this group is carbonate (CO_3), usually occurring as the bicarbonate (HCO_3) often forming up to 15 per cent, and in the great majority of cases, over 10 per cent of the total ions.

Sulphate ions are the third most abundant, and are present to the extent of 5-7 per cent of the total ions.

As regards the metallic ions, those present are mainly sodium, calcium and magnesium, in that order. Sodium ions range from 20-25 per cent, with calcium (5-7 per cent) and magnesium (4-6 per cent) of the total ions present.

In groundwater within Precambrian rocks, the proportion of chlorine ions may range from 25-40 per cent, carbonate ions also have a similar wide range, from 6-30 per cent and sulphate from 4-30 per cent.

Sodium is the highest of the metallic ions, ranging from 15-25 per cent, with calcium and magnesium roughly equal and ranging from 5-9 per cent.

The salinity of these aquifers reflects the intake occurring along the stream courses. Salinities of less than 900 mg per litre occur in aquifers in the vicinity of Brownhill Creek and other creeks traversing the Para Fault Block. West of the Para Fault, salinity of the shallow aquifers is generally higher, with the better quality water ranging from 1 000 to 1 500 mg per litre, near the Torrens River. Water with a salinity of 1 000 to 1 500 mg per litre is also found over a limited area of coastal sand dunes north of Grange.

High salinity groundwater within Pleistocene to Holocene sediments occurs near the Patawalonga Creek and near the Torrens River outlet. Notable salinity also exists in the vicinity of Adelaide, in the northern part of the Para Fault Block, for example at Northfield. Salinity of shallow groundwater in the low lying coastal zone is also high, rising in places to more than 30 000 mg per litre and in the area west of a line from Kilburn to Henley Beach it usually exceeds 4 000 mg per litre.

In the Northern Adelaide Plains low salinity groundwater, generally less than 1 000 mg per litre occurs adjacent to the Gawler and Little Para Rivers. There is some intake to a shallow aquifer where Dry Creek traverses the Para Fault, where a salinity of less than 1 500 mg per litre has been recorded.

YIELDS AND USAGE OF GROUNDWATER

Pressure Aquifers

Bores in the Tertiary aquifers of the Adelaide Plains may yield up to 135 000 litres per hour but the average yield would be within the range 45 000 to 68 000 litres per hour. In some areas the Pliocene sands of Aquifer *A* are unconsolidated and present problems in development. In these cases if a suitable sand-free supply cannot be obtained it is necessary to deepen the bore into the lower part of Aquifer *A* or into Aquifer *B*.

In the Northern Adelaide Plains, north of Grand Junction Road, groundwater is used extensively for irrigation of market gardens and fodder crops. In the southern Adelaide Plains, large quantities are probably being pumped for use in industry and for the watering of golf courses and recreation grounds. On occasions it has been necessary to augment the Metropolitan water supply from groundwater sources; the last time this occurred was in the 1967-68 summer, following an exceedingly dry year. During the period September, 1967 to April, 1968 up to 40 government bores were pumped for a total of 9 470 150 cubic metres.

Shallow Aquifers

Few records are available for yields from shallow aquifers as most bores were drilled originally for stock supplies or for the watering of small gardens. Some bores are known to yield more than 23 000 litres per hour and these are located in the most favourable area as regards recharge. In the Northern Adelaide Plains, shallow aquifers are pumped for market gardens, mainly near the Gawler and Little Para Rivers. In the Adelaide area little use is now made of the water of shallow aquifers. However, several bores in the eastern suburbs, yielding up to 9 000 litres per hour are used for watering of sports grounds.

Sand dunes (Semaphore Sand) in the coastal strip northward from Grange contain small quantities of groundwater, which has been developed in the Semaphore area as a useful supplementary supply for garden watering. In the area east of the coastal dunes the groundwater table is at shallow depth, often less than three metres. In the more low lying areas in the vicinity of Port Reach the water table may be less than one metre, and corresponds closely to surface water level in the channel. In general, with the exception of the coastal sand dunes, groundwater occurring in the area below the eight metre surface contour is at a depth of three metres or less, and in fact, in the more low lying areas it occurs very close to the ground surface.

On the Para Fault Block, shallow aquifers are well developed in the vicinity of the larger streams, including the Torrens and Sturt Rivers. Adjacent to these streams the aquifers consist of coarse sand, grading to gravel toward the Burnside escarpment. Sand and gravel have also been deposited along the courses of the smaller streams, including the numerous short, consequent streams from the escarpment, which are generally less than 2·5 kilometres in length. These thin sand or coarse gravel beds, with an irregular distribution, are found along the foothills zone. Some of them contain water for short periods following rain, drying out each summer, while others contain permanent water.

Adjacent to the streams groundwater may occur at depths of 4·5 to 6 metres and occasionally at 1·5 to 3 metres. Perched water tables also occur in several areas, particularly North Adelaide, where it is saline and commonly less than 3 metres from the surface.

UNDERGROUND WATER IN THE ADELAIDE HILLS

Within the Adelaide System of the Mount Lofty Ranges, groundwater occurs in various rock types including sandstone, quartzite, dolomite and slate. The strike of the rocks trends generally northerly, and in places a well developed joint system has developed. Apart from the Para, Eden and Burnside Faults there are a number of sub-parallel faults further east (see Chapter 2). Water is stored in joints and other openings and occasionally it is under pressure. The best aquifers are within the Aldgate Sandstone, particularly where jointing and fracturing is well developed. Other rock types such as dolomite and slate generally yield smaller supplies.

Within the Adelaide Hills, groundwater is used for market gardening in areas where quality is good and yields are sufficient. Yields are not generally large but 13 500 to 18 000 litres per hour is obtained in a number of bores and yields up to 45 500 litres per hour are known.

Occasionally, in fault zones large yields are obtained; for example, a bore in the Burnside Fault Zone was reported to yield 91 000 litres per hour of low salinity water. Such yields are unusual within the basement rocks of the hills and would only be obtained in areas were jointing or fracturing has resulted in a relatively high permeability and storage capacity of the rock mass.

The salinity of groundwater in Adelaide System rocks ranges over wide limits and depends largely on the rocks in which it is stored, the degree of weathering and on recharge conditions. Salinity of water in the Aldgate Sandstone in areas of high rainfall may be as low as 100 mg per litre. Salinity ranges up to 3 000 mg per litre in areas of unjointed slate in a lower rainfall area, particularly in the O'Halloran Hill-Morphett Vale district. Apart from stock purposes little use is made of higher salinity groundwater, and no data are available on yields. Few bores have been tested and most stock bores are equipped only with windmills pumping at 1 400 to 1 800 litres per hour.

Small quantities of groundwater also occur in thin alluvial sand and gravel beds along the larger streams in the Adelaide Hills zone.

CHAPTER 5

CLIMATE IN RELATION TO SOILS

The nature of the present soils and the natural problems of stability of building foundations on them are clearly related to the climate of the Adelaide region. In particular, the rainfall and its effect on soil moisture in the annual cycle needs to be basically understood, even though this cannot be applied to the artificial and widely varying conditions of closely built-over land. The climate of the region is generally considered to be essentially unchanged since the end of the last great arid period 4 000 to 5 000 years ago. It is presumed therefore that the majority of the soils which have developed profiles are associated with the present climatic regime, which is characterized by a cool moist winter followed by an increasingly hot and dry period through the summer.

METEOROLOGICAL DATA

Climatological data for key sites representing four specific environments in the region are given in Table 4. Of these, the data for Adelaide city apply to the main coastal plain at lower levels (less than 60 metres contour); those for Tea Tree Gully and the Waite Agricultural Research Institute are related to the Upper Outwash Plain close to the foot of the Eden escarpment. The Belair station typifies the top of the escarpment and Blackwood, a section of the main Eden Fault Block. The rainfall isohyets (Fig. 6) show the overall distribution for the whole region in intervals of 50 millimetres.

The data for the five stations in Table 4 offer some interesting comparisons. There is a considerable rainfall gradient of 25 millimetres per 23 metres rise in elevation between Adelaide city and Glen Osmond at the upper limit of the outwash plain in the central metropolitan area. Continuing from Glen Osmond to the Belair station, ascending the escarpment, the increase is 25 millimetres per 60 metres elevation. The rate of increase between the Adelaide city and Tea Tree Gully stations is 25 millimetres per 25 metres rise in elevation.

The Eden Fault Block is represented here only by the Blackwood rainfall data which are lower than those for the rising surface towards Mount Lofty and Norton Summit. Actually the variation in rainfall near Blackwood is itself considerable, possibly due to natural features such as the Sturt River valley. Belair at the same elevation has somewhat higher rainfall as it may receive more effective rain-bearing winds sweeping round the escarpment from the Gulf.

The leaching capacity of rainfall at the Waite Research Institute, Glen Osmond, on parent material from argillaceous rocks has produced typical red-brown earths while at Tea Tree Gully the greater precipitation on siliceous material has resulted in podzolic soil types.

Podzolic soils have developed generally on all kinds of parent rock on the Eden Fault Block surface. This relationship has been tied approximately to the 675 millimetre isohyet as a minimum rainfall from field observation of soil occurrences. The exceptions are for particular parent material such as calcareous rocks.

The intensity of rainfall is important in considering soils and building foundations. Records for one station showing this are in Table 5.

TABLE 5

RAINFALL INTENSITY—WAITE AGRICULTURAL RESEARCH INSTITUTE, GLEN OSMOND

Period	Average rainfall	*Average number of wet days	Amount per wet day
	mm		mm
January	22	3·0	7
February	28	3·0	9
March	20	3·2	6
April	52	7·3	7
May	81	10·3	8
June	74	11·0	7
July	82	13·5	6
August	71	12·5	6
September	58	9·8	6
October	52	8·8	6
November	39	5·7	7
December	30	4·8	6
Year	609	92·9	7

* Average number of wet days with rainfall equal to 1 millimetre or more. These figures apply to 75 to 80 per cent of the days in which some rain fell.

A more detailed examination of records shows that the continuous sequence of five months, May to September, with a rainfall in excess of evaporation and with an average of nearly 50 per cent of rain days, is the key to depth of soil wetting, while the remaining seven months show progressive, normally unrelieved, dessication of the soil profile. This comment applies to open ground not subject to flooding or irrigation or excessive run off. The rapidity and depth of drying depends on the amount and type of vegetation cover as well as climatic influences. Naturally, individual years may have a pattern biased one way or the other.

TABLE 4

CLIMATOLOGICAL DATA FOR ADELAIDE REGION

Location	Adelaide City Altitude 43 m				Waite Research Institute Altitude 124 m				Tea Tree Gully Alt. 208 m	Belair (Kalyra) (Altitude 310 m)				Blackwood Alt. 269 m
Record as Averages	Rainfall mm	Evapn. mm	Temperature C° Max.	Temperature C° Min.	Rainfall mm	Evapn. mm	Temperature C° Max.	Temperature C° Min.	Rainfall mm	Rainfall mm	Evapn. mm	Temperature C° Max.	Temperature C° Min.	Rainfall mm
January	19	232	29·7	16·4	22	215	27·4	15·7	24	27	212	26·4	14·4	23
February	20	188	29·4	16·6	28	176	27·2	15·9	23	20	167	26·7	15·3	26
March	24	156	26·9	15·0	20	160	25·8	15·3	28	31	132	23·9	14·2	23
April	43	95	22·7	12·6	52	100	21·2	12·4	57	49	85	19·7	11·7	61
May	68	57	18·7	10·2	81	68	18·5	10·4	83	90	55	16·7	10·0	85
June	72	37	15·8	8·3	74	44	14·9	8·1	100	115	37	13·1	7·5	85
July	65	37	14·9	7·2	82	44	14·1	7·4	84	92	37	12·2	6·0	91
August	61	52	16·4	7·8	71	57	15·1	7·7	84	91	52	13·6	7·5	82
September	50	80	18·9	8·9	58	80	17·6	8·9	70	75	78	16·1	8·6	64
October	43	126	22·1	10·7	52	116	20·2	10·4	58	55	112	19·2	10·0	57
November	30	170	25·3	12·9	39	155	23·5	12·7	40	26	155	22·8	12·2	40
December	26	215	27·8	14·9	30	196	26·0	14·4	33	30	198	24·7	13·6	32
Year	520	1 445	22·4	12·1	609	1 161	20·9	11·6	684	721	1 320	19·6	11·0	669

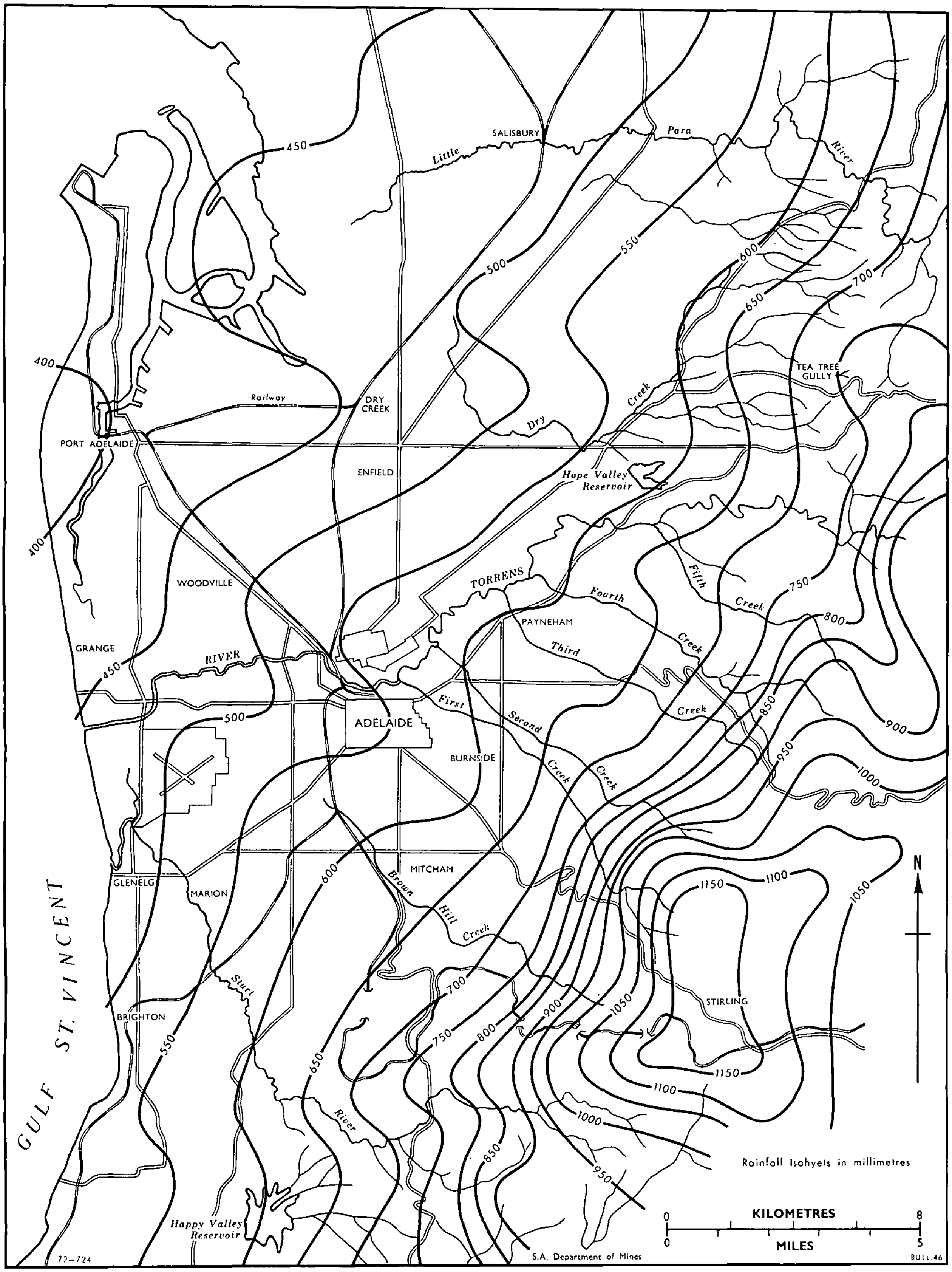

Fig. 6—Rainfall distribution in the Adelaide region showing isohyets at 50 mm intervals.

Prepared by the Commonwealth Bureau of Meteorology

SOIL MOISTURE VARIATION

A more precise illustration of the effects of climate on soil moisture has been given by Aitchison and Holmes (1953) who studied the depth of penetration of rainfall on two typical soils of the Adelaide region through three successive years, one of which was a dry year (Fig. 7). The observations showed that the correlation of soil moisture changes with rainfall and evaporation in a red-brown earth are marked, particularly the response to heavy falls of rain at depths of 0·3, 0·6 and 1·2 metres. Following the break of season, normally in April, the upper 0·6 metres are moistened to field capacity* in about one month; the wetting front then reaches 1·2 metres in about two months and 1·8 metres in about four to five months. It may be assumed that any changes below the 1·8 metre depth are limited to one or two months (August-September). On the drying aspect it seems the upper 1·2 metres dry out to wilting point† by December while this state is not reached at 1·8 metres until January. In the black earth profile, drying to wilting point is more restricted and from 1·2 metres downward the soil is in a variably moist state, remaining more or less at field capacity at 1·8 metres. Aitchison and Holmes (1953) have illustrated the soil moisture changes in both soil types from wettest to driest condition.

Undoubtedly both red-brown earth and black earth soils, given favourable seasonal conditions, wet steadily to more than 1·8 metres during the winter. Any circumstance which allows a build-up of free water in a subsoil horizon which overlies one of low permeability will tend to accentuate the ultimate penetration of water to greater depth. Under natural conditions, a balance is normally struck during the annual cycle between rainfall penetration, accumulation of water in horizons and withdrawal by vegetation. This factor has been very important in the development of characteristic soil profiles. Conversely, urban development has created conditions in the soils far removed from the original climatic environment. These, while very important in regard to engineering values, do not affect the pedological classification of the soil.

The potential evapo-transpiration affecting moisture changes in the soil indicates an average five-month period of moisture accumulation and seven months of progressive drying out. As a complication, about one year in five or six has a low rainfall in which the dry state exceeds nine months and one year in about five when rainfall is notably higher than average. A further examination of data for three stations shows:—

Adelaide City—very low, 66 per cent average rainfall—1 in 10 years; low, 80 per cent average rainfall—1 in 4·3 years.

Tea Tree Gully—very low, 66 per cent average rainfall—1 in 18 years; low, 80 per cent average rainfall—1 in 5 years.

Blackwood—very low, 66 per cent average rainfall—1 in 21 years; low, 80 per cent average rainfall—1 in 6 years.

It is reasonable to infer that in years of low rainfall, penetration of water into the soil would be restricted probably to not more than 1·2 metres and in drought years any change in soil water would be temporary. In years of average rainfall most soils appear to wet to little more than 1·8 metres, but to considerably greater depths in years of abnormally high rainfall.

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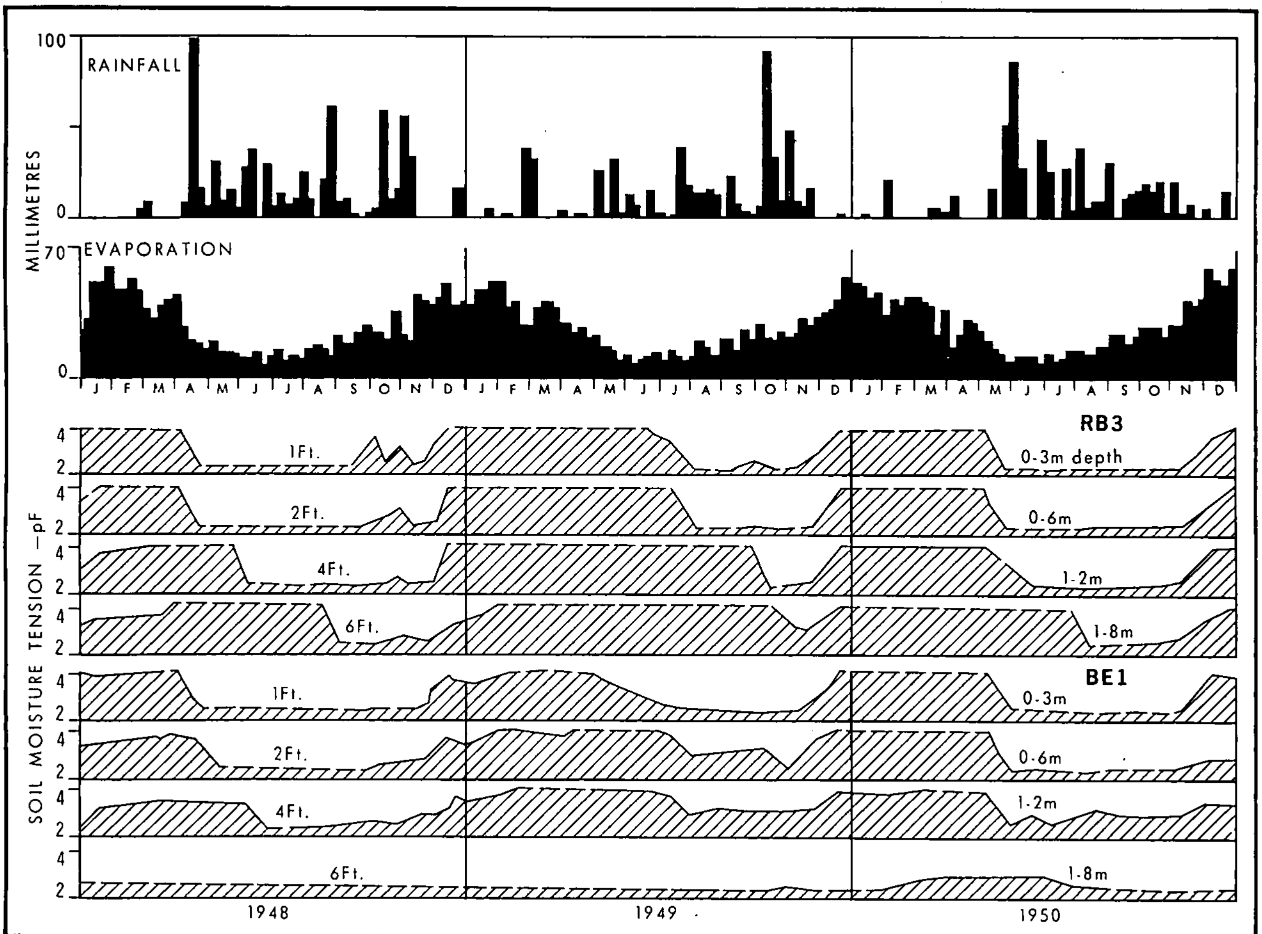
* Field capacity is the moisture condition in a soil at which drainage to a lower depth ceases. The soil is in a state close to maximum expansion.

† Wilting point is taken as the stage of dryness at which the capacity of a soil to supply water to growing soft plants is insufficient to keep them turgid. While soils will dry to a greater degree than wilting point, the shrinkage of those with expandable clays will have progressed to a significant but not maximum extent with cracking.



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S.A. Department of Mines

Fig. 7—Rainfall, evaporation from a free water surface, and soil moisture tension (expressed on the pF scale) in profiles of a red-brown earth (Type RB3) and a black earth (Type BE) for three consecutive years 1948, 1949, 1950.

After Aitchison and Holmes (1953)

The method of measurement of soil moisture only permitted changes between wilting point (pF 4·2 approx.) and field capacity (pF 2·5 approx.) to be observed. The upper and lower broken lines on the graphs represent these limits. It may be assumed that in equilibrium at pF 4·2 the soil will have shown significant cracking and be approaching a clay state of maximum shrinkage; conversely, in equilibrium at pF 2·5 the soil is close to a moist state of maximum expansion. The progressive wetting or delay in drying out at different depths directly reflects the influence of rainfall and evaporation. This influence in some years extends much below 2 metres from the surface.

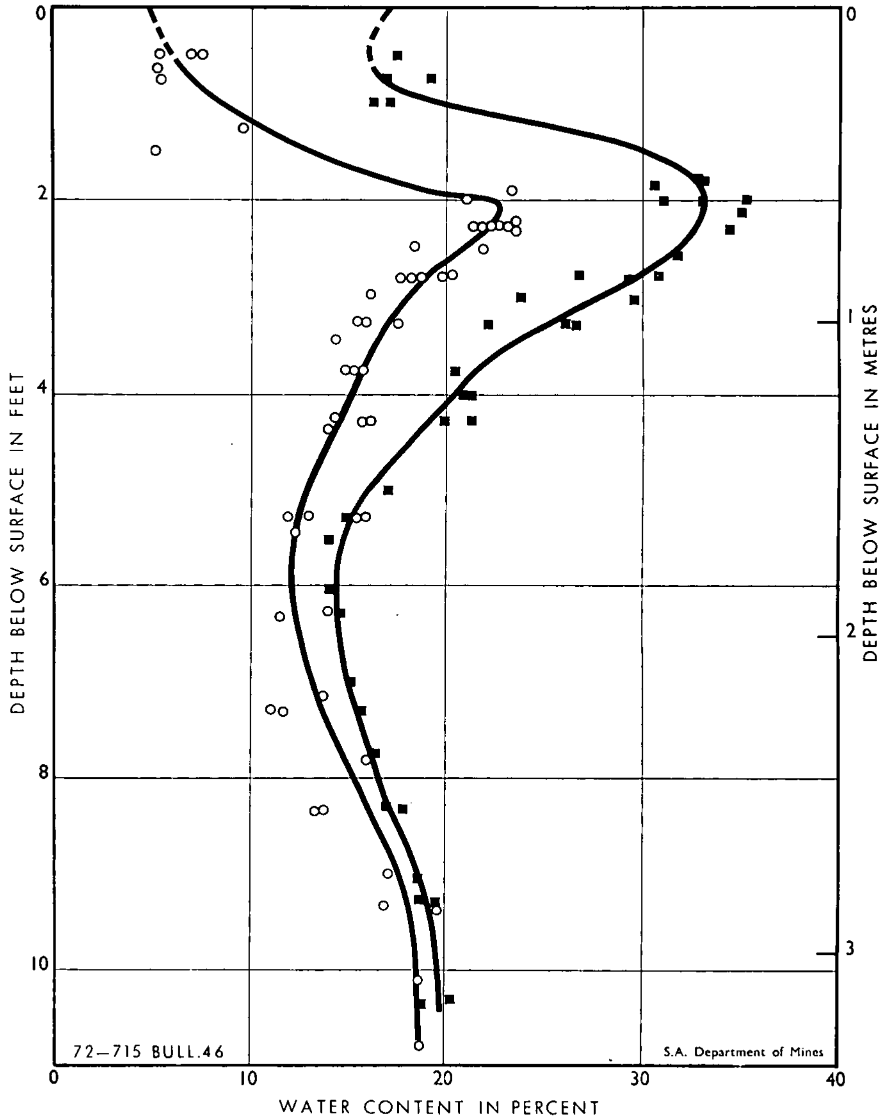

Fig. 8—Water content as per cent of dry soil *v*. depth at the wet and dry limits of seasonal variation for profiles of a red-brown earth (Type RB3) and a black earth (Type BE).

After Aitchison and Holmes (1953)

CHAPTER 6

SOIL CLASSIFICATION

For many years engineers have, in some countries and more recently in Australia, recognized the value of assistance from geologists and pedologists in solving foundation and construction problems. Geologists, by their understanding of the distribution and nature of surface sedimentary layers and of the underlying rocks, have provided essential data for the building of large structures such as dams, tunnels and multi-storey buildings. One of the contributions of pedology is the definition of soil units with specific characteristics, which may be allied to engineering properties of soils affecting the design of stable foundations for small buildings.

GENERAL DISCUSSION

Soil classification has been studied for 100 years, mainly with a bias towards agricultural use. In the last 30 years the possibility of devising a system to apply to engineering requirements has been sought, in particular to bring the principles of both uses into conformity, although the tests and criteria for each may vary. In each case a system of soil classification is required that allows a prediction of how soils will respond to different kinds of management.

Classification of soils serves three main purposes. First, to facilitate the clear definition of soil types for identification and for comparison with others. Second, to enable the distribution of like kinds of soil with the same behaviour to be shown through field survey and on maps. Third, to permit correlation of response of defined soil types to management.

A scheme of classification can easily be made complicated and over detailed. The more soils are studied in the field, the more evident it becomes that real differences distinguishing them in the sense of affecting their use, are often relatively few in number.

Combinations of soil characteristics which are considered to have practical significance are used to define soil types. It is necessary to know as much as possible about the occurrences of these characteristics from field examination. Some of the obvious examples likely to be significant are:—

Differences in thickness of soil horizons.

Nature and structure of clays.

Expandability of clay layers on wetting, and shrinkage and cracking on drying.

Presence of deeper layers of low permeability and of hardpans or bedrock.

Presence of lime in varying amounts, and of soluble salts.

Presence of fluctuating water tables.

Presence of organic material and of stones.

Unfortunately, the significance of these soil characteristics in relation to house foundations are not all known, but it is possible to attempt their evaluation when a basic classification on pedological grounds is defined. Such classification permits selection of standard samples which can be tested in the laboratory to determine their engineering properties. This information can then be applied to wider occurrences of the same soil types.

Stability of building foundations is dependent on the soil type and on site management. However, in a soil classification, management must be disregarded as a variable factor, not measurable in advance. A distinction has to be made between soil features which can be observed or readily measured in the field, and those which arise from inter-action of the soil with treatment imposed on it affecting its quality for the intended use. These many inter-actions are variable and stability of buildings can only be ensured by their control. An example is the moisture regime under the foundations of a building. If economic considerations were not involved, all structures could be made stable. The problem is to assess the minimum treatment to achieve stability on a soil of known characteristics, combined with economic foundation design.

THE BASIS OF SOIL CLASSIFICATION

Pedologists have attempted to classify soils on a world basis by setting up what have been termed *Great Soil Groups*. These are not all universal, although mostly they are very broad groups; and interpretation of them may vary between countries. In Australia, about 50 great soil groups have been defined and the classification used in this bulletin is based on seven of them. The assumed basis for a great soil group is that soils result from different pedogenic processes operating on a parent material, and that these find expression in mature soil profiles with specific characteristics. The controlling factors are—parent material—or in general, geology; climate—involving rainfall and temperature; relief—which includes topography and local water regimes; organisms—ranging from bacteria to forest trees; and time. With the exception of time, these are inter-dependent variable and their combination results in a wide range of soils. It has been considered possible to group these soils into recognizable great soil groups, and the broad characteristics of those relevant to the Adelaide region are described in Chapter 7. Provision is also made in the classification scheme used in the soil map for immature soils without normal profile form, for example, recent river alluvium or sand dunes. The great soil groups, from their broadness, are of reduced value for applied use and in some groups it is necessary to set up subgroups as "soil types" for specific application.

Aitchison, Sprigg and Cochrane (1954) made use of a system of soil classification applicable to engineering properties of soils in the Adelaide region, based initially on great soil groups. They set up "soil types" within the framework of the great soil groups to be used in defining and comparing the kinds of soils in relation to shallow building foundations. These were based on the character of the soil profile allied to its engineering properties, which were given precision by laboratory tests. The soil type has been used in agricultural surveys for a long time; when it is applied to engineering qualities, the criteria need to be altered. For example, the surface soil is of prime concern agriculturally, but rarely affects engineering design. The subsoil (B horizon and deeper layers) is the key to the engineering properties, together with the depth to underlying rock, if conveniently reached.

In practice, the soil types of Aitchison *et al.* (*op. cit*) have proved useful and, in the subsequent work of classification and mapping included in this bulletin, they have been adopted, because they have achieved some meaning among engineers and architects. In all, these authors made use of 14 soil types and ten sub-types within six great soil groups; five other groups of immature soils were defined. During the last five years, eight additional types or groups have been added to cover new units; only two of the original sub-types have been retained. The complete list of 25 units used in the field survey and in preparing the soil map—consisting of 19 soil types belonging to seven great soil groups and six units of immature soils without profile form —is set out in Table 6.

THE SOIL MAP AND MAPPING UNITS

It would be useful if the occurrence of soil types could be shown individually on a soil map. This is not possible, except on very small areas, due to the variability of soils over short distances, and the impracticability of surveying complex patterns of soils in detail. Consequently, any soil map of larger areas can give only an approximate picture of soil distribution. A comparatively large amount of reference data on individual sites for house building in the Adelaide region, is available from records of the Department of Mines and those of consulting engineers.

TABLE 6
SOIL UNITS

Soil Group	Group symbol	Soil Type symbol	Occurrence in Soil Association No.
Red-brown earths	RB*	RBI*	VIII, XI, XIV
		RB2*	XII
		RB3*, 3a*, 3b*	II, III, XII, XIV
		RB4	V
		RB5*, 5a	II, III, XVI
		RB6*	XXI
		RB7*	XXI
		RB8	V
		RB9*	XVI, XX
Black earths	BE*	BE*	III, IV, V, VI, VII, XI
Rendzina	RZ*	RZ*	V, VI, XI, XIV
Terra rossa	TR*	TR*	IV, V, VI, XI
Podzolic soils	P*	P1	IX, XIII
		P2*	X, XIII, XV
		P3	XIII, XV
		P4	XV
Solodic soils	S	S1	IX, XIII
		S2	XIII
Brown solonized soils		BS*	IV
Alluvial soils	AL	AL* (as TA1, TA2, TA3)	II, III, XI, XII, XVI, XIX, XXI
Estuarine muds and sands	EMS*	EMS* (as EM)	XIX, XXI
Dune sands	DS*	DSI*	XVII, XIX
		DS2*	XVIII, XIX
Slopewash	SW	SW	I, XI
Skeletal soils	SK*	SK*	V, VIII, X, XI, XIII

* Defined and used by Aitchison, Sprigg and Cochrane (1954) in Bulletin 32 of The Geological Survey of South Australia.

It must be recognized also, that soil occurrences cannot always be neatly fitted into the pigeonholes of a classification; some profiles are not classifiable into any accepted types at all. A soil type consists of a modal soil profile surrounded by a population of related profiles, all with similar characteristics impressed on them during formation, though they may differ in lesser ways, for example, in thickness of horizons or in content of lime. In all mapping, approximations are made to the nearest type. As a

TABLE 7

SOIL ASSOCIATIONS

Soil Association	Dominant Soil Types	Minor Soil Types	Equivalent to Bull. 32	Principal Occurrence
I	AL—Alluvium	SW, EMS	Torrens River Complex	Along Torrens and Sturt Rivers and all major creek lines
II	RB5—RB5a, Red-brown earth	RB3 and intergrades, AL, RB9	Edwardstown Association	Lower portion of the Upper Outwash Plain south from Torrens Valley to coast at Brighton
III	RB3—Red-brown earth	RB5, RB3a,—3b, BE intergrades, AL.	Urrbrae Association	Higher portion of the Upper Outwash Plain south from Torrens Valley to near coast at Darlington
IV	BS—TR—Brown solonized soils—Terra rossa	BE	Enfield Association	Western portion of Para Fault Block north from Adelaide City and at Marino
V	RB4—TR—RB8—Red-brown earths—Terra rossa	SK, RZ, BE	—	Central portion of Para Fault Block surface mainly in drainage zone of Dry Creek
VI	RZ—BE and intergrades, Rendzina—Black earth	TR	Gilles Plains Association	Central portion of Para Fault Block surface north of Modbury
VII	BE—Black earth	BE—RB intergrades	Claremont—St. Mary's—Paradise Association	Widespread in Para Fault Block surface and Upper Outwash Plains
VIII	RB1—RB3—BE—Red-brown earths—Black earth	P, SK	—	Lower slopes of Eden escarpment and outwash of Fifth Creek
IX	P—S—Podzolic—Solodic soils	—	—	Eastern portions of Para Fault Block surface north of Torrens Valley

TABLE 7

SOIL ASSOCIATIONS—*continued*

Soil Association	Dominant Soil Types	Minor Soil Types	Equivalent to Bull. 32	Principal Occurrence
X	SK—Skeletal	P2	—	Generally on Eden Fault Block surface and escarpment
XI	SW, RB1, RB3a—slopewash Red-brown earths	SK, BE, AL, RZ, TR	Netherby Association	Lower slopes of Eden escarpment south of Torrens Valley to Sturt River
XII	RB2—Red-brown earth	RB3a, RB3b, AL	Knightsbridge Association	Middle course of First, Second and Stonyfell Creeks
XIII	P2—Podzolic soils	P1, P3, S2, SK	Stonyfell Association	Generally on Eden Fault Block surface and upper escarpment slopes
XIV	RZ—TR—Rendzina—Terra rossa	RB1, RB3a	Beaumont Association	Eden escarpment at Beaumont and Seacombe
XV	P4—Lateritic podzolic soils	P2, P3	—	Highest ridge tops on Eden Fault Block surface
XVI	RB9—Red-brown earth	RB3, RB5—5a, BE, AL	Brayville Association	Lower Outwash Plain related to Sturt River
XVII	DS1—Dune sand	—	Osborne Association	Subcoastal dunes between Glenelg and Royal Park
XVIII	DS2—Dune sand	—	Semaphore Association	Coast line between Seacliff and Port Adelaide
XIX	EMS—Estuarine muds and sands	RB5a, DS1, DS2, AL and intergrades	Patawalonga Association	Low lying plain behind coastal dunes between Glenelg and Port Adelaide
XX	Poorly drained grey outwash soils	AL, RB9, RB5	Plympton Association	Lower Outwash Plain sediments from Brownhill and Glen Osmond Creeks
XXI	RB6—RB7—Red-brown earths	AL, EMS	Hindmarsh Association	Lower Outwash Plain north of Torrens River

principle, these are related as far as possible to probable engineering responses as, for example, intergrades between two accepted types are generally downgraded to the one with poorer foundation character.

The soil map has been compiled in terms of "soil associations". (Aitchison *et al.*, 1954). A soil association is a group of soils found as a typical recurring pattern in a landscape and is made up of one or more dominant soil types associated with one or more minor types *likely to be found in a given locality*, without attempting to be precise at any particular site. This can only be ascertained finally by an examination at the site itself.

The 21 soil associations and their constituent types are shown in Table 7, together with the geography of their principal occurrence.

In preparing the soil map at the scale used it has been necessary to omit some details shown on the maps already published in the Metropolitan Soil Map Series (Steel and Taylor, 1968; Taylor 1969, 1970a and 1970b). The principal distribution of the soils should be correlatable with the parent material and geomorphology of the area (see Chapter 8).

CHAPTER 7

SOIL TYPES AND THE GREAT SOIL GROUPS

Different soil forms with specific features may be produced by many processes. These include leaching under variable chemical conditions, types of weathering, or the introduction of foreign material by water or wind action. They are also dependent on the nature of the parent material. All these factors combine to produce an identifiable soil profile. Recently formed soils, which have not yet developed a profile, are described as amorphic.

The Great Soil Groups have a genetic history, and each according to the mode of its formation shows a developed soil profile with recognizable horizons. Seven of these groups, together with five groups of amorphic soils have been recognized in the Adelaide region (Table 6). A brief description of each soil type follows and typical profiles are given in Appendix 1. The descriptions are given in broad terms only as it is impossible to devise a workable classification to cover all variations.

RED-BROWN EARTHS (RB)

These are the most extensive of the Great Soil Groups occurring in the Adelaide region. They have been formed mostly on the transported sediments of the outwash plain, but some are residual on bedrock. They have in common a brown or grey-brown fine sandy or silty A horizon* overlying, with a sharp change, a strongly red-brown to red clay B horizon, which passes to a browner and variably calcareous Bca horizon at a depth of less than one metre. The Bca horizon tends to merge with the C horizon as a BC layer or may affect underlying parent rock by infiltration of lime along cracks and joints.

Nine different soil types may be recognized within this group. Structure, lime content and colour of the B horizons may vary significantly for each type. Texture can also vary, from sandy clays to stiff, highly plastic clays.

An unexpected feature of the B horizon clays of Types RB1, RB3, RB4, RB5 and RB8 is the similarity of their physical composition. This is irrespective of their structural form or whether they are residual or transported soils. The clay content of the B horizon is very high, generally between 50 and 80 per cent. Lower figures are usual on the low-lying parts of the Lower Outwash Plain (Types RB6, RB7 and RB9) with clay contents of about 40 per cent.

The nine soil types forming the red-brown earth group are next described in greater detail.

Type RB1

This type occurs on moderate to steep and mainly smooth slopes along the mid and lower portion of the Eden escarpment, where it is subject to colluviation and to dissection by active creeks. It is mainly found between 170 and 225 metres elevation, but in some areas occurs higher up on the escarpment where it is probably associated with a particular parent material. The soils are partly residual, usually on slates and quartzites, and always contain angular stone fragments throughout the profile. They generally have some lime accumulation as a thin Bca horizon.

Surface erosion and downslope accretion have affected the soil materials, but they have been in place long enough to develop recognizable red-brown earth profiles. At higher levels, where they are subject to higher rainfall and greater leaching or erosion, the RB1 soils grade into skeletal soils or, in some areas, into podzolic types. On the lower slopes where strongly calcareous rocks occur (*e.g.* Beaumont), they are replaced by rendzina and terra rossa soils. Undifferentiated, stony slopewash is associated with Type RB1 soil along the creeks.

Type RB1 profiles may show considerable variation in the depth and nature of soil horizons, but weathered rock is usually not more than 60 to 100 cm below the surface.

Absorption of water is rapid in the surface soil but the formation is subject to heavy run off on the steep slopes. The greater rainfall on the rising escarpment ensures profile wetting and considerbale seepage is expected along the soil-rock interface.

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* Soil profile layers derived genetically during pedologic development are called "horizons". These are referred to broadly as A (surface soil) B (subsoil) and C (weathering parent material) horizons. Each may be subdivided *e.g.* A1 (having some organic accumulation)—A2, B1—Bca (having lime accumulation by downward leaching). Transitional horizons are referred to by combination *e.g.* BC. In amorphic soils the term "layers" is used to distinguish different materials.

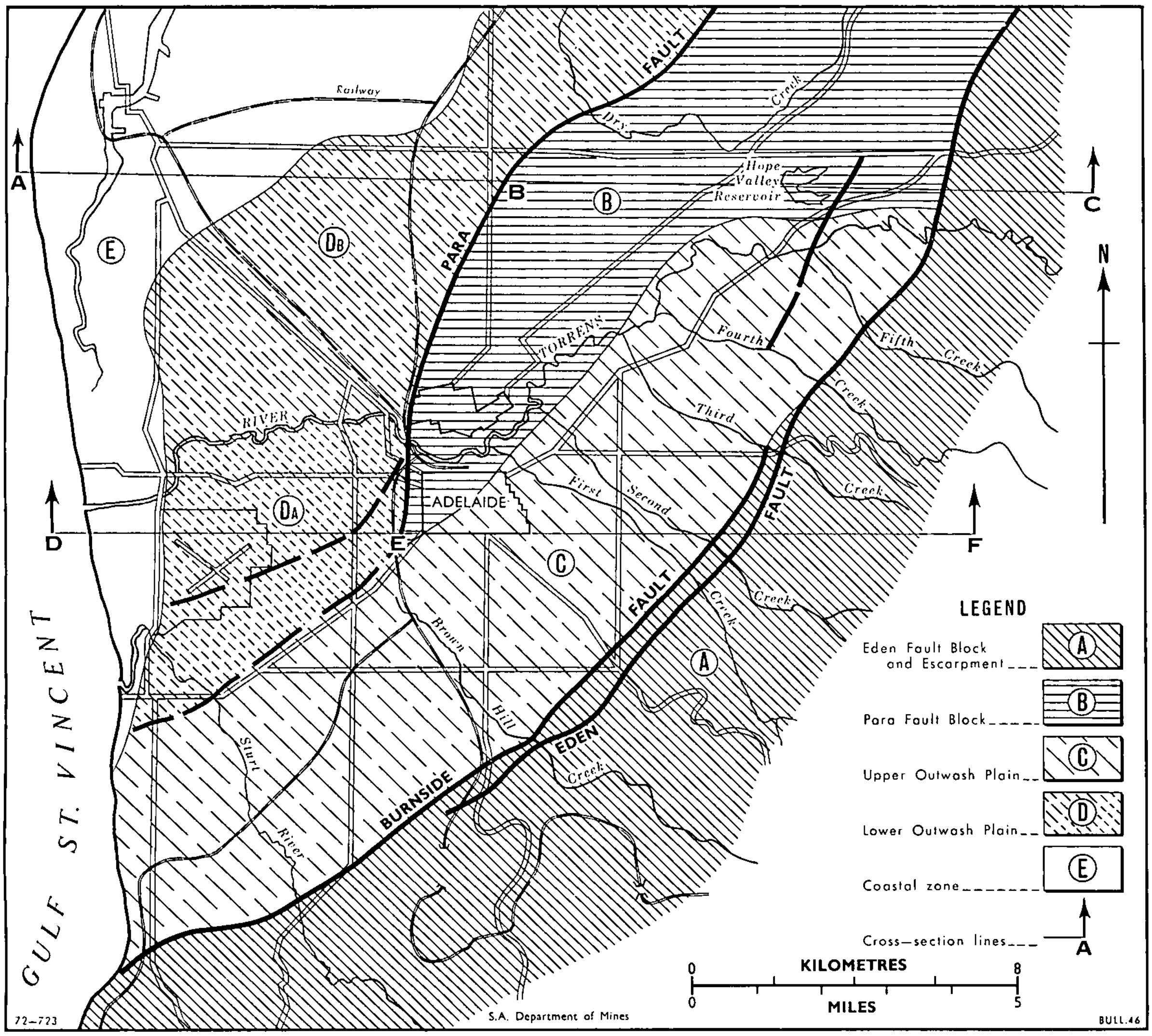

Fig. 9—Map showing the geographic units used in describing the distribution of soils in the Adelaide region. The cross sections illustrated in Figs. 11 and 12 are marked A-B, D-E and B-C, E-F.

Type RB2

These soils are red-brown earths developed on relatively coarse alluvium with little lime in the profile. The parent material comprises the outwash fans of the First, Second and Stonyfell (Third) Creeks which occur close to their emergence from the foothills. Although these streams are now only active in wet periods, in the past they have strongly eroded the quartzite formation on the escarpment and deposited highly siliceous sediments. Type RB2 soils have affinities with both the alluvial soil group (AL), and with Type RB5 of the outwash plain. They occur over most of the Burnside, Tusmore, Erindale and Kensington Park districts and lie approximately between the 90 to 150 metre contours. Similar soils may also be found closely following the courses of other major creeks.

The type is characterized by a non-expansive red-brown earth profile, low in lime, with horizons often not very well developed. It usually overlies sandy or gravelly substrata.

Surface absorption of water is high. The profile is freely permeable and has rapid internal drainage without development of wetness or water tables.

Type RB3

The typical RB3 profile has developed on deep fine-textured sediments of the alluvial fans which form the main outwash plain below the Eden escarpment. Its usual occurrence is on smooth, moderate to gentle slopes associated with the drainage systems of the Torrens and Sturt Rivers, and the very numerous creek lines with undefined channels issuing briefly from the escarpment. The type appears as a broad band bounded on the higher level by the steep foothills slope, and at lower level merging with Type RB5 as the plain becomes flatter. At its northern end near the Torrens valley, the Type RB3 zone lies generally between 60 metres and 130 metres elevation; at its southern end near the Sturt River it lies between the 30 and 60 metre contours.

The main feature of the profile is the B horizon clay. This has a pronounced red-brown colour and a well developed prismatic to angular blocky structure which on drying breaks into coarse units with bright surfaces. In the dry state shrinkage cracks are severe, and often extend to the surface.

Surface absorption of water in all Type RB3 profiles is moderate to rapid and internal drainage through the profile moderate to slow while allowing steady, deep, wetting in normal winters.

Type RB3 Variants

Two variants of Type RB3 have been distinguished as sub-types.

Sub-type RB3a is a stony form usually occurring at higher levels between 80 and 150 metre contours and is associated with faster surface drainage and stone movement.

Sub-type RB3b is a form with deep light textured sandy or silty surface soil occurring at higher levels on the plain, and associated with drainage lines and surface wash.

Type RB4

Type RB4 occurs on the undulating broadly dissected terrain of the Para Block where it is traversed by the numerous tributary drainage lines of the Dry Creek system. It also occurs in the Hope Valley area. Slopes are generally moderate to steep and the type occurs at all levels except in valley bottoms. The main areas appear to lie between the 100 and 150 metre elevations.

The soil is a residual formation underlain by variably calcareous slates or siltstones and has clearly developed the horizons of a shallow red-brown earth. Near the eastern boundary of its occurrence, it may have been influenced by accessions of windblown lime. Type RB4 tends towards a terra rossa on more calcareous parent material, especially in shallower profiles. On less calcareous rocks, it has some characteristics of Type RB1, apart from a general lack of stonyness in the profile. It is also associated with Type RB8 in the Hope Valley area and with rendzinas in the North Modbury district. Intergrade forms with these other types result from variations in lime content of the parent material and from topographic position.

Type RB4 has a sandy to silty A horizon, sharply separated from a red clay B horizon, which passes into the lime-rich zone and weathering rock.

External drainage on slopes is rapid although surface absorption is also moderately rapid. The profiles are moderately permeable and wet freely. Seepage downslope occurs along the soil-rock interface under moist conditions.

Type RB5

Type RB5 is formed on fine textured outwash material deposited as alluvial fans and as creek and river terraces. It is found on smooth gently sloping or nearly flat plains generally at elevations less than 30 metres, but in places up to 60 metres along the courses of presently active or buried former creek lines. The main occurrence is on the lower plains where they maintain good drainage before merging into the wet subcoastal zone.

Type RB5 is characterized by a sandy or silty A horizon, sharply separated from a clay B horizon with granular structure, grading into the usual Bca horizon of red-brown earths. As transported sediments derived mainly from argillaceous slates and shales, the soil materials of this type may develop profiles representing all gradations between types RB3 and RB5.

Type RB5 Variants

Type RB5a is a sub-type that conforms generally to the standard profile of Type RB5 and may be assumed to have the same engineering characteristics. It occurs at low elevations close to the coast, often adjacent to the present coastal dune system. It seldom reaches the level of the 15 metre contour and is mainly noted between the lower course of the Sturt River and the coast. It has some affinities with Type RB2 and RB7.

RB5 transitional to recent alluvium. Along the course of the Sturt River, over the upper and middle section of the outwash plain and along the margin of the Torrens Valley from Paradise to the city, the alluvial flood plain is bordered on one or both banks by an older low terrace. This consists of a band of light textured soils of RB5 type which are considered to be less mature red-brown earths and transitional to the normal type. In most characters, except for a sandy understratum and a less sharply defined B horizon, the variant is similar to Type RB5.

Absorption of water by all Type RB5 soils, and in particular the variants described, is rapid and profiles wet freely to considerable depth. The granular structured clay of the B horizon freely transmits water although in the moist state it is sticky and highly plastic.

Types RB6-RB7

It is convenient to discuss these types together as they are found in very close association and grade into each other. There does not seem to be any discrete area of any size in which either occurs separately. It may be seen on Fig. 2 that the outwash fan of the Torrens River spreads broadly northwest towards Port Adelaide from the Para Fault Block escarpment zone. It is in this wide area between the escarpment and the sea, and mainly north of the present river course, that Types RB6 and RB7 are found. The only other soils in this region are alluvial sediments which tend to merge with Type RB7. Many of the Type RB7 soils are juvenile forms of red-brown earths and do not have the sharply defined horizons of the other types described in this Great Soil Group. They show a more gradual transition in the profile and in some ways resemble the Type RB5 transitional form. They are often low in lime content and on the whole, quite sandy in the lower profile. Both types RB6 and RB7 are on very gently sloping plains from the foot of the Para escarpment at about 15 metres elevation and drop gradually down to about 8 metres near the coast. Type RB6 is reported as being affected by high groundwater tables and salinity. Wherever groundwater salinity has been effective over a long period the profiles may show differences in structure of the B horizon, such as a coarse, prismatic form and a bleaching of the lower A horizon.

The internal drainage of the profile is moderate to rapid, and external drainage is slow. At lower elevations the groundwater will normally rise to within two metres of the surface, and higher under wet seasonal conditions.

Type RB7 has previously been described by Aitchison *et al.* (1954) as part of the well drained Lower Outwash Plain. North of the Torrens valley the relatively higher levels of this plain have largely Type RB7 soils. A number of creeks rising on the western portion of the Para Fault Block take their courses northwest quickly losing their present identity on the plain. Formerly they must have been active streams because the influence of these and of the Torrens River is shown by the sandy sediments generally found at about one metre depth. These are generally micaceous and become coarse textured deposits along the immediate courses of buried streams. In general, the profiles are low in lime content with the horizons gradational rather than sharply defined as in most of the other red-brown earths, but they have the typical red-brown and brown colours of the group. They are however, quite variable in physical constitution.

The profile of Type RB7 is normally moist, without the influence of shallow water tables, apart from local occurrences towards the lower levels of the outwash plain where Type RB6 is dominant. Internal drainage of the profile is rapid.

Type RB8

Type RB8 occurs chiefly on the higher parts of an undulating landscape on the Para Fault Block north of the Torrens valley and west of Hope Valley Reservoir. The soil profile appears to have been derived from more than one parent material and varies considerably in some features such as amount of lime present.

The origin of the red clays of the upper B horizon is not properly understood and they may represent transported material. The high concentration of lime usually present is possibly due to accessions of windblown lime from coastal sources. Beneath are clays derived from Tertiary sandstone, but in some more western occurrences the deep mottled layers appear similar to the Hindmarsh Clay commonly found in this part of the Para Fault Block.

The type does not occur in wide single areas but in association with other soils such as Type RB4, and terra rossa (TR). Along the Torrens valley margin, soils intergrading to the black earths (BE) are found.

Soils of Type RB8 have been mapped in association with other soils rather than as distinct unit areas. From the engineering aspect they are soils likely to present foundation problems and merge gradually either into soils with black earth characteristics (BE) or, in the west, to brown solonized soils (BS).

Absorption of water at the surface, particularly when this is sandy, is rapid and the profile wets moderately rapidly. The intergrade forms trending towards black earth are assumed to act as black earths.

Type RB9

Near the coast at Glenelg the lower course of the Sturt River is marked by a wide zone of outwash soils modified both by flooding and by a reduced rate of internal drainage. Although the river apparently maintained a course, there was sufficient impedance of through drainage to cause regular flooding of lower lying lands, only remedied after settlement by channelling. The result of this periodic saturation is shown in the features of the soil profile typical of conditions of slow drainage and temporary saturation.

Following the Sturt River from the foot of the Eden escarpment the descending sequence of red-brown earths is a follows:—

Type RB3 (well-drained)—RB5 (well-drained)—RB5a (less well-drained)—RB9 (poorly drained and at low level).

Type RB9 has a number of minor variants because of its association with Type RB5a and with alluvial and estuarine deposits. The frequent flooding with both fresh and saline waters has caused local modifications. In consequence the soils have had a veneer of both finer and coarser alluvial deposits spread over them.

Under present control of drainage, surface absorption of water and internal drainage of the upper profile is rapid. Previously, Type RB9 areas must have remained wet for considerable periods. Some of the soils observed showed evidence of saline influences, which might show up as strongly prismatic structured clays with black cleavage faces. These are more likely to occur towards the lower fringe touching the estuarine soils.

BLACK EARTHS (BE)

In the Adelaide area the black earth group consists of an assemblage of dark coloured, expansive clay soils. These have a wide variety of profile characteristics connected with the origin of the parent material in different localities*. Almost all have been formed on fine grained alluvium subject to slow drainage and periodic wetness.

North of the Torrens River, large areas of uniform black earths are found at Gilles Plains, Modbury and Hope Valley. The origin of the soil material for this area is obscure. South of the Torrens, the soils occur mostly in smaller patches. These are related to the escarpment drainage where the streams lose their channels and flood the surface causing alternate wetting and slow drainage of the soil profile. Similarly for spring seepages, any slight depression on the plain, involving wet conditions through the winter, will cause the formation of black earth soils. The two areas of black earths found on the Eden Block are on a nearly flat surface, directly overlying unrelated country rock.

In their original state the larger areas of black earths were grassy plains with few trees. The localized occurrences associated with stream flooding are sometimes covered by large red gum trees. Undoubtedly there are minor differences between the soils of these two landscapes, and the tree covered areas probably have a better internal drainage. For practical purposes, they conform to the same Great Soil Group and should exhibit the same engineering characteristics for foundations. All have high shrinkage and expansion properties, with some extreme cases.

South of the Torrens valley, black earths occupy a position on the outwash plain similar to the red-brown earth, Type RB3. Indeed, the types grade into each other and some typical black earth areas are shown with intergrade BE-RB soils partly surrounding them. In other places, black earths grade into rendzinas and these are shown as BE-RZ.

* Aitchison *et al.* (1954) defined sub-types BE1, BE2, BE3. In the present Bulletin no distinction has been made.

A strongly variable feature of black earth profiles is the content of lime and its depth of occurrence. It ranges from small amounts of soft lime and some hard fragments, to calcareous zones as much as 60 cm thick, and whose upper boundary may vary from a depth of 30 to 100 cm in a distance of two metres. This irregular and unpredictable occurrence of the lime rich horizon is of great significance in foundation problems.

The surface layer of a black earth profile is normally a dark grey to black clay often, in the dry state, with a hard granular structure and in the wet, extremely sticky, very firm and highly plastic. On drying, the soils develop wide, fissure-like shrinkage cracks extending down to as much as one metre and showing a roughly hexagonal pattern at the surface. Ground surface may be uneven with low mounds and depressions which are known as gilgai.

Absorption of water is at first rapid through the granular surface and passing down shrinkage cracks until swelling of the wetted clay closes them; the profile otherwise is only slowly permeable, except in the calcareous horizon which may become saturated due to reduced rate of drainage through the deeper clay. This condition is intensified if surface drainage round buildings allows undue wetness to develop in the calcareous zone. Under natural conditions it is at least partly countered by the de-watering action of vegetation.

RENDZINA (RZ) TERRA ROSSA (TR) AND BROWN SOLONIZED SOILS (BS)

In the Adelaide region, soils which have developed residually on calcareous rocks, are normally shallow and range in colour from black, through dark brown and red-brown, to red. The rendzina typifies the darker end of this spectrum and the terra rossa the red end. Classification of intermediate colour positions tends to be arbitrary. Since the two groups often have similar characteristics for building purposes, there is no need for fine distinction except where the profiles are deeper than usual.

It has been assumed that the brown solonized soils (Type BS) are formed from calcareous sands and silts of windblown origin, confined to a zone relatively close to the coast. One theory is that calcareous loessial material was swept inland from the sea floor at periods of low sea level, and deposited as a veneer on a variety of existing land surfaces. It is probable that many soils in the Para Fault Block (black earths, red-brown earths and even the solodic soils) received some of this adventitious lime. Wherever deposits were thick enough, brown highly calcareous sandy soils formed, and these are nominated as Type BS.

Rendzinas (RZ)

Rendzinas are soils of a lime-rich environment, developed on calcareous slates or limestones, or affected by accretion of lime by wind or water action. The carbonate removed from the upper soil is concentrated typically as a layer of calcrete up to 5 cm thick, resting on calcareous silt overlying the weathering parent material. This is usually found within 30 to 45 cm of the surface. Where the soil profile is deeper, rendzinas grade towards black earths, and become a calcareous black earth if the overlying clay is more than 60 cm thick.

Type RZ occurs mainly on moderate to steep slopes on the Para Fault Block or on the escarpment of the Eden Fault Block. The largest area is north of Modbury, in a complex with black earths (RZ-BE). Intermixed with other shallow soils, it also occurs extensively between the Sturt River and the coast. At Beaumont and other local spots on the Eden escarpment, it is typically associated with terra rossa soil.

The profile consists essentially of a dark coloured topsoil showing little horizon separation, overlying a lime-rich zone which passes finally to parent rock.

Internally, the soil profile is permeable and absorbs water freely at the surface; run off is related to slope angle and intensity of rain.

Terra rossa (TR)

Terra rossa soils are shallow residual formations, red or red-brown in colour and developed from limestones or other highly calcareous rocks. In some localities, particularly towards the escarpment of the Para Fault Block in the Ingle Farm district, these soils are strongly influenced by windblown lime and are closely associated with the brown solonized soils. In few cases are there any notable discrete areas of the terra rossas, the most significant being near Brighton.

Generally these soils are less than 45 cm thick above the lime-rich layer and show little development of profile horizons.

Type TR soils absorb surface water freely and allow little run off on moderate slopes.

Brown Solonized Soils (BS)

Unlike the rendzina and terra rossa, this group of highly calcareous soils is derived primarily from windblown material. Mixtures of fine and coarse mineral material have given rise to a wide variety of soil profiles, whose common physical characteristic is the zone of lime-rich silt and limestone nodules at shallow depth. The soils may be grey, brown or reddish-brown, and may be loose and powdery or firm. Soft lime may be dispersed or in pockets, while hard lime occurs as nodules and lumps in a sandy to clayey matrix. When moist this matrix loses its bearing capacity, producing what are known as "collapsing" soils. Type BS soils are alkaline and often contain significant amounts of soluble salts.

Brown solonized soils occur principally on the western side of the Para Fault Block and its escarpment, from Ingle Farm to South Adelaide. Here the land slopes are smooth and moderate and are cut by a number of short stream lines. At Ingle Farm, where calcareous slates are at relatively shallow depths, Type BS is associated with the red-brown earth, Type RB4. On the adjacent escarpment it has associated terra rossa soils on some stream slopes and generally overlies the Hindmarsh Clay, at depths of around one metre. The main spread of the brown solonized soils is the broad band running down from Para Hills to cover the northern city area and continuing past the Torrens valley to the southern margin of the central city block. Over most of the city area, Type BS soils vary from a thin layer up to three metres thick, overlying the Hindmarsh Clay.

Soils of a character similar to those on the Para Fault Block occur at Brighton, but there the lime appears to be derived partly from the calcareous parent material which outcrops on the escarpment. It is not clear how the observed lime concentrations have developed but they vary in consistency from compact forms to loose rather powdery occurrences. The powdery forms appear to show "collapse" features and may contain as much as 70 per cent calcium carbonate but in engineering properties, they are related to the Type BS soils. The more compact soils appear to retain some bearing capacity when moist and are therefore assigned to the terra rossa or rendzina category. Since Type BS soils are closely associated with the rendzinas at higher levels and with the terra rossa at lower levels it is desirable to examine sites closely, as the engineering character of the soil is a matter of local decision.

These lime-rich soils overlie various substrata from rock to mottled clay. On the higher slopes they are always shallow (less than a metre) and at lower levels with the terra rossa may be considerably deeper. In a few localities black earth-like soils (Type BE) have been noted probably where a clay substratum low in lime has been exposed to soil profile development.

External drainage is slight due to rapid surface absorption and the highly permeable profile.

PODZOLIC SOILS (P)

The podzolic soils occur on the Eden Fault Block where they form the most important group of mature soils within that part of the block covered by this bulletin. They are all essentially residual in origin and produced at elevations of 325 metres or more, under relatively high rainfall and acid leaching conditions. Variations are caused by differing parent material such as sandiness, or in the amount of iron bearing minerals. In this area, pedologic processes are not severe enough to affect calcareous materials, which explains the absence of these podzolic soils west of the Sturt River.

Four podzolic types have been distinguished and are described below:—

Type P1—Podzolic soils formed on Tertiary sandstone and sands

These soils are confined to the eastern part of the Para Fault Block north of the Torrens River. They have been formed over sandstones on the higher levels of the undulating foothill slopes of the Eden escarpment. They also occur lower down on the deep coarse sand deposits and sandy outwash from a number of creeks. In this area, land surface is gently to moderately undulating and much dissected by short creeks from the escarpment.

The profile which has developed from the mottled sands has a typically coarse textured A horizon over a mottled red, grey and yellow sandy clay B horizon, which gradually merges to the C horizon. The thickness of horizons and of the soil profile is variable and dependent on topographic position, amount of transported material and on wind action. In this way the sand of the A horizon ranges in depth from about 15 cm to as much as 2·5 m, with an average thickness of about 40 to 50 cm. The thicker sections are wind-piled sands in a relatively loose state, subject to consolidation on wetting or under load.

The sharp change of texture between the highly permeable A and the rather slowly permeable B horizon causes seepage downslope under wet seasonal conditions, which is a material problem in under drainage of buildings. The upper 2 or 3 cm of the B horizon show evidence of this wetness in a partly degraded condition with dull dark grey and mottled colours. The whole sandy clay layer is compact, but allows satisfactory infiltration of water and through drainage.

Type P2—Yellow podzolic soils

The yellow podzolic soils are found on the dissected highlands of the Eden Fault Block where weathering and erosion have permitted soil accumulation. Wherever pockets of deeper soil occur on the steep ascent of the escarpment there is a change from shallow red-brown earths to podzolic types at approximately 225 metres elevation. Again, these soils are allied to their parent materials which are mainly slates, quartzites, and sandstones. On the slates a yellow or yellow-brown blocky clay B horizon is expected while on sandstone the tendency is to produce sandy clay textures. The soils are generally shallow (1 metre) except on mid to lower slopes to creeks where greater depth may have come from deeper weathering or by colluviation. The colluvial soils have denser, mottled clays and show signs of restricted drainage with longer periods of seasonal moistness.

Type P2 is associated with the red podzolic Type P3, the lateritic podzolic Type P4 and, on the steeper slopes, with skeletal soils (SK).

External drainage is generally rapid because of the steepness of slopes but is less on gentler slopes due to ready surface absorption. Internal drainage is moderate with some lateral seepage along the sand-clay and clay-rock interfaces.

Type P3—Red podzolic soils

These soils occur in scattered places within the yellow podzolic soil zone, usually on mid and lower slopes. It is thought that the parent material is higher in iron bearing minerals than surrounding podzolic soils and in consequence, the clay B horizon is both strongly red and is stabilized in a granular structure from the effects of the hydrated ferric oxides. Many cases occur of soils with mottled red and yellow clays; the distinction between red and yellow podzolic soils for field indentification is in the structure of the clay horizon.

The soils have a shallow sandy topsoil changing sharply to a clay horizon, which has both a marked red colour and a coarse granular structure.

At a variable depth the clay becomes red and mottled with frequent stone fragments, grading to parent rock.

Type P4—Lateritic podzolic soils

The Tertiary landscape on the Eden Fault Block has been modified by peneplanation and extensive laterite formation. Little evidence of the original surface remains, but on higher ridges lateritic podzolic soils, developed from the degradation of the old laterite surface, occur as relics. Breakdown of the laterite under podzolizing influences has produced a soil profile with a sandy textured A horizon, containing considerable pisolitic and nodular ironstone gravel. This overlies a yellow or red and brown mottled clay apparently weathered from the original mottled zone, which may still be seen in deep cuttings in the Adelaide Hills, (*e.g.* Belair railway station). The mottled clay passes into less altered and greyer clays of the same weakly expansive, kaolinitic nature. The profile is essentially podzolic in character but has the mark of parent material of an ancient laterite soil profile.

Surface run-off would be slow because of the terrain and the absorptive surface soil. The clay of the profile transmits water readily and normally wets deeply. It is not affected by water logging, but other podzolic soils on slopes below Type P4 may be affected by seepage under a high winter rainfall.

SOLODIC SOILS (S)

Although solodic soils are widely distributed in the main zone of podzolic soils, they are of less importance because of their sporadic occurrence. Where they are recognized, they merit attention as having engineering characteristics less favourable for house foundations than the associated podzolic soils.

Solodic soils are thought to be the end result of profile formation when parent materials have first passed through a process of leaching in the presence of soluble sodium salts. These soils have then been subjected to continued leaching under acid, podzolizing influences. The first stage produced a highly alkaline clay B horizon, strongly structured in prismatic or columnar forms. In the second stage, this degraded to a dense, but less highly structured state, while becoming progressively less alkaline. The lower surface soil (A2 horizon) shows extreme leaching effects as a pale, bleached fine sand. The solodic soil resembles a podzolic type in many features, but it is considerably denser in the B horizon.

These soils occur on nearly flat to gentle slopes on both the Para and Eden Fault Blocks but not on the escarpment slopes. On the Para Fault Block they are formed on Tertiary sandstones (Type S1), are confined to the eastern part of the block and, with one exception, are all north of the Torrens River. On the Eden Fault Block solodic soils (Type S2) occur in all topographic situations, except on steep slopes, and are associated with the podzolic (Type P2) soils.

The principal profile features are the sandy highly leached A horizon and the mottled clay B horizon which shows stronger mottling and a more sandy texture in Type S1.

AMORPHIC SOILS

Those soils which have not developed a recognizable profile due to origin or age are termed amorphic. Five main groups occur in the Adelaide region.

Alluvial Soils (AL)

These are immature sediments laid down on narrow belts along the courses of streams, past or present, and so juvenile that profile forming processes have not had time to affect them. There are no pedologic horizons except for some accumulation of organic matter in the first few inches. The sandy deposits may show current bedding and, at the other extreme, there may be thicknesses of fine sandy or silty clays.

The alluvium ranges widely in composition from pebble beds through sandy layers to low plasticity silty clays. There are no clays of an expandable nature in this group. It should be recognized that they grade into outwash soils with some profile development and different engineering character. Buried alluvial soil is to be expected where creeks have changed course in the past or where short streams have lost their channels in the plain.

It must be emphasized that, while only the flood plains of major streams have been shown on the soil map, alluvial soils exist along all distributary streams flowing from the escarpment. These alluvial deposits show a wide range of colour and lithology but in general it may be said that:—

(*a*) Dominantly sandy alluvial deposits occur closely along all stream lines in the Upper and most of the Lower Outwash Plain from the Eden escarpment. Occasionally, gravel and pebble beds have been noted.

(*b*) Sands, clayey sands and some fine sandy clays are common in the Torrens River, Dry Creek, Brown Hill Creek and Sturt River flood plains.

(*c*) Along the immediate levee bank of the lower Torrens River, below the Para escarpment, deep very sandy formations have been noted.

(*d*) Along the Torrens River near the subcoastal zone, silty clays and sandy clays, with more sandy layers included, are common and merge indistinguishably into the Estuarine Plain.

(*e*) The courses of the streams south of the Torrens River down to the Sturt River passing through the Lower Outwash Plain are marked by silty clays, fine sandy clays and with some included sand layers.

(*f*) The courses of the streams issuing from the Para escarpment north of Adelaide city centre are usually sandy.

(*g*) A layer of alluvium up to 50 cm thick occurs on a truncated red-brown earth along the major incised creeks and in the upper parts of smaller creeks near the Eden escarpment. In these areas a grey and yellow mottling of the upper clay horizons indicates temporary periods of water-logging.

(*h*) Along the Torrens and Sturt Rivers, in their passage over the Para Fault Block, are found rising terraces as a transitional zone with immature red-brown earths grading into an alluvial formation.

Internal drainage is rapid due to high permeability but, on account of their topographic position and flatness, the alluvial soils may be subject to temporary wetness from surface flooding. Approaching the coast, groundwater tables are found at relatively shallow depths, varying with the wetness of the season.

Estuarine Deposits (EMS)

A belt of silty to sandy deposits containing organic accumulations occurs in the coastal area behind the present dune frontage. These were formed between the effects of past marine incursions and the alluvium deposited by the Torrens River. This estuarine zone is well developed between Glenelg and Port Adelaide. It is virtually flat, originally having a network of sluggish drainage channels leading north towards the Port River and alternatively into the Patawalonga Creek.

The formation is dominantly sandy below one metre depth although finer textured materials are present in the transition from Torrens alluvium. There is also a merging to the poorly drained fringe of the Lower Outwash Plain in the vicinity of the Adelaide Airport. The dividing line is at approximately the 6 m contour.

These estuarine muds and sands are grey, dark grey or mottled, with a tendency to a bluish-grey sand below the water table. The water table various seasonally to as little as 0·6 m below the surface. The mottling is indicative of water-logging.

In certain areas, deposition took place under swampy conditions as in the old Reed Beds area. This brought about a build-up in organic matter in the surface layer which showed as black organic silty clay. In places remains of reeds still occur below the water table.

The estuarine zone has in places been modified by grading of sand from coastal dunes as a sheet over the low lying area. This appears to have happened at West Beach although, if the frontage dunes had become unstable, the sand sheet could have spread naturally. Extensive drainage has lowered the dangerously high water tables in some areas, allowing house building to proceed, as internal drainage of the soils is rapid.

Conditions of deposition have led to the addition of lime in some areas but there is no general evidence of this. Shell beds in a sand layer at about one metre depth have been observed in some locations.

As a group the EMS soils are commonly saline. Up to 5 000 mg/litre dissolved salts have been recorded in the upper layers and the water table may be considerably more saline. This situation would change with drainage of the soils and leaching of the salt to a lowered water table.

Slopewash (SW)

Undifferentiated clayey and sandy material collected by colluviation at the lower line of steep slopes has been termed "slopewash". It may have a surface layer of coarser nature due to recent sheet erosion further up the hill-slope.

There is no profile development and the whole layer may be less than one metre thick, although much greater thicknesses have been seen. The soil material always contains fragmental rock in various stages of weathering. No distinction has been made between derivatives of softer calcareous shales and hard quartzitic rocks. In its stonier form it trends toward scree deposits.

Since slopewash is found on all kinds of steep slopes, and is particularly well developed along creek dissections, there are no common levels of occurrence. It occurs anywhere between the lower foothill slopes of the Eden escarpment and the valleys on the top of the Eden Fault Block.

Most of the slopewash material is red-brown or grey-brown and, proceeding up the slope it often grades into a red-brown earth (Type RB1) or sometimes into terra rossa, rendzina or skeletal soils.

As a soil formation the slopewash is generally permeable and internal drainage, medium to rapid; it is subject to consolidation.

Skeletal Soils (SK)

These consist of very shallow soil materials developed from older rocks such as slates, shales and quartzites. The soils are mainly confined to the steepest escarpment slopes and the more rugged hills of the Eden Fault Block, where rock outcrops are common. On smoother slopes and in other local patches where weathering has permitted, shallow stony podzolic soils (Type P2) and shallow-rendzina soils are associated.

Dune Sands (DS)

Dune systems, associated with past or present sea levels, are in evidence in the coastal and sub-coastal zone of the Adelaide region. Two of these are distinguished. The older, related to the Flandrian high sea level (see p. 15), is now stranded inland, and the younger is still lining the coast. The earlier dunes were described previously as the Osborne Association (Aitchison *et al.*, 1954).

There are two types of dunes, showing specific differences both in appearance and engineering character:—

*Type DS*1

This occurs as a discontinuous belt mostly of low dunes, spread along a subcoastal line from Glenelg to near Port Adelaide. It possibly extended southward towards Brighton at one time where there are indications of other obliterated dunes.

The dunes principally follow the inland margin of the low lying estaurine zone (Group EMS) and some outliers nearer the coast are surrounded by these soils.

In general, Type DS1 dunes have a lower limit at the 6 metre contour level and rarely rise above the 12 metre contour at their crests. The interdune depressions have shallow sands over older outwash soils or estaurine formations.

Type DS1 dunes have been used largely for golf courses and at one time covered part of the Adelaide Airport. Some of their lower slopes were once graded for market gardens and the sand was also dragged over adjacent estaurine soils for the same use. This should be kept in mind as all these brown sands, normally considered good foundation soils, may be only a thin veneer. Only the existing dunes are shown on the Soil Map, including, unavoidably, some interdune depressions of different character.

This dune type is without profile form, although there appear to be layer changes by compaction and occasionally some increase in clay content. Soils grouped in the type for convenience vary a good deal in colour, but the principal criteria are sand throughout, compactness in some or most layers, and their occurrence in topographically raised positions even if only a metre or two above the general plain level.

The normal colours of the soil layers are brown or reddish-brown but yellow-brown and grey-brown are common; the texture rarely reaches clayey sand. None of the sands of fine to medium grade are loose even when dry and all have some dry strength. They are highly absorbent and very well drained.

Type DS2

Present coastal dunes, included in Type DS2, extend in a continuous chain from Outer Harbor on the LeFevre Peninsula to Seacliff. South of Port Adelaide they are a narrow band, in places greatly reduced by the practice of spreading the sand as a sheet over adjacent low land. The dunes have been stable although, due to disturbance, the balance is sometimes upset. The lower limit of the formation on the landward side is taken as the 6 m contour; the range in height seems to be up to 12 m and occasionally 15 m.

Type DS2 consists of loose siliceous sands of considerable depth. It has no profile form and normally is grey at the surface due to slight organic accumulation over pale grey to white and sometimes light yellow sand. None of the layers shows signs of compaction in the natural state.

UNCLASSIFIED SOILS

In some portions of the Eden Fault Block there is a close relationship between geology and soils, also shown in the land surface. This is especially obvious where either phyllites and calcareous siltstones or some feldspathic sandstones occur, all of which weather readily and deeply. The soils on the phyllites are granular red clays with engineering properties similar to terra rossa. On the sandstones yellow sandy clays, allied to the more common yellow podzolic soils occur, but of a less expansive character than normally expected for that type. In both cases the soils are relatively deep, and the landform consists of rounded smooth hills and slopes; more slopewash is found in the valleys.

None of these soil varieties has been shown on the present soil map since very little of them is found in the area. Progress of building and subdivision further into parts of the Adelaide Hills region will encounter them and the geological map will serve as a reasonable guide at this stage.

CHAPTER 8

THE DEVELOPMENT AND GEOGRAPHY OF SOIL GROUPS

FACTORS INFLUENCING SOIL FORMATION

The complexity of soil maps is due to the variability of soil characteristics over short distances. This is caused by variation in the type of parent materials and processes of change in these under chemical and physical influences. The original soil material may be residual from weathering rock or may have been transported by water or wind before deposition, or both.

The geological history of the region has been given in Chapter 2. The key geological factors affecting the development of the present soil pattern have been:—

....parent rock type
....upward faulting in the ranges
....variations in sea level
....incorporation of wind blown material

In addition, the normal geological processes of weathering, erosion and deposition will have varied according to changes in climatic conditions.

The great alluvial apron which extends from the Torrens valley southward to the coast near Brighton is a result of erosion and dissection of the Eden and Para Fault Blocks.

North of the Torrens, erosion of the Para Fault Block by the Dry Creek system has removed a portion of the Tertiary sandstones exposing the underlying Precambrian rocks. These have weathered to form the black clays which have been deposited in the flatter parts of the plain. Alluvial deposition of this type has occurred widely in the past and may be seen today on the narrow flood plains of the many streams which drain the escarpment.

Other sediments have been provided by deposition under estuarine conditions close to the coast. Windblown calcareous and siliceous material has formed the present coastal dunes, the older inland dunes (*e.g.* the Fulham Sand, see p. 15) and the mantle of calcareous earth overlying the western Para Fault Block, north of Adelaide.

Offshore winds have also carried in small quantities of soluble salts either as droplets of sea spray or as fine evaporative crystals. This is often referred to as cyclic salt and can have a significant effect on the chemistry of clay soils if not removed by leaching. The presence of the sodium ion in clay soils is believed to be partly responsible for their expansiveness.

THE DISTRIBUTION OF SOIL GROUPS

The distribution of the soil groups and the character of the soils in different sections of the Adelaide region may conveniently be discussed for five major units. (Fig. 9.)

Eden Fault Block and Escarpment

Since the climate affecting the high land of the Eden Fault Block at 300 metres or more above sea level has involved moderately high rainfall and relatively cool moist conditions during much of the year, the dominant force in soil formation has been leaching under acid conditions. With those exceptions where highly calcareous rocks were concerned, the result has been to produce podzolic soils, varying according to the mineralogy of the parent rocks. The amelioration of the conditions descending the escarpment, with a shorter, less intensive period for leaching, may be one reason for the change from podzolic to red-brown earth type soils.

The Eden Fault Block around Tea Tree Gully has the typical ridge and gully formation of the Adelaide Hills region. It is completely dominated by thin podzolic soils (mainly Type P2), always shallow on ridge crests, and by skeletal soils (SK). Tertiary sandstones on the lower levels of the escarpment of the Eden Fault Block above Tea Tree Gully develop podzolic soils of a different nature (Type P1) which are general as far south as the Torrens valley. These have been strongly eroded by numerous creeks coming off the escarpment, thus providing coarse sandy material as outwash sheets on the eastern plain of the Para Fault Block.

Continuing southward from the Torrens valley, the Eden Fault Block is still dominated by podzolic soils (mainly Type P2) and skeletal soils (SK). Much of this area consists of large sections, undeveloped for housing. With few exceptions, the thinly built-over subdivisions have been confined to lower slopes or to relatively flat and narrow strips on ridge crests. However, the steep ascent to the Belair and Blackwood districts has been much more developed and subdivision has extended over the Eden Fault Block without regard to slope or

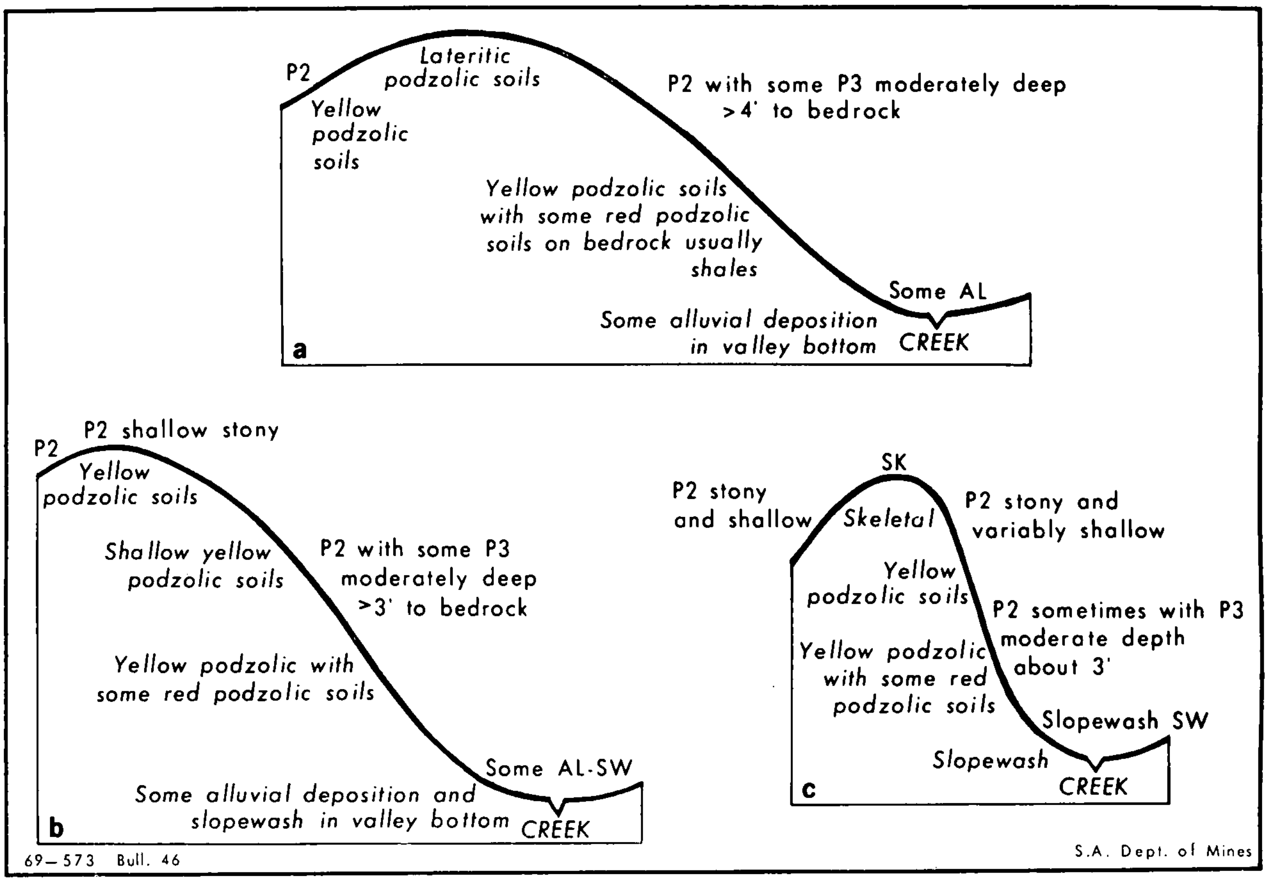

Fig. 10—Diagrammatic sections typical of the ridge and valley formations on the Eden Fault Block surface showing relationship to soil types.

(a) High ridge with flat tops.

(b) Broad ridge with moderate slope.

(c) Steep sided ridge.

land form. This part of the hills region has been extensively dissected by the Brownhill Creek and Sturt River and their tributaries. Under these conditions, there are many problems affecting house construction and maintenance relating to site topography and drainage rather than the actual soil types concerned.

Above about the 200 metre level the escarpment usually becomes very steep and has dominantly skeletal soils with occasional pockets of deeper soil among rock outcrops. At variable elevation, but generally at about 225 metres the soils, where profile development has occurred, change from red-brown earth to podzolic types, except where calcareous parent rock has given rise to shallow rendzinas and terra rossas.

The surface of the Eden Fault Block in the Belair-Blackwood area shows a variety of land forms according to where smooth remnants of an old lateritic (Tertiary) surface remain, or where there has been vigorous dissection and erosion to steep-sided narrow ridges. In the former case lateritic podzolic (Type P4), and in the latter other podzolic (Types P2, P3) soils of varying depth and stoniness occur. Three principal patterns have been noted (Fig. 10).

High ridges with flat tops (*Fig.* 10*a*)

On the crest—sandy surface soils with variable amounts of ironstone gravel and occasional ironstone boulders, over yellow, mottled yellow and red, or red and grey clay with a friable granular structure, passing ultimately to weathered bedrock at 1·2 metres or deeper. (Type P4.)

On slopes—sandy surface soils over mottled yellow and grey clay, of angular blocky structure, on weathered bedrock at about 1·2 to 2 metres. Usually stony and shallower in higher parts of slopes. (Type P2.)

In valley bottoms—may have narrow bands of creek alluvium and slopewash. (AL-SW.)

Broad ridge with moderate slopes (*Fig.* 10*b*)

On the crest—shallow grey sandy and stony surface soil, over mottled yellow and grey clay, with bedrock within 60 cm. (Type P2.)

On slopes—sandy surface soil over mottled yellow and grey clay, angular blocky structure, on weathered bedrock mostly at about 1 to 1·6 metres. Slope soils may be stony and shallower on higher parts and have red podzolic soils (Type P3) associated on lower portions (Types P2-P3).

In valley bottom—may have narrow band of creek alluvium and/or slopewash (AL-SW).

Steep sided ridge (Fig. 10c)

On crest—skeletal soils with outcropping rock and in pockets shallow stony podzolic soils (SK).

On slope—variably deep yellow podzolic, sometimes with red podzolic soils (see Fig. 10b) but frequently shallower, less than 60 cm to bedrock (Types P2-P3). At the foot of steeper slopes soils may have local accumulation of colluvial slopewash (SW).

There are exceptions to the dominantly podzolic and red-brown earth soil pattern on the lower escarpment slope. In the Beaumont district, the lower escarpment zone up to approximately the 220 metre contour has an extremely mixed body of soils dependent on parent material, and their relation to stream dissection, to surface run off and to seepage conditions. The soils are very largely shallow on bedrock which is variably calcareous and in places dolomitic. According to slope angle, soils of the black earth, terra rossa and rendzina groups (Types BE, TR and RZ) occur in close association, and this is complicated by old as well as recent accumulations of slopewash (SW). Narrow alluvial strips (AL) follow the major creek lines leading onto areas of red-brown earth (Types RB3, RB3a, RB3b) as the drainage spills out on the higher margin of the Upper Outwash Plain.

In the Glen Osmond and Mitcham districts, the escarpment has been deeply and extensively dissected with steep-sided gullies to active creeks, which have a considerable gradient. Colluviation has here also markedly affected the lower slopes above the outwash plain and below about the 185 metre contour, a mixed and unpredictable collection of stony soils occur. Where the influence of old or presently active streams is apparent, deep soils of a variety of red-brown earths, mainly in the RB3 type, are noted: in moister spots there may be a red-brown earth developed under less well drained conditions which grades into a black earth. On the lower escarpment slopes there are all gradations between the red-brown earth Type RB1, occurring to shallow depth over bedrock, and variable, deep and stony slopewash without profile form, also over rock. There are also differences due to the amount of carbonate in the parent rock.

In the Panorama district, the escarpment at about the 120 metre contour becomes in places less steeply sloping between the numerous creeks. The slower drainage and wet conditions have produced soils similar to heavy red-brown earths, low in lime, but otherwise related to Type RB3. These occur in a complex mixture with black earths, also low in lime. Both soils are highly expansive types formed on colluvial wash, which frequently contains stone fragments, or possibly are on remnants of an old perched alluvial surface. They are generally deep, sometimes more than two metres.

The main surface of the Eden Fault Block slopes from the Blackwood district, at an elevation of 300 metres down to a level of about 150 metres at Seacombe Heights. There is also a change in base rock from non-calcareous quartzites, slates and sandstone to calcareous slates, shales and limestones, which are increasingly evident west of the Sturt River. From about this line also the topography is more rounded and the higher levels are dominated by skeletal soils or very shallow rendzinas which, in local spots of deeper soil and slower drainage, trend toward black earths (BE) with a high lime content. At the highest level on O'Halloran Hill, black earths appear to be formed on a remnant of an ancient alluvial plain. Terra rossa (TR) soils occur further down, more in a mid-slope position, and are usually deeper soils. It is thought they may have their development influenced by lime seepage from the weathering of calcareous rocks at higher levels. With decreasing surface gradient, at about 2 degrees of slope, they give way to red-brown earths from approximately the 23 metre contour.

The lime factor is complicated by an assumed invasion of loessial calcareous material, deposited in late Pleistocene time over a coastal zone. It is thought this was erratically effective for not more than 1·6 kilometres from the present coast, but it had the effect of producing soils classified as Type BS in close association with rendzinas (RZ) at higher levels and terra rossa (TR) at lower. The additions of calcareous material on the Lower Outwash Plain were small, or have been removed, but the accumulation on the escarpments at Brighton and Marino was presumed to be considerable, though not so distinctive as on the Para Fault Block north of Adelaide city (see pp. 16-17).

North Para Fault Block

The escarpment of the Para Fault first comes into prominence at the southwestern edge of the parklands in the vicinity of Mile End, and continues roughly northward to Enfield, thence rising to the northeast. The surface of the fault block north of the Torrens valley rises gently and is marked by three zones with very dissimilar soils.

The overall pattern of the typical soil occurrence is shown in Fig. 11 as an east-west cross section relating soils to topography. Obviously the single section cannot take account of all the soil distribution indicated in the text.

The escarpment and western edge

The western escarpment of the fault block has been affected by calcareous windblown material spread as an irregular sheet over the earlier alluvial deposits of the Hindmarsh Clay. One theory advanced is that these deposits of sand and clay with large amounts of lime are adventitious, and were laid down by wind action as a mantle on a pre-existing surface of old alluvial sediments or on weathered rock. The material is assumed to have come from an exposed sea floor of the St. Vincent Gulf when sea level fell markedly. The sand and finer particles and lime came from weathered shell beds so exposed and they were carried inland by prevailing winds, which effected a winnowing action. The resulting calcareous earth came to rest in large amounts on the nearest obstruction which here was the escarpment of the Para Fault Block. The result has been development of shallow brown solonized soils (Type BS), about one metre thick over a dense, slowly pervious clay. This zone has been dissected by 12 or more short drainage lines in addition to the main stream of Dry Creek. Some of these are deep enough to reach basement rock but most are incised into Hindmarsh Clay. In places on the slopes, soils similar to terra rossa (Type TR) appear, but in general, the western edge of the Para Fault Block has Type BS soils of varying sandiness, depth and lime content. These are all potential problem soils in relation to house foundations. Because of their very permeable nature, there is a danger of loss of bearing capacity in the calcareous layers lying close to the surface if subjected to overwatering of lawns or gardens. The formation extends southward across the Torrens valley to cover the major part of the central city area, with the layer of brown solonized soils (Type BS), up to three metres deep, above the Hindmarsh Clay.

The Central Precambrian Belt

In a zone about 5 to 6 kilometres wide through the centre of the Para Fault Block, north of the Torrens River, Proterozoic rocks of the Adelaide System occur, mostly within 1 to 3 metres of the surface. The Dry Creek drainage extensively dissects this area, giving a land surface ranging from nearly flat to steeply sloping. The soil parent material varies in lime content, but it also seems likely that windblown lime influenced the soils either residually or by concentration by wash and seepage. Most of the soils fall into five groups.

....the very shallow rendzina like soils (RZ) of Para Hills.

....the rendzina and black earth complex (RZ-BE) on the higher land at Modbury North on flat to moderate slopes.

....the shallow more or less calcareous red-brown earths (Type RB4), common on slopes to the Dry Creek drainage system; there are also interspersed patches of terra rossa (TR).

....the black earths (BE) of nearly flat areas, at Modbury and Gilles Plains and sometimes overlying Hindmarsh Clay.

....a small alluvial (AL) flood plain along parts of the mid-course of Dry Creek.

The Para Hills high land has a mixed collection of shallow soils, some rock outcrop, much calcrete in large fragments, and generally a sandy rendzina-like soil, changing down-slope to shallow calcareous red-brown earths. To the east around Modbury North the soils deepen and are dominated on the flatter higher land by black earth-like soils, possibly developed on the Keswick Clay (see p. 14). On moderate slopes rendzina-soils with calcrete layers are widespread. This area has building problems and apparently corrosion of buried metals may also occur.

The extensive span of red-brown earths is the main background to the Dry Creek drainage system. They are invariably shallow (about one metre), developed on slates and shales, some of which are calcareous, and are possibly also affected by some adventitious lime. A different situation seems to exist west of Hope Valley where a red-brown earth (Type RB8), with much heavier profile and again with a large amount of lime in the lower B horizon, overlies either Hindmarsh Clay or Tertiary sandstone, neither of which contribute to the red-brown earth profile. Type RB8 merges with typical black earths (BE)

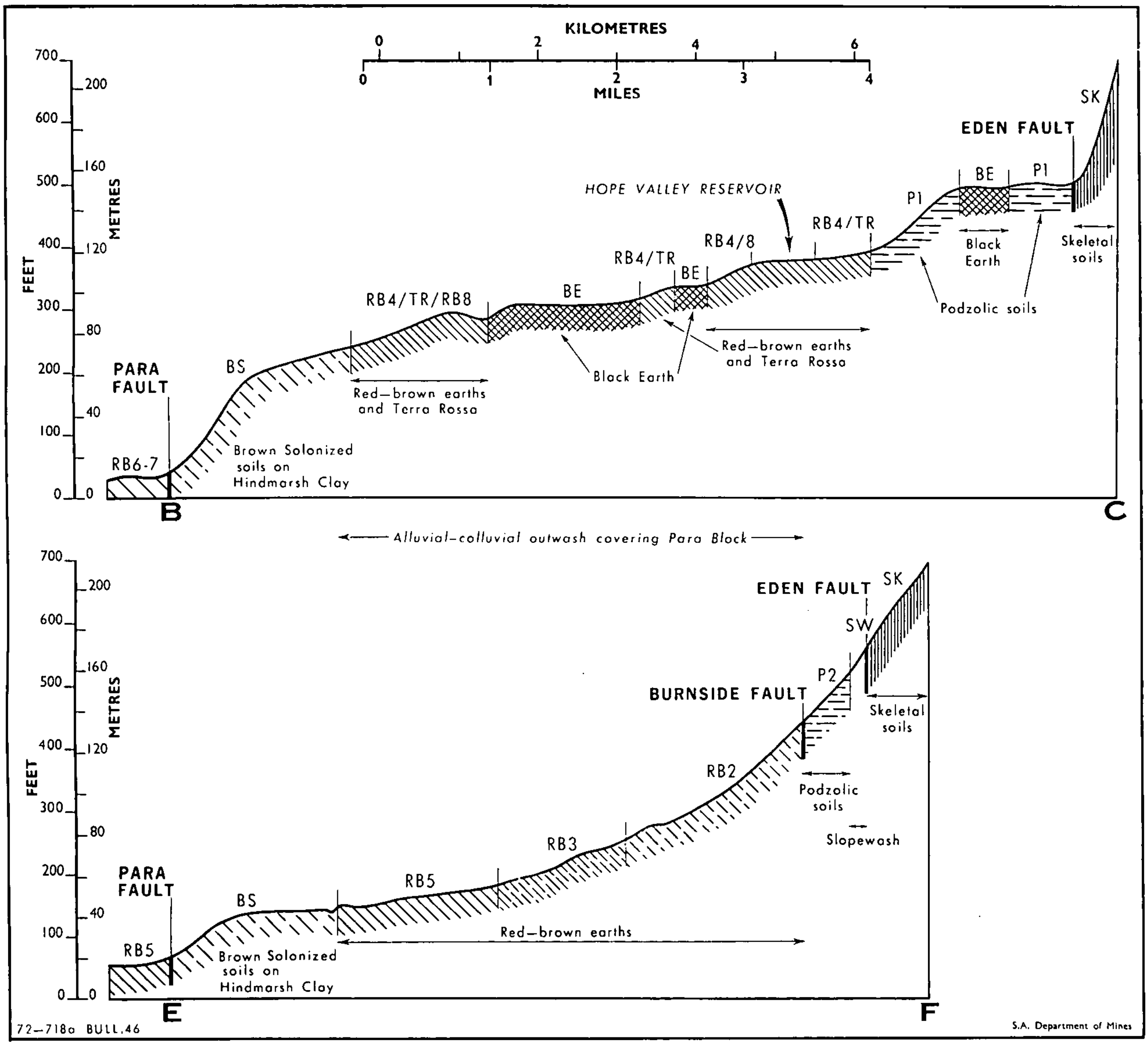

Fig. 11—Cross-sections showing relationship of soil types to topography and land form typical of the Upper Outwash Plain. See Fig. 9 for location of section lines.

toward the Torrens River and westward towards Gilles Plains. There are clearly intergrade forms. The origin of the sediments and of the lime from which the profile formed is not clear, but it is thought the sediments were water laid, possibly part of the Keswick Clay formation, and the lime partly windblown.

The black earths (BE) occur in two large, and some lesser, unit areas. The topography is mainly a gently sloping plain, derived presumably from past alluvial deposition although some patches are associated with Dry Creek or Torrens Valley drainage. To some extent these patches may be affected by groundwater seepage moving downslope on buried Tertiary sandstone *e.g.* at Highbury and Hope Valley. The Gilles Plains area appears to overlie Hindmarsh Clay, as noted at Northfield, where a very heavy accumulation of lime (0·5 metres thick) also occurs at 15 to 45 cm from the surface.

The eastern Tertiary belt

Extending in a belt 1·5 to 2·5 kilometres wide from the foot of the Eden escarpment as a gently sloping pediment, is a group of podzolic soils developed on Tertiary sandstones and sands. Some are residual and not more than one metre deep, some are formed on outwash material overlying sandstone at a varying depth and in places, windblown dunes up to three metres deep have been drifted from the sandy outwash. All these are potentially podzolic soils of a more sandy nature and are classified as Type P1. A complication is that, for reasons not yet explained, solodic soils (Type S1) occur, though in no definable pattern. Some of these Type S1 soils have a much more reactive clay B horizon, but in general, they are not materially different on engineering grounds from the podzolic soils. The deeper sandy surfaces are not well consolidated. In a few soils some lime occurs just above the C horizon, but it could not be from the parent Tertiary sandstone. This Bca horizon is strongly alkaline compared with the acid to neutral overlying soil.

A tongue of Tertiary sandstone occurs as an outlier from the main belt at Hope Valley, along the north bank of the Torrens River. It has typical Type P1 soils, but the sandstone also has been noted at depths of 1·5 metres or more, both further west and north of the Hope Valley reservoir, and there the surface soil formation is a red-brown earth of different origin.

Upper Outwash Plain—south of the Torrens Valley

As indicated in Chapter 3, the Upper Outwash Plain is formed by the coalescing fans of a large number of streams which, with two exceptions, rise in the escarpment zone. The relationship of the Upper and Lower Outwash Plains is shown in the cross section E-F in Fig. 11 in which detail of the soil pattern of the Upper Outwash Plain is given. This cannot take account of the occurrence of other areas of major soil types discussed in the text.

According to parent material, the sediments vary from coarse to fine, partly dependent on the rocks of the catchments, but also partly on their relation to actual present or past stream courses. For this reason, a large unit area of a coarse textured red-brown earth (Type RB2) is found on the outwash of First, Second and Stonyfell Creeks which once drained, with vigorous erosion, an area of quartzites. These soils are related to alluvial soils. The channels of the streams meandering over their deposited sediments have left many sandy sub-strata now buried but still acting as aquifers.

From their variability some deposits are younger, some have been affected by soluble salts and some have been wet enough to permit a build up of organic matter, even to form black organic clay layers under local swamp conditions. Along the major streams, particularly the Torrens and Sturt Rivers, younger and older terraces occur, exhibiting increasing signs of maturity in profile development (see Twidale, 1968). The present flood plain of the Torrens is quite narrow over much of the river's course. Above it is a young terrace on which little alteration of the material is yet evident, though it is no longer subject to frequent inundation. Gradually rising from this level is a zone of immature red-brown earths transitional to the mature profiles on the surface of the plain in which the valley is entrenched. The pattern is quite clear in the Torrens valley from Campbelltown to Adelaide. The Sturt River has a somewhat similar occurrence of a low terrace of juvenile red-brown earths along part of its course in the Marion district.

The history of both rivers as they approach the coast is one of regular flooding over large areas with the formation of layered sediments, often recent, complicated by the effect of salt from marine sources. The River Torrens alluvium varies from coarse sand and pebbles close to the Eden escarpment to silty and sandy clays in the sub-coastal region.

Quite a large proportion of the numerous escarpment streams lose their identity within 1·6 kilometres of the foot of the Eden escarpment. A section across a stream line (*cf* Fig. 4, p. 19) however weak it now is, shows a general sequence of red-brown earth soils, which are Type RB5, closely flanking the channel sediments grading outward into Type RB3. In interpreting a site within the influence of a drainage line, the likelihood of occurrence of red-brown earths of quite different engineering character, as well as transitional soils, should be investigated. Also, where the streams fade out, usually at a change of slope to flatter gradient, the soils have been subject to greater wetness and local patches of black earth (BE) are sometimes found. The same parent materials have given rise to the red-brown earth Type RB3 and to the black earth (BE), according to the state of continued wetness and slow drainage.

The large unit area of black earth (BE) in the Paradise—Campbelltown district, apart from a slightly lower slope gradient, has only one feature distinguishing it from the Upper Outwash Plain otherwise largely occupied by red-brown earths. This is that no through drainage lines cross this black earth area and very few of the escarpment streams seem to enter it. This is not likely to be the whole explanation of the occurrence but it may have significance and be worthy of consideration in the present rapid development of this zone.

Lower Outwash Plain

South of Torrens River

The Lower Outwash Plain is bounded by the line of the Para Fault swinging away southward to near the coast on approximately the 15 metre

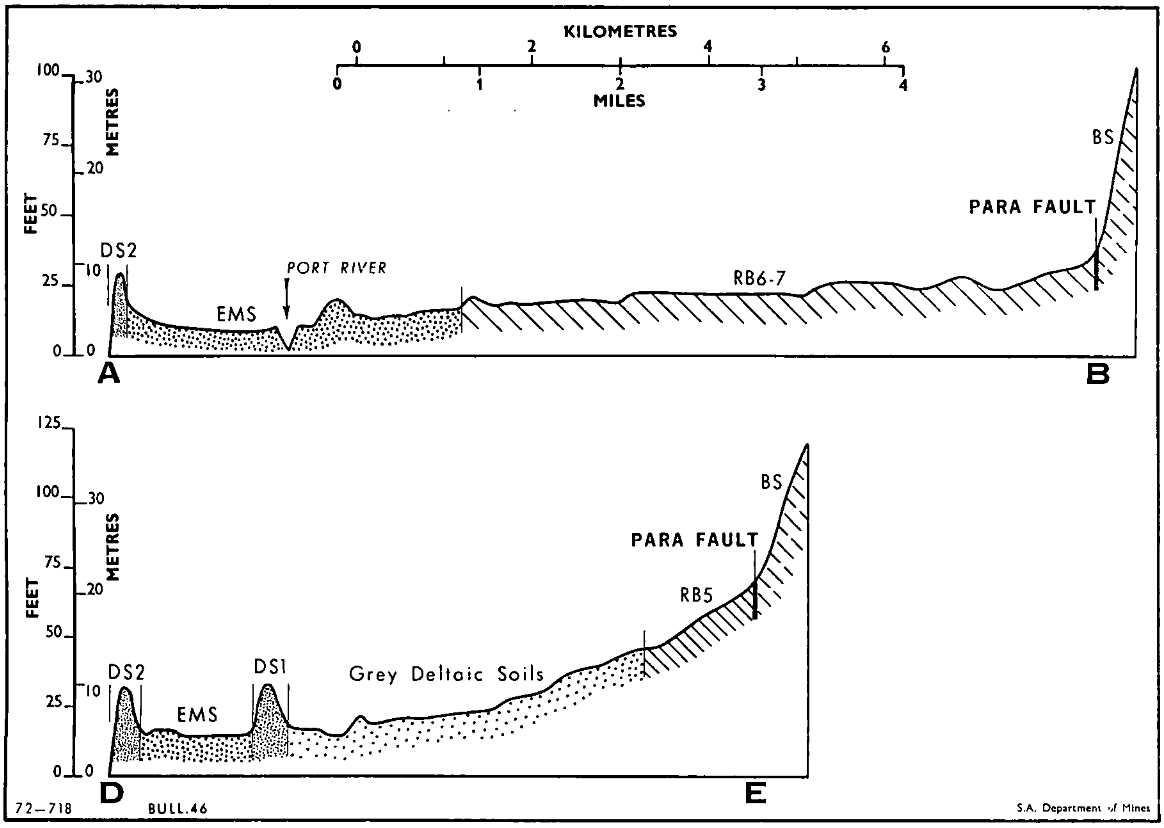

Fig. 12—Cross-sections showing relationship of soil types to topography typical of the Lower Outwash Plain. See Fig. 9 for section lines.

contour. The fault is concealed by recent sediments, southwards from about the south-western corner of the City of Adelaide. Fig. 12 shows the pattern of the soils of the Lower Outwash Plain in typical cross sections DE and AB south and north of the Torrens River, combined with the coastal plain.

The Sturt River has spread out alluvium extensively in the absence of a significantly formed valley and in its lower course has contributed largely to the Lower Outwash Plain. This plain is cut by the Sturt River, but now only partially by the Brownhill Creek, and was subject to considerable uncontrolled drainage outflow before suburban development. At one stage an old dune line Type DS1 (Fulham Sand), must have been almost continuous from Glenelg northward to the Port River at Royal Park, or at least, sufficiently so to prevent the free egress of creeks except in the flood flows which occurred occasionally each year. In particular, flow of the Brownhill Creek was ponded behind the old dunes at the site of the Adelaide Airport, the recent graded alluvium being deposited as poorly drained grey soils. These overlaid earlier sediments of the Lower Outwash Plain at slightly higher levels (about 6 to 12 metres) and their finer material settled in lagoonal areas at about 6 metres. At the same time, the sediments were waterlogged for long periods in the year, and were liable to become saline. The wandering stream courses laid down stratified sandy deposits, found scattered erratically over their distributing area, and these are important from their relation to building foundations and potentially higher groundwater levels. Some local areas of organic soils have been observed, presumably representing earlier semi-permanent swamps.

The triangular shaped area (shown as soil Association XX) encompasses these soils which are extremely mixed. Most of them are hydromorphic, and vary from unorganized alluvial deposits, some of which are organic, to profiles akin to red-brown earths similar to Types RB9 and RB5, with an overlying layer up to one metre thick of grey or mottled clayey material*. It is impossible to define these soils; each site requires close examination.

Close to the Torrens River below the Para Fault occurs an area of red-brown earths of less mature and, generally, of lighter profile. These are Types RB6 and RB7, together grouped as

* These soils approximate to the Types PA1, and PA2, of Aitchison, *et al.*, 1954.

Soil Association XXI. The river is bordered on both south and north sides by a broad band of coarse textured sandy and silty alluvium (AL) variably stratified, but not notably clayey until it reaches to within two kilometres of the coast.

The outfall of the Sturt River from Morphettville onwards, with a very low gradient of about four metres per kilometre again has mixed soils with a notable proportion of heavier textured alluvial soils (AL), darkened at the top with organic matter. These are mainly silty clays with bands of clayey sands and clayey silts beneath. The red-brown earth Type RB9 forms the main outwash soil, apart from the main channel deposits. All kinds of gradations occur from it to the better drained deltaic soils described earlier in this section. This assembly of soils on the lower course of the Sturt River becomes less typical, and it indistinguishably merges into the estuarine soils near the coast. All these soils are subject to a high water table, fluctuating from about three metres to as high as one metre below the surface.

Southward of Glenelg towards Brighton occurs the variety of red-brown earth classified as Type RB5a. It presumably represents the red-brown earth found at lowest levels, probably more comparable in engineering character to Type RB7 and not subject to inundation or temporary wetness of high water tables. It merges into less well drained soils and hydromorphic variants at its lower boundary, but there is not a sharp delineation, nor with any of the other well drained soils passing through to the poorly drained soils described previously.

North of Torrens River

A single simple Soil Association, XXI, covers the Lower Outwash Plain north of the alluvial fringe to the Torrens River. It represents deposition from the Torrens in an early northwestward course (see Fig. 2), and from five or more creeks rising on the Para Fault Block whose courses generally disappear in the plain a short distance from the fault line. The area is seamed with buried drainage lines only observable through the presence of stratified, more or less coarse material (AL) in site examination. In the main however, the soils are alluvial outwash which has developed a red-brown earth morphology in its upper one to two metres.

The less mature Type RB7 tends to be nearer to the fault line or seems to adjoin old stream courses when it appears much further west. The more mature Type RB6 not only has a more clayey profile, but has well defined horizons and, where it has come under saline influences nearer the coast, has a well developed, prismatic clay B horizon. In general, no boundary can be even approximately indicated between the two types. The break to the estuarine soils is reasonably clear cut somewhere about the six metre elevation.

From the line of the Para Fault, the general fall of the land towards the coast is on a low gradient of about three metres or less per kilometre. The gradient, where not complicated by former buried stream lines, is reflected in the soils, Type RB6 at lower levels and Type RB7 slightly higher and along the stream lines generally. The effect of water tables, fluctuating in winter at relatively shallow depths is greatest in Type RB6, and, in places the groundwater is saline. It is difficult to reconstruct the landscape before urbanization caused its present condition, but there must have been numerous cases of impeded drainage or even swampiness in this region (see Fig. 13, p. 57).

Coastal Zone

In this zone the most common soil units are estuarine muds and sands and sand dune formations (see Fig. 13). Connecting the entrances of the Port River and Patawalonga Creek is a belt of low lying soils, roughly bounded by a line at less than six metres elevation, which owe their origin to deposition of sediments by marine and fresh water floodings on a rising coastline. The stratified sediments have no profile form, but consist of layers of material from coarse sand to silts and clays and also some of organic origin, collectively grouped as estuarine muds and sands—EMS. If anything, the coarser soils are to the south, the organic in the Henley region—the old Reed Beds area—and finer deposits to the north, but this can only be a generalization. Reclamation by drainage, and spreading of sand has obliterated much of the original state.

The Torrens River in its present course has deposited fine and coarse alluvium, the former mostly in evidence below the eight metre contour. This overlies and merges with the estuarine deposits in a quite indefinite manner, as for example at Fulham. These soils are a silty to clayey type of alluvium (AL).

The coastal dune line (Type DS2) forms a nearly continuous barrier, broken only by the openings of the Port River, the Torrens River, and the Patawalonga Creek, preserving in this way the estuarine plain behind it. The brown sand dunes, (Type DS1), marking the shoreline of the Flandrian high sea level, border the estuarine zone on the inland side, and are set in a background of alluvial deposits from all major stream lines and the lower fringe of the outwash plain.

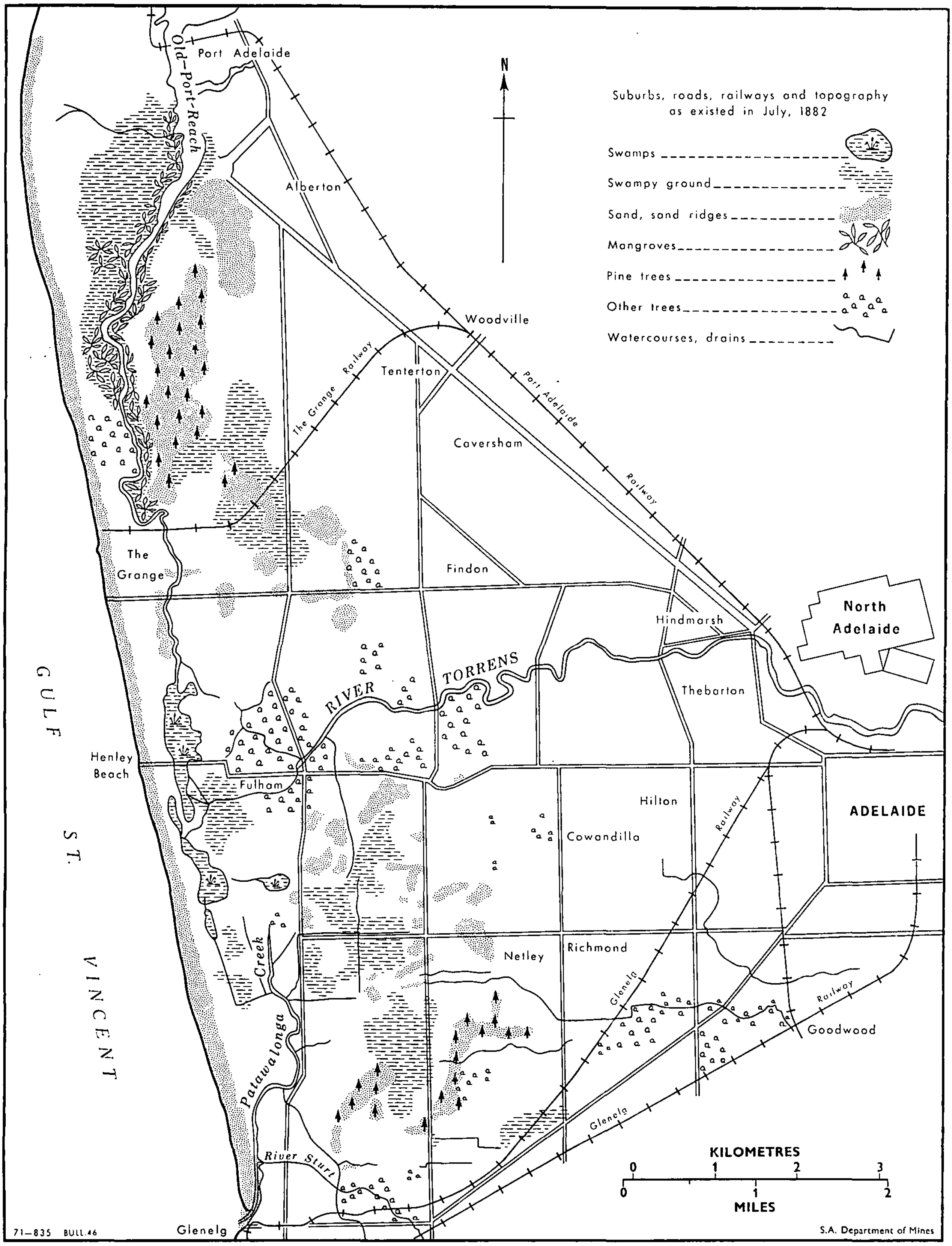

Fig. 13—Map of the coastal portion of the Adelaide region west of the city, prepared in 1882. It shows the poorly drained zone close to the coast, the irregular chain of inland sand rises (Fulham Sand—Type DS1) and the state of largely uncontrolled drainage, all of which have been modified beyond present day recognition.

Map supplied by the South Australian Department of Lands

CHAPTER 9

PROBLEMS ASSOCIATED WITH SOILS AND ENVIRONMENT

SOIL STABILITY

For the purpose of relating soil types to suitable building foundations, the soils can be considered in four main groups. The group in which each soil type can be classified is shown in Appendix 1 which gives some properties of the individual soil types as far as they are known to the authors from available engineering data or, by inference from their pedology.

Precise engineering properties of soil types are not discussed in this bulletin, nor are data given on any inferred performance of small buildings from laboratory tests. Comments made are based on the information presented originally in Geological Survey of South Australia Bulletin 32 (Aitchison *et al.*, 1954), together with accumulated experiences from pedological field observation. Later engineering data have not yet been published and, what is more significant, comparative field tests on performance of buildings on the various soils and with different footings have not been conducted to enable more accurate correlation of soil types and their response to loading.

An attempt has been made to assemble practical information on problems concerned with the environment and this is summarized in Table 1 of Appendix 1 dealing, for convenience, with geomorphological land units. Frequently, site qualities may overshadow the engineering properties of the soils concerned as the controlling factor in the building of stable structures and, for this reason, detailed observations on the spot should never be neglected. The table indicates potential problems associated with one or more of the soil types listed; each type has to be viewed individually in the background of its environment.

Stable soils

These are soils or foundation materials in which soil movements are not significant in their effect on small buildings. They include compact silts and sands, gravelly soils, weathered rock, and may also include properly compacted fills of suitable type.

Expansive soils

These have well-defined clay layers containing minerals which react to moisture changes. The clays swell on wetting and shrink on drying, and are termed expansive. They may be slightly, moderately or highly expansive.

The important effect of an increase in soil moisture in expansive clays, is that vertical movements occur within the clay mass and are translated to the soil surface. The movements are accompanied by strong uplift forces which can cause damage to buildings. Differential surface movements may also result from variability of soil profiles or soil moisture over small lateral distances.

Lack of precise information on the expansiveness of various soil types leads only to the use of informed guesswork and there are a number of questions unanswered. For example, there is not yet a completely satisfying reason for the difference in field performance of Types RB3 and RB5, which, by the results of analytical testing and engineering data, appear to be similar*. One explanation is based on the under drainage of the soil profile. Type RB5 frequently shows an increasing coarseness in soil composition with depth and it may pass into sandy clay or clayey sand at less than two metres. On the other hand, Type RB3 continues in depth as a highly expansive clay or silty clay. Although both soil profiles transmit water readily, the tendency is for moisture equilibrium to be attained more rapidly in Type RB5. However, there are all gradations in profile character and in foundation response between the two types.

One significant point is that expandability of a soil is not clearly related to the amount of clay present. The mineralogy of the clay, its chemistry and dispersiveness and the nature of its structural aggregates seem to be important factors. To illustrate the first of these, the known low expandability of a kaolinitic clay makes possible an estimate of the reaction of a lateritic podzolic soil, such as Type P4. The second factor has been indicated in the example of Types RB3 and RB5 mentioned above. The type and

* The single feature arising from analysis is the amount of exchangeable sodium on the clay as a percentage of total exchangeable cations and this conforms with the degree of dispersion of the soil aggregates when immersed in water (Emerson, 1967). Analysis of four samples showed—

Type RB3—Exch. Na 7·6%; moderate dispersion.
Type RB3—BE transition—Exch. Na 10·0%; high dispersion.
Type RB3—RB5 transition—Exch. Na 3·1%; slight dispersion.
Type RB5—Exch. Na 5·3%; slight dispersion.

degree of soil aggregate structure is important as it effects soil moisture changes, both intake and loss.

There still remains much to be learned from laboratory and field tests on soil types, particularly as to the explanation of the results. It is not known if there are minor, perhaps significant, differences in the properties of black earths (Type BE) of different origin, such as those of the Gilles Plains area and the localized patches associated with impeded drainage on the Upper Outwash Plain. There are differences to be seen in solodic soil profiles and some, from their morphology (see Plate 12), are much more suspect in engineering character. At present, in general, they are not separated in regard to foundation characteristics. The yellow and red podzolic soils are not differentiated on the soil map though the red podzolic soils, interpreted pedologically, should have more permeable and somewhat less expansive clays.

Soft or compressible soils

These are soils which are unable to carry building loads, without showing significant settlements. Such soils are commonly silts, clays or sands originally deposited under water, and are usually associated with high water tables or restricted surface drainage. They are often underlain at depth by more stable materials of higher strength which can be utilized for foundations.

Collapsing soils

These are soils which show a decrease in volume when their moisture content is increased. They are liable to "collapse" or sudden settlement under small loads if wetted beyond a certain limit. This increased wetting, and resultant collapse affecting a foundation, can be caused by such factors as ponding of water from roof run-off or by flooding due to a broken service line close to foundations.

In some soil profiles, lime as calcium carbonate is concentrated in layers close to the ground surface and it is collapse of these layers which results in loss of bearing capacity. The main collapsing soils are the brown solonized soils (BS), some black earths (BE), and, to a lesser extent, some terra rossa and rendzina (TR and RZ). The qualification of a collapsing soil is that the lime-rich layer begins to lose strength at moisture content equal to field capacity and progressively weakens up to saturation. The collapse may be intensified if a perched water table has been built up on a deeper layer of low permeability, thus affecting the permanent moisture status of the overlying soil. These conditions apply particularly to the Type BS soils.

Black earths (BE) with a highly calcareous layer at shallow depths, say less than 30 centimetres (see Fig. 14), may have a combined problem in bearing capacity and expandability on wetting, to be appreciated in foundation design. The calcareous earths in terra rossa and rendzina profiles normally have admixed clay from weathering *in situ* of parent rock, giving a compactness which is liable to a material drop in bearing capacity only at saturation.

The effects of "collapse" discussed above are paralleled by the consolidation of dune sands on wetting due to re-arrangement and packing of the sand-sized particles. Any recent wind-blown sand accumulation is liable to this state. Wetting and compaction by rolling prior to construction provides a permanent solution in sand soils. In other collapsing soils, it is necessary to prevent ponding near foundations.

DRAINAGE AND FORMATION OF GILGAI STRUCTURES

A feature which is basic to all studies of soil expandability is the absorption and depth of penetration of water (see Chapter 5). Most investigation in Adelaide has been concentrated on black earth profiles (Type BE) which give a first impression of low permeability. Ready intake of water and downward soakage are accounted for by the well structured, granular clays in the surface layer; the fissuring of dry soils, at times to depths of one metre; and quite often by the presence of calcareous layers occurring at less than 60 cm. The fact that the ground surface is often flat enough to allow only slow run-off increases the possibility of water absorption influencing the soil profile. The presence at shallow depth of a highly calcareous layer overlying a clay of restricted permeability becomes important when the calcareous soil is regularly saturated by surface soakage or lateral seepage. If it becomes a water-logged zone, free water may continue to seep slowly downward according to the presence of the cleavage planes between soil aggregates and reach a relatively considerable depth. This may even be sufficient to build a water table on an impervious stratum, such as bedrock, beneath.

These conditions have been observed, but the effect of this deep water on the soil aggregates is not known. The question is, what degree of future expansion is possible by further wetting, or alternatively, is the clay in the soil aggregates

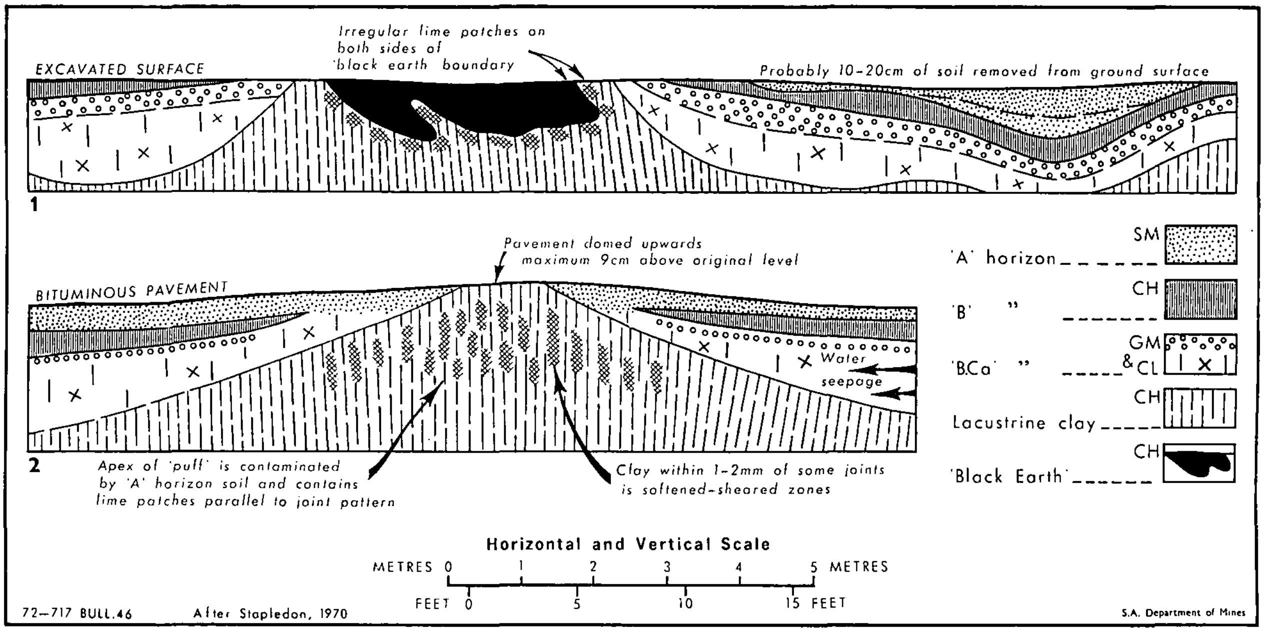

Fig. 14—Gilgai type structures in clays, Adelaide area. 1. South Parklands. 2. Adelaide High School.

After Stapledon, (1970)

wet to field capacity and therefore in a fully expanded state? The problem of expansion is specifically illustrated in gilgai formations* on black earth. Figure 14 shows the extraordinary heave effect accompanied by the lifting of the lime-rich zone to the surface. The differential absorption and concentration of water is clearly important in affecting ground movement, demonstrated where the deeper clay layers have heaved in rounded waves pushing parts of the surface up. The movement of these soils is a continuing process subject to natural moisture changes so that they are not stabilized. At the same time the depressions in the sub-surface clay layers are liable to accumulate water as a local perched groundwater table.

The gilgai effect in the black earths of the Adelaide region usually appears with relatively small micro-relief, although the capacity of the clay layers to heave may be considerable. Surface erosion has distributed some of the up-thrust soil and in levelling soils, man has planed off the natural unevenness. The force of the movement is well shown in the distortion of fence lines and poles sunk in these soils and the effect on buildings of inadequate design could be catastrophic.

Underlying portions of the Para Fault Block surface, especially in the Adelaide City area, is the layer known as Hindmarsh Clay, now covered by one to three metres of unrelated calcareous earth. The Hindmarsh Clay quite commonly shows a gilgai effect (see Allchurch, 1965) which may be of large amplitude (perhaps 1·5 metres), but this condition is presumed inactive at present unless subjected to prolonged moisture change by exposure through excavation or artificial wetting.

A number of the soil types, either through the form of their profile or their position on slopes, lend themselves to lateral seepage of water under wet conditions. The evidence of this is usually clear on cuttings or pit faces in some degradation of the top one or two centimetres of the B horizon clay, as may be seen in the podzolic soils on Tertiary sandstone at Tea Tree Gully. Another case in the Adelaide Hills is the presence of mottled colours of soil profiles situated on lower slopes where sub-drainage has slowed down.

PRESENCE OF UNDERLYING BEDROCK

A feature of some importance from the engineering aspect is the relative depth to underlying rock, particularly where the clays of the soil profile are highly reactive types.

If the rock occurs at relatively shallow depth then this would provide an ideal stable foundation for a building, and where possible building

* Gilgai—Aboriginal word meaning a small waterhole. This micro-relief is also known as crab-holey, Bay of Biscay, *etc.* Engineering and geological features associated with gilgai formations are discussed by Allchurch (1965), Stapledon (1970) and Cox (1970). The term Bay of Biscay soils has been loosely applied in the Adelaide area to cover the moderately to highly expansive type soils *e.g.* soils of the BE and RB3 types, which can exhibit gilgai structures.

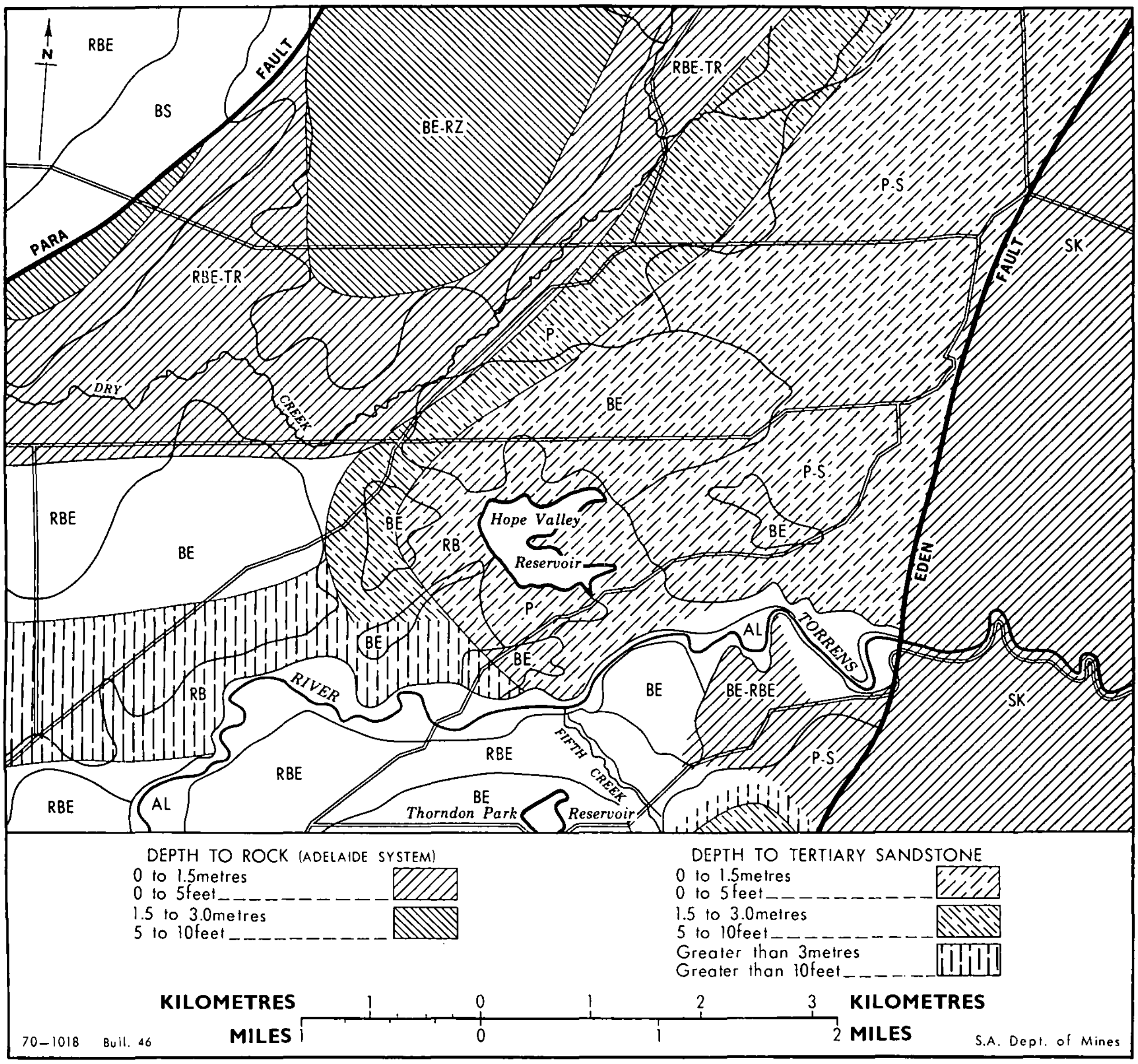

Fig. 15—Map of portion of the Para Fault Block surface showing approximate depth to bedrock beneath soil types, based on records of the South Australian Department of Mines.
After Boucaut and Taylor (1970)

foundations should be extended to depths to take advantage of this stability. For domestic type building it would probably be economic to do this only if the depth to rock is of the order of 1 to 2 metres, but for larger buildings the use of deep piers or driven piles would be warranted.

In areas with steep slopes in the Adelaide Hills region and on the Eden escarpment, bedrock can normally be expected at depths of less than two metres, but on the plains with gentle slopes it is difficult to tell from surface appearances if bedrock occurs close to the ground surface, and in fact in most areas it is at a depth of many metres. However, in the northeastern portion of the Metropolitan area stable rock does occur close to the ground surface. Available data on depth to rock have been summarized and assembled on Figure 15. The boundaries and depths indicated are approximations based on scattered observations of variable frequency and should be used only as a guide.

The underlying rock formations have been defined separately as Tertiary sandstone and the metamorphic rocks of the Adelaide System. The metamorphic rocks are quartzites, slates, and phyllites, which, when near the ground surface, are affected to varying degrees by weathering. The quartzites are generally strong and only slightly affected, but the phyllites are usually weathered and weak to a depth of several feet. The slates are characterized by the presence of lime and are variably weathered. It should be noted that the surface soil is not always related directly to the underlying rock.

North of the River Torrens the Tertiary sandstone occurs close to the ground surface over a large area at the foot of the Eden escarpment and dips away gradually to the west. It disappears westward from the vicinity of Hope Valley Reservoir, where it is only a few feet from the surface.

The higher North Modbury area of black earth-rendzina soils, (BE-RZ) has mainly deep clays, but where the land surface slopes more steeply towards Dry Creek and in the Dry Creek valley itself, bedrock (either sandstone or metamorphic rocks) is generally within one metre of the surface. In the northwestern portion of the map (Fig. 15) in the area shown as brown solonized soils, (BS) the upper soil profile is frequently underlain by mottled grey clay (Hindmarsh Clay), which probably extends to depth.

South of the River Torrens in the locality of Fifth Creek and the foot of the Eden escarpment there are some shallow occurrences of rock with a few outcrops mainly of slates and quartzites, but also of some Tertiary sandstone in one local area.

SLOPE STABILITY

In the area of steeper slopes of the foothills, water may move freely downslope at the soil-rock interface and under suitable conditions, this may set in motion slumps or land slips. Old slips may be seen quite commonly along the foothills and the possibility of their occurrence in abnormally wet years is a point to be taken into account, particularly throughout the escarpment area. Slump soils often show disorganized profiles or are churned by their movement into mixed deposits, and, according to their age, are subject to some consolidation under load. Alluvial slopewash, which has not developed a profile, is naturally liable to the same consolidation problem.

DAMAGE TO BUILDINGS DURING EARTHQUAKES

It is quite possible that during an earthquake a structure several hundred metres from the fault on which movement occurred could be damaged in a way similar to one immediately above the epicentre.

Detailed observations in those parts of the world where earthquakes are common have shown that there are three main factors which influence the amount of damage to buildings during earthquakes, namely:—

....Distance from the epicentre or epicentral zone. In some cases, there is visible dislocation of the ground surface along the fault trace during earthquakes (*e.g.* Meckering earthquake, Western Australia). The zone in which ground dislocations occur is commonly termed the "complete destruction" zone.

....The type of foundation material upon which buildings are located. Generally, the greatest damage occurs to buildings located on unconsolidated fills and alluvial soils. Buildings located on rock are usually the least damaged.

....The type of construction. It has been found that structures can be designed and built so as to minimize, but not eliminate entirely, the damage due to earthquakes. Special building codes have been developed in countries and regions which have frequent earthquakes. However, even where structural collapse of buildings is prevented, there is still a relatively high danger of fire, and damage to services—water, gas and electricity. A code for the Design of Earthquake Resistant Buildings has been issued in Draft form by the Standards Association of Australia, and will be published as an Australian Standard after completion of the review period.

PHYSICAL PROPERTIES OF SOIL TYPES

The physical characteristics of individual soil types affecting some of their engineering properties and relevant to the stability of building foundations, are set out in Appendix 1. The relationships of the soil types to the environment and associated problems is also summarized in Table 1 of this Appendix.

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APPENDIX 1

PHYSICAL PROPERTIES OF SOIL TYPES RELEVANT TO BUILDING FOUNDATIONS

Any movement of the soil due to swelling, shrinking or consolidation is detrimental, but according to the type of construction may vary in effect and hence in significance. The general terms used here to describe soil movement and drainage are relative. In very approximate terms a movement at the soil surface due to moisture changes equal to 25 millimetres would be rated as *large* and one less than 12 millimetres as *moderate.*

Drainage of soil profiles can also only be given in approximate form which in the past, has usually been related agriculturally to the health of plants, not to its effect on buildings. One criterion which has been used, is the effect of water ponded temporarily on the surface of a soil at field capacity. Thus *very rapid* indicates the soil never becomes saturated; *rapid,* saturation is restricted to a few hours; *moderate,* the upper profile remains above field capacity for less than two days; *slow,* the upper profile remains above field capacity for more than two days.

Indications of bearing capacity of soil layers relate to the average loads of houses of masonry construction. Apart from bearing capacity it is not always possible to apply simple tests for either soil movement or drainage, so the relative descriptive terms given in the table are based on field observation and pedological inference from profile characteristics.

Soil Group—Red-Brown Earth

*Type RB*1

Soil profiles always occur on sloping sites and may vary in depth up to one metre. Clay horizons are subject to moderate to large shrinking and swelling movements. Soil slip may occur on steeper sites with deeper soil cover.

*Type RB*2

Shrinking and swelling movements are small and negligible in all horizons of the profile. Bearing capacity adequate for shallow foundations. Internal drainage rapid.

*Type RB*3

Large shrinking and swelling movements occur in the upper clay (B) horizon and to a lesser extent in the calcareous (Bca) horizon below. Large soil movements can also occur in clays at greater depth if subject to sufficient moisture changes. Bearing capacity of clay horizons is usually high. Internal drainage moderate.

*Type RB*3*a*

Shrinking and swelling movements as for RB3, but significantly reduced if stone fragments are abundant. Bearing capacity of clay horizons usually high.

*Type RB*3*b*

Shrinking and swelling movements as for RB3, but the expansive B horizon is less subject to moisture changes, being covered by a thick absorbent and non-expansive sandy or silty topsoil.

*Type RB*4

Moderate to large shrinking and swelling movements probably occur in the B horizon. Calcareous subsoils and layers with rock fragments are less expansive. Many soils are shallow to bedrock. Soils have high bearing capacity.

*Type RB*5

Clay horizons are subject to moderate shrinking and swelling movements, but the total movement at the surface is usually small. Bearing capacity of soil horizons is adequate for footings of domestic buildings. All gradations between Types RB5 and RB3 occur. Internal drainage moderate to rapid.

*Type RB*5*a*

As for Type 5. Under drainage usually rapid; liable to fluctuating water table in lower areas. Gradation to Type RB9.

*Type RB*6

Shrinking and swelling movements normally small in upper B horizon clay but in some cases may be more significant. Bearing capacity of horizons adequate for domestic buildings. Internal drainage moderate to rapid. Liability to high water tables in some areas.

*Type RB*7

Shrinkage and swelling movements small to negligible. Bearing capacity adequate for domestic buildings. Internal drainage rapid.

*Type RB*8

Clay B horizons probably undergo moderate to large shrinking and swelling movements. Calcareous horizons liable to soften and may lose bearing capacity. Deep underlying clay highly expansive.

*Type RB*9

Moderate shrinking and swelling movements occur in the upper clay B horizon, tending to decrease with depth and siltiness. Under drainage usually moderate to rapid; liable to fluctuating water table. Gradation to Type RB5a and to AL.

Soil Group—Black Earth

Type BE

Large shrinking and swelling movements occur in all clay horizons and these may extend to considerable depth. Differential movements may result from variability of soil profiles, often over very short distances. Soil materials generally have high bearing capacity, except where lime is abundant.

Soil Group—Rendzina

Type RZ

Soil horizons are usually shallow overlying bedrock and are considered to undergo small shrinking and swelling movements. Deeper profiles however, can grade towards black earths and have greater movement. Bearing capacity of soil and underlying weathered rock materials usually high. Some powdery forms of lime, if present as a layer, tend to lose strength on wetting.

Soil Group—Terra Rossa

Type TR

Soil horizons are usually shallow overlying bedrock or non-expansive calcareous earth. Deeper profiles may grade towards red-brown earths which are liable to some shrinking and swelling movements. Bearing capacity of soil and underlying weathered rock materials is usually high. Powdery forms of lime, if present as a layer tend to lose strength on wetting.

Soil Group—Brown Solonized Soils

Type BS

Soil horizons subject to negligible shrinkage and swelling movements. Calcareous layers often of low density and bearing capacity and liable to "collapse" on wetting. Type BS frequently overlies a clay of highly expansive nature at depths of less than three metres, capable of creating a water table in the overlying highly permeable soil.

Soil Group—Podzolic Soils

Type P1

Clay horizons undergo moderate shrinkage and swelling movements. Surface sand layer loose, subject to some compaction, and of variable depth, up to 60 centimetres. Bearing capacity of clay and underlying weathered sandstone high. Internal drainage moderate.

Type P2

Clay horizons are considered to undergo moderate to large shrinking and swelling movements according to depth and position on slope, but frequently overlie bedrock at relatively shallow depth. Soil slip may occur on steep slopes. Internal drainage is slow to moderate. Down slope seepage may occur at the soil-rock interface.

Type P3

Clay horizons are considered to undergo moderate shrinkage and swelling movements but usually overlie bedrock at shallow depth. Bearing capacity of clays is high. Internal drainage is moderate to rapid. Down slope seepage may occur at soil-rock interface.

Type P4

Clay horizons are considered to be liable to only small shrinking and swelling movements. Bearing capacity of clays and underlying layers is usually high. Internal drainage is rapid.

Soil Group—Solodic Soils

Type S1

Moderate to large shrinkage and swelling movements likely in the B horizon clay. Surface sands often loose and usually shallow. Clays have high bearing capacity. Internal drainage slow to moderate.

Type S2

Large shrinkage and swelling movements of clay B horizon according to depth and location and similar to, or greater than, those of Type P2. Bedrock usually at moderate depth. Bearing capacity of clays high. Internal drainage of profile slow.

Amorphic Soils

Alluvial Soils AL

Soil horizons do not undergo shrinking and swelling movements of any significance. Bearing capacity is adequate for most types of buildings. Soils may be subject to temporary wetness.

Dune Soils DS1

Stable sandy soil subject to little compaction. Internal drainage rapid.

DS2

Loose sand layers are subject to considerable compaction. Internal drainage is very rapid.

Estuarine Soils EMS

Soils not subject to significant shrinkage and swelling movement. Liable to be affected by water tables and, in places, salinity. Reclaimed swamp areas may be consolidated.

Skeletal Soils SK

Very shallow soil on rock.

Slopewash SW

Not subject to significant shrinkage and swelling movement. Soils could be liable to consolidation under load or become unstable by over wetting either directly or by sub-surface seepage.

An attempt has also been made to assemble practical information on problems concerned with the environment and this is summarised in Table 1 dealing for convenience, with geomorphological land units. It is true that site qualities may overshadow the engineering properties of the soils concerned as the controlling factor in the building of stable structures and, for this reason, detailed observations on the spot should never be neglected. The table indicates potential problems associated with one or more of the soil types listed; each type should be viewed individually in the background of its environment.

TABLE 1

PROBLEMS ASSOCIATED WITH SOILS AND ENVIRONMENT

Zone	Soil Groups (types in brackets)	Special Soil Features to be Observed	Site Problems to be considered for Specific Soil Types and Locations
Eden Fault Block Surface	Podzolic soils (P1, P2, P3, P4) skeletal soils (SK), slopewash (SW)	Stoniness; depth; nature of parent material; residual or colluvial origin	Slip liability; drainage; local wetness (gullies); seepage; erosion; slope angle; consolidation
Eden Escarpment	Podzolic soils, (P1, P2), skeletal soils (SK), slopewash (SW), black earth (BE), rendzina (RZ), red-brown earth (RB1)	Stoniness; depth; nature of parent material; residual or colluvial origin	Slip liability; drainage; seepage; local wetness; slope angle; consolidation
Para Fault Block—*North of Torrens valley*	Podzolic soils, (P1), black earth (BE), rendzina (RZ), terra rossa (TR), brown solonized soils (BS), red-brown earths (RB4 and RB8)	Depth; nature of parent material; origin of soils; underlying clay stratum	Drainage; seepage; slope angle; collapse; expansiveness of clays; variability over short distances
Upper Outwash Plain	Red-brown earths (RB2, RB3, RB5) black earths (BE), alluvial soils (AL)	Presence of active and buried former stream lines; old shallow depressions	Drainage; expansiveness of clays; variability over short distances; local wetness and springs
Lower Outwash Plain (*a*) *North of Torrens valley*	Red-brown earths (RB6, RB7) alluvial soils (AL)	Presence of buried former stream lines; effect of salinity	Flatness and drainage; fluctuating water tables; salinity
Lower Outwash Plain (*b*) *South of Torrens valley*	Red-brown earth (RB5, RB5a, RB9), alluvial soils (AL), grey hydromorphic soils	Presence of buried former stream lines; effects of salinity; presence of organic matter	Fluctuating water tables; flatness and drainage; salinity
River Alluvium—*Torrens and Sturt Rivers and Brownhill and Dry Creeks*	Unaltered alluvium, variable depth. (AL)	Stratification; variability of textures	Temporary wetness; locality of flooding
Coastal Zone	Estuarine muds and sands (EMS). Sand dunes. (DS1, DS2)	Stratification; effects of salinity; immaturity; presence of organic matter	Surface drainage; fluctuating water tables; erosion of recent dunes; consolidation of recent dunes; bearing capacity of reclaimed estuarine soils

APPENDIX 2

DESCRIPTION OF SOIL TYPE PROFILES

Typical profiles of the units used in soil mapping are detailed below. These should be interpreted in association with the general descriptive material in the main text (Chapter 7). The nature of some of the amorphic types does not permit the description of a typical profile. The soils have been classified using the Unified Soils Classification (See p. 73).

Red-Brown Earths—RB

Type RB1

A Horizon . . . . 7 to 12 cm	Sandy soil (SC-SM); brown to grey-brown. Stone fragments are mainly small and occur in variable amounts.
	Sharp change to
B Horizon . . . . Normally thin if present	Clay soil, high plasticity (CH), sometimes sandy: brown or red-brown. Lime usually present in small amounts, sometimes cemented and penetrating into the parent rock beneath, along cracks and joints.
B-C Horizons . . . . . Normally thin if present	Clay soil, high plasticity (CH), sometimes sandy: brown or red-brown. Lime usually present in small amounts, sometimes cemented and penetrating into the parent rock beneath, along cracks and joints.

Type RB2

A Horizon . . . . 30 to 45 cm	Sandy soil (SP-SM); brown or grey-brown becoming red-brown in lower part of the horizon. Compact, hard when dry.
	Clear to gradual change to
B Horizon	Clay soil, sandy to silty, low plasticity (CL-SC); red-brown becoming brown with depth. Lime is often present in small amounts in the lower B horizon but also may be visually absent. Structure—granular soft when moist.
	Profile becomes increasingly sandy with depth and may then contain coarse sand and gravel.

Type RB3

A Horizon . . . . 10 to 25 cm	Sandy or silty soil (SM-SC); grey-brown to red-brown usually lighter coloured in lower part; may be bleached at base.
	Sharp change to
B Horizon . . . . 30 to 60 cm	Clay soil, high plasticity (CH); well defined red, red-brown or dark red-brown colour. Structure—coarse prismatic, breaking into angular blocky units, which when dry, are hard and have bright faces; clay develops a pattern of mainly vertical shrinkage cracks; in the dry state a horizontal crack may also be present at contact with A horizon.
Bca Horizon . . . . . usually more than 100 cm	Clay or sandy clay soil of lower plasticity (CL-CH); and lighter colour than B horizon. Structure—tendency to angular blocky, with dull unit faces. Lime is present in variable but usually moderate amounts, mainly as earthy pockets, but sometimes as hard nodules; the lime generally decreases with depth and the clay, from about 2 m, then becomes more characteristically hard and blocky with darker mottled colours.

Type RB3 Variants

RB3a, a stony form of the type, which usually occurs at higher levels, between the 80 m and 150 m contours and is associated with faster surface drainage and stone movement; stone fragments are distributed through the profile but are especially prominent in the topsoils. Otherwise it conforms to the character of the normal Type RB3.

RB3b, a form with deep light-textured surface, which occurs at higher levels on the plain, is associated with drainage lines and is subject to accumulation of surface wash. The A horizon is 45 cm or more deep, and other horizons may be modified by inclusion of some sandy material. Otherwise it conforms to the character of the normal Type RB3.

Type RB4

A Horizon . . . . 10 to 15 cm	Mainly sandy or silty soil (SM-ML); uniform brown to red-brown. Structure—granular to crumb; on drying may show some shrinkage cracks to surface.
B Horizon . . . . Normally less than 30 cm	Clay soil, high plasticity (CH); strongly red to dark red. Structure—granular to fine prismatic; units show bright faces; on drying develops a pattern of mainly vertical shrinkage cracks.
B-C Horizon	Clay soil of lower plasticity (CL-CH) and lighter in colour than B horizon; some whitish inclusions of weathered rock fragments.
	Lime present in variable amounts, mainly as earthy pockets, but also as rubbly fragments in a thin band. A thin, strongly cemented, calcrete layer may be formed at the surface of the weathering parent rock.

Type RB5

A Horizon . . . . 15 to 30 cm	Sandy or silty soil (SC-SM); grey-brown to brown, and usually becoming light reddish-brown in the lower part.
	Sharp change to
B Horizon . . . . 40 to 50 cm	Clay soil, high plasticity (CH); red-brown sometimes with grey-brown mottling. Structure—typically granular, or if weakly blocky, readily breaks to granular form; friable when moist, but may show fine irregular shrinkage cracks when dry.
Bca Horizon . . . . . . Usually more than 100 cm	Clay soil, medium plasticity (CL-CH); usually more silty or sandy than the B horizon: dull brown to light red-brown. Structure—granular, but in less well developed form than B horizon; friable when moist. Lime present in moderate amounts, mainly in earthy pockets, but with some hard nodular fragments. Lime also tends to decrease with depth below 2 m and the soil to become coarser textured.

Type RB5a

The features distinguishing RB5a from RB5 are—

(*a*) colour of the B horizon tends to be browner than the normal red-brown and rather duller.

(*b*) the A horizon is frequently deeper and often sandier.

(*c*) the horizons are less sharply separated tending to be more gradational layers.

(*d*) the B horizon tends to be a silty clay or fine sandy clay with a granular structure.

(*e*) there is noticeably less lime in the lower B horizon and it frequently is in the form of small hard lumps or concretions.

(*f*) the profile is underlain at a depth of 1·5 m with a more sandy layer, usually a fine sandy material with a low to high percentage of clay fines.

Type RB6

A Horizon . . . . 28 cm	Sandy soil; brown.
B Horizon . . . . 16 cm	Clay, sandy; reddish-brown. Structure—coarse prismatic or blocky structure.
B-C Horizon . . . . . . 9 cm	Clay, sandy; reddish-brown to light brown Lime moderate.
continuing	Clay sandy; reddish-brown.

Type RB7

A Horizon . . . . About 30 cm	Sandy soil (SW-SC); brown to reddish-brown. Soft, coherent.
	Clear to gradual change to
B Horizon . . . . About 30 cm	Clay, sandy (CL); red-brown. Structure—granular. Gradual transition to
Bca Horizon . . . . . . About 30 cm	Clay, sandy (CL); light brown. Lime variable, small to moderate amount in pockets. Structure—granular. Transition to underlying stratum.
Indefinite . . . . thickness	Sandy soil, fine sandy or silty (SC-SM); light brown. Micaceous.

Aitchison *et al.* (1954) record that "visible salt accumulations sometimes occur in the profile, while pockets of gypsum have been noted in the substrata".

Type RB8

A Horizon . . . . less than 15 cm	Sandy soil (SP-SC); brown to grey-brown; more clayey on flatter areas, more sandy when affected by nearby higher level Tertiary sandstone formation.
	Sharp change to
B Horizon . . . . less than 30 cm	Clay soil, high plasticity (CH); red to red-brown. Structure—prismatic or angular blocky, cracking when dry.
Bca Horizon . . . . . . variable thickness	Clay or silty clay soil, moderate to low plasticity (CL); sometimes sandy; dull brownish merging to light brown mottled clay with depth. Lime present in medium to very large amounts as earthy pockets in the clay, but also as cemented rubble or nodular fragments; in some situations profiles contain very high concentrations of lime in layers.
BC Horizon . . . . . . variable depth	Clay, sandy (CH-SC); depending on content of weathering sandstone; brown and mottled passing to underlying sandstone, or clay; high plasticity (CH); related to stratigraphic layer of the Hindmarsh Clay; grey and mottled colours.

Type RB9

The main features of the Type RB9 profile, bearing in mind the considerable range of variants, are:—

15 to 30 cm	Sandy or silty soil (SC-SM); grey-brown, dark grey-brown or dark grey. Where it is deeper it is darker coloured, probably influenced by surface wash and organic matter.
About 22 cm	Clay or silty clay soil, medium to high plasticity (CL-CH); yellow-brown, grey-brown and brown mottled. Structure—angular blocky but varying from sub-prismatic to granular. Black coatings on aggregates frequent.
About 30 cm	Clay or silty clay soil, medium plasticity (CL-CH); brown to dull red-brown. Structure—granular, friable.
About 37 cm	Clay or silty clay soil, medium to high plasticity (CL-CH); yellow-brown, grey-brown and brown mottled. Structure—angular blocky but varying from sub-prismatic to granular. Black coatings on aggregates frequent.
About 30 cm	Clay or silty clay soil, medium plasticity (CL-CH); brown to dull red-brown. Structure—granular, friable.
About 37 cm	Clay or silty clay soil, medium plasticity (CL); light brown. Structure—granular. Lime present in small amounts often as small hard fragments.
Indefinite . . . . thickness	Silty to fine sandy soil (SC-SM); grey, grey-brown bluish-grey. Soft and moist—affected by high water table which at times may reach within 1·2 m of the surface.

Black Earth—BE

Some of the distinguishing characteristics of the profile of the black earth, Type BE, are:—

Clay soil, low to high plasticity (CL-CH) sometimes silty or sandy; dark grey to black and usually as a surface layer about 5 cm thick. Structure; granular becoming small angular-blocky. Extensive shrinkage cracking develops on drying.

Clay soil, high plasticity (CH); colours are variable, dull and often mottled, and include black, dark grey, olive grey, red-brown and yellow-brown. May include several near horizontal layers with different colours or mottling. Structure; well developed massive to angular blocky, sometimes prismatic, with bright unit faces. On drying, pronounced vertical and radial cracking develops. Lime is present in varying amounts, either as discrete pockets or disseminated in the soil as a layer, frequently thick, at depths varying from 38 to 90 cm from the surface. In some areas, lime, in the soft form, constitutes as much as 50 per cent of the Bca horizon as large pockets.

Clay soil, underlying, high plasticity (CH); colours variable always mottled and usually grey and brown. Structure; large angular blocky with shear faces. This layer(s) may or may not be directly related to the soil profile above but affects it by potential expandability.

Soils Derived from Calcareous Materials

Rendzina—RZ

Sandy to clayey soil (SC-CL), usually uniform in texture for full depth; black to dark brown. Surface soil (<8 cm) may be loose and granular.

Structure—friable when moist, hard and granular when dry; more clayey profiles may show some shrinkage cracks.

Calcareous layer; often capped by sheet of calcrete up to 5 cm thick; varies from powdery, poorly compacted material to firm, lime-rich silt. Stone fragments of underlying rock may be present, partially weathered and lime coated.

The parent rock is usually fragmented and partly weathered to some depth.

Terra rossa—TR

Sandy to clayey soil (SC-CL); brown to red-brown and normally darkened by organic content in a thin surface layer only. Structure—fine granular to crumb, friable when moist.

Clay soil, low plasticity (CL); sandy, usually a little more clayey than topsoil; strongly red or red-brown. Structure—soft granular, friable when moist.

Calcareous layer; firm, compact lime-rich silt often with lumps of calcrete at top. Grades into parent rock with lime coated fragments; rock weathered and fragmented.

Brown Solonized Soils—BS

A Horizon . . . . 15 to 30 cm	Sandy soil (SP-SM); dull brown to grey-brown; some fragments of cemented lime may be present; loose or powdery soil when dry.
B Horizon . . . . 15 to 30 cm	Clayey sands to sandy clay soil (SC-CL); dull brown; usually thin layer only, less than 30 cm thick.
Bca Horizon . . . . . variable thickness	Silty or sandy soil, some fines (SM-SC); whitish to pale brown. Very high in lime both soft and rubble types. Powdery when dry. Continues as calcareous earth down to understratum—clay or rock.

Podzolic Soils

Type P1

A Horizon . . . . variable depth	Sand, medium to coarse grained (SP); dark-grey with organic matter, becoming finer grained and lighter coloured in lower part. Sharp change to
B Horizon	Clay soil, medium to high plasticity, sandy (CL-CH); red, yellow and grey mottled. Structure—poorly developed angular blocky, dull surface on unit faces. Shrinkage cracks may develop on drying. Pockets of weathered sandstone appear at depth transitional to parent rock.

Type P2

A1 Horizon . . . . . 5 to 10 cm	Sand, medium grained, (SM); greyish.
A2 Horizon . . . . . 10 to 20 cm	Sand, medium grained (SP); pale grey. Sharp change to
B Horizon . . . . 25 to 50 cm	Clay soil, medium to high plasticity (CH); yellow with grey or red-brown mottling. Structure—angular blocky; irregular shrinkage cracking, sometimes severe, develops on drying; becomes less blocky with depth and includes increasing amounts of weathered rock fragments.

Weathered rock normally occurs between 60-150 cm from the surface.

Type P3

A1 Horizon . . . . . 5 to 10 cm	Sand, medium grained, silty (SP-SM); grey or dark grey, with organic matter.
A2 Horizon . . . . . 5 to 10 cm	Sand, medium grained, silty (SP-SM); light grey, less bleached than in Type P2.
B Horizon . . . . 25 to 50 cm	Clay soil, medium to high plasticity (CL-CH); red or red-brown, often dark shades. Structure—coarse granular, minor shrinkage cracking occurs on drying.

At variable depth the clay becomes red and mottled, with frequent stone fragments, grading to parent rock.

Type P4

A1 Horizon . . . . . 7 to 12 cm	Sand, silty (SP-SM); grey or grey-brown with some ironstone gravel.
A2 Horizon . . . . . 17 to 30 cm	Sand, silty (SP-SM); light brown or light grey-brown with large amount of ironstone gravel. Sharp change to
B Horizon . . . . 35 to 45 cm	Clay soil, low plasticity (CL); yellow or with red and brown mottling, slight gravel. Structure—granular, plastic and friable when moist.
BC Horizon . . . . . Up to 125 cm	Clay soil, low plasticity (CL); mottled, yellow, red and grey. Structure—granular, plastic and friable when moist. Slightly to completely weathered rock fragments occur which increase with depth from about 1·2 m down to underlying weathered shale.

Solodic Soils

Type S2

A1 Horizon . . . . . 7 to 15 cm	Sand, fine grained, sometimes silty (SC-SM); grey or grey-brown.
A2 Horizon . . . . . 7 to 15 cm	Sand, fine grained (SP); white or very pale grey, usually powdery but sometimes sets hard on drying, infiltrated in cracks of B horizon. Sharp change to
B Horizon . . . . 100 cm	Clay soil, high plasticity (CH); grey, yellow and mottled. Structure—angular blocky to prismatic; hard when dry, highly plastic when moist; cracking vertical and irregular.
BC Horizon	Increasing rock fragments in mottled clay overlying bedrock.

Type S1

Solodic soils (Type S1) formed on Tertiary sandstone have general characteristics similar to Type S2 but are influenced by the coarse sandy parent material; from this develops a sandy clay B horizon of less intractable nature with strong red, yellow and grey mottling. In some cases small amounts of lime occur in the BC horizon.

THE UNIFIED SOILS CLASSIFICATION

COARSE-GRAINED SOILS — More than 50% of material is larger than No. 200 B.S. sieve size

	FIELD INVESTIGATION PROCEDURES Excluding particles larger than 7·5cm and basing fractions on estimated weights		GROUP SYMBOL	GROUP NAME and typical materials	LABORATORY CLASSIFICATION CRITERIA	
GRAVELS More than 50% of the coarse fraction is larger than 2mm. (retained on B.S.7 sieve)	**CLEAN GRAVELS** Little or no fines	Wide range in grain sizes, and substantial amounts of all intermediate particle sizes	GW	**GRAVEL, well graded;** gravel sand mixtures, little or no fines	$Cu = D60/D10$ Greater than 4 $Cc = (D30)^2/(D10 \times D60)$ Between 1 and 3	
		Predominantly one size or a range of sizes, with some intermediate sizes missing	GP	**GRAVEL, poorly graded;** gravel sand mixtures, little or no fines	Not meeting all gradation requirements for **GW**	
	DIRTY GRAVELS Appreciable amount of fines	Non-plastic fines—for indentification see **ML** below	GM	**GRAVEL, excess silty fines;** poorly graded gravel-sand-silt mixtures	Atterberg limits below "A" line or PI less than 4	Above "A" line with PI between 4 and 7 are borderline cases requiring use of dual symbols
		Plastic fines—for identification see **CL** below	GC	**GRAVEL, excess clayey fines;** poorly graded gravel-sand-clay mixtures	Atterberg limits below "A" line or PI greater than 7	
SANDS More than 50% of the coarse fraction is smaller than 2mm. (passing B.S.7 sieve)	**CLEAN SANDS** Little or no fines	Wide range in grain sizes, and substantial amounts of all intermediate particle sizes	SW	**SAND, well graded;** well graded sands, gravelly sands, little or no fines	$Cu = D60/D10$ Greater than 6 $Cc = (D30)^2/(D10 \times D60)$ Between 1 and 3	
		Predominantly one size or a range of sizes, with some intermediate sizes missing	SP	**SAND, poorly graded;** poorly graded sands, gravelly sands, little or no fines	Not meeting all gradation requirements for **SW**	
	DIRTY SANDS Appreciable amount of fines	Non-plastic fines—for indentification see **ML** below	SM	**SAND, excess silty fines;** poorly graded sand-silt mixtures	Atterberg limits below "A" line or PI less than 4	Above "A" line with PI between 4 and 7 are borderline cases requiring use of dual symbols
		Plastic fines—for identification see **CL** below	SC	**SAND, excess clayey fines;** poorly graded sand-clay mixtures	Atterberg limits below "A" line or PI greater than 7	

GRAIN SIZE CURVES to be used to identify soil fractions

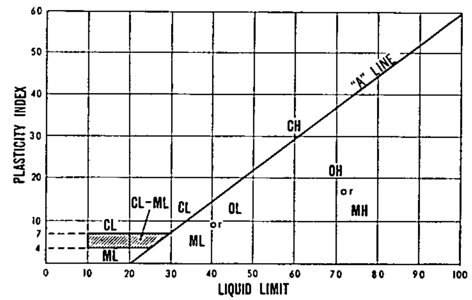
Coarse-grained soil classified on basis of percentage of fines, as follows

PERCENT OF FINES	GRAVELS	SANDS
Less than 5	GW GP	SW SP
More than 12	GM GC	SM SC
5 to 12	Borderline cases, use 2 symbols	

FINE-GRAINED SOILS — More than 50% of material is smaller than No. 200 B.S. sieve size

FIELD INVESTIGATION PROCEDURES on fraction smaller than 0.4mm. (passing B.S. 36 sieve)

	SOIL CAST (soil wet)	SOIL THREAD	SHINE	DILATANCY	ODOUR	DRY STRENGTH	GROUP SYMBOL	GROUP NAME and typical materials
SILTS AND CLAYS Liquid limit less than 50	Forms fragile cast Cracks form when kneaded while moist	Thick crumbly thread; easily broken	None to very dull	Distinct	Not significant	None to slight	ML	**SILT SOIL, low plasticity;** inorganic silts and very fine silty or clayey sands, rock flour
	Cast maybe handled freely without breaking Can be kneaded moist without cracking Material adheres to the hand	Thread can be pointed as fine as a lead pencil but is fragile	Moderate	None to slight	Not significant	Moderate	CL	**CLAY SOIL, low plasticity;** inorganic clays of low to medium plasticity, gravelly clay, sand, clays, silty clays, lean clays
	Cast fragile to cohesive material will adhere somewhat to the hand	Soft, weak thread	None to very dull	Slight to distinct	Decayed organic matter	Low	OL	**ORGANIC SOIL, low plasticity;** organic silts and silt clays of low plasticity
SILTS AND CLAYS Liquid limit more than 50	Moderately plastic and cohesive Material adheres somewhat to the hand	Weak to medium thread May be crumbly	Dull	None to slight	Not significant	Moderate Powdered soil feels floury	MH	**SILT SOIL, high plasticity;** inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts
	Very plastic and cohesive Material very sticky to the hand Greasy to touch	Very tough thread, can be rolled to a pin point	Very glossy	None	Strong earthy	High to very high Cannot be powdered by finger pressure	CH	**CLAY SOIL, high plasticity;** inorganic clays of high plasticity, fat clays
	Plastic and cohesive Feels slightly spongy Greasy to touch	Weak to medium thread Often soft and fibrous	Moderate to very glossy	None	Decayed organic matter	Moderate to high Powdered soil may be fibrous	OH	**ORGANIC SOIL, high plasticity;** organic clays of medium to high plasticity
	Readily identified by colour, odour, spongy feel and frequently by fibrous texture						Pt	**PEATY SOIL;** Peat and other highly organic soils



PLASTICITY CHART
FOR LABORATORY CLASSIFICATION OF FINE-GRAINED SOILS

NOTE: BOUNDARY CLASSIFICATIONS: Soil possessing characteristics of two groups are shown as a combination of two group symbols, eg. GW-GC, well graded gravel with clay binder.

Based on "The Unified Soil Classification System" United States Department of the Interior, Bureau of Reclamation "Earth Manual" First Edition, Denver COLARADO 1960.

70-641

PLATE 1

Red-brown earth
Type RB 3

0 cm

Silt soil (ML), with clay fines, dark grey-brown.

12 cm

Silt soil with clay fines (ML-CL), compact; light brown.

40 cm

Clay soil (CH), high plasticity, dark red-brown, subangular blocky structure.

Thin gravel band at 68 cm.

68 cm

Clay soil (CH), high plasticity; dark red-brown; prismatic structure, shiny interfaces.

108 cm

Clay soil (CL), high plasticity, light red-brown; granular structure; moderate lime mostly concretionary.

125 cm

Clay soil (CH), high plasticity, dull red-brown subangular blocky to granular structure; slight lime concretions.

190 cm

Clay soil (CL), silty, moderate plasticity, light red-brown to light brown becoming more silty.

PLATE 2

Red-brown earth
Type RB 4

0 cm

Silt soil with clay fines (SM), grey-brown.

16 cm

Clay soil, high plasticity (CH), dark brown to red-brown, coarse blocky structure.

64 cm

Clay soil (CL), light brown, high lime content.

96 cm Weathered bedrock.

PLATE 3

Red-brown earth
Type RB 5

0 cm

Sand (SC) with some clay fines, few pebbles, dark grey.

20 cm

Sand soil (SC) with some clay fines, light brown.

25 cm

30 cm

Clay soil (CL), very sandy and silty, low plasticity, light red-brown.

Clay soil (CL-CH), high plasticity, red-brown, granular structure, dark grey interfaces.

75 cm

Clay soil (CL), moderate to high plasticity, light red-brown; granular structure; moderate to high lime mainly as concretions. Some pebbles.

135 cm

Clay soil (CL), silty to sandy, moderate plasticity, light red-brown, slight lime concretions. Few pebbles.

180 cm Continuing silty and sandy.

PLATE 4

Red-brown earth
Type RB 6

0 cm

Silt soil (SM-SC), (organic) very dark grey.

15 cm

Silt soil (SM-SC), light grey-brown, compact.

44 cm

Clay soil, high plasticity (CH), red-brown, blocky to prismatic structure with black interfaces on aggregates.

58 cm

Clay soil, high plasticity (CH), red-brown, blocky structure, softer with silt increasing with moderate lime.

100 cm Clay with silt and sand (CL-SM), light brown to light red-brown, becoming more sandy with depth.

PLATE 5

Red-brown earth
Type RB 9

0 cm

Silty soil with clay fines (SM), dark grey (organic).

30 cm

Clay soil, high plasticity (CH), very dark grey, blocky to prismatic structure (cracking).

40 cm

Clay soil, high plasticity (CH), red-brown, blocky to prismatic structure (cracking).

60 cm

Clay soil, high plasticity (CH-CL), red-brown to light red-brown, small blocky structure, moderate lime content.

95 cm

Clay soil, silty, moderate plasticity (CL), mottled grey and grey-brown, slight fragmental lime.

120 cm Continuing as silty clay to fine sandy clay, (CL-SM) low plasticity, light grey-brown.

PLATE 6

Black earth

Type BE

0 cm

Clay soil (CH) with some sand, high plasticity, sticky, black; somewhat granular structure at surface.

18 cm

Clay soil (CH), high plasticity, black; angular blocky structure, dense and hard.

42 cm

Clay soil (CH), high plasticity, black; prismatic structure, dense and hard.

105 cm

Clay soil (CH), high plasticity, yellowish grey; blocky structure, dense; slight lime concretions decreasing with depth.

142 cm

Clay soil (CH), high plasticity, yellowish grey, blocky structure, dense.

160 cm Continuing yellowish-grey clay.

PLATE 7

Brown solonized soil
Type BS

0 cm

Sand soil (SC), some clay fines, dark grey.

13-20 cm

Clay soil (CL), very sandy, low plasticity, light red-brown.

28 cm

Clay soil (CL), high plasticity, red-brown; subangular blocky structure.

50 cm

Calcareous earth with calcrete nodules.

70 cm

Calcareous earth with some inclusions of red-brown clay.

135 cm

Clay soil (CH), moderate to high plasticity, grey with red inclusions, lime in pockets (Transition zone).

160 cm Clay soil (CH), high plasticity, dense; grey (Hindmarsh Clay).

PLATE 8

Terra rossa
Type TR

0 cm	
	Sandy silty soil (ML), very dark brown.
18 cm	
	Clay, moderate plasticity (CL), red to red-brown, granular structure.
36 cm	
	Clay, low plasticity (CL), light red-brown, calcrete and very high lime.
75 cm	
	Clay with inclusions of weathered slate.
100 cm	Weathered slate bedrock.

PLATE 9

Podzolic soil
Type P1a

0 cm

Sand soil (SP), dark grey to grey-brown (organic).

14 cm

Sand soil (SP), light grey-brown with some dark pockets.

55 cm

Sand soil, light yellow, large amount ironstone gravel.

80 cm

Clay, sandy, moderate plasticity (CH-CL), red and yellow mottled, small blocky structure.

145 cm Soft weathered sandstone.

PLATE 10

Podzolic soil
Type P2

0 cm	
	Sand soil (SC), grey to dark grey.
12 cm	
	Sand soil (SW-SC), grey.
25 cm	
	Clay soil, high plasticity (CH), mottled red-brown and grey, coarse blocky structure.
70 cm	
	Clay soil, high plasticity (CH), mottled light grey and red-brown, coarse blocky structure, inclusions of weathered siltstone.
110 cm	On weathered siltstone.

PLATE 11

Podzolic soil
Type P4

0 cm

Sand soil (SW-SC), grey to grey-brown.

20 cm

Sand soil (SW), light grey with fine ironstone gravel.

36 cm

Clay soil, moderate plasticity (CL), yellow with reddish mottling, granular structure, slight ironstone gravel.

60 cm

Clay soil (CL), large amount coarse ironstone gravel.

84 cm

Clay soil, moderate plasticity (CL), light grey and yellow mottled, coarse blocky structure, slight ironstone gravel.

120 cm Continuing to weathered bedrock.

PLATE 12

Solodic soil
Type S2

0 cm	Sandy silty soil (SM), very dark grey.
5 cm	Sandy silty soil (SM), light grey.
32 cm	Sand, fine (SP), very pale grey to white.
40 cm	Clay soil, high plasticity (CH), yellowish grey and mottled, coarse blocky structure, severe cracking.
84 cm	Clay soil, high plasticity (CH), yellow and grey mottled, blocky structure.