SOILS

PHOTOGRAPH ABOVE: Planting sugar cane on a deep, permeable loam soil (A1 soil) near Innisfail, north Queensland.

This photograph and Figure 6 by Australian Information Service; Figures 1-5 by F. T. Bullen.

INTRODUCTION

The purpose of the accompanying map, and this text, is to describe Australian soil resources in terms of those inherent properties that are particularly important for land management. This is a departure from more traditional approaches to soil maps; indeed, it is a first attempt at presenting an *interpretative* soil map in the *Atlas of Australian Resources.*

The present map is the third in the Atlas. The first 'Soils', 1952, was at 1:6 000 000, and was a standard continental soil map. It was drawn directly from Prescott's soil map of Australia (Prescott 1944), the most comprehensive information then available, although the mapping units of Prescott's original map were rearranged in the map legend to indicate broad climatic relationships. The accompanying booklet commentary discussed soils as naturally occurring materials of the surface of the earth (Taylor 1953). While this first map showed eighteen mapping units, the second edition of 1963 (also at 1:6 000 000) showed thirty-two mapping units (Stephens 1963), which was indicative of the increase in soils information. It was compiled by Stephens from his soil map of Australia published at 1:5 000 000 (Stephens 1961), again with the legend recast to emphasise climatic zonation and hence point to land use. Stephens' commentary for this second edition ranged widely, although necessarily briefly, over many topics including the nature and composition, classification, productivity and use of the soils.

Since then, three maps of Australian soils at continental scales have been published. The *Atlas of Australian Soils,* at its publication scale of 1:2 000 000 in thirteen sheets*, is one of the most detailed soil maps available for any comparable area (Northcote and others 1960-68). The soils for this new work were mapped as 'soil-landscapes', while the soils themselves were classified as 'principal profile forms' (Northcote 1971)—see Appendixes 1 and 2 and Figure 7. The thirteen Atlas sheets then provided the basis for 'A Soil Map of Australia' at a scale of 1:10 000 000 (Stace and others 1968), and more recently for a 1:5 000 000 soil map for *A Description of Australian Soils* (Northcote and others 1975). The legend for the 1:10 000 000 map was arranged to show *general* relationships between the principal profile forms and the older 'great soil groups'. The 1:5 000 000 map, although only slightly larger than the soils maps in the first and second series of the *Atlas of Australian Resources*, contains 102 main soil units and describes the relative relief as well. The increase in the number of map units alone suggests something of the growth in knowledge concerning Australian soils that has taken place in recent years. At the same time it may well mean that fewer people can readily comprehend the increased soils information now available, even though it is expressed in much less forbidding words than used for either the older great soil groups or the newer FAO and U.S. Soil Survey classifications (Appendix 1). Therefore, it seemed timely to attempt an interpretative map more suitable for the general reader, with fewer mapping groups and closely related to land use and capability.

The accompanying map presents four primary soil groupings and these are divided into a total of 29 mapping groups. These units are all derived from, and are integrated with, the principal profile forms of the standard 1:5 000 000 soil map of 1975, as well as the sheets of the *Atlas of Australian Soils.*

LAND AND SOIL

Soil is a very old word connected ultimately with Latin *solum*, the ground. As dictionaries show, it has had many meanings in common usage, to which have been added in modern times the more specialised meanings of soil scientists, engineers and geographers. *Land*, too, has had a variety of meanings. The word in its simple, basic meaning denotes the solid portion of the earth's surface, as opposed to water. In its modern meaning, however, the concept of land is much more sophisticated, especially for those concerned with natural resources and planning. For them, the word *land* signifies that complex of all factors of the land surface of importance to man's existence and success (Christian 1958). Thus, both natural and man-made resources are included, and moreover man himself is considered as a factor of the land environment.

Whether or not this holistic view is accepted, there will always be certain natural attributes of land and of its environment that can be, and moreover will always need to be, observed and measured. These are climate, geology (both lithology and history), topography, hydrology, soil and vegetation. Soil has a special significance, as the other five attributes have contributed to its formation, and are integrated within its constitution. On this account, the probability of soil variation is considerable, so much so that the soil at a site is clearly unique.

Human activity on a soil-site (small area of land) (Appendix 2) needs to be in harmony with the soil of that site to achieve optimum satisfaction by, and for, that activity. To help achieve this harmony soil-sites can be grouped into classes with observable and measurable degrees of similarity. The remarkable thing is that, although soil variability is infinite, soil-sites can be grouped together usefully. It is important for all users of land to understand this situation as soil is one of the central factors, very often the key factor, in the use of land. Unfortunately, facts and figures remain limited, and interpretations are therefore doubtful. Nevertheless, as interpretations of soil performance form the core of sound land use, it is important to list and discuss those soil interpretations available to us.

Agriculturists, foresters, ecologists and others rightly regard soil as the natural medium for the growth of land plants: it provides the specialised environment in which plant roots live. On the other hand, engineers consider soil to be all the unconsolidated earthy material above bedrock. They are primarily concerned with soil as a foundation or construction material. It is clear that these two appreciations of soil are very different. Nevertheless, there are some points of common interest, and modern pedological studies provide engineering as well as agricultural information. When land is used for recreational purposes both these aspects of soil are involved, and the general public may be interested in one or both aspects.

Workers in other sciences often have special interests. Geographers have a broader interest in soil, being concerned mostly with large areas in relation to land use or to some environmental attribute such as climate. Geologists and geomorphologists too have a broad interest in soil, the former about what the soil may indicate regarding the underlying geology and its minerals, and the latter about what information soil provides regarding the formation and structure of the earth's surface. Archaeologists may use soil as a means of defining a time-scale for their archaeological finds, either deduced by dating charcoal fragments etc. found in a soil layer, or from the estimated rate of soil development. In all these cases, modern pedological studies can provide both a general framework and specific data.

The emphasis in this Atlas topic is on those inherent soil properties that impose or have imposed limitations of a greater or lesser extent on the use of the soil. For example, the cracking clays (Cb1, Cb2) have a great shrink-swell capacity that exerts a predominant influence on their use for agriculture or engineering, irrespective of the climate or topography. That is, the shrink-swell property remains as a highly significant factor in the use of cracking clays no matter whether they occur in hot moist climates with a winter dry season as near Darwin, or in dry hot to warm climates as on the Barkly Tableland, or in temperate moist climates with wet winters as near Adelaide and Melbourne. Admittedly, the degree of the shrink-swell capacity may differ between climatic zones, but then it may also vary within any one zone due to abnormally wet or dry periods. However, the *kind* of limitation, as distinct from its *degree*, remains always that of the shrink-swell capacity of the clay minerals found in these soils. In this commentary, the kind of limitation will be emphasised, although it is recognised that its severity requires evaluation at more detailed levels of enquiry. Ultimately, enquiry must be made at soil-sites, especially for foundations of buildings, and even for growing individual plants etc.

For further discussion about soil classification, soil-sites and soil maps, see Appendixes 1 and 2.

THE INTERPRETATIVE SOIL GROUPS SHOWN ON THE ACCOMPANYING MAP

These groups are made up of soil units placed together on the basis of soil properties that place constraints on the use of land irrespective of climate. Such limitations are not to be regarded as prohibitions but rather as properties capable of being changed or modified so that better and/or more productive use of land may result. These soil limitations are primarily physico-chemical. Group B includes all soils in which limitations are predominantly chemical, while group C includes soils with predominantly physical limitations. This is a great simplification of what are always complex physico-chemical interactions. Group A was created for soils with few drawbacks. All organic soils are placed in group O; they are separated from the three groups of mineral soils because of their high water-storage capacity and liability to irreversible drying under arable farming.

Furthermore, there is a distinct biochemical aspect to soil use that has not been used in defining the present units because data seem inadequate and are not clearly related to recognised soil groups. For example, the nitrogen status of continuously cultivated hard red duplex soils (*Dr2.23* of Appendix 3†) in the Barossa Valley is 25-50 per cent lower than in uncultivated areas of the same soil; the lower nitrogen levels are indicative of a decrease in biological activity in the surface soil resulting in a loss in soil fertility and a lessening in the rate of water acceptance by the soil. It may well be that biochemical conditions are of a more localised nature than is being considered here. On the other hand, soil architecture—the physical building up of the soil—discussed in relation to some duplex soils such as those of groups Cc1 or Cd2, while sparked by reaction to physico-chemical difficulties, clearly involves changes in soil organic matter and thus in the biochemistry of the soil.

Appendixes 3 and 4 supplement and complement the text and map and should be used with them. In Appendix 3 the principal profile forms are listed, and in Appendix 4 they are put into the map groups. Their descriptions in the latter table are given in physico-chemical terms, rather than morphological ones, although morphology provides the basis for the physico-chemical interpretations. It is clear from the descriptions that the map groups represent ranges of soil conditions. For example, permeability sequences begin with more permeable (often red) soils and pass to less permeable (often mottled-yellow) soils.

The plain fact is that Australian soils are generally difficult to manage and are infertile. They present a range of management problems that over the years have been overshadowed first by climate, that by

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* The *Atlas* is also available now in six sheets, drawn to facilitate its presentation as a single wall map (entitled *Soil Map: Australia* and published by the Division of Soils, CSIRO, Adelaide, 1978).

† Factual Key notation is used, *italicised*, where necessary to make finer distinctions than are shown on the map—see also Appendix 4.

contrast to the climate of Britain hit the early settlers so hard, and second by the great effort that had to be made to arrest dramatically falling crop yields and stock dying due to nutrient deficiencies. Now that these problems are largely solved, the knowledge so gained can be incorporated into new methods of soil management that may more than double yields, for example see under Cc1 below.

A. SOILS GENERALLY WITHOUT LIMITING CHEMICAL OR PHYSICAL PROPERTIES

The soils of group A are those that seem to be among the most easily managed of Australian soils at the present time. Generally, these soils have a good moisture storage capacity, allow plant roots to penetrate deeply, and are thus suitable for a wide range of uses with a minimum of the manipulation or amelioration required by the soils of the other groups, and especially so when their phosphorus, nitrogen and occasional trace-element deficiencies are met (Appendix 4).

The deep loam soils, A1, are permeable and moderately fertile. They occur typically in relatively small areas on river terraces (as in the Hunter Valley of N.S.W.), plains and some hill slopes mainly in the seasonally humid regions of sub-coastal south-eastern Australia, and to a lesser extent elsewhere. Parent materials are Quaternary alluvium and colluvium derived from a variety of rocks. Unfortunately, their aggregate area probably totals less than 1% of Australia. Their usefulness for horticulture has been clearly recognised with good results. Buildings are rarely erected on these soils but under load it seems likely that some settlement of foundations could take place.

Duplex soils are second only to sand soils in the total area they cover in Australia (Northcote and others 1975), and for present purposes they have been placed in six groups, A2, Bb5, Bd3, Cc1, Cd2 and Ce2. Group A2, which accounts for about 20-25% of all duplex soils, includes the best of them. As shown in Appendix 4, they are deep, friable and permeable soils even though subsoil permeability declines slightly from the *Dr* soils, through *Db*, to the *Dy* soils. They are widely distributed throughout the seasonally humid lands of eastern and southern Australia, with smaller areas in Western Australia, mostly where annual rainfalls range from 350 to 1000 mm. Their topographic range includes plains, fans, terraces, valley slopes and slopes of dissected plateaux, hills and mountains. Parent materials are largely Quaternary alluvium and colluvium derived from a wide variety of rocks. The major occurrence of *Dr2.21* soils is in eastern Victoria and the larger areas of *Dr2.23* soils are in the Adelaide-Quorn region of South Australia and around Parkes and Tamworth-Manilla in New South Wales. Significant areas of *Dy3.22* soils cover the slopes of the Barossa hills in South Australia. All these soils are used for sheep and cattle grazing to a large extent on sown pastures, but wherever the terrain and climate are suitable they are cultivated for cereal, vegetable or horticultural crops. The very ease and frequency of cultivation has caused loss of organic matter and deterioration of tilth in surface soils, which serves to highlight weaknesses in their general management.

Some A2 soils, notably *Dr2.23*, have subsoil clays with significant shrink-swell properties that necessitate appropriate foundation practices (Aitchison and others 1954). However, for domestic dwellings, where the surface soil is more than 30 cm thick, there may be a sufficient cushioning effect to allow surface foundations to be used. Generally, bearing capacity is moderate to high in these soils. On steep slopes precautions against soil creep are desirable and, where there is significant wear on unprotected surface soils, erosion must be expected. Furthermore, should the well aggregated clay subsoils be exposed, gully erosion can be expected due to water flow separating and carrying away subsoil peds (natural soil aggregates).

B. SOILS WITH PREDOMINANTLY CHEMICAL LIMITATIONS

Generally, the correction of nutrient deficiencies (Ba, Bb and Bc) or complete, or partial, removal of salt (Bd) will improve plant growth. The physical properties of the soils of the Ba, Bb and Bc groups, so desirable for agriculture, cause their own special kinds of problems for building and construction.

Ba. Deep, Highly Structured Soils with High Initial Fertility

There are two main soil properties that allow the soils of this group to be placed together. They are their highly desirable physical condition coupled with a chemical fertility that declines with agricultural land use from relatively high initial levels.

The Ba soils developed mainly on basalts and other basic igneous rocks, but also on shales, phyllites, schists, mudstones, some granites and acid igneous rocks, by deep *in situ* weathering in wetter phases of earlier Quaternary climates. Such deep weathering removed bases by leaching but allowed sufficient silica, alumina, and iron oxides to be retained to form large amounts of kaolinitic clays and hydrated iron oxides capable of maintaining soil flocculation. The redder soils, for example, contain 15 to 30% of ferric oxide. Although particle-size analyses show that Ba soils are mainly clays, their surface soils behave like friable loams, clay loams, or sometimes light clays due to the intimate incorporation of organic matter with the flocculated clays. The content of organic matter ranges from 2-3% to about 15% depending on present rainfall and vegetation. The organic matter decreases with depth to about half by 30 cm. However, the influence of organic matter often continues to 50-60 cm in depth. Its gradually decreasing content with depth is the principal reason for the apparent textural gradation found in the soils of group Ba3. The soils of group Ba2, on the other hand, are among those that have lower organic matter contents (<5%).

The desirable physical condition of the soils of group Ba, a direct result of the above factors, is now evidenced by their highly pedal structure that allows plant roots to grow freely and extensively. This property is well known and is particularly clearly demonstrated in the redder soils such as *Gn3.11* or *Gn4.11*. Pedality becomes relatively coarser, and thus friability tends to decrease sequentially through the browner and black forms to the yellow and grey ones. It also decreases where discernible subsurface colour horizons are present. Although the greyer soils such as *Gn3.9* are less friable than the red soils, they are still pedal, whereas the comparable soils of group Bb4 (*Gn2.8, Gn2.9*) are not.

While these properties create soils physically suitable for all forms of cultivation, they may cause some engineering problems. Road cuttings, for example, fret and erode as peds readily separate and fall to the base of the cutting, gradually accumulating until an angle of repose of some 45-60° to the vertical is attained. Cuttings in the massive earths (Bb4) do not fret and remain vertical. Again, the control of seepage in earth structures may necessitate stabilisation, for example with sodium tripolyphosphate (Wickham and Harris 1976).

Chemical fertility in these soils was relatively high on newly cleared land but, with continuous and intensive use, levels of nitrogen and phosphorus rapidly declined (Northcote and others 1975). By Australian standards these soils have high phosphorus contents. They generally range from 0.03 to about 0.6% phosphorus for surface soils (0-10 cm). The higher contents are from soils with basaltic parent materials. Another feature is their relatively high capacity to immobilise applied phosphorus from fertilisers thus making it relatively unavailable to plants. Responses to phosphorus, nitrogen, sulphur, and molybdenum are now commonly obtained; while applications of potassium, manganese, copper, zinc, and cobalt (for animals) may be necessary in some areas or for some crops. Thus, to achieve continuing productive agricultural use of the land, these soils primarily require correct fertiliser application together with the maintenance of soil organic matter. *This state of affairs develops after use, whereas for the soils of the Bb group correction of nutrient element deficiencies is largely a condition of their use from the time of initial clearing.*

Soils of the Ba group occur in Tasmania and extend throughout eastern and northern Australia mainly in the wetter coastal areas with annual rainfalls of 500 mm or higher but also ranging down to 380 mm in some more inland areas. They developed wherever suitable parent rocks are present, such as Plio-Pleistocene basalts, or where older lithologically suitable rocks have been exposed by the removal of overlying Tertiary materials as a result of geological events since that time. Although the aggregate area of these soils is small (<4% of the total area of Australia), they have been eagerly sought and intensively developed for a wide range of crops and pastures. Originally, forests ranging from temperate to tropical rain forests and to sclerophyll eucalypt forests clothed most areas. Some areas, often in steep country, remain in forest.

Further developments depend very largely on correct fertilisation for individual soils in relation to particular crops or pastures. On the other hand, engineering developments largely depend on soil stabilisation.

Bb. Soils Naturally Low in Nutrients

The massive earths of group Bb4 are among the most widespread and least well known of Australian soils. They occupy about 17% of the total land area of Australia—from Darwin in the north to the desert areas of the Centre and to the Murchison and northern wheat belt in Western Australia, and from the western plains and slopes of New South Wales and Queensland to the coastal rain forest areas—but they are only of minor extent in the southern third of the continent. Together with the morphologically similar earthy loams, Bb1, and earthy clays, Bb3, and the morphologically dissimilar ironstone gravelly, yellow duplex soils, Bb5, they developed on materials derived from the deeply weathered mantle of the Australian Tertiary land surfaces; and they are often associated with laterites and silcretes. Because of this long history of weathering, it is not surprising that they now range over several present-day climatic zones. Nor is it surprising that clay minerals are largely kaolinitic and natural contents of phosphorus, potassium and calcium, elements that give a clue to the fertility of the soil, are low to very low. Phosphorus contents in surface soils (0-10 cm), for example, range from 0.004 to 0.03%. Indeed, deficiencies of all nutrient elements are common, although there is some variation with location and particular crops or pastures (Isbell and Smith 1976, Northcote and others 1975, Northcote and Tucker 1948).

Figure 1. *A deep massive earth naturally low in nutrients (Bb4) with a fertilised soybean crop near Narromine, New South Wales.*

The massive earths, earthy loams and earthy clays have a higher sand content than do the soils of Ba3 and this, together with the low activity of their kaolinitic clay minerals and relatively low contents of iron oxides (<1 to <5% ferric oxide) have contributed to giving them a massive, porous and earthy fabric of a particularly stable nature. Physically, then, these soils are suitable for many agricultural and constructional purposes. However, low contents of organic matter in surface soils, especially in soils from the drier areas (<1% in the 0-10 cm layer), allow surface crusting to develop upon cultivation. The red soils have naturally free soil drainage and aeration but, as may be expected, internal soil drainage becomes progressively more restricted in the yellow and grey forms, that is in the sequence *Gn2.2– Gn2.3– Gn2.6– Gn2.7– Gn2.8– Gn2.9.* Field observation suggests that some of the yellow and grey forms may have waterlogged subsoils, periodically. Nevertheless, a further significant problem in using all these soils, especially in areas subject to dry periods, is their low water-holding capacity, which means low water storage in the soil after rain.

The ironstone gravelly, yellow duplex soils, Bb5, are prone to serious subsurface waterlogging. It becomes particularly manifest in late spring and early summer when water moves laterally along the top of the subsoil clays without soaking into them, thus decreasing soil-water storage and so decreasing summer production of pastures and crops. The sandy to loamy surface soils become so sloppy that they lose stability. Earth roads may become impassable and foundations of buildings have been known to sink slowly into the soil. Soils of this grouping cover some 3-4% of Australia, notably in the southern winter rainfall zones with annual rainfalls ranging from 350 mm to over 1000 mm, for example in the south-west of Western Australia and on Kangaroo Island. Their location in such areas with moderately good, and moreover reasonably reliable, rainfall makes them important soils which, now that their nutrient element problems are known (Carter 1958), require study to improve their moisture characteristics, perhaps along the lines recommended for Cc1 soils.

The other soils placed in the Bb group, namely the organic loam soils, Bb2, actually stand somewhere between this group and that of the fully organic soils of group O, because of the high contents of organic matter in their surface soils. While this is always less than 30% in the top 30 cm of soil, and is thus not as high as that of the organic soils, it is much higher than that of the other soils in the Bb group. Nevertheless, their naturally low level of fertility (Northcote and others 1975) places them here. The Bb2 soils have developed on Quaternary colluvium from a wide range of rocks, including basalts and granites, throughout the alpine and sub-alpine areas of Tasmania and south-eastern mainland Australia. In aggregate, they occupy less than 1% of the total land area of Australia, which is hardly a true measure of their importance to the Australian economy, for they are the soils that exert a significant influence on the water resources used for the larger irrigation areas.

Bc. Calcareous Soils

All the soils of group Bc are calcareous, one result of this being that sensitive plants are liable to lime-induced chlorosis while other introduced plants, not subject to chlorosis, need special attention to their nutrient requirements. These soils, although not confined to southern Australia, do predominate in the southern third of the continent. Not all calcareous soils are included here, because some are very shallow and these are included with group Cf, for which the limitation is primarily soil depth.

The calcareous sands, Bc1, have calcium carbonate contents varying from about 10 to >70% of the fine earth, mainly as shell fragments. They are found on Recent calcareous beach ridges, dunes and sand sheets along the coastline of the Australian continent and associated islands, and may extend some distance behind the modern beach. Their aggregate area is about 1% of the area of Australia and many locations remain unused. When not vegetated they are particularly liable to wind and water erosion, a condition related to their highly permeable, excessively drained and thus droughty and loose physical state, which is of major concern for all constructional and engineering purposes. Nutrient deficiencies of cobalt, copper, zinc, boron, iron and manganese, as well as nitrogen, phosphorus and potassium, have been reported from areas like Yorke Peninsula, South Australia, where there has been some development of sown pastures of annual medics and lucerne, and of cereals particularly barley. 'Coast disease' due to deficiencies of cobalt and copper occurs in sheep and cattle grazed on the natural grasslands of the Bass Strait islands and the southern mainland coast unless corrective measures are taken.

The calcareous earths, Bc2, have calcium carbonate contents ranging from as low as 0.3 to about 10% in the fine earth of the surface soils. One of their most easily observed features is an increase in carbonate content in the fine earth with depth and the presence there of hard carbonate nodules or fragments as well. The combined effect of the fine, and hard, carbonates is to produce a layer of maximum carbonate concentration in the subsoil. This layer may contain 15-30% calcium carbonate in the fine earth plus hard carbonate segregations ranging up to 50% or more. These subsoil layers are also sodic to strongly sodic (Appendix 4, footnote), and are an important factor in the use of these soils both for building and construction and for agriculture. When thoroughly wet they tend to flow and to collapse under load. Permeabilities become severely restricted, with the result that salinity problems develop under irrigation unless drainage is adequate. The *Gc1.2* soils are more permeable than the *Gc1.1* soils and thus cause fewer problems during use.

Natural fertility levels are low to moderate and soil productivity is greatly enhanced by applications of superphosphate and the use of medic leys to improve levels of soil nitrogen. Zinc, manganese and iron deficiencies have been recorded. Where rainfall exceeds 250 mm per annum, cereals, notably wheat and barley, are grown. Lucerne and medic leys are utilised successfully too. In the more arid areas grazing of sheep and cattle on native herbage becomes the main activity. Where water is available for irrigation, as along the Murray River in south-eastern Australia, these soils are used for horticulture, with the less calcareous *Gc1.2* soils being the more favoured. Indeed, there is a good relationship between the kind of horticultural crop grown and the texture and depth of surface soil, for example the deeper, sandier soils are preferred for citrus (Northcote 1949).

The area of calcareous earths totals about 6% of Australia, mainly in the semi-arid to arid lands of southern Australia with the largest areas extending generally eastwards from the Nullarbor Plain to cover the western half of the old Murravian Gulf, that is, the present Murray-Darling mallee lands. Of special interest are smaller areas associated with margins of salt lake systems in southern Western Australia. Here, saline and calcareous alluvium was swept off valley and lake floors to form aeolian sheets (lake parnas) on the eastern and south-eastern margins of the lake chains (Bettenay 1962), and *Gc* soils developed therein. However, the source of the carbonates for the larger *Gc* occurrences east of the Nullarbor Plain has not been clearly determined. Crocker's (1946) hypothesis of the carbonates coming from calcareous loess derived from the exposure of the continental shelf during the Pleistocene should be reviewed along with other possible sources of the carbonates such as the vast area of Miocene limestones of the Nullarbor Plain. Aeolian activity during the Recent arid cycles fashioned the present dune landscape (Northcote 1951) with its complex of soils that then formed on locally transported sediments and on deflated residual materials.

Bd. Saline Soils

Three groups of soils with high contents of soluble salts, often with 0.1% sodium chloride or more in surface soils and 1% sodium chloride or more in subsoils, are recognised. Such high soluble salt contents mean that soil clays are strongly sodic as well. These properties directly decrease soil stability and dramatically so when wet, as slippery roads with wash-outs and gullies demonstrate. Agriculturally, their limit of usefulness is to provide salt-tolerant native herbage for sheep and cattle. They could be used more intensively if it were ever worthwhile leaching the soil of salts.

The calcareous and siliceous loams, Bd1, cover <1% of Australia. They occur on young riverine alluvia which are often gypseous as well as saline, and fringe old saline valley and salt-lake systems that extend from arid to sub-humid areas in the Northern Territory and Western Australia. North of Geraldton in Western Australia, they are formed also on calcareous sediments of saline marshes and tidal flats. Apart from salinity, natural soil fertility levels are low.

The various saline clay soils, Bd2, also cover <1% of Australia. They have formed on young sediments of coastal and sub-coastal plains, tidal flats and salt pans around the wetter parts of the Australian coast, mainly but not exclusively in the north. All are slowly permeable soils of low nutrient status.

The crusty red duplex soils, Bd3, are much more extensive and cover about 3% of Australia. They are found in arid areas on the extensive stony plains, pediments, tablelands and some flood-plains from near the head of Spencer Gulf in South Australia north-west to near Alice Springs, and north-east and east into the adjoining parts of Queensland and New South Wales. Smaller areas occur in Western Australia.

Figure 2. *A red duplex soil with crusty surface (Bd3) near Wilcannia, New South Wales, supporting a saltbush pasture with herbs growing after recent rain.*

The surface of Bd3 soils is often covered by a partially imbedded pavement of gravels, pebbles or stones of silcrete, ironstone, quartzite or other country rock up to 15 cm in diameter. Another surface feature is varying gilgai microrelief expressed as irregularly distributed depressions in which cracking clays (see Cb), such as *Ug5.38* (Northcote and others 1975), occur. The depressions are often stone free, and are seldom more than 20-30 cm below the flat intervening area of the crusty red duplex soils. These latter soils have sandy loam to clay loam surfaces, soft and weakly crusted from 1 to 30 cm thick, sharply overlying red structured clay subsoils that may be calcareous and/or gypseous in their lower part. Indeed gypsum is generally present in large amounts beginning between 40 and 100 cm in depth.

Such well developed and differentiated soils are not usual in arid regions. Jessup (1960) considered that these soils were developed in deposits of aeolian clays. However, the micromorphological studies reported by Stace and others (1968) suggest rather that they formed by leaching of gypsum and carbonates together with clay illuviation of sedimentary and layered parent materials. These findings considered together with the geographic occurrence of Bd3 soils, aligned as they are with palaeodrainage systems that probably entered Spencer Gulf, suggest that their parent sediments may well represent the waning phases of riverine deposition during Plio-Pleistocene times. This suggestion seems to agree with Wopfner and Twidale's (1967) gypsite formation.

C. SOILS WITH PREDOMINANTLY PHYSICAL LIMITATIONS

Soils placed in group C have predominantly physical limitations. Of course, some physical limitations may have a chemical origin as, for example, the low permeability of sodic soils. However, such soils are placed here because both agricultural and engineering practices first encounter these limitations as a physical constraint. Moreover, their correction could well involve physical means as well as chemical. Perhaps too little attention has been given to the art of correcting or modifying physical soil problems in Australia; it is known that their correction can be rewarding and can compound the value of improvements already made chemically.

Ca. Deep Coarse-textured Soils

All these sand soils, Ca1, are coarse-grained and loose. They are liable to severe wind and water erosion if their protective vegetative cover is disturbed or removed. Their general lack of coherence, especially when disturbed, indicates their main weaknesses not only for structural and engineering purposes but also for agriculture. Their moisture properties are characterised by high permeability causing excessive drainage through the soil which in turn results in a low water-storage capacity. Consequently, they are not only highly erodible soils but are also droughty. Nevertheless, where water is available they may prove useful for irrigated agriculture, but careful management is required to prevent seepage in areas marginal to less permeable soils. All have low inherent fertility with low N,P,K contents and some trace element deficiencies.

They cover about 18% of Australia, the most widespread being the siliceous sands, *Uc1.2,* which cover about 10% of the continent. Of these the red siliceous sands, *Uc1.23,* of the dune-swale systems of the great Australian sand deserts (Great Sandy, Gibson, Victoria and Simpson Deserts) are the most prominent. Other areas of siliceous sands, mainly *Uc1.21* and *.22,* occur not only on coastal dune and beach-ridge formations, but also on dunes and sand-sheets adjacent to channels of both present and former drainageways that traverse the riverine plains west of the Great Dividing Range. The ultimate source of the red desert sands, *Uc1.23,* is probably the once extensive Tertiary deep weathering surfaces whereas the other sands were derived from a variety of sources usually close to the present occurrence. Extensive, and often intense, aeolian activity, particularly during the arid phases of the Quaternary but continuing to the present time, fashioned the dune-swale and related landforms on which these soils are so common. Some of these soils in the arid areas are currently being modified. One expected result of this mode of formation in arid to semi-arid climates is that little pedologic organisation takes place in the soil profile (Northcote and others 1975).

Figure 3. *Deep sand soil (Ca1) in the Queensland Channel Country with green pasture plants after rain and deeper rooted trees (mulga).*

The next most extensive sands are the calcareous brownish ones, *Uc5.1.* They are prominent on dunes throughout some areas of the calcareous earths, Bc2. These semi-arid areas are often marginal in the south of the continent to the red siliceous sands of the arid areas. Soil formation is due to Quaternary aeolian activity followed by some leaching of calcium carbonate by the slightly higher rainfalls. These brownish sands were originally classed with the solonised brown soils, and have usually been managed in the same way as the more loamy, stable calcareous earths also originally included in that great soil group, for both agricultural and engineering purposes. As a result they often became the foci for severe wind erosion that plagues many areas of Australia's mallee lands during droughts. Where irrigation water is available *Uc5.1* sands can be used for horticulture, mainly citrus. Seepage, which is usually salty, may develop at the base of the dune unless considerable care is exercised.

The largest area of the *Uc4.2* sands occurs in the sub-humid lands of the south-west of Western Australia. They are present, notably, on sub-coastal dunes of intermediate age behind the younger systems, and on some coastal plains. The moister climate has allowed subsurface and coloured subsoil horizons to develop. Low water-storage capacity and low inherent fertility limit their development. Some forests of indigenous hardwoods and introduced softwoods are being maintained.

The *Uc2.2* sands have a strongly developed, bleached subsurface horizon and a coloured subsoil horizon which agrees with their formation on the older coastal and sub-coastal dunes and sand-plains of the sub-humid to humid areas. These soils are extensively distributed in southern Australia and throughout eastern Australia, with some of the largest areas in coastal south-west Western Australia and Queensland. Many areas have remained largely undeveloped because of their droughtiness and acute N, P, K, Ca and trace element deficiencies. However, some cropping, improved pastures, horticulture, and forest plantations have been developed with variable success, which often depends on the presence of clayey layers below the sand soil at shallower depths than usual (between 1 to 2 m).

Cb. Cracking Clays

These soils have clay contents, commonly ranging between 40 and 80%, throughout the profile. Their signal property is their great capacity for shrinking and swelling, usually right to the ground surface, in response to periodic drying and wetting. The dry soil opens into cracks from 6 mm to about 30 cm wide in more extreme cases. The cracks penetrate to at least 30 cm in depth and often to 1-2 m or more. Heavy rains can pour down the cracks. The clays swell and rapidly close the cracks, so that the moist to wet soil then has a very low permeability and a high runoff. The presence of carbonates and soluble salts in subsoils at shallow depths is evidence of this limited penetration of rain and lack of leaching. Moreover, the carbonate layers occur unevenly in the profile and may reach the soil surface as gilgai mounds. The presence of gilgai, surface micro-relief phenomena that have a variety of forms and sizes, are a further manifestation of the shrink-swell activity of these soils.

The forces of these differential soil movements are clearly demonstrated by the distortion of fences, poles, and other structures, so that special attention to the design of foundations and buildings is necessary. Apart from this, their bearing capacity is high excepting where there are heavy accumulations of carbonates.

Agriculturally, they are highly suitable soils for cereal production, but high clay contents and low permeabilities may adversely affect cultivation and trafficability. Water erosion can be serious on slopes where incautious furrows have been made by cultivation, the more finely structured, self-mulching group of cracking clays, Cb1, being more liable to erosion than the coarser clays of Cb2. However, it is this finer surface-soil structure of the Cb1 clays that accepts rain more readily, and thus becomes more thoroughly wetted, that makes them better agriculturally than the Cb2 clays. In both Cb1 and Cb2 the size of the peds varies, as may be expected. Undoubtedly, there is an opportunity to seek practical means of improving surface soil structure in the coarser kinds.

Figure 4. *A black self-mulching and finely structured cracking clay (Cb1) growing sorghum near Emerald, Queensland.*

The cracking clays cover about 11% of Australia; the most widespread are the grey forms of the Cb1 soils (*Ug5.2*) that occur in a great arc from the south-east of South Australia and the Wimmera of Victoria to the Gulf of Carpentaria and the Barkly Tableland. Smaller but important areas are found in the Kimberley region of north-western Australia and the Top End of the Northern Territory. Minor areas, too small to show on the map, occur in south-west Western Australia and in Tasmania. The brown cracking clays, *Ug5.3,* are intermingled in many areas but reach their most extensive and typical development on the gently rolling downs of arid north-western New South Wales and western Queensland. Annual rainfalls vary greatly, commonly in the range of 130 to 600 mm for the *Ug5.3* clays, and in the range of 100 to more than 1000 mm for the *Ug5.2* clays. The black cracking clays, *Ug5.1,* occur mainly in regions of 500-1000 mm annual rainfall on plains and rolling to low hilly uplands, notably in eastern Australia from southern Tasmania to the base of Cape York Peninsula. Minor areas occur elsewhere.

The coarser forms of the cracking clays, Cb2 (*Ug5.4* and *Ug5.5*), are often associated with the more finely structured forms. The black *Ug5.4* soils occur in association with Cb1 clays (and are mapped with them) in parts of the Riverina, New South Wales. Together with the grey *Ug5.5* clays they occur also in northern Australia in sub-coastal and inland regions between Cape York Peninsula and the Top End of the Northern Territory and in remnants of river valleys elsewhere.

Parent materials of the cracking clays range from Quaternary unconsolidated clay colluvium and alluvium to rocks that on weathering produce highly clayey materials. In both cases, the clays have high to moderate amounts of calcium and/or magnesium, being derived from the more basic types of rocks such as basalts, calcareous sedimentary rocks, and limestones. Consequently, many of the cracking clays, and especially *Ug5.1,* were moderately fertile soils but, with prolonged use for cereal and other crops, both phosphatic and nitrogenous fertilisers are being used increasingly, together with trace elements for specific crops, such as molybdenum for leguminous crops. Mostly, the greater areas of cracking clays are natural grasslands and shrublands that have been used since earliest settlement for grazing of sheep and cattle. Where rainfall is sufficient or where it can be supplemented by moisture storage under bare fallow, large and increasing areas are now cultivated for cereals, other grain and feed crops and improved pastures. Again, where water is available for irrigation, as in New South Wales and Queensland, increasing areas are being used for rice, cotton, sown pastures and fodder crops.

Cc. Hard-setting Soils with Dispersible Clay Subsoils

Chief among the common morphological properties of Cc1 soils are their decidedly duplex character with a clearly seen, sharp change from the mostly thin, hard-setting, sandy to loamy surface soils to the tough, harsh clays of the subsoil. The clay subsoils may have a blocky, prismatic or columnar structure but they are friable only over a very limited moisture range due to their sodic to highly sodic nature (Appendix 4). Moreover, in most cases the magnesium content of the soil clays is higher than the calcium and this also serves to increase the dispersibility of the clay. Thus, when these clays become wet they disperse, resulting in a rapid decrease in vertical soil permeability and the surface may become waterlogged. Generally, permeability decreases from those soils with red to brown clay subsoils through those with yellow clays to the black ones.

Figure 5. *A hard-setting soil with dispersible clay subsoil (Cc1) growing sunflowers near Narrabri, New South Wales.*

For agricultural use, gypsum has proved an effective ameliorant. It supplies calcium ions to replace the sodium ions and part of the magnesium ions of the soil clays. Under rain-fed cereal cropping, gypsum applied to the surface soil counteracts its hard-setting property so that cultivation becomes easier, and the sealing effect of the surface soil is broken allowing seedlings to emerge without damage. Under irrigation, ripping the subsoil to depths of 60 cm together with an injection of gypsum slurry or free flowing powder greatly improves soil permeability. Where horticultural crops are grown there is considerable opportunity to tailor these soils to the requirement of the crop. Special management practices based on gypsum treatment, building up a greater depth of surface soil within the crop row (at the expense of exposing the subsoil between rows), adequate fertiliser application, and mulching (for instance with straw) are giving large increases in the growth of peach trees and their yields at Tatura, Victoria. This is really a case of building up the soil to grow the crop, a kind of soil architecture. Soils of group Cc1 lend themselves to studies of the practices required to make friable, well aerated soils with an improved water-storage capacity from these naturally hard-setting, shallow-surfaced and sodic duplex soils.

Generally, the bearing capacity of these soils is not high but is adequate for light structures such as houses. Engineering problems may generally be related to the instability of the clay subsoils, which becomes more pronounced when the protective skin of surface soil is lost. Liability to erosion by water is great where these soils occur on even slight slopes if their clay subsoils are exposed, and trafficability is seriously decreased in the same circumstances.

These soils are widely distributed, especially throughout eastern, southern and western Australia on plains, terraces and valley slopes, the alkaline *Dr2.33* soils being particularly widespread on many of the large riverine plains. In general, duplex soils cover about 20% of Australia, and from one quarter to one third belong in Cc1.

Parent materials are largely Quaternary alluvium and colluvium derived from a wide range of rock types. Differences in parent rocks and rainfall are reflected in the principal profile forms developed in different localities. Generally, the acid forms are found in the moister areas (>600 mm annual rainfall) on alluvium or colluvium derived from the more acidic rocks such as some gneisses and granites; neutral forms occur in slightly drier situations (400-600 mm annual rainfall), where they have been derived from intermediate rocks (granodiorite, shales etc.); and the alkaline forms are found in the lower rainfall areas (250-500 mm annual rainfall) and have been derived from the more basic rocks (slates, calcareous shales etc.).

Most of these soils have low phosphorus and nitrogen contents and most respond well to fertiliser applications. Potassium levels are moderate. Trace element deficiencies vary with the individual soil (principal profile form) and with the crops and pastures being grown.

Cd. Soils with Periodic Subsurface Waterlogging

All Cd soils have thick bleached subsurface soils indicative of their saturated condition following heavy and/or prolonged rainfalls. At such times the perched water renders this subsurface horizon unstable and if lateral support is removed, for example by trenching, the bleached subsurface soil actually flows. Furthermore, under natural conditions this perched water moves laterally to drainageways and is lost to the soil. Consequently, the capacity of the soil to store subsoil water for use by plants during dry periods is considerably decreased.

In the sand soils, Cd1, the surface and subsurface sands are highly permeable but the subsoil pans are only very slowly permeable (Northcote and others 1975). It is on these pans that the perched water accumulates and rises to saturate the subsurface sand. The duration of saturation depends on rainfall incidence and site. Before these soils can be fully utilised for agricultural or engineering purposes suitable drainage works are necessary.

The Cd1 soils have developed in highly siliceous parent materials in the moist coastal and sub-coastal areas of eastern and southern Australia where there is abundant moisture supply as rainfall or run-on water. Their occurrence in the higher rainfall areas makes them fairly important soils even though they cover less than 1% of Australia and have extremely low inherent fertility. They are acid, leached soils in which the full range of nutrient-element deficiencies are found.

In the duplex soils, Cd2, surface and subsurface soils are moderately (*Dy2, Dy3*) to highly (*Dy5*) permeable but their sodic to highly sodic subsoil clays are only slowly permeable, resulting in intermittent perched water in the bleached subsurface horizon and partial saturation of the upper clay subsoil during wet periods. Ideally, for both agricultural and engineering purposes some form of drainage suitable for the site is desirable. While this is usually recognised for the more extreme cases, *Dy5* soils, it has not been widely recognised in other cases such as *Dy3* or *Dr3*. Furthermore, because the subsoil clays are sodic, they disperse when wet but are tough and harsh when dry, as for the subsoil clays of group Cc1.

Deep ripping and the injection of gypsum as for Cc1 would provide a suitable ameliorative measure which would improve the water holding capacity of subsoils. Little has been done to develop management techniques that could be used to build up Cd2 soils in much the same way that Cc1 soils are starting to be tailored for different crops.

These Cd2 soils occur extensively throughout northern, eastern, southern and south-western Australia on a great variety of parent materials in regions with annual rainfalls ranging from 500 to over

Figure 6. *Aerial application of superphosphate to sown pasture on a Cd2 soil near Yass, New South Wales. The banks across the gullies are designed to prevent further erosion of the bleached, dispersible subsurface soil.*

1000 mm. Most occurrences are on undulating plains, river levees, rolling lands, hill slopes and crests and cover some 7% of Australia. They are thus important soils, are suitable for improved pastures or arable agriculture, and are capable of increased productivity if new methods of physical soil management can be developed. Generally, inherent fertility levels are low. Deficiencies include phosphorus, nitrogen and sometimes potassium; calcium contents are very low in some soils; and responses to molybdenum, sulphur, copper and zinc are recorded.

Ce. Soils with Periodic Surface Waterlogging

All these gleyed soils (Appendix 4) are only slowly permeable and occupy low-lying sites so that surface waterlogging occurs regularly following heavy or prolonged falls of rain. The aggregate area is about 1% of Australia.

In the clay soils, Ce1, the soil material is impermeable from the ground surface, and consequently waterlogging is almost immediate following rain. Drainage is, therefore, a prerequisite to the use of these clays. Mostly, they occupy wet alluvial marine plains along the south-eastern, eastern and northern coasts of Australia and also areas on alluvial and colluvial slopes in north-west Tasmania but the only area large enough to be shown on the map is in northern Arnhem land. Natural fertility levels vary but phosphate contents are usually low.

In the duplex gley soils, Ce2, there is a thin (5 cm), loamy, hard-setting surface soil over the gley clay subsoil in *Dg2.4* but in *Dg4.1* the loamy surface soils are thicker (20-30 cm) and may be capped by fibrous peat. Both groups of soils occur in areas where the annual rainfall exceeds 750 mm, the former being the periodically wet soils of the poorly drained coastal plains and lower hill slopes and the latter, *Dg4.1,* of swamplands in coastal eastern Australia. It is the gleyed clay subsoils that impede water entry and allow the surface soil to become saturated, usually with free-standing water above the soil surface. Drainage is needed before development for most purposes can take place. For agriculture, fertiliser application is a necessity and includes not only phosphorus, nitrogen and potassium but also trace elements.

Cf. Shallow Soils

More than one-quarter of the surface of Australia is covered by shallow soils and about 75% of these are found on difficult terrain, mainly steep slopes. These shallow soils, which are less than 60 cm thick, are prominent in nearly all climatic zones from the arid to the alpine. Depth is the main soil property that has relegated most occurrences to some form of pastoral use.

The shallow sandy soils, Cf1 and Cf2, account for more than 50% of all the shallow soils. They are permeable soils the use of which is largely controlled by their limited water storage capacity (Appendix 4). Natural fertility varies but is mostly low to moderate and the soils are responsive to phosphatic fertilisers. Similar comments apply to the shallow loam soils, Cf3, which occupy nearly 50% of the shallow soil area. The shallow clay soils, Cf4, cover about 1% of the area and, while some are moderately fertile, their shallow depth severely limits their capacity to store moisture.

Unit Cf5, shown on the map as two occurrences inland from Townsville, covers less than 1% of Australia but is interesting in that soil development is restricted to very minor pockets in the otherwise rock surface of Quaternary basalts.

O. ORGANIC SOILS

The organic matter content of the top 30 cm of these soils, O1, is over 20% where the clay content is less than 15% and over 30% where the clay content is more than 15%. Such soils cover less than 1% of Australia and their predominant properties of low bulk density and high water-storage capacity result from their organic matter content (Appendix 4). Generally, bulk density decreases with increasing organic content and may be very low in true peats with organic content exceeding 70%.

These organic soils occupy low-lying poorly drained areas in regions of high rainfall and hill slopes and elevated sites in cold regions where total rainfall is high and rains are frequent. They may overlie sandy, clayey or gravelly sediments, rock detritus or hard rocks. The acid forms are more common in Australia than the neutral and alkaline forms. There are many small occurrences in south-western Australia and on the wet coastal plains of north Queensland but especially on the high mountains and plateaux of the alpine and sub-alpine areas of Tasmania, Victoria and New South Wales, where their high water-storage capacity naturally regulates water release to streams and rivers. The lowland occurrences are associated with depressions in the wetter coastal and sub-coastal plains, two of the three occurrences large enough to show on the map being of this kind (eastern Victoria).

Generally, fertility is very low owing to extreme acidity and gross deficiencies of both the major and minor nutrient elements. The neutral and alkaline forms, which are usually more fertile, often have trace-element deficiencies. Their occurrence is restricted to small areas in the south-east of South Australia and south-west Western Australia too small to be shown on the map. Under arable farming, surface soils can dry to a point where they are not able to re-moisten. This irreversible drying is a real problem in the management of highly organic soils, especially peats.

APPENDIX 1. SOIL CLASSIFICATION

The Factual Key for the Recognition of Australian Soils (Northcote 1971) was used as the basic soil classification from which to derive the map groups used here, since it is easy to interpret principal profile forms for specific purposes. These are the main units of the Key, and represent groupings of natural soil profiles. Furthermore, they indicate soil relationships and permit reasonably concise statements to be made about soil properties and use. Again, they may be extended to include more detail, even to that required for a soil-site. Principal profile forms may be grouped to have an approximate equivalence to the great soil groups used earlier (Stace and others 1968) but the former are more tightly defined.

In the Key, all soils are divided at the beginning into four broad divisions denoted by the letters *U, G, D* and *O*—see Figure 7 and Appendix 3, footnotes. They have eleven subdivisions between them.

The *U* group includes all those mineral soils with little change in texture between surface soils and subsoils; that is, their texture profiles are *Uniform.* Thus the *U* soils range from being sandy throughout (*Uc*), to those that are loamy throughout (*Um*), and then to those that are clayey throughout (*Uf* and *Ug*).

In the *G* group there is a gradual increase in fine particles (clay) from the surface soil down into the subsoil; that is, their texture profiles are *Gradational.*

In the *D* group, there is a sudden change from sandy or loamy surface soils to decidedly more clayey subsoils; that is, their texture profiles have a texture contrast, and hence they are termed *Duplex.*

The *O* soils are those composed mainly of *Organic* materials, such as peat; only small areas occur in Australia.

The primary groupings *U, G, D* and *O* are subdivided further—see Figure 7—to obtain the principal profile forms that are the main operational units of the classification. Where more detail is required, as in most surveys with map scales larger than 1:2 000 000, the addition of further data to the principal profile form descriptions is straightforward (see Figure 8).

The symbols used for the principal profile forms provide a shorthand system for communicating a great deal of soils information—see Figures 7 and 8. It is this and related data that can be interpreted for specific uses, for example, the properties of *Gc* soils that control horticultural plantings when these soils are irrigated (Northcote 1949 and 1951).

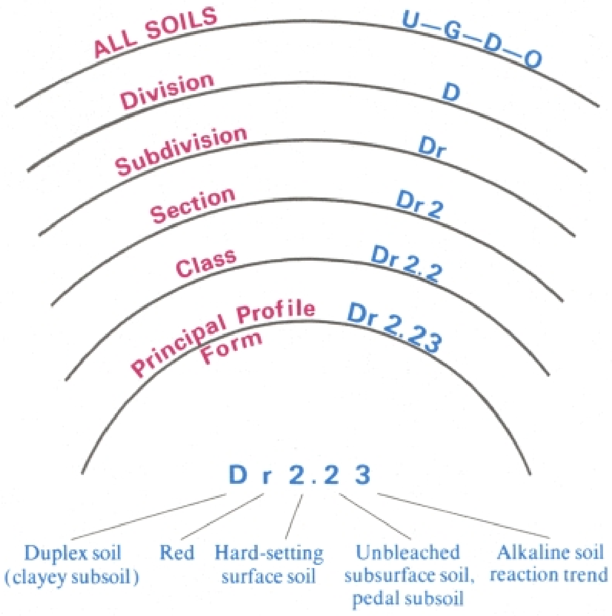


Figure 7. Categories of the Factual Key for the Recognition of Australian Soils

The above example of the morphological meaning of the principal profile form Dr 2.23 *indicates a soil of good physico-chemical constitution but, as the soil is naturally hard-setting, farming practices that make and maintain good surface tilth are needed; and at least 30 cm of surface soil is required to buffer the shrink-swell effect of the clay subsoil on foundations.*

While the Factual Key has been used throughout Australia and while it is applicable to some overseas soils (as found by the author), it is unlikely, without some extensions, to apply to the soils of all overseas countries. There is no universally accepted system of soil classification and nomenclature comparable to those that exist, for example, for rock types, plants or animals. Perhaps the only fully international scheme is that produced by FAO for use in their soil map of the world (FAO/Unesco 1974). Some correlations between their world soil map units and principal profile forms have been made (Northcote and others 1975).

From 1951, the U.S. Soil Survey became involved in a far-reaching study of American soil classification. They went through a number of stages, or *approximations.* Eventually, the new *Soil Taxonomy* (Soil Survey Staff 1975) was published. This classification is hierarchical with six categories: orders, sub-orders, great groups, sub-groups, families and series. There are 10 orders, 47 sub-orders, and 230 great groups. Furthermore, new terms were invented, for example, duplex soils belong to either the order Alfisols or Ultisols, some Californian non-calcic brown soils became Haploxeralfs at the great group level, and so on. Definitions of properties and classes became lengthy and complicated in phraseology to the extent that meanings become blurred for the reader. Nevertheless, it has attracted much international interest and some measure of adoption, particularly among less developed countries. Further studies and some renovations are being made, and there is dissatisfaction with the way it classifies soils of tropical areas, and soils of geologically old land surfaces (Australia, Africa). For example, the classical Prescott (1931) red-brown earth of the grounds of the Waite Agricultural Research Institute (Urrbrae loam) keys out as a rhodoxeralf, which is the new name for soils called terra rossa in the 1938 U.S. soil classification (Soil Survey Staff 1975). Most Australian soil workers are well aware of the differences between red-brown earths and terra rossa soils (Stace and others 1968), and will not be satisfied to lump them together, even under a new name.

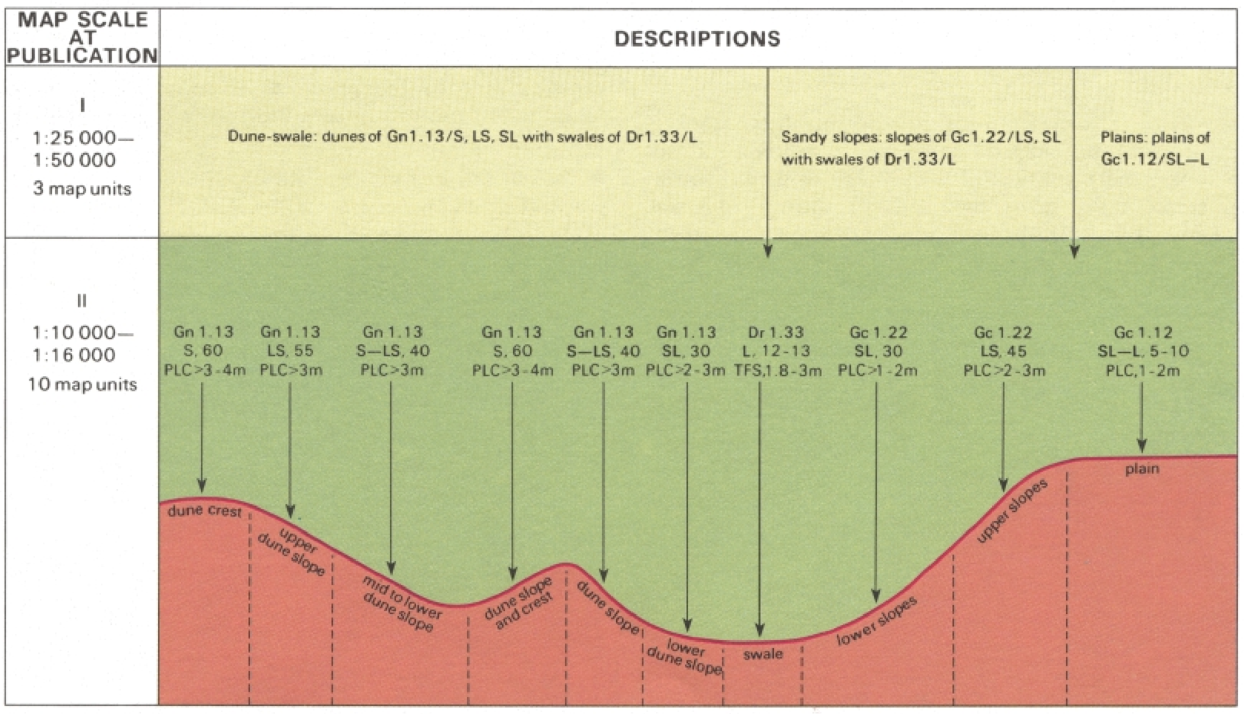


Figure 8. Diagrammatic Cross-section of Soil-landscapes

Based on Northcote (1951) for an area near Coomealla, N.S.W. (upstream on Murray River from Wentworth), and expressed in terms of the Factual Key for the Recognition of Australian Soils.

I. *The degree of detail of soil surveys and maps suitable for general planning of a new irrigation area.*

II. *The detail necessary for locating specific plantings of irrigated horticultural crops within a farm. Specific locations within any of these units are equivalent to soil-sites.*

Expanded Factual Key Notations

Surface Soil Texture and Thickness

S = *sand*
SL = *sandy loam*
60 = *60 cm*
LS = *loamy sand*
L = *loam*

Material underlying the Soil (subsolum) and Depth

PLC = *Pleistocene clay*
>3–4m = *depth in metres to subsolum*
TFS = *Tertiary freestone*

There is accumulating evidence that soil variation may increase with distance. If this is so, then international soil classifications like those mentioned will be useful mainly for making only the broadest of comparisons, whereas national soil classifications will provide more practical information. One other point is that most international soil classifications have been dominated by experience in the northern hemisphere, where old soils were swept away by Pleistocene glaciations, a series of geological events that did not affect the greater part of Australia and associated Gondwanaland countries (Africa and South America).

APPENDIX 2. SOIL-SITES, SOIL-LANDSCAPES AND SOIL MAPS

SOIL-SITES

The most intensive examination of soils is made at a soil-site; here all pertinent soil features and properties can be observed, recorded and measured. Soil-sites range from single soil profiles to several neighbouring profiles and include their surface topography. Such intensive examinations are usually made on sites that have a surface area ranging from about 30 cm² for typifying specific soil profiles to part of a hectare for building foundations, for example. It would be far too costly to draw soil maps of large areas based solely on such intensive soil-site examinations. The concept of soil-landscapes developed for the *Atlas of Australian Soils* offers one way of handling the problem.

SOIL-LANDSCAPES

Soil-landscapes in their simplest form are groups of similar soil-sites, that is, they are groups of similar soil profiles that occur in similar topography. For mapping, topography becomes the key feature because it is much more easily and quickly recognised and mapped, and was formed moreover by the same geologic and geomorphic events that were responsible for providing the parent materials of present-day soils. Thus, it is possible to consider a specific topographic feature, dunes for example, and on examination find that their soil profiles are, say, *Uc5.11*. In this example, the dunes of *Uc5.11* soil in an area form a soil-landscape. Such a soil-landscape occurs as observable areas that may be shown on a map, provided the scale is adequate. For dunes, the map scale would need to be about 1:10 000.

When map scales are smaller, soil-landscapes are usually made more complex. For example *Uc5.11* dunes are often separated by intervening swales (inter-dune corridors or depressions) in which the soils are *Gc1.12*, and the composite soil-landscape may be described as 'dunes and swales: dunes of brownish sands (*Uc5.11*) with intervening swales of highly calcareous earths (*Gc1.12*)'. This soil-landscape would be useful for mapping at a scale of about 1:25 000 to 1:50 000.

Hence, soil-landscapes may be defined as natural areas of land of recognisable and specified topographies and soils that are capable of presentation on maps and of being described by concise statements, always bearing in mind that the basis of the soil-landscape concept remains that of soil-sites.

Since a number of soils may occur in the broader kinds of soil-landscapes used for smaller scale mapping, it may be necessary for clarity of presentation to show only the dominant soil as was done, for example, by distinctive colours and patterns in the *Atlas of Australian Soils*. In that atlas the dominant soil was determined most commonly as the soil covering 60% or more of the area of a soil-landscape. A second form of dominance seemed necessary where no soil covered 60% of the area, but it did not have to be used a great deal: for example, where two soils covered about equal areas, say 35% each, the dominant was chosen as that exerting a greater influence on soil conditions in its soil-landscape. Thus where a duplex soil and a shallow uniform textured soil occurred in about equal proportions, the duplex soil would be the better choice because it would better indicate soil genesis and land use capabilities.

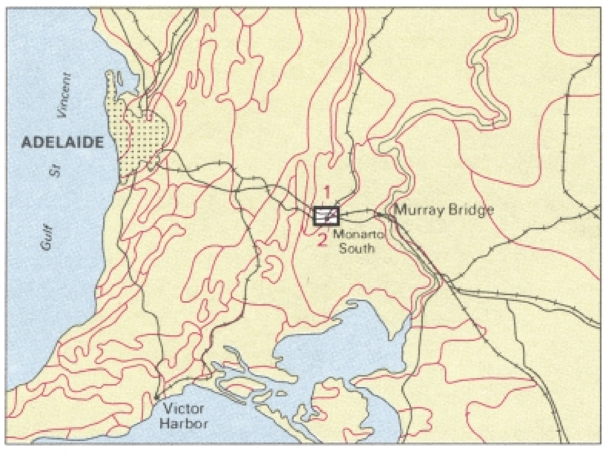
SOIL MAPS

Whereas soil-sites provide considerable detail about a limited area, soil maps of continental proportions provide only a general picture of soils, often without showing differences over many thousands of square kilometres. Between the usual scales for continental soil maps and studies of soil-sites, soil maps may be drawn at many scales. The most detailed are those drawn at about 1:10 000 to 1:15 000, usually in connection with irrigated agriculture. Such maps can convey much more soil and associated environmental information than continental maps, a self-evident point not always fully appreciated by people unfamiliar with maps. The progression of decreasing soils information with decreasing map scale is illustrated in Figures 8 and 9. The use of the principal profile form, and its expansion to cover local varieties, as envisaged previously (Northcote 1971, p.2), forms an integral part of such progressive accumulation of soil information.

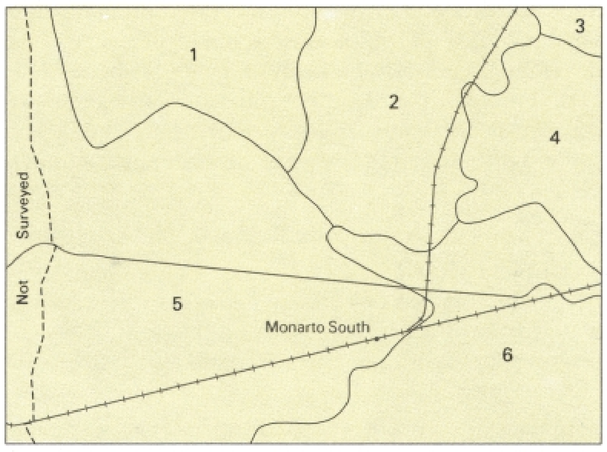
The smallest scale at which soil maps have some degree of practical significance is 1:2 000 000. The sheets of the *Atlas of Australian Soils* are at this scale and have been used in preliminary planning, for example for roads, geological prospecting and new agricultural ventures, so that more detailed investigations are confined to the most desirable areas, thus reducing costs.

Figure 9. Soil Survey Information and Map Scale

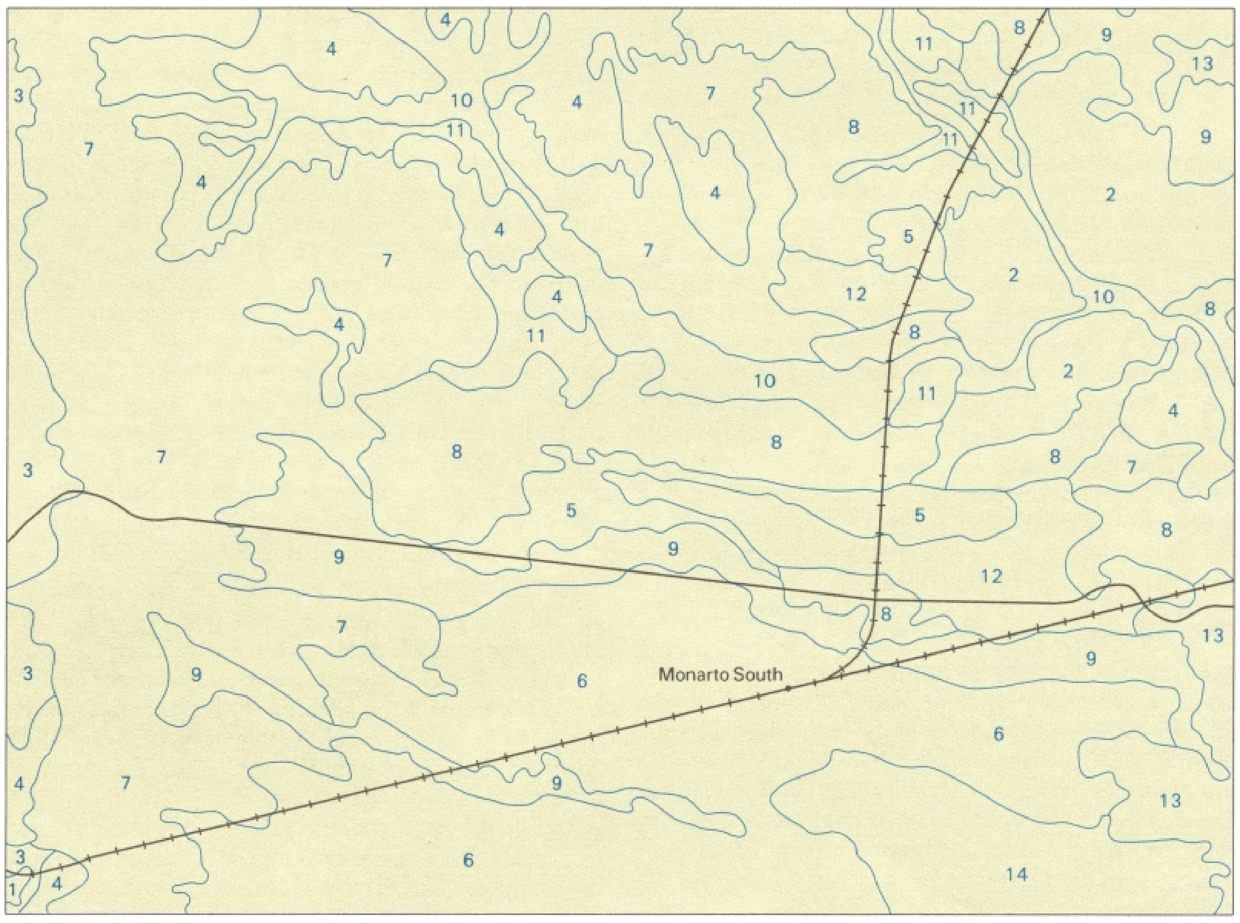
The purpose of a soil survey determines the amount of information gathered and its degree of detail, which is reflected in the scale of the map produced. Here, simplified extracts from mapping of the same area at three scales are represented. For all three the soil-landscape method of mapping and the Factual Key for the Recognition of Australian Soils were used.



MAP 1, SCALE 1:2 000 000 (Northcote and others 1960-68): This map is taken from the general purpose Atlas of Australian Soils, *in which the mapping units (broad-scale soil-landscapes) are typified by their dominant soils. These units typically have 6-10 components described in the booklets accompanying each sheet of the Atlas. The portion of the Monarto South district shown is covered by two mapping units.*



MAP 2, SCALE 1:100 000 (Chittleborough and Wright 1973): From the map made from a soil and environmental survey undertaken to aid in selecting the general site for a proposed new town. Six mapping units (soil-landscapes) occur in the area shown, each with 3-10 components described in the text with this map.



MAP 3, SCALE 1:50 000 (Wright, Maschmedt and Chittleborough 1975-76): From a map and report in preparation made to aid in the location of housing, parks, roads etc. Such a map could also be used to plan agricultural land use. In the area shown 14 mapping units (soil-landscapes) occur, each with 2-5 dominant soils and 7 or 8 minor soils described.

Sometimes it is desirable to derive smaller overview soil maps for areas like Australia, which even at 1:2 000 000 covers 2 m². Such maps at scales of 1:10 000 000 and 1:5 000 000 have been drawn from the soils atlas, as stated previously. The interpretative map 'Soil Resources' differs from its parent standard overview map at the same scale in that it deals only with selected soil properties—those properties that impose constraints on land management. All of this information in the parent soil map has been retained (although a great deal of other information, irrelevant for this purpose, has been left out).