# 3. GEOLOGY AND SOILS

**K.L. Tinley***

## 3.1 Geology

The Abydos-Woodstock Reserve is in the centre of the Pilbara Block which forms the northernmost part of the Archaean Western Australian granite shield. The Reserve lies across the junction where gneissic granite batholith domes abut greenstone layered volcanic rocks also of Archaean Age which occur as broad synclinal linear to arcuate belts (Figure 3.1). The greenstone assemblage consists chiefly of basic to intermediate lavas and volcanoclastic rocks with lesser occurrences of sediments and acid volcanic rocks.

Fault patterns in the granites are predominantly NNE trending with ESE cross-faults, trends followed closely by long outcrop ridges of basic dolerite dykes. In the greenstone and Proterozoic fold belt associated faults occur in complex fracture zones of radial and parallel patterns with high density cross-faulting (see Marble Bar geological sheet in Hickman & Lipple 1978). The most common dykes in the granitic area are dolerites with lesser occurrences of quartz, microgranite and pyroxenite dykes. In the fold ranges dykes are formed mainly by cherts, ultramafic rocks and felsic porphyry.

The lower part of the layered greenstone succession is composed mainly of ultramafic, mafic (basic) and felsic (acid) volcanic and intrusive rocks intercalated with thin chert layers throughout. The upper part of the greenstone sequence is predominantly a sedimentary assemblage of banded-iron formations, mudstones and sandstones with water-laid basalt pillow lavas. The ultramafic rocks which are saturated with ferromagnesian minerals include amphibolite, dunite, peridotite, pyroxenite and pyroxenite peridotite (Blockley 1975; Hickman & Lipple 1978). These weather into red clayey calcareous soils. The greenstone succession is intruded by granites in parts.

The fold belt area along the eastern margin of the Reserve contains probably the most diverse mix of rock types on the continent. "The extent of these greenstone belts and the quality of their exposure ranks the (Marble Bar) sheet as a key area in the understanding of Australian Archaean geology. Lithologically the succession is very diverse and contains most of the rock types present in other greenstone sequences of the world" (Hickman & Lipple 1978).

Four kinds of granitic rocks are represented in the Reserve area, all of which have a high alkali calcium and potassium content designating them as adamellite granites. Two also have granodioritic properties with lower silica and higher magnesium and calcium content. The granites, like their rhyolitic volcanic equivalent, weather to mainly sandy soils though many develop duplex profiles, and vary from acid to alkaline pH.

Resting unconformably on the deeply eroded surface of the Archaean rocks is a partial cover of a folded Lower Proterozoic rock succession of the Fortescue Group consisting of basalts and andesites with thick intercalations of tuff, shale, sandstone, grit

*C/o Western Australian Museum, Francis Street, Perth, Western Australia 6000.

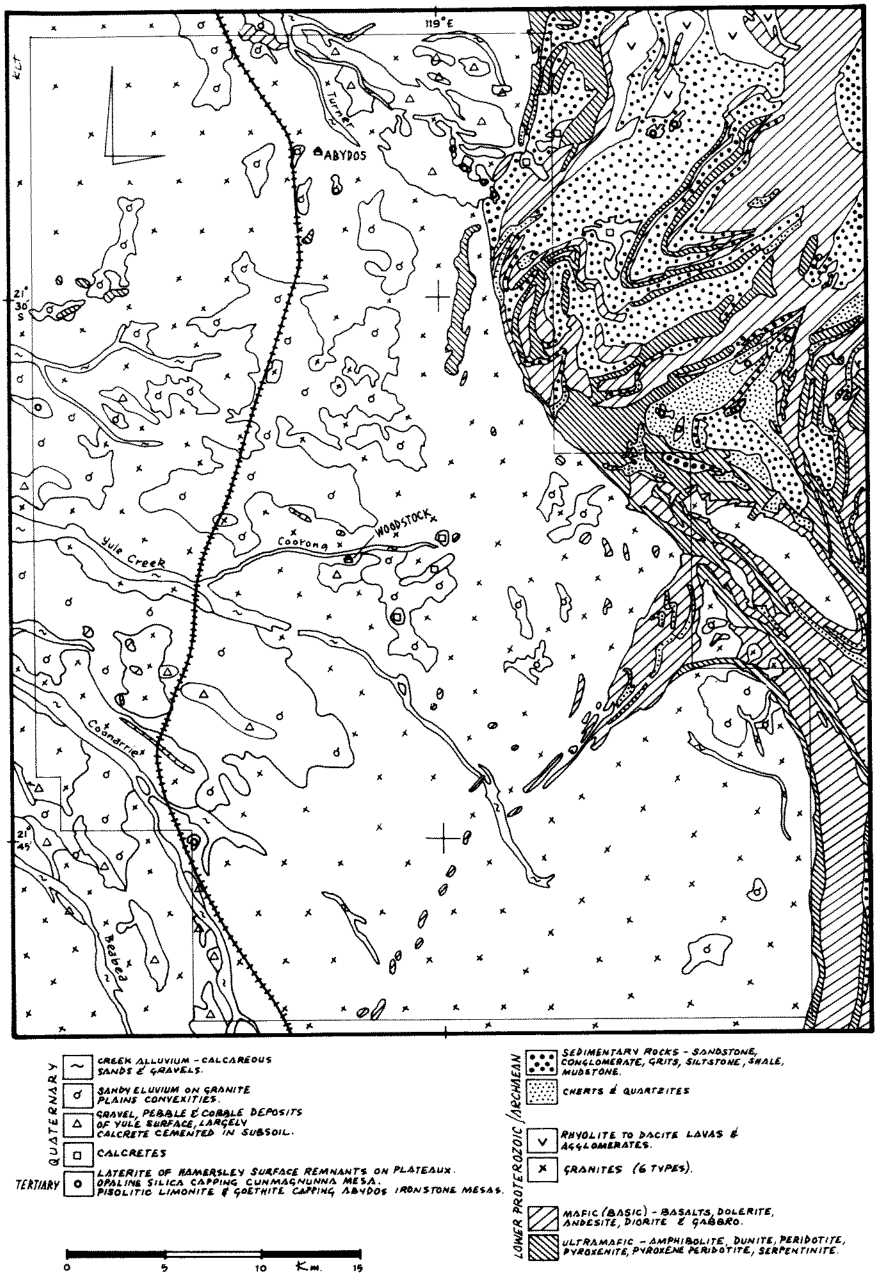


**Figure 3.1** Geology of the Abydos-Woodstock Area.

and conglomerate (Blockley 1975; Hickman & Lipple 1978). Mesozoic rocks of Jurassic and Cretaceous Ages are absent from the Marble Bar geological sheet area, but appear on the adjacent coastal Port Hedland-Bedout Island sheet in the Great Sandy Desert geology which terminates against the De Grey Delta.

Tertiary rock occurrences are few, small and isolated capping dissected tablelands where they represent the remnants of the once vast Hamersley Planation Surface (Kriewaldt & Ryan 1967; Hickman & Lipple 1978). The rocks are chiefly ironstone laterites, some pisolitic limonite and geothite with fossil wood, and a relatively rare occurrence of opaline silica rocks caps Cunmugnunna mesa in the SW of the Reserve (Figure 3.1). Not all Tertiary rocks belong to the Hamersley Surface.

The Quaternary to Recent geology is made up of both outwash and lag deposits. Five groups occur in the Reserve area including valley calcretes, poorly consolidated gravel deposits of the Yule Surface, creek sediments of sand, silt and gravel, with eluvial surfaces developed on the granite plains and gilgai heave soils on basalts and fine clays (Kriewaldt & Ryan 1967; Hickman & Lipple 1978).

As noted under physiography, markedly contrasting landscapes have developed on the major geological units of the Pilbara Block. Flat to gently undulating sandplains on the granites and associated outwash sediment deposits from adjacent uplands which are formed by the rounded-serrate fold ridges developed on the steeply dipping greenstone and Proterozoic volcanic, metamorphic and sedimentary rock strata (Figure 2.2; Plates 1, 2, 16, 59, 60).

## 3.2 Soils

Australian soils are classified into *four* major divisions based on the textural and horizon properties of the soil profile as observed in the field. Profile assessment is made from the surface down to the rock weathering front (saprolite) or to 2 m depth in deep soils. These primary profile forms are (1) *Organic* soils — O, (2) *Uniform* textured profiles — U, (3) *Gradational* textured profiles — G, and (4) *Duplex* (contrasting textured) profiles — D. The main subdivisions of these are based on pH in organic soils, texture in uniform soils, presence or absence of calcium carbonate in gradational soils, and colour (red to grey/gley) in Duplex soils (Northcote 1960, McDonald *et. al.* 1984).

The two dominant soils in the region are each related to one of the main physiographic units. Soils with duplex profiles occur on the granite plains, and those with uniform profiles on the upland fold ranges. The main subordinate soil types in the Reserve are those of bottomlands and the creek alluvia. Gilgai cracking clays or heave soils cover large areas outside the Reserve on basalt flats but are confined to small patches in the north of the Reserve on fine clays of interfluvial depressions.

On the map sheets of the Atlas of Australian Soils 1:2 million series mapping units are the dominant soil of soil associations delineated by landscape or physiographic divisions (Bettenay *et al.* 1967). Their map notation for duplex soils on granite plains is Oc 62-64 identified as alkaline hard-setting loamy soils with red clayey subsoils and a sporadically bleached A2 horizon (Dr 2.33 in the Northcote notation). The map symbol for the dominant fold range soil is Gf1 which is a brown shallow friable loamy porous soil (Um 6.23).

Examples of uniform, gradational and duplex profiles are however encountered in the soil associations of each physiographic unit due to the single or combined influences of local relief and change in rock type on processes and composition of soils. Soils of the arid zone are either loose sands or compact hard setting (patena forming) soils with low organic matter content, and accumulation of base salts in the subsoil due to partial or incomplete leaching. The latter feature is enhanced in the Pilbara Block as the prevalent parent rocks are alkali granites and mafic and ultramafic geology. As can be expected most soils of the region are alkaline throughout their profiles.

Broadly the main soil forming processes in the region are denudation and colluviation (slope wash) in the upland fold range unit, eluviation and illuviation on planar surfaces, with seasonal or episodic saltatory erosion and deposition along drainage. The impeded drainage of bottomlands and the plains dambos are subject to seasonal or episodic hydromorphism followed by extreme desiccation for the greater part of the year.

Once particular plant-soil associations have been identified from examination of profiles recognition of the spatial disposition of different soils is greatly aided by the use of plant indicators. Of these the spinifex grass species and the gums and wattles amongst the woody plants are pre-eminent as a guide to the profile and/or edaphic characteristics of an area or site. Such correlations have been broadly identified previously in the Pilbara Region by earlier workers including Clarke (1926), Burbidge (1945, 1959) and Beard (1970, 1975). A detailed soil survey correlated with geomorphology of the Strelley tributary catchment of the De Grey River immediately NNE of the Reserve by Churchward & McArthur (1981) has been used as a guide for the land system mapping from air photographs in the present study.

The main soil associations in each physiographic unit and the drainage systems that interconnect them are noted under the headings of (1) Upland Fold Ranges, (2) Plains, and (3) Bottomlands and Creeks. Soil pits and auger samples to bedrock, or to 2 m in deep profiles, were made in distinct habitats and across ecotones of representative landscape units. Samples were collected from each horizon, and these were later analysed. These data are depicted here by means of Habitat Profile Diagrams drawn to scale in the field (Figures 4.1-4.9).

## Upland Fold Ranges

In this unit of steep relief complex soils patterns have developed where topographical catena sequences of repeated soil types are superimposed over a great diversity of lithological sequences. Nevertheless the main differences, as conspicuously shown by the mosaic of single species dominance of the two indicator spinifex hummock grasses, seem to be the presence or absence of lime rather than from variations in texture or horizon.

Stony skeletal soils or lithosols attaining a maximum average depth of about 60 cm are typical. They are non-sodic dark reddish brown alkaline clayey earths, extremely stony throughout the profile which varies from uniform to gradational and duplex. They are overdrained xeric or droughty soils as indicated by the nearly treeless pure spinifex grassland cover over large areas of the fold ranges. The duplex profiles are probably waterlogged temporarily after exceptional rains.

The dominant soils are non-calcareous and calcareous forms, where large areas of hills are covered by a monospecific grassland of the glaucous hard spinifex *Triodia brizoides* indicative of non-calcareous dark red stony sandy loams over medium clays. Calcareous soils are indicated by a monospecific grass cover of the dark green hairy-collared spinifex *Triodia wiseana*, which are dark brown light medium clays over a reddish brown sandy clay loam. A thin calcrete crust often occurs at the surface as well as deeper in the profile. Where the two soils merge the two spinifex species overlap and even grow through each other to form single hummocks (Figure 4.9; Plate 54).

Calcrete terraces and small mesas eroded out of colluvial footslope deposits are gradational reddish brown clayey lime soils with clay content increasing down to a calcrete hardpan at 50 cm depth. The soils support a savanna cover of the dark green spinifex and trees of bloodwood gum or snappy gum (Figure 4.3).

**Plains**

The gently undulating landscape of the plainsland unit is dominated by dark red alkaline duplex earths designated as fersiallitic latosols or oxisols on a world scale. These are tropical partially leached soils still with appreciable reserves of weatherable materials particularly rich in ferro-magnesian minerals, their base saturation over 40 percent.

Despite their alkalinity these soils are non-sodic and non-calcareous with a higher pH (7.4 to 8.3) in the sandier loam topsoil and a lower pH (7.2 to 7.4) in the clayey loam subsoil. Depending on local relief and distance of granite rock from the surface auger samples showed uniform and gradational varieties with a common soil depth of about 100 cm to the saprolite. Profiles reached over 200 cm in faint depressions, and to 40 or 50 cm in the vicinity of granite outcrops and where plains slopes meet bottomlands. These kinds of red earths are covered over vast areas by a short open tree savanna of Ranji wattle, *Acacia pyrifolia* with a groundlayer of soft spinifex *Triodia pungens* hummock grassland (Figure 4.5). Local edaphic variations support a mosaic of other smaller wattles which occur in a clumped distribution.

Five main kinds of soils make up the plainsland surface:

(1) the dominant duplex red earths noted above with a cover of *Acacia pyrifolia/Triodia pungens* savanna (Figure 4.5).

(2) leached slightly acid shallow stony red earths on granite dominated by a dense small tree savanna of weeping wattle *Acacia orthocarpa* (Figure 4.6).

(3) Dambo drainage line duplex soils, treeless pure grassland of *Triodia lanigera* spinifex on seasonally waterlogged slopes. Leached topsoil with slightly calcareous and sodic subsoils. Refer to Figure 4.8.

(4) Pediment soils of three kinds:

(a) deep, stone-free gradational dark reddish brown alkaline and compact clayey sand to 150 cm depth, of inclined pediment junction between fold range and plains units.

Though base deficient throughout pH changes from 8.3 in the topsoil through 7.9 in the middle to 8.1 in the subsoil where occurrence of calcrete rock are patchily distributed. Covered by a mosaic savanna of Ranji wattle and bloodwood-gum *Eucalyptus terminalis* with a soft spinifex groundlayer.

(b) stony ferricrete soil dark red stony duplex or gradational slightly alkaline medium textured soil with ferricrete at 65 cm depth, supporting a mostly treeless pure grassland of glaucous *Triodia brizoides* spinifex (Figure 2.1).

(c) stony calcrete soil — dark reddish brown strongly alkaline gradational medium clayey sand soil with a base-deficient topsoil and calcareous, nonsodic, subsoil and with calcrete duricrust beyond 65 cm depth. Supporting a clumped savanna of bloodwood on deeper soil pockets with a groundlayer of dark green hairy-collar spinifex grassland (*Triodia wiseana*). Refer to Figure 2.1; Plates 33, 34.

Both (b) and (c) pediment soils are those from near the Ironstone Mesa group of hills in the northern Abydos Section of the Reserve. The deeper soil pockets on the calcareous interfluves appear to be filled-in incipient sink holes. Calcretes appear to underlie most of this incised pediment area as they outcrop along gully slopes and floors, including those with subsoil ferricretes. Seasonal waterlogging followed by extreme desiccation has resulted in the development of pan horizons in both these pediment soils and would determine the predominance of a treeless pure grass cover similar to dambos.

(5) Strongly alkaline mafic and ultramafic dyke soils criss-cross the granite plains forming bands of a highly calcareous clayey sand to sandy clay loam matrix to masses of pebbles and boulders overlying a solid calcrete matrix at shallow depth between 35 and 50 cm. These soils carry bands of hard dark green *Triodia wiseana* spinifex across the plains and form abrupt junctions on both sides with the mildly alkaline, base deficient deep red earths supporting Ranji wattle and soft spinifex savanna.

**Bottomlands and Creeks**

Valley soils are accumulations of water transported sediments from upstream and locally eroded materials plus colluvial slope wash of sediment from the sides. Sediments of similar characteristics tend to occur together due to their differential sorting by flowing water. Anastomosing stream courses and fan deposits develop laterally alternating sequences of fines and sandy soils referred to as fan or alluvio-catenas. Floodplain soils are generally coarser closer to the riverbank and finer further away. Most creek deposits are also changed vertically with every flood, by scour and truncation of existing horizons and superimposition of fresh layers creating stratified profiles.

Bottomland flats, which began as faint overbank depressions or infilled flats at tributary junctions where these had been blocked off by bank deposits of the main river, have accumulated base-saturated silts and sands resulting in the development of Solonetzic-type halomorphic soils by the processes of eluviation and illuviation. With the exception of bottomland flats, except where these are now being incised by headward erosion of gullies, all drainage and sloped terrain undergo high erosive and depositional activity of short duration with the occurrence of seasonal or episodic flood rains.

Six main types of valley soils are identified, some are terrace deposits and other old alluvia left behind on valley sides as the rivers have incised their courses down to new levels. These are now mostly undergoing denudation leaving benchlike and mesaform duricrust remnants. Others are contemporary, within reach of the present flood and ebb of todays creek drainage systems. The soils and river deposits which are all alkaline include:

(1) Creek bed silts, sands and gravels which lack significant profile development but sequences of different sediments result in stratification often with contrasting layers. With year round deep water supply in their sandy beds creek alluvia support the densest and tallest woody vegetation in the region, of river-gum and cadjeput trees (Figure 4.1, Plate 19).

(2) Floodplain alluvium — brown alkaline clayey sands, calcareous and non-sodic throughout the profile to standing water sample depth at 100 cm. Supports a dense wooded grassland of wattle scrub over a medium height tufted grass groundlayer (see Figure 4.1, Plate 21). Splay deposits are sandier.

(3) Bottomland saline flats are a mosaic of soils each with quite different physical, chemical and edaphic properties, the identification of which is facilitated by the different spinifex grasses and dwarf woody plants growing on each (see Figure 4.7; Plates 50, 51).

(a) Very strongly alkaline duplex friable clayey sand topsoil over compact massive columnar sandy clay subsoils often patchily duricrusted in thin sheets, followed by a strongly mottled lighter coloured friable sandy clay loam. The profile is highly alkaline and calcareous throughout, with a non-sodic topsoil and an extremely saline Chorizon below the columnar layer. On Valley flats in the hill zone there are often gypsic deposits on the surface. These soils are identified by the presence of a large hummock forming hard glaucous spinifex *Triodia longiceps* (Figure 4.7).

(b) Where the topsoil of the above profile has been truncated the columnar horizon, now at the surface, develops an indurated laterite capping. This in turn is covered with a veneer of silty soil and accumulations of loose sand and silty sands mounded up to 50 cm depth beneath the radial stoloniferous growth of the spine-leaved spinifex *Triodia secunda*, which form an important habitat for burrowing animals (Figure 4.7).

(c) Deep loamy gradational soil moderately to strongly alkaline, non-sodic to increasingly calcareous throughout, or, with leached A and B horizons lime appearing only at depth. This soil profile is indicated by a pure cover of the dark green hairy collar spinifex *Triodia wiseana* often with an overstorey of dwarf poverty bush *Acacia translucens*. This soil is similar to those dominated by bloodwood-gum savanna (cf. Figure 4.3).

(4) Savanna of bloodwood-gum and dark green spinifex on deep calcareous, non-sodic, pallid sandy clay loams with a moderate to high alkalinity (Figure 4.3; Plates 30-34).

(5) Tea-tree scrub-thicket on deep duplex pallid calcareous clays over calcrete with a slightly saline, brak, subsoil and very strongly alkaline throughout (Figure 4.2; Plates 26, 27).

(6) Stony lithosol with a powdery loam matrix on calcrete mesa summits, highly calcareous and non-sodic supporting dark green spinifex with a variety of calcicolous woody plants such as bloodwood and *Acacia bivenosa*.

**Edaphic Gradients: Soil Moisture Balance**

Pure grasslands devoid of woody plants are indicators of quite opposite soil moisture balance regimes. Either extremely over-drained xeric conditions or the converse, excessive waterlogging from seasonal high watertable conditions which, in the arid and mesic climatic zones, is followed by extreme desiccation (Tinley 1982 and in Walter & Breckle 1986: 112-117). In the Pilbara Region drought stricken soils are indicated by the predominance of nearly treeless spinifex grassland on the slopes of hills and ranges, and the latter conditions on planar surfaces such as pediments, plateaux, dambo-type drainage, cracking clays, fans and deltas.

The soil moisture gradient from the driest to the moistest extremes in the Reserve are clearly identified by the density and height of woody plant growth and the predominance of xeric or mesic plants. Starting with xeric bare rock surfaces, truncated hard patina surfaced bare soils, lithosols on slopes covered by widely spaced xeric hummock grassland, intermediate conditions by the wattle and gum savannas on plains and plateau summits, and on and around rocky outcrops, deep lime clays (tea-tree scrub-thicket), the tributary creeks and finally the wettest in the gradient in ravines and especially along the main creek banks and in their braided sand bed sediments.

Following a protracted rainless torrid spell since January 1988 11 mm of rain fell in the week immediately prior to floods at the end of March. Forty-eight hours after the 11 mm of rain was recorded profile cuts were made in different soils to ascertain to what depth the moisture had penetrated. In all situations moisture had permeated deepest to between 22 and 25 cm beneath or around runoff surfaces such as the base of trees, shrubs, and beneath spinifex hummocks or surface boulders. Beneath the intervening bare flat soil surfaces the wetted horizon only reached to between 5 and 15 cm depth forming an undulating front related to surface microrelief. The rain had penetrated deepest to 30 cm in the sand mounds formed by the radial stoloniferous growth of *Triodia secunda* on saltflats. The subsequent flood rains of 233 mm wetted all soils to bedrock or beyond 2 m to the saprolite in deeper pockets of red earths, turning many soils into a porridge-like condition.

The distribution of ferricrete or laterite as old planation surface remnants of fossil subsoils is confined to the fold ranges where they cap the summits of plateaux at two levels. The highest at 400 m altitude is part of the once vast Hamersley Surface, and a lower planation surface at 300 m is preserved on the Ironstone Mesas in the Abydos sector of the Reserve. In contemporary profiles subsoil ferricrete was only encountered in two sites. In the non-calcareous subsoils of the pediment incised by the head drainage of the Turner River which surrounds the above mesas, and in developmental form as a groundwater laterite in the dambo drainage of the plains. Here the subsoils have a pan horizon of compact base saturated and ferromagnesian-rich mottled sandy clays. Apart from these two sites contemporary ferricretes are absent from the entire landscape, and calcretes are confined to valleys, dykes and the fold range hills composed of base saturated rocks.

Desert duripan, a fine-grained siliceous laterite or ferricrete, reported from the arid mulga plains country between Newman to Mt Magnet and inland (Bettenay & Churchward 1974) was not enountered in the study area.