DOI: 10.18195/issn.0313-122x.61.2000.029-075
Records of the Western Australian Museum Supplement No. 61: 29–75 (2000).

Geoecological setting of the Carnarvon Basin, Western Australia: geology, geomorphology and soils of selected sites

Karl-Heinz Wyrwoll[1], Trevor Stoneman[2], Greg Elliott[3] and Peter Sandercock[1]

[1] Department of Geography, The University of Western Australia, Nedlands, Western Australia 6907, Australia

[2] 112 Rosedale Street, Floreat Park, Western Australia 6014, Australia

[3] Australian Nuclear Science and Technology Organisation, Lucas Heights, New South Wales 2234, Australia

Abstract – Soil profile and geomorphic attribute data are provided for 63 quadrats positioned in a stratified random array throughout the southern part of the Carnarvon Basin. The geomorphology of the region is also reviewed. Together, these two scales of data provide a geoecological setting for interpreting biogeographical patterns in the region.

INTRODUCTION

This chapter outlines the geological, geomorphological and pedological context of 63 terrestrial quadrats sampled for plant and animal species during a biological survey of the southern part of the Carnarvon Basin. Thus, it provides one part of a 'matrix' which attempts to identify the links between the biota and the physical components of the region's environment. Much of the original data on which the paper is based are given in Appendices 1 and 2. These data are summarised in a form that would facilitate the characterisation of a site in a manner that defines an ecological matrix suitable for statistical analyses. Quadrat-size, and the basis on which they were positioned, is described in Burbidge *et al.* (2000). Figure 1 is a map showing the areas in which quadrats were positioned, as well as other localities named in text.

Processes operating at both local and regional scales, and in the past as well as the present, affect a site's substrate characteristics. Thus, a number of scales should be considered in deciding which physical data are most likely to explain the site's biological characteristics. The relevant spatial and temporal scales are defined by the history and spatial heterogeneity of the landscape, linked to the specifics of the biogeographical questions/issues addressed. A high degree of historical imprint is traditionally recognised as being a characteristic attribute of the Western Australian landscape. In the case of the Carnarvon Basin, relatively long-term Cenozoic time scales are of special significance. However, what is often not fully recognised is that, while the regional-scale geomorphological architecture of the landscapes is of considerable antiquity, more recent elements are also present. Some of these reflect environmental changes that will have had far-reaching ecological impacts and are linked to periods of regional and continental scale morphodynamic instability.

In approaching the study three spatial scales are defined: (i) the scale of the Carnarvon Basin as a morphotectonic entity – this is discussed only by way of an introduction; (ii) the scale of the region defined by geomorphological and soil divisions; and (iii) the scale of the sample quadrats.

An equivalent hierarchy may be recognised in the biota. At broad scales, biogeographical patterns are determined by the effect of long-term interactions between climatic and morphotectonic processes on evolutionary and dispersal processes. Across regional landscapes, the biota are patterned by a range of ecological processes, including local modifiers of climate, geomorphology, hydrology and soils. These link to species resource requirements ('source' or 'sink' habitats). The distribution of drainage lines and sand plains, and patterns of erosion and chemical weathering are examples. Processes such as resource partitioning within guilds (e.g. microhabitat selection and host-symbiotic interactions) determine species composition at the local scale (within a quadrat or a habitat patch).

REGIONAL CONTEXT

The Carnarvon Basin is one of the major sedimentary basins of western Australia, and has a depositional history that spans much of the Phanerozoic. Much of our present knowledge of the geology of the Carnarvon Basin has been compiled by Hocking *et al.* (1987), and the discussion of the geology, which follows, has been largely summarised from this publication.

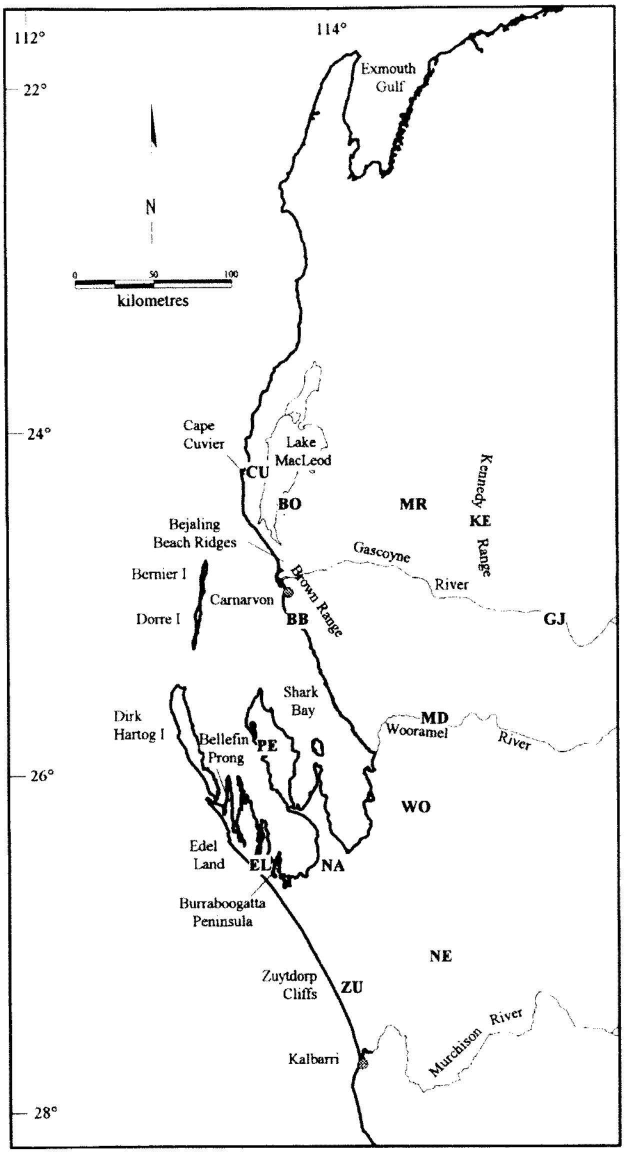

Figure 1 Location of sites mentioned in text.

Geology and Morphotectonic Evolution

The Carnarvon Basin is bounded in the east by the Archean and Proterozoic terrains of the Yilgarn Block, the Gascoyne Province, Hamersley Basin and Ashburton Trough. In the south, the margins of the basin are defined by faulted contact of the Precambrian Northampton Block. The northern limit of the Carnarvon Basin is bounded by the Canning Basin. The details of the surface geology are summarised in Figure 2, and a stratigraphic summary of the succession is given in Figure 3.

The geomorphology of the Carnarvon Basin retains a strong imprint of Phanerozoic tectonic events, which is directly expressed in the large-scale relief configuration of the basin (Figure 4). The basin originated during the Early Paleozoic when Australia was part of the Gondwana supercontinent. But it was not until the Silurian that marine deposition extended as far south as the Carnarvon and northern Perth Basins. This southward migration of marine deposition with time may reflect the progressive southward opening of a divergent margin, with the development of failed arms off it. During the Carboniferous, the Carnarvon Basin moved southwards from a position of 25°–30°S in the Visean to 60°–70°S in the Westphalian. Tectonic activity combined with the low sea levels of the end of the Visean led to the exposure of much of the Carnarvon Basin to subaerial erosion. During the Late Carboniferous the Carnarvon and Perth Basins are thought to have formed an elongate gulf. Basin subsidence continued as the result of the developing infrarift setting. At the end of the Permian the depositional basins began to assume a more linear form. This change in style of the environment of deposition was associated with faulting and the development of rift valleys.

Graben structures developed along the western margin during the Triassic. A pronounced, north-east trending infrarift basin developed, with widespread uplift of the onshore parts of the basin. Grabens were active particularly in the Late Triassic.

The Jurassic was the time when Gondwana began to break-up, with a mid-ocean ridge entering the northwest coast of Australia. Some renewed graben development took place in the Late Jurassic, and this was the forerunner of later episodes of rifting. This was a time of extensive tectonic activity in the Carnarvon Basin.

During the Cretaceous the coastal margins of Western Australia began to take on much of their present form. During the mid-Neocomian, a mid-ocean ridge developed between Australia and Greater India, accompanied by widespread uplift. At the same time India moved away from Australia and the separation has continued to the present day. From the time of the break up (127 Ma) until the Early Tertiary (53 Ma), Australia and India were separated by mid-ocean ridge spreading systems and were thus on separate lithospheric plates.

The coastal margin of the Carnarvon Basin has experienced considerable tectonic activity during the Cenozoic, and the tectonic activity has a strong morphotectonic expression. The distribution of the shallow tectonic elements and related depositional provinces in the central coastal areas of the Carnarvon Basin are shown in Figure 5. The western coastal areas have been named the Bullara Sunkland. It is bounded in the west by the Edel-Quobba Ridge, a geomorphic feature formed by the Dirk Hartog, Cuvier, Gnaraloo, Warroora and Cape Range anticlines and complexes of high dune ridges that lap onto the uplifts and fill the structural depressions between them. The eastern margin is sharply defined by flanking uplifts (Giralia, Chargoo, Geridi, Chirrida and Grierson anticlines) or merges into low alluvial plains that extend into the hinterland.

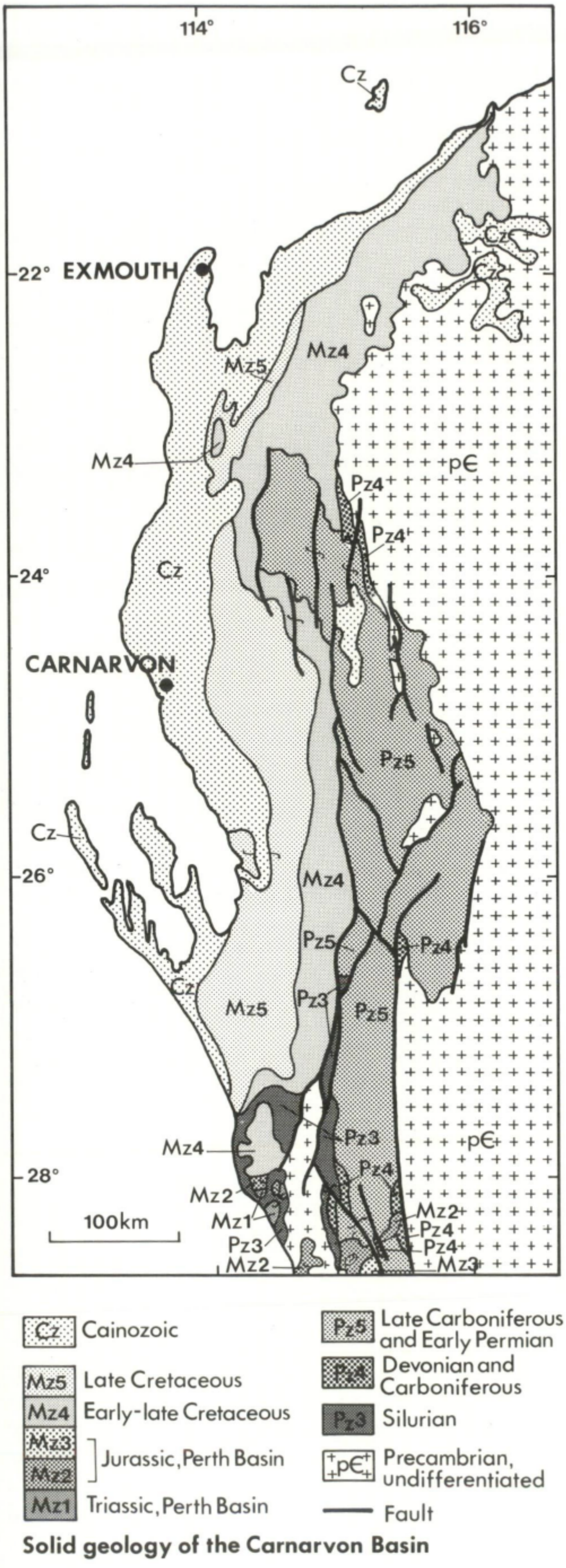

Figure 2 Geology of the Carnarvon Basin (Hocking *et al.*, 1987).

The two most prominent morphotectonic features of the area are the uplands bordering the Exmouth Gulf (the Cape, Rough and Giralia Ranges) and the Lake MacLeod Basin. The three ranges correspond to the respective anticlinal axes shown in Figure 5, and are thought to have resulted from reverse movement on underlying normal faults. The Lake MacLeod basin is a north trending graben paralleled by anticlines. The anticlinal flexures bounding the basin are thought to be associated with bounding faults. The structures, which are defined by undulations in the Tertiary strata, form the major features of topographic relief along the graben margins.

Geomorphology and Surficial Geology

The combination of geology, tectonics and denudation had, by the end of the Tertiary, essentially set in place the major terrain divisions that are present today. These were further modified through geomorphological events driven by the climate fluctuations of the Quaternary.

Much of the Carnarvon Basin is covered by surficial deposits which have their origin as weathering residual, after deep weathering in the Late Cenozoic; surface calcretes and valley calcretes, which have formed under the more arid climates of the Late Cenozoic; and the extensive largely Quaternary eolian and alluvial sequences.

The study area falls into a three-fold geomorphological division of (i) a predominantly erosional eastern margin; (ii) the depositional terrains of the central region; and (iii) the coastal margins.

Erosional Eastern Terrains and Deep Weathering Events

The region corresponds with a hinterland terrain of faulted Tertiary, Mesozoic and Paleozoic sedimentary rocks of limited relief, extensively dissected and frequently deeply weathered with strong ferricrete and silcrete development. This part of the basin has a generally restricted cover of surficial sediments, although in some regions, especially the Kennedy Range, a thick cover of surficial sediment is present.

Deeply weathered outcrops are conspicuous elements of the region, to the extent that the deep weathering events of the Cenozoic provide the starting point for the development of much of the present-day geomorphology. Both ferricretes and silcretes, with their associated weathering profiles, are found in virtually all pre-Miocene outcrop areas, and also over some Miocene and younger (?) formations. Deep weathering has been the main influence on subsequent geomorphological development, through essentially controlling etchplain development, especially in the eastern parts of the Carnarvon Basin, and through releasing

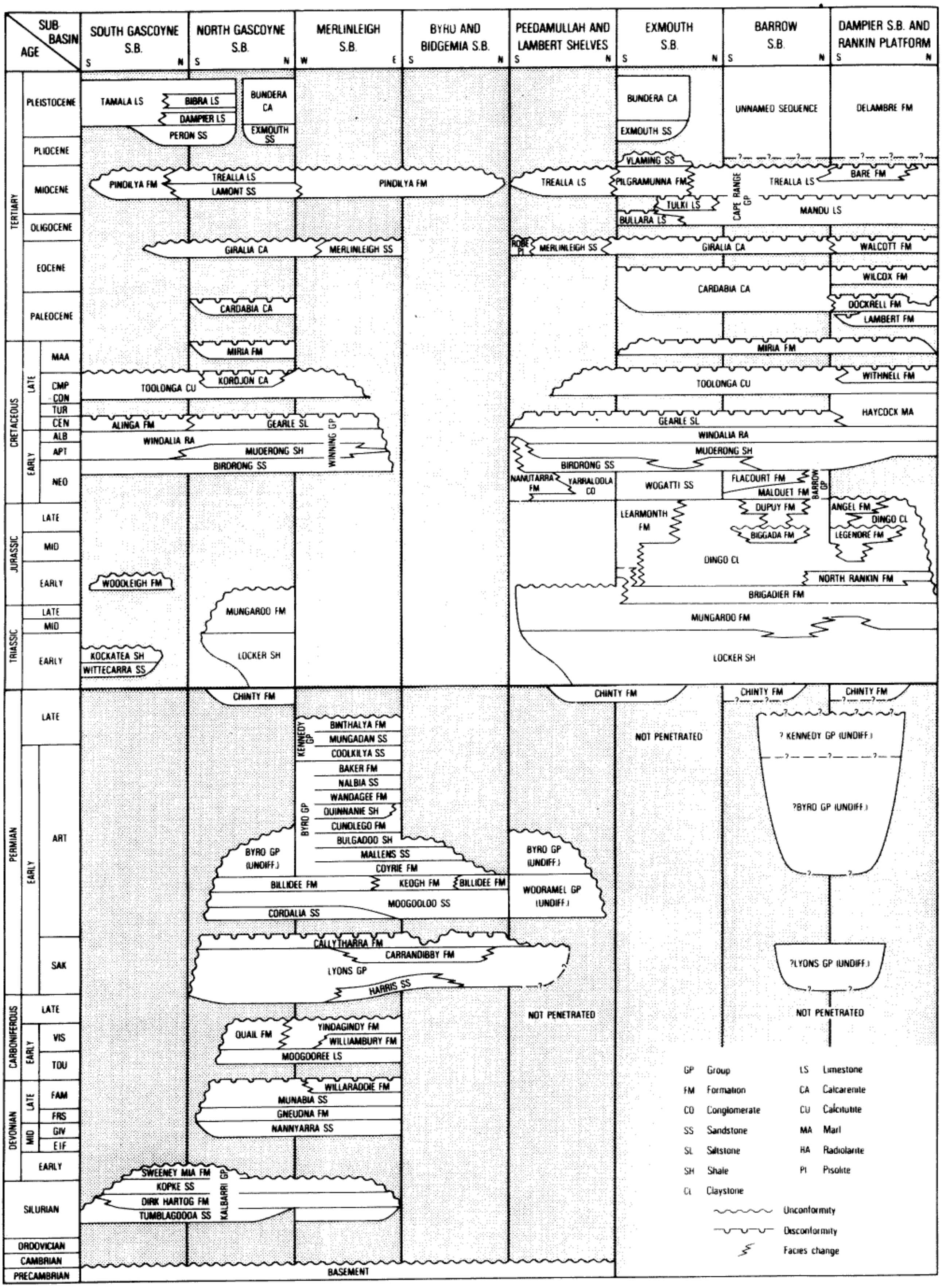

Figure 3 Generalised stratigraphy of the Carnarvon Basin (from Hocking *et al.*, 1987).

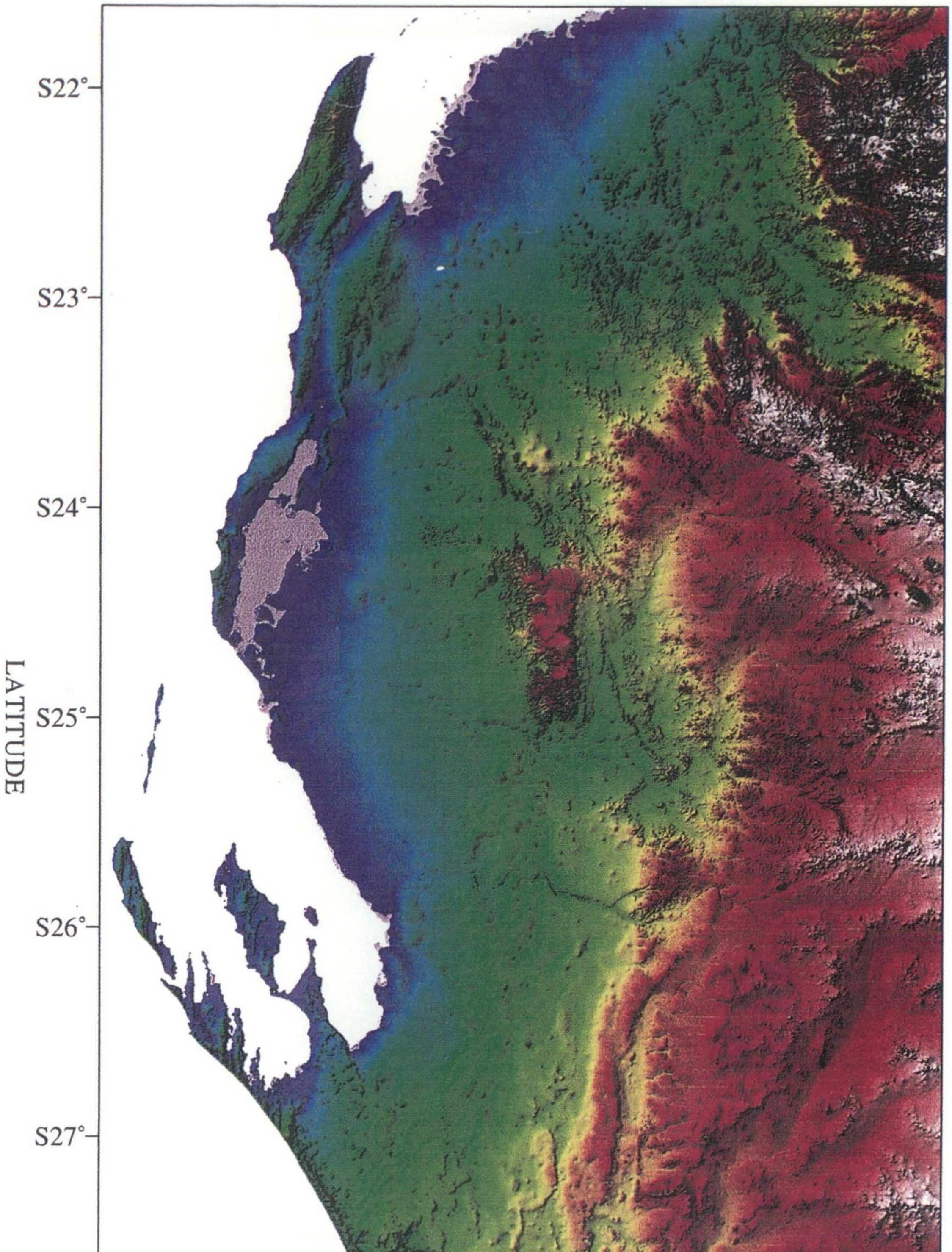

Figure 4 Relief characteristics of the Carnarvon Basin.

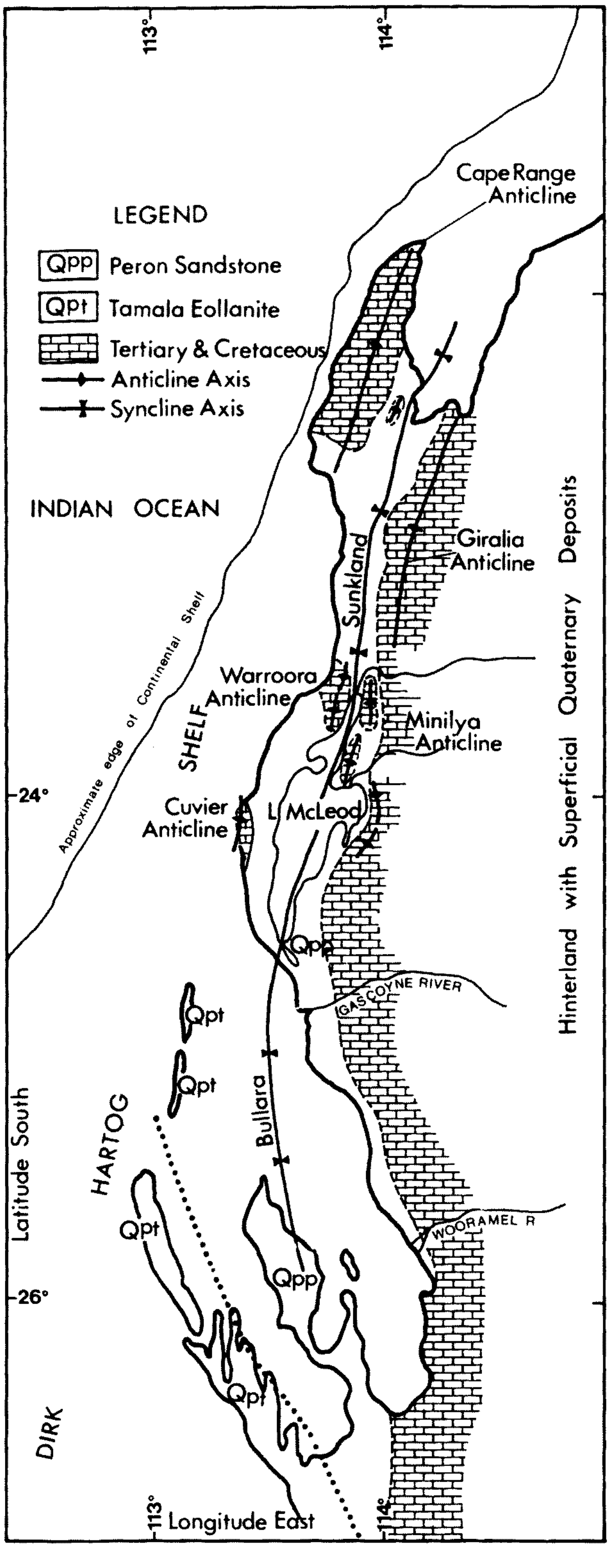

Figure 5 Shallow tectonic elements of the Carnarvon Basin (after Logan *et al.*, 1970).

large volumes of sand in the course of saprolite development. These sands have since been reworked into the surficial formations so widespread throughout much of the Carnarvon Basin.

The development of ferricrete and silcrete appears to be partly related to bedrock control. Hocking *et al.* (1987) note that there is preferential development of silcrete over the Windalia Radiolarite and other clayey bedrock. But there are also catenary controls that operate and are controlled by the geochemical mobility of the major ions involved in chemical weathering. This is evidenced by the way ferricrete often grades upslope into silcrete (see van de Graaff, 1983).

Silcrete development is widespread in the Carnarvon Basin. Silcrete outcrops can take a variety of forms, ranging from massive, pisolitic, laminar to cone shaped forms. Silcrete cone development is a very distinctive feature of silcrete occurrence in the Kennedy Range region, and gives rise to some spectacular areas of outcrop.

There is at present some doubt as to the timing of the deep weathering event (events?). Kemp (1978) concludes that prior to the Oligocene humid and warm conditions prevailed in the Australian region, with rain forest extending to the presently arid centre of the continent. This is clearly indicated by plant beds that occur over much of the central and southern Yilgarn Block. It is thought that by the Oligocene a reduction in precipitation had already occurred. The general view still prevails that during the Miocene a change to greater aridity became established, and that laterisation generally ceased by the mid-Miocene at the latest.

There have been suggestions that silcretes may pre-date the ferricretes (van de Graaff, 1983), and on this basis it was proposed that an Eocene-Oligocene age was appropriate for the silcrete. However, from the manner in which clasts of silcrete are enclosed in ferricrete profiles and vice versa, this suggestion is seen as invalid and it is more likely that the formation of silcrete and ferricrete were essentially synchronous.

It has also been suggested (Hocking *et al.*, 1987) that there were two major periods and one minor period of laterisation (ferricrete formation) and silcretization in the Carnarvon Basin. It is argued that in the Giralia Range, laterite is locally present on the Eocene Giralia calcarenite and beneath the Miocene Lamont Sandstone and Trealla Limestone. Elsewhere north of the Gascoyne River, the Eocene Merlinleigh Sandstone is either laterized or silcreted, while the few outcrops of Trealla Limestone away from the coastal anticlines are not. It was therefore concluded that in this area laterization and silcretization occurred in the Oligocene. However, recent work in the Yilgarn Craton at Lake Lefroy has suggested that intense chemical weathering may well have occurred <10 Ma (H. Zheng pers. comm). This inference may be of relevance to the finding that, south of the Gascoyne River, the Miocene Lamont Sandstone and Miocene (?) Pidilya Formation are locally laterized indicating post-Middle Miocene laterization.

The claim for a third phase of laterization during the Late Pliocene to Pleistocene comes from the evidence of laterite post-dating the main phase of laterization in the Murchison Gorge area. The details of this claim have however, not been given. From evidence in other parts of the Carnarvon Basin and adjacent Yilgarn Block it is clear that silcrete and ferricrete development, of varying degrees, were an ongoing feature of the Late Cenozoic, with silcrete formation continuing to the present. But their formation cannot be equated with the ferricrete/silcrete formation associated with the intense deep weathering phases of the Tertiary, and care has to be taken to recognise this difference.

Calcretes are the other weathering/pedogenic product that requires consideration. Calcretes need to be clearly separated into two categories: (i) the formation of K horizons in soil profiles which eventually become 'plugged' and result in calcretes, and (ii) the formation of extensive groundwater or valley calcretes. But it is often difficult to distinguish between the two. In light of the general Late Quaternary climatic setting of the region, the widespread development of pedocalcic horizons is to be expected.

Groundwater and valley calcretes [see Mann and Horwitz (1979) for a discussion of their formation] are widespread in the eastern part of the area. They have given rise to strong cementation of alluvial units and are inevitably associated with extensive silicification. Calcrete formation has been a feature of this region for much of the Late Cenozoic, and it is clear from invertebrate fossils associated with some calcrete 'sealed' units that calcrete formation is ongoing. An understanding of the timing and controls on calcrete formation is often closely tied to an understanding of alluvial stratigraphy.

Central Region of the Study Area: Alluvial and Eolian Events

A central region of low relief is associated with widespread alluvial and eolian deposition. Large alluvial complexes and avulsion plains are prominent along the Gascoyne and Wooramel Rivers. The dune fields are very extensive and are part of a larger complex that extends from the northern Perth Basin to the northern parts of the Carnarvon Basin.

Alluvial Environments: Widespread alluvial deposition has occurred/occurs along most of the major streams of the region. The alluvial deposits of the region are important elements of the present geomorphology of the Carnarvon Basin and potentially hold the key to an understanding of the Quaternary paleohydrology/paleoclimatology of the region.

The Gascoyne River is the most important of the streams of the Carnarvon Basin and dominates the geomorphology of the central part of the area. It is a large low-sinuosity, coarse-bedload, ephemeral stream, with an effective drainage area of about 70 x 10^3 km^2. Channel flow occurs through relatively short-lived and infrequent flows. Discharge records (Stokes, 1978) indicate that periods of up to one year without flow are common but periods of two years or longer are less frequent. In the seventy years of record, there have been four cases when no flow occurred for two years or more, the longest period being some 43 months between May 1910 and January 1914.

High rates of suspended sediment transport are clearly indicated by the pattern of flood plain depositions with well developed crevasse splays and levee forms. During large floods the Gascoyne River has the potential to flood extensive areas of the flood plain and partially reactivate old channel courses. Extensive flooding, and flood plain waterlogging is clearly indicated by the widespread pan formation that has taken place over parts of the floodplain. The Wooramel River displays similar floodplain characteristics.

The restriction imposed on the Gascoyne along the southern part of the Kennedy Range and possibly other more confined channel reaches leads to the development of high unit stream power values. Consequently, the likelihood of channel breaching immediately downstream of confined channel reaches is high. This results in channel avulsion and accounts for the development of the large avulsion plain that has developed on the Gascoyne River west of the Kennedy Range. Poor exposure makes it impossible to establish the alluvial architecture of the avulsion plain.

Dune fields: Large desert dunes, which have a complex sedimentological and climatic history, as well as other eolian sediments, cover much of the area. Figure 6 shows the regional dune trend and indicates the areas where clearly identifiable dune forms can be recognised. The figure represents a compilation of information from topographic and geological maps of the 1: 250 000 series. While the maps provide a guide to many of the dunefields, they do omit some important occurrences of dunes. These omissions were filled in using aerial photographs and Landsat imagery.

In the areas adjacent to the Gascoyne River channel avulsion and overbank flooding have led to the partial destruction of dune form and organisation and, in places, created interdune claypans often ringed by a well defined lunette. A southward traverse reveals a marked change in dune field organisation and definition of dune shape; both features tending to break down in the higher rainfall areas.

The bulk of the dune units show a general correspondence between dune trends and the dominant prevailing wind regime. A striking feature of the regional dune trend is the northward deflection that occurs towards the coastal areas.

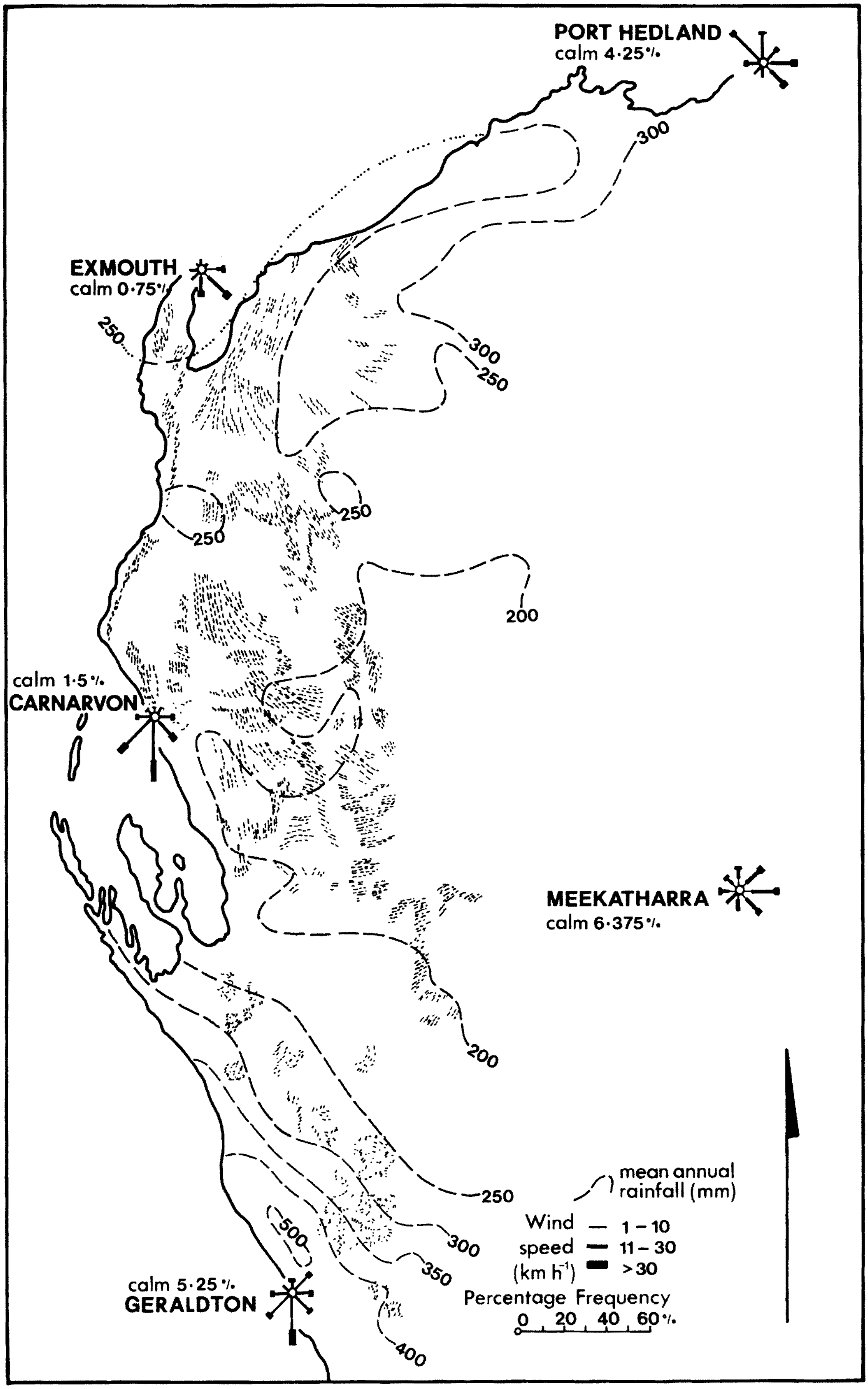

Figure 6 Dune fields of the Carnarvon Basin. Wind directions and are means of the information given in the Climatic Atlas of Australia (1979) of the months of January, April, July and October.

Along the Wooramel River, for instance, an almost total deflection occurs in dune orientation from a west-east trend to an almost north-south trend over a distance of some 80 km. A similarly strong deflection from an almost east-west direction to a north-south direction occurs in the Gascoyne River-Exmouth Gulf area.

A feature of some importance in the overall dune distribution is the occurrence of well-defined dune fields on the Kennedy Range. From the occurrence of well-developed linear dunes in these areas it would appear that sand was not transported any great distance during dune formation.

Geomorphology of the Coastal Margin: Carbonate Terrains and Evaporite Basins

The western areas largely consist of Tertiary and Quaternary marine deposits, some of which have undergone significant tectonic deformation. Large deltaic complexes are associated with the Gascoyne River. The Shark Bay and Lake MacLeod terrains are closely linked to the sea level history of the Pleistocene. The Shark Bay area provides evidence for three Pleistocene transgressions (Kendrick *et al.*, 1991).

The Edel region of Shark Bay is characterised by large (40–60 m) dunes that are largely stable. The western margin of the region is defined by cliffs (Zuytdorp Cliffs) which extend as far south as Kalbarri. The eastern margin of the region is formed by small inlets and bays. The Peron Sandstone terrains of Shark Bay exhibit an irregular, transverse (?) dunal topography with interdunal depressions containing evaporite pans and marine lagoons.

The Lake MacLeod region is bounded in the west by a barrier that forms a steep cliff line. This has developed in Tertiary and Pleistocene carbonate lithologies and, in places, is associated with Holocene coastal dunes. Lake MacLeod has developed behind the barrier and ponds the discharge from the streams running into it from the east. During high flood events, floodways from the Gascoyne River discharge into the southern parts of Lake MacLeod. Lake MacLeod was more open to the sea during the Last Interglacial, and exchange was sufficient to allow significant coral growth. The lake was closed during the middle/late Holocene through the development of a beach-ridge plain at its southern margin, and now forms a large evaporite basin.

Large Pleistocene barrier-complexes are prominent elements in the coastal geomorphology of the Carnarvon areas. The Brown Range – Coolillee – Lyell is the most prominent structure (Logan *et al.*, 1970). These are extensively rubefied and have been reworked by wind into smaller dune bedforms.

Environmental Degradation and Erosional Status

An overriding concern of any consideration of the geomorphology and soils of the Carnarvon Basin is the erosional status of the region. There has been pastoral activity in the Basin since 1876 (Williams *et al.*, 1980). It is thought to have caused significant environmental degradation, resulting in severe erosional problems in some areas. By 1900 the number of sheep in the catchment of the Gascoyne River had reached 60% of the peak level attained immediately prior to the disastrous drought of 1936. The increases in sheep numbers in the 1920s–1930s corresponded to good seasonal conditions and the economic pressures of the Great Depression.

Heavy rains within the Gascoyne catchment in January and February 1961 caused severe flooding in Carnarvon. The run-off from the catchment was considered to be excessive, and caused by the 100 years of heavy grazing (Williams *et al.*, 1980). An aerial reconnaissance of the catchment was completed by the Western Australian Department of Agriculture immediately after the flood. It was concluded that excess run-off was due to degradation of the area and that steps should be taken to prevent further degradation.

Following aerial reconnaissance work, 14 percent of the catchment's area was classified as badly eroded — it could become irreversibly degraded unless excess grazing stock were removed. Another 52 percent was classified as degraded — it had some erosion, and required careful use to prevent further degradation.

The eroded areas were those that had erosion-susceptible soils capable of supporting palatable and durable pastures. They received frequent run-on water from areas upslope, were readily accessible to sheep, and had maintained high levels of animal production. It was believed that their preferential use, when combined with a heavy continuous grazing regime, had produced the observed distribution of severely eroded areas. In general terms, all rangelands utilised during the period 1920 to 1939 were moderately to seriously degraded. The natural vegetation of perennial saltbush and associated species, from which successful pastoral production had previously been achieved, had changed to unproductive short-lived annuals (Williams *et al.*, 1980).

From these observations it was suggested that the disruption of the soil-surface conditions, the removal of vegetation and the current active erosion had the potential to make these areas highly unstable – with a high erosional hazard. The new erosion networks and the increased area of bare compacted soil were thought to have resulted in greater and more rapid run-off.

Williams *et al.* (1980) suggested that the erosion-degradation status of the Gascoyne catchment provided an example of desertification.

Desertification is the diminution of the biological potential of land which escalates from a disharmony between land use and management on the one hand, and the soil and prevailing climate on the other (Biswas *et al.*, 1980). It is a process of ecological degradation by which economically productive land becomes less productive and in extreme cases, develops a desert like landscape incapable of sustaining the communities that once depended on it (Allan-Diaz, 1996).

The Carnarvon Basin with its frequent and severe drought is susceptible to desertification. Drought reduces the number, phytomass, and ground cover of plants and hence reduces the protection of the soil against water and wind erosion. Drought can therefore lead to an increase in the vulnerability of the land to desertification (Bullock and Houeron, 1996). Desertified soils lose much of their depth and ability to store water and nutrients. The worst case scenario is where nearly all perennials are removed. Without permanent vegetation:

- insolation dessicates and oxidises the organic layer of sand surfaces so less water is held in the upper profile where most of the biological activity occurs,
- finer-textured soil surfaces, sealed and crusted by raindrop splash, are made increasingly impervious to water intake and become more prone to erosion by running water.

The result is a drier environment (Belnap, 1995; Bullock and Houreron, 1996). Thus a spiral of self perpetuating aridity is triggered and the situation may become irreversible (Belnap, 1995).

The initial study by Williams *et al.* (1980) has not been extended from the Gascoyne catchment, and the overall erosional-degradation status of the Carnarvon Basin remains unclear. Similarly, the claim of desertification must be seen in the context of the present views of the issue, and requires further study.

REGIONAL-SCALE GEOMORPHOLOGY AND SOILS

The geomorphological divisions advocated by van de Graaff (in Hocking *et al.*, 1987), and shown in Figure 7, are adopted as a basis for the present discussion. The terrestrial quadrats sampled in each division are listed in brackets. The geomorphological descriptions are supplemented by the regional soil information provided by Payne *et al.* (1987).

Bidgemia Region (Gascoyne Junction: GJ1)

These regions are well developed etchplains that have developed primarily on the fine-grained sediments of the Permian Byro Group. Duricrust remnants are rare. At the end of duricrust formation, these regions were probably already the site of the ancestral Murchison – upper Wooramel, Gascoyne and Minilya Rivers. The lateral downcutting and subsequent shifting of the river courses developed the etchplains in the Pliocene and Pleistocene. Relief varies over 30–40 m; erosional surfaces and taluvial slopes.

Rudosols and Kandosols are the dominant soils of the region. They occur on mesas, plateaux, hills and upper footslopes and upland areas. The rudusols occur in pockets, some 30 cm deep, and are surrounded by sandstone outcrop. Stony mantles and profiles are common, soil colour is red or reddish-brown and texture is sand or loamy sand. Soil surface pH varies from 6.0 to 6.5. The Kandosols have gradational soil texture profiles and are calcareous. Surface pH is about 8.

Texture contrast soils occur on stony plains, flood plains and alluvial fans. They are variable in depth. They are described as having a thin A horizon (15–40 cm deep) of sandy loam, over a clayey B horizon of light medium clay or medium clay. Soil colour is reddish-brown or dark red. These soils may be calcareous or non-calcareous with a pH from 7.5 to 8.5 or 6.5 to 8.0, respectively and trending alkaline or neutral.

Binthalya Region (Mardathuna: MR1)

These are semi-stripped etchplains with varying amounts of preserved duricrust. It is difficult to place their overall development into a convincing time context, and the question of degree of modification since the deep weathering event is open. The Binthalya region is a gently undulating area, with dense dendritic drainage and minor silcrete remnants, underlain by Windalia Radiolarite. Towards the west it consists of stony calcrete plains with a thin colluvial and alluvial cover developed over the Cretaceous Korojon Calcarenite.

Non-calcareous gradational soils dominate the broad plains of the district. Soil depth varies from 50 cm to >1 m. Soil textures are either loams over clays or sands over loams. Soil colour is dark red or dusky red. The surface pH is between 6.0 and 6.5. Calcareous gradational soils occur over limestone on lower footslopes and plains. Limestone or Windalia radiolarite clasts form surface lags, and also occur throughout the profiles. Textures are predominantly loams over clays with some sands over loams. Soil colour is either reddish-brown or red and the pH varies between 7.5 and 8.5.

Non-calcareous loams occur in stony plains and narrow drainage floors. Depth varies from 40 cm to > 1 m and textures range from loamy fine sand to silty clay loam. Gravel lags occur on the surface and clasts are found throughout the profile.

Calcareous loams occur over calcretes. They vary in depth from 10 cm to 40 cm. Soil pH is consistently about 8.5. The soil textures are either

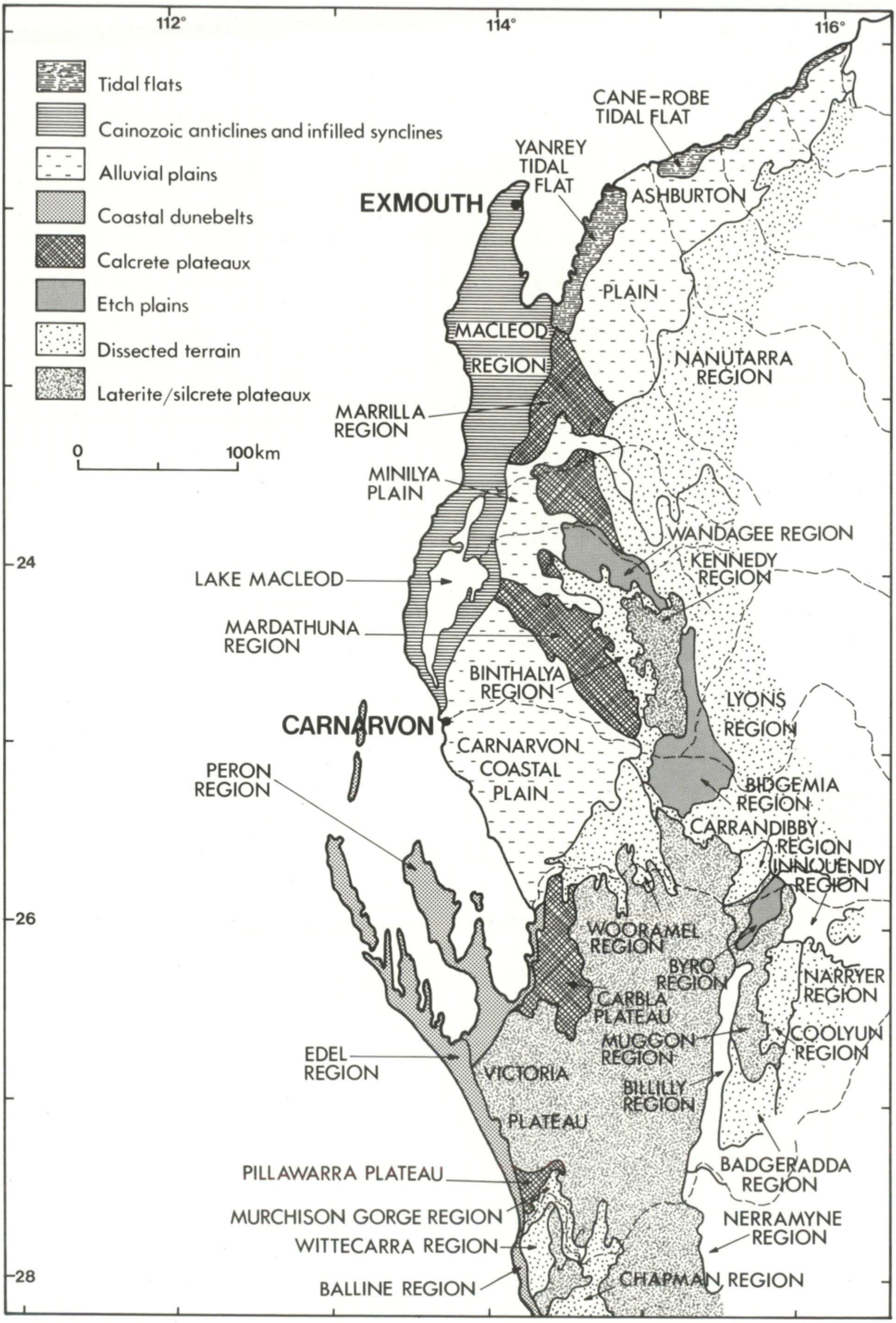

Figure 7 The geomorphological regions of the Carnarvon Basin (from Hocking *et al.*, 1987).

fine sandy loam or loam, with soil colours dark red or red.

Rudosols are restricted to the higher land units within this district, where they are associated with rock outcrops.

Carbla Plateau (Woodleigh: WO3 – WO5)

These areas are characterised by a well developed calcrete that reflects the extent of the Cretaceous Toolonga Calcilutite. Shallow, stony calcareous gradational soils are common. These are often associated with skeletal soils that may occur nearby, associated with carbonate bedrock. The gradational soils have stony limestone surfaces with profiles that contain limestone clasts. Soil depth is variable but in the range 20–100 cm. The soils are red to reddish-brown, surface pH ranges from 7.0 to 9.0 and the reaction trend is alkaline to neutral.

Carnarvon Coastal Plain (Gascoyne Junction: GJ2 – GJ5; Bush Bay: BB1 – BB5)

The Plain displays massive deposition of alluvial deposits associated with stream avulsion events and large-scale channel migration. Paleochannels are prominent elements of the geomorphology. Some of these are still occupied during extreme flood events. Extensive overbank deposition has occurred. The alluvial deposits have, in part been the source of sediments for more recently formed linear dunes. Pan development with lunette forms is evident on parts of the floodplain.

Marine units underlie the coastal margins of the alluvial deposits of the Gascoyne River. During the Quaternary the Gascoyne River built three deltas – the Brown, Boodalia and present-day deltas. The present-day Gascoyne delta is a wave dominated arid zone delta, in which the northwards longshore drift, under the influence of waves, has produced a major beach ridge complex – the Bejaling beach ridges, which barred the southern end of Lake MacLeod. During flooding of the Gascoyne River, numerous crevasse-splay flood channels that spread out from the main channel in classical fan-delta-fan shape, became active. These extend from the Brown delta in the south to Cardabia Creek in the north, and have deposited a veneer of Holocene sediments over the deltaic sequences.

The Boodalia delta is a well-preserved presently inactive, highly destructive delta with a fringe of mangrove swamps backed by saline supratidal flats. The Brown delta is largely obscured by the younger Boodalia delta, and has been affected by extensive coastal erosion. The Brown Range is probably an old beach-ridge complex associated with the Brown Delta.

On the immediate coastal margins, supratidal-flats and associated minor coastal dunes, older dune barrier complexes, with pan development in the intervening swales, extend inland from the present shoreline.

Duplex soils are widespread. Soil depth is commonly greater than 1 m and the profile consists of a thin layer (10–45 cm) of sand, loamy sand or sandy loam, over sandy clay loam or sandy clay. Soil colour is usually dark red or dusky red, but may be yellowish red or reddish brown towards the coast. The soils are predominantly calcareous, and often have calcareous gravel in the B horizon. Non-calcareous duplex soils are less common. Soil pH ranges from 6.5 to 8.5, subsoils trending neutral to alkaline. Gradational texture profile soils are also present, and have texture ranges, colours and pH values similar to the duplex soils. Both duplex and gradational soils commonly have sodic subsoils.

Deep sandy soils occur on the dunes, sandy banks and sandplains. The soils are highly porous and are either loose sand or earthy sand. The soil colour is usually red or dark red. The soils are predominantly non-calcareous, with pH ranging from 6.0 to 7.5, and less commonly 8.5.

Minor areas of deep calcareous sands occur on the coastal margins of the area. These soils attain pH values of 8.5 throughout their profile. Uniform fine textured clays occur on saline plains and alluvial plains. Soil profiles are usually more than a metre deep. Soil textures are variable ranging from silty clay, sandy clay, fine-sand clay, medium or heavy clay. Soil colour is dusky red or reddish brown, with soil pH ranging from 7.0 to 8.5.

Edel Region (Edel: EL1 – EL2; Zuytdorp: ZU1 – ZU2)

These regions are areas of considerable calcareous dune build-up, now extensively lithified - the Tamala Limestone. The terrains have little surface drainage development. In the Edel Region the dune build-up has culminated in the Zuytdorp Cliffs, which form the western boundary of the Edel region, and continue onto Dirk Hartog Island. A sizeable area of unconsolidated Holocene (Late Quaternary ?) dunes is present in parts of the region. This is the type area of the Tamala Limestone. In the Zuytdorp Cliffs the various members of the Tamala Limestone are separated by well developed paleosols. Marine members (Bibra and Dampier equivalent) are widespread on benches of dunal calcarenite (Baba Bight), but can also make up a significant part of the Tamala Limestone. An example of this is provided by Boorabugatta Well where two marine units - possible Wooramel Cliff age equivalent (see Hewgill *et al.*, 1983) – are exposed in the well shaft.

These Tamala dunes have a north-south alignment reflected in the orientation of the array of 'prongs' along the eastern side of the Edel Land Peninsula, and Dorre and Bernier Islands, indicating that Pleistocene wind directions were similar to the present day prevailing winds. The development of dunes predated the Last Interglacial but continued through into the Late

Pleistocene. Active dune fields cover most of the Bellefin Prong (26°20'S 113°20'E). In this region clear indication can be obtained of prong formation, where large transverse bedforms are confined between 'side barriers' and migrate in the direction of the prevailing wind.

The calcareous soils on the currently active dunes are pale- to reddish-brown sand over loamy sand, and have deep profiles with a pH close to 8.5. Sands with minimal development occur on coastal dunes and sandplains; they have profiles more than a metre deep and are reddish-yellow or yellow in colour. Shallow Rudosols (skeletal sandy soils) are present in pockets 10–40 cm thick. Their surface has a lag of carbonate clasts, and clasts are distributed through their sandy or loamy sand profile, and a pH of 6.0 to 7.0 with neutral trend, or of 8.5 with alkaline trend.

Kennedy Region (Kennedy Range: KE1 – KE5)

The Kennedy Region consists of the sand covered and duricrusted (extensive silcretes) Kennedy Range. The plateau edges are deeply dissected, with extensive scree/talus/colluvium development – the eastern part of the plateau margin shows 'flat-iron' forms. Isolated dunes are found to descend the western scarp. The plateau surface is covered by massive linear dunes. These dunes are some of the largest in the Carnarvon Basin, and because of their fixed location on the plateau, must have formed from a local source. In part the dunes at the plateau edges (western) form sediment sources for material transported by streams onto the Binthalya Plain.

Texture contrast soils (Sodosols and Chromosols) and shallow Leptic Rudosols occur on the eroded and deeply dissected country surrounding the sandy plateau of the Kennedy Region. The duplex soils are described as being sandy loam over medium clay, red coloured throughout the profile, and may be calcareous or non-calcareous. The Leptic Rudosols are shelly and gravelly, frequently occurring in pockets between surface rocks and with a stony mantle over the soil surface. The soils are reddish brown loamy soils with a pH of 6.0 to 6.5.

The plateau dunes and swales are all deep red sands, with pH values between 5 and 7. (Basic or Acidic, Arenic Rudosols).

MacLeod Region (Cape Cuvier: CU1 – CU6; Boolathana: BO1 – BO5)

The area has a strong morphotectonic expression, characterised by a series of variably dissected anticlinal domes separated by low-lying areas of marine and eolian/alluvial sediments. The northern part of the region is most distinctive, with a strong contrast between the geomorphology of the southern and western parts and that of the eastern part of the Exmouth Gulf. The region is dominated by Lake MacLeod, which is a large coastal playa, now isolated from the open sea. Extensive gypcrete development has occurred in the area east of Lake MacLeod, which has a long Pleistocene history and was open to the sea during the Last Interglacial. Oceanic exchange during the Holocene was more restricted and the playa was cut off from the open ocean with the development of the Bejaling Beach Ridges.

Sand plains with linear dunes occur around the margins of Lake MacLeod. Strong carbonate marine and eolian units (equivalent to the Tamala Limestone) are especially prominent along the western coastal margins, where they give rise to a cliffed coastline. Calcrete surfaces are widespread, especially around the western margin of Lake MacLeod. Former (Holocene ?) tidal flats and some associated beach ridge units are well represented along parts of the eastern margin of the lake. Calcretised Pleistocene marine units extend out from the lake margins – some of these are coral-rich.

The soils of the coastal dunes are calcareous sands with minimal profile development. The areas marginal to the lake consist of saline, calcareous or gypsiferous muds and red duplex soils with surface and sub-surface pHs greater than 8. Calcareous brownish sands make up the dune areas to the west of Lake MacLeod. Deep sandy soils are also a feature of the large sand complexes to the east of the lake.

Mardathuna Region (Mardathuna: MR2 – MR5)

These are calcrete duricrusted areas, which are extensively covered by dunes. In part, the calcrete overlies a 'billy' gravel. The calcrete is strongly developed taking both massive, laminar and pisolitic forms. A well developed dune complex dominates the region, and separates the largely erosional terrains of the east of the region from the strongly depositional terrains of the west, these being associated with the coastal and riverine settings.

Deep sands account for the vast majority of soils in this district. Soils classified as Basic Arenic Rudosols occur on the sandplains, interdunal corridors and interdunal plains (Yalbalgo, Giralia, Uaroo, Kennedy and Divide). These are earthy sands that are highly porous and have depths well in excess of 1 m. Surfaces are commonly fine sand and increasing slightly in clay content with depth. Soil colour is typically red and soil pH is predominantly neutral, ranging from 6.0 to 7.0, although on Towrana Pastoral Lease it is more acidic with a pH that varies between 5.0 and 6.0. On linear dunes these loose sands are highly porous. Soil texture is predominantly sand and occasionally loamy sand. Soil colour is dark red or dusky red. Soil surface pH varies from 6.0–7.0 and always has a neutral trend.

Peron Region (Peron: PE1 — PE5; Nanga: NA1 - NA5)

The Peron region is characterised by large undulating sandplains with strong transverse to irregular arrangement - the Peron Sandstone - overlain by the recent linear dunes, named the Nilemah Sands (Logan *et al.*, 1970). In this area the 'sands' find their best expression on the Peron Peninsular. The landscape of the peninsular is dominated by a broad and undulating topography with the red dune sands fixed by a thick cover of sclerophyllous scrub.

Many of the interdune depressions contain evaporite pans (Birrida). Most of the pans lie in closed, amphitheatre-like depressions surrounded by dunes. They are often only a hundred metres or so in width, and are usually surfaced by a hard white crust of white, fine-grained gypsum that supports a flora of halophytes. On parts of some pans, the fine-grained gypsum crust is replaced by large swallow tail crystals of gypsum.

The Nilemah Sands overlie the Bibra Formation (marine), which has now been shown to be Last Interglacial in age (Hewgill *et al.*, 1983). No further time resolution can be advanced. The Peron Sandstone is a thick unit of massive, weakly indurated, medium-grained red sand. In the upper part of the formation a strong nodular pedocalcic horizon has developed which can reach a thickness of up to 2 m. The Peron Sandstone underlies the Dampier Formation (marine) - which is known to be of Last Interglacial age (Hewgill *et al.*, 1983).

The origin of the Peron Sandstone has not been convincingly demonstrated, and there are indications that the formation may be more complex than generally recognised. There are suggestions that alluvial (?) members may be represented in the formation. There are also suggestions that in part the Peron Sandstone may be simply a partly rubefied coastal dune unit.

During the Holocene the region saw an extensive development of coquina beach ridges, composed of *Fragum erugatum* (analogous Last Interglacial ridges are also present). Tidal flats are prominent in the region.

Deep calcareous and siliceous red or brownish-red sands are associated with the Peron sandstone. These are deep, highly porous sands or loamy sands. Sands with minimal development occur on coastal dunes and sandplains. These soils have profiles more than a metre deep and are reddish-yellow or yellow in colour.

Victoria Plateau (Woodleigh: WO1 - WO2; Nerren Nerren: NE1 - NE5; Zuytdorp: ZU3 - ZU5; Meedo: MD4 - MD5)

In the Carnarvon Basin, the Victoria Plateau is a continuation of its southern counterpart, being a gently undulating sandplain, with minor dunefields underlain by deeply weathered profiles and associated ferricrete and silcrete. It appears that significant portions of the sandplain are *in situ* weathering products, being essentially fixed to a local source. Very little drainage development is present over large parts of the region.

The district is dominated by sand textured soils. Slightly coherent, earthy sands are most widespread. Soil profiles are > 1 m and textures are sand over loamy sand or, less commonly, sandy loam. Soil colours range from pale brown to dark red, and soil surface pH is commonly between 5.5 and 7.5.

Wooramel Region (Meedo: MD1 - MD3)

This area is transitional between the Victoria and Carbla Plateaux and the Carnarvon Coastal Plain. The southern part of the region is dominated by a broad paleodrainage valley associated with the Wooramel River, while the northern part is a linear dunefield underlain by laterite and silcrete with some calcrete near the margins.

In its central part the Wooramel River is set into a complex of Quaternary alluvial fills. The floodplain is extensively reworked into an arrangement of dunes/lunettes fringing pans. In its lower part the Wooramel is a wide coarse bedload stream, which through injection of siliciclastic material into Shark Bay, may have been an important control on the nature of deposition in the Shark Bay area.

Deep sandy soils occur on the dunes, sandy banks and sandplains. The soils are highly porous and are either loose sand or earthy sands. The soil colour is usually red or dark red. The soils are predominantly non-calcareous, with pH ranging from 6.0 to 7.5, and less commonly 8.5.

Duplex soils are widespread. Soil depth is commonly greater than 1 m and the profile consists of a thin layer (10–45 cm) of sand, loamy sand or sandy loam, over sandy clay loam or sandy clay. Soil colour is usually dark red or dusky red, but may be yellowish red or reddish brown towards the coast. The soils are predominantly calcareous, and often have calcareous gravel in the B horizon. Non-calcareous duplex soils are less common. Subsoils are frequently sodic. Soil pH ranges from 6.5 to 8.5, subsoils trending neutral to alkaline.

QUADRAT-SCALE GEOMORPHOLOGY AND SOILS

The wider geomorphological setting of some of the quadrat sites is illustrated through aerial photographs. However, aerial photographs of suitable quality are not available for all sites. In the soil description provided below, 'PPF' refers to Principal Profile Form - Northcote classification (see McDonald *et al.*, 1990).

Bush Bay (BB1 – BB5) – Figure 8

BB1 is a saline gradational profile with a sodic clay subsoil. The soils at BB2 and BB4 are similar deep, red, medium sands, with BB2 being strongly alkaline throughout (and very slightly calcareous), while BB4 is only slightly alkaline. BB3 is a saline duplex soil, brown sandy loam over reddish sodic and calcareous clay, while BB5 is a shelly sand with little profile development.

BB1: 25°07'33.7"S 113°49'22.3"E
Geomorphology: Flat/level alluvial plain of the paleo-Gascoyne. Some eolian reworking, with sporadic low 'dune' bedforms and isolated irregular small deflation 'mounds'.
Soil: Eutrophic Red Kandosol: thin, non-gravelly, sandy, clayey, deep. Substrate unconsolidated alluvium.
PPF: Gn2.23

BB2: 25°08'04.4"S 113°48'20.3"E
Geomorphology: Side slopes of large dune, product of reworking of large Pleistocene coastal barrier (regressive) complex which extends to the present coast.
Soil: Basic, Arenic, Rudosol: non-gravelly, sandy. Well sorted, medium-fine, red sand.
PPF: Uc5.11

BB3: 25°04'40.1"S 113° 42'35.9"E
Geomorphology: Samphire flat/interdunal corridor – element of Pleistocene barrier complex; possibly former tidal flat. Interrupted by low linear banks, with coarse sand and clasts, which may represent former cheniers.
Soil: Hypocalcic, Effervescent Red Sodosol: thick, non-gravelly, loamy, clayey, deep. Gypsum and bioclastic material present.
PPF: Dr1.63

BB4: 25°06'57.4"S 113°43'45.1"E
Geomorphology: Low (8 m) linear dune, now rubefied, part of former (Pleistocene?) coastal barrier complex. Associated with level 'plain', with veneer of bioclastic debris – which may have been a supratidal flat during the middle Holocene (?). The possible effect of tidal/storm surges is unknown.
Soil: Basic, Arenic, Rudosol: non-gravelly, sandy.
PPF: Uc1.23

BB5: 25°07'53.7"S 113°46'05.3"E
Geomorphology: Gently, landward sloping (2–3°) Holocene tidal/supra-tidal flat. This grades into a coastal barrier complex. Low chenier-forms appear to be present.
Soil: Shelly, Rudosol: non-gravelly, sandy. Skeletal carbonate coarse fragments are common across the surface (10–20%), ranging in size from 2–3 cm. The substrate is pale coloured, shelly sand that extends to at least a meter in depth. Limited profile differentiation.
PPF: Uc1.13

Boolathana (BO1 – BO5) – Figure 9

Both BO1 (saltbush plain) and BO2 (samphire plain) have saline soils with sandy surfaces over sodic calcareous clay subsoils at about 40–45 cm depth, and are underlain by shelly material at about 1 m depth. BO3, BO4 and BO5 are sandy profiles with BO5, on a sand dune, having the least pedological development, and BO3 and BO4 having slightly more development – increased colour at a depth in BO4 and some carbonate segregations at depth in BO3.

BO1: 24°24'48.6"S 113°39'47.2"E
Geomorphology: Paleo-tidal flat, essentially featureless; now susceptible to flood inundation. Microrelief consists of surface mounds 1 m apart with a vertical relief of less then 20 cm.
Soil: Hypocalcic Mesonatric, Red Sodosol: medium non-gravelly sandy, clayey, moderate. A saline water repellent soil with sandy surfaces over clay subsoils at about 40–45 cm depth. At a depth of about 1 m a very bioclastic predominantly shell bed occurs. Significant coarse sand component covering parts of the surface.
PPF: Dr1.53

BO2: 24°24'49.0"S 113°40'29.6"E
Geomorphology: Paleo-tidal flat, now susceptible to flood inundation.
Soil: Subnatric Red Sodosol: medium, non-gravelly, sandy, clayey, moderate. A saline water repellent soil with sandy surfaces over clay subsoils at about 40–45 cm in depth with a shell rich and associated nodular carbonate concretions unit at a depth of about 1 m. Abundance of bioclasts on surface.
PPF: Dr1.53

BO3: 24°24'48.6"S 113°42'23.8"E
Geomorphology: Lake margin sand complex
Soil: Calcareous, Lutic, Rudosol: non-gravelly, sandy. The soil is developed in a yellowish red, medium-fine sand. Weak, earthy, carbonate segregations at depth.
PPF: Uc5.21

BO4: 24°24'50.0"S 113°44'43.1"E
Geomorphology: Part of the lake marginal sand complex which rises in height to the east via a series of undulating rises that are 3–4 m in height.
Soil: Basic, Arenic, Rudosol: non-gravelly, sandy. Absence of carbonate segregations. Fine-medium sand; limited profile differentiation.
PPF: Uc4.32

Figure 8 General setting of the Bush Bay quadrats.

BO5: 24°24'49.3"S 113°45'48.6"E
Geomorphology: Linear dune, part of a series of gently undulating sand plains and dunes with a vertical relief of 8–10 m. Dune crest mobile, parts intensively eroded and associated depositional areas.
Soil: Basic, Arenic, Rudosol: non-gravelly, sandy. No pedological development.

Cape Cuvier (CU1–CU6) – Figure 10

In very general terms, the six quadrat sites represent few different soils. CU1 at the edge of Lake MacLeod is a very saline, calcareous, gypsiferous loamy sand over a shallow calcrete with a shallow saline groundwater table; CU2, 4 and 5 are red, usually calcareous sands over calcrete at 0.5 m or more in depth, CU3 a sand dune has very deep fine red sand which is calcareous throughout, and CU6 is a very deep shelly calcareous sand on a coastal dune.

CU1: 24°14'41.1"S 113°32'06.9"E
Location: Eastern margins of Lake MacLeod. Lower slope of red dune, spilling over a Tamala Limestone (equivalent) ridge. This dune lies within a series of moderately inclined (10–32%) rolling rises, 9–30 m in height.
Geomorphology: Western margin formed by a low (3–4 m high) ridge of fine – grained calcarenite (Tamala Limestone equivalent) with red (siliceous rich) sand dune spilling over the ridge. Colluvial; strong karst forms in the limestone; sand-rich apron overlying a calcrete that has developed in a bioclastic rich sand – abundance of bivalves with minor corals. Eastern part of the site extends out into the calcretized margins of the lake. Dense calcrete surface, fossil-rich, laminar, with dissolution characteristics. Overlies a pale mud-dominated unit that is highly fossiliferous, abundance of non-articulated bivalves. Isolated occurrences of loose, sand-bioclastic rich low ridges and mounds. Areas of sand/mud veneers over the calcrete. Water table within c. 1 m of the surface. Extensive ponding evident after rain.
Soil: Epicalcareous, Hypersalic, Hydrosol; thin, slightly gravelly, sandy, shallow. These soils are typically associated with saline playa lakes. The presence of a shallow saline ground water table is a notable characteristic of hypersalic hydrosols. No profile differentiation.
PPF: Uc5.12

CU2: 24°13'22.3"S 113°30'11.6"E
Geomorphology: The quadrat lies within a broad gentle slope of a sand plain. Level to gently undulating plain with a maximum relief of 9 m (1–3%), and a low hummocky 'dune' microrelief of c.1 m.
Soil: Petrocalcic, Leptic, Rudosol: Non-gravelly, sandy, shallow, isolated outcrops of calcrete – fossiliferous deposits. The sand has high infiltration rates with moderately deep profiles c. 1.5 m, though the soil sampling site had calcrete at 45 cm depth.
PPF: Uc5.12

CU3: 24°13'23.2"S 113°29'29.0"E
Geomorphology: The dune has steep waxing sides with a recorded slope value of 18–20° extending for approximately 30 m. The vertical height of these

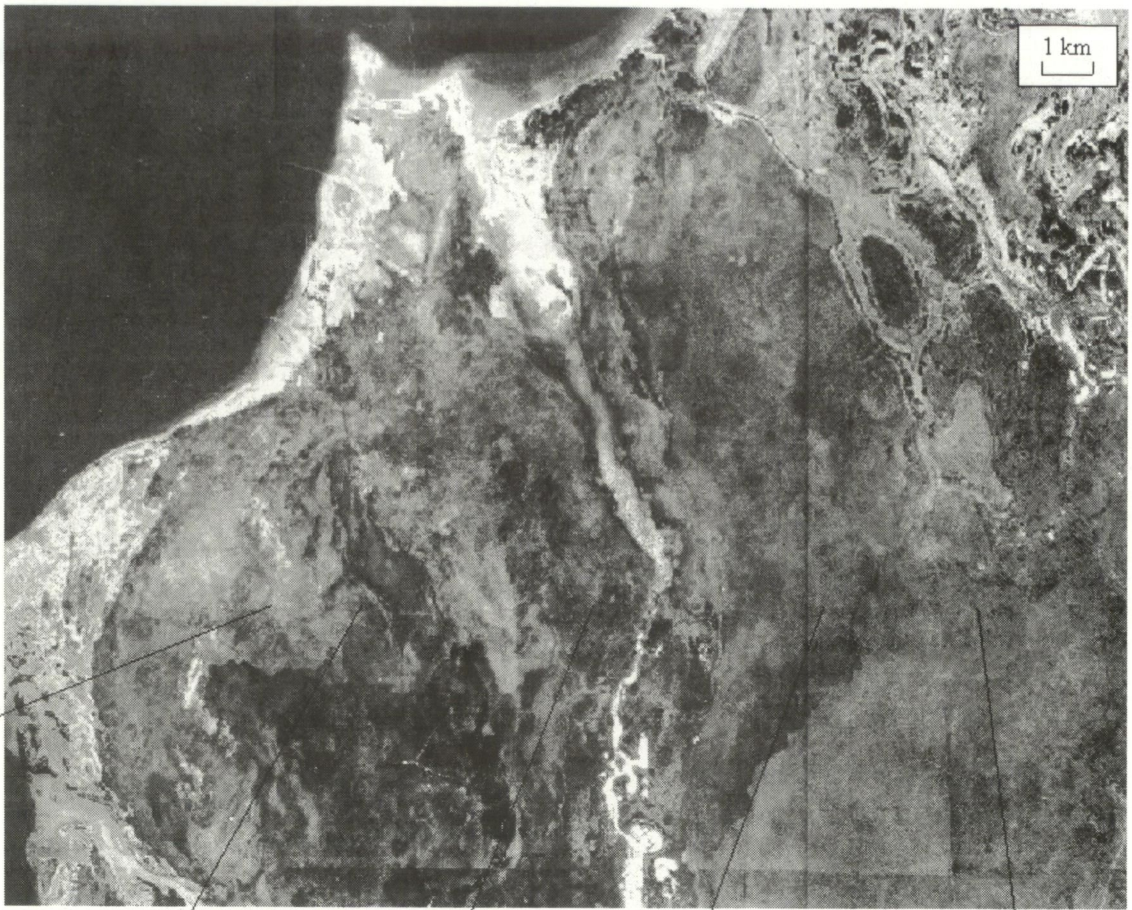

Figure 9 General setting of the Boolathana quadrats.

dunes is difficult to determine. From swale to crest there is a vertical height of approximately 30 m, however this may be controlled by the underlying surface, in which case the dune height is 10 m. The dune crest has a mound/depression pattern of microrelief with a vertical height of 2 m, indicating instability.

Soil: Calcareous, Arenic, Rudosol: non-gravelly, sandy, very deep. The profile consists of fine red sand, which is calcareous throughout, except for the surface 10 cm. A paleosol is evident at a depth of approximately 4 m and is marked by carbonate nodules.

PPF: Ucl.12

CU4: 24°13′26.8″S 113°27′41.4″E

Geomorphology: This quadrat is located within a corridor between two low ridges; eastern – linear dune; western – heavily calcretised bedrock. Areas of calcrete outcrop in the swale. The corridor is essentially flat with minor relief of 1–2 m in the corridor, which may be bedrock controlled. Sand over calcrete – possibly up to 1 m thick. Microrelief consists of minor development of hummocks that are controlled by outcrop and wind blown sand accumulations.

Soil: Peterocalcic, Leptic, Rudosol: non-gravelly, sandy, shallow. Calcareous red coloured sandy soils overly a calcrete at about 0.5 m or more in depth. Strong, laminar-nodular developed calcrete crops out in the corridor. The calcrete has developed in a well sorted medium of grained calcarenite.

PPF: Uc5.12

CU5: 24°11′35.0″S 113°27′19.0″E

Geomorphology: Linear dune, moderately defined – dune side slopes up to 8° grades into interdunal corridor. Dune overlies a strong laminar calcrete. Suggestion of paleosol horizon at depth of c. 2 m – indicated by colour change. Upper part contains loose cross-bedded sediments. Below the paleosol horizon suggestion of a plinth of reasonably consolidated sediments. This passes into a corridor and then into a linear dune east. The immediate geomorphological setting is a relict aggraded dune that is now stabilised. Minor hummocks are evidence of minor microrelief and there is some minor to moderate active wind and sheet wash erosion, although there is no presence of rills or gullies.

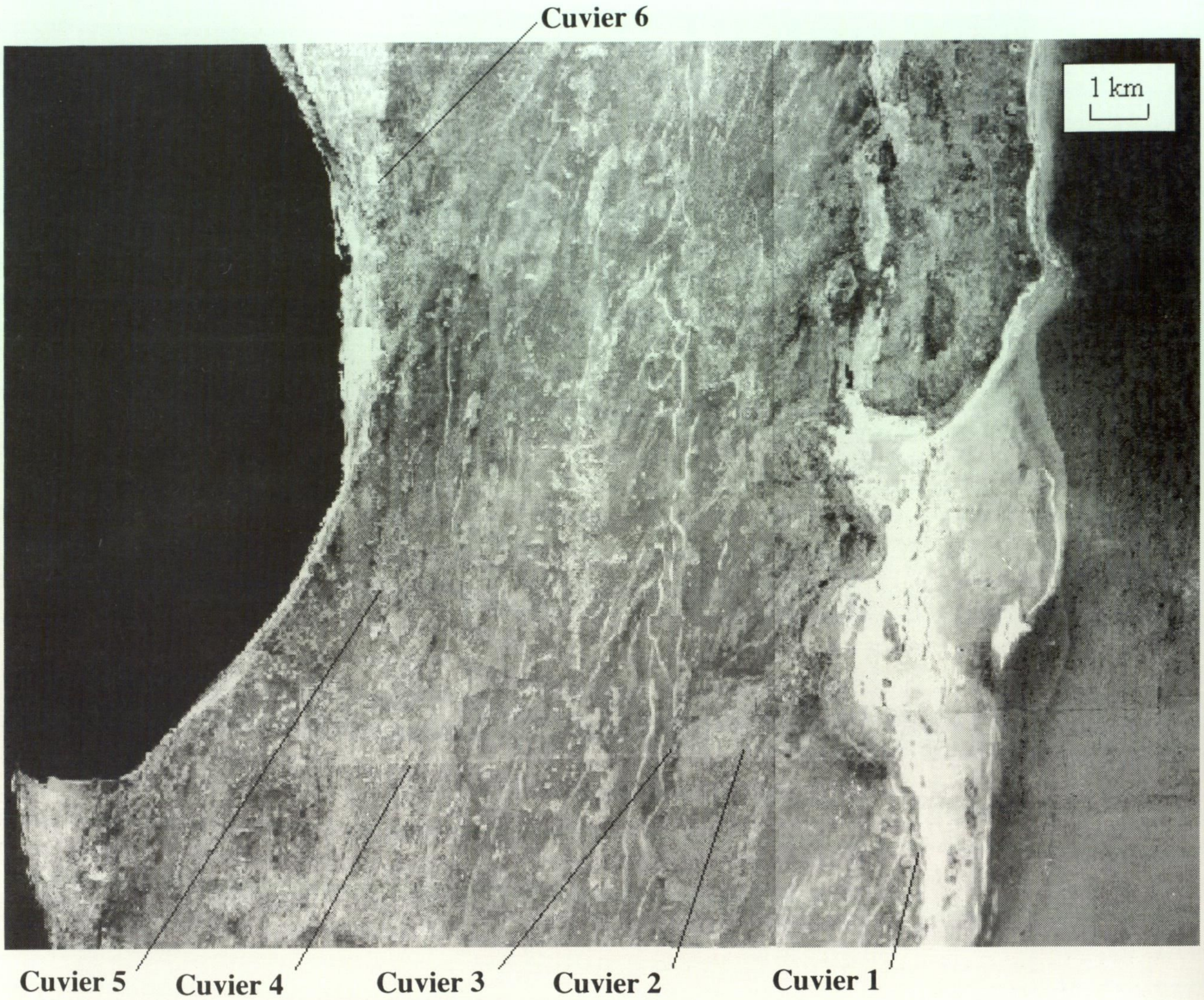

Figure 10 General setting of the Cuvier quadrats.

Soil: Petrocalcic, Leptic, Rudosol: non-gravelly, sandy, shallow. This soil is developed over a strong white laminar calcrete.
PPF: Uc5.12

CU6: 24°08'19.2"S 113°26'45.7"E
Geomorphology: Coastal dune complex. Moderate to steep dune slope with a relief of 10 m. Set within a series of small hummocky parabolic dunes with mobile lobes spilling into a swale. Prominent deflation bowl – deflation to bedrock. Prominent escarpment evident at the seaward margin. Large volumes of sand have been transported up the escarpment during the Holocene.
Soil: Shelly Rudosol. Non-gravelly, sandy. Outcrop of calcretes are prominently developed over and associated with outcrops of the Trealla Limestone (Middle Miocene). This forms the upper part and surface of the escarpment and consists of calcirudite to calcilutite.
PPF: Uc1.11

Edel Land (EL1 – EL2) – Figure 11
The soils are neutral pale coloured sands over limestone at shallow depth.

EL1: 26°31'39.4"S 113°31'36.1"E
Geomorphology: Dune side – within complex of large dunes with elevation of up to 100 m. Dune sides have an inclination of c. 10°.
Soil: Petrocalcic, Leptic, Rudosol: non gravelly, sandy, shallow. Calcarenite/calcrete coarse fragments are commonly present at the surface, varying in size from gravels to small pebbles, round.
PPF: Uc5.12

EL2: 26°31'44.4"S 113°29'56.76"E
Geomorphology: Crest of large dune – essentially level to slopes of 2° leading to middle dune slope facets that reach slopes of c.15°. Heavily vegetated, with some bare areas that are being reworked – some low mound topography with a microrelief elevation of approximately 20–30 cm.

Soil: Petrocalcic, Leptic, Rudosol: non-gravelly, sandy, shallow carbonate calcrete coarse gravels (2–6 mm) and medium pebbles (6–20 mm) common. Soil profile grades from dark-light brown sand into pale sand. There is no distinct contrast between 'A' and lower 'B', all seems very much the same. The pale base is associated with carbonate/calcrete nodules.
PPF: Uc5.12

Gascoyne Junction (GJ1 – GJ5) – Figure 12

The soils at GJ1, GJ3 and GJ5 have similar gradational texture profiles, but GJ1 and GJ5 are alkaline throughout, while GJ3 is slightly acid in reaction. GJ5 is also sodic and saline in the subsoil. GJ4 is a stony shallow red soil, mainly alkaline in reaction and sodic in the clay subsoil, while GJ2 is a deep red slightly alkaline sand profile.

GJ1: 25°12'35.6"S 115°30'51.5"E
Geomorphology: Talus covered hillslope (10–15°) with three distinct slope facets: (i) upper slope – rock slope supplying talus and sand-sized sediments; (ii) middle section – part of the slope is extensively scree covered, talus section but extensive erosion; and (iii) taluvial/colluvial and overbank deposition associated with flood events. Gully erosion is evident on the site to a depth of less than 1.5 meters.
Soil: Haplic, Red Kandosol, medium, slightly gravelly, sandy, loamy, shallow. Large clasts and bedrock rock outcrops abundant. The mid-slope is extensively scree covered, with angular, platy arenite clasts, many of which are ferricreted and silicified; also the occurrence of shale. The colluvial cover is generally thin and bedrock outcrop is evident in the midslope sections (grey/green, fine sandstone). In the lower part of the slope some outcrops of soft, silty sandstone are present, with weathering this results in sand cover. This passes into a very fine sandstone/mudstone unit yielding more clay textured soils. Some calcrete occurs, associated with limestone.
PPF: Gn2.25

GJ2: 25°10'31.4"S 115°29'18.6"E
Geomorphology: Low dune slope peripheral to an alluvial flat. Area has formed as part of an alluvial fill reworked by wind, eroded and piled into a 'hummock' topography. The area is flat, monotonous. A strong calcrete pan occurs and forms an effective aquiclude, which gives rise to ponding after heavy rain. Falls within the inundation area of high flood stage events.
Soil: Basic, Arenic, Rudosol: non-gravelly, sandy. The sand is a deflation product from the alluvial fill. Alluvial sediments are associated with the wider sites and a calcrete is present.
PPF: Uc5.12

GJ3: 25°07'10.1"S 115°25'35.9"E
Geomorphology: This alluvial plain/fill complex, eroded through wash and eolian processes. A microrelief exists of wind hummocks and wash depressions over the surface. These wind accumulated mounds/depressions have a vertical relief of ~ 1 m. Inundation in this area has a likely frequency of 1 in 10 years. Evidence of sheet wash pervasive.
Soil: Haplic, Mesotrophic, Red Kandosol: thin, non-gravelly, sandy, loamy, deep. Away from the immediate area of the quadrat extensive development of pebble pavement indicates an erosional origin/removal of fines and concentration of pebble-sized clasts. These pavements are associated with a coarse sand substrate. In other areas, more clay-texture material is present. Carbonate cemented pan outcrops at places and provides an effective barrier to infiltration.
PPF: Gn2.11

GJ4: 25°05'17.8"S 115°22'48.1"E
Geomorphology: Side of low hill, slope has an inclination of 5–8°, the surface is a boulder strewn pavement with intervening sand patches. A strongly erosional setting. Up to 90% of the slope surface is covered by pebbles/boulder clasts in part. Outcrop towards the top of the hill of well sorted fine-medium friable green sandstone. On weathering this releases the sand which occurs on the slope. A strong ferricrete has developed on the sandstone, with a massive boulder strewn land

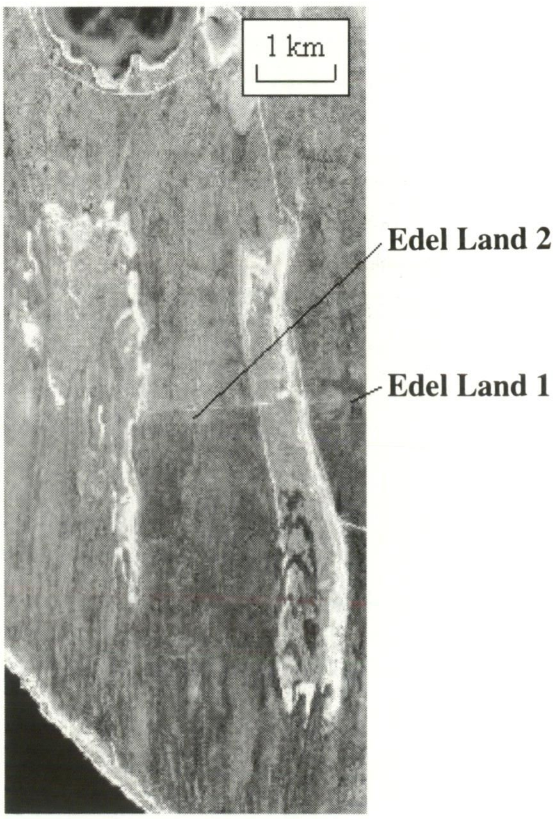

Figure 11 General setting of the Edel Land quadrats.

surface evident around this hill. A poorly sorted arenite/conglomerate, containing large 15–20 cm diameter quartz/quartzite clasts overlies the sandstone. The clasts are released on weathering and this has resulted in the clast pavements.
Soil: Eutrophic, Mesonetric, Red Sodosol: thin, slightly gravelly, sandy, clayey, moderate. Coarse fragments are very abundant over the surface ranging in size from gravels (2 mm) through to boulders (1–2 m). A diversity of lithologies such as ferricretes, quartz sandstone, quartz arenite. Areas of rock outcrops prominent.
PPF: Dr4.13

GJ5: 25°03'18.4"S 115°17'38.4"E
Geomorphology: Level, monotonous alluvial plain/fill complex. Extensively, reworked/eroded by wind, surface wash processes and large overbank flood events which has arranged the surface into mounds (vertical relief = 1 m). The area is susceptible to surface water ponding – pan development.
Soil: Eutrophic Red Kandosol: thin, non-gravelly, sandy, loamy, deep. Red, fine-medium sand. A coarse sand substrate, with strong pedogenic imprint – blocky ped forms, soft carbonate segregations.
PPF: Gn2.13

Kennedy Range (KE1 – KE5) – Figure 13

The red, deep medium sands of KE1, KE2, and KE5 are very similar; KE3 has a stony surface over a brown coloured profile of sandy loam over a shallow well structured saline and sodic clay, while KE4 is a shallow stony loamy sand over weathering rock.

KE1: 24°29'35.7"S 115°01'51.3"E
Geomorphology: Crest of a linear dune located within a dune field of large linear dunes with heights of up to 30 m. The dune sides are moderately to steeply inclined and grade into a well defined, wide interdunal corridor. The dune crest has significant vertical microrelief with deflation hollows and reworked mounds that give an elevation difference of as much as 3 m.
Soil: Basic, Arenic, Rudosol: non-gravelly, sandy. Developed in fine-medium textured sands.
PPF: Uc5.21

KE2: 24°30'04.3"S 115°01'03.4"E
Geomorphology: Broad interdunal corridor with slight hummock topography associated with spinifex stands extending over a very low level to moderately inclined slope.
Soil: Basic, Arenic, Rudosol: non-gravelly, sandy. Substrate material is not exposed at the sample site but nearby these are of a friable, grey, weathered sandstone associated with ferricrete pisolites and silcrete.
PPF: Uc5.21

KE3: 24°31'23.2"S 114°57'55.5"E
Geomorphology: Taluvial slope grades downslope into a colluvial apron. This moderate to steep waxing talus-covered slope has a vertical relief of 70–100 m, and is one of a series of steep hillslope/escarpment margins that define the region. A slope catena exists with a flat crest; an upper slope of 8–10°; a middle slope of 20–30° which is frequent on outcrops and near vertical steps; and a lower slope which is gently inclined with low slopes of 2–4°

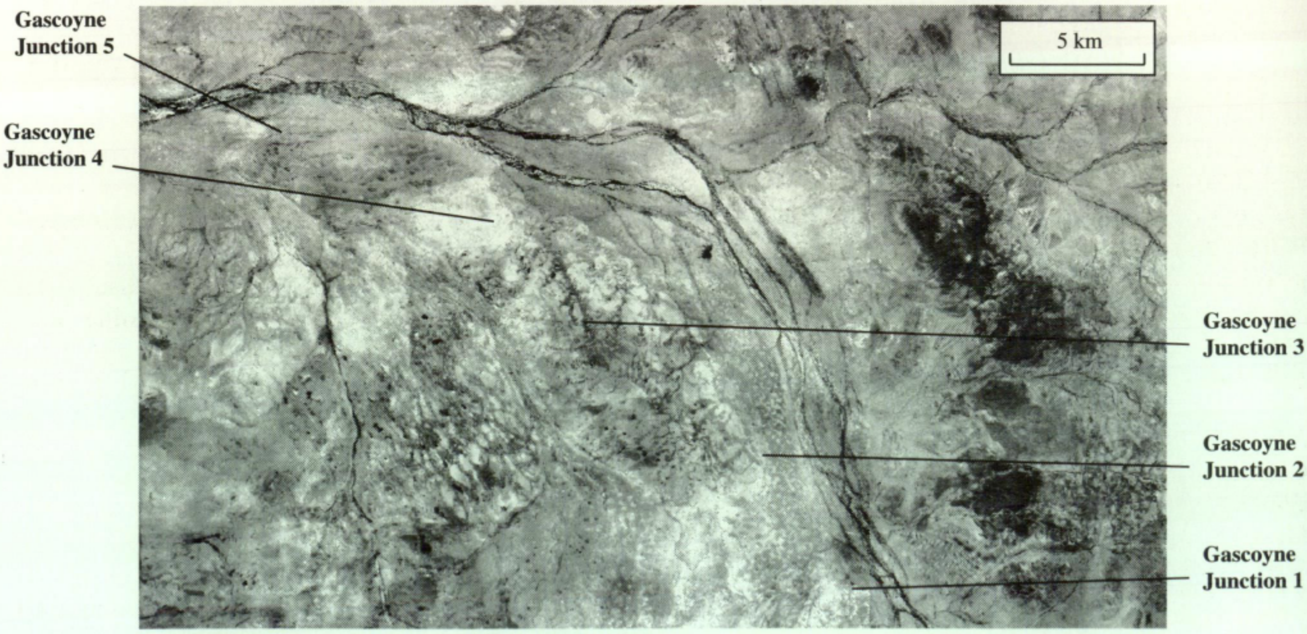

Figure 12 General setting of the Gascoyne Junction quadrats.

leading to a stream channel. Unstable – severe erosion. Geologically the slope constitutes a staircase arrangement, reflecting the outcropping of different lithologies. The lower slope contains sandstone units, followed by partly silicified, soft siltstone/mudstone units in the middle to upper slopes (these yield small platy fragments approximately 4–6 cm and less, while the arenites yield the small and larger boulder sized material). Sandstone, ferricrete, and silcrete talus clasts mantle the upper part of the slope. The top of the escarpment contains friable ferruginised sandstones that are also silicified. A clear breakaway/free face forms the upper part of the slope. The alternation in lithologies gives the slope this stepped appearance. The presence of nodular silcrete is characteristic of this site.
Soil: Pedaric, Brown Sodosol: thin moderately gravelly, loamy, clayey, deep. Coarse fragments are extremely abundant on the middle and upper slopes (> 90%) and only common on the lower foot slopes (2–20%). The size of these coarse fragments is variable, from coarse gravelly large pebbles (20–60 mm) to large boulders (> 2 m). A variety of lithologies including arenite, silcrete, ferricrete, fine siltstone and mudstone (porcellenite). On the alluvial footslopes there is largely no bedrock exposed.
PPF: Dy4.12

KE4: 24°33'04.6"S 114°57'31.5"E
Geomorphology: General setting of hillslopes undergoing sheet and minor channelled erosion stream flow. The quadrat lies within an area that has probably been infilled by sediments from the adjacent upland areas. Erosional and alluvial stream channel development is evident, with a slowly migrating shallow channel form. Active erosion is evident on the surface by the presence of rills and gullies. These gullies vary in depth from less than 1.5 m to greater than 3 m.
Soil: Paralithic, Leptic, Rudosol: moderately gravelly, sandy, shallow. The abundance of coarse fragments on the surface is variable from common (10–20%) to very abundant (50–90%), and these range in size from 2 mm – 60 cm. Dominant lithology of coarse fragments, silcrete and porcellenite. Associated with this porcellenite/silcrete veneer is a substrate of sand/clay textured material.
PPF: Uc5.21

KE5: 24°34'12.9"S 114°57'11.7"E
Geomorphology: Localised sand 'plain' possibly direct weathering product of underlying arenite or localised aggradation.
Soil: Acidic, Arenic, Rudosol: non-gravelly sandy. Absence of coarse fragments or outcrop. Limited profile differentiation.
PPF: Uc5.21

Meedo: (MD1 – MD5) – Figure 14

The soils at MD1A, MD4 and MD5 are physically very similar being deep red sands; MD5 is strongly acidic, while the other two are slightly alkaline. MD1B and MD2 are red coloured duplex soils with sodic and saline clay subsoils. MD3 is a river terrace deposit of mixed sand, grit and gravel, brown in colour and alkaline in reaction.

MD1: 25°37'30.8"S 114°42'15.6"E

Comprises a lunette (MD1A) surrounding a pan (MD1B). These landforms have developed on a Pleistocene alluvial terrace.
Geomorphology: MD1A — crest of low, sand lunette. The dune has a vertical relief of c. 6 m with level to moderately inclined slopes (up to 15°). Mound/depression microrelief of 1 meter exists on the dune crest. The crests of these dunes are eroded and mobile, with a vegetation cover of only 50%. Broad gullies occur on the sides of the lunette, particularly noticeable on the foot of the dunes where minor rilling and sheet wash have taken place. Where an underlying clay-rich unit is close to the surface, this can become very marked, with wide erosion embayments, erosion steps, rills and minor gullies. MD1B — clay-pan ringed by a lunette. The pans have formed as a result of overbank flow, exploiting initial 'depressions' on the alluvial terrace, which are subsequently enhanced by deflation processes. The pans are relatively impervious and readily pond water.
Soil: MD1A — Basic, Arenic, Rudosol: non-gravelly, sandy. Fine-medium, well sorted sand. A clay-rich unit is evident towards the base of the dunes. Coarse sands are prominent at the base of the dunes. MD1B — Mesotrophic, Submatric Red Sodosol: thin, non-gravelly, sandy, clayey, deep. A pervasive organic mat cover. Surface lag of small pebble material 2–4 cm, generally < 2 cm covering about 5–10% of surface. Duplex soil: sand over shallow red clay.
PPF: MD1A — Uc1.22; MD1B — Dr4.52

MD2: 25°37'22.6"S 114°41'39.4"E
Geomorphology: The side of a sand lunette associated with a large clay-pan – bowl structure. Significant runoff and erosion from dune slope, also wind erosion. Extensive erosion, rills, small gullies and sheet wash erosion on the pan. Essentially no infiltration into the areas at the margin of the pan. Very high runoff due to compact 'sealed' nature of the surface materials of the pan and the presence of an organic mat that is water repellent. When the mat is disturbed erosion takes place to the level of the indurated surface.
Soil: (Footslope of lunette next to claypan) Mesotrophic Subnatric Red Sodosol: medium, non-gravelly, sandy, clayey, deep. Pan developed in a coarse sand, bedload, alluvial sediments and

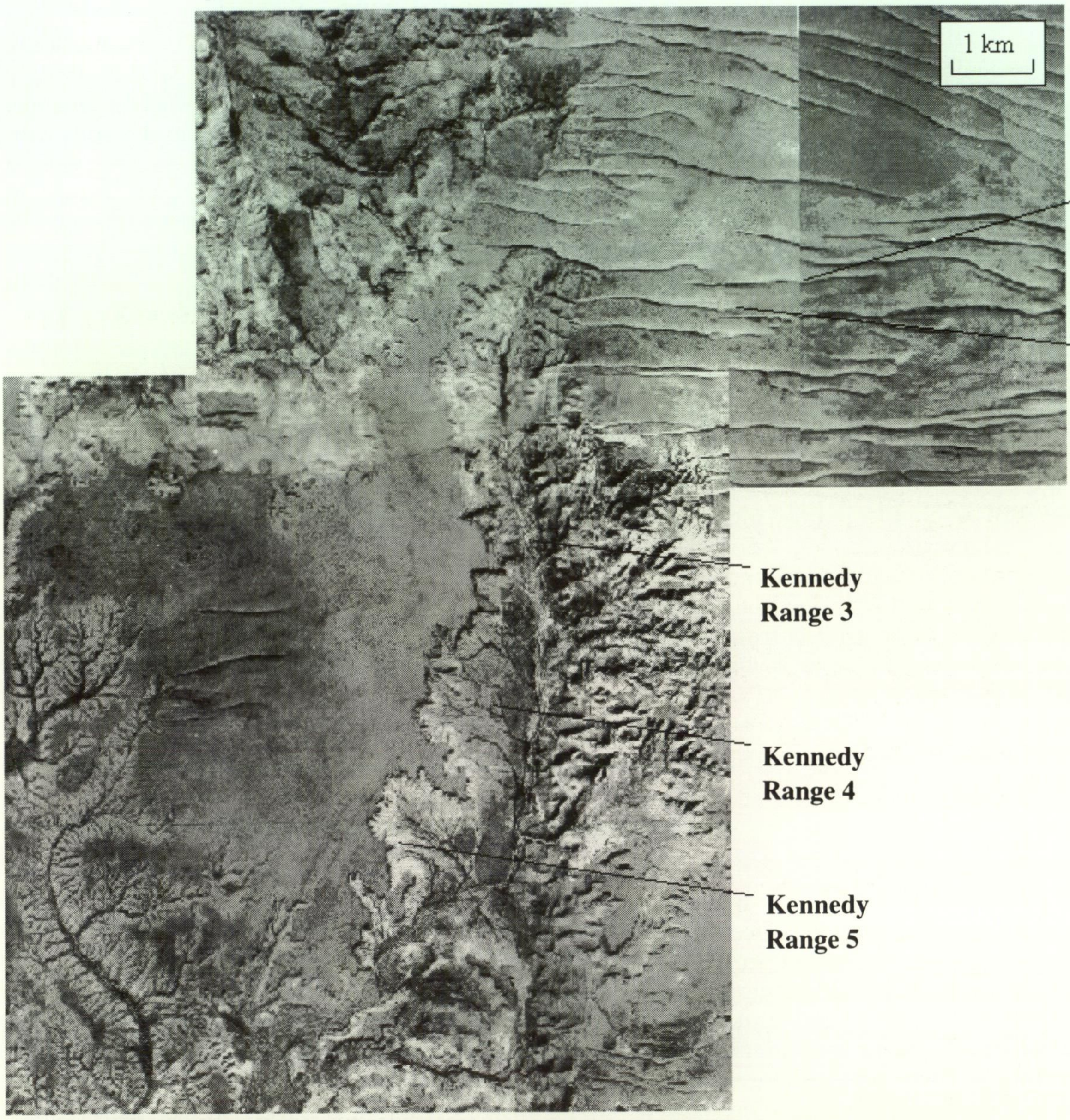

Figure 13 General setting of the Kennedy Range quadrats.

associated finer textured sediments. Strongly indurated material. Duplex soil: sand over shallow red clay.
PPF: Dr4.53

MD3: 25°39'14.4"S 114°37'33.1"E
Geomorphology: Inset alluvial fill/ active floodplain of the Wooramel River. Adjacent to a level coarse bedload channel with low bedforms. The floodplain is frequently inundated, with elongated mounds of linear vegetation linked closely to bar accumulations, and the incidence of minor scour channels controlled by vegetation. Some gullies are dissected/incised into the fill, partly the result from channelled runoff from a bounding Pleistocene alluvial fill. Vegetation bars have given rise to a very irregular topography on the flood plain. Flow velocity across the flood plain estimated as being very high as evident from the transport of large tree branches. Lateral accretion bars are also present. High rates of floodplain deposition are evident from burial of trees. The floodplain is experiencing an active state of gully and stream bank erosion which is severe on the older, higher alluvial fill. Inundation of quadrat site is predicted as having a frequency of 1 in 2 to 5 years (which should equal the general frequency of bankfull events). Potential for very high flow velocities.
Soil: Basic, Stratic, Rudosol: non-gravelly, sandy. Fine-textured alluvial fill, fine sand but with patches of coarse even – medium textured sand accumulations.
PPF: Uc1.22

MD4: 25°40'50.1"S 114°37'18.5"E
Geomorphology: Flat, monotonous sandplain

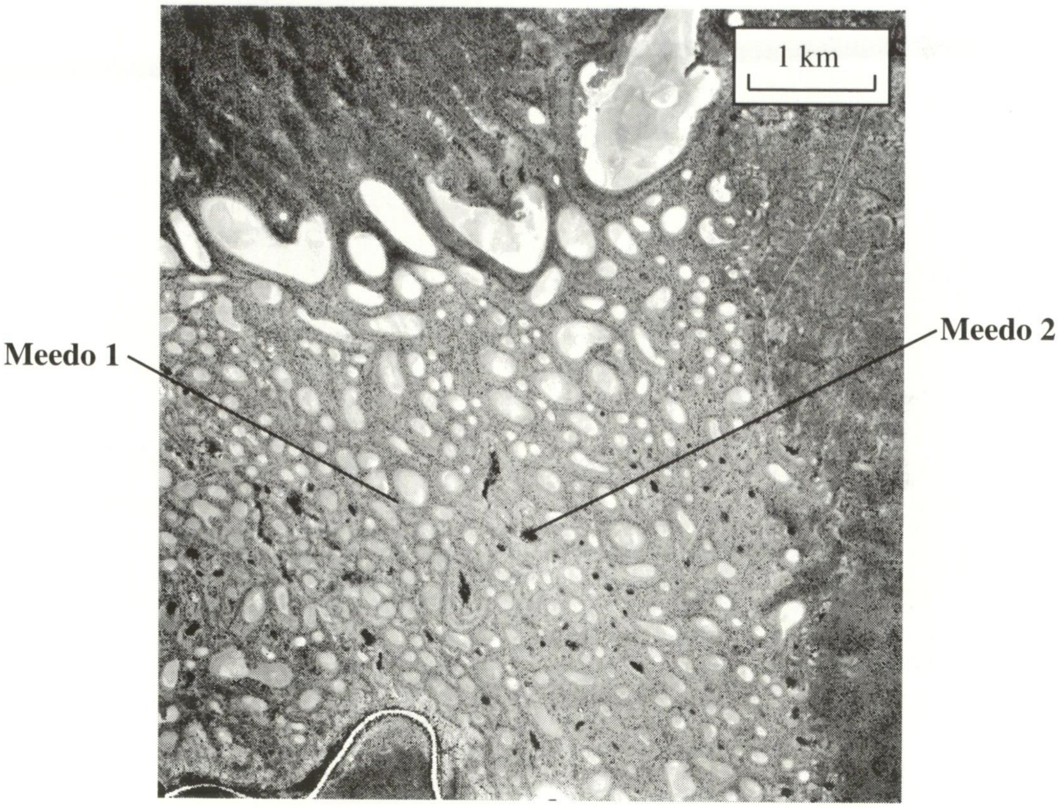

Figure 14 General setting of the Meedo (1 and 2) quadrats.

associated with linear dunes. Minor wind erosion.
Soil: Basic, Arenic, Rudosol: non-gravelly, sandy. The sand is medium sand.
PPF: Uc5.12

MD5: 25°42'39.7"S 114°35'59.3"E
Geomorphology: Flat, monotonous sandplain overall vertical relief c. 1 m. Minor wind erosion.
Soil: Acidic, Arenic, Rudosol: non-gravelly, sandy, medium sand.
PPF: Uc5.21

Mardathuna (MR1 – MR5)

Two soils are described within MR1, both over calcrete; its eastern side has a thin layer of sand over calcrete, while the western part has a gradational profile with a sodic subsoil. The soils of MR2 – MR5 are all very similar, having deep red fine sand profiles.

MR1: 24°30'40.9"S 114°38'12.6"E
Geomorphology: Gently undulating to rolling calcrete terrain – isolated calcrete ridge forms with height of c. 2 m. Some soil cover/development in parts of the quadrat. Moderate erosion status – surface is essentially impervious in parts.
Soil: (1) East end of quadrat: Petrocalcic, Leptic Rudosol: gravelly, sandy, very shallow. The soil profile attains depths of c. 20 cm. Moderate strong calcrete development (status of 'crystalline limestone' in some outcrops) with associated minor karst forms. (2) West end of quadrat: Hypocalcic Subnatric Red Sodosol: medium, non-gravelly, sandy, clay loamy substrate. Profile attains a depth of c. 55 cm. Overlies calcrete. Surface calcrete absent.
PPF: (1) Uc5.12; (2) Gc1.22

MR2: 24°26'35.9"S 114°30'43.4"E
Geomorphology: Open, level depression set in an interdunal corridor between linear dunes. Stable surface.
Soil: Basic, Arenic, Rudosol: non gravelly, sandy. Limited profile differentiation.
PPF: Uc5.21

MR3: 24°25'43.5"S 114°29'59.5"E
Geomorphology: Associated with the crest of a linear dune within a series of rolling dunes with a relief of c. 10 m. Area has been the site of a recent large fire. Strong wind erosion, as evidenced by hummock/ depression microrelief. Overall dune-scale bedform is stable. The microrelief attains 1–2 m. Irregular surface on the crest that is extensively reworked – deflation in parts of approximately 4 m on a 10 m dune. Severe wind erosion is active.
Soil: Basic, Arenic, Rudosol: non-gravelly, sandy. Limited profile development.
PPF: Uc1.23

MR4: 24°24'25.7"S 114°28'23.8"E
Geomorphology: Low mound within a sand plain. Gentle slopes of 1–2° occur to the north and west of the site.
Soil: Basic, Arenic, Rudosol: non-gravelly, sandy. Some clasts evident – small Kt pebbles are present.
PPF: Uc5.21

MR5: 24°24'20.5"S 114°26'40.3"E
Geomorphology: Level sandplain and associated low linear dune – giving an 'open depression to linear dune'. Minor wind erosion on the sand plain but dune crest is unstable. Partly dissipated dune topography.
Soil: Basic, Arenic, Rudosol: non-gravelly, sandy. Some Kt pebbles evident.
PPF: Uc5.21

Nanga (NA1 – NA5) – Figure 15
The soil at NA1 is a deep sandy material, brown to red in colour, calcareous and saline throughout and gypsiferous at depth. NA2 – NA5 all have deep red alkaline sands.

NA1: 26°28'40.1"S 114°04'33.6"E
Geomorphology: Forms part of a beach/ridge chenier plain extending east from the base of a Peron ridge. Undulating with closely spaced ridges, sand-textured sediments, and intervening swales which are gypsiferous, with a polygonal structured, collapsing surface. The elevation difference between the swales and the ridges is about 1.5–2 m. Poorly drained, high water table.
Soil: Calcareous, Lutic, Rudosol: non-gravelly, sandy. Extensive scatter/pavement of molluscs over the surface. Calcrete clasts present. Sections show a lower green clay unit containing molluscs overlain by a rubefied, more sandy textured unit. The upper unit displays pedological differentiation. In a section through one ridge-form, there is a concentration of calcrete nodules and calcrete coated shells, tightly bound/partly cemented to a depth of approximately 40 cm.
PPF: Uc1.13

NA2: 26°29'23.1"S 114°03'20.9"E
Geomorphology: Large, undulating, 'dune-form' (Peron Sandstone) terrains – with a relief of 60–100 m. The site is located towards the upper sections of a 'dune'.
Soil: Basic, Arenic, Rudosol: non-gravelly, sandy. Well sorted, medium-fine sand.
PPF: Uc1.23

NA3: 26°31'21.3"S 114°00'08.6"E
Geomorphology: In a large depression set in the undulating, 'dune-form' (Peron Sandstone) terrains. Waxing slopes are gentle to moderately inclined with a relief of 30–40 m.
Soil: Basic, Arenic, Rudosol: non-gravelly, sandy. Well sorted, medium-fine sand.
PPF: Uc1.23

NA4: 26°32'46.6"S 113°57'48.7"E
Geomorphology: A series of low, gently undulating rises/'linear bedform-like' (?) poorly defined forms. Overall vertical relief of the order of 20m, with slopes of 2–4°. Site is located on a slope.
Soil: Basic, Arenic, Rudosol: non-gravelly, sandy. Well sorted, medium-fine sand.
PPF: Uc1.23

NA5: 26°35'33.7"S 113°53'22.6"E
Geomorphology: Interdunal corridor within low undulating dune topography, which has a vertical relief of approximately 20 m. Very gentle to gently inclined waxing slopes of 3–5°, leading in to the interdunal corridor.
Soil: Basic, Arenic, Rudosol: non-gravelly, sandy. Well sorted, medium – fine sand.
PPF: Uc1.23

Nerren Nerren (NE1 – NE5)
The soils at all five quadrats are very similar, being deep reddish coloured sand profiles, usually strongly acid in reaction (i.e. pH < 5.5, 1:5 soil water suspension).

NE1: 27°02'49.6"S 114°34'23.3"E
Geomorphology: Sandplain associated with a dune field. Area has a slight, gently undulating slope to the south and a more level slope going to the west, with an overall vertical relief of 10–15 meters. Minor surface modifications producing a microrelief of accumulations of approximately 20 cm, indicative of eolian reworking.
Soil: Acidic, Arenic, Rudosol: non-gravelly, sandy. Medium-fine grained, well sorted sand. Limited profile differentiation.
PPF: Uc5.21

NE2: 27°03'23.9"S 114°35'21.0"E
Geomorphology: Dissipative/ill-defined dune form/ undulating sandplain with a vertical relief of 10–15 m and slopes of ~ 3°. Minor eolian reworking of surface.
Soil: Acidic, Arenic, Rudosol: non-gravelly, sandy.
PPF: Uc5.21

NE3: 27°07'23.7"S 114°46'40.8"E
Geomorphology: Undulating sandplain with an overall relief of 20 m (from NE1 to NE5). The changes in relief occur via a series of undulating rises.
Soil: Basic, Arenic, Rudosol: non-gravelly, sandy.
PPF: Uc5.21

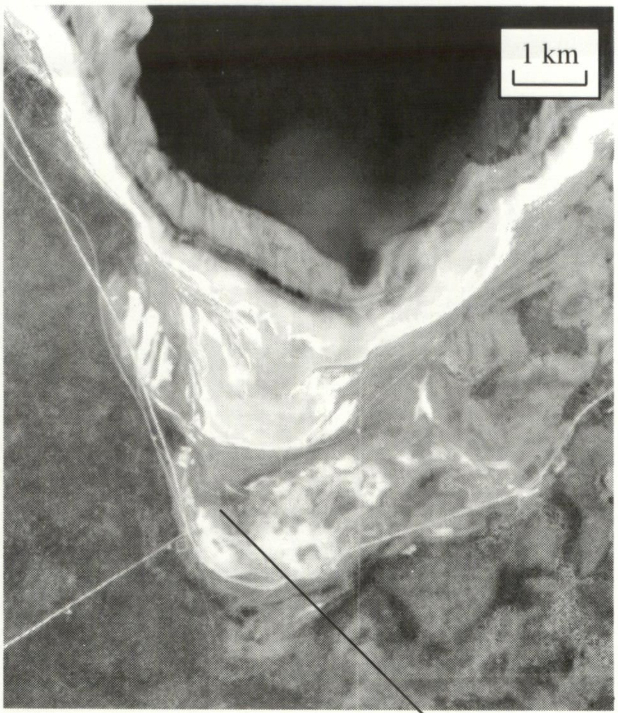

Figure 15 General setting of Nanga 1 quadrat.

NE4: 27°07'22.1"S 114°47'57.5"E
Geomorphology: Undulating sandplain with an overall relief of 20 m.
Soil: Acidic, Arenic, Rudosol: non-gravelly, sandy.
PPF: Uc4.22

NE5: 27°07'21.3"S 114°49'04.8"E
Geomorphology: Undulating sandplain with an overall relief of 20 m.
Soil: Acidic, Arenic, Rudosol: non-gravelly, sandy.
PPF: Uc5.21

Peron (PE1–PE5) – Figure 16

The bed of mixed salt crystals over coarse sand at PE1 is not a soil. The soils at PE2–PE5 inclusive are all red coloured deep sands; PE2, PE3 and PE5 are highly calcareous whereas PE4 is only slightly alkaline in reaction.

PE1: 25°52'53.6"S 113°32'42.6"E
Geomorphology: Large, elevated evaporite pan – birrida. Moat form with a central elevated area rising to a height of c. 1.5 m above the outer edge. Some large collapse/solution-like small doline-like structures, 1 m in diameter and smaller, which are especially prominent around the edges of the rim. Rills present around the edges function to erode the edge of the birrida, causing collapse along the margins.
Soil: Soil classification not appropriate: Surfaces of gypsiferous sediments, with raised crust and loose sand cover. A weak pale (carbonate ?) crust is also evident around the moat. A sticky clay soft surface is evident along the margins. Abundance of organic mats. No soil development. Upper 10 cm of loose gypsum-sand. The crust is indurated with larger gypsum crystals, 3 mm in length and strongly interlocked.

PE2: 25°52'31.1"S 113°33'01.3"E
Geomorphology: Undulating, (Peron Sandstone) sandplain terrains – with a relief of 30–40 m. Middle and lower reaches of a slope facing south – slope angles of c. 4–5°.
Soil: Calcareous, Arenic, Rudosol: non-gravelly, sandy. Medium-fine sand. Fine, gravelly, subrounded to rounded calcrete nodules. Gastropod shells abundant. The substrate contains shell fragments and is highly calcareous.
PPF: Uc5.21

PE3: 25°49'14.2"S 113°32'21.5"E
Geomorphology: Large, undulating, 'dune-form' (Peron Sandstone) terrains – with a relief of 50–60 m. The area is relatively flat with the quadrat sloping 1–3° towards the west. To the east of 10° is a steep slope that passes into a swale.
Soil: Calcareous, Arenic, Rudosol: non-gravelly, sandy. Medium-fine sand. Isolated gastropod shells present.
PPF: Uc5.21

PE4: 25°50'20.0"S 113°36'23.1"E
Geomorphology: Undulating sandplain – Peron Sandstone terrains. Towards the top of a hill (relief of 30–40 m) with low slopes towards the south and west of the order of 1–2°.
Soil: Basic, Arenic, Rudosol: non-gravelly, sandy. Medium-fine sand. Some small calcrete nodules generally less then 3 mm in size, some 5–10 mm, and gastropod shell material is present.
PPF: Uc5.21

PE5: 25°58'33.4"S 113°34'15.8"E
Geomorphology: Mid – slope of the east face of a gentle to moderately inclined dune: height 20–30 m, slope of 7°–8°, steeper in the upper part to 10°.
Soil: Calcareous, Arenic, Rudosol: non-gravelly, sandy. Medium-fine sand. Some calcrete nodules and gastropod shells and other shell debris.
PPF: Uc1.13

Woodleigh (WO3–WO5)

The soils at WO1 and WO2 are both deep red coloured sandy profiles, strongly acid in reaction below 10 cm depth. WO3 and WO4 are shallow red sandy soils over limestone/calcrete, with WO3 being only slightly alkaline in reaction, and WO4 very alkaline and calcareous throughout. The soil at WO5 is a red duplex soil of sand over clay subsoil which is alkaline, calcareous, saline and sodic.

WO1: 26°13'02.7"S 114°35'56.7"E
Geomorphology: Level to very gently inclined (2°–3°) sandplain in a broad, gently undulating terrain.
Soil: Basic, Arenic, Rudosol: non-gravelly, sandy. Sand over calcrete. The sand cover may have a thickness of approximately 1 m, but this is variable. The calcrete is strongly developed, contains crystalline 'segregations' with enclosed red sand grains – showing a genetic association with the sand.
PPF: Uc5.21

WO2: 26°12'30.8"S 114°34'35.0"E
Geomorphology: Sandplain, on a westward facing slope with an inclination of 2°–3° and a relief of 30–40 m.
Soil: Acidic, Arenic, Rudosol: non-gravelly, sandy. Sand over calcrete. The sand cover may have a thickness of approximately 1 m, but this is variable. The calcrete is strongly developed, contains crystalline 'segregations' with enclosed red sand grains – showing a genetic association with the sand.
PPF: Uc5.21

WO3: 26°11'46.4"S 114°32'15.6"E
Geomorphology: A level, slightly undulating, 'bench' upland surface, relief up to c. 5 m, sand with outcrops of calcrete.
Soil: Petrocalcic, Leptic, Rudosol; non-gravelly, sandy, shallow. Surface consists of a sand cover of varying depth (from a few 10 cm to 1 m) overlying a calcrete (nodular, but also massive with sandy fabric) developed on a limestone.
PPF: Uc5.12

WO4: 26°11'29.8"S 114°30'33.9"E
Geomorphology: Essentially level to slightly undulating (irregular) calcrete surface, with patches of pale sand – vertical relief of c. 20 cm.
Soil: Petrocalcic, Leptic, Rudosol: gravelly, sandy, shallow. Calcrete abundant. Sand, pale and finer.
PPF: Uc5.12

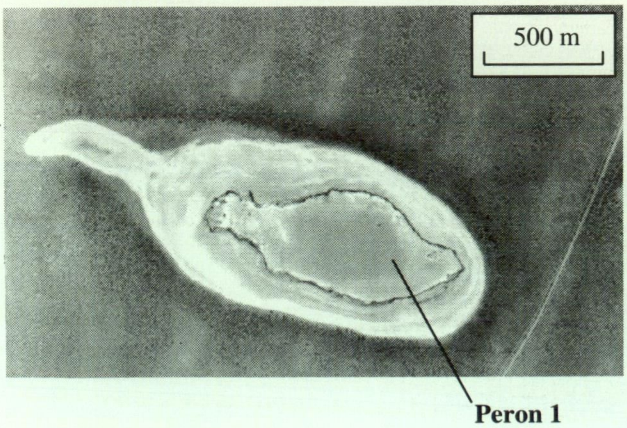

Figure 16 General setting of the Peron quadrat.

WO5: 26°11'44.2"S 114°25'24.1"E
Geomorphology: Level sandplain – relief variation c. 3 m.
Soil: Sodic, Mesotrophic, Red Chromosol, thin, non-gravelly, sandy, clayey, moderate. Sand can be quite coarse. Isolated outcrops of calcrete in wider area.
PPF: Dr4.63

Zuytdorp (ZU1–ZU5) – Figure 17

The soil at ZU1 is a neutral yellow sand, shallow onto limestone. Although limestone outcrops very commonly at ZU1 and quite frequently at ZU2, both soils are not calcareous. The soils at ZU2 – ZU5 inclusive are all deep sands, slightly acid to neutral in reaction. ZU3 is a red sand profile, while the other three sites are yellow sands.

ZU1: 27°15'42.0"S 114°01'08.7"E
Geomorphology: Tamala Limestone waxing slope facing east with an inclination of 3°– 4°, relief of c. 30 m. Surface mound sand patches, in places, microrelief of 10–30 cm. Low hummocky micro-relief also due to underlying calcrete. Limited infiltration capacity and some evidence of wash processes. Calcrete surface (c. 20–30 % cover) with strong karst dissolution features, developed on a calcarenite of the Tamala Limestone Formation. Overlain in pockets by yellow sand (10–20 cm deep).
Soil: Petrocalcic, Leptic, Rudosol: non-gravelly, sandy, shallow. The surface of the quadrat consists of a very strong calcrete, with strong karst dissolution features, developed on the calcarenite of the Tamala Limestone formation. This strong calcrete is overlain in pockets by yellow sand (10–20 cm deep). Calcrete outcrop is widespread within the quadrat at 20–30% cover, as are coarse fragments/clasts (calcrete) ranging in size from < 1 cm to > 30 cm.
PPF: Uc.5.12

ZU2: 27°15'41.1"S 114°01'47.5"E
Geomorphology: Colluvial infilled (sand), bedrock bench, in Tamala Limestone dune terrains – with level to gently inclined slopes. High runoff. Minor hummocks with a microrelief of 5 cm are present over the surface.
Soil: Basic, Arenic, Rudosol: non-gravelly, sandy. Associated with calcretes over calcarenites.
PPF: Uc.5.12

ZU3: 27°15'34.3"S 114°04'02.5"E
Geomorphology: West facing slope with an inclination of 3°–5°, at the eastern edge of the Tamala Limestone terrains. Slope undulations bedrock controlled.
Soil: Basic, Arenic, Rudosol: non-gravelly, sandy. Sand cover over bedrock. Calcrete over Tamala

Limestone calcarenite associated with yellow sand. A strong ferricrete developed in a coarse medium sand outcrops in the upper and middle sections of the slope. Ferricrete, nodular, strongly cemented, pisolites and coarse red sands associated with outcrop.
PPF: Uc.5.11

ZU4: 27°15'28.2"S 114°09'01.8"E
Geomorphology: Sandplain with dunes. Site lies in a depression between two dunes, which have a height of c. 10 m.
Soil: Basic, Arenic, Rudosol: non-gravelly, sandy. The sands are yellow in colour.
PPF: Uc.5.11

ZU5: 27°15'25.3"S 114°11'15.9"E
Geomorphology: Sandplain with low dunes (c. 10 m), with the site located on a low dune.
Soil: Siliceous, Arenic, Rudosol: non-gravelly, shallow – yellow sand.
PPF Uc.5.11

SURFACE STABILITY

Given the nature of the survey it proved difficult to obtain reliable 'impressions' of the contemporary soil erosional stability/status of many of the quadrats. Consequently, we used caesium-137 (^{137}Cs) inventory to determine the stability or otherwise of a number of these sites.

The ^{137}Cs isotope found in our environment is essentially all of anthropogenic origin. It is produced by the fission of uranium-235 at the rate of about 6.7% of fission events. When produced by atmospheric testing of nuclear devices it was injected into the stratosphere, where the residence time was about two years. After this time deposition at the Earth's surface occurred. The amount of deposition was a function of hemisphere air exchange, latitude and rainfall patterns (Bachhuber *et al.*, 1987; Sutherland, 1990). It had accumulated in soil to detectable levels by 1954. Most nations ceased atmospheric testing in 1970, but some tests continued through 1980.

^{137}Cs in rain may be retained temporarily on smooth vegetation surfaces, probably in association with dust, or mid term on bark (Ertel and Zeigler, 1991). When finally deposited on the Earth's surface, ^{137}Cs is rapidly and irreversibly adsorbed by soil particles (Tamura, 1964; Lomenick and Tamura, 1965), preferentially by clay and silt size particles. The irreversible exchange of caesium onto soil colloid slurries is on a scale of seconds. The distribution of ^{137}Cs in soils is correlated with the frequency of wetting. This suggests a time scale for adsorption similar to that of infiltration and drying, i.e. days. Singh and Gilkes (1990) found that even in soil of small colloid content, most of the caesium in contact with soil is retained.

Application of the ^{137}Cs technique then depends on three assumptions:

1. There has been a uniform deposition of ^{137}Cs in a local geo-climatic area.

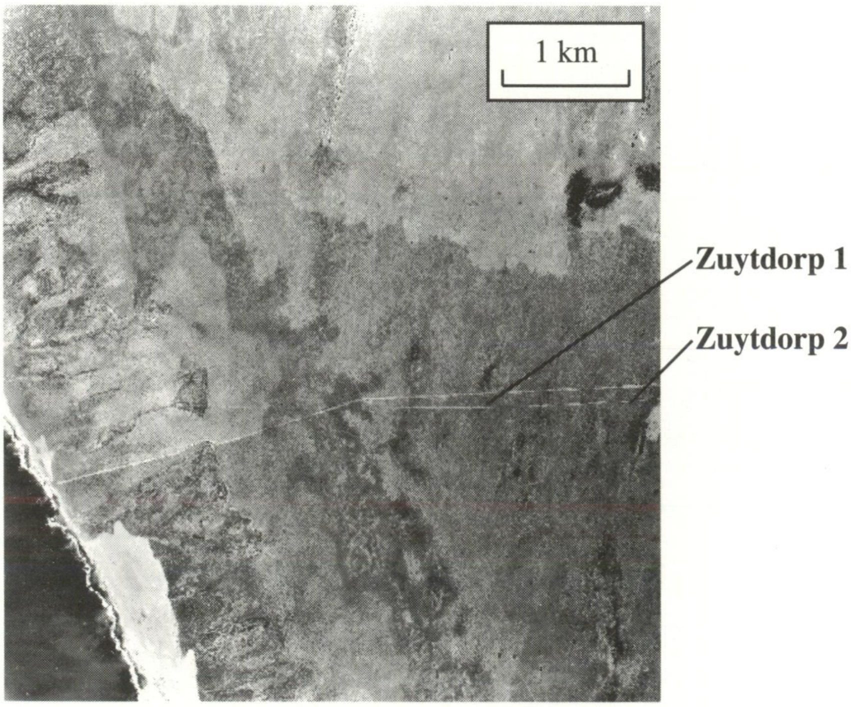

Figure 17 General setting of the Zuytdorp (1and 2) quadrats.

2. The amount of deposition can be estimated by measurement at a recognisable stable, non-eroded reference site.
3. There has been no significant redistribution of ^{137}Cs in local runoff before attachment to soil particles.

During the course of field work we noticed that soils commonly had a surface mat of algae. It is possible that ^{137}Cs absorbs into the mat and is subsequently lost by wind erosion when the mat either dries or burns. ^{137}Cs loss may then occur with little or no soil erosion. Algal mats are prominent on many of the sample quadrats, so this may be an issue.

The disparate effects of particle size sorting during erosion on total ^{137}Cs loss can be compensated by the empirical calibration of measured ^{137}Cs loss at sites of soil loss measurement. Indeed, the effects of any redistribution of ^{137}Cs in runoff before soil labelling may also be at least partially compensated for by an empirical calibration.

^{137}Cs Sampling and Measurement

Reference samples are usually taken from within a steel frame about 20 by 50 cm, with replicate cores. Broad area samples are usually taken along transects or in grid patterns using a steel cylinder 10 cm ID and 20 cm long. Samples are dried at 105°C and crushed to pass a 0.7 mm sieve. Any plant material included with a sample is manually separated, ashed at 230°C and returned to the crushed soil.

The thoroughly mixed soil sample is subsampled and analysed for barium-137m activity at the 661.6 kEv photopeak using a hyper-pure lithium drifted germanium crystal gamma detector system (Campbell *et al.*, 1988). Barium-137m ($t^1/_2$, 2.44 m) is the daughter of ^{137}Cs ($t^1/_2$, 30.17 y) and its measurement is an indirect estimator of ^{137}Cs activity. The precision of this measurement is generally better than 7%. A correction is applied for the contribution of bismuth-214 (^{214}Bi) in the region of interest around the 662 kEv photopeak by subtracting 0.034 times the net count rate in the bismuth-214 609 kEv photopeak.

The total ^{137}Cs activity per unit area A (Bq m^{-2}) at each site is calculated from:

$$A = c*m*a^{-1} \quad \text{.................... (1)}$$

where 'c' is the activity (Bq g^{-1}) corrected for ^{214}Bi, 'm' is the mass of the dried sample <2 mm (g), and 'a' is the area of the sampling device (m^2). For comparison purposes, the isotope activities are decay-corrected to an arbitrary common date. Detectors are calibrated against the IAEA SDN-2 standard and IAEA SL-3 standard materials and the IAEA Soil6 standard prepared as a secondary standard by dilution 1:20 with natural soil containing no ^{137}Cs.

Interpretation of ^{137}Cs Redistribution

The ^{137}Cs activity in soil, relative to that in the non-eroded reference site, may be interpreted using an empirical calibration derived from Australian data. The equation is an amendment of that presented by Elliott *et al.* (1990) following the correction to measured sediment yields identified by Lang (1992):

$$Y = 17.49*(1.0821)^X (n=34, r=+0.84) \quad \text{............. (2)}$$

where 'Y' is net soil loss for uncultivated sites (kg ha^{-1} y^{-1}) and 'x' is percentage ^{137}Cs loss, compared with the reference value. (A calibration for cultivated sites is also available).

Because ^{137}Cs gives information on both erosion and deposition, the percentage loss or gain of ^{137}Cs, compared with the reference value, was used as a quantitative indicator of net soil loss or gain, respectively, assuming that the isotope was uniformly distributed across the landscape. Net soil accumulation was calculated using the above equation in reverse mode for sites that had gained ^{137}Cs. In this case, 'Y' is net soil gain and 'x' is percentage ^{137}Cs gain, compared with the reference value.

Estimates of Soil Erosion and Assessment of Surface Stability

Gascoyne Junction

At Gascoyne Junction, the average annual rainfall for the period 1958 to 1997 was 204 mm (6022) and 205 mm (6027). Numbers on brackets are the Australian Meteorological Bureau rainfall station codes. A ^{137}Cs reference site was sampled at 25° 05'18"S 115°22'48"E, the lower slope facet of quadrat GJ5. The sand at the sample location was very compacted at a depth of c. 20 cm. The depth-interval values for the site are listed below. Note that 'nd' indicates that ^{137}Cs concentration is below its detection limit of about 6 Bq m^{-2}. The site's total activity value, 200 ± 3 Bq m^{-2} (sample code = 960615), is in good agreement with other studies but the distribution of ^{137}Cs within the reference sample site was atypical:

Depth (cm)	^{137}Cs (Bq m^{-2})
0 – 5	122 ± 9
5 – 10	28 ± 7
10 – 15	14 ± 3
15 – 20	nd
20 – 25	36 ± 7
25 – 30	nd
TOTAL	200

Core sample results and erosion estimates:

Sample	^{137}Cs activity (Bq m^{-2})	Soil erosion (kg $ha^{-1}y^{-1}$)
1	180 ± 3	40
2A (GJ4)	160 ± 20, 170 ± 10	60 – 80
2B (GJ4)	260 ± 20	deposition, 190
3A (GJ5)	150 ± 20	130
3B (GJ5)	150 ± 30	130

These results indicate that a very low rate of soil erosion prevails, with perhaps only very short flow paths and limited redistribution of the isotope and labelled soil in the landscape.

Kennedy Range

Two reference sites were sampled for ^{137}Cs at 24°28'18"S 115°00'46"E. Rainfall is expected to be similar to that at Mardathuna (see below). The depth-interval values are listed below. The total ^{137}Cs activity in the first site, 180 ± 3 Bq m^{-2} (960615), exceeds the total in the second, but it appears that sampling was not complete in the second site and the totals to a depth of 14 cm at both sites are 157 and 158 Bq m^{-2} respectively.

Sample 1		Sample 2	
Depth (cm)	^{137}Cs (Bq m^{-2})	Depth (cm)	^{137}Cs(Bq m^{-2})
0 – 2.5	116 ± 9	0 – 5	92 ± 8
2.5 – 9	25 ± 4	5 – 10	47 ± 1
9 – 14	16 ± 5	10 – 15	23 ± 11
14 – 19	23 ± 6		
19 – 24	nd		
TOTAL	180 ± 3		

The core sample results and derived erosion estimates, listed below, assume a reference value of 180 Bq m^{-2}. They were all obtained in the immediate vicinity of quadrat KE2. The first set of cores was taken from a relatively higher topographic position. The second set of core samples suggests a bimodal distribution of ^{137}Cs in a relatively lower topographic position, which is consistent with soil erosion occurring at a rate of about 900 kg ha^{-1}y^{-1} over two thirds of the area. The remaining area may be characterised by a zero flux of eroded soil. There are clearly very variable conditions over a limited area. This attests to considerable spatial variability in the erosion/deposition pattern in these areas.

Sample	^{137}Cs activity (Bq m^{-2})	Soil erosion (kg ha^{-1}y^{-1})
1A	58 ± 13	3400
1B	60 ± 30	
2A	110 ± 20	380
2B	90 ± 10	980
2C	190 ± 30	0
2D	150 ± 30	0
2E	80 ± 20	1300
2F	90 ± 20	980

Samples were also obtained from banks of a small incised alluvial channel at the foot of the Kennedy Range (24°36'8.7"S 114°56'23.5"E). ^{137}Cs concentrations in these sediment samples, taken at approximately 20 cm intervals down the side of an incised drainage channel, are listed below. They suggest relatively very rapid deposition and reworking. The alluvial build-up is clearly ongoing and is responding to high sediment yields derived from the escarpment margins.

Sample and depth (cm)	^{137}Cs (Bq m^{-2})
1. 0 – 4	36 ± 4
2. 24 – 29	44 ± 7
3. 44 – 49	19 ± 5
4. 64 – 69	24 ± 5
5. 84 – 89	16 ± 4
6. 104 – 109	12 ± 2

Mardathuna

The average annual rainfall at Mardathuna for the period 1958 to 1997 was 227 mm (6019) and 240 mm (6032). The ^{137}Cs reference value was 192 ± 10 Bq m^{-2} (960615) at 24°26'37"S 114°30'43"E (quadrat MR2); its depth-interval values are listed below. The total is in good agreement with other studies but the distribution of ^{137}Cs within the reference sample site was again atypical:

Depth (cm)	^{137}Cs (Bq m^{-2})
0 – 5	122 ± 9
5 – 10	28 ± 7
10 – 15	14 ± 3
15 – 20	nd
20 – 25	36 ± 7
25 – 30	nd

Total core sample activity and erosion estimate from MR2 (below) indicate that a very small rate of soil erosion prevails, with perhaps only very short flow paths and limited redistribution of the isotope and labelled soil in the landscape. MR2 has a strong algal mat development over the surface and gives a general impression of stability:

Sample	^{137}Cs activity (Bq m^{-2})	Soil erosion (kg ha^{-1}y^{-1})
1. (MR2)	130 ± 60	220

Nanga

Average rainfall at Nanga for the period 1958 to 1997 was 221 mm (6025), similar to that at Peron and other Carnarvon stations; the ^{137}Cs concentrations recorded at various depths in the profiles of the three reference sites sampled are listed below. Although it is consistent with core results from broad areas, the total ^{137}Cs activity at 26°28'40"S 114°04'34"E (the first site) is 287 ± 3 Bq m^{2} (960615) and exceeds the totals in the others. The other two reference sites sampled were at 26°35'35"S 113°53'10"E; they yielded total ^{137}Cs concentrations of 207 ± 3 and 174 ± 4 Bq m^{-2} (960615), respectively.

Depth (cm)	Sample 1 ^{137}Cs (Bq m^{-2})	Sample 2 ^{137}Cs (Bq m^{-2})	Sample 3 Depth (cm)	Sample 3 ^{137}Cs (Bq m^{-2})
0 – 5	97 ± 8	85 ± 7	0 – 2.5	94 ± 8
5 – 10	30 ± 6	40 ± 7	2.5 – 7.5	40 ± 7
10 – 15	77 ± 5	24 ± 5	7.5 – 12.5	13 ± 3
15 – 20	36 ± 7	31 ± 7	12.5 – 17.5	nd
20 – 25	12 ± 2	27 ± 7	17.5 – 22.5	27 ± 9
25 – 30	35 ± 7	nd	22.5 – 27.5	nd
TOTAL	287 ± 3	207 ± 3		174 ± 4

The core sample results and derived erosion estimates listed below assume a reference value of 287 Bq m^{-2} for the first sample (NA1) and 190 Bq m^{-2} for the other six. Core samples 2A and 2B (quadrat NA5) suggest a bimodal distribution of ^{137}Cs, which is consistent with soil erosion occurring at a rate of about 1500 kg ha^{-1}y^{-1}. The upper part of a large 'dune form' structure located between NA3 and NA4 (samples 2C to 2F) had ^{137}Cs activity of 170 ± 40 Bq m^{-2}, and may be characterised by a zero flux of eroded soil.

Sample	^{137}Cs activity (Bq m^{-2})	Soil erosion (kg ha^{-1}y^{-1})
1. (NA1)	230 ± 20	0
2A (NA5)	90 ± 14	1150
2B (NA5)	75 ± 14	1990
2C	158 ± 10	0
2D	166 ± 30	0
2E	130 ± 30	0
2F	230 ± 50	0

Nerren Nerren

The ^{137}Cs reference value for Nerren Nerren is 376 ± 3 Bq m^{-2} (960615 – at 27°02'50"S 114°34'23"E). Its profile components are listed below. This reference value was rather larger than that at the other locations and, while it appears to be consistent with the values measured in cores from broad areas, might reflect sediment accumulation.

Depth (cm)	^{137}Cs (Bq m^{-2})
0 – 5	202 ± 9
5 – 10	56 ± 7
10 – 15	41 ± 7
15 – 20	24 ± 7
20 – 25	22 ± 7
25 – 30	31 ± 4

Core sample results and erosion estimates at quadrats:

Sample	^{137}Cs activity (Bq m^{-2})	Soil erosion (kg ha^{-1}y^{-1})
1. (NE2)	260 ± 20	200
3. (NE3)	140 ± 20	2500
5. (NE5)	240 ± 20	300

Sediment samples taken in an ill defined drainage channel (between NE3 and NE5) suggest that relatively very little deposition of eroded soil is occurring, although some reworking is apparent:

Sample and depth	^{137}Cs (Bq m^{-2})
1. 15 cm	nd
2. 45 cm	nd

Peron

The average annual rainfall for the period 1958 to date was 222 mm (6044). The ^{137}Cs reference value was 223 ± 5 Bq m^{-2} (960615) at 25°49'14"S 113°32'21"E. The total is in good agreement with other studies but the distribution of ^{137}Cs within the reference sample site was again atypical:

Depth (cm)	^{137}Cs (Bq m^{-2})
0 – 5	87 ± 6
5 – 10	56 ± 7
10 – 15	50 ± 5
15 – 20	26 ± 8
20 – 25	nd
25 – 30	27 ± 8

Core sample results and erosion estimates from PE3, near the top of a large 'dune form', are listed below. Reworking/erosion through wind can be expected; a very unstable surface.

Sample	^{137}Cs activity (Bq m^{-2})	Soil erosion (kg ha^{-1}y^{-1})
1. (PE3)	34 ± 11	13800

Woodleigh

At Woodleigh, the average annual rainfall for the period 1958 to 1997 was 222 mm and 198 mm. The ^{137}Cs reference value was 248 ± 3 Bq m^{-2} at 26°13'03"S 114°35'57"E (on quadrat WO1). Another reference value was 218 ± 3 Bq m^{-2} (960615) at 26°11'30"S 114°30'34"E (quadrat WO4). The total is in good agreement with other studies, but the distribution of ^{137}Cs within the second reference sample site was atypical, strongly suggesting the effects of the presence of a relatively impermeable illuvial soil horizon.

Depth (cm)	^{137}Cs (Bq m^{-2})	
	WO1	WO4
0 – 5	140 ± 9	121 ± 6
5 – 10	30 ± 7	47 ± 7
10 – 15	49 ± 8	16 ± 6
15 – 20	15 ± 6	nd
20 – 25	14 ± 3	14 ± 5
25 – 30	nd	20 ± 6

The core sample results and erosion estimates are presented below:

Sample	^{137}Cs activity (Bq m^{-2})	Soil erosion (kg ha^{-1}y^{-1})
1. (WO1)	240 ± 40	0
4. (WO4)	110 ± 20	800

WO1 represents a stable sand plain surface – see site description, whereas WO4 is a site characterised by locally reworked sand over calcrete.

Zuytdorp

The ^{137}Cs 'reference' value at 27°15'43"S 114°01'59"E (between ZU2 and ZU3) was 477 ± 3 Bq m^{-2} (960615). This is the largest reference value recorded anywhere in the study area, and is disproportionately large compared with rainfall. The value may represent sediment accretion in the relatively dense coastal vegetation east of major sediment sources. Note that there is no similar effect on the Peron Peninsular where no such sources adjoin the sample area. The surface is unstable, with addition of material from upslope. Note also that the relatively shallow sampling may not have intersected all of the profile ^{137}Cs.

Depth (cm)	^{137}Cs (Bq m^{-2})
0 – 5	167 ± 6
5 – 10	140 ± 6
10 – 15	42 ± 2
15 – 20	28 ± 7

Discussion of the Caesium Results

The results of this limited reconnaissance survey strongly suggest that the environmental isotope ^{137}Cs can be used to identify areas ranging from stable to unstable with respect to soil erosion. This is despite the low rainfall and the fact that the soils are very low in colloid content, and therefore the ^{137}Cs inputs have been low compared with other areas where ^{137}Cs has been used successfully. There was good uniformity of reference values and, indeed, ^{137}Cs may be tracing colloid complex movement to an illuvial soil horizon.

The erosion rates that have been suggested are low (stable surface) at the Mardathuna and Gascoyne Junction sites, and moderate to high in the Kennedy Range, Peron and Woodleigh sites. The Kennedy Range samples indicate the enormous range in surface stability (erosion rates) that can occur within even a very confined area. The stability of the Mardathuna site is also indicated by field characteristics: A strong algal mat is evident over the site and effectively seals the surface. Such mats are prominent throughout the area and play an important role in controlling surface stability. Extensive surface erosion can occur where this mat is destroyed (e.g. at quadrat MD2).

Two conclusions emerge: (1) a wide range of spatial heterogeneity/variability occurs in the erosional/stability status of the sample sites, and (2) the technique has the potential to discriminate between stable and unstable sites, which is not always possible on the basis of field observations. While it is clear that the caesium technique has the ability to answer detailed questions about specific sites, the limited isotope work we have been able to carry out did not allow any analysis of the affect of surface instability on the biology of the quadrats.

SOIL CHEMICAL ANALYSIS

Soil particle size and chemical properties of soil samples collected from representative sites on all quadrats were determined at the Western Australian Government Chemical Laboratories (Chemcentre) in Perth. Details of the analysis procedures are provided in Appendix 1. Appendix 2 includes the soil data.

While the statistical relationships between the various soil attributes and the biological data are discussed elsewhere in this publication, a number of general observations can be made concerning soil fertility levels, i.e. concentration of nitrogen, phosphorus and potassium.

Only surface soil samples (0–10 cm) were analysed for total nitrogen content, as this is the most important soil layer in arid regions with respect to available nutrients (Charley and Cawling, 1968; Queensland Division of Land Utilisation, 1974) and nitrogen contents below this depth are usually very low. Values ranging from 0.005% to 0.085% with the great majority being 0.02% or less, were obtained. Using the standards of Payne *et al.* (1988), values of 0.02% nitrogen are regarded as high. Only three samples exceeded 0.05% nitrogen – at CU1E on the edge of Lake MacLeod, CU4 an interdune sandy swale, and BB3, a samphire flat.

Payne *et al.* (1988) adopted standards for plant available phosphorus (bicarbonate extraction) in the Ashburton rangelands of 5 ppm or less as being very low, and over 30 ppm as very high. The great majority of our soil samples fell into the very low and low categories, three notable exceptions being the soils at BB2, BB3 and BB5 where moderate to high values occurred in the top 30 cm of soil. BB2 is located on the lower slope of a small dune, BB3 is a samphire flat, and BB5 is a shelly sand in which the phosphorous is presumably associated with the shell remains.

'Available' Potassium (bicarbonate extraction) measures water-soluble and exchangeable potassium, the water soluble form only being of consequence where water soluble salts have accumulated. Using a value of 100 ppm potassium to indicate an adequate supply for plant growth (McArthur, 1991), all quadrats at Boolathana and Gascoyne Junction have satisfactory levels. At the other extreme all quadrats at Nanga, Nerren Nerren and Zuytdorp have low levels of potassium (< 50 ppm). At Woodleigh, Cape Cuvier, Meedo and Kennedy Ranges, all of the deep sand profiles have low potassium contents, while the remaining quadrats have good supplies of potassium. Deep sand profiles at Mardathuna, Bush Bay and Peron are generally low to very low in their potassium content, but not consistently so: MR2, MR4, MR5, BB2 and PE4 are all deep sandy profiles, but have potassium levels > 100 ppm. Adequate potassium levels were found on the quadrats in these areas that had higher clay content in their soil profiles.

CONCLUDING COMMENT

The physical data collected during this preliminary study provide part of an environmental matrix that can be used to analyse biogeographical data from the region. We hope that our results will provoke more specific, problem-orientated studies.

ACKNOWLEDGEMENTS

Dave Allen of the Chemistry Centre of Western Australia carried out the chemical analyses on our soil samples. M.N. Lyons prepared Figure 1. Funding was provided by the Commonwealth through the National Reserves System Co-operative Program of the Australian Nature Conservation Agency, and by the Western Australian Department of Conservation and Land Management.

REFERENCES

Allan-Diaz, B. (1996). Rangelands in a changing climate: impacts, adaptations, and mitigation. *In* R.T. Watson, M.C. Zinyowera and R.H. Moss (eds), *Impacts, Adaptations and Mitigation of Climate Change. Technical Analysis. Contribution of Working Group II to the Second Assessment Report of the Intergovernmental Panel on Climate Change*: 131–158. Cambridge University Press, New York.

Bachhuber, H., Bungl, K. and Schimmack, W. (1987). Spatial variability of fallout ^{137}Cs in the soil of a cultivated field. *Environmental Monitoring and Assessment* **8**: 93–101.

Belnap, J. (1995) Surface disturbances – their role in accelerating desertification. *Environmental Monitoring and Assessment* **37**(1–3): 39–57.

Biswas, M.R. and Biswas, A.K. (eds) (1980). *Desertification: Associated case studies prepared for the United Nations Conference on Desertification*. Pergamon Press, New York.

Bullock, P., and Houerou, H.L. (1996). Land degradation and desertification. *In* R.T. Watson, M.C. Zinyowera and R.H. Moss (eds), *Impacts, Adaptations and Mitigation of Climate Change. Technical Analysis. Contribution of Working Group II to the Second Assessment Report of the Intergovernmental Panel on Climate Change*: 171–189. Cambridge University Press, New York.

Burbidge, A.H., McKenzie, N.L. and Harvey, M.S. (2000). A biogeographic survey of the southern Carnarvon Basin, Western Australia: background and methods. *Records of the Western Australian Museum* Supplement No. 61: 1–12.

Campbell, B.L., Loughan, R.J. and Elliott, G.L. (1988). A method for determining sediment budgets using caesium-137. *International Association of Hydrological Sciences Publication* **174**: 171–179.

Charley, J.C. and Cawling, S.W. (1968). Changes in soil nutrient status resulting from overgrazing and their consequences in plant communities in semi-arid areas. *Proceedings of the Ecological Society of Australia* **3**: 28–38.

Elliott, G.L., Loughan, R.J. and Campbell, B.L. (1990). Correlation of erosion measurement and soil caesium-137 content. *International Journal of Radiation and Applied Instrumentation, Part A, Applied Radiation and Isotopes* **41**: 713–717.

Ertel, J. and Zeigler, H. (1991). Cs-134/137 contamination and root uptake of different forest trees before and after the Chernobyl accident. *Radiation and Environmental Biophysics* **30**: 147–157.

Hewgill, F.R., Kendrick, G.W. and Wyrwoll, K.-H. (1983). Routine ESR dating of Pleistocene marine units in Western Australia. *Search* **14**: 215–217.

Hocking, R.M., Moors, H.T. and van de Graaff, W.J.E, (1987). Geology of the Carnarvon Basin. *Bulletin 133*. Geological Survey of Western Australia, Perth.

Isbell, R.F. (1996). *The Australian Soil Classification,*. **4**. CSIRO, Melbourne.

Kemp, E.M. (1978). Tertiary climatic evolution and vegetation history in the southeast Indian Ocean region. *Palaeogeography, Palaeoclimatology, Palaeoecology* **24**: 169–208.

Kendrick, G.W., Wyrwoll, K.-H. and Szabo, B.J. (1991). Pliocene-Pleistocene coastal events and history along the western margin of Australia. *Quaternary Science Reviews* **5**: 419–439.

Lang, R.D. (1992). Accuracy of two sampling methods used to estimate sediment concentrations in runoff from soil loss plots. *Earth Surface Processes and Landforms* **17**: 841–844

Logan, B.W., Read, J.F. and Davies, G.R. (1970). History of carbonate sedimentation, Quaternary epoch. *In* B.W. Logan, G.R. Davies, J.F. Read and D.E. Cebulski (eds), *Carbonate Sedimentation and Environments, Shark Bay, Western Australia*: 38–84. Memoir 13. American Association of Petroleum Geologists, Tulsa, Los Angeles.

Lomenick, T.F. and Tamura, T. (1965). Naturally occurring fixation of caesium-137 on sediments of lacustrine origin. *Soil Science Society of America Proceedings* **29**: 383–386.

Mann, A.W., and Horwitz, R.C. (1979). Groundwater calcrete deposits in Australia: some observations from Western Australia. *Geological Society of Australia Journal* **26**: 972–989.

Marshall, T.J. (1947). Mechanical Composition of Soil in Relation to Field Descriptions of Texture. *Bulletin No. 224*. CSIRO, Australia.

McArthur, W.M. (1991). *Reference Soils of South-western Australia*. Western Australian Department of Agriculture and Australian Society of Soil Science (W.A. Branch), Perth.

McDonald, R.C., Isbell, R.F., Speight, J.G., Walker, J. and Hopkins, M.S. (1990). *Australian Soil and Land Survey Field Handbook*, 2nd edition. Inkata Press, Melbourne.

Payne, A. L., Curry, P. J. and Spencer, G. F. (1987). An Inventory and Condition Survey of Rangelands in the Carnarvon Basin, Western Australia. *Technical Bulletin No. 73*. Western Australia Department of Agriculture, Perth.

Payne, A.C., Mitchell, A.A. and Holmer, W.F. (1988). An Inventory and Condition Survey in the Ashburton River Catchment, Western Australia. *Technical Bulletin No. 62*. Western Australian Department of Agriculture, Perth.

Queensland Division of Land Utilisation (1974). Western arid region land use survey. Part 1. *Technical Bulletin No. 12*. Department of of Primary Industries, Brisbane.

Singh, B. and Gilkes, R.J. (1990). Sorption-desorption behaviour of caesium in some Western Australian soils. *Australian Journal of Soil Research* **28**: 939–946.

Stokes, R.A. (1978). Gascoyne River Simulation. *Water Resources Technical Report No. 80*. Public Works Department, Western Australia.

Sutherland, R.A. (1990). Quantification of soil redistribution in cultivated fields using Cs-137: Outlook, Saskatchewan *In* R.B. Bryan (ed.), *Soil Erosion – Experiment*. *Catena*, Supplement **17**: 177–193.

Tamura, T. (1964). Selective sorption of caesium with soil minerals. *Nuclear Safety* **5**: 262–268.

Van de Graaf, W.J.E. (1983). Silcrete in Western Australia: geomorphological settings, textures, structures, and their genetic implications. *In* R.C.L. Wilson (ed.), *Residual Deposits: Surface Related Weathering Processes and Materials*: 159–166. Special Publication No 11. Geological Society, London.

Williams, O.B., Suijdendorp, H. and Wilcox, D.G. (1980). The Gascoyne Basin. *In* M.R. Biswas and A.K. Biswas (eds), *Desertification: Associated Case Studies Prepared for the United Nations Conference on Desertification*: 3–106. Pergamon Press, New York.

Wetherby, K.G. (1995). *Soil Description Book*. Cleve, South Australia.

Manuscript received 5 August 1998. accepted 3 February 2000.

APPENDIX 1: MATRIX CODES AND DESCRIPTORS

The following gives a summary reference to all codes and shorthand abbreviations listed in the matrix. Many of the codings and descriptors have been either directly derived, or modified from recently published land and soil survey systems (Isbell, 1996; McDonald *et. al.*, 1990).

Location

Quadrat site (q_name) – Coded identifiers are given for each cluster of quadrats, with the following abbreviations:

BB = Bush Bay	MR = Mardathuna
BO = Boolathana	NA = Nanga
CU = Cuvier	NE = Nerren Nerren
EL = Edel Land	PE = Peron
GJ = Gascoyne Junction	WO = Woodleigh
KE = Kennedy Range	ZU = Zuytdorp
MD = Meedo	

Soil Profile

The following soil parameters are available for the total soil profile (p), top (t) = 0–10 cm, middle (m) = 10–30 cm, and bottom (b) = 30-N cm. To prevent repetition the descriptors and their codings are expressed only once using an asterix (*) to signify the substitution of any of the above described profile layers, except where otherwise specified. Soil chemistry analytical procedures were carried out at the Western Australian Chemistry Centre (Department of Minerals and Energy). Details of these procedures are provided in Appendix B on page 572 of this volume.

Soil Classification (*_clord and *_clsub) – Soils are classified to Order and Suborder:

***_clord** (Order)	***_clsub** (Suborder)
C = Chromosol .	b = Brown
	r = Red
H = Hydrosol	h = Hypersalic
K = Kandosol	k = Red
R = Rudosol	a = Arenic
	y = Shelly
	l = Leptic
	u = Lutic
	s = Stratic
S Sodosol	z = Red
	w = Brown
X = Not Appropriate	x = Not Appropriate

Exchangeable cation extraction method (exch-meth):

a 1M NH_4Cl — pH 7.0 — (Method S22.0)
b 0.1M $BaCl_2$ — (Method S21)
c 1M NH_4Cl — pH 8.5 (Method S22.1)

Estimated Depth of Soil Profile (so_depth) – The average estimated soil depth at each quadrat.

0 Bare Rock
1 < 30 cm
2 > 30 cm, < 50 cm
3 > 50 cm

Analytical Soil Profile Depth (*_depth) – The depth of the soil profile to which geochemical analysis was completed (cm).

Surface Shear Strength (*h_shst; *l_shst; *x_shst) – Highest mean, lowest mean and averaged shear vane readings (VS^2) were given for each geomorphological setting. These VS^2 readings were taken only for the top (t) and middle (m) profile. Values are expressed in kPa.

Electrical conductivity (*_elcond) – Average electrical conductivity determined for the entire soil profile (mS/m).

pH (*_phcacl) – Average acidity/alkalinity determined for the entire soil profile, expressed as a pH value.

Soil Texture (*_text) – The entire profile was analysed in terms of percent sand, silt and clay. The texture was determined with the aid of a triangular texture diagram (Marshall, 1947) based on international fractions.

*_text	Textural Class
1	Sand
2	Loamy Sand
3	Sandy Loam
4	Sandy Clay Loam
5	Clay Loam
6	Sandy Clay
7	Silty clay loam
8	Heavy Clay
9	Distinct

Soil Moisture Index (*_mind) – This was determined from theoretical tables (Wetherby, 1995) produced through repetitive analysis of moisture index of differing textured profiles. A given moisture index value is simply given as an output for a prescribed soil texture. Values are expressed in mm/cm (between field capacity and permanent wilting point 8–1500 kPa)

Textural Class	***_mind**
Sand	0.62
Loamy Sand	0.86
Sandy Loam	1.15
Sandy Clay Loam	1.43
Clay Loam	1.48
Sandy Clay	1.49
Silty clay loam	2.34
Heavy Clay	1.20
Not Appropriate	–9999

Organic Carbon Content (*_cwb) – Percentage organic content within the soil profile, determined only for the top 10 cm of the profile.

Total Phosphorus (*_ptot) – Average concentration of Total Phosphorous present within a soil profile (ppm).

Available Phosphorus (*_phco3) – Average concentration of phosphorous present in the form available for plant nutrition within the soil profile (ppm).

Available Potassium (*_khco3) – Average concentration of potassium present in the form

available for plant nutrition within the soil profile (ppm)
Percentage Calcium Carbonate Content (*_caco3) – Average percentage $CaCO_3$ content within the soil profile.
Percentage Aluminium Cation (*_alexme) – Average percentage aluminium cation exchange content within the soil profile.
Percentage Calcium Cation (*_caexme) – Average percentage calcium cation exchange content within the soil profile.
Percentage Magnesium Cation (*_mgexme) – Average percentage magnesium cation exchange content within the soil profile.
Percentage Manganese Cation (*_mnexme) – Average percentage manganese cation exchange content within the soil profile.
Percentage Sodium Cation (*_naexme) – Average percentage sodium cation content within the soil profile.
Percentage Total Cation (*_totex) – Average percentage total cation content within the soil profile: exCa + exMg + exMn + exK + exNa.
Percentage Gypsum Content (*_gypsum) – Average percentage gypsum present within the soil profile.
Salt (*_salt) – Average percentage NaCl within the soil profile.

Surface Characteristics and Geology

Coarse Fragments (g_cfrag) – Abundance of coarse fragments present on the surface:

0	No coarse fragments	0
1	Very few	< 2%
2	Few	2%–10%
3	Common	10%–20%
4	Many	20%–50%
5	Abundant	50%–90%
6	Very abundant	> 90%

Rock Outcrop (g_outcrp) – Abundance of rock outcrop on the surface:

0	No bedrock exposed	0
1	Very slightly rocky	< 2%
2	Slightly rocky	2–10%
3	Rocky	10–20%
4	Very rocky	20–50%
5	Rockland	> 50%

Substrate Lithology – Codings define the lithology of the substrate within the quadrat. There are 12 lithological types with the following column headings:

l_sandst	Sandstone
l_mudst	Mudstone
l_calc	Calcrete
l_calcar	Calcarenite
l_silcr	Silcrete
l_limest	Limestone
l_ferric	Ferricrete
l_alluv	Unconsolidated Alluvial (water transported) Sediments
l_eolian	Unconsolidated Eolian Sediments
l_tidal	Unconsolidated Tidal Flat Sediments
l_birrid	Unconsolidated Birrida Sediments
l_pan	Unconsolidated Pan Sediments

At each quadrat for each lithology, the presence of the respective lithologies is noted by the following criteria:

A Absent
P Present

Genesis

Mode of Geomorphological Activity – Codings define the mode of gradational or anti-gradational activities that are responsible for the evolution of landform present at the quadrat. Two modes of geomorphological activity are noted as column headings:

ge_erod Eroded
ge_agrad Aggraded

At each quadrat site the role of these two processes in landform development are noted by the following criteria:

A Absent
N Minor Importance
M Moderate Importance
D Dominant Process (s)

Geomorphological Agent (s) – Codings define the geomorphological agents; past and present that are responsible for the evolution of the landform present at the quadrat. There are 9 recognised geomorphological agents with their respective column headings:

ga_chann	Channelled stream flow
ga_eust	Eustasy: changes in sea level
ga_grav	Gravity
ga_over	Overbank stream flow, unchannelled
ga_sheet	Sheet flow, sheet wash, surface wash
ga_inund	Inundation/flooding, Soil moisture status changes
ga_solut	Solution
ga_marin	Marine influence; tides, waves
ga_wind	Wind

The role of these geomorphological agents is distinguished as follows:

A Absent
N Minor Importance
M Moderate Importance
D Dominant Process (s)

Status of Geomorphological Activity – Codings distinguish whether the geomorphological processes continue at this present time, from those which are no longer active. One column exists alongside that for each geomorphological agent as described above with the following column headings:

gs_chann	Channelled stream flow
gs_eust	Eustasy: changes in sea level
gs_grav	Gravity

gs_over	Overbank stream flow, unchannelled
gs_sheet	Sheet flow, sheet wash, surface wash
gs_inund	Inundation/flooding, Soil moisture status changes
gs_solut	Solution
gs_marin	Marine Influence; tides, waves
gs_wind	Wind

The status of these geomorphological agents is distinguished as follows:

- C Continuously active
- F Frequently active
- S Seldom active
- B Barely active to inactive
- R Relict
- N Not Appropriate

Landform

Slope (g_slope) – Codings define the relative inclination of the slope. The codings given in the matrix are:

1. Level
2. Very gently inclined
3. Gently inclined
4. Moderately inclined
5. Steep
6. Very steep

Runon Velocity (g_runon) – The codings which define runon velocity as represented in the matrix have the following descriptors:

VL	Very low velocity	<< 300 mm/s
L	Low velocity	< 300 mm/s
I	Low/High Velocity	
H	High velocity	> 300 mm/s

Runoff (g_runoff) – These codings define the runoff which is the relative rate at which water runs off the soil surface:

0	No runoff.	
1	Very slow.	Free water on surface for long periods, or water enters soil immediately. Soils usually either level to nearly level or loose and porous.
2	Slow.	Free water on surface for significant periods or water enters soil relatively rapidly. Soils usually nearly level to gently sloping or relatively porous.
3	Moderately rapid.	Free water on surface for short periods only; moderate proportion of water enters soil.
4	Rapid.	Large proportion of water runs off; small proportion enters soil. Water runs off as fast as it is added. Soils usually have steep to very steep slopes and low infiltration rates.
5	Very rapid.	Very large proportion of water runs off; very small proportion enters soil. Water runs off as fast as it is added. Soils usually have steep to very steep slopes and low infiltration rates.

APPENDIX 2: SOIL ANALYSES – SEE APPENDIX 1 FOR CODE DETAILS

q_name	p_clord	p_clsub	so_depth	p_depth	p_elcond	p_phcacl	p_text	p_mind	p_cwb	p_ptot
BB1	K	k	3	100	294	7.6	4	1.43	0.22	170
BB2	R	a	3	100	5	7.8	1	0.62	0.3	198
BB3	S	z	3	100	354	8.5	3	1.15	0.6	210
BB4	R	a	3	100	2	6.1	1	0.62	0.14	138
BB5	R	y	3	100	20	8.7	1	0.62	0.35	69
BO1	S	z	3	100	74	8.2	3	1.15	0.15	151
BO2	S	z	3	50	126	8.6	3	1.15	0.15	115
BO3	R	a	3	50	7	8.3	1	0.62	0.16	123
BO4	R	a	3	50	2	6.9	1	0.62	0.2	133
BO5	R	a	3	50	1	5.6	1	0.62	0.14	97
CU01e	H	h	2	45	585	8.5	3	1.15	0.94	203
CU01w	H	h	2	40	398	8.3	3	1.15	0.41	210
CU02	R	l	3	40	9	7.6	1	0.62	0.24	74
CU03	R	a	3	90	5	8.3	1	0.62	0.18	42
CU04e	R	l	3	50	7	8.2	1	0.62	0.42	100
CU04mid	R	l	3	50	7	8.1	3	1.15	0.49	123
CU05	R	l	3	30	6	8.2	3	1.15	0.28	98
CU06	R	a	3	30	6	8.4	1	0.62	0.12	530
EL1			3	100	31	8.4	1	0.62	0.53	616
EL2			3	100	11	8.2	2	0.86	0.7	510
GJ1	K	k	1	45	4	7.5	3	1.15	0.15	110
GJ2	R	a	3	90	2	6.5	1	0.62	0.1	106
GJ3	K	k	3	100	1	4.8	2	0.86	0.21	123
GJ4	S	r	3	30	19	6.5	3	1.15	0.11	150
GJ5	T	o	3	100	16	6.9	3	1.15	0.08	118
KE01	R	a	3	100	1	5.8	1	0.62	0.08	41
KE02	R	a	3	100	1	4.6	3	1.15	0.08	54
KE03	S	b	2	100	397	6.9	8	1.2	0.2	164
KE04	R	l	3	30	1	5	1	0.62	0.17	120
KE05	R	a	3	100	1	4.2	1	0.62	0.16	152
MD1A	R	a	3	100	3	6.5	1	0.62	0.09	99
MD1B	S	z	3	50	10	6	4	1.43	0.12	237
MD2	C	r	3	100	27	6.2	3	1.15	0.06	170
MD3	C	r	3	50	2	6.9	1	0.62	0.14	123
MD4	R	s	3	100	2	6.8	1	0.62	0.12	101
MD5	R	a	3	100	2	4.3	1	0.62	0.18	101
MR01e	R	l	2	20	7	8.2	1	0.62	0.18	135
MR01w	S	z	3	55	6	7.9	3	1.15	0.26	160
MR02	R	a	3	75	1	4.9	3	1.15	0.12	117
MR03	R	a	3	50	1	6.5	1	0.62	0.12	78
MR04	R	a	3	100	1	5.4	3	1.15	0.1	113
MR05	R	a	3	100	1	5.2	3	1.15	0.08	118
NA1	R	b	3	80	267	8.3	2	0.86	0.42	132
NA2	R	a	3	100	3	6.5	1	0.62	0.14	53
NA3	R	a	3	100	3	7.6	1	0.62	0.23	33
NA4	R	a	3	100	5	7.7	1	0.62	0.21	35
NA5	R	a	3	100	3	7.9	1	0.62	0.24	35
NE1	R	a	3	100	1	4.4	1	0.62	0.2	41
NE2	R	a	3	100	1	4.4	1	0.62	0.3	39
NE3	R	a	3	100	1	5	3	1.15	0.42	64
NE4	R	a	3	100	1	4.5	3	1.15	0.33	61
NE5	R	a	3	100	2	4.2	3	1.15	0.45	56
PE1	X	x	3	10	538	8.4	9		0.47	98
PE2	R	y	3	100	6	8.3	3	1.15	0.24	86
PE3	R	a	3	100	7	8.3	3	1.15	0.38	88
PE4	R	a	3	100	6	7.5	1	0.62	0.39	96
PE5	R	a	3	100	9	8.4	1	0.62	0.24	193
WO1	R	a	3	100	2	4.9	2	0.86	0.26	110
WO2	R	a	3	100	1	4.5	1	0.62	0.14	107
WO3	R	a	2	30	2	6.5	1	0.62	0.16	135
WO4	R	a	1	30	27	8.1	2	0.86	0.21	120
WO5	K	k	3	100	184	8	4	1.43	0.14	130
ZU1	R	a	1	50	5	5.9	1	0.62	0.61	42
ZU2	R	a	2	100	3	6	1	0.62	0.42	29
ZU3	R	a	3	100	3	5.5	1	0.62	0.55	56
ZU4	R	a	3	100	1	5.3	1	0.62	0.34	24
ZU5	R	a	3	100	2	5.7	1	0.62	0.32	20
q_name	s_clord	s_clsub	so_depth	s_depth	s_elcond	s_phcacl	s_text	s_mind	s_cwb	s_ptot

p_phco3	p_khco3	p_caco3	p_alexme	p_caexme	p_mgexme	p_mnexme	p_kexme	p_naexme	p_totex
7	478	1	0	1.49	1.89	0	1.16	0.45	4.99
18	177	1	0	1.65	0.54	0	0.42	0.1	2.71
16	447	10	0	2.83	3.95	0	0.98	1.4	9.16
12	48	0	0	0.67	0.24	0	0.09	0.02	1.02
10	32	4	0	1.17	0.7	0	0.08	0.35	2.3
9	281	4	0	1.32	0.96	0	0.66	0.69	3.63
6	263	9	0	1.52	1.27	0	0.52	0.3	3.61
6	160	2	0	2.49	0.46	0	0.29	0.02	3.26
6	143	1	0	1.62	0.33	0	0.3	0.04	2.29
3	107	60	0	0.8	0.36	0	0.21	0.04	1.41
9	277	41	0	0	0	0	0	0	0
6	215	57	0	0	0	0	0	0	0
3	125	1	0	1.7	0.4	0	0.25	0.1	2.45
2	27	2	0	1.55	0.08	0	0.04	0.01	1.68
3	61	16	0	2.63	0.31	0	0.13	0.01	3.08
2	117	17	0	3.39	0.45	0	0.27	0.01	4.12
2	58	5	0	2.6	0.22	0	0.11	0.01	2.94
11	20	69	0	1.46	0.25	0	0.05	0.01	1.77
7	53	86	0	2.13	0.51	0	0.16	0.45	3.25
11	53	80	0	3.03	0.82	0	0.15	0.15	4.15
4	177	1	0	2.91	0.54	0	0.34	0.01	3.8
3	145	0	0	1.24	0.53	0	0.32	0.01	2.1
3	125	0	0.05	0.62	0.3	0.01	0.23	0.02	1.18
6	195	1	0	1.13	2.99	0	0.38	0.64	5.14
5	178	1	0	2.12	1.73	0	0.33	0.56	4.74
1	28	0	0	0.52	0.11	0	0.05	0.03	0.71
1	52	0	0.08	0.27	0.23	0.02	0.07	0.02	0.61
3	548	0	0	4.39	7.13	0	1.22	4.4	17.14
4	190	0	0	1.7	0.93	0	0.35	0.06	3.04
2	72	0	0.36	0.15	0.1	0.01	0.09	0.03	0.38
3	99	0	0	0.83	0.24	0	0.2	0.04	1.31
10	130	0	0	3.54	1.26	0	0.28	0.73	5.81
9	74	1	0	2.19	1.81	0	0.19	0.52	4.71
5	137	1	0	2.14	0.91	0	0.21	0.02	3.28
4	74	1	0	1.06	0.26	0	0.16	0.28	1.76
3	52	0	0.22	0.2	0.08	0.01	0.09	0.02	0.4
9	240	2	0	3.86	0.58	0	0.53	0.01	4.98
8	323	1	0	3.58	1.85	0	0.81	0.31	6.55
3	108	0	0	0.84	0.49	0	0.2	0.09	1.62
2	52	0	0	1.25	0.16	0	0.09	0.03	1.53
3	94	0	0	1.29	0.51	0	0.2	0.05	2.05
3	102	0	0	1.35	0.55	0	0.21	0.05	2.16
4	227	30	0	2.22	1.07	0	0.38	0.56	4.23
4	24	1	0	0.88	0.16	0	0.04	0.02	1.1
2	14	1	0	1.05	0.13	0	0.02	0.04	1.24
2	28	1	0	1.21	0.34	0	0.03	0.04	1.62
2	25	1	0	1.32	0.26	0	0.03	0.04	1.65
2	12	0	0.25	0.06	0.04	0.01	0.02	0.04	0.17
1	12	0	0.2	0.23	0.09	0.01	0.02	0.02	0.37
2	17	0	0.02	0.56	0.23	0.02	0.02	0.03	0.86
2	24	0	0.16	0.26	0.14	0.01	0.04	0.03	0.48
1	27	0	0.39	0.19	0.08	0.01	0.04	0.03	0.35
0	0	3	0	0	0	0	0	0	0
4	69	7	0	2.36	0.38	0	0.1	0.07	2.91
3	75	7	0	2.62	0.42	0	0.14	0.04	3.22
9	130	1	0	1.58	0.3	0	0.27	0.02	2.17
10	43	21	0	2.18	0.38	0	0.1	0.01	2.67
4	52	0	0.07	0.48	0.14	0.02	0.07	0.03	0.74
4	41	0	0.16	0.27	0.15	0.02	0.07	0.02	0.53
8	125	0	0	1.29	0.25	0	0.27	0.08	1.89
7	210	5	0	2.38	0.53	0	0.52	0.11	3.54
7	513	2	0	1.9	2.12	0	1.32	0.48	5.82
2	29	0	0.02	1.61	0.36	0.01	0.07	0.03	2.08
1	17	0	0.01	0.76	0.24	0.01	0.03	0.03	1.07
2	24	0	0.01	1.32	0.25	0.01	0.05	0.03	1.66
1	11	0	0.02	0.38	0.24	0.01	0.02	0.03	0.68
1	8	0	0.01	0.51	0.12	0.01	0.01	0.04	0.69
s_phco3	s_khco3	s_caco3	s_alexme	s_caexme	s_mgexme	s_mnexme	s_kexme	s_naexme	s_totex

p_gypsum	p_salt	t_depth	th_shst	tl_shst	tx_shst	t_text	t_mind	t_elcond	t_phcacl	t_cwb
0	0	10	13.9	7.9	10.9	1	0.86	100	6.6	0.22
0	0	10	9.2	5.3	6.6	1	0.86	6	7.4	0.3
0.3	0.9	10	10.2	3.9	7.0	3	1.15	290	8.3	0.6
0	0	10	6.5	4.2	5.4	1	0.86	3	6.2	0.14
0	0	10	6.9	4.4	5.6	1	0.86	13	8.5	0.35
0	0	10	33.8	18.0	25.5	1	0.62	4	7.4	0.15
0	0	10	20.5	10.9	31.4	1	0.62	8	8.5	0.15
0	0	10	15.3	10.9	26.2	1	0.62	9	8.2	0.16
0	0	10	15.6	13.0	14.3	1	0.62	3	6.8	0.2
0	0	10	7.6	4.6	6.1	1	0.62	1	5.6	0.14
9.2	1.2	10				2	0.6	642	8.3	0.94
2.6	0.7	10				2	0.86	430	8.3	0.41
0	0	10	10.4	5.8	8.1	1	0.62	6	7.2	0.24
0	0	10	8.0	5.3	6.3	1	0.62	5	8.4	0.18
0	0	10	9.6	7.0	8.3	1	0.62	7	8.2	0.42
0	0	10	9.6	7.0	8.3	1	0.62	7	8.1	0.49
0	0	10	8.8	7.1	7.9	1	0.62	6	8.2	0.28
0	0	10	4.6	3.1	3.8	1	0.62	6	8.4	0.12
0		10	6.8	4.7	5.8	1	0.62	25	8.3	0.53
0		10				2	0.86	11	8.1	0.7
0	0	10	13.8	8.4	11.6	1	0.86	3	7.2	0.21
0	0	10	12.2	9.6	10.9	1	0.86	1	5.9	0.1
0	0	10	26.3	9.8	23.1	1	0.86	1	4.9	0.21
0	0	10				1	0.86	1	5.6	0.11
0	0	10	15.7	10.3	13.0	1	0.86	1	5.9	0.08
0	0	10	8.0	4.1	5.9	1	0.62	1	5.8	0.08
0	0	10	14.3	9.2	11.8	1	0.62	1	4.2	0.08
6	1	10				3	1.01	9	6.4	0.2
0	0	10				1	0.86	1	4.9	0.17
0	0	10				1	0.86	1	4.2	0.16
0	0	10	9.2	4.3	6.3	1	0.86	2	6.3	0.09
0	0	10	21.1	14.6	17.9	2	0.86	1	5.7	0.12
0	0	10	10.5	6.7	8.6	1	0.62	1	5.5	0.06
0	0	10	11.2	8.4	9.8	1	0.62	3	6.5	0.14
0	0	10	12.8	9.7	11.3	1	0.62	2	6.2	0.12
0	0	10	16.8	12.1	14.4	1	0.62	2	4.6	0.18
0	0	10	43.2	20.7	31.9	1	0.62	7	8.2	0.18
0	0	10	43.2	20.7	31.9	3	1.15	4	7.1	0.26
0	0	10	18.7	14.4	16.5	1	0.62	1	4.6	0.12
0	0	10	5.9	5.0	5.5	1	0.62	1	6.2	0.12
0	0	10	14.1	9.5	11.8	1	0.62	1	5	0.1
0	0	10	14.2	6.5	10.3	1	0.62	1	5	0.08
0.5	0.2	10	17.3	10.7	14.0	2	0.86	141	8.1	0.42
0	0	10	7.3	5.4	6.3	1	0.62	5	8.2	0.14
0	0	10	5.6	4.2	4.9	1	0.62	5	8.2	0.23
0	0	10	6.2	4.6	5.4	1	0.62	8	8.2	0.21
0	0	10	5.2	4.1	4.7	1	0.62	5	8.3	0.24
0	0	10	7.5	5.9	6.7	1	0.86	1	4.5	0.2
0	0	10	7.0	6.2	7.0	1	0.86	1	4.8	0.3
0	0	10	7.1	5.9	6.5	1	0.86	1	5.1	0.42
0	0	10	8.1	6.3	7.2	1	0.86	1	4.5	0.33
0	0	10	8.7	6.8	7.7	1	0.86	2	4.4	0.45
90	0.9	10	6.0	9.5	7.8	9		606	8.4	0.47
0	0	10	7.8	6.0	6.9	1	0.62	6	8.3	0.24
0	0	10	8.2	4.7	6.4	1	0.62	7	8.3	0.38
0	0	10	7.5	4.7	6.1	1	0.62	14	7.4	0.39
0	0	10	5.9	3.7	4.8	1	0.62	7	8.4	0.24
0	0	10	15.4	11.4	13.4	1	0.62	2	5.6	0.26
0	0	10	13.9	10.1	12.0	1	0.62	1	5	0.14
0	0	10	20.0	13.9	16.8	1	0.62	2	6.4	0.16
0	0	10	17.5	12.8	15.2	2	0.86	7	8.1	0.21
0	0	10	23.6	13.8	18.7	2	0.86	16	6.8	0.14
0	0	10	9.2	6.8	8.0	1	0.62	4	5.3	0.61
0	0	10	13.1	8.1	10.6	1	0.62	4	5.6	0.42
0	0	10	4.2	2.8	3.5	1	0.62	6	5.5	0.55
0	0	10	6.8	5.0	5.8	1	0.62	2	5.4	0.34
0	0	10	5.9	4.3	5.1	1	0.62	2	5.7	0.32
s_gypsum	s_salt	t_depth	th_shst	tl_shst	tx_shst	t_text	t_mind	t_elcond	t_phcacl	t_cwb

t_ptot	t_phco3	t_khco3	t_caco3	t_alexme	t_caexme	t_mgexme	t_mnexme	t_kexme	t_naexme
150	8	320	0	0	0.88	0.83	0	0.61	0.47
200	25	210	1	0	1.35	1.09	0	0.44	0.4
240	31	210	11	0	3.95	2.96	0	0.38	0.37
130	14	56	0	0	0.7	0.29	0	0.1	0.04
77	14	38	3	0	1.65	0.88	0	0.1	0.36
160	13	190	1	0	1.05	0.42	0	0.35	0.03
120	9	160	1	0	1.54	0.82	0	0.35	0.02
130	11	140	1	0	2.47	0.38	0	0.26	0.01
150	10	140	1	0	1.48	0.35	0	0.3	0.04
100	5	140	0	0	0.77	0.34	0	0.25	0.03
350	17	310	38	0	0	0	0	0	0
210	4	150	55	0	0	0	0	0	0
73	4	96	1	0	1.22	0.28	0	0.17	0.01
42	3	34	1	0	1.38	0.09	0	0.06	0.01
100	6	70	14	0	2.85	0.21	0	0.09	0.01
120	4	92	13	0	3.71	0.32	0	0.21	0.01
85	2	66	3	0	2.45	0.19	0	0.13	0.01
540	12	20	70	0	1.48	0.25	0	0.06	0.01
630	16	37	83	0	2.48	0.56	0	0.13	0.38
562	28	39	78	0	3.36	0.44	0	0.12	0.04
120	8	170	1	0	1.87	0.46	0	0.27	0.01
120	6	120	0	0	0.93	0.45	0	0.2	0.01
140	5	150	0	0	0.6	0.34	0	0.31	0.01
170	9	150	0	0	0.63	1.1	0	0.23	0.03
130	9	160	0	0	1.16	0.82	0	0.24	0.02
45	1	29	0	0	0.61	0.08	0	0.02	0.04
57	2	29	0	0.17	0.14	0.12	0.02	0.03	0.02
170	5	340	0	0	2.18	3.5	0	0.66	1.3
120	5	170	0	0	1.3	0.74	0	0.3	0.04
160	4	66	0	0.35	0.18	0.1	0.01	0.08	0.02
110	5	79	0	0	0.94	0.22	0	0.14	0.01
210	14	150	0	0	1.42	1.11	0	0.25	0.05
140	10	73	0	0	0.57	0.36	0	0.12	0.02
140	9	150	0	0	2	1	0	0.23	0.01
110	8	80	0	0	1.07	0.4	0	0.19	0.01
120	5	61	0	0.09	0.31	0.14	0.01	0.08	0.02
140	11	270	1	0	3.52	0.56	0	0.61	0.01
190	18	300	0	0	3.4	0.76	0	0.71	0.04
110	4	64	0	0	0.6	0.31	0	0.15	0.12
80	3	57	0	0	1.11	0.15	0	0.08	0.01
100	4	70	0	0	0.74	0.27	0	0.11	0.07
120	2	98	0	0	1.22	0.4	0	0.21	0.05
160	8	190	32	0	2.44	1.11	0	0.37	0.55
56	7	22	1	0	1.1	0.11	0	0.02	0.01
33	2	15	1	0	1.44	0.12	0	0.03	0.05
35	3	26	1	0	1.25	0.17	0	0.03	0.04
38	2	21	1	0	1.42	0.21	0	0.02	0.04
51	3	14	0	0.15	0.07	0.06	0.01	0.01	0.04
51	1	16	0	0.07	0.35	0.09	0.02	0.02	0.01
73	4	26	0	0.02	0.54	0.29	0.01	0.02	0.02
70	3	20	0	0.13	0.27	0.14	0.01	0.03	0.04
66	2	46	0	0.17	0.4	0.16	0.01	0.08	0.02
160	0	0	5	0	0	0	0	0	0
66	6	51	2	0	1.97	0.2	0	0.06	0.05
82	5	56	3	0	2.55	0.22	0	0.08	0.03
87	15	150	1	0	2.19	0.4	0	0.32	0.02
170	20	34	18	0	1.87	0.16	0	0.07	0.01
130	7	64	0	0.01	0.74	0.17	0.01	0.1	0.04
120	8	41	0	0.03	0.32	0.18	0.02	0.07	0.01
140	10	130	0	0	1.16	0.26	0	0.27	0.01
120	10	200	4	0	2.55	0.44	0	0.5	0.02
140	11	280	0	0	1.54	1.11	0	0.72	0.42
39	2	28	0	0.06	1.52	0.3	0.01	0.06	0.06
28	1	18	0	0.01	1.03	0.26	0.01	0.04	0.05
53	2	23	0	0.01	1.88	0.28	0.01	0.03	0.06
28	2	16	0	0.02	0.7	0.16	0.01	0.01	0.03
22	2	15	0	0.01	0.76	0.14	0.01	0.01	0.02
t_ptot	t_phco3	t_khco3	t_caco3	t_alexme	t_caexme	t_mgexme	t_mnexme	t_kexme	t_naexme

t_totex	t_gypsum	t_salt	m_depth	mh_shst	ml_shst	mx_shst	m_text	m_mind	m_elcond	m_phcacl	m_ptot
2.79	0	0	20	88.0	55.8	71.9	3	1.15	167	7	170
3.28	0	0	20	65.7	18.0	31.6	1	0.62	4	7.5	200
7.66	0.2	0.6	20	56.2	41.1	48.7	3	1.15	296	8.6	170
1.13	0	0	20	22.2	16.6	19.4	1	0.62	1	6	140
2.99	0	0	20	31.2	25.3	28.8	1	0.62	31	8.6	76
1.85	0	0	20	56.9	39.7	49.6	2	0.86	10	7.4	140
2.73	0	0	20	94.6	82.3	88.4	4	1.43	51	8.8	110
3.12	0	0	20	64.3	47.0	55.7	1	0.62	6	8.3	120
2.17	0	0	20	46.5	33.0	39.7	1	0.62	2	6.9	130
1.39	0	0	20	29.6	27.7	28.6	1	0.62	1	5.4	98
0	0.7	1.4	15				2	0.86	679	8.5	130
0	3	0.7	30				2	0.86	367	8.3	210
1.68	0	0	20	23.7	14.4	19.1	1	0.62	8	7.3	78
1.54	0	0	20	24.0	12.2	19.7	1	0.62	5	8.3	40
3.16	0	0	20	24.2	18.5	21.3	1	0.62	7	8.2	100
4.25	0	0	20	24.2	18.5	21.3	1	0.62	7	8.2	120
2.78	0	0	20	21.2	16.7	18.9	1	0.62	7	8.1	110
1.8	0	0	20	36.7	18.1	27.4	1	0.62	7	8.4	520
3.55	0		20	19.5	13.0	16.2	1	0.62	34	8.4	621
3.96	0		20				2	0.86	11	8.1	538
2.61	0	0	20	24.3	16.8	20.6	2	0.86	4	7.5	110
1.59	0	0	20	30.1	21.7	25.9	1	0.62	2	6.5	99
1.26	0	0	20	64.8	10.3	37.5	2	0.86	1	4.8	120
1.99	0	0	20				4	1.43	37	7.3	130
2.24	0	0	20	36.2	11.7	23.9	1	0.62	3	6.4	110
0.75	0	0	20	18.3	12.2	16.3	1	0.62	1	5.9	41
0.33	0	0	20	23.3	17.1	20.2	1	0.62	2	4.4	53
7.64	0	0	20				5	1.48	198	7.3	170
2.38	0	0	20				1	0.62	1	5.1	120
0.39	0	0	20				1	0.62	1	4.2	150
1.31	0	0	20	21.0	14.1	18.2	1	0.62	2	6.6	96
2.83	0	0	20	97.3	65.7	81.5	4	1.43	8	5.8	260
1.07	0	0	20	84.4	58.6	71.5	1	0.62	1	5.5	140
3.24	0	0	20	36.1	23.8	29.9	1	0.62	2	7	120
1.67	0	0	20	22.1	10.8	16.5	1	0.62	1	6.6	98
0.56	0	0	20	12.5	10.0	11.3	1	0.62	1	4.2	96
4.7	0	0	20				2	0.86	6	8.3	130
4.91	0	0	20				3	1.15	7	8.2	150
1.18	0	0	20	28.1	12.9	20.5	1	0.62	1	4.8	120
1.35	0	0	20	15.8	14.9	15.3	1	0.62	1	6.5	75
1.19	0	0	20	22.6	12.7	17.7	1	0.62	1	5	110
1.88	0	0	20	14.0	13.9	13.9	1	0.62	1	4.9	120
4.47	0	0	20				2	0.86	196	8.4	130
1.24	0	0	20	16.9	10.5	13.7	1	0.62	3	7.3	52
1.64	0	0	20	18.5	10.9	14.7	1	0.62	2	7.5	35
1.49	0	0	20	30.4	16.3	23.4	1	0.62	5	7.5	34
1.69	0	0	20	27.7	17.9	22.8	1	0.62	3	7.9	33
0.19	0	0	20	17.4	13.1	15.2	1	0.62	1	4.4	37
0.49	0	0	20	17.4	13.3	15.4	1	0.62	1	4.4	34
0.88	0	0	20	18.5	14.1	16.3	1	0.62	0	4.7	59
0.49	0	0	20	30.4	16.3	23.4	1	0.62	1	4.3	60
0.67	0	0	20	28.4	16.3	22.3	2	0.86	1	4.2	51
0	90	0.9	20	9.5	6.0	7.8	9		470	8.5	36
2.28	0	0	20	33.0	21.8	27.4	1	0.62	6	8.3	92
2.88	0	0	20	38.7	18.1	28.4	1	0.62	6	8.3	93
2.93	0	0	20	39.2	28.8	34.0	1	0.62	5	7.4	110
2.11	0	0	20	31.4	22.8	27.1	1	0.62	14	8.4	210
1.06	0	0	20	15.2	10.7	13.0	1	0.62	2	4.5	110
0.6	0	0	20	41.5	13.9	27.7	1	0.62	1	4.4	110
1.7	0	0	20	37.2	11.2	24.2	1	0.62	2	6.6	130
3.51	0	0	20				2	0.86	47	8.2	120
3.79	0	0	20	44.7	13.7	29.2	2	0.86	185	8.2	130
1.95	0	0	20				1	0.62	5	6	45
1.39	0	0	20	30.2	22.9	26.6	1	0.62	3	6.1	26
2.26	0	0	20	25.8	14.2	20.0	1	0.62	4	5.7	54
0.91	0	0	20	25.1	17.2	21.2	1	0.62	1	4.8	18
0.94	0	0	20	33.6	25.4	29.5	1	0.62	3	5.8	18
t_totex	t_gypsum	t_salt	m_depth	mh_shst	ml_shst	mx_shst	m_text	m_mind	m_elcond	m_phcacl	m_ptot

m_phco3	m_khco3	m_caco3	m_alexme	m_caexme	m_mgexme	m_mnexme	m_kexme	m_naexme	m_totex
6	440	0	0	1.15	1.98	0	1.04	0.55	4.72
18	170	1	0	1.65	0.38	0	0.41	0.01	2.45
9	270	14	0	2.34	3.08	0	0.53	0.86	6.81
12	43	0	0	0.73	0.23	0	0.08	0.02	1.06
12	34	1	0	1.06	0.85	0	0.11	0.48	2.5
10	300	1	0	1.05	0.44	0	0.3	0.27	2.06
5	210	1	0	1.29	1.06	0	0.46	0.36	3.17
4	160	1	0	2.46	0.46	0	0.27	0.06	3.25
4	150	1	0	1.6	0.34	0	0.31	0.01	2.26
2	97	0	0	0.86	0.37	0	0.2	0.05	1.48
7	260	37	0	0	0	0	0	0	0
7	280	58	0	0	0	0	0	0	0
3	160	1	0	1.7	0.34	0	0.34	0.06	2.44
2	26	1	0	1.57	0.06	0	0.04	0.01	1.68
2	54	16	0	2.56	0.32	0	0.12	0.01	3.01
2	130	16	0	3.33	0.41	0	0.3	0.01	4.05
1	49	8	0	2.75	0.26	0	0.1	0.01	3.12
10	20	68	0	1.44	0.26	0	0.04	0.01	1.75
2	56	87	0	2.24	0.46	0	0.17	0.62	3.49
3	63	79	0	3.55	0.74	0	0.17	0.26	4.72
2	160	1	0	2.95	0.52	0	0.31	0.01	3.79
2	140	0	0	1.18	0.48	0	0.29	0.01	1.96
1	120	0	0	0.64	0.23	0	0.25	0	1.12
2	240	1	0	1.63	4.88	0	0.52	1.25	8.28
4	180	0	0	2.01	1.51	0	0.31	0.25	4.08
1	24	0	0	0.58	0.12	0	0.06	0.03	0.79
1	63	0	0.09	0.25	0.19	0.03	0.06	0.03	0.56
2	680	0	0	6.6	13.77	0	1.77	7.51	29.65
2	210	0	0	2.1	1.12	0	0.39	0.08	3.69
2	67	0	0.4	0.09	0.05	0.01	0.07	0.03	0.25
3	130	0	0	0.77	0.2	0	0.27	0.01	1.25
10	110	0	0	3.4	2.68	0	0.24	0.86	7.18
9	65	0	0	0.62	0.44	0	0.13	0.07	1.26
3	140	1	0	2.55	1.01	0	0.22	0.01	3.79
3	69	0	0	1.42	0.28	0	0.17	1.05	2.92
2	45	0	0.35	0.09	0.04	0.01	0.05	0.02	0.21
6	210	4	0	4.21	0.61	0	0.45	0.01	5.28
4	370	1	0	5.29	0.68	0	0.93	0.02	6.92
2	91	0	0	0.83	0.49	0	0.2	0.08	1.6
1	54	0	0	1.36	0.14	0	0.1	0.05	1.65
2	86	0	0	0.89	0.38	0	0.18	0.04	1.49
5	92	0	0	0.84	0.42	0	0.16	0.03	1.45
3	250	31	0	2.15	1.03	0	0.37	0.53	4.08
2	26	1	0	1.19	0.08	0	0.03	0.03	1.33
2	14	1	0	1.16	0.11	0	0.02	0.04	1.33
2	30	1	0	1.14	0.19	0	0.04	0.03	1.4
2	26	1	0	1.42	0.19	0	0.03	0.02	1.66
2	13	0	0.27	0.07	0.04	0.01	0.03	0.03	0.18
1	10	0	0.18	0.25	0.06	0.01	0.01	0.01	0.34
1	13	0	0.05	0.44	0.18	0.02	0.03	0.03	0.7
1	27	0	0.22	0.21	0.1	0.01	0.04	0.03	0.39
1	21	0	0.32	0.19	0.07	0.01	0.03	0.01	0.31
0	0	1	0	0	0	0	0	0	0
3	80	6	0	2.46	0.26	0	0.11	0.04	2.87
3	75	6	0	2.74	0.29	0	0.11	0.03	3.17
7	130	1	0	1.69	0.31	0	0.28	0.05	2.33
6	53	21	0	2.67	0.35	0	0.11	0.01	3.14
2	57	0	0.15	0.32	0.09	0.02	0.08	0.02	0.53
3	41	0	0.24	0.14	0.06	0.01	0.07	0.02	0.3
5	120	0	0	1.43	0.24	0	0.26	0.14	2.07
4	220	6	0	2.21	0.63	0	0.54	0.2	3.58
6	590	1	0	1.61	1.48	0	1.29	0.43	4.81
2	25	0	0	1.57	0.31	0	0.08	0.02	1.98
1	17	0	0	0.81	0.21	0	0.04	0.01	1.07
2	22	0	0	1.48	0.24	0	0.04	0.02	1.78
1	5	0	0.04	0.16	0.12	0.01	0.01	0.02	0.32
1	5	0	0	0.61	0.12	0	0.01	0.01	0.75
m_phco3	m_khco3	m_caco3	m_alexme	m_caexme	m_mgexme	m_mnexme	m_kexme	m_naexme	m_totex

m_gypsum	m_salt	b_depth	b_text	b_mind	b_elcond	b_phcacl	b_ptot	b_phco3	b_khco3	b_caco3
0	0	70	6	1.49	455	8.3	190	6	675	3
0	0	70	3	1.15	6	8.2	195	11	150	1
0.4	0.8	60	8	1.2	476	8.7	220	7	860	4
0	0	70	1	0.62	1	6	145	10	46	0
0	0	70	1	0.62	19	8.8	55	4	23	6
0	0	70	3	1.15	119	8.6	153	4	353	7
0	0	20	4	1.43	223	8.6	115	4	420	18
0	0	20	1	0.62	7	8.3	120	2	180	5
0	0	20	1	0.62	1	7.1	120	3	140	1
0	0	20	1	0.62	1	5.7	92	2	84	0
26	1.2	20	3	1.15	434	8.6	130	2	260	48
2.2	0.8									
0	0	10	1	0.62	12	8.2	71	2	120	1
0	0	60	1	0.62	5	8.3	43	2	21	4
0	0	20	1	0.62	7	8.2	100	2	59	17
0	0	20	1	0.62	8	8.1	130	1	130	21
0	0									
0	0									
0		70	1	0.62	35	8.5	600	2	66	87
0		70	2	0.86	10	8.3	430	3	57	82
0	0	15	3	1.15	4	7.9	100	1	200	1
0	0	60	1	0.62	2	6.8	100	2	175	0
0	0	70	3	1.15	1	4.8	110	2	105	0
0	0									
0	0	70	3	1.15	31	7.6	115	2	195	1
0	0	70	1	0.62	1	5.8	37	1	30	0
0	0	70	1	0.62	1	4.7	52	1	65	0
0	0	70	7	2.34	592	7	153	2	623	0
0	0									
0	0	70	1	0.62	1	4.2	145	1	84	0
0	0	70	1	0.62	4	6.5	92	2	88	0
0	0	20	8	1.2	20	6.6	240	7	130	0
0	0	70	4	1.43	53	6.9	230	8	85	1
0	0	20	1	0.62	2	7.3	110	3	120	1
0	0	70	1	0.62	2	7.3	95	2	74	1
0	0	70	1	0.62	2	4.2	87	1	51	0
0	0									
0	0	25	3	1.15	7	8.3	140	2	300	1
0	0	45	1	0.62	1	5.1	120	2	170	0
0	0	20	1	0.62	1	6.8	79	1	44	0
0	0	70	1	0.62	1	5.7	130	2	125	0
0	0	70	3	1.15	1	5.4	115	2	115	0
0	0	50	1	0.62	365	8.4	105	2	240	29
0	0	70	1	0.62	1	5.4	51	2	24	0
0	0	70	1	0.62	3	7.3	32	1	14	1
0	0	70	1	0.62	4	7.5	37	1	27	1
0	0	70	1	0.62	2	7.8	33	2	27	1
0	0	70	1	0.62	1	4.3	35	2	8	0
0	0	70	1	0.62	1	4.3	31	1	11	0
0	0	70	2	0.86	1	5.2	61	1	12	0
0	0	70	1	0.62	1	4.3	54	1	26	0
0	0	70	2	0.86	2	4.1	50	1	15	0
89	0.7									
0	0	70	1	0.62	7	8.3	100	2	76	10
0	0	70	1	0.62	8	8.3	90	2	95	10
0	0	70	1	0.62	3	7.5	92	4	110	1
0	0	70	1	0.62	9	8.4	200	4	42	22
0	0	70	1	0.62	3	4.8	90	3	36	0
0	0	70	1	0.62	1	4.4	92	2	42	0
0	0									
0	0									
0	0	70	5	1.48	267	8.4	120	5	670	3
0	0	20	1	0.62	5	6.4	41	1	34	0
0	0	70	1	0.62	2	6.2	32	1	17	0
0	0	70	1	0.62	2	5.5	61	2	28	0
0	0	70	1	0.62	1	5.6	25	1	13	0
0	0	70	1	0.62	2	5.7	19	1	5	0
m_gypsum	m_salt	b_depth	b_text	b_mind	b_elcond	b_phcacl	b_ptot	b_phco3	b_khco3	b_caco3

b_alexme	b_caexme	b_mgexme	b_mnexme	b_kexme	b_naexme	b_totex	b_gypsum	b_salt	g_cfrag	g_outcrp
0	1.97	2.38	0	1.49	0.39	6.23	0	0	0	0
0	1.8	0.34	0	0.41	0.01	2.56	0	0	0	0
0	2.19	5.8	0	2.04	2.98	13.01	0.3	1.3	3	0
0	0.62	0.23	0	0.09	0.02	0.96	0	0	0	0
0	1	0.51	0	0.06	0.28	1.85	0	0	3	0
0	1.6	1.49	0	0.94	1.18	5.21	0	0	0	0
0	1.64	1.59	0	0.62	0.42	4.27	0	0	0	0
0	2.55	0.54	0	0.33	0.01	3.43	0	0	0	0
0	1.78	0.31	0	0.29	0.06	2.44	0	0	0	0
0	0.77	0.38	0	0.19	0.04	1.38	0	0	0	0
0	0	0	0	0	0	0	0.9	1.2	0	0
									0	0
0	2.18	0.58	0	0.24	0.14	3.14	0	0	0	1
0	1.62	0.08	0	0.04	0.01	1.75	0	0	0	0
0	2.47	0.39	0	0.13	0.01	3	0	0	0	0
0	3.14	0.63	0	0.3	0.01	4.08	0	0	0	2
									0	0
									0	0
0	1.66	0.52	0	0.17	0.36	2.71	0		0	0
0	2.19	1.28	0	0.15	0.15	3.77	0		0	0
0	3.91	0.63	0	0.43	0.01	4.98	0	0	5	3
0	1.42	0.58	0	0.38	0.01	2.39	0	0	1	0
0.11	0.61	0.3	0.01	0.17	0.03	1.12	0	0	0	0
									5	3
0	2.66	2.29	0	0.4	0.98	6.33	0	0	0	0
0	0.44	0.12	0	0.06	0.03	0.65	0	0	0	0
0.03	0.34	0.3	0.01	0.08	0.02	0.75	0	0	0	0
0	0	0	0	0	0	0	10.1	1.2	5	3
									3	0
0.35	0.17	0.13	0.02	0.1	0.04	0.46	0	0	0	0
0	0.8	0.27	0	0.19	0.08	1.34	0	0	2	0
0	5.79	4.4	0	0.35	1.27	11.81	0	0	2	0
0	3.79	3.22	0	0.25	1	8.26	0	0	0	0
0	1.88	0.73	0	0.18	0.04	2.83	0	0	0	0
0	1.38	0.18	0	0.14	0.02	1.72	0	0	0	0
0.22	0.21	0.08	0.01	0.06	0.02	0.38	0	0	0	0
									0	1
0	2.04	4.12	0	0.8	0.88	7.84	0	0	4	0
0	0.98	0.59	0	0.23	0.08	1.88	0	0	0	0
0	1.28	0.19	0	0.09	0.04	1.6	0	0	0	0
0	1.76	0.69	0	0.26	0.05	2.76	0	0	1	0
0	1.66	0.7	0	0.24	0.06	2.66	0	0	0	0
0	2.06	1.08	0	0.39	0.59	4.12	1	0.5	3	0
0	0.63	0.22	0	0.07	0.02	0.94	0	0	0	0
0	0.8	0.14	0	0.02	0.05	1.01	0	0	0	0
0	1.23	0.31	0	0.03	0.05	1.62	0	0	0	0
0	1.23	0.31	0	0.03	0.04	1.61	0	0	0	0
0.28	0.06	0.04	0.01	0.01	0.03	0.15	0	0	0	0
0.24	0.18	0.11	0.01	0.02	0.03	0.35	0	0	0	0
0.01	0.64	0.26	0.01	0.01	0.02	0.94	0	0	0	0
0.15	0.29	0.16	0.01	0.04	0.05	0.55	0	0	0	0
0.53	0.09	0.16	0.01	0.01	0.02	0.29	0	0	0	0
									0	0
0	2.5	0.52	0	0.11	0.09	3.22	0	0	3	0
0	2.5	0.52	0	0.11	0.09	3.22	0	0	1	0
0	1.22	0.26	0	0.24	0.01	1.73	0	0	3	0
0	2.08	0.5	0	0.13	0.01	2.72	0	0	3	0
0.06	0.44	0.15	0.03	0.05	0.03	0.7	0	0	0	2
0.18	0.31	0.13	0.01	0.07	0.03	0.55	0	0	0	0
									1	2
									4	2
0	2.28	2.94	0	1.63	0.54	7.39	0	0	0	3
0	1.73	0.46	0	0.08	0.02	2.29	0	0	4	4
0	0.6	0.24	0	0.02	0.01	0.87	0	0	3	2
0	0.95	0.25	0	0.06	0.01	1.27	0	0	4	2
0.01	0.33	0.35	0.01	0.03	0.03	0.75	0	0	0	0
0.01	0.33	0.12	0.01	0.01	0.06	0.53	0	0	0	0
b_alexme	b_caexme	b_mgexme	b_mnexme	b_kexme	b_naexme	b_totex	b_gypsum	b_salt	g_cfrag	g_outcrp

l_sandst	l_mudst	l_calc	l_calcar	l_silcr	l_limest	l_ferric	l_alluv	l_eolian	l_tidal	l_birrid	l_pan	ge_erod
A	A	P	A	A	A	A	P	P	A	A	A	D
A	A	A	A	A	A	A	A	P	A	A	A	N
A	A	A	A	A	A	A	P	A	P	A	A	A
A	A	P	A	A	A	A	A	A	A	A	A	A
A	A	A	A	A	A	A	A	A	P	A	A	D
A	A	A	A	A	A	A	A	A	P	A	A	A
A	A	A	A	A	A	A	A	A	P	A	A	A
A	A	A	A	A	A	A	A	P	A	A	A	A
A	A	A	A	A	A	A	A	P	A	A	A	A
A	A	A	A	A	A	A	A	P	A	A	A	A
A	A	P	A	A	P	A	A	P	A	A	A	A
A	A	P	P	A	A	A	A	A	A	A	A	D
A	A	P	A	A	A	A	A	A	A	A	A	A
A	A	P	P	A	A	A	A	A	A	A	A	A
A	A	P	A	A	A	A	A	A	A	A	A	M
A	A	P	A	A	A	A	A	A	A	A	A	A
A	A	P	A	A	A	A	A	A	A	A	A	D
A	A	P	A	A	A	A	A	A	A	A	A	D
A	A	P	A	A	A	A	A	A	A	A	A	M
A	A	P	A	A	A	A	A	A	A	A	A	N
P	P	A	A	A	P	A	A	A	A	A	A	D
A	A	P	A	A	A	A	P	A	A	A	A	M
A	A	P	A	A	A	A	A	A	A	A	A	D
P	A	A	A	A	A	P	A	A	A	A	A	D
A	A	P	A	A	A	A	P	A	A	A	A	A
A	A	P	A	A	A	A	A	P	A	A	A	A
P	A	A	A	P	A	P	A	A	A	A	A	D
P	P	A	A	P	A	P	P	A	A	A	A	D
P	P	A	A	P	A	A	P	A	A	A	A	D
P	A	A	A	A	A	A	P	A	A	A	A	A
A	A	A	A	A	A	A	P	A	A	A	A	D
A	A	A	A	A	A	A	P	A	A	A	A	D
A	A	A	A	A	A	A	P	A	A	A	A	A
A	A	A	A	A	A	A	P	A	A	A	A	A
A	A	A	A	A	A	A	A	P	A	A	A	A
A	A	A	A	A	A	A	A	P	A	A	A	N
A	A	P	A	A	A	A	A	A	A	A	A	D
A	A	P	A	A	A	A	A	A	A	A	A	D
A	A	A	A	A	A	A	A	P	A	A	A	A
A	A	A	A	A	A	A	A	P	A	A	A	M
A	A	A	P	A	A	A	A	A	A	A	A	A
A	A	A	P	A	A	A	A	A	A	A	A	D
A	A	P	A	A	A	A	A	A	P	P	A	N
A	A	A	A	A	A	A	A	P	A	A	A	N
A	A	A	A	A	A	A	A	P	A	A	A	A
A	A	A	A	A	A	A	A	P	A	A	A	A
A	A	A	A	A	A	A	A	P	A	A	A	A
A	A	A	A	A	A	A	A	P	A	A	A	N
A	A	A	A	A	A	A	A	P	A	A	A	N
A	A	A	A	A	A	A	A	P	A	A	A	N
A	A	A	A	A	A	A	A	P	A	A	A	N
A	A	A	A	A	A	A	A	P	A	A	A	N
A	A	A	A	A	A	A	A	A	A	P	A	N
A	A	A	A	A	A	A	A	P	A	A	A	N
A	A	A	A	A	A	A	A	P	A	A	A	N
A	A	A	A	A	A	A	A	P	A	A	A	N
A	A	A	A	A	A	A	A	P	A	A	A	N
A	A	P	A	A	A	A	A	A	A	A	A	A
A	A	P	A	A	A	A	A	A	A	A	A	M
A	A	P	A	A	A	A	A	A	A	A	A	D
A	A	P	A	A	A	A	A	A	A	A	A	D
A	A	P	A	A	A	A	A	A	A	A	A	D
P	A	P	P	A	A	A	A	A	A	A	A	D
P	A	P	P	A	A	A	A	A	A	A	A	D
P	A	P	P	A	A	A	A	A	A	A	A	D
P	A	P	P	A	A	A	A	A	A	A	A	D
P	A	P	P	A	A	A	A	A	A	A	A	D
l_sandst	l_mudst	l_calc	l_calcar	l_silcr	l_limest	l_ferric	l_alluv	l_eolian	l_tidal	l_birrid	l_pan	ge_erod

ge_agrad	ga_chann	gs_chann	ga_eust	gs_eust	ga_grav	gs_grav	ga_over	gs_over	ga_sheet	gs_sheet
D	D	R	A	N	A	N	A	N	A	N
D	A	N	A	N	A	N	A	N	A	N
D	A	N	D	R	A	N	A	N	A	F
D	A	N	M	R	A	N	A	N	A	N
D	A	N	D	R	A	N	A	N	A	N
D	A	N	D	R	A	N	A	N	A	N
D	A	N	D	R	A	N	A	N	A	N
D	A	N	D	N	A	N	A	N	A	N
D	A	N	A	N	A	N	A	N	A	N
D	A	N	A	N	A	N	A	N	A	N
M	A	N	D	R	A	N	A	N	D	F
N	A	N	D	R	A	N	A	N	D	F
D	A	N	A	N	A	N	A	N	N	N
D	A	N	A	N	A	N	A	N	A	N
D	A	N	A	N	A	N	A	N	N	F
D	A	N	A	N	A	N	A	N	D	F
D	A	N	A	N	A	N	A	N	N	F
D	A	N	A	N	A	N	A	N	A	N
D	A	N	A	N	A	N	A	N	A	N
D	A	N	A	N	A	N	A	N	A	N
D	D	F	A	N	D	F	D	F	D	F
D	D	S	A	N	A	N	D	F	N	F
A	D	S	A	N	A	N	M	S	D	F
A	A	N	A	N	A	N	A	N	D	F
D	A	F	A	N	A	N	D	F	N	F
D	A	N	A	N	A	N	A	N	A	N
D	A	N	A	N	A	N	A	N	A	N
D	D	F	A	F	D	N	D	F	D	F
A	N	F	A	N	A	N	A	N	D	F
D	A	N	A	N	A	N	A	N	D	F
D	A	N	A	N	A	N	A	N	D	F
N	A	F	A	N	A	N	M	S	D	F
D	A	N	A	N	A	N	M	S	D	F
D	D	F	A	N	A	N	D	F	A	N
D	A	N	A	N	A	N	A	N	A	N
D	A	N	A	N	A	N	A	N	N	F
N	D	F	A	N	A	N	A	N	D	F
N	M	F	A	N	A	N	A	N	N	F
D	A	N	A	N	A	N	A	N	A	N
D	A	N	A	N	A	N	A	N	A	N
D	A	N	A	N	A	N	A	N	A	N
D	A	N	A	N	A	N	A	N	A	N
D	A	N	D	R	A	N	A	N	D	C
D	A	N	A	N	A	N	A	N	A	N
D	A	N	A	N	A	N	A	N	A	N
D	A	N	A	N	A	N	A	N	A	N
D	A	N	A	N	A	N	A	N	A	N
D	A	N	A	N	A	N	A	N	A	N
D	A	N	A	N	A	N	A	N	D	F
D	A	N	A	N	A	N	A	N	D	F
D	A	N	A	N	A	N	A	N	D	F
D	A	N	A	N	A	N	A	N	A	N
D	A	N	M	R	A	N	A	N	A	N
D	A	N	A	N	A	N	A	N	A	N
D	A	N	A	N	A	N	A	N	A	N
D	A	N	A	N	A	N	A	N	A	N
D	A	N	A	N	A	N	A	N	A	N
D	A	N	A	N	A	N	A	N	D	F
D	A	N	A	N	A	N	A	N	N	F
N	A	N	A	N	A	N	A	N	A	N
D	A	N	A	N	A	N	A	N	A	N
D	A	N	A	N	A	N	A	N	A	F
D	A	N	A	N	A	N	A	N	D	F
D	A	N	A	N	A	N	A	N	D	F
D	A	N	A	N	A	N	A	N	D	F
D	A	N	A	N	A	N	A	N	D	F
D	A	N	A	N	A	N	A	N	D	F
ge_agrad	ga_chann	gs_chann	ga_eust	gs_eust	ga_grav	gs_grav	ga_over	gs_over	ga_sheet	gs_sheet

ga_inund	gs_inund	ga_solut	gs_solut	ga_wind	gs_wind	ga_marin	gs_marin	g_slope	g_runon	g_runoff
A	N	A	N	D	C	A	N	1	V	0
A	N	A	N	D	C	A	N	3	L	0
M	F	A	N	A	R	D	B	1	L	0
A	N	A	N	D	B	M	R	4	L	0
M	F	A	N	D	B	D	R	2	L	0
M	F	A	N	M	C	D	R	1	V	0
M	F	A	N	M	C	D	R	1	L	0
A	N	A	N	D	C	A	N	1	L	0.5
A	N	A	N	D	C	A	N	2	L	0.5
A	N	A	N	D	C	A	N	3	V	0
M	F	M	C	N	N	D	R	1.5	VL	0
A	N	M	C	D	C	D	R	1.5	L	0
A	N	A	N	D	F	A	N	1	I	1
A	N	A	N	D	F	A	N	5	V	0
D	N	N	C	D	F	A	N	5	L	1
A	N	N	N	D	F	A	N	1	L	1
A	N	N	C	D	R	A	N	2	V	1
A	N	N	C	D	C	A	N	4	V	1
A	N	A	N	D	C	A	N	4	L	0
A	N	A	N	D	C	A	N	2	L	0
A	F	A	N	N	F	A	N	4	H	3
A	F	A	N	D	N	A	N	1	I	2
A	F	A	N	A	F	A	N	1	L	2
A	N	A	N	N	S	A	N	2	F	3
D	F	A	N	D	C	A	N	1	I	1
A	N	A	N	D	C	A	N	4	L	0
A	N	A	N	D	C	A	N	1	V	0
A	N	A	N	A	R	A	N	4	H	5
A	N	A	N	A	R	A	N	2	I	0.5
A	N	A	N	N	F	A	N	1	I	0.5
A	N	A	N	D	C	A	N	4	H	3
D	F	A	N	M	C	A	N	1	L	0
A	F	A	N	D	C	A	N	4	H	2.5
A	F	A	N	A	N	A	N	2	H	0
A	N	A	N	D	C	A	N	1	L	1
A	N	A	N	M	C	A	N	1	L	1
A	N	N	C	N	F	A	N	2	L	2
A	N	N	C	N	F	A	N	2	L	2
A	N	A	N	D	C	A	N	1	L	0
A	N	A	N	D	C	A	N	4	L	0.5
A	N	A	N	D	C	A	N	2	L	2
A	N	A	N	D	C	A	N	1	L	0
M	F	A	N	D	C	D	R	1	L	1
A	N	A	N	D	C	A	N	2	L	0
A	N	A	N	D	C	A	N	3	L	0
A	N	A	N	D	C	A	N	2	L	0
A	N	A	N	D	C	A	N	2	L	0
A	N	A	N	D	C	A	N	2	L	0
A	N	A	N	D	C	A	N	3	V	2
A	N	A	N	D	C	A	N	2	V	2
A	N	A	N	D	C	A	N	1	V	1
A	N	A	N	W	C	A	N	2	V	0
D	F	M	C	A	N	A	N	1	L	1
A	N	A	N	D	C	A	N	2	L	0.5
A	N	A	N	D	C	A	N	2	L	0.5
A	N	A	N	D	C	A	N	2	L	0.5
A	N	A	N	D	C	A	N	3	L	0
A	N	A	N	D	C	A	N	1	L	0.5
A	N	A	N	D	C	A	N	2	V	1
A	N	N	C	M	C	A	N	1	L	2
A	N	N	C	D	C	A	N	1	L	0
A	N	N	C	D	C	A	N	1	L	0.5
A	N	D	C	D	C	A	N	2	V	0
A	N	D	C	N	C	A	N	2	L	1
A	N	N	C	D	C	A	N	3	L	2
A	N	A	N	A	C	A	N	2	L	1
A	N	A	N	D	C	A	N	2	L	0

ga_inund gs_inund ga_solut gs_solut ga_wind gs_wind ga_marin gs_marin g_slope g_runon g_runoff