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REGOLITH–LANDFORM RESOURCES OF THE GERALDTON 1:50 000 SHEET

by R. L. Langford

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

DEPARTMENT OF MINERALS AND ENERGY

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Regolith–landform resources of the Geraldton 1:50 000 sheet

by

R. L. Langford

Abstract

Regolith–landform mapping of the GERALDTON 1:50 000 map sheet, located about 420 km north of Perth, has defined five land systems, and provided a subdivision of the seabed materials and morphology. The onshore systems are the Moresby, Spearwood, Greenough, Greenough Alluvium, and Quindalup Systems. These are defined on the basis of the dominant underlying parent materials. The Moresby System is a plateau and sideslopes composed of residual materials and colluvial deposits over weathered Jurassic rocks, with minor occurrences of Triassic and Proterozoic rocks. The Spearwood System is equivalent to the Pleistocene Tamala Limestone, and is composed of residual sand over calcarenite in a series of deflated dunes. The Greenough System is composed of alluvial terraces and channels related to the upper reaches of the Chapman River, and the Greenough Alluvium System is the local development of an alluvial plain on the Chapman and Greenough rivers. The Quindalup System is equivalent to the Safety Bay Sand, and comprises Holocene dunes and coastal deposits. The Marine System occupies the bulk of the GERALDTON sheet, and includes an offshore marine plain, and nearshore seabed and shoreface.

Each system has been divided into mapping units based on vegetation, landform elements and patterns, and regolith characteristics. These units, combined with knowledge of the subsurface geology, have been used to provide information on landuse, mineral potential, geological processes such as weathering and erosion, and hazards related to landforms. The most significant hazard is flooding of the alluvial plains at times of exceptional rainfall, either locally or in the larger catchment. Other possible hazards include wind erosion in the coastal dunes, and coastal erosion during storms.

The mineral resource potential of GERALDTON is limited to gravel, sand, limestone, limesand, and clay, mostly for use in construction and infrastructure development. There are no recorded occurrences of base metals in the basement rocks, no heavy mineral sand concentrations have been located in the coastal sands, and no coal has been reported in the Jurassic Cattamarra Coal Measures.

KEYWORDS: Geraldton, urban geology, geomorphology, mineral resources, industrial minerals, construction materials, regolith–landform, landuse, land systems, hazards.

Introduction

The GERALDTON regolith–landform resources map is designed to facilitate landuse planning, the sustainable development of mineral resources, including construction materials (basic raw materials), and identification of hazards, both onshore and in shallow marine areas. The map will be of use to Government departments and agencies, local government and public utilities, the resource, construction, agricultural, and tourism industries, and of interest to the general public.

The map provides information on the regolith (engineering soils) and underlying rocks, on the landforms (landscape), topography and infrastructure, and on the mineral resources of GERALDTON. Land systems are identified as areas with recurring patterns of landform, regolith, and vegetation; each system contains discrete landform elements or materials. These regolith–landform units are related to geological and hydro-geological units, and can be used for identifying landuse and mineral resources potential.

The accompanying CD-ROM contains the data used to compile the map and report, the files necessary for viewing the data in a Geographical Information System (GIS) environment, and a self-loading version of the ArcExplorer™ software package.

Location

The GERALDTON* 1:50 000 map sheet (SH50-1-1840-III) lies between latitudes 28° 45' and 29° 00'S, and longitudes 114° 30' and 114° 45'E (Fig. 1). The sheet lies in the Mid West Region of Western Australia, and covers

*Capitalized names refer to standard map sheets parts of the City of Geraldton and the Shire of Greenough. Perth, the capital city of Western Australia, lies about 420 km to the south-southeast. The land area of the sheet is 251 km^2, and the offshore area is about 425 km^2. The populations of the City, and Greenough Shire are about 21 000 and 12 000 respectively, although both population centres extend into the adjacent map sheets to the north and east.

Infrastructure

The City of Geraldton is at the northern end of the Brand Highway, and the southern end of the North West Coastal Highway. These two highways form one of the major road routes connecting Perth with the north of the State, the other being the inland Great Northern Highway. There is also a major road to the east, the Geraldton – Mount Magnet Road, connecting Geraldton to Mount Magnet through Mullewa.

There is a railway line heading southeast out of the city that divides at Narngulu into a line heading east towards Mullewa, Perenjori, Wongan Hills, and Northam, and a line heading southeast towards Dongara, Mingenew, Three Springs, and Moora. The lines, operated by Westrail, are used exclusively for bulk products, including grain, mineral sands, and talc.

Geraldton Airport, owned and operated by the Shire of Greenough, is about 15 km east of the city. The airport provides a scheduled domestic air service to Perth, and services to a number of smaller communities and mine sites in the Mid West Region. The Port of Geraldton, located at the railhead in Champion Bay, is primarily for the export of grain and mineral sands from the hinterland. An access channel for the port has been dredged through the shallow nearshore seabed.

Significant road and rail infrastructure developments are planned. These include a realignment of the North West Coastal Highway and Brand Highway to skirt densely populated urban areas, and the development of a Southern Transport Corridor. These developments will remove the railway from the city centre, improving access to the port from the Narngulu area (Fig. 2). A rail link is also planned to link north from Moonyoonooka along

Figure 1. Location of GERALDTON in Western Australia

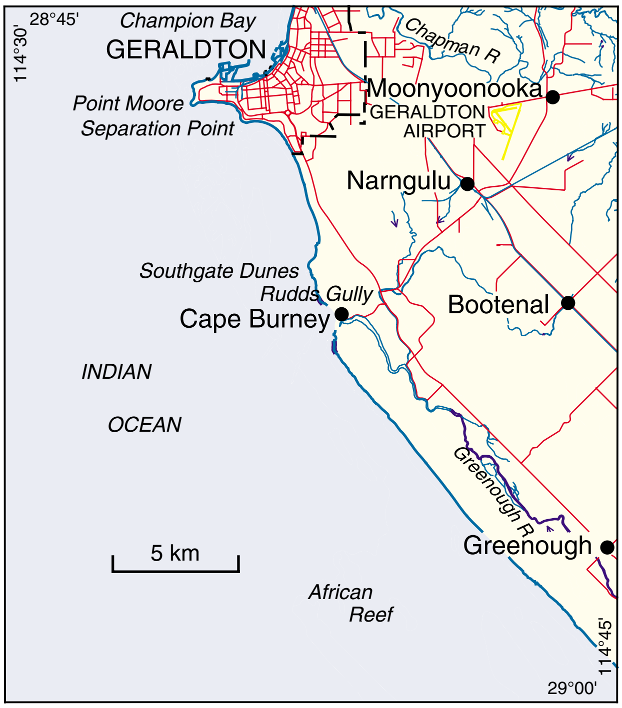

Figure 2. Infrastructure and drainage

the Chapman River valley to the proposed industrial development at Oakajee, about 20 km north of Geraldton (Department of Resources Development, 1999).

The Geraldton Region has limited potable surface water resources, and relies heavily on groundwater supplies from the Allanooka Water Reserve, 50 km southeast of Geraldton. This is distributed through a pipeline that runs alongside the railway and road from Walkaway.

Natural gas is available from the Bunbury–Dampier pipeline, and independent gas supplies are available from West Australian Petroleum (WAPET) at Dongara and from Boral Energy's Beharra Springs Gas Facility 35 km south of Dongara.

Landuse

McArthur (1991) and Rogers (1996) documented in detail the history of settlement in the region. Aboriginal people have occupied the land for about 40 000 years prior to European settlement. The first exploration by European colonists was by Lieutenant Grey in 1839. The Gregory brothers, who explored the district in 1846 and 1848, noted good agricultural land, and discovered lead and coal nearby. Geraldton, which was settled in 1851, derived its name from the Geraldine lead mine 120 km to the north. Pastoral blocks were first established inland from 1849 to 1862, and agricultural settlements were established on the Greenough Flats between 1853 and 1857. The Midland Railway, linking Perth and Geraldton, was completed in 1894.

The first town jetty was built in 1874, extending 244 m north of Gregory Street. In 1893 a new 290 m jetty was built northwards from Durlacher Street. Work on the present port began in 1924, and a 670 m breakwater was completed in 1926. Wharf construction began in 1928, and the first reinforced concrete berth was opened in 1931. Expansion has continued to the present day with the recent construction of No. 6 berth, and planned re-construction of No. 1 and No. 2 berths in 2000. The port can handle ships up to 200 m long, and with a fully laden capacity of up to 20 000 tonnes, with access along an approach channel dredged to 9.6 m depth.

The dominant landuses on GERALDTON are urban, infrastructure and industrial developments, recreation reserves, and agricultural production. Urban development today is expanding the City of Geraldton along the coast to the north and south. The principal component of infrastructure is the Port of Geraldton, which has been expanded by land reclamation. Geraldton airport, the Geraldton – Mount Magnet Road, and the railway all utilize the flat land of the Chapman River – Bootenal – Walkaway area, whereas the Brand Highway traverses the Greenough Flats. Land has been reserved to the east and southeast of the city for the future development of the Southern Transport Corridor. The alluvial plain between the Chapman River and Rudds Gully Road includes a thriving horticultural industry, and the Narngulu industrial estate is also in this area, adjacent to the railway line about 8 km from the city. Recreation reserves occupy parts of the coastal dunes southeast of the city.

Based on the criteria given by Dye et al. (1990), no prime agricultural land has been identified on GERALDTON. However, high-quality land has been identified on the Chapman River – Bootenal – Walkaway alluvial plain and on the Greenough Flats (Dye et al., 1990). The area of high-quality agricultural land has been estimated from this regolith–landform survey as 9070 ha, or 36% of the total land area (Fig. 3). This total includes land that has been sterilized by urban, industrial, and infrastructure development, and the amount of available land is less than 30%.

There is very little mineral production on GERALDTON, and it is all for industrial or construction uses. Production is from a limesand operation south of the city, two active limestone quarries southeast of the city, and a clay pit adjacent to the brickworks at Bootenal. In addition, there are a number of gravel pits in the hills around Moonyoonooka, and a few small sand pits supplying the building industry, mostly located close to the city.

Vegetation

The GERALDTON sheet area lies in the Irwin Botanical District of the Northern Sandplains District, which is part of the Southwest Botanical Province (Beard, 1990; Rogers, 1996; Table 1). The district is divided into two vegetation systems on GERALDTON; the Greenough and the Northampton. The Greenough system forms a 5 to 15 km wide strip along the coast, and the Northampton system covers all the inland hilly areas underlain by the Proterozoic Northampton Complex and by Jurassic strata.

Climate

The climate is classified as Extra-dry Mediterranean (Beard, 1990), and is characterized by mild, wet winters and warm to hot, dry summers (Tables 2, 3). Rainfall ranges from 450 to over 500 mm a year, with the lowest rainfall on the coast north of Geraldton, and the highest on the hills around the Chapman Valley.

January and February are the hottest months for coastal areas influenced by heat troughs, and July and August are the coldest months (Table 3). Frosts can occur from June to September, averaging less than one day a year near the coast (Geraldton) to three days a year inland (Northampton). The area is noted for its strong summer winds (Table 4).

Previous investigations

The land around what is now the City of Geraldton was explored by George Grey in 1839 (Grey, 1841), who noted on his maps that the hills were underlain by limestone, and that the valleys were fertile or rich country. The earliest geological descriptions that included GERALDTON were in the mid-1800s, but the first systematic survey was by Playford et al. (1970) at 1:250 000 scale. The most recent appraisal of the geology of GERALDTON is in an unpublished report by Gozzard et al. (1988) on the geology, hydrogeology, and mineral resources of the Geraldton Region. There have recently been two surveys of the soils and landforms of the area around Geraldton (Dye et al., 1990; Rogers, 1996).

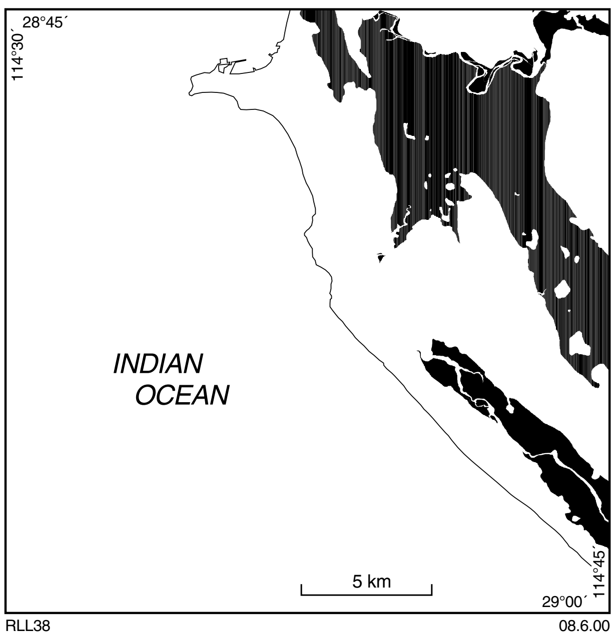

Figure 3. High-quality agricultural land (*GaA$_a$*, *GaA$_t$*, and *GeA$_t$* land system units, shaded black) (after Dye et al., 1990)

Land systems methodology

Regolith–landform mapping of GERALDTON was completed between August 1998 and July 1999 using 1 m-resolution colour orthophotographs flown in 1997 by Kevron Aerial Surveys for the Department of Land Administration (DOLA). The orthophotographs were combined with 5 m topographic contours supplied by DOLA, and printed at 1:10 000 scale for field mapping. The offshore was mapped in shallow waters using the orthophotographs, and in deeper water using Landsat TM imagery enhanced by DOLA and combined with 2 m-resolution bathymetry supplied by the Department of Transport. A total of 191 sites were documented in the area, at which 150 photographs and 83 soil or rock samples were taken. Hand-augered soil samples accounted for 74 of the total samples collected.

The mapping system used in this study is based on soil catenas (Milne, 1935). These are similar to regolith

Table 1. Vegetation of the Greenough area (after Rogers, 1996)

Soil and physiography	*Characteristic vegetation*
Greenough Vegetation System	
Recent dunes	*Acacia ligulata*
Rocky ridges near the coast	Thickets of *Acacia rostellifera* and *Melaleuca cardiophylla* and *M. huegelii*
Sand-covered limestone	Acacia–banksia scrub
Alluvial flats	Low forest of *Acacia rostellifera* and occasional *Eucalyptus camaldulensis*
Creek lines	*Eucalyptus camaldulensis* and *Casuarina obesa*
Northampton Vegetation System	
Duricrust on flat-topped mesas	Scrub heath of *Gastrolobium oxyloboides, Allocasuarina campestris, Dryandra ashbyi, Isopogon divergens* and others
Sandy areas on mesas	Scrub heath of Banksia, Acacia, Dryandra and *Allocasuarina* spp.
Stony sideslopes of mesas	Thickets of *Melaleuca megacephala* and *Hakea pycnoneura*
Ferruginous sideslopes of mesas	*Allocasuarina campestris* and *Melaleuca uncinata*
Undulating red loamy soils over granite and granulite	Scrub of acacias and hakeas with scattered trees of *Eucalyptus loxophleba* and *E. camaldulensis.*
Gravelly soils	Thickets of *Allocasuarina campestris*

Table 2. Annual average monthly rainfall and rain days recorded at Narra Tarra Estate, 1899–1988 (Rogers, 1996)

	Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Total*
Rainfall (mm)	5	11	16	29	75	121	105	76	39	23	9	3	512
Rain days	1	1	2	4	8	12	12	10	6	4	2	1	63

Table 3. Annual average monthly temperature and evaporation recorded at Geraldton, 1941–1987 (Rogers, 1996)

	Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
Max. ºC	32	32	31	27	24	21	19	20	22	24	26	29
Min. ºC	18	19	18	15	13	11	9	9	9	11	14	16
Mean daily evaporation (mm/day)	8.6	8.4	6.8	4.7	3.3	2.3	2.2	2.6	3.6	4.9	6.4	7.6

toposequences described by Pain et al. (1994), who chose to use this term (rather than the widely used soil catena) because they believed it to have a stronger geological context.

Catenas are groups of soils or regolith types that occur together on the same parent material to form a land pattern. Mapping of regolith–landform units relies on the identification of catenas, and the resulting mapping units are therefore areas with a particular association of regolith materials, bedrock geology, and landforms (Anand et al., 1993). The classification of landforms and slopes used for land surveys have been documented by McDonald et al. (1984). The terminology used for slopes is given in Appendix 2.

Land systems have been used in Australia to define areas with recurring patterns of topography, soil, and vegetation (Christian and Stewart, 1953). The system is hierarchical, and divided into regions, provinces, zones, systems, and subsystems. GERALDTON lies in the Western Region, covering the western half of Western Australia (Bettenay, 1983; Rogers, 1996). The systems adopted by Rogers (1996) have been broadly applied and refined in this survey, with the emphasis on regolith material at depth, together with its relationship to the underlying bedrock in a specific landform context.

Table 4. Wind patterns in the Geraldton area (Rogers, 1996)

Controlling weather pattern	*Dominant wind directions*	*Characteristics*
Summer		
Subtropical high pressure ridge	South through east to north	Strong (to 28 knots) coastal sea breeze 10 am to noon
Trough between highs	Calm	Delays or stops sea breeze
Winter		
Cold fronts from the Indian Ocean	East to northwest ahead of cold front	Erosive wind
	West to southwest behind cold front	Cool and moist wind

Geology and geomorphology

Proterozoic

The Northampton Complex (Fig. 4) is a Mesoproterozoic metamorphic complex within the Pinjarra Orogen that formed between 1150 and 1000 Ma (Myers, 1990; Tyler et al., 1998; Brugier et al., 1999; see Appendix 4). The complex consists of a group of high-grade metamorphosed rocks that were originally sedimentary rocks cut by granitic and gabbroic intrusions. The dominant lithologies in the complex are granulite, granite, and migmatite (Playford et al., 1970), and regionally the complex is cut by mafic dykes and quartz veins.

The Northampton Complex is well exposed to the north and east of the GERALDTON sheet, has limited exposure in the northeastern part of GERALDTON, and has been found in a number of drillholes on GERALDTON. There are isolated exposures of Proterozoic basement in the colluvial footslopes around Moonyoonooka. On Giles Road, granulite basement consisting of fine-grained, banded migmatitic granite gneiss is exposed in a road cutting within a few metres of Jurassic sedimentary rocks (MGA 278150E 6815640N)*. Exposures of fine-grained, garnetiferous felsic granulite can be seen in an old stream channel close to the Moonyoonooka–Narratarra Road (MGA 277240E 68156650N).

* Locations mentioned in text are referenced using Map Grid of Australia (MGA) coordinates, Zone 50. All locations are quoted to the nearest 5 m.

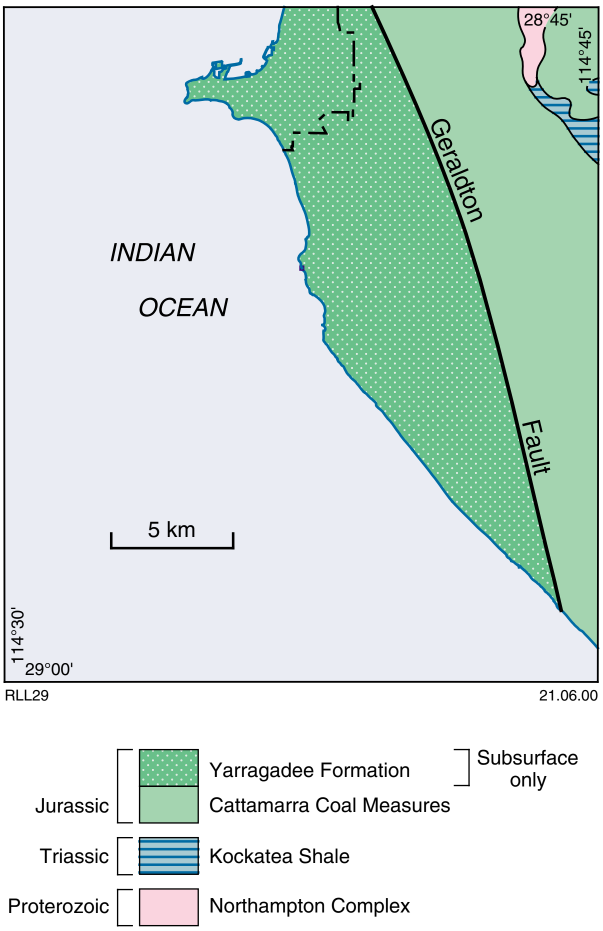

Figure 4. Interpreted onshore bedrock geology

Mesozoic

The outcrop of Mesozoic strata of the Perth Basin on GERALDTON (Playford et al.,1976; Mory and Iasky, 1996) includes the Lower Triassic Kockatea Shale and the Lower Jurassic Cattamarra Coal Measures. There are also subsurface occurrences of the Jurassic Yarragadee Formation, which overlies the Cadda Formation.

Triassic

The Kockatea Shale is the only part of the Triassic succession represented on GERALDTON, where it lies unconformably above the Northampton Complex. The dominant lithologies in the formation are sandstone and shale, which contains marine microfossils (Cockbain, 1990).

There are few exposures of the Kockatea Shale on GERALDTON, and they are all located on the low hills south of Moonyoonooka. An unconformity between the Triassic siltstones and overlying Jurassic sandstones is exposed between the abattoir and Geraldton – Mount Magnet Road (MGA 279840E 6814250N). Here, a low scarp about 2 m high consists of 0.2–0.3 m of pebbly sandstone over about 2 m of highly weathered, thinly laminated (~1mm) shale and light-grey clay. The thickness of the Kockatea Shale on these hills is estimated at 20 to 40 m. The formation thickens to the west, from about 40 m thick in bore GS7 (MGA 276234E 6810366N) to 137 m in petroleum exploration well Greenough 1 (MGA 271385E 6806070N).

Jurassic

Jurassic strata on GERALDTON can be divided into the Cattamarra Coal Measures, which rest unconformably on the Triassic Kockatea Shale, and the conformably overlying Cadda and Yarragadee Formations. Only the Cattamarra Coal Measures outcrop; the other two formations have been identified only in drillholes. No coal or carbonaceous material was identified in the weathered rock exposures in the area. The dominant lithologies are sandstone and siltstone, with a minor, but distinctive, marine limestone (Newmarracarra Limestone) in the Cadda Formation. The Yarragadee Formation is up to 150 m thick, overlying 10–15 m of Cadda Formation; the underlying Cattamarra Coal Measures are around 150 m thick.

Jurassic strata underlie most of the land area of GERALDTON (Fig. 4), and can be divided into two broad areas; east and west of the Geraldton Fault. To the west of the fault there is no exposure of Jurassic rocks, and the subcrop comprises the Yarragadee Formation. The lithology of this formation in the petroleum exploration well Greenough 1 (MGA 271385E 6806070N) is dominantly subrounded to subangular, moderately to poorly sorted, fine- to medium-grained sandstone, with minor siltstone and gravelly layers. The underlying Cadda Formation comprises sandstone with minor amounts of limestone and siltstone.

To the east of the fault the Cattamarra Coal Measures are exposed between Mount Fairfax on HOWATHARRA and the Chapman River, around Moonyoonooka, and on the flanks of Wizard Peak on WALKAWAY. The formation is probably no more than 50 m thick, and where exposed is typically moderately to highly weathered sandstone and siltstone. The sandstone is mostly poorly bedded, coarse to medium grained, with pebbly or gravelly horizons up to 5 cm thick. These coarser units contain pebbles up to 7 cm across and subangular quartz up to 2 cm across, and there may also be siltstone clasts up to 3 cm long. The sandstone commonly contains beds of thinly laminated siltstone 1 to 10 cm thick.

Cainozoic

Cainozoic material on GERALDTON includes residual materials, and colluvial (mass wasting), fluvial, eolian, coastal, and marine deposits. They are spread over the entire sheet area and, although they can be up to 75 m thick in large dunes and depositional basins, they commonly form a veneer only a metre or so thick.

The oldest Cainozoic materials are the residual sands and duricrust gravels formed on a dissected plateau underlain by weathered rock. These materials formed in situ by weathering of the bedrock, probably mostly during the Oligocene (34–24 Ma) (Hocking et al., 1987). However, their formation may have extended back to the Middle to Late Eocene (49–34 Ma) (van de Graaff, 1983) as sea levels fell from highs of up to 300 m above the present level.

The erosion of the plateau to form the scarp and colluvial slopes largely pre-dates the deposition of the eolian sands of Pleistocene (< 1.8 Ma) age, as these locally overlie the slope deposits. The widespread preservation of mottling and induration of the deposits indicates that they have been weathered in situ, and that they have not been significantly eroded. The maximum age of the colluvial slopes is unknown, but because the deposits have a uniform appearance down the hillslopes to near present-day sea level, they probably post-date the last major marine transgression (sea-level rise) in the Miocene (24–5 Ma).

The Lower to Middle Pleistocene Tamala Limestone is widespread both offshore and onshore up to the flanks of the dissected plateau. Weathering of the formerly uniform calcareous dune sands has produced a calcrete cap and overlying residual quartz sand on this calcarenite. The combined thickness of these deflated transgressive barrier, parabolic, and longitudinal dunes is up to about 80 m, although the residual sand probably rarely exceeds 20 m in thickness. Erosion of the dunes took place in the Middle Pleistocene at a sea-level highstand of about 5 m that formed a scarp along the northeastern side of the Greenough Flats. Corals that grew in shallow water about 3 km from this palaeoshoreline have been dated by Johnson et al. (1995) at 120–132 ka (see Appendix 4) before present (BP). Coastal erosion probably also took place between 105 and 85 ka BP at a sea-level low of around -20 m CD (Chart Datum), which is the lowest astronomical tide.

The fluvial deposits in the Chapman River – Bootenal – Walkaway area and the Greenough Flats formed both prior to and following the deposition of the Pleistocene eolian sands. Based on the limited lithification and weathering, the older, coarser deposits that lie below the eolian deposits probably range in age from Pliocene to Early Pleistocene. The younger fluvial deposits are probably Late Pleistocene to Holocene, as they have been deeply incised by present-day river channels. The erosional channel in Pleistocene limestone offshore from the mouth of the Greenough River probably relates to a Pleistocene sea-level lowstand of around 30–40 ka BP.

The youngest Cainozoic deposits are eolian dunes and associated coastal deposits of the Safety Bay Sand. These are dominantly Holocene in age, within which three generations of parabolic dune formation are recognized. The oldest two sets of deflated dunes are of unknown age, but coastal erosion to form cliffs and over-steepened dunes in the City of Geraldton indicates that they must pre-date the 2 to 3 m Holocene sea-level high at around 5000 years BP. The tombolo on which the port and city were developed post-dates this sea-level high, and dune formation and erosion are both currently active.

Major geological structures

Only one major geological structure has been identified on GERALDTON, namely the Geraldton Fault (Fig. 4). This normal fault can be inferred from the stratigraphy identified in Greenough 1, GS6 (MGA 273448E 6808556N), and GS7 drillholes, from which a downthrow to the west of about 160 m is calculated. There is no geophysical evidence for the exact position of this fault on GERALDTON, but in adjacent areas to the south, the northward extension of aeromagnetic lineaments in the Dongara area (Mory and Iasky, 1996, fig. 39) has been used to refine the position of the fault on GERALDTON.

Regolith–landform systems

The GERALDTON sheet has been divided into five regolith–landform land systems, plus a marine system (Fig. 5). The land system nomenclature is based on that defined by Rogers (1996), and to a lesser extent on the earlier work of Dye et al. (1990). The only departure from the names employed by Rogers (1996) is a change of the Tamala System to the Spearwood System. This makes the naming more compatible with that adopted for the geomorphic elements of McArthur and Bettenay (1960) and physiographic regions of Playford et al. (1976).

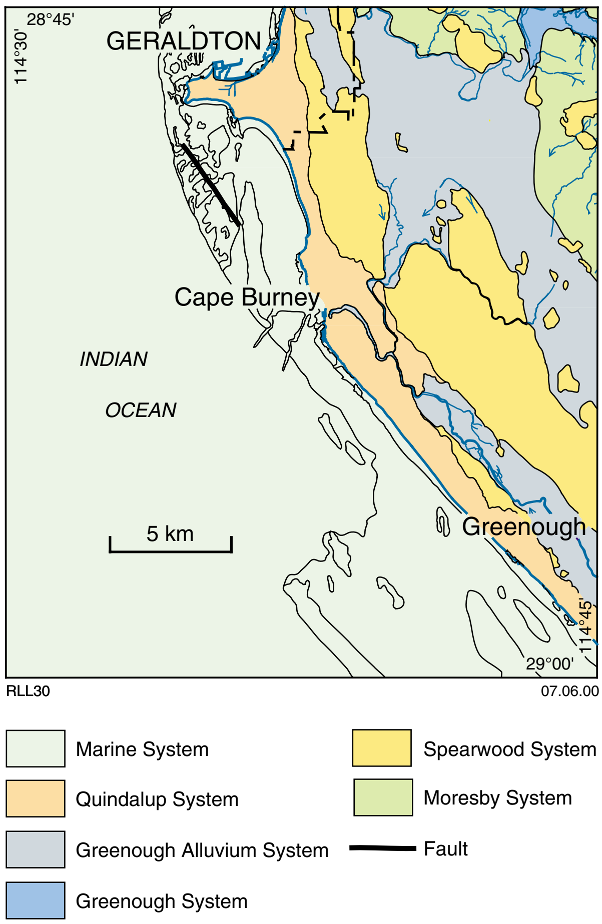

Figure 5. Distribution of land systems

Moresby System (*Mo*)

Land of the Moresby System occupies 2800 ha (4%) of GERALDTON (Fig. 6, Table 5), and is a plateau and sideslopes composed of residual materials and colluvial deposits over weathered Jurassic rocks, with minor occurrences of Triassic and Proterozoic rocks. The cemented pisolitic duricrust on the summit surface is a source of gravel, and has been worked in several pits around Moonyoonooka.

Landform and distribution

The Moresby System is a plateau and associated footslopes and sideslopes (Fig. 7). The plateau is formed of residual materials above scarps in weathered Jurassic sedimentary rocks, with minor outcrops of Triassic strata and Proterozoic basement rocks. The extensive footslopes and sideslopes consist of thin colluvial materials over weathered rock, with small talus slopes below some of the scarps. Narrow alluvial channels cut the colluvial slopes (Fig. 8).

The Moresby System occupies two adjacent areas in the northeast of the sheet. The larger of the two areas is between Moonyoonooka and the western flanks of Wizard Peak (WALKAWAY). The other area is north of the Chapman River, on the southern flanks of Mount Fairfax (HOWATHARRA).

West of Wizard Peak the footslope is level to very gently inclined. Around Moonyoonooka there are level hillcrests above locally moderately inclined to steep scarps. The moderately inclined sideslopes pass laterally into the adjacent Greenough and Greenough Alluvium Systems.

The level to very gently inclined footslopes to the scarp on Mount Fairfax extend south and west down to the Chapman River. The gently inclined slopes southeast of Mount Fairfax include small scarps, talus slopes, and hillcrests, with moderately inclined slopes in and adjacent to stream channels.

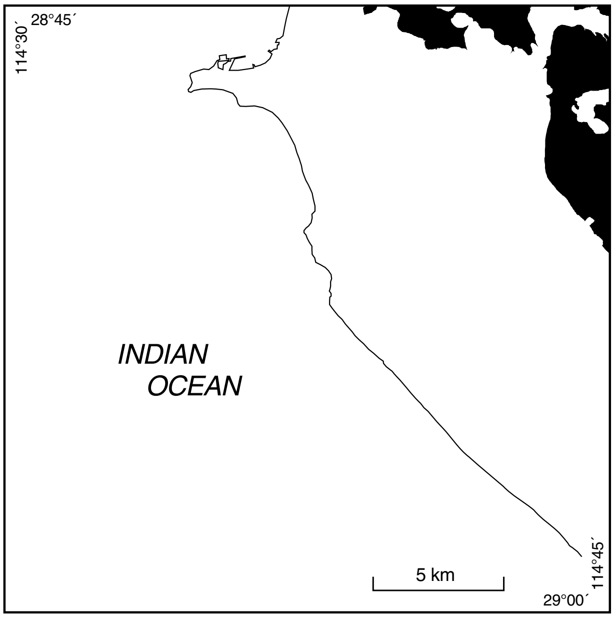

Figure 6. Distribution of the Moresby System (*Mo*)

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Figure 7. Landform, landuse, and vegetation in the Moresby System (*Mo*) southeast of Moonyoonooka (MGA 279985E 6812850N). Exposures of Triassic Kockatea Shale in the foreground, with Wizard Peak (WALKAWAY) in the background

Table 5. Components of the Moresby System

Unit name, map symbol, and area	*Process, landform, and material*	*Typical occurrence*
Footslope colluvium *MoC$_f$* 1 665 ha (60%)	Colluvial Footslopes; mostly westerly facing; level to very gently inclined; locally gently inclined; typically 20–60 m AHD; up to 105 m AHD on the southern flanks of Mount Fairfax Up to 0.3 m of loose gravelly soil over weathered rock debris, gravel, and boulders, grading downslope to gravelly silty sand; over residual soil of mottled sandy clay to highly weathered silty sandstone	Chapman River, Deepdale (MGA 272865E 6815930N) Up to 8 m of mottled colluvium exposed adjacent to the river; to the southeast this is covered by red loamy alluvium Colluvium; dark red 10R 3/6[1] (Munsell Color, 1994) and brownish yellow 10YR 6/8; gravelly sandy clay; increasingly gravelly with depth; includes transported duricrust gravel up to 1 cm
Colluvium *MoC* 989 ha (36%)	Colluvial Undivided slopes; west to northwest facing; mostly gently inclined; locally level; includes hillcrests; range from 45–110 m AHD Material as above	2 km south-southeast of Mount Fairfax (MGA 275815E 6815995N) Sheetwash sand overlying colluvium Colluvium; light yellowish brown 2.5YR 6/4; slightly mottled yellowish brown 10YR 5/8 and red 10R 4/8; soft to firm; gravelly and sandy clay; some coarser angular quartz
Stream channel *MoA$_c$* 57 ha (2%)	Alluvial Stream channel; mostly very gently inclined; 20–90 m AHD typically 20–50 m wide; comprises stream bed and stream banks; seasonally active; stream bed in weathered bedrock and thin alluvium; banks in eroded slope deposits Material as above	Southeast of Mount Fairfax, near farm buildings (MGA 276440E 6817550N) Stream channel has banks 3 m high and a bed 5–10 m wide; channel 25–30 m wide Exposures of hardpanized, mottled massive colluvium; quartz-rich; poorly developed matrix; possibly some weathered sandstone
Ferruginous duricrust gravel *MoRf$_p$* 42 ha (2%)	Residual Hillcrests and summit surface to plateau; level to gently inclined; several areas ranging from 65–110 m AHD Ferruginous pisolitic duricrust over mottled soil (weathered bedrock)	Disused gravel pits north of Mount Magnet Road (MGA 279100E 6815755N) Extensive areas of gravel extraction with some trenches and cut faces up to 2 m high Cemented gravel layer 1 m thick over mottled soil; above gravel is 0.2 m of pale sand with abundant dark reddish brown nodules Duricrust; reddish yellow 7.5YR 6/6; dense; medium gravel; thin cutans
Quartz sand *MoRz* 7 ha (< 1%)	Residual Hillcrest; gently inclined; 60–70 m AHD Quartz sand over weathered duricrust and mottled soil	2 km southeast of Mount Fairfax (MGA 276770E 6816570N) Residual sand over mottled colluvium and weathered rock Quartz sand; reddish yellow 7.5YR 6/8; loose; slightly silty; medium sand; mostly 0.25–0.5 mm; up to 1.4 mm; noticeable content of fine mafic mineral
Talus *MoC$_t$* 2 ha (< 1%)	Colluvial Talus slope to escarpment; dominantly moderately inclined; east to southeast facing slope; 85–95 m AHD Weathered rock debris; gravel and boulders in colluvial matrix	South of Mount Fairfax (MGA 275435E 6816850N) At least 2 m of sandstone and siltstone bedrock exposed above boulder-strewn slope

Table 5. Components of the Moresby System (continued)

Unit name, map symbol, and area	*Process, landform, and material*	*Typical occurrence*
Jurassic Cattamarra Coal Measures *Jc* 13 ha (< 1%)	Bedrock Scarps, stream beds, eroded slopes, and road cuttings Weathered thinly bedded sandstone, gravelly sandstone and laminated siltstone	North of Abattoir Road Moonyoonooka (MGA 279760E 6815150N) Gravel at least 1 m thick; above at least 2 m of mottled weathered residual soil; above 6–8 m of highly weathered sandstone Sandstone and arkosic sandstone with beds of siltstone up to 1 cm and gravelly beds up to 5 cm; generally poorly bedded; dominantly medium grained but grades into coarse grained; probably 20–30% feldspar or lithic clasts
Proterozoic Northampton Complex *ƁmNO* 1 ha (< 1%)	Bedrock Stream beds and road cuttings Fresh to weathered, undivided granulite and metamorphosed granite gneiss	Giles Road, Moonyoonooka (MGA 278155E 6815510N) Banded granulite; 5 mm scale; dipping 46° southeast; contorted in parts; granitic composition with a grain size 0.2–1.0 mm (fine grained); moderately to highly weathered
Triassic Kockatea Shale *Ꝛk* < 1 ha (< 1%)	Bedrock Eroded slopes Weathered laminated siltstone	Moonyoonooka gravel and sand pits (MGA 279985E 6812850N) Small low hill in weathered and partly ferruginized siltstone Shale; weathered; ferruginized; thinly laminated (mostly < 5 mm)

Regolith and rock materials

The regolith materials of the Moresby System are derived from weathering and erosion of the underlying dominantly siliciclastic sedimentary rocks of the Jurassic Cattamarra Coal Measures. There are also isolated exposures in the colluvial footslopes of the Proterozoic Northampton Complex and the Triassic Kockatea Shale.

Cemented pisolitic duricrust is typically exposed on summit surfaces of the plateau, and can be up to 3 m thick. A residual quartz sand, derived from the weathering of the underlying ferruginous duricrust, may be developed on hillcrests. Weathered and ferruginized bedrock may be exposed on the scarp slope below the duricrust. Talus slopes are not usually well developed in this area, but where present are composed of bouldery to gravelly colluvium.

Mass wasting deposits on the colluvial slopes range in thickness from 1 m to more than 8 m. Weathered rock debris, gravel, and boulders dominate on the proximal slopes. On the more distal slopes, the colluvium grades to gravelly silty sand, which may be indurated and mottled (Fig. 9). These deposits rest on weathered bedrock that ranges from a residual soil of mottled sandy clay to highly weathered silty sandstone. Narrow, seasonally active channels on the colluvial sideslopes and footslopes contain small amounts of fluvially deposited silty sandy clay.

Figure 8. Colluvial footslope landform pattern with narrow incised channel in the Moresby System (*Mo*), adjacent to the Spearwood System (*Sp*) and Greenough Alluvium System (*Ga*), 3 km south of Mount Fairfax (HOWATHARRA). 1:25 000-scale orthophotograph with contours at 5 m interval

RLL45 29.5.00

Figure 9. Colluvial material (*MoC_r*) in the Moresby System near the Chapman River (MGA 273340E 6815685N). Thin yellow sheetwash sand over mottled, indurated, gravelly silty sand (10 cm scale bar)

Mineral resource potential

The only mineral resource potential in the Moresby System on GERALDTON is gravel for use as a construction material. The most prospective area is north of the Mount Magnet – Geraldton Road at Moonyoonooka, where parts of some of the gravel deposits have been worked.

Three additional areas have gravel resources potential. The area south of the Mount Magnet – Geraldton Road at Moonyoonooka includes several abandoned pits, whereas the area north of the road includes one large, intermittently working pit. A potential resource on a hillcrest west of the Narratarra–Moonyoonooka Road (MGA 276750E 6816550N) comprises thick residual sand over weathered rock and duricrust of unknown thickness.

Active processes and hazards

Rainfall is the only significant agent driving regolith–landform processes. Erosion is the dominant active process, as duricrust and colluvium formation is not currently significant. Heavy rainfall does not normally result in flooding on the free-draining slopes in the Moresby System, but it often causes severe channel erosion in the streams, and gully erosion on devegetated and disturbed ground on the scarps and talus slopes. However, flooding of the Bootenal area in the Greenough Alluvium System can back up onto the lower parts of the footslopes to the north.

Rock collapse has been noted on some scarps. This has become more of a hazard since land clearance for grazing and cropping resulted in the removal of bush that previously helped stabilize the slopes. Current agricultural practices can lead to wind erosion of residual and colluvial sand on footslopes and hillcrests, but this is not a significant process on GERALDTON.

Landuse, vegetation, and drainage

Land within the Moresby System is mostly used for farming, but the area includes the Moonyoonooka Recreation Reserve. The land has mostly been cleared for cropping and grazing, but some of the steeper sideslopes and gravelly summit surfaces of the plateau are only partially cleared of native vegetation.

There are several narrow drainage channels feeding the Chapman River, and one channel that traverses the gently inclined footslopes north of Bootenal. These channels are all seasonal, with little or no water present in the dry season.

Relationships

Erosion of weathered rocks underlying the Moresby System is a source of material for the alluvial deposits of both the Greenough System and the Greenough Alluvium System. The Moresby System passes laterally downslope into the Greenough System in Chapman Valley, and into the Greenough Alluvium System west of Wizard Peak. To the south and southwest the Moresby System is cut by the Chapman River and overlain by the Greenough Alluvium System.

Geological history

The Moresby System is underlain by Jurassic (205–141 Ma) sedimentary rocks (Playford et al., 1976) that have been weathered and eroded to form a dissected plateau surface of Cainozoic age (65–1.6 Ma). To the north and east of Geraldton this plateau is underlain in part by Cretaceous rocks (141–65 Ma), which are also weathered.

Duricrust formation was probably mostly during the Oligocene (34–24 Ma) (Hocking et al., 1987), but may have extended back to the Middle to Late Eocene (55–34 Ma) (van de Graaff, 1983) as sea levels fell from highs of up to 300 m above the present level. The erosion of the plateau to form the scarp and colluvial slopes predates the deposition of the eolian sands of the Pleistocene (1.8–0.04 Ma) Spearwood System, as the slopes are covered in part by remnants of that system. The maximum age of the colluvium is unknown, but it probably postdates the last major transgression in the Miocene (24–5 Ma). The widespread preservation of mottling and induration of the deposits indicates that they have been weathered in situ, and that they have not been significantly eroded since formation.

Spearwood System (*Sp*)

The Spearwood System occupies 8000 ha (12%) of GERALDTON (Fig. 10, Table 6), and is equivalent to the Pleistocene Tamala Limestone. The system is composed of residual sand overlying calcarenite in a series of deflated dunes (Fig. 11). The sand is worked in small pits for use in the building industry, and the calcarenite is a source of rock for land reclamation. Heavy mineral sands have been recorded from a number of strandlines around Greenough, but this resource potential is low relative to strandlines such as those found at Eneabba.

Landform and distribution

The Spearwood System is mostly level to gently inclined dunes, with a few steep to precipitous rocky slopes. The dominantly eolian deflated dunes and swales have been formed by southerly winds, and morphologically are a combination of parabolic, longitudinal, and transgressive barrier dunes. Physiographically the system is also referred to as the Spearwood Dune System (McArthur and Bettenay, 1960).

The dunes have also been eroded by coastal processes that were active about 125 000 years ago to form a westerly facing scarp to the northeast of the Greenough Flats (Fig. 12). Associated with this old coastline, which formed at a 5 m sea-level high, there is a rare marine facies of biogenic reef exposed at a few localities near the coast. The best of these is at Cape Burney (Johnson et al., 1995).

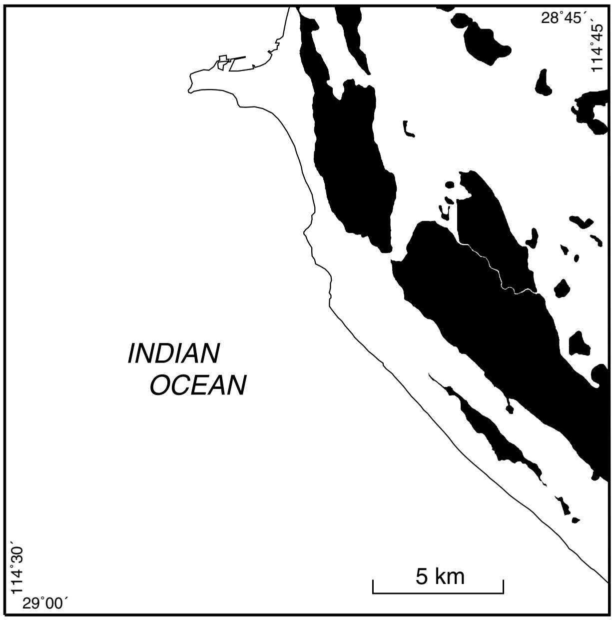

Figure 10. Distribution of the Spearwood System (*Sp*)

The Spearwood System is observed in two discrete areas. The larger of these is within a broadly continuous belt that extends parallel to the Greenough River from the southeast of the sheet through to the City of Geraldton. This belt is covered by the Quindalup System to the southwest, and by the Greenough Alluvium System along the Greenough Flats and in the Chapman River – Bootenal – Walkaway area, where there are also a few

Figure 11. Landform and vegetation over exposed Spearwood System calcarenite (*SpEk*) near the Chapman River (MGA 275825E 6815205N)

Table 6. Components of the Spearwood System

Unit name, map symbol, and area	*Process, landform, and material*	*Typical occurrence*
Deflated dunes *SpE* 5 654 ha (70%)	Eolian Low hills and rises of deflated transgressive barrier, parabolic, and longitudinal dunes; dominantly easterly and westerly facing slopes to dune ridges; level to gently inclined; mostly 15–40 m AHD, up to 100 m AHD; low sandy rises in plains of the Greenough and Greenough Alluvium Systems Yellowish red to brownish yellow residual quartz sand (Table 7) over calcarenite; minor exposures of calcrete over calcarenite	Sand pit south of Rudds Gully Road (MGA 274620E 6808590N) 1–2 m of loose, brownish yellow 10YR 6/8, slightly silty medium sand composed of quartz, over karstic limestone
Calcareous eolianite *SpEk* 1 903 ha (24%)	Eolian West to southwesterly facing scarp face, gently to moderately inclined; isolated hillcrests and ridges exposing the cores of the dune system, mostly gently inclined; west to northwest and east to southeast slopes dominant; mostly 20–60 m AHD; up to 85 m AHD White to pale brown calcrete above calcarenite composed of lithified carbonate-rich shell and quartz sand; locally overlain by brown to reddish brown residual sand	New development north of Panorama Heights, Tarcoola (MGA 268800E 6809680N) Steep slopes exposing strong to moderately strong, very pale brown 10YR 8/3, carbonate-cemented medium sand composed of quartz and carbonate (Tamala Limestone)
Footslope colluvium SpC_f 479 ha (6%)	Colluvial Footslopes to southwesterly facing scarp face; dominantly gently inclined, with moderately inclined upper slopes and level lower slopes; 10–30 m AHD, up to 50 m AHD Decomposed calcareous eolian shell and quartz sand; calcarenite and calcrete rock fragments	Between the Brand Highway and Southgate Dunes (MGA 269795E 6807640N) Uniform slope in slope debris composed of calcareous sand; some calcarenite or calcrete debris (excavated in old Telecom trench); shallow auger hole to 1.2 m in brown 7.5YR 5/3 slightly silty to gravelly sand with calcareous silt, containing calcareous nodules
Swampy swales SpE_w 3 ha (< 1%)	Eolian Waterlogged hollows in dune system; mostly level; 12–15 m AHD Peaty or organic soil over residual quartz sand	3 km south of Narngulu (MGA 275100E 6806950N) Subcircular depression about 150 m across; contains water-dependent vegetation

small, isolated relics of the Spearwood System. The second, smaller area is on the western flanks of Wizard Peak and the southern flanks of Mount Fairfax, where a number of isolated occurrences lie above the Moresby System.

Regolith and rock materials

The Spearwood System is dominated by two types of regolith and rock materials. The dominant exposed regolith originally was calcareous dune sand, but was weathered by surface leaching and groundwater precipitation to form yellow and red residual quartz sand (Fig. 13). This lies above a white to light brown, strong (Geotechnical Control Office, 1988; Appendix 3) calcrete. The calcrete is a relatively thin, hard surface coating to the underlying variably lithified calcarenite (limestone), which is the dominant composition of the system at depth. The calcarenite, calcrete capping, and residual sand are usually referred to as the Tamala Limestone. The coarse- to medium-grained calcarenite is composed largely of skeletal fragments of foraminifers and molluscs, with variable amounts of quartz sand (Fig. 14, Table 7).

Small waterlogged or swampy areas fill the swales or depressions between the dunes. These contain the same residual quartz sand as on the adjacent hills, but have a peaty, organic content and also may be slightly more clayey. The footslopes to the westerly facing scarp

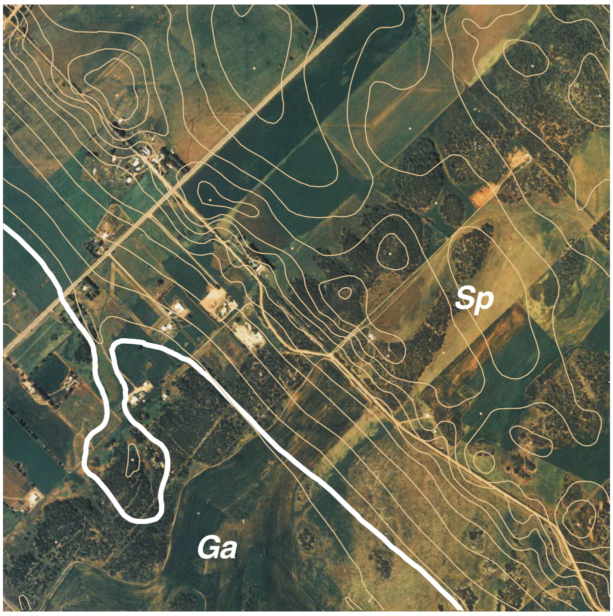

Figure 12. Colluvial footslopes southwest of a steep rocky landform pattern in the Spearwood System (*Sp*), adjacent to the Greenough Alluvium System (*Ga*), 4 km northwest of Greenough. 1:25 000-scale orthophotograph with contours at 5 m interval

Figure 13. Thick yellow residual sand in the Spearwood System (MGA 275150E 6815120N). Sand pit near the Chapman River

adjacent to the Greenough Flats are composed of calcareous colluvium. This formed by disintegration and erosion of the adjacent limestone scarp that was initially formed by marine erosion.

Mineral resource potential

The Spearwood System is a locally important source of construction limestone, building sand, and fill for land reclamation. There are a number of small pits in the area, from which either sand or limestone is extracted (Fig. 13).

Nearly all areas of the Spearwood System are underlain by limestone (calcrete and calcarenite) at depth, but the most prospective areas are those where the limestone is exposed or is close to the surface. These areas are generally on hillcrests and steep scarps, and are commonly covered in remnant vegetation. Sand is widespread throughout the system, but is of variable quality. The more silty red sands are preferred for building pads, and these are usually found close to the limestone.

There are up to three possible strandlines related to sea-level highstands that contain heavy mineral sands (Woods and Associates, 1992). These include titanium and zirconium minerals, and garnet. The potential for finding economic concentrations of heavy mineral sands is considered to be poor.

Active processes and hazards

Rainfall and wind erosion are minor agents driving current regolith–landform processes in the Spearwood System. There are no known significant hazards in the Spearwood System. The highest risk is associated with the steeper limestone slopes (Fig. 11). No signs of rock collapse are recorded on any of these slopes.

Landuse, vegetation, and drainage

The Spearwood System has been extensively cleared for cropping and grazing, dominantly in areas where the soil is sandy. Areas underlain by limestone are mostly uncleared. These pockets of remnant vegetation are a distinctive feature of the limestone substrate.

Both the cleared sandy soils and areas underlain by limestone have been favoured for urban development east and south of Geraldton, partly because the soils (compared to the alluvial flats and colluvial slopes) are unsuitable for agriculture, and partly because of the elevated position the land affords. There is some industrial development, notably on the low hills around Narngulu, but most has been on the adjacent alluvial plain of the Greenough Alluvium System which is preferred because it is level.

The sandy soils are free draining, and there are no mappable channels or streams. There is, however, a major drainage channel that cuts the Spearwood System and is part of the Greenough Alluvium System. This connects the alluvial plain at Bootenal to the channel system in Rudds Gully.

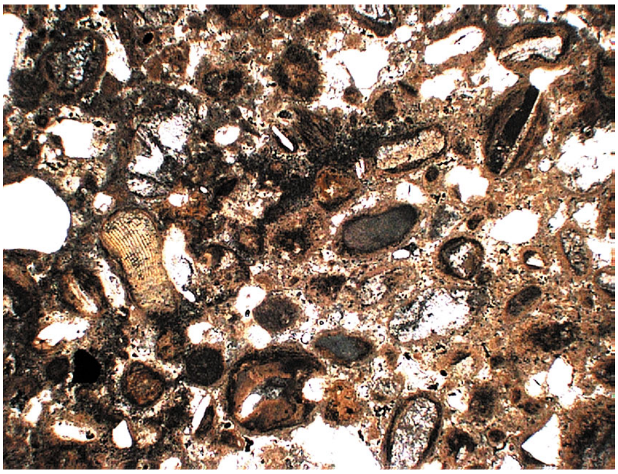

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Figure 14. Photomicrograph (thin section) of Spearwood System calcarenite (Tamala Limestone) composed of foraminifers, molluscs, and quartz sand; 2 km southwest of Greenough (MGA 278720E 6795185N). Width of view 2.5 mm

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Figure 15. Pleistocene coral reef (Tamala Limestone) below Quindalup System eolian sand at Cape Burney (MGA 269200E 6804345N)

Relationships

The Spearwood System is interbedded with fluvial deposits of the Greenough Alluvium System. These relationships are well exposed in the Meru landfill site, where red silty sand sits above calcrete and yellow sand of the Spearwood System, below which is at least 12 m of red and brown, gravelly sandy silt and clay. The Spearwood System is overlain by the Quindalup System in a broad belt parallel to the coast, and overlies the Moresby System on the flanks of Mount Fairfax and Wizard Peak, and around Moonyoonooka.

Geological history

The Spearwood System is the equivalent of the Pleistocene (1.6–0.04 Ma) Tamala Limestone, which is fully described by Playford et al. (1976). The Tamala Limestone formed as a series of dunes and associated minor marine deposits that also form several lines of offshore islands and reefs. The best examples of these islands are within the Houtman–Abrolhos Group lying 50–100 km west of Geraldton. Locally, the offshore reefs are dominantly composed of Tamala Limestone, which was formed by eolian processes and eroded by coastal processes during various sea-level high- and lowstands. The edge of the nearshore platform and included reefs marks a sea-level low of about -20 m AHD that probably dates from about 80 ka.

The best constrained of the sea-level highstands on GERALDTON is associated with the deposition of a marine reef facies (for example at Cape Burney, Figure 15), and low sea cliffs inland. The reef has been constrained in age to a narrow interval from about 128 ka to 121 ka (Stirling et al., 1998). The sea cliffs associated with this interglacial sea-level high lie adjacent to the Greenough Flats. The dune slopes, now covered by colluvial deposits, were over-steepened by marine erosion at a coastline that was at least 3 m above the present sea level.

Greenough System (*Ge*)

The Greenough System occupies 400 ha (1%) of GERALDTON (Fig. 16, Table 8), and is composed of alluvial terraces and channels related to the upper reaches of the Chapman River. The system may be a source of sand and gravel for construction.

Landform and distribution

The Greenough System is characterized by level to very gently inclined fluvial terraces, and locally steep to cliffed terrace scarps adjacent to channels of the Chapman River (Fig. 17). The Greenough System lies adjacent to the plateau and hills of the Moresby System, in which the colluvial footslopes pass laterally downslope into the terraces of the Greenough System (Fig. 18).

The Greenough System is a regionally significant system that has been mapped by Rogers (1996) to include the river beds, terraces, and flats associated with the

Table 7. Particle-size distribution for samples from the Spearwood System. Grain-size classification (Appendix 5) from Geotechnical Control Office (1988) and Standards Australia (1993)

Map symbol	*Sample No.*	*Location*	*Sample description*	*Gravel (%)*	*Coarse sand(%)*	*Medium sand(%)*	*Fine sand(%)*	*Silt/clay (%)*
SpE	161308	Georgina Road (MGA 277530E 6800135N)	Light brown silty gravelly medium sand with carbonate nodules	5.6	10.1	58.1	18.6	7.6
SpE	161309	West of junction of Phelps Road and Georgina Road (MGA 278740E 6801400N)	Red 2.5YR 4/8 medium sand	0.0	5.4	82.8	11.0	0.8
SpE	161372	Adjacent to railway line (MGA 279560E 6812470N)	Loose, brownish red slightly silty medium sand	0.0	7.2	81.8	8.1	2.9
SpE	161382	Phelps Road (MGA 277615E 6802940N)	Loose, red 2.5YR 5.5/8 slightly silty medium sand	0.0	22.0	61.7	13.3	2.9
SpE	161385	East of Greenough Regional Prison (MGA 275935E 6808085N)	Loose, strong brown 7.5YR 5/7 medium sand	0.0	4.3	68.2	26.4	1.1

Greenough, Murchison, Hutt, and Chapman river systems. The Greenough System only occurs in the northeast of GERALDTON, in a single small area that extends northwards into HOWATHARRA, and passes into locally developed plains of the Greenough Alluvium System to the south. Definition of the boundary between these two systems is based on a change in landform from alluvial plain to terraces.

Regolith and rock materials

The Greenough System has been formed by fluvial deposition of silty sandy clay (Fig. 19) from the Chapman River on terraced flood plains and in valleys between the adjacent escarpments. Incised channels in the terraces expose up to 10 m of red, silty sandy clay (loam). The channels are dominantly erosional, with a little sandy silt deposited in the stream bed. No rock was seen exposed in the narrow channels east of Giles Road, but exposures of Northampton Complex granulite adjacent to the Narratarra–Moonyoonooka Road indicate that the alluvium is little more than 10 m thick.

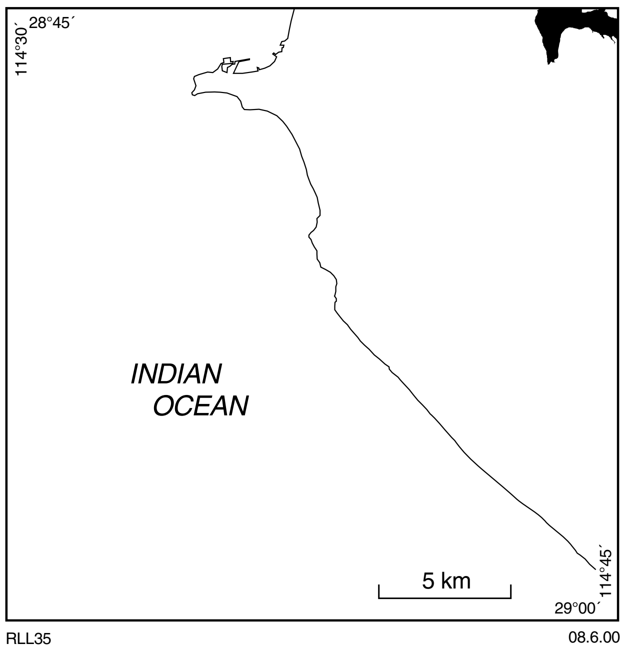

Figure 16. Distribution of the Greenough System (*Ge*)

Mineral resource potential

The slightly steeper slopes in the Greenough System, compared with the Greenough Alluvium System, have less clayey and silty alluvial deposits that could be a source of sand and gravel for fill. There are no sand or gravel pits in the fluvial deposits of the Greenough System, and no indication that these materials have been worked. There is no other mineral resource potential noted within the system.

Active processes and hazards

The only significant active processes are stream erosion, flooding, and sedimentation associated with rainfall. Heavy rainfall can cause local flooding in level, poorly drained areas adjacent to the Chapman River, and severe channel erosion both in the river and its tributaries. The moderately inclined stream banks can be undercut by stream erosion in times of flood, and in places show signs of previous collapse.

Landuse, vegetation, and drainage

Land within the Greenough System is mainly used for grazing and cropping, with no urban or industrial development. Much of the native vegetation has been

Table 8. Components of the Greenough System

Unit name, map symbol, and area	*Process, landform, and material*	*Typical occurrence*
Alluvial terrace GeA_t 263 ha (66%)	Alluvial Terrace, locally incised by stream channels (stream bed and stream banks); dominantly level; west to northwest facing slopes; mostly 45–55 m AHD; up to 80 m AHD Silty sandy clay	Giles Road, Moonyoonooka (MGA 278430E 6817255N) Red silty sandy clay (loam) evident in tracks and seen in terraces nearby; very gentle slope down to the west (Chapman River)
Stream bed or channel (bed and banks) GeA_b 89 ha (22%) (database only: within GeA_c on map)	Alluvial Bed adjacent to stream banks, or bed with very narrow (< 5m) banks; mostly level, locally gently to moderately inclined; mostly 35–55 m AHD; usually water-filled Silty sandy clay	Adjacent to Narratarra–Moonyoonooka Road (MGA 277300E 6816300N) Material as above; may include rock exposures (Northampton Complex) and gravel; banks 5–7 m high, 15–45 m wide; bed 130 m wide
Stream banks GeA_c 48 ha (12%)	Alluvial Stream banks adjacent to stream bed; gently to moderately inclined; mostly 35–45 m AHD Cut in to silty sandy clay of the terraces	As above

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Figure 17. Landform, landuse, and vegetation in an alluvial terrace (*GeA_t*) of the Greenough System east of the Chapman River (MGA 278430E 6817255N). Mount Fairfax (HOWATHARRA) in the background

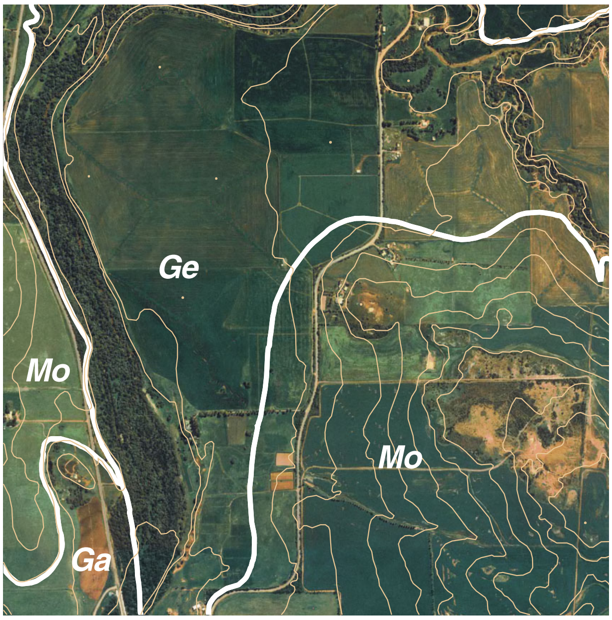

Figure 18. Alluvial terrace east of a stream channel in the Greenough System (*Ge*), adjacent to the Moresby System (*Mo*) and Greenough Alluvium System (*Ga*), 3 km northeast of Moonyoonooka. 1:25 000-scale orthophotograph with contours at 5 m

cleared, except in river channels. The Chapman River channel is mostly Vacant Crown Land or Public Recreation Reserve, and includes the Cutubury Nature Reserve (MGA 277000E 6816850N). This A-class reserve covers about 15 ha of land in the Moresby and Greenough Systems, straddling the Narratarra–Moonyoonooka Road.

The Chapman River is an important regional drainage channel, extending from Yuna, about 65 km northeast of Geraldton, through to the ocean at Geraldton. The river channel is 200 to 300 m wide on GERALDTON, but is strongly seasonal in flow volumes, reducing to a shallow, easily traversed stream in the dry season.

Relationships

To the southwest the Greenough System passes into the Greenough Alluvium System, and the boundary between these two is defined by a change in landform from terraces to alluvial plain. The source of the material in the Greenough System is, in part, the weathered sedimentary rocks and duricrust of the surrounding Moresby System, but there is also a contribution from the larger catchment to the northeast.

Geological history

The formation of the fluvial deposits in the Greenough System probably pre-dates the formation of the eolian dunes of the Spearwood System. There is very little evidence of Holocene deposition, and some of the terrace formation can probably be assigned to the Pleistocene red alluvium unit of Wyrwoll (1984). This unit post-dates the 120 ka marine transgression closer to the present-day coast, but can only be constrained at the upper end to being older than 40 ka. Although aggradation took place over a considerable period, the nature of the deposits indicates that infrequent large-scale flood events in a braided stream environment were the dominant mechanism of deposition (Wyrwoll, 1984).

Figure 19. Typical yellowish red 5YR 4/6, alluvial silty sand in the Greenough System (MGA 277355E 6818910N). Adjacent to the Chapman River on HOWATHARRA

Greenough Alluvium System (*Ga*)

The Greenough Alluvium System occupies 9400 ha (14%) of GERALDTON (Fig. 20, Table 9), and is the result of the development of an alluvial plain on the Chapman and Greenough rivers. The system is a potential source of sand and gravel, and includes a clay resource at Bootenal that is being used in brick making.

Landform and distribution

The Greenough Alluvium System is largely a level alluvial plain, with local stream channels and terraces. The terrace slopes are steep to cliffed in some places (Fig. 21). The system has formed by fluvial deposition from the Greenough and Chapman rivers on flood plains (Fig. 22) between dunes of the Spearwood and Quindalup Systems, and the inland plateau of the Moresby System.

The Greenough Alluvium System occupies two distinct areas: the Greenough Flats to the south, and the Chapman River – Bootenal – Walkaway area stretching from the eastern to the northern edge of the sheet. This has been historically referred to as the Back Flats, and more recently as the Bootenal alluvial plain (Dye et al., 1990).

The Greenough Flats lie on both sides of the Greenough River, forming a level plain that ranges in height from 15 m AHD in the southeast to 5 m AHD in the northwest. The Back Flats or Chapman River – Bootenal – Walkaway area can be divided into four areas based on slopes and altitude. The most southerly area is around Bootenal, where there is a depression ranging from 15 m AHD near Bootenal to 20 m AHD to the east and north. To the north is the largest area, which is a plain ranging from 40 m AHD, adjacent to the Greenough System, to an average of 20–30 m AHD across the northern part of the unit. The third area includes the channel systems of the Chapman River and Rudds Gully, both of which fall to 10 m AHD. The fourth area is on the flats between the Spearwood System dunes in the northern part of the city, which fall to 10 m AHD towards the Chapman River on HOWATHARRA.

Regolith and rock materials

The Greenough Alluvium System was formed by fluvial deposition from the Greenough and Chapman rivers, and is dominantly red, silty sandy clay over sandy gravel (Fig. 23, Table 10). There are also interbedded clayey units, and pockets of clay, such as that around the brickworks at Bootenal. Sections observed in terraces and stream banks show up to 12 m of interbedded alluvial and eolian deposits, and drillholes have intersected at least 40 m of alluvium overlying bedrock. There are also small swamps underlain by waterlogged organic soil.

Mineral resource potential

The Greenough Alluvium System contains alluvial deposits that are a potential source of sand and gravel for fill. There is one pit within these fluvial deposits,

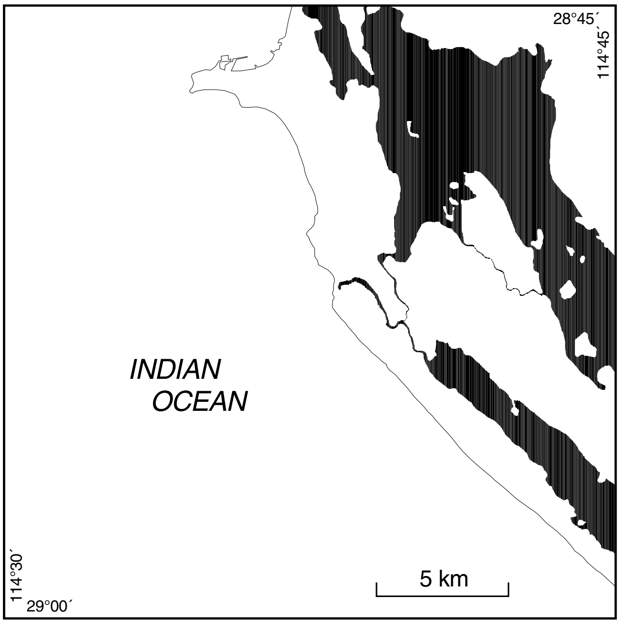

Figure 20. Distribution of the Greenough Alluvium System (*Ga*)

adjacent to the Chapman River (MGA 275150E 6815120N), in which the poorly bedded alluvium has been excavated to a depth of 2 m. However, the prime focus of this pit is sand from the Spearwood System.

Clay is extracted from a pit adjacent to the brickworks at Bootenal, where it is used to supplement imported clay for brick making. The clay contains small fragments of limestone, and has been deposited in a former wetland or lake in a drainage depression. Floodwater from Wizard Peak crosses a broad level plain before passing through a narrow channel to Rudds Gully, giving an opportunity for the finer material to accumulate in the restricted basin at Bootenal.

Another area with clay deposits also has restricted drainage. This is in the Rangeway district about 3 km east-southeast of the Geraldton city centre. Within this district at least 4 m of sandy, cracking clay overlies sand of the Spearwood System. The clay can be seen in a drainage sump near Callistemon Court (MGA 269400E 6813400N). Clay has also been recorded in the site investigation for the Meru landfill site, and it is likely that similar deposits could be located beneath other areas of the alluvial plain.

Active processes and hazards

Historically, the most significant process with an associated hazard is flooding of the Greenough Flats and the Chapman River – Bootenal – Walkaway area. There are many newspaper accounts of flooding, notably in 1862, 1872, 1888, and 1952. As recently as 1999, large parts of the Greenough Flats, as well as parts of the Chapman River – Bootenal – Walkaway area, were flooded following heavy rain locally and in the hinterland.

Table 9. Components of the Greenough Alluvium System

Unit name, map symbol, and area	*Process, landform, and material*	*Typical occurrence*
Alluvial plain GaA_a 8 663 ha (92%)	Alluvial Level plain; 5–40 m AHD Silty sandy clay over sandy gravel in Chapman River–Bootenal–Walkaway area; more clayey on the Greenough Flats	1. Chapman River – Bootenal – Walkaway area, drainage sump, Dwyer Street (MGA 269415E 6816480N) About 4 m deep; bedding medium to thin; loose; red 2.5YR 5/8; slightly silty very gravelly medium sand; composed of quartz with minor rock clasts including granulite and vein quartz 2. Greenough Flats 1.3 km southwest of old Greenough townsite (MGA 279015E 6795450N) Shallow auger in alluvial sand; yellowish brown; silty clayey fine sand; some coarse sand to fine gravel
Stream bed or channel (bed and banks) GaA_c 328 ha (3%)	Alluvial Gently to moderately inclined stream channel banks; includes stream bed and banks where both are very narrow; usually water-filled Silty sandy clay (Table 10)	Chapman River, Deepdale (MGA 274905E 6814945N) 12 m-high section through alluvium and underlying dune sand Youngest alluvium 1–2 m above stream: sandy silty clay Younger terrace 2–5 m above: thin- to medium-bedded yellowish red 5YR 5/6 silty sand Oldest terrace 9–12m above: 2 m of reddish brown silty sand above 0.5–1.5 m of reddish brown 5YR 4/4 gravelly sand Eolian sand below, partly covered by younger terrace
Stream bed GaA_b 263 ha (3%) (database only: within GaA_c on map)	Alluvial Broad, level to gently inclined stream bed, distinct from adjacent channel banks Silty clayey sand	As above
Alluvial terrace GaA_t 146 ha (2%)	Alluvial Level to gently inclined, 5–35 m AHD Silty sandy clay	Rudds Gully Road near the Brand Highway (MGA 271310E 6806125N) Up to 5 m of alluvium exposed on the south side of the road and 2 m on the north side; yellowish red 5YR 5/6 silty sand with bands of gravel up to 20 cm thick containing clasts at least up to 5 mm; shallow dip west
Swamp GaA_w 3 ha (< 1%)	Alluvial Level, 18 m AHD. Waterlogged organic soil over silty sandy clay	Bootenal Road, Bootenal (MGA 278800E 6806250N) Swampy hollow with trees and marshy vegetation; on the line of drainage from the flanks of Wizard Peak to Rudds Gully

The severe flood of 1888 was reputedly caused by a heavy thunderstorm inland, following which all the Greenough Flats, and up to three-quarters of the Chapman River – Bootenal – Walkaway area, were under water up to 3 m deep. The beach sand barring the Chapman and Greenough river mouths is liable to severe erosion or destruction during these flooding events, but is quickly re-established by winter storm and wave action.

There is a significant flooding hazard in the level, poorly drained areas around Bootenal. This area is isolated from drainage into the Chapman River by a topographic high of about 6 m. Floodwater from the hills to the east is impeded in its westerly flow because it has to pass through a long, narrow channel linking Bootenal with Rudds Gully. During seasonal increases in run-off there is often erosion of the banks of the stream channels. This can be severe in areas where stock grazing has damaged the banks.

Landuse, vegetation, and drainage

The land of the Greenough Alluvium System is mainly used for agriculture and horticulture, but there is also some urban and industrial development. The flat nature of the ground makes it a suitable location for both Geraldton Airport and the principal rail route to the south. Almost all native vegetation has been cleared, except in river channels and poorly drained areas.

RLL53 30.5.00

Figure 21. Landform, landuse, and vegetation in the Chapman River alluvial channel (*GaA$_c$*) below terraced slopes to the alluvial plain (*GaA$_p$*) of the Greenough Alluvium System (MGA 274905E 6814945N)

There are three important drainage channels. The largest is the Chapman River, running along the northern boundary of the Greenough Alluvium System adjacent to the Moresby System colluvial footslopes and overlying Spearwood System sand dunes. The second is Rudds Gully, which is fed both from the plain to the north and from a narrow channel through the Spearwood System to the east. This channel drains the Bootenal depression, an area prone to flooding. The third channel is the Greenough River on the Greenough Flats, which is linked upstream to the alluvial plain near Walkaway, east of GERALDTON.

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Figure 22. Alluvial plain incised by the Chapman River stream channel in the Greenough Alluvium System (*Ga*) near Geraldton airport. 1:25 000-scale orthophotograph with contours at 5 m intervals

Relationships

In the northeast, the Greenough Alluvium System passes into the Greenough System along the Chapman River valley. The source of the material in the Greenough Alluvium System is in part the weathered sedimentary rock and duricrust of the surrounding Moresby System, but there is also a contribution from the larger catchment to the northeast along the Chapman River and east along the Greenough River. Sections through the alluvium, seen in terraces along the Chapman River, in the Meru landfill site, and in drillholes, show the alluvium to be interbedded with residual sand and calcarenite (Tamala Limestone) of the Spearwood System. To the west, the Greenough Alluvium System is overlain by the Quindalup System, and probably is linked to the relict erosional channels offshore from Cape Burney.

Geological history

Deposition of the deeper fluvial deposits in the Chapman River – Bootenal – Walkaway area probably pre-dates the formation of the eolian dunes of the Spearwood System. On the alluvial plain there are rises of Spearwood System sand and limestone as relics of the flooded eolian land surface. A thin veneer of younger alluvium, typically less

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Figure 23. Typical red 2.5YR 5/8, poorly bedded, gravelly medium sand below the alluvial plain (GaA_p) in the Greenough Alluvium System (MGA 269415E 6816480N). Drainage sump on Dwyer Street, Webberton

than 5 m thick, covers these relics. Along the Greenough River, the alluvial plain is largely the result of filling of a relict eolian deflation hollow between dunes of the Spearwood System.

There is some evidence of Holocene deposition adjacent to active river channels, but the younger parts of the alluvial plain are probably Pleistocene (Wyrwoll, 1984), and post-date the 120 ka marine transgression that formed the southwest-facing scarp in the Spearwood System adjacent to the Greenough Flats. Although aggradation took place over a considerable period, the nature of the deposits indicates that infrequent large-scale flood events in a braided stream environment were the dominant mechanism of deposition (Wyrwoll, 1984). The deeper, thicker parts of the succession pre-date parts of the Tamala Limestone, but cannot be further constrained in age.

Table 10. Particle-size distribution for samples from the Greenough Alluvium System. Grain-size classification (Appendix 5) from Geotechnical Control Office (1988) and Standards Australia (1993)

Map symbol	*Sample No.*	*Location*	*Sample description*	*Gravel (%)*	*Coarse sand(%)*	*Medium sand (%)*	*Fine sand (%)*	*Silt/clay (%)*
GaA_a	161371	Moonyoonooka–Narngulu Road (MGA 277540E 6813260N)	Loose, red slightly silty clayey medium quartz sand	0.1	32.0	44.2	17.9	5.8
GaA_a	161380	Georgina Road near Kennedy Road (MGA 279685E 6802330N)	Loose, red 2.5YR 4/6 slightly silty gravelly medium quartz sand	0.0	4.8	57.8	33.1	4.2
GaA_c	161364	Scott Road (MGA 271790E 6807195N)	Loose, dark reddish brown 2.5YR 3/4 slightly silty clayey medium to fine sand	0.1	19.3	52.8	22.0	5.8
GaA_c	161438	Chapman River, Deepdale (MGA 274905E 6814945N)	Thin to medium-bedded yellowish red 5YR 5/6 silty sand	3.2	12.6	59.0	16.9	8.2
GaA_c	161436	Chapman River, Deepdale (MGA 274905E 6814945N)	Reddish brown 5YR 4/4 gravelly sand	41.1	36.0	16.8	4.3	1.7

Quindalup System (*Qu*)

The Quindalup System occupies 4500 ha (6%) of GERALDTON (Fig. 24, Table 11), and is equivalent to the Holocene Safety Bay Sand, which comprises calcareous sand in dunes and coastal deposits. The system is an important source of limesand for agricultural applications, and is a source of limestone for road building. There is limited potential for heavy mineral sands.

Distribution and landform

The Quindalup System comprises a belt of eolian dunes and swales up to 3 km wide, parallel to the coast on GERALDTON. This belt can be divided into three distinct areas. In the south, a belt of parabolic dunes and minor blowouts, between 1 and 2 km wide, extends from the southeasterly margin of the sheet towards Cape Burney (Fig. 25). In an area extending up to 7 km north and south from Cape Burney, these parabolic dunes include large blowouts, and encroach onto older, deflated dunes within the Quindalup System. In the third area, around the City of Geraldton, a tombolo has formed in the most recent eolian and beach deposits against a scarp of older dunes to the east.

The western margin of the Quindalup System is a beach backed by a foredune (Fig. 26). Around the City of Geraldton a beach ridge plain has developed behind the foredune, marking the stages in the development of the tombolo that progressively connected the offshore reefs to the mainland following the latest sea-level highstand.

The Quindalup System includes older deflated dune-fields composed of calcareous soils overlying weakly lithified calcarenite. Small swampy swales containing waterlogged organic soil have been mapped 2 to 2.5 km southeast of Cape Burney. Slopes range from very short (< 10 m) and up to 40º on easterly facing foredune fronts, to long (> 250 m) and as little as 2º on deflated dunes. Relief ranges from 1 m on the beach ridge plain to 25 m in the parabolic dunes. The parabolic dunes mostly have gently to moderately inclined slopes, although they are very steep in some places on the northeasterly facing advancing dune front.

Regolith and rock materials

The dominant material in the Quindalup System is eolian sand composed of comminuted shell debris and quartz grains, with a minor component of garnet and other heavy minerals (Table 12). The shell material comes from the marine environment, and has been transported by marine and coastal processes into the dominantly eolian environment.

The eolian sands are largely unconsolidated to weakly lithified, well-sorted, calcareous medium sand. Carbonate clasts are subrounded, smooth, flat to elongate shell fragments, and the quartz is subrounded and glassy. Many of the sands contain minor amounts of subrounded pink garnet. The source of these clasts is both reworked marine shell and fluvial quartz sand, with the latter mainly from weathered Jurassic and Proterozoic rocks in the hinterland.

The dunes have varying degrees of lithification at depth, depending in part on their age. The younger parabolic dunes may have very weakly cemented calcarenite cores (Fig. 27), whereas the older, deflated

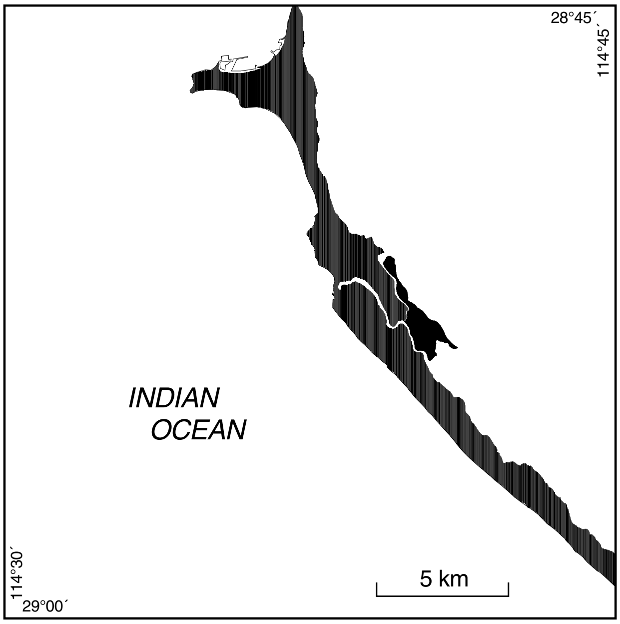

Figure 24. Distribution of the Quindalup System (*Qu*)

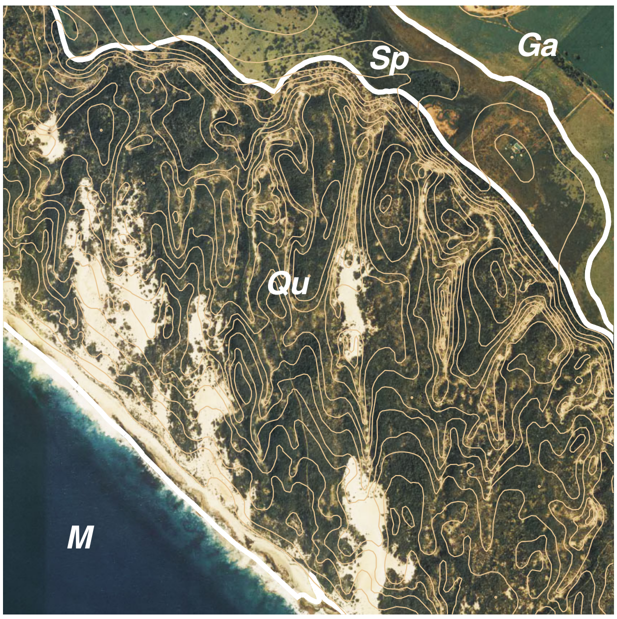

Figure 25. Landform pattern of parabolic dunes and blowouts in the Quindalup System (*Qu*), adjacent to the Spearwood (*Sp*), Greenough Alluvium (*Ga*) and Marine (*M*) Systems, 3 km west of Greenough. 1:25 000-scale orthophotograph with contours at 5 m intervals

Table 11. Components of the Quindalup System

Unit name, map symbol, and area	*Process, landform, and material*	*Typical occurrence*
Parabolic dunefield $QuE1_a$ 1 781 ha (39%)	Eolian Two areas; west of the Greenough Flats, and in the City of Geraldton 1. Greenough: mostly moderately to gently inclined, occasionally steeply inclined ridges forming a parabolic pattern; mostly less than 50 m AHD, but up to 70 m AHD; dominant slope aspect west to northwest 2. Geraldton: generally level (anthropogenic) slopes; up to 20 m AHD Eolian shell and quartz sand (Table 12)	1. Greenough: African Reef Boulevard, Westbank Estate (MGA 273200E 6800195N) Series of parabolic dune ridges and broad swales; dune ridges have cores of weakly cemented medium-grained calcarenite 2. Geraldton: Shenton Street near Regional Hospital (MGA 266690E 6813845N) Drainage sump excavated to 3 m; loose, light yellowish brown 2.5YR 6/3, medium sand, composed of shell fragments and quartz; minor soft calcarenite development
Older dunefield *QuE2* 1 125 ha (25%)	Eolian Mostly gently inclined, ranging from level to moderately inclined; slope aspect north-west to north; mostly 5–40 m AHD, but up to 60 m AHD Eolian shell and quartz sand	Hutchinson Street, Geraldton (MGA 267935E 6813495N) Weakly cemented, thickly laminated (5–20 mm) very pale brown 10YR 7/4 calcarenite about 2.5 m down in the crest of the dune (road cutting); small rhizomes to 5 mm diameter; coarse beds containing well-rounded clasts up to 1 mm; finer beds typically 0.5 mm maximum grain size; platy shell fragments aligned parallel to bedding
Deflated older dunefield *QuE3* 529 ha (12%)	Eolian Mostly level to gently inclined; locally moderately inclined adjacent to the Greenough River; dominant slope aspect westerly; 5–20 m AHD; up to 30 m AHD Weakly lithified eolian shell and quartz sand	Devlin Pool Road, Greenough (MGA 273110E 6801875N) Shallow auger hole to 1.2 m in calcareous soil with calcarenite fragments; slope grades gently down to the alluvial flats with a poorly defined break in slope; loose pale brown 10YR 6/3, silty, slightly gravelly medium sand; shell and quartz with soft calcarenite gravel
Blowout $QuE1_b$ 466 ha (10%)	Eolian Mostly gently inclined, up to 60 m AHD; slope aspect west to northwest; actively eroding Eolian shell and quartz sand	Southgate Dunes (MGA 268920E 6808555N) At least 6 m of sand exposed above old land surface below advancing dune front; excavated in limesand operation; loose, very pale brown 10YR 7/3, medium to fine sand; composed of shell fragments and subrounded quartz
Beach ridge plain QuB_r 357 ha (8%)	Coastal Numerous elongate low ridges built up by waves and modified by wind, lying behind and lower than the foredune; 1–2 m AHD Eolian shell and quartz sand	North of Point Moore, Geraldton (MGA 263605E 6814030N) Shallow auger hole to 1.2 m in dunes behind foredune; dunes typically 1–1.5 m high, with foredune about 0.5–1.0 m higher; loose, light grey 10YR 7/2, shell and quartz sand
Beach QuB_b 145 ha (3%)	Coastal Narrow, laterally extensive, gently to moderately inclined simple slope built up by waves; almost continuous along the coast; absent at the Greenough River mouth and along the rocky shoreline at Cape Burney; buried by reclamation or rebuilt by marine processes adjacent to manmade structures; mostly gently inclined southwesterly to westerly facing slopes; up to 6m AHD; rarely over 8 m AHD Marine shell and quartz sand; eolian in part	North of Point Moore, Geraldton (MGA 263540E 6814190N) Beach in front of 1.5 m high foredune; shallow auger hole to 1.0 m depth (waterlogged); light grey 10YR 7/2, medium sand, shell and quartz with minor garnet

Table 11. Components of the Quindalup System (continued)

Unit name, map symbol, and area	*Process, landform, and material*	*Typical occurrence*
Foredune *QuB$_d$* 107 ha (2%) (database only: within *QuB$_b$* on map)	Coastal Narrow, laterally extensive, gently to moderately inclined southwesterly to westerly facing slopes built up by wind from material from the adjacent beach; 4–12 m AHD; almost continuous along the coast; absent at the Greenough River mouth near Cape Burney; buried by reclamation or levelled by development west and north of Geraldton Eolian shell and quartz sand; marine in part	Tarcoola (MGA 268395E 6809155N) 4–5 m high foredune with moderately inclined to steep windward slope and steep to very steep lee slope; at the back of a 15–20 m deep beach, beach ridge plain behind
Swampy swale *QuE1$_w$* 3 ha (< 1%)	Eolian Level to gently inclined Waterlogged organic soil over eolian shell and quartz sand	2.5 km southeast of Cape Burney (MGA 271250E 6803000N) Concave break in slope between parabolic dunes and an area of water-dependent vegetation

dunes are composed of calcareous soils overlying moderately weakly cemented rock. Calcium carbonate content varies considerably (Table 13), ranging from about 40 to 95%. The beach sands tend to be coarser grained than the adjacent eolian deposits, and can include beach rock, which is a lithified beach deposit found at, or slightly above, the zone of wave action.

Mineral resource potential

The Quindalup System is an important source of limesand for agricultural applications. There are also quarries in the older, lithified calcarenites for material to be used in road-base construction. Sands in the system can also be used for construction and for beach rebuilding.

There is one active limesand operation within the Quindalup System, based in the advancing front of the Southgate Dunes about 6 km south of Geraldton. Limestone quarries adjacent to the Brand Highway are a source of material for road building. There is limited potential for titanium and zirconium minerals, and garnet, in the beach and dune sands.

Active processes and hazards

Marine transport of reworked shell and quartz is the dominant process in the coastal zone, resulting in seasonal deposition and erosion of beaches and river bars. This process is most active during storms, when there is often a significant increase in the erosion of coastal deposits. Beach regeneration is usually a natural seasonal process, and only in exceptional circumstances, such as cyclonic weather systems, has there been long-lasting change.

An important process in the Quindalup System is eolian transport of dune sand, and this is most active in blowouts, and areas where the vegetation has been damaged or stripped. The morphology of the parabolic dunes indicates a wind direction mainly from the south or south-southwest, which is well illustrated by the migration of sand northwards through the Southgate Dunes.

Migrating sand from blowouts is a minor hazard, and storm wave action is an important factor in erosion and deposition along the narrow coastal zone. The steep dune faces and loose sand make navigation over the dunes hazardous both on foot and by vehicle.

Landuse, vegetation, and drainage

Landuses within the Quindalup System include urban and industrial development, recreation, and agriculture. Much of the system is covered by natural vegetation, including large areas of Vacant Crown Land and some A-class reserves. Parts that have been cleared are used for urban development or agriculture.

Recreational use of the younger dunes and beaches, by 4WD and bike drivers and people seeking access to the coast, has destroyed the stabilizing vegetation cover in places, leading to degradation by eolian processes. The older dunes with associated less alkaline soils have level to gently inclined slopes, and are mostly cleared for cropping and grazing. These dunes are usually underlain by well-drained sand, have no permanent channels, and are not susceptible to gully erosion after heavy rainfall.

Relationships

The Quindalup System is currently active, and overlies the Greenough Alluvium and Spearwood Systems to the east. Beach deposits in the system have also progressively covered marine reefs, probably within the Tamala Limestone, near Point Moore. The older parts of the Quindalup System lie against a westerly facing scarp in the Spearwood System (Tamala Limestone) that formed at the 120 ka sea-level high of about 5 m AHD.

Geological history

The Quindalup System is composed of the Holocene (< 40 000 years BP) Safety Bay Sand, which is defined as the coastal sand dunes and shallow marine to littoral sands (Passmore, 1967, 1970). The older Quindalup System dunes form a westerly facing scarp, best developed in the City of Geraldton, that was eroded by coastal processes during the 5000 years BP sea-level high of up to 3 m AHD (Playford, 1983). The subsequent drop in sea level to its present stand is coincident with the development of the low dunes and beach ridge plain between Point Moore and the City. This tombolo has developed between the offshore reefs that would have been progressively exposed with the dropping sea level.

Table 12. Particle-size distribution for samples from the Quindalup System. Grain-size classification (Appendix 5) from Geotechnical Control Office (1988) and Standards Australia (1993)

Map symbol	*Sample No.*	*Location*	*Sample description*	*Gravel (%)*	*Coarse sand (%)*	*Medium sand (%)*	*Fine sand (%)*	*Silt/clay (%)*
$QuE1_a$	161361	Southeast of Cape Burney (MGA 269610E 6803235N)	Weak red 10R 5/3 medium sand	0.0	5.7	78.5	15.5	0.3
$QuE1_a$	161391	Brand Highway near Broadhead Avenue (MGA 267845E 6811500N)	Loose, very pale brown 10YR 8/2 to 7/3 medium sand with pink garnet	0.0	0.2	43.6	56.1	0.1

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Figure 26. Landform, landuse, and vegetation of the beach (QuB_b) and foredune (QuB_d) in the Quindalup System at Southgate Dunes (MGA 268585E 6805980N)

Table 13. Calcium carbonate ($CaCO_3$) content of selected sand samples from the Quindalup System (analysed by Chemistry Centre WA)

Map symbol	*Sample No.*	*Location*	*Description*	*$CaCO_3$ (%)*
QuB_r	161401	North of Point Moore (MGA 263605E 6814030N)	Light grey 10YR 7/2 calcareous sand	94.5
$QuE1_a$	161359	African Reef Boulevard, Westbank Estate (MGA 273200E 6800195N)	Dune crest composed of weakly cemented medium calcarenite	64.6
$QuE1_a$	161392	Askew Road (MGA 267325E 6813950N)	Loose brown 10YR 5/3 slightly clayey medium eolian calcareous sand; grey sandy clay augered below the bottom of the sump	70.0
$QuE1_b$	161441	Southgate Dunes (MGA 268920E 6808555N)	Very pale brown 10YR 7/3 medium to fine calcareous sand in old land surface beneath advancing front of dunes; the old surface is hard and littered with carbonized wood fragments	82.5
QuE2	168539	Water tower near Cook Rise (MGA 268475E 6810925N)	Very pale brown 10YR 7/4 medium to coarse calcareous sand with minor pink garnet; local limestone (calcrete) debris contains poorly preserved shell fragments	76.0
QuE2	168541	Flag Motel on Brand Highway (MGA 267755E 6811905N)	Moderately weak medium calcareous sand; cut slope behind motel in steep westerly facing slope of dune	38.7
QuE3	161363	2 km northeast of Cape Burney (MGA 270955E 6805515N)	Yellowish brown 10YR 5/4 poorly cemented eolian calcareous sand	45.0
QuE3	168536	Devlin Pool Road (MGA 273110E 6801875N)	Loose pale brown 10YR 6/3 silty slightly gravelly medium calcareous sand	63.8

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Figure 27. Weakly lithified calcarenite with well-preserved, cm-scale dune bedding, exposed in a blowout in the Quindalup System at Southgate Dunes (MGA 269400E 6805130N)

Marine System (*M*)

The Marine System occupies 42 500 ha (63%) of GERALDTON (Fig. 28, Table 14), and includes the offshore marine plain, nearshore seabed, and adjacent shoreface. Reefs form a significant proportion of the nearshore (Fig. 29). The shallow waters hold potential resources of limesand, sand, and limestone.

Morphology and distribution

The Marine System occupies the bulk of the GERALDTON sheet, and includes all seabed materials and morphological features up to Chart Datum (CD). The major components of the Marine System are an offshore level marine plain, and nearshore level to gently inclined seabed adjacent to a gently inclined shoreface.

The nearshore and inshore zones includes numerous low, submerged rocky ridges or reefs (Fig. 30). The reefs are often exposed in the littoral zone, between high and low water, as inshore or nearshore rock platforms, such as at Separation Point. Erosional channels offshore from Cape Burney are a relic of the fluvial palaeochannels associated with the Chapman River at a Pleistocene sea-level lowstand.

The Marine System also includes those areas of artificial fill or reclamation that modify the coastline (Fig. 31). These fill platforms typically extend 2 to 5 m above the water, and induce changes in the adjacent coastline by changing currents and wave action. The areas of fill at the Port of Geraldton also have associated dredged basins and channels.

Seabed materials

The seabed is dominantly covered with poorly sorted shell and quartz sand. This has formed by a variety of processes, including the reworking of fluvially sourced material from weathered hinterland rocks, erosion of the reefs, and biogenic processes. The reefs or rock flats are composed of calcarenite, and often have a coating of biogenic reef growth on the surface. The calcarenite is eolian in origin, and is mostly Tamala Limestone as found onshore in the Spearwood System.

Mineral resource potential

The Marine System is a possible source of limesand, sand, or limestone for agricultural applications, construction, beach rebuilding, or land reclamation. Much of the offshore area on GERALDTON is covered by water in excess of 15 m depth, which significantly reduces the potential for dredging. The nearshore and inshore areas, which are typically under 5 to 10 m of water, are underlain by calcareous sands that may be a source of limesand. Beneath the sand, and underlying all the reefs, is Tamala Limestone, which is quarried in onshore areas for armour stone and fill.

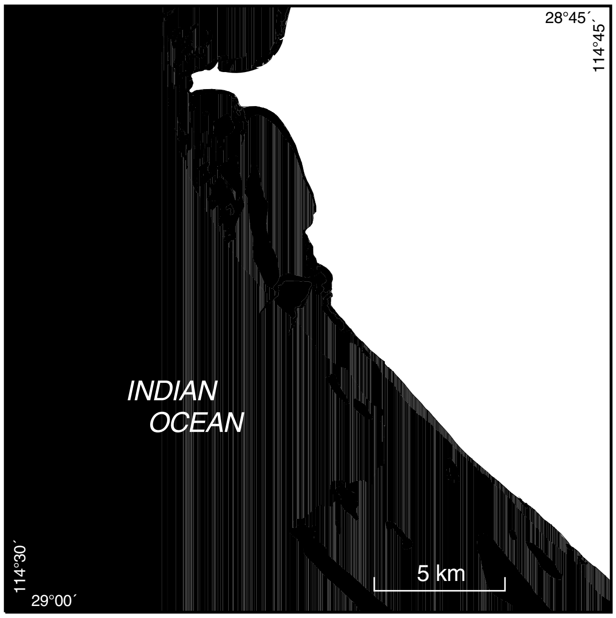

Figure 28. Distribution of the Marine System (*M*)

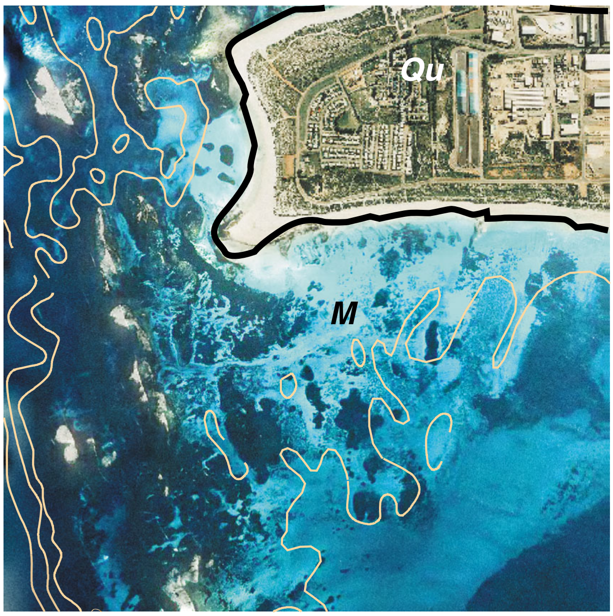

Figure 29. Marine reef and partly vegetated nearshore sandplain in the Marine System (*M*), adjacent to the Quindalup System (*Qu*), at Point Moore. 1:25 000-scale enhanced orthophotograph with bathymetry at 5 m intervals

Geologically, the offshore area is the source of the sand that forms beaches and foredunes. This sand is then modified by eolian processes to form the coastal dunes. The nearshore sands are a suitable source of material for beach reconstruction, as this sand most closely matches that found in existing beaches.

Table 14. Components of the Marine System

Map symbol, and area	*Process, landform, and material*	*Typical occurrence (based on bathymetry and enhanced Landsat TM imagery)*
M_p 29 622 ha (70%)	Marine Offshore sand plain; level; -15 to -20 m CD deepening to the southwest to more than -40 m CD Shell and quartz sand	West of Point Moore (MGA 260000E 6813000N)
M_n 9 393 ha (22%)	Marine Nearshore sand plain and sandy hollows; level to gently inclined; -5 to -15 m CD in the north; -10 to -20 m CD to the south Shell and quartz sand; minor rock ridges and flats	North of Point Moore (MGA 263200E 6813900N)
M_r 2 404 ha (6%)	Marine Reef or rock flat; mostly gently inclined, but includes moderately inclined narrow ridges; exposed at low tide (up to 2 m AHD) and found down to –20 m CD Undivided eolian calcarenite, biogenic reef and beach rock	North of Point Moore (MGA 263400E 6814200N)
M_s 887 ha (2%)	Marine Shoreface; mostly gentle slopes; 0 to -5 m CD in the north, deepening to -10 m CD to the south Shell and quartz sand; minor rock platform	North of Point Moore (MGA 263350E 6813700N)
M_v 122 ha (< 1%)	Marine Channel; relict erosional fluvial channel; level to gently inclined; narrow; -5 to -22 m CD Shell and quartz sand	West of Cape Burney (MGA 268400E 6804300N)
M_f 53 ha (< 1%)	Marine Man-made fill or reclamation; level platforms with steep sides; mostly 5–10 m AHD Rock rubble and earth fill	Reclamation area north of Connell Road, Geraldton Port (MGA 264750E 6814950N)

Active processes and hazards

The Marine System is the most active area on GERALDTON, with constantly active processes that include erosion and deposition by marine tides, currents, and wave action. The most active part of the system is the inshore area, which extends from the limit of wave action at depth, up to the lower edge of the beach. On GERALDTON the inshore zone mostly extends down to 5 m below CD, but can also extend to 10 m below CD in areas where nearshore reefs modify wave action. Longshore drift from south to north is constantly modifying the inshore shoreface, as well as the adjacent beach in the Quindalup System.

The shallow reefs in the nearshore zone typically range from those at African Reef, which are up to 15 m below CD, to those at Separation Point and Point Moore, which can be exposed at exceptionally low tides. The reefs are composed of limestone, with additional biogenic reef growth on the surface, and are a hazard to shipping.

During storms there is often a significant increase in wave action that can rapidly erode inshore deposits, and may damage reefs. Regeneration of the shoreface and adjacent beach is usually a naturally occurring seasonal process, and only in exceptional circumstances, such as cyclonic weather systems, will there be long-lasting damage in the inshore zone.

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Figure 30. Lithified calcarenite forming a reef (*M_r*) in the Marine System, exposed at low tide below beach sand one km south of Cape Burney (MGA 269610E 6803235N)

Figure 31. Landform and landuse for reclaimed areas (*M_f*) in the Marine System at Geraldton Port (MGA 264500E 6814800N); photograph by Geraldton Port Authority

Seabed use

The seabed has a significant impact on shipping, the local fishing industry, and recreation. Seabed materials and morphology have some importance for both recreational and commercial fishing, as the location of reefs, and the composition of seabed materials, can be a factor in finding fish and crayfish stocks. The position of reefs and ease of excavation of seabed materials is of concern to the Port of Geraldton, who maintain access channels for the docks to a depth of about 10 m below CD.

Relationships

The seabed is a currently active regime that is underlain by undivided older reefs composed of the Pleistocene Tamala Limestone. The marine processes offshore are closely linked to the coastal and eolian processes in the adjacent Quindalup System.

Geological history

The age of the seabed materials is dominantly Holocene, as the older reefs are often covered by a variable thickness of biogenic growth. The limestone that forms the reefs rests unconformably on strata of probable Jurassic age, but the extent and depth of these strata are uncertain.

Mineral resource potential

Overview

The mineral resource potential of Geraldton is limited to a small range of construction and industrial minerals (Fig. 32). These include gravel, sand, limestone, limesand, and clay (Flint et al., 2000). This group of minerals is also referred to as basic raw materials. There is potential for the extraction of large quantities of all of these resources except clay, but at present there is a limited market that is adequately serviced by existing extractive operations in the region. There are no recorded occurrences of base metals in the basement rocks, no titanium, zirconium, or garnet mineral sand concentrations have been located in the coastal sands, and no coal has been recorded in the Jurassic Cattamarra Coal Measures beneath Geraldton. The mineral resources of the Mid West have been reviewed by Flint et al. (2000).

Gravel

The ferruginous duricrust capping hills in the Moresby System ranges from strongly cemented to loose, and overlies mottled residual soil. The duricrust and soil were formed by weathering of the underlying bedrock, which in this area is dominantly siltstone and sandstone of the Jurassic Cattamarra Coal Measures. Looser gravels are preferred for road building, as they can be easily excavated and require no further processing. These gravels can be up to 2 m thick, and are used for roadbase, farm tracks, and unsealed shire roads.

Extracting gravel resources is limited by a number of factors, including land ownership and conservation requirements. Gravel resources are always located on steep-sided summit surfaces of the plateau, making vehicular access so difficult that this can effectively sterilize the resource. If the duricrust is strongly cemented it may prove very difficult to extract gravel for road building, and if the looser parts of such deposits are less than 1 m thick they may be subeconomic.

Sand

Thick deposits of yellow and red sand have been formed by the weathering of calcareous sand in the Spearwood System. The resulting quartz-rich sand is discoloured by small amounts of iron-oxide rich clay; goethite produces a yellow to brown colour, and hematite gives a distinctive red colour. The slightly more clayey, red sands are preferred for building pads. The resource is widespread throughout the Spearwood System, and is typically over 2 m thick above calcrete and calcarenite.

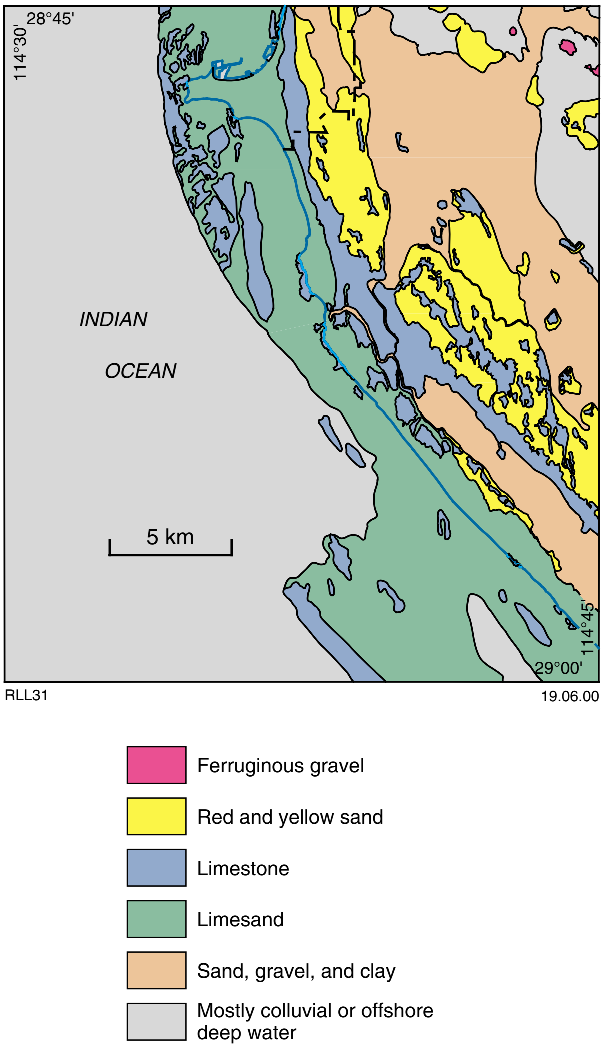

Figure 32. Construction and industrial-mineral resource potential of Geraldton

Sand and gravel

Fluvial deposits are often good sources of sand and gravel for low-grade construction aggregate such as building site fill. Grading and composition, as well as the available thickness, determine the viability of such materials. Deposits with little gravel, especially coarse fractions such as cobbles or boulders, are generally preferred. The presence of clay, particularly cracking clays, can cause drainage problems at construction sites, although some silt and clay is needed for cohesion.

Sand from the Spearwood System is preferred locally as a source of fill as it is better graded and less silty and clayey than the alluvium. However, the Greenough System in particular may provide suitable sources of sand and gravel for local use in the absence of other sources.

Limestone

The calcarenite and calcrete of the Spearwood System (Tamala Limestone), and the weakly cemented calcarenite of the Quindalup System (Safety Bay Sand) are generally referred to as limestone. Limestone can be used as a cement raw material, as an aggregate or roadbase, as a dimension stone (building stone), and in a variety of industrial applications. In the Geraldton area the only use of limestone has been as an aggregate or roadbase.

Limesand

Limesand is commonly used to correct soil deficiencies, as it helps to reduce soil acidity, and increases calcium and magnesium levels, both of which increase the supply of other nutrients. Limesand can also be used as a source of lime, and there are two operations at Dongara, south of GERALDTON, that produce lime for the mining industry.

Limesand is composed of comminuted shell fragments of marine origin, with minor quantities of quartz and other minerals derived from weathering and erosion of rocks inland. The calcium carbonate content of the loose sands that form the Quindalup System is typically over 60% (Table 13), and has been analysed at up to 94.5% for a sand from the beach ridge plain at Point Moore. Limesand samples from the rifle range near Greenough and the Mahomet Flats (Abeysinghe, 1998) contain 81.4–84.4% $CaCO_3$, and 3.0–6.5% $MgCO_3$.

The preferred conditions for limesand operations are blowouts in the mobile dunes, followed by vegetated dunes. The Midwest Sand Supplies operation at the northern end of Southgate Dunes is on the advancing front of a large blowout.

Common clay

Geraldton Brick Pty Ltd operates a small clay pit and brickworks at Bootenal (MGA 278400E 6805480N). The company extracts clay containing small fragments of limestone to supplement the imported clay feedstock for the kilns. The Bootenal area is prospective for common clays. Other level, poorly drained areas of the alluvial plains may also have clay resources.

Titanium, zirconium, and garnet

Eolian and coastal sands in the Swan Coastal Plain contain minor amounts of titanium and zirconium minerals, and garnet, also known as heavy mineral sands. The most important economic deposits are in the Eneabba Strandline. This feature may have equivalents in the Spearwood System on GERALDTON, in which at least three Pleistocene shorelines have been identified ranging from 0 to 60 m AHD (Woods and Associates, 1991, 1992).

Table 15. Hydrogeology of rock units on Geraldton (after Gozzard et al., 1988)

Land systems	*Stratigraphic unit*	*Age*	*Hydrogeology*
Spearwood and below Greenough Alluvium	Tamala Limestone	Pleistocene	Groundwater salinity increases towards the coast and with depth; bores and wells are shallow, and yield is limited to avoid drawing in saline water from below; salinity exceeds 1500 mg/l
Below Greenough Alluvium, Spearwood, and Quindalup, west of Geraldton Fault	Yarragadee Formation	Jurassic	Fresh water inland, but saline nearer the coast; best aquifer in the Geraldton Region
Below all systems	Cattamarra Coal Measures	Jurassic	Generally unsaturated or low yielding
Below all systems	Kockatea Shale	Triassic	Bore yields very low and mostly saline
Below all systems	Northampton Complex	Proterozoic	Generally shallow and low yield; fresh to saline

Exploratory drilling has identified up to 14% garnet-rich heavy mineral sands, with intersections of 11 m at 7.5% and 5 m at 8.9%, in the dune sands northeast of the Greenough Flats (Woods and Associates, 1991). Overall, the results of this exploration are that there is a potential to host shoreline-related heavy mineral sands, but that the grades are poor.

Garnet is often associated with heavy mineral sands, and is found in economic quantities at Port Gregory, about 75 km north-northwest of Geraldton. There are no recorded economic concentrations on GERALDTON.

Base metals

The Northampton Complex is prospective for lead and copper, and was the location of the State's first lead mine at Geraldine, about 120 km north of Geraldton. Exposures of the complex on GERALDTON are limited in extent, and show no signs of vein-hosted sulfide mineralization.

Hydrogeology

Gozzard et al. (1988) give the most recent account of the hydrogeology of GERALDTON, summarized in Table 15.

Acknowlegements

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References

ABEYSINGHE, P. B., 1998, Limestone and limesand resources of Western Australia: Western Australia Geological Survey, Mineral Resources Bulletin 18, 140p.

ANAND, R. R., CHURCHWARD, H. M., SMITH, R. E., SMITH, K., GOZZARD, J. R., CRAIG, M. A., and MUNDAY, T. J., 1993, Classification and atlas of Regolith–landform mapping units. Exploration perspectives for the Yilgarn Craton: Australia, CSIRO Division of Exploration and Mining, Restricted Report 440R (unpublished).

BEARD, J. S., 1990, Plant life of Western Australia: Kenthurst, NSW, Kangaroo Press, 319p.

BETTENAY, E., 1983, Western Region (II), *in* Soils: an Australian viewpoint: Australia, CSIRO Division of Soils, p.179–187.

BRUGIER, O., BOSCH, D., PIDGEON, R. T., BYRNE, D., and HARRIS, L., 1999, U–Pb chronology of the Northampton Complex, Western Australia — Evidence for Grenvillian sedimentation, metamorphism and deformation and geodynamic implications: Contributions to Mineralogy and Petrology, v. 136, p. 258–272.

CHRISTIAN, C. S., and STEWART, G. A., 1953, General report on the survey of Katherine–Darwin region, 1946: Australia, CSIRO, Land Research Series No. 1.

COCKBAIN, A. E., 1990, Perth Basin, *in* Geology and mineral resources of Western Australia: Western Australia Geological Survey, Memoir 3, p. 495–524.

DEPARTMENT OF RESOURCES DEVELOPMENT, 1999, Mid West — building on its infrastructure: Western Australia, Department of Resources Development, Prospect, September–November 1999, p. 18–19.

DYE, R. A., VAN VREESWYK, A. M. E., and MOORE, G. A., 1990, Geraldton rural–residential land capability study: Agriculture Western Australia, Land Resources Series, No. 4, 51 p.

FLINT, D. J., ABEYSINGHE, P., GAO M., PAGEL, J., TOWNSEND, D. B., VANDERHOR, F., and JOCKEL, F., 2000, Geology and mineral resources of the Mid West region: Western Australia Geological Survey, Record 2000/14.

GEOTECHNICAL CONTROL OFFICE, 1988, Guide to rock and soil description: Hong Kong, Civil Engineering Services Department, Geoguide No. 3, 189p.

GOZZARD, J. R., BLOCKLEY, J. G., and COMMANDER, D. P., 1988, Geology and mineral resources of the Geraldton Region: Western Australia Geological Survey, Environmental Geology Report EV 39, 20p. (unpublished).

GREY, G., 1841, Journals of two expeditions of discovery in north-west and western Australia during the years 1837, 38, and 39, (Volume 1, 412 p., Volume 2, 482 p.): Perth, Hesperian Press, (Volume 1 reprinted in 1983 and Volume 2 in 1984).

HOCKING, R. M., MOORS, H. T., and van de GRAAFF, W. J. E., 1987, Geology of the Carnarvon Basin, Western Australia: Western Australia Geological Survey, Bulletin 133, 289p.

JOHNSON, M. E., BAARLI, B. G., and SCOTT, J. H., 1995, Colonization and reef growth on a Late Pleistocene rocky shore and abrasion platform in Western Australia: Lethaia, 28, p. 85–98.

McARTHUR, W. M., 1991, Reference soils of south-western Australia: Agriculture Western Australia, 265p.

McARTHUR, W. M., and BETTENAY, E., 1960, The development and distribution of the soils of the Swan Coastal Plain, Western Australia: Australia CSIRO, Soil Publication 16, 55p.

McDONALD, R. C., ISBELL, R. F., SPEIGHT, J. G., WALKER, J., and HOPKINS, M. S., 1984, Australian soil and land survey field handbook: Melbourne, Inkata Press, 160p.

MILNE, G., 1935, Some suggested units of classification and mapping particularly for East African Soils: Soil Research, 4, No. 3.

MORY, A. J., and IASKY, R. P., 1996, Stratigraphy and structure of the onshore northern Perth Basin, Western Australia: Western Australia Geological Survey, Report 46, p. 781–789.

MUNSELL COLOR, 1994, Munsell soil color charts: New York, GretagMacbeth.

MYERS, J. S., 1990, Pinjarra Orogen, *in* Geology and mineral resources of Western Australia: Western Australia Geological Survey, Memoir 3, p. 264–274.

PAIN, C. F., WILFORD, J. R., and DOHRENWEND, J. C., 1994, Regolith–landform of the Ebagoola 1:250 000 Sheet Area (SD54-12) North Queensland: Australian Geological Survey Organisation, Record 1994/7, 38p.

PASSMORE, J. R., 1967, The geology, hydrology and contamination of shallow coastal aquifers in the Rockingham district, Western Australia: University of Western Australia, PhD thesis, 260p. (unpublished).

PASSMORE, J. R., 1970, Shallow coastal aquifers in the Rockingham District, Western Australia: Water Research Foundation of Australia, Bulletin 18, 83p.

PLAYFORD, P. E., 1983, Geological research on Rottnest Island: Royal Society of Western Australia, Journal, v. 66, p. 10–15.

PLAYFORD, P. E., COCKBAIN, A. E., and LOW, G. H., 1976, Geology of the Perth Basin, Western Australia: Western Australia Geological Survey, Bulletin 124, 311p.

PLAYFORD, P. E., HORWITZ, R. C., PEERS, R., and BAXTER, J. L., 1970, Geraldton, W.A.: Western Australia Geological Survey, 1:250 000 Geological Series Explanatory Notes, 39p.

ROGERS, L. G., 1996, Geraldton Region Land Resources Survey: Agriculture Western Australia, Land Resources Series, No. 13, 198p.

STANDARDS AUSTRALIA, 1993, Australian Standard, Geotechnical site investigation: Standards Australia, Homebush, NSW, 38p.

STIRLING, C. H., ESAT, T. M., LAMBECK, K., and McCULLOCH, M. T., 1998, Timing and duration of the Last Interglacial: evidence for a restricted interval of widespread coral reef growth: Earth and Planetary Science Letters, 160, p. 745–762.

TYLER I. M., PIRAJNO, F., BAGAS, L., MYERS, J. S., and PRESTON, W. A., 1998, The geology and mineral deposits of the Proterozoic in Western Australia: Australian Geological Survey Organisation, Journal of Australian Geology and Geophysics, 17 (3), p. 223–244.

van de GRAAFF, W. J. E., 1983, Silcrete in Australia: geomorphological settings, textures, structures, and their genetic implications, *in* Residual deposits: surface related weathering processes and materials *edited by* R. C. L. WILSON: Geological Society of London, Special Publication no. 11, p. 159–166.

WOODS, P. J. and ASSOCIATES, 1991, Annual Report, E70/846, 877, 879, 886, 887 and 930: Western Australia Geological Survey, M-Series, A32762 (unpublished).

WOODS, P. J. and ASSOCIATES , 1992, Annual Report, E70/846, 877, 879, 886, 887 and 930: Western Australia Geological Survey, M-Series, A35331 (unpublished).

WYRWOLL, K.-H., 1984, The sedimentology, stratigraphy and paleoenvironmental significance of a Late Pleistocene alluvial fill: central coastal areas of Western Australia: Catena, v. 11, p. 201–218.

Appendix 1

Gazetteer of localities on GERALDTON

	Easting	Northing		Easting	Northing
4 Fathom Bank	263000	6814900	Moresby	273100	6816700
Ackland Park	268100	6811200	Mount Fairfax (HOWATHARRA)	275500	6817700
African Reef	267900	6793500	Mount Scott	267200	6814500
Alexander Park	270600	6814000	Mount Tarcoola Suburb	268400	6810600
Allendale Primary School	268000	6815800	Mount Tarcoola Primary School	268600	6811700
Almafarm Homestead	279800	6807800	Narngulu	274800	6810200
Back Beach	266800	6812500	Narngulu Research Station	274100	6810100
Batavia Coast Boat Harbour	266700	6815700	Narra Tarra Estate (HOWATHARRA)	277100	6825200
Beachlands Suburb	265800	6813100	Pages Beach	264100	6814400
Beachlands Primary School	262200	6813300	Paringa Park	268200	6811700
Beresford Suburb	267600	6817100	Pioneer Memorial Park	267300	6816500
Bootenal	278300	6805900	Point Moore	263400	6813500
Bootenal Spring	274500	6801200	Point Moore Reefs	262900	6812700
Cape Burney	269200	6804400	Port Grey	266100	6812200
Cape Burney (locality)	270100	6805500	Rangeway Suburb	269400	6813900
Carney Hill	279600	6836500	Rangeway Primary School	268500	6814100
Champion Bay	266100	6816200	Rowan Reserve	271600	6816300
Champion Bay Beach	267200	6816200	Rudds Gully	272100	6807200
Corringle Homestead	275700	6800700	Separation Point	265400	6812900
Cutubury Nature Reserve	277000	6817000	Southgate Dunes	268300	6807000
Cutubury Pool	277400	6815200	Southgate Reef	266400	6807800
Deepdale Suburb	273600	6814700	St Francis Xavier Primary School	267100	6814300
Devlin Pool	272200	6803100	St John's School	268300	6813700
Geraldton City	267100	6814200	St Lawrence's School	267800	6818100
Geraldton Aerodrome	275600	6812700	Strathalbyn Suburb	270100	6817200
Geraldton Grammar School	267500	6815300	Strathalbyn Christian College	269900	6817200
Geraldton Primary School	266400	6814100	Tarcoola Beach Suburb	267800	6811200
Geraldton Secondary College	266800	6814000	The Convict Bridge	279900	6795700
Glendinning Park	267900	6810900	Town Beach	266100	6814600
Greenough	280100	6796200	Una Brook	279100	6817400
Greenough Oval	271100	6814400	Utakarra Suburb	270200	6814200
Greenough Reef	269000	6804200	Utakarra Repeater Station	270700	6813900
Greys Beach	264800	6813600	Waggrakine Primary School	269200	6820900
Hinton Farm	208200	6800100	Walkaway (WALKAWAY)	285700	6796700
Holland Street School	266700	6814000	Wandina Suburb	269100	6809200
Kadewa Well	267600	6844400	Webberton Suburb	268600	6816700
Karloo Suburb	269100	6811200	Webberton Research Station	267400	6817500
Karloo Park Reserve	270000	6812900	West End Suburb	264600	6813800
Little African Reef	270000	6795700	Wizard Peak (WALKAWAY)	284300	6809800
Meekawaya Aboriginal Pre-School	266100	6814300	Wonthella Suburb	268700	6816500
Meru	274100	6811700	Woorree Suburb	271600	6814700
Moonyoonooka	278100	6814200	Woorree Park Reserve	271600	6815600

Source: Department of Land Administration (Western Australia)

Appendix 2

Slope classification system

(McDonald et al., 1984)

Slope (degrees)	*Slope symbol*	*Slope name*
0 – 0.6	LE	level
0.6 – 1.75	VG	very gently inclined
1.75 – 5.75	GE	gently inclined
5.75 – 18	MO	moderately inclined
18 – 30	ST	steep
30 – 45	VS	very steep
45 – 72	PR	precipitous
72 – 90	CL	cliffed

Appendix 3

Classification of rock material strength

(Geotechnical Control Office, 1988; Standards Australia, 1993)

	--	-----------	*TEST METHOD*	-----------------------------	----------------------------
STRENGTH	*Hand*	*Thumbnail*	*Pocket knife*	*Geological pick*	*Hand specimen*
EXTREMELY WEAK	easily crumbled	indented deeply			
VERY WEAK	crumbled with difficulty	scratched easily	peeled		
WEAK	broken into pieces	scratched	peeled	deep indentations (<5 mm)	broken by single light hammer blow
MODERATELY WEAK	broken with difficulty	scratched with difficulty	difficult to peel but easily scratched	shallow indentations easily made	usually broken by single light hammer blow
MODERATELY STRONG			scratched	shallow indentations with firm blow	usually broken by single firm hammer blow
STRONG				superficial surface damage with firm blow	more than one firm hammer blow to break
VERY STRONG					many hammer blows required to break
EXTREMELY STRONG					only chipped by hammer blows

Appendix 4

Abbreviations

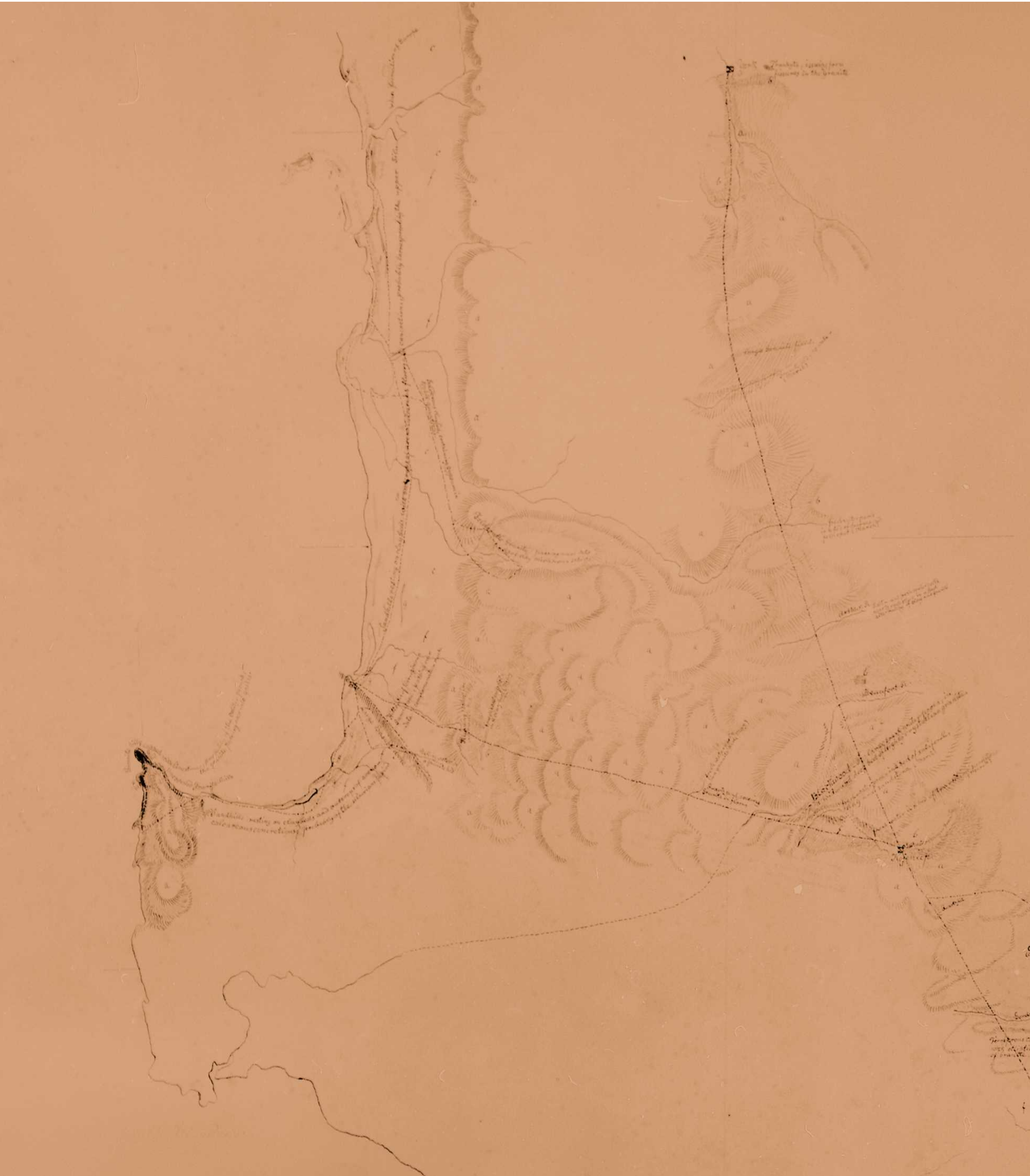
AHD	Australian Height Datum (mean sea level)
BP	Before present
CD	Chart Datum (lowest astronomical tide)
ka	Thousands of years (kilo anna)
Ma	Millions of years (mega anna)
MGA	Map Grid of Australia

Appendix 5

Grain-size ranges for field classification and particle-size determinations of regolith

(Geotechnical Control Office, 1988; Standards Australia, 1993)

	Size range (mm)	*Sieve size range (mm)*
boulders	>200	
cobbles	200 – 60	
coarse gravel	60 – 20	>2.36
medium gravel	20 – 6	
fine gravel	6 – 2	
coarse sand	2 – 0.6	0.6 – 2.36
medium sand	0.6 – 0.2	0.212 – 0.6
fine sand	0.2 – 0.06	0.075 – 0.212



LANGFORD

Regolith–landform resources of the Geraldton 1:50 000 sheet

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GERALDTON

WESTERN AUSTRALIA 1:50 000 REGOLITH—LANDFORM RESOURCES SERIES

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

SHEET 1840 - III FIRST EDITION 2000

SYMBOLS

Geological boundary
- exposed
Fault or shear
- exposed
- normal, tick on downthrown side
Bedding, showing strike and dip
- inclined
Gneissic banding, showing strike and dip
- inclined
Fracture or jointing, showing strike and dip
- vertical

Highway with national route marker
Formed road; bridge
Track
Railway, with siding — Narngulu
Fence, generally with track
Reserve boundary
Local government area boundary
Townsite,
- population more than 10 000 — GERALDTON
- less than 1 000 — Greenough
Locality — Bootenal
Building, yard — Yard
Microwave repeater station

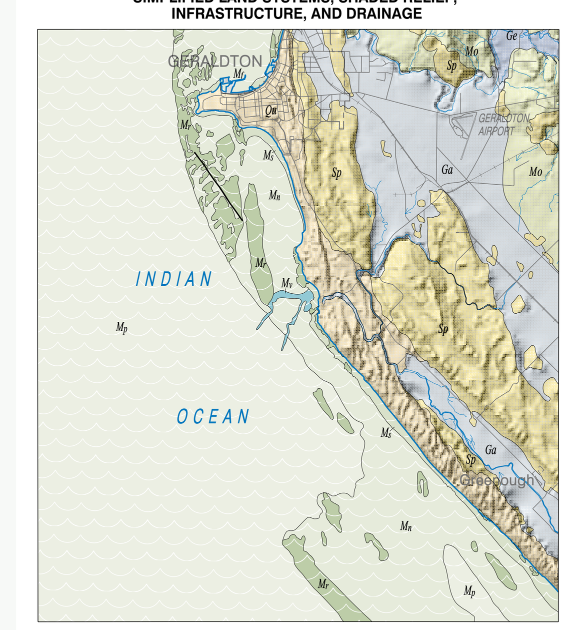
Horizontal control, major
Sand dune
Swale line
Contour, height in metres — 20

Watercourse
Bathymetric contour, depth in metres — 10
Lake
Drain — drain
Bore or well
Dam, tank
Lighthouse
Wharf, jetty or pier
Wave pattern denotes permanent water

Petroleum exploration well
- stratigraphic — St
Made ground or quarry

Mineral and rock commodities
- Clay — Cy
- Limesand — Lsd
- Gravel — Gvl
- Limestone — Lst
- Sand — Sv

SIMPLIFIED LAND SYSTEMS, SHADED RELIEF, INFRASTRUCTURE, AND DRAINAGE



The Geraldton Regolith-Landform Resources map provides information on the regolith (soils) and underlying rocks, on the landforms (landscape), topography, infrastructure, and on the mineral and construction material resources of Geraldton. This map will be of value in landuse planning, the sustainable development of resources, and in identifying natural hazards, both onshore and in shallow nearshore areas.

The map also delineates land systems, which are areas of discrete recurring patterns of landform, regolith, materials, and vegetation. These patterns are related to geological and hydrogeological units, and form the basis of identifying landuse including mineral resource potential.

Mf	Ms	Mn	Mp	Mv	Mr

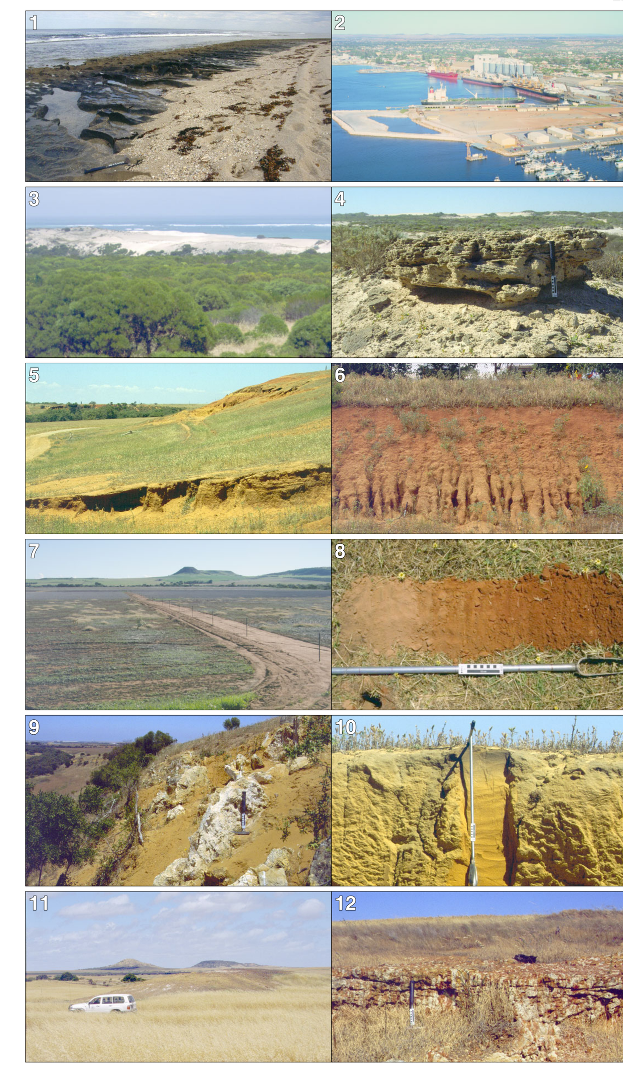
- *Mf* Reclamation
- *Ms* Marine shore face
- *Mn* Marine nearshore
- *Mp* Marine offshore
- *Mv* Marine channel
- *Mr* Marine reef

- *Qu* Quindalup System—beach and dunefields
- *Ga* Greenough Alluvium System—alluvial plain
- *Ge* Greenough System—alluvial terraces and channels
- *Sp* Spearwood System—deflated dunes
- *Mo* Moresby System—plateau and footslopes underlain by Jurassic rocks

SCALE 1:250 000

0 5 10 Kilometres

LEGEND



Marine

MARINE—42,500 ha 63%

Offshore level seabed, and nearshore level to gently inclined seabed, with low, submerged rocky ridges or reefs. Inshore rock platforms (1) and gently inclined shore face. Erosion and deposition by marine tides, currents, and wave action. Small areas of man-made reclamation in urban areas at the coast (2). Dominantly shell and quartz sand formed by biogenic processes, reworking of fluvially sourced material from weathered hinterland rocks, or by erosion of reefs. Reefs or rock flats composed predominantly of eolian calcarenite. Currently active system that includes undivided older reefs probably of the Spearwood System. Primarily used for shipping, fishing industry, and recreation. Possible source of sand or limestone for construction, beach rebuilding, and reclamation. Shallow reefs are a hazard to shipping. Rapid deposition and erosion of coastal deposits can also occur during storms.

Photograph 2 reproduced with permission of the Geraldton Port Authority

Qu

QUINDALUP SYSTEM—4500 ha 6% (Safety Bay Sand)

Mostly gently to moderately inclined dunes, occasionally very steep. Eolian processes dominant, with wave action important for erosion and deposition in the narrow coastal zone. Dunes and swales formed by southerly winds and eroded by coastal processes to form a westerly facing shoreline. Actively eroding to form blowouts in areas of vegetation loss (3). Includes older deflated dunefields composed of weakly lithified calcarenite (4). Small swampy swales contain waterlogged organic soil. Currently active system that overlies the Greenough Alluvium and Spearwood Systems. Landuses include urban and industrial development, and recreation. Crop cultivation and grazing on the older dunes. Source of limesand, limestone, and sand for construction and beach restoration. Used as fill for reclamation. Migrating sand from blowouts is a minor hazard.

Ga

GREENOUGH ALLUVIUM SYSTEM—9400 ha 14%

Level plain with locally steep to cliffed terrace slopes (5). Formed by fluvial deposition from the Greenough and Chapman rivers on flood plains between the dunes and inland escarpment. Dominantly red silty sandy clay over sandy gravel (6), interbedded in places with residual sand and calcarenite of the Spearwood System. Rare swamps with waterlogged organic soil. Overlain by the Quindalup System to the west. Interbedded with the Spearwood System. Lateral equivalent of the Greenough System, and partially sourced from the Moresby System to the north and east. Dominantly used for agriculture and horticulture, with some urban and industrial development. Almost all native vegetation has been cleared, except in river channels and poorly drained areas. Major flooding hazard in level, poorly drained areas, with severe erosion of stream channels also possible.

Ge

GREENOUGH SYSTEM—400 ha 1%

Level to very gently inclined terrace (7) with locally steep to cliffed terrace scarps. Formed by fluvial deposition of silty sandy clay (8) from the Chapman River on flood plains and in valleys between the adjacent escarpments. Lateral equivalent of the Greenough Alluvium System downstream to the southwest, and derived from the surrounding Moresby System. Dominantly used for agriculture, with no urban or industrial development. Much of the native vegetation has been cleared, except in river channels. Heavy rainfall can cause local flooding in level, poorly drained areas, and severe channel erosion in the river and streams.

Sp

SPEARWOOD SYSTEM—8000 Ha 12% (Tamala Limestone)

Mostly level to gently inclined dunes, with rare steep to precipitous rocky slopes (9). Dominantly eolian deflated dunes and swales formed by southerly winds and eroded by coastal processes to form a westerly facing scarp. Rare marine facies of biogenic reef near the coast. Forms low sandy rises in the Greenough Alluvium System. Originally calcareous dune sand, now weathered by surface leaching and groundwater precipitation to form yellow (10) and red residual quartz sand over a white to light brown calcrete surface to the underlying calcarenite (limestone). Swampy swales contain waterlogged organic soil. Calcareous slopewash colluvium on the westerly facing footslopes to the scarp is derived from weathered calcarenite. Component of the reefs in offshore areas. Overlain by the Quindalup System to the west. Overlies the Moresby System on the hills to the north and east. Interbedded with the Greenough Alluvium System. Source of construction limestone, building sand, and fill for reclamation. Extensively cleared for cropping and grazing. Areas underlain by limestone are often uncleared. Also used for urban and industrial development. Minor hazard on rocky slopes.

Mo

MORESBY SYSTEM—2800 ha 4%

Very gently inclined hillcrests above locally steep to very steep scarps. Moderate to steeply inclined sideslopes and level to gently inclined footslopes (11). Residual quartz sand and ferruginous duricrust over mottled soil (weathered rock) on hillcrests (12). Mass wasting deposits ranging from proximal weathered rock debris, gravel, and boulders, to distal silty sand over mottled sandy clay. Seasonally active fluvial deposition of silty sandy clay on sideslopes and footslopes. Hillcrests and plateaus, locally above a scarp exposing weathered Jurassic sedimentary rocks. Minor exposures of Triassic strata and Proterozoic basement rocks on hillslopes. Overlain locally by the Spearwood System. Source of material for the Greenough and Greenough Alluvium systems to the southwest. Mostly cleared for cropping and grazing, but the steeper sideslopes and some gravelly flat tops are only partially cleared of native vegetation. Source of gravel for road building. Heavy rainfall can cause severe channel erosion in the streams, and landslides on the steeper slopes.

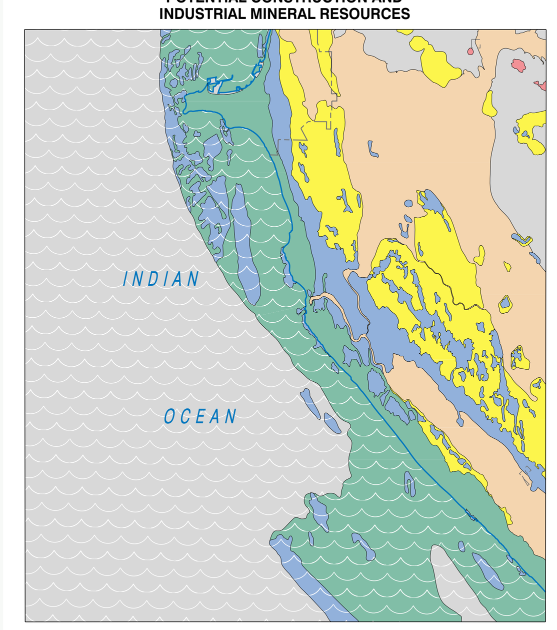
REFERENCE

Land System \ Age	Phanerozoic: Cainozoic: Holocene	Phanerozoic: Cainozoic: Pleistocene	Phanerozoic: Cainozoic: undivided	Phanerozoic: Mesozoic: Jurassic	Phanerozoic: Mesozoic: Triassic	Proterozoic
	Mf	*Mv*	*Mr*			
	Ms					
	Mn					
	Mp					
Quindalup (*Qu*)	*QuBb*					
	QuBr					
	QuE1a					
	QuE1b					
	QuE1w					
	QuE2					
	QuE3					
Greenough Alluvium (*Ga*)	*GaAc*	*GaAt*				
	GaAw	*GaAa*				
Greenough (*Ge*)	*GeAc*	*GeAt*				
Spearwood (*Sp*)	*SpEw*	*SpE*	*SpCf*			
		SpEk				
Moresby (*Mo*)	*MoAc*		*MoC*	Jy	Ŧk	₽mNO
			MoCf	Jd		
			MoCt	Jc		
			MoRz			
			MoRfp			

Description

- *Mf* Marine. Man-made fill or reclamation; rock rubble and earth fill
- *Ms* Marine. Shore face; shell and quartz sand; minor rock platform
- *Mn* Marine. Nearshore sand plain and sandy hollows; shell and quartz sand; minor rock ridges and flats
- *Mp* Marine. Offshore sand plain; shell and quartz sand
- *Mv* Marine. Channel; relict erosional fluvial channel
- *Mr* Marine. Reef or rock flat; undivided eolian calcarenite, biogenic reef, and beach rock
- *QuBb* Coastal. Beach; includes foredune; marine shell and quartz sand; eolian in part
- *QuBr* Coastal. Beach ridge plain; eolian shell and quartz sand
- *QuE1a* Eolian. Parabolic dunefield; eolian shell and quartz sand
- *QuE1b* Eolian. Blowout; actively eroding eolian shell and quartz sand
- *QuE1w* Eolian. Swampy swale; waterloged organic soil over eolian shell and quartz sand
- *QuE2* Eolian. Older dunefield; eolian shell and quartz sand
- *QuE3* Eolian. Deflated older dunefield; weakly lithified eolian shell and quartz sand
- *GaAc* Alluvial. Stream channel; includes bed and banks; seasonally water-filled; silty sandy clay
- *GaAw* Alluvial. Swamp; waterlogged organic soil over silty sandy clay
- *GaAt* Alluvial. Terrace; silty sandy clay
- *GaAa* Alluvial. Alluvial plain; silty sandy clay over sandy gravel
- *GeAc* Alluvial. Stream channel; includes bed and banks; usually water-filled; silty sandy clay
- *GeAt* Alluvial. Terrace; silty sandy clay
- *SpEw* Eolian. Swampy swale; waterlogged organic soil over residual quartz sand
- *SpE* Eolian. Deflated dunes of residual quartz sand over calcarenite; low sandy rise in alluvial plain
- *SpEk* Eolian. Calcareous eolianite; calcrete above lithified eolian shell and quartz sand
- *SpCf* Colluvial. Footslope colluvium; decomposed eolian shell and quartz sand
- *MoAc* Alluvial. Stream channel; includes bed and banks; seasonally active; slope deposits, silty sandy clay, and weathered bedrock
- *MoC* Colluvial. Undivided slopes; silty sand over mottled sandy clay
- *MoCf* Colluvial. Footslopes; silty sand over mottled sandy clay
- *MoCt* Colluvial. Talus slope to escarpment; weathered rock debris; gravel and boulders
- *MoRz* Residual. Quartz sand over weathered duricrust and mottled soil
- *MoRfp* Residual. Ferruginous pisolitic duricrust over mottled soil (weathered bedrock)
- Jy **YARRAGADEE FORMATION:** sandstone, siltstone, and claystone with minor conglomerate and coal (subsurface only)
- Jd **CADDA FORMATION:** shale, siltstone, and sandstone with shelly sandy limestone (subsurface only)
- Jc **CATTAMARRA COAL MEASURES:** thinly bedded sandstone, gravelly sandstone, and laminated siltstone; carbonaceous in parts
- Ŧk **KOCKATEA SHALE:** laminated siltstone and shale with minor sandstone
- ₽mNO Northampton Complex: granulite and metamorphosed granite

POTENTIAL CONSTRUCTION AND INDUSTRIAL MINERAL RESOURCES



Ferruginous gravel— *MoRfp, MoRz*

Cemented ferruginous pisolitic duricrust cappings on low hills and escarpments, locally concealed by residual quartz sand. Potential source of aggregate for road construction.

Red and yellow sand— *SpE, SpEw*

Quartz-rich eolian sand formed as a weathered residuum over limestone. Potential source of sand for building platforms and construction.

Limestone— *QuE2, QuE3, SpEk, SpCf, Mr*

Calcrete and calcarenite (limestone) formed by weathering of carbonate-rich sand dunes. Rock strength varies from moderately weak to very strong, and may be excavated as aggregate or boulders. Overlain by variable thickness of yellow and red sand. Limestone may be used for road base, large-scale fill, harbour installations, and sand for building.

Limesand— *QuBb, QuBr, QuE1a, QuE1b, Ms, Mn, Mv*

Mostly unlithified shell-rich sand of eolian and marine origin, with calcium carbonate contents up to 94%. May be suitable for agricultural applications.

Sand, gravel and clay— *GaAc, GeAc, GaAt, GeAt, GaAa*

Fluvial sediments ranging from silty clay to sandy gravel. Potential source of aggregate-quality sand and gravel for building and fill. Includes clay suitable for brick-making

QuE1w, MoAc, MoC, MoCf, MoCt, Mp, Mv

Mostly colluvial sand, gravel, and clay, with some weathered rock or offshore deep water sand plain

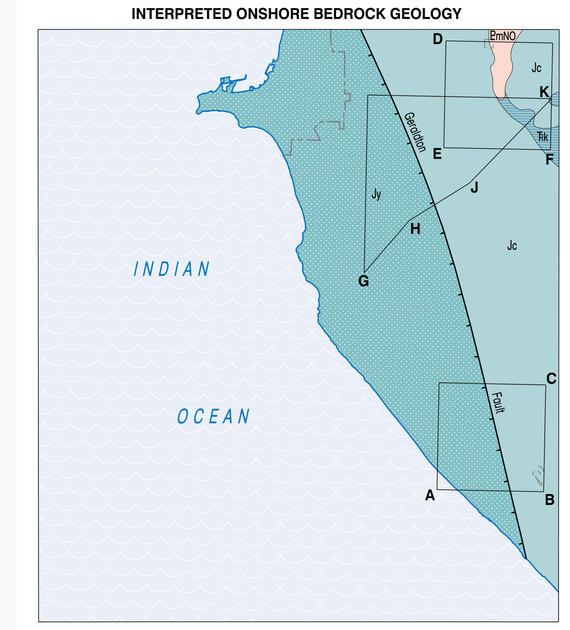
SCALE 1:250 000

0 5 10 Kilometres

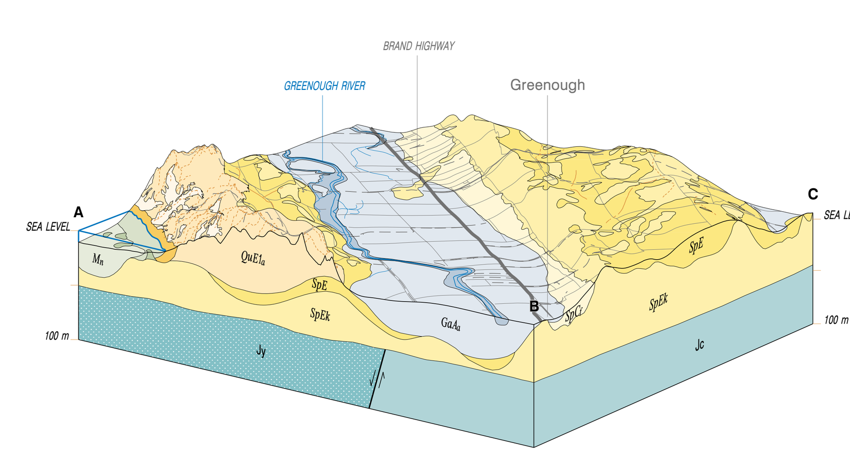
LANDSAT TM IMAGE WITH FIELD SITE LOCATIONS

Date of imagery 23 August 1992

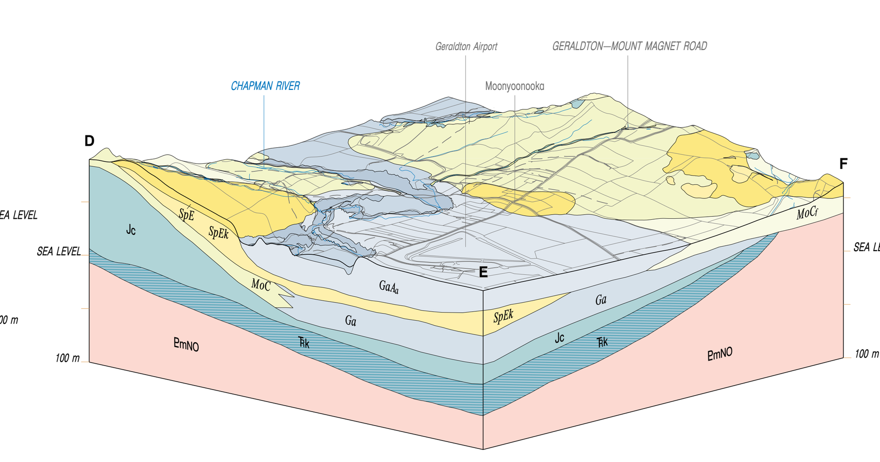
INTERPRETED ONSHORE BEDROCK GEOLOGY



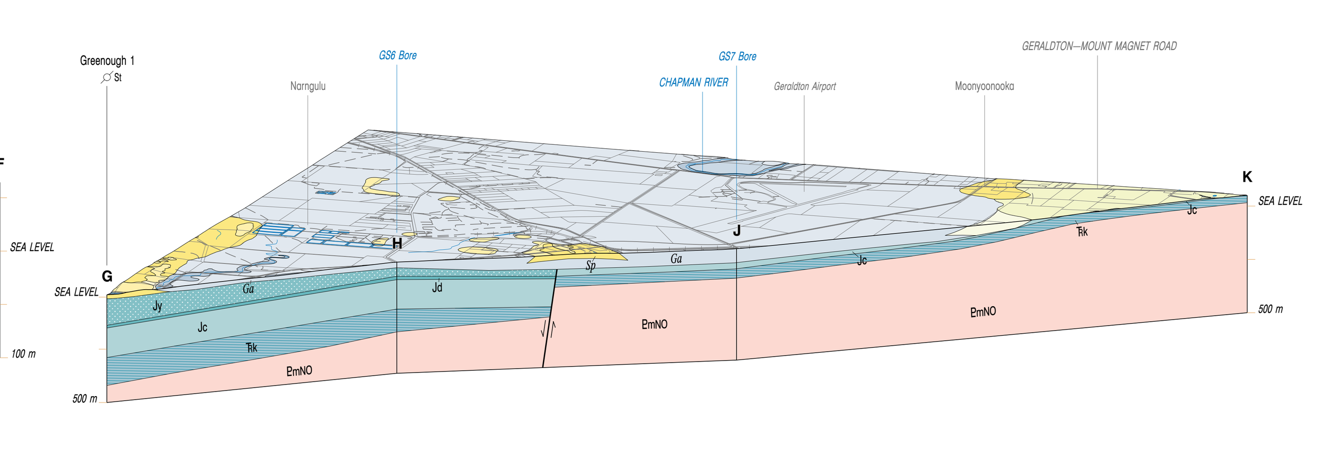
BLOCK DIAGRAMS



Vertical exaggeration $\frac{V}{H} = 10$



Vertical exaggeration $\frac{V}{H} = 10$



Vertical exaggeration $\frac{V}{H} = 2$

Normal fault, showing relative displacement

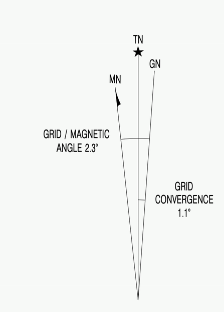
GERALDTON MINERAL OCCURRENCES

NUMBER*	COMMODITY	EASTING	NORTHING
INDUSTRIAL MINERAL—Cy, Lsd			
Sedimentary—undivided			
4338	Cy	278400	6805480
6608	Lsd	268920	6808555
CONSTRUCTION MATERIAL—Gvl, Lst, Sv			
Undivided			
6590	Sv	269300	6817360
6591	Gvl	278420	6816390
6592	Gvl	279100	6815755
6593	Sv	275150	6815120
6596	Gvl	280270	6814820
6598	Gvl	280290	6814010
6599	Gvl	279765	6813830
6600	Sv	280320	6813580
6602	Gvl	280265	6812890
6603	Sv	279560	6812470
6604	Sv	279910	6811950
6605	Sv	272090	6811600
6605	Lst	272090	6811600
6606	Sv	271000	6808730
6606	Lst	271000	6808730
6607	Lst	275080	6808810
6609	Sv	274620	6808590
6613	Sv	269860	6807300
6614	Gvl	271220	6806070
6615	Sv	273830	6805770
6617	Lst	271915	6804535
6618	Lst	274750	6804170
6619	Sv	274500	6803040
6620	Lst	277120	6799940
6621	Sv	278030	6799390
6680	Lst	269780	6816910
6681	Lst	273170	6802880

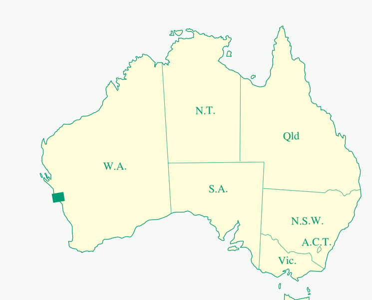
* KEY TO OPERATING STATUS

Bold numbers (i.e. 6592)	Operating quarry
Bold and italic numbers (i.e. 6609)	Abandoned quarry

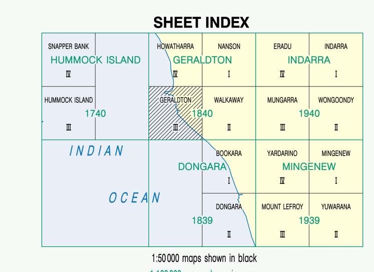
Numbers refer to GSWA WAMIN mineral occurrence database



True north, grid north and magnetic north are shown diagrammatically for the centre of the map. Magnetic north is correct for 2000 and moves easterly by about 0.1° in 2 years.



SHEET INDEX



Geology by R. L. Langford 1998–99

Edited by D. Ferdinando and G. Loan

Cartography by S. Collopy, J. Kirk, and B. Williams

Topography from the Department of Land Administration Sheet SH 50-1, 1840, with modifications from geological field survey

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Bathymetric data supplied by the Department of Transport. This map is not intended for marine navigation

Bore and well data supplied by the Water and Rivers Commission

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This map is also available in digital form

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DEPARTMENT OF MINERALS AND ENERGY
L. C. RANFORD, DIRECTOR GENERAL

GOVERNMENT OF WESTERN AUSTRALIA
HON. NORMAN MOORE, M.L.C.
MINISTER FOR MINES

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA
DAVID BLIGHT, DIRECTOR

SCALE 1:50 000

1000 500 0 Metres — 1 2 3 4 5 Kilometres

UNIVERSAL TRANSVERSE MERCATOR PROJECTION
HORIZONTAL DATUM: GEOCENTRIC DATUM OF AUSTRALIA 1994
VERTICAL DATUM: AUSTRALIAN HEIGHT DATUM
BATHYMETRIC DATUM: LOWEST LOW SEA LEVEL

Grid lines indicate 1000 metre interval of the Map Grid Australia Zone 50

The Map Grid Australia (MGA) is based on the Geocentric Datum of Australia 1994 (GDA94). GDA94 positions are compatible within one metre of the datum WGS84 positions.

WESTERN AUSTRALIA 1:50 000 REGOLITH—LANDFORM RESOURCES SERIES

GERALDTON

SHEET 1840 - III FIRST EDITION 2000