



Government of **Western Australia**
Department of **Mines and Petroleum**

SEA TO SCARP

**Geology, landscape, and land use planning
in the southern Swan Coastal Plain**

by JR (Bob) Gozzard



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Western Australia**



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Cover

The mouth of the Moore River at Guilderton

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Hence it appears that the numerical amount of our population, their varied occupations and the fundamental sources of their industry and wealth, depend, in a great degree, upon the geological character of the strata on which they live.

William Buckland, 1836

Geology and Mineralogy considered with reference to Natural Theology, Bridgewater Treatise No. 6, William Pickering, London.

Sea to scarp

Geology, landscape, and land use planning in the southern Swan Coastal Plain

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Introduction

Land is a vital resource to all of us, and modern society places many demands on it. These need not be conflicting demands if sequential or simultaneous land use planning is applied sensibly to ensure that the most efficient use is made of the land and its resources.

Geology has an important role to play in land use planning because it provides essential information about resources of minerals, water, and basic raw materials, as well as potential geohazards such as coastal erosion, flooding, and foundation conditions.

In planning terms, 'sterilize' describes the action of preventing or hindering the use of a geological resource. Building houses on deposits of the basic raw materials needed to build more houses and roads sterilizes those resources and increases the cost of future urban expansion. This is an example of why geologists must both gather information about the land, and communicate that information to planners and developers in a way that is easily understood by non-geologists. If communicated successfully, land information can be incorporated into local and regional planning policies and frameworks to the greater benefit of all Western Australians.

Southwest Western Australia, from Geraldton to Albany, is experiencing an unprecedented demand for urban and rural residential and industrial land and the infrastructure to support it. In particular, development along the coastal plain between Geraldton and Dunsborough is accelerating the depletion or sterilization of important deposits of basic raw materials. This area is also potentially subject to a range of geohazards, as well as having significant geological and biological heritage values.

This publication shows the extent of the Geological Survey of Western Australia's (GSWA) updated geological mapping along the coastal plain between Lancelin and Dunsborough. A series of factual maps show particular aspects of the geology of the area, such as the nature and distribution of surface material types, landscape features, quarries and pits, geoheritage sites and geotechnical properties. Thematic or interpretative maps, which are derived from the basic data, define characteristics of particular interest such as resources of minerals and construction materials, geohazards, and development potential. The text accompanying each map describes and explains the theme of the map.

An accompanying digital package for this product is available on USB drive.

Location

The map (Fig. 4) shows, in red, the outline of the region characterized by the datasets presented in this publication. The region covers an area of about 20 000 km², includes most of the country between the edge of the Darling Plateau in the east and the Indian Ocean in the west. It extends over 300 km from Lancelin in the north to the Leeuwin–Naturaliste Region in the south.

The southern Swan Coastal Plain, shown in olive in Figure 4, is the relatively low lying ground between the Darling, Gingin and Whicher Scarps and the Indian Ocean.

The region includes all or part of 45 local authorities, 40 of which extend on to the Swan Coastal Plain.



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Figure 1. Perth skyline



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Figure 2. Aerial view of Bunbury



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Figure 3. Aerial view of Busselton

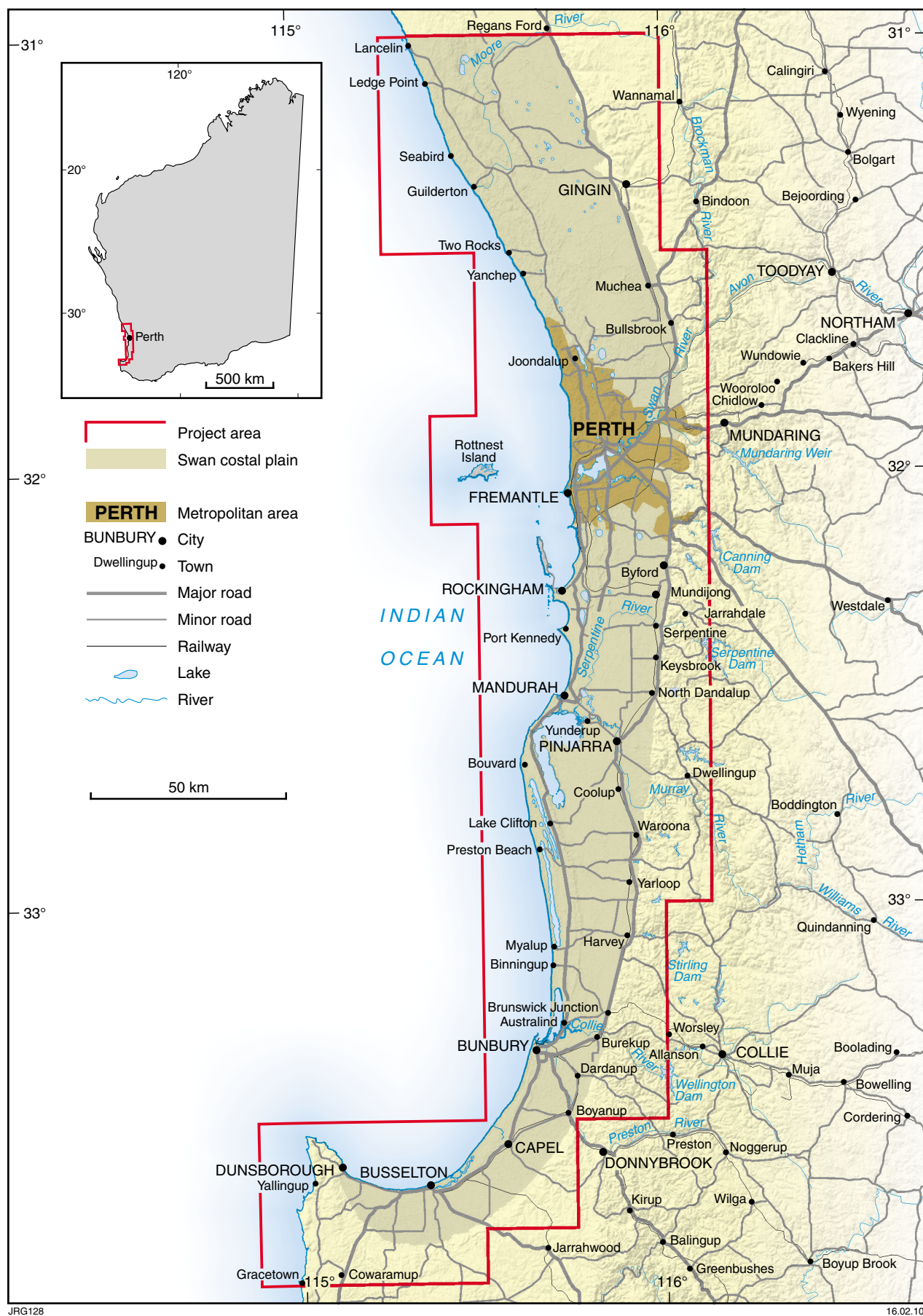


Figure 4. Extent of the Southern Swan Coastal Plain

Geology

In these times of greater environmental awareness many people have become interested in all aspects of the landscape, and want to understand geology as the underpinning framework. Understanding the landscape is the first step in appreciating its value and the need to use and manage it sustainably.

Furthermore, the above maps also form the basis for many of the other maps in the publication. For example, an interpretation of the surface geology provides information on basic raw materials such as sand, gravel and limestone. Hence, a surface geology map also provides information on geohazards and the engineering characteristics of surface materials. Consequently they can yield important information about the development potential of an area.



Figure 5. Granite outcrop on the Darling Scarp

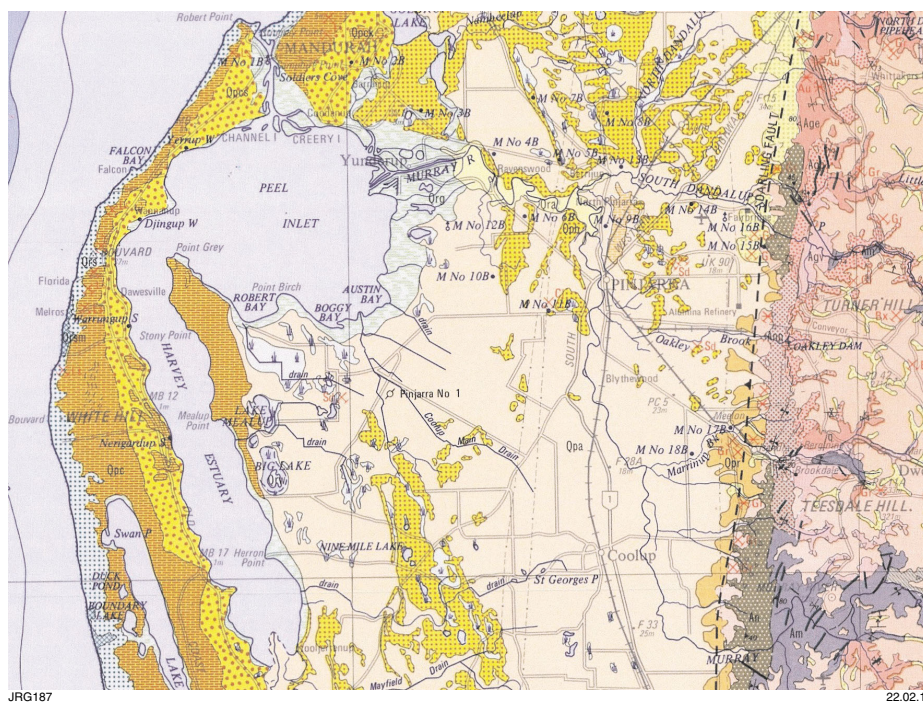


Figure 6. Part of Pinjarra 1:250 000-scale Geological Series map

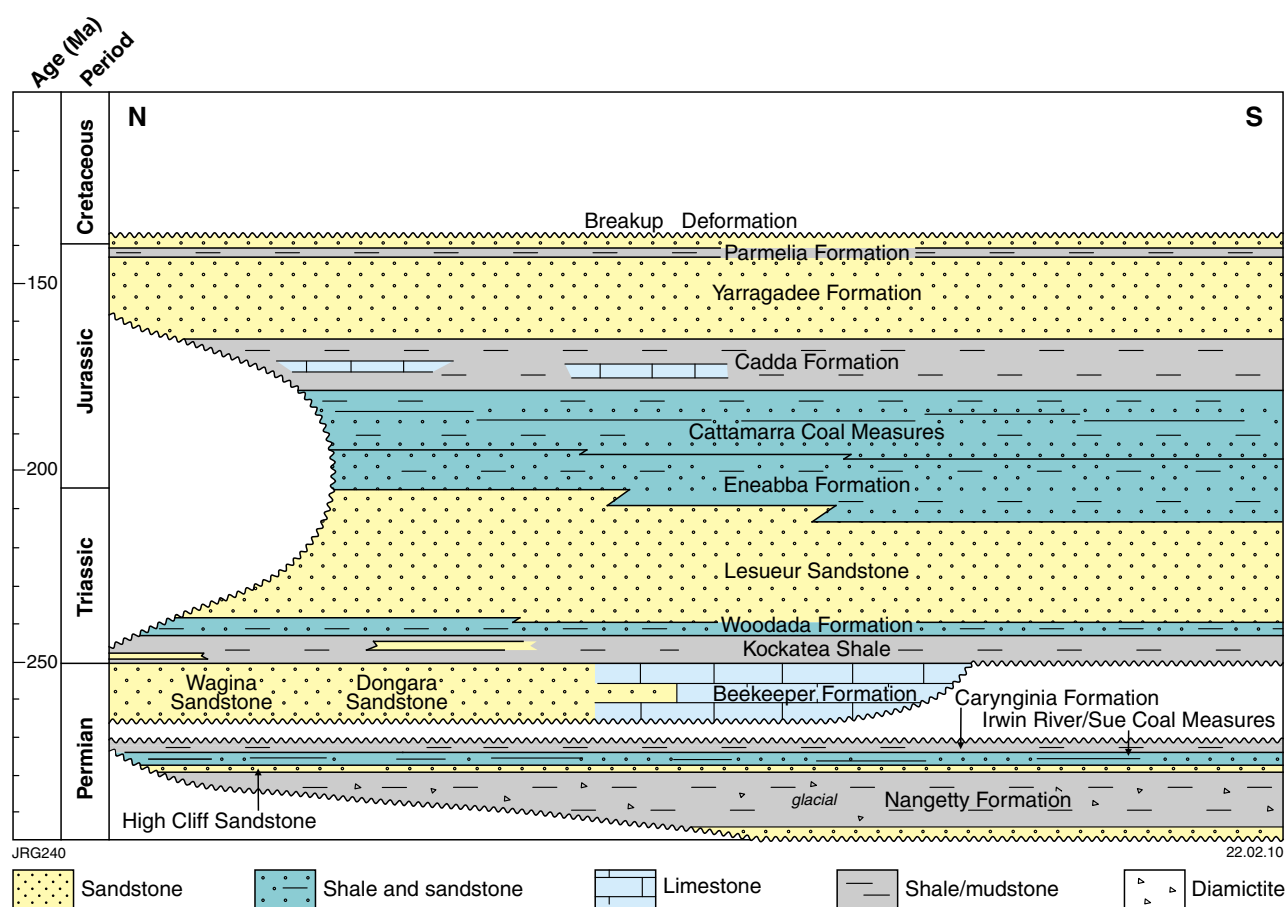


Figure 7. Stratigraphy of the Perth Basin

Bedrock age

Topographic maps, aerial photographs and land use maps are important sources of information for land managers and decision makers. Nevertheless, they do not tell the whole story of the nature and makeup of the landscape. While most land uses take place in the top few metres, several go much deeper. For example, water wells may go down several hundred metres, as may some types of underground mines. Petroleum exploration wells are commonly drilled to thousands of metres depth. Useful information about what lies beneath our feet comes from bedrock geology maps.

The term bedrock is used to describe the consolidated rocks of an area. Information on bedrock age and rock types (Bedrock geology) is the foundation of other themes in this atlas. While these derived (thematic) datasets are fundamentally important in assessing issues related to land quality, geohazards and mineral resources, the bedrock units themselves also provide useful information. For example, understanding the detailed geological evolution of an area can provide us with knowledge and clues about past climates and environments that can improve our understanding of present day climate change and the influence of events such as tsunamis and storm surges.

In geological terms, the southern Swan Coastal Plain and its environs can be broadly divided into three areas. The oldest rocks are the Archean rocks of the Darling Plateau. These can be traced back at least 3340 million years — by comparison the Earth is over 4600 million years old.

The next oldest rocks are found in the Leeuwin–Naturaliste Region and date back to between 1100 and 650 million years ago — a time when some of the earliest life-forms were appearing on Earth. Both these and the rocks of the Darling Plateau are igneous and metamorphic rocks that formed at high temperatures and pressures.

Between the Darling Range and the Leeuwin–Naturaliste Region is a trough-shaped sedimentary basin — the Perth Basin, with its thick succession of much younger

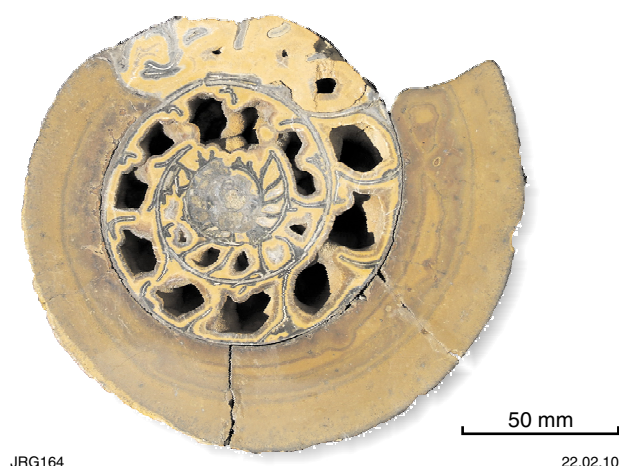


Figure 8. Geologists use fossils such as this Permian ammonite to date sedimentary rocks.

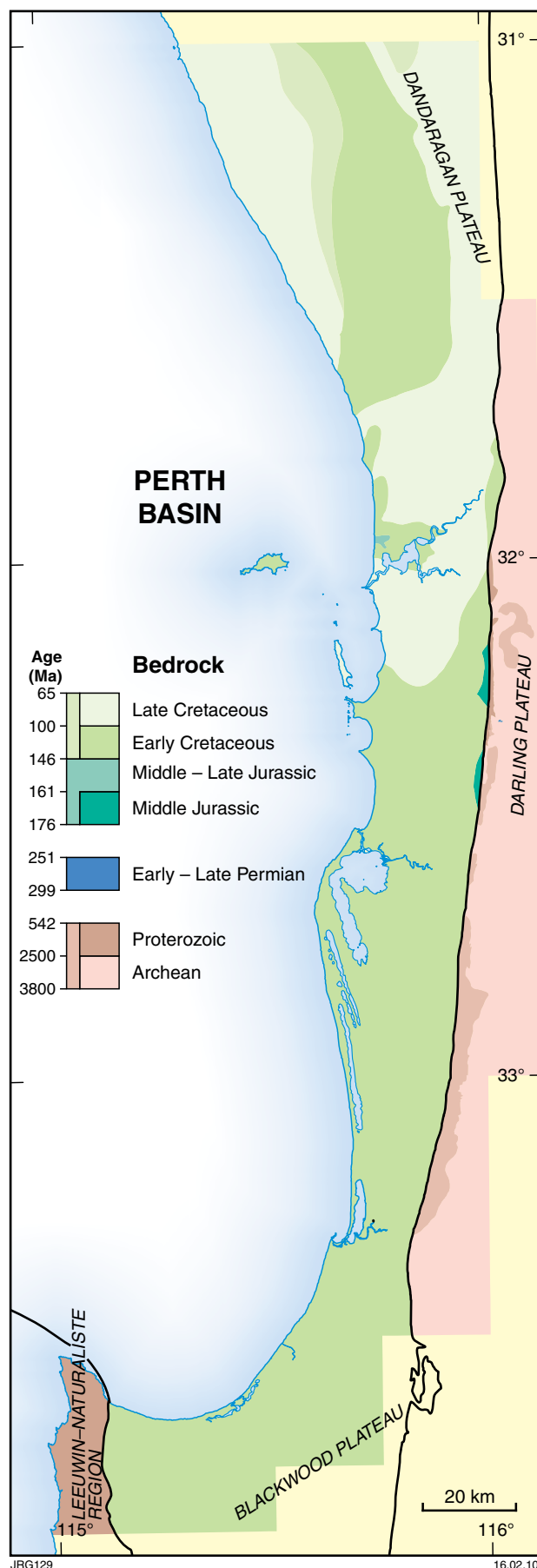


Figure 9. Geological age of bedrock units

sedimentary rocks that underlie the flat Swan Coastal Plain and Blackwood and Dandaragan Plateaux. Sediments started to accumulate in the Perth Basin about 320 million years ago in the Carboniferous period. Sedimentation ranged from alluvial to shallow marine settings through to Late Jurassic and earliest Cretaceous time 160 to 120 million years ago. The structure and sedimentary rocks of the Perth Basin largely reflect events during the breakup of the Gondwana supercontinent when Antarctica, India and Western Australia were joined together.

The map opposite (Fig. 9) is based on the interpreted bedrock geology map of Western Australia, which is also available as digital information at a scale of 1:500 000.

The bedrock geology map is a compilation based on previously published geological maps in the 1:100 000- and 1:250 000-scale series, together with GSWA and Geoscience Australia (GA) maps at scales from 1:250 000 to 1:1 000 000. Some of these maps are available from GSWA's Data Centre <<http://mapserver.doir.wa.gov.au/datacentre/>>. Geophysical data (magnetic and gravity) and recent geological mapping have been used to refine the map wherever possible.

Bedrock geology

Above the bedrock is usually a mantle of less consolidated superficial material that can be very thick in places. If the blanket of superficial material were to be stripped away, the bedrock geology would be revealed. Where there is no unconsolidated superficial material the bedrock geology and surface geology are identical.

The map (Fig. 11) shows the distribution and composition of the bedrock types. In the Darling Plateau and Leeuwin–Naturaliste Region bedrock outcrops extensively. The interpretation of the bedrock geology in these two regions is therefore based on field investigations. In contrast, bedrock of the Perth Basin outcrops in only a very few localities. Its interpretation is therefore based mainly on information from thousands of water bores, oil and gas exploration wells, and geophysical surveys.

There are many rock types in the Darling Plateau but the most common are granite, dolerite and metamorphic rocks such as schist and gneiss. Most of the metamorphic rocks were originally muds and sands that were deposited in an ancient sea. Earth movements about 3000 million years ago altered these ancient sedimentary rocks into the rocks we see today.

Although the granitic rocks look very similar to one another, there is a considerable amount of compositional variation that shows them to have been intruded into



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Figure 10. GSWA geologists examine a bedrock outcrop.

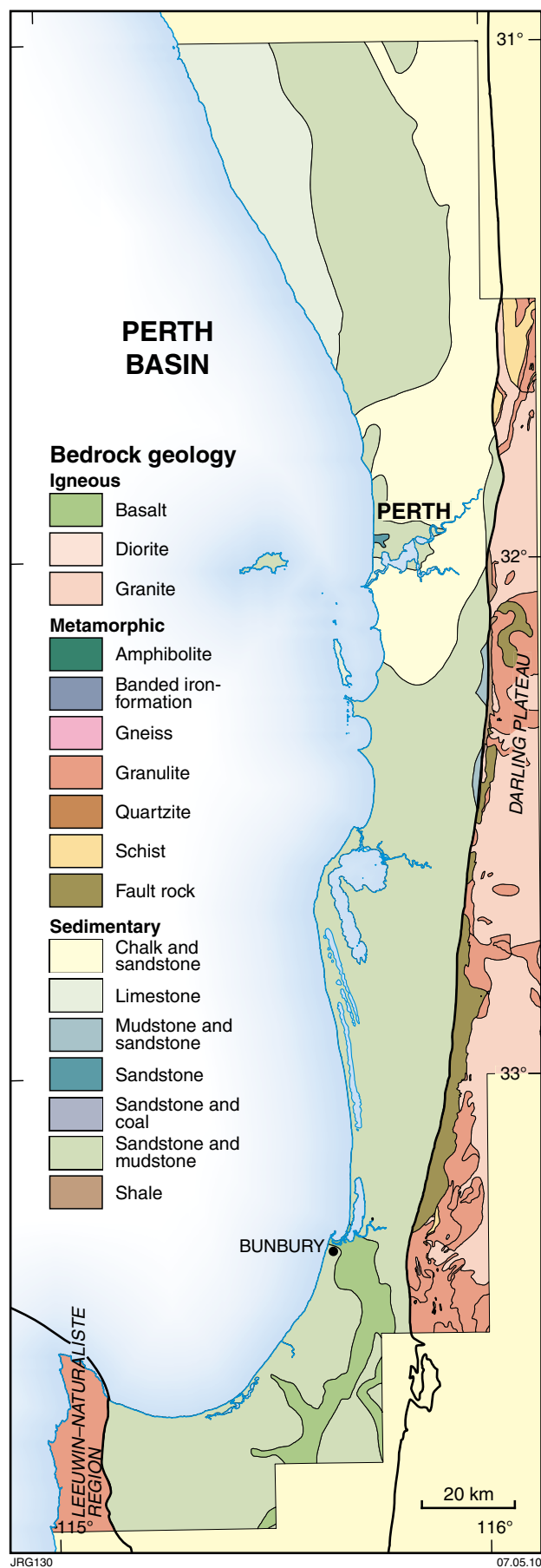


Figure 11. Rock types

the older metamorphic rocks as several discrete large bodies called batholiths. The largest is the Darling Range Batholith — a huge body of molten granitic rock that forced its way into the pre-existing rocks of the Yilgarn Craton about 2600 million years ago. When cool the granite became the bedrock for the whole area between Perth, York and Collie.

The Leeuwin–Naturaliste Region consists almost exclusively of gneissic rocks intruded by younger granites. The gneisses were originally sedimentary rocks, mostly sandstones, intermixed with basalt lava flows. They all became greatly altered and deformed by extreme temperatures and pressures during earth movements about 600 million years ago.

The rocks of the Perth Basin are up to 15 km thick. The oldest comprise mostly sandstones and mudstones that were deposited in a continental environment when Australia was part of the Gondwana supercontinent. Other Gondwana-stage rock types include glacial deposits, coal measures, and the Bunbury Basalt. Surprisingly, the ages of individual mineral grains in these rocks do not correspond to the ages of rocks in and behind the Darling Plateau indicating they were originally eroded from rocks further afield. Chalks found north of Perth accumulated when oceanic circulation patterns changed after the breakup of Gondwana.

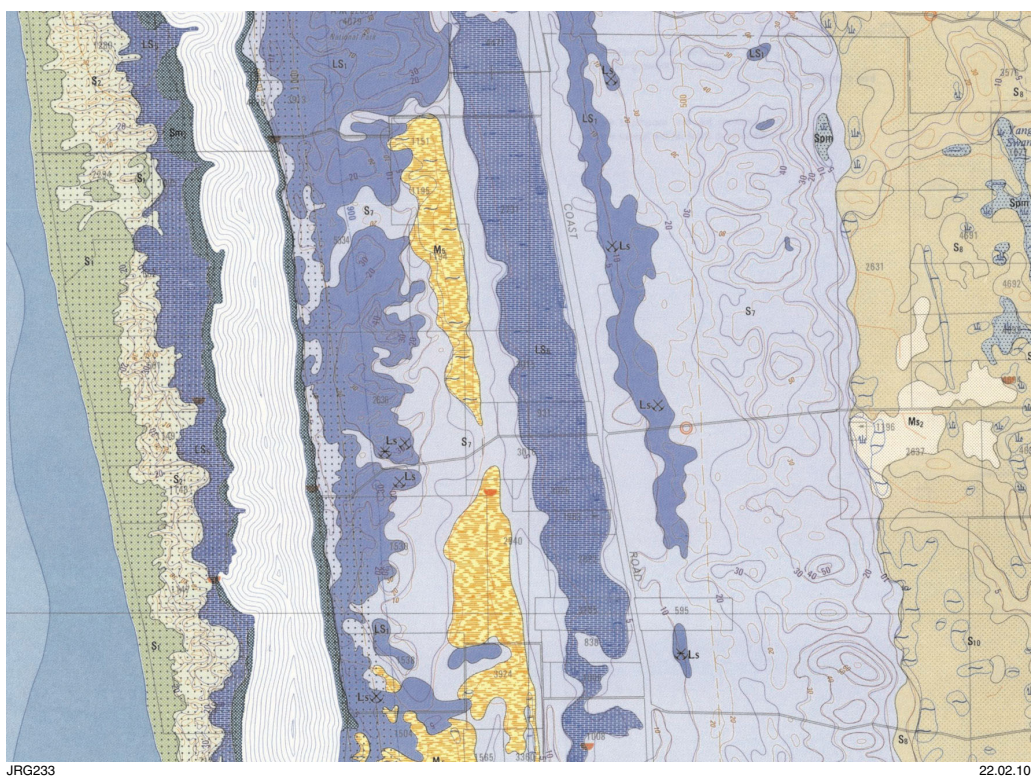


Figure 12. Part of Lake Clifton–Hamel Environmental Geology map



Figure 13. Soil augers are used to help map surface materials

Surficial geology

Surficial geology (Fig. 14) refers to those unconsolidated or partly consolidated materials that lie on top of the bedrock. It is also commonly referred to as Quaternary geology because many of the surficial deposits were formed or deposited during the Quaternary period — the last 1.81 million years of earth history. They are the youngest geological deposits we see.

Most of the surface deposits are unconsolidated sands, gravels, silts and clays, but there are also cemented materials, such as limestone and lateritic duricrust (ironstone and pisolitic gravel). They are mostly of marine (i.e. laid down in the sea), estuarine (i.e. deposited in the brackish water of an estuary) and eolian (i.e. deposited by wind) origins. Their formation is related to periods of higher and lower sea levels which resulted from the waxing and waning of continental ice sheets during the past two million years.

It is important to understand the nature and distribution of surface materials because of the influence they have on so many aspects of life. Knowledge of the makeup of the materials at the surface and in the near-surface is essential in land use planning because it is these materials that determine foundation conditions and the potential for geohazards such as coastal erosion, flooding, and ground subsidence. They are also the source of water, basic raw materials and minerals.

The characteristics of the materials and their mode of origin are also the major factors that have determined the nature of the landscape as we see it today. The most common expression of a significant change in the nature of geological materials at the surface of the Earth is a change in the landform. This correlation emerges because geology is the basis of geomorphology and landforms. This correlation is so strong that simple geological maps can be created solely on the basis of topography.

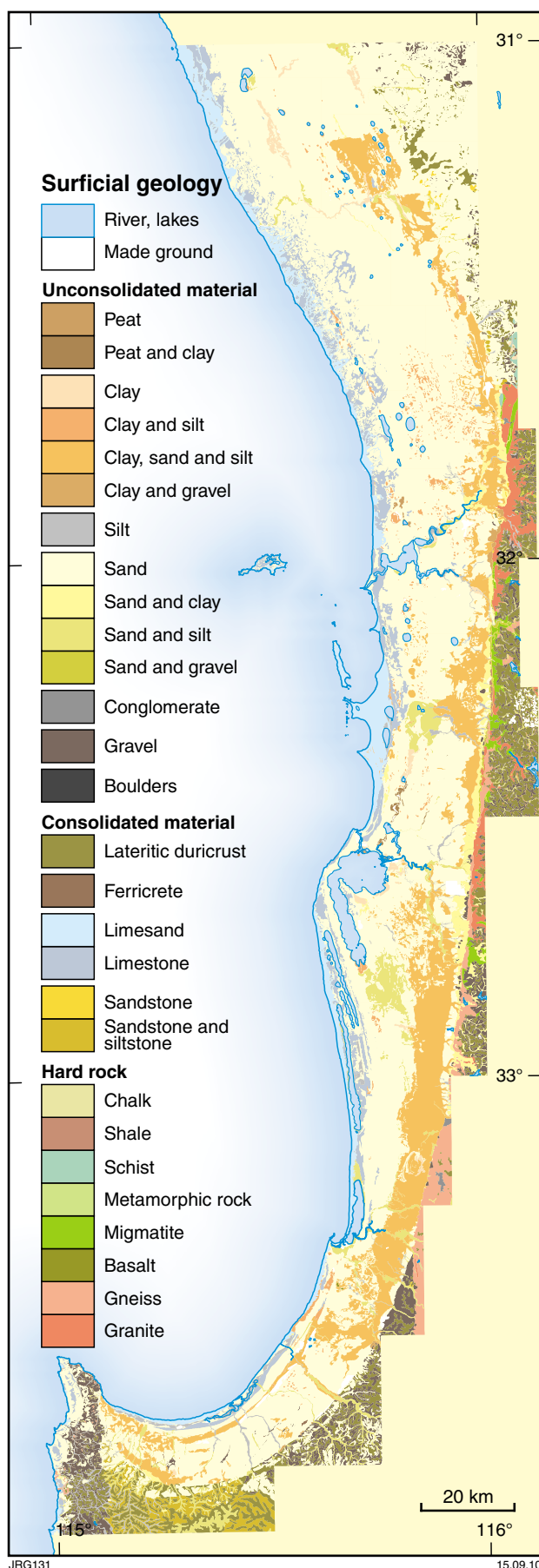


Figure 14. Surface geology

Thickness of surficial deposits

Surficial deposits are those loose, unconsolidated and partly lithified materials that are of recent geological origin. They cover almost all the southern Swan Coastal Plain and its environs (see Fig. 14).

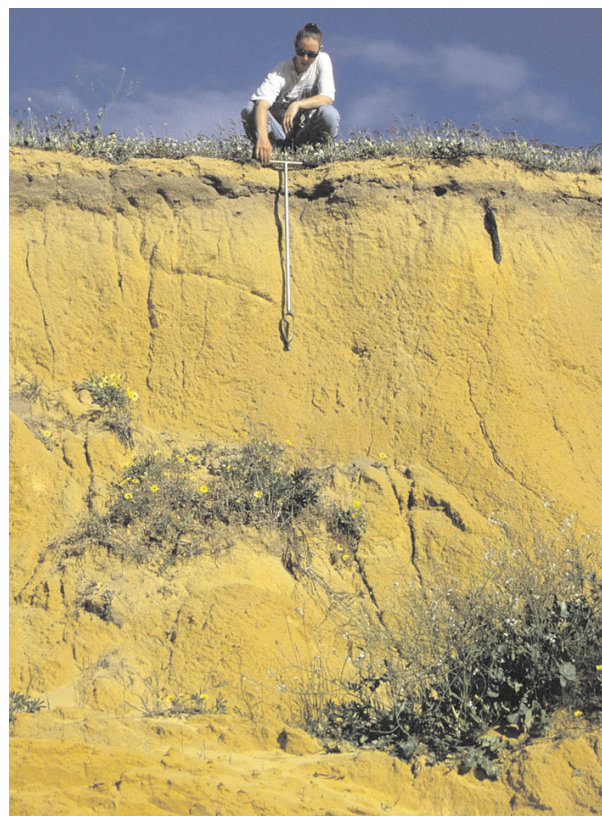
Knowledge of the thickness of the surficial deposits is often critical. It is important that the foundations of large engineering structures such as bridges and high-rise buildings rest on a solid base. If the surficial materials are unable to support the weight of these heavy structures their foundations must be supported by piles driven through the unconsolidated material to rest on solid bedrock. The length, type and construction of the piles are determined by the type and thickness of the surficial material.

In the context of groundwater, knowledge of the thickness and characteristics of the surficial deposits can help hydrogeologists understand the possible spreading paths of contaminants from landfill sites, underground storage tanks and other potential hazardous waste spills. If thick enough and of a suitable material, the surficial deposits may also contain a significant groundwater resource. This is certainly true along much of the southern Swan Coastal Plain, where the surficial deposits are a major shallow groundwater aquifer.

The thickness of the surficial deposits was determined by comparing the land surface elevation and the elevation of the bedrock surface. To achieve this information from approximately 12 000 boreholes was used to construct a map of the elevation of the bedrock surface.

Surficial materials are thickest north of the Swan River. They include the limestone and sands of the Spearwood and Bassendean Dune Systems.

This map is a regional overview and is intended to be used in a regional context. It is not intended to replace detailed on-site investigation. In populated areas in particular, detailed information is vital to site planning. In contrast, regional maps such as this place local, detailed mapping in context, they permit the extrapolation of data into unmapped areas, and show large-scale regional geological features and patterns that may be beyond the scope of local, detailed mapping.



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Figure 15. Geological section in Tamala Sand

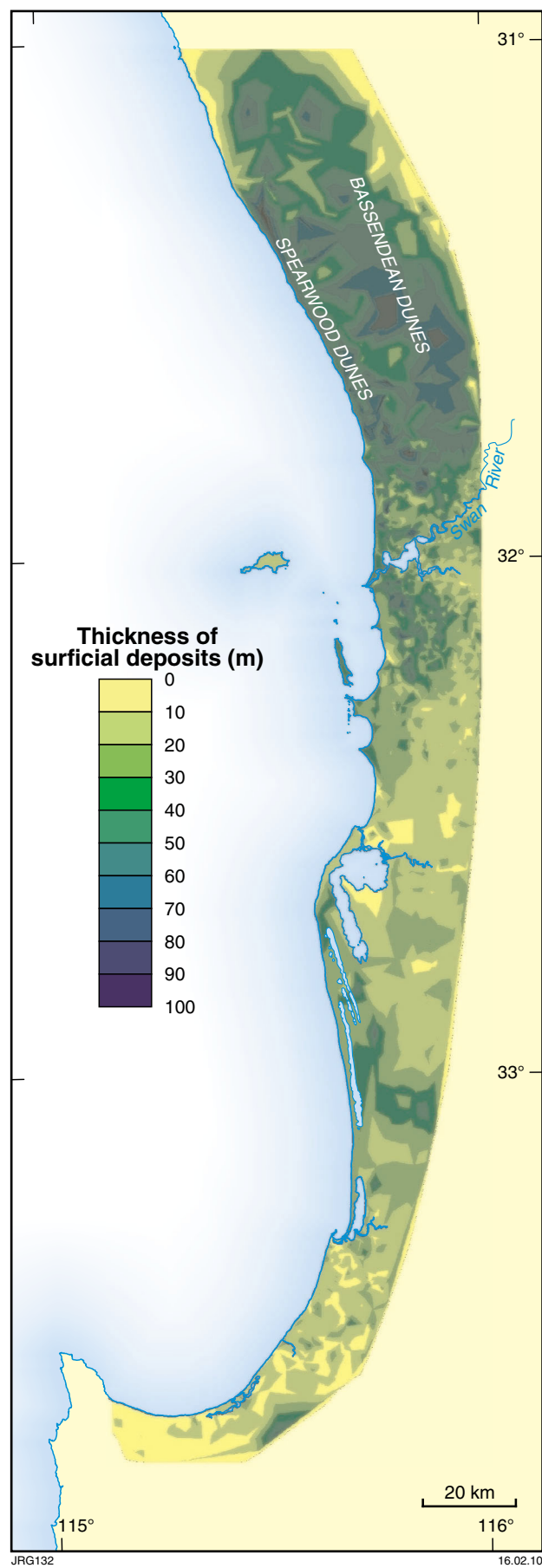


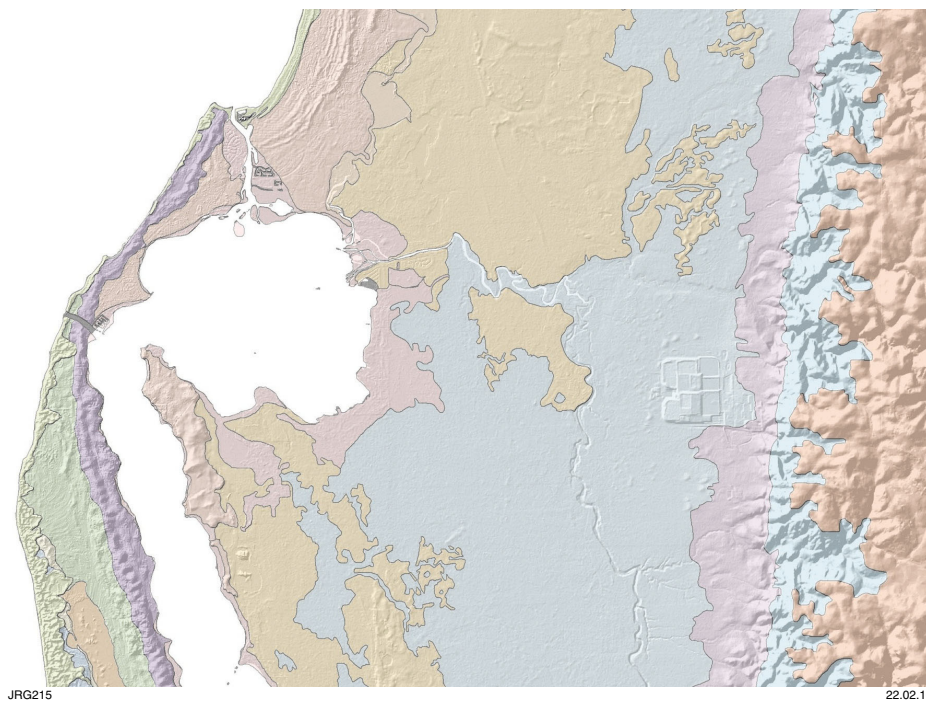
Figure 16. Thickness of surficial deposits



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Figure 17. View across the Swan Coastal Plain to the Darling Scarp south of Binningup



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Figure 18. Surface geology draped over shaded relief model

Physiography

The landscape is intimately related to the nature of the underlying geology. Many striking landforms in the southern Swan Coastal Plain provide insights to the geological history of the region, and to the development of the landscape as we see it today; the landforms of the coastal areas record the fluctuating sea level, which were the result of the glaciations of the Pleistocene; exposed riverbanks and subtle landforms of the Swan Valley reveal the history of the migrating river systems of the past; sedimentary rocks of marine origin at the foot of the Darling Scarp are evidence for an ancient shore line, when the ocean covered all of what is now the Swan Coastal Plain; and quarries on the Darling Plateau reveal the complex history of the Yilgarn Craton, where large areas of already metamorphosed rocks were intruded by large volumes of granitic rocks which then eroded and became deeply and intensely weathered over many millions of years.

However, the landscape is many things to many people — to mining companies it is a source of mineral wealth; to farmers a source of agricultural wealth; to construction companies a setting for major infrastructure projects; to waste disposal providers a receptacle for rubbish; to government, industry and environmental lobby groups a challenge of sustainable development in which competing land uses can be combined with a respect for the natural environment.

The maps in this section describe the landscape in terms of the physiography of the area, or the patterns in the natural environment. They have been derived from digital elevation data and the mapping of landforms and natural landscape patterns that make up the landscape. Aerial photographs and satellite imagery were used to map the landforms.

These data are important to the understanding of the potential of the landscape for a variety of land uses. Slope, in particular, can be a severe limiting factor in the assessment of land capability.



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Figure 19. Chains of lakes at Lakes Clifton and Preston

SRTM physiography

The Shuttle Radar Topography Mission (SRTM) obtained elevation data on a near-global scale to generate the most complete high-resolution digital topographic database of Earth to date. SRTM consisted of a specially modified radar system that flew onboard the Space Shuttle Endeavour during an 11-day mission in February 2000. SRTM was a collaborative mission by NASA, the National Imagery and Mapping Agency of the U. S. Department of Defense, the German Aerospace Center and the Italian Space Agency.

NASA released the data for Australia at a ground resolution of approximately 90 m, clipped around shorelines. According to the mission specifications, SRTM was expected to generate digital elevation data with a vertical error of 16 m. However, trials in GSWA have shown that the actual error of the data for Western Australia is of the order of 4 m, which makes SRTM data the best quality, freely available, digital elevation data for Western Australia. Data at 30 m-resolution do exist for Australia, but they are held by the Australian Federal Government's Defence Imagery and Geospatial Organisation on a confidential basis for security reasons.

Manipulation of digital elevation data is one of the most common methods of extracting topographic information. Datasets derived from digital elevation data

help people visualize the landscape and they are also essential for landscape analysis and geomorphometric modelling.

The map (Fig. 21) shows a three-dimensional representation of the relief of the southern Swan Coastal Plain. Relief is represented by simulated sunlight and shadows. Portions of the surface that face away from the light source reflect less light toward the viewer, and thus appear darker. Because of their pseudo-three-dimensional nature, these types of shaded relief models are very helpful in visualizing the topography of a landscape.

The map clearly shows the contrast between the subdued topography of the coastal plain and the deeply dissected Darling Plateau. The orange-brown tones highlight the higher ground of the Darling, Gingin and Blackwood Plateaux and the Leeuwin-Naturaliste Region. The green tones reflect the landforms of the coastal plain and delineate various physiographic units.

Integrating this map with other thematic datasets, such as a slope map and a map of surface geology, greatly enhances the ability to identify those natural factors that have a significant bearing on the development potential of an area.



Figure 20. Three-dimensional perspective of a shaded relief model

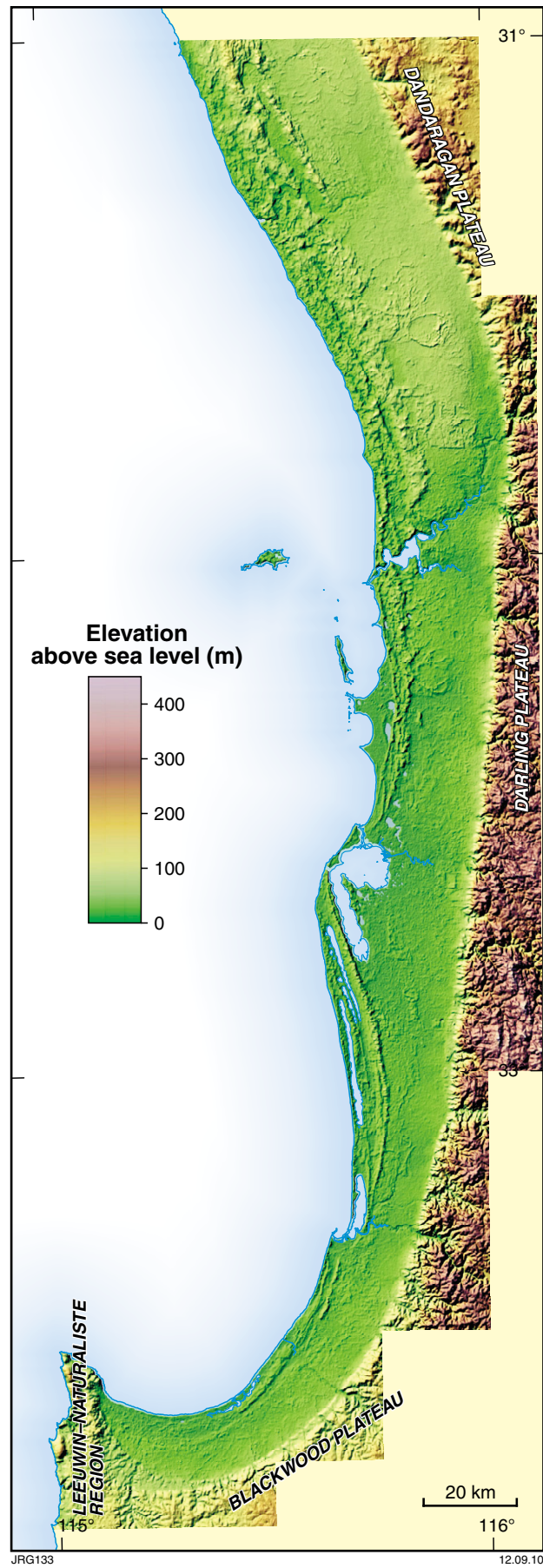


Figure 21. SRTM physiography

Physiographic regions

The sea to scarp region is characterized by a generally subdued topography, with the most obvious features being the Swan Coastal Plain west of the Gingin, Whicher and Darling Scarps, the Dandaragan, Blackwood and Darling Plateaux east of the scarps, and the Leeuwin–Naturaliste Region in the southwest (Fig. 23).

The landscape is the result of processes and events that have taken place over many millions of years but the most dramatic effects on the landscape we see today happened during the last two to three million years, when sea-level fluctuations changed the position of the coastline from the Darling Scarp to beyond Rottnest Island and then back to its present position.

The Darling Plateau is not a smooth or flat surface — the action of streams and rivers has cut deeply into it, producing a landscape of hills and valleys. The eastern part is characterized by flat-topped hills bound by breakaways and more prominent hills — known as monadnocks — that protrude above the general level of the plateau. The valleys to the west have steep, rocky slopes and narrow, flat valley floors. The Darling Scarp forms the western edge of the Darling Plateau. It is most prominent south of Bullsbrook, where there is an abrupt 250 m rise from the coastal plain to the edge of the plateau over a horizontal distance of only 1 to 2 km.

The Dandaragan and Blackwood Plateaux both form wedge-shaped areas. In the northern Swan Coastal Plain the Dandaragan Plateau is flanked by the Darling

Scarp to the east and the Gingin Scarp to the west. The Blackwood Plateau in the south on the other hand is confined by the Darling Scarp to the east and Whicher Scarp to the northwest. Both plateaux have an elevation of about 200 m. There are few rivers and streams on the Dandaragan Plateau, but many on the Blackwood Plateau in the wetter southwest of Western Australia.

The Leeuwin–Naturaliste Region is a prominent ridge of granitic hills. In general, the elevation decreases towards the south. In the north, the region is incised by many streams but, further south the landscape is dominated by broad, shallow depressions with gently undulating rises.

The Swan Coastal Plain extends west from the Darling, Gingin and Whicher Scarps to the Indian Ocean. It includes several geomorphological units that are distributed roughly parallel to the present-day coastline. The sediments of these units are mainly alluvial (deposited by rivers) in the east and eolian (deposited by wind) in the west. The easternmost unit is the Piedmont Zone that has developed as a series of spurs and colluvial (formed by sediment transported by processes such as mass-wasting and slope wash) slopes that form the foothills of the Darling Scarp. West of the Piedmont Zone are the Pinjarra and Abba Plains, which consist of alluvial fans near the scarps and floodplains along the rivers. West of the plains are three generations of dunes: the Bassendean, Spearwood and Quindalup Dune Systems. Between Mandurah and Bunbury the Spearwood Dune System can be further subdivided into a number of discrete geomorphological units.



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Figure 22. View from the Darling Scarp near Pinjarra.

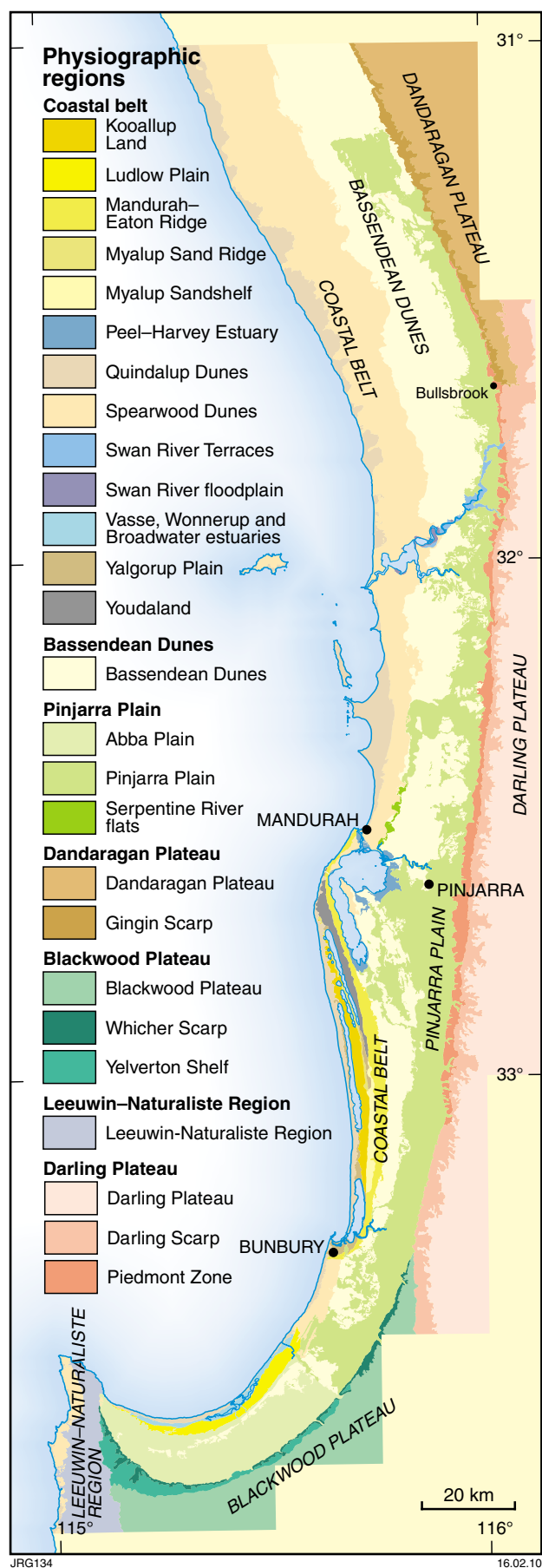


Figure 23. Physiographic regions

Slope categories

Slope steepness is of considerable importance in land management. It has a major control on surface materials and processes and may be the critical restricting factor determining some land uses. Although work elsewhere has shown that there appear to be critical slope angles for selected activities, slope class boundary values vary arbitrarily between organizations. Also, there appears to be no observed natural clustering of slope values. Australian soil and land surveyors therefore use slope class boundaries to separate slope terms in common use. These boundaries are adjusted to regular logarithmic intervals (see Table 1 below).

Table 1. Slope categories

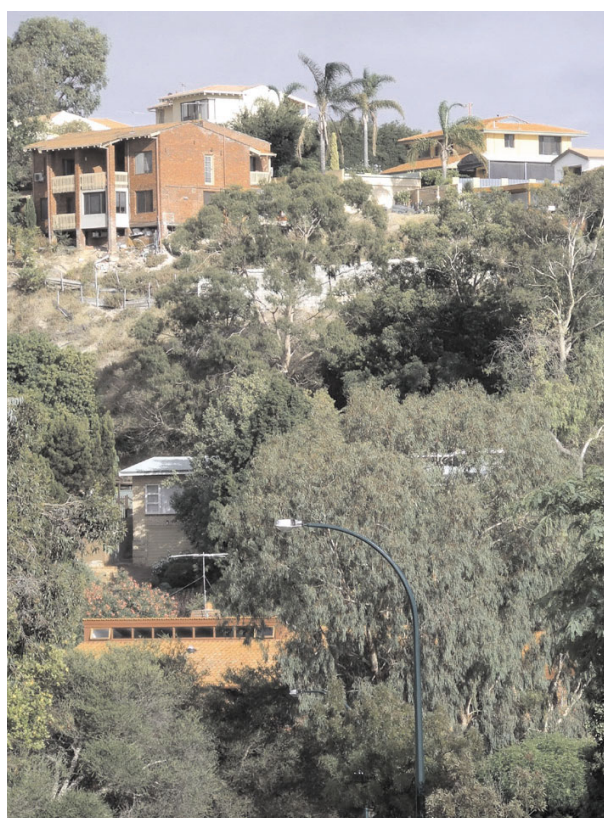
<i>Slope class</i>	<i>Slope range (°)</i>
Level	0–0.6
Very gently inclined	0.6–1.75
Gently inclined	1.75–5.75
Moderately inclined	5.75–18
Steep	18–30
Very steep	30–45
Precipitous	45–72
Cliffed	72–90

Slope maps are a valuable tool in developing appropriate land use strategies. They can be used to ascertain some critical practical limits to the use of the ground or to determine various land qualities. For example, on slopes greater than 5.75° (gradient greater than 10%) the risk of water and wind erosion is increased on most soils unless appropriate hazard reduction strategies are used.

There are a number of basic techniques for constructing slope classification maps. They range from digital elevation data, contoured topographic maps, photogrammetry to field surveys.

The map (Fig. 25) shows slope categories derived from high-resolution digital elevation data. A wide range of slopes can be seen. Steeper slopes are found along the Darling, Gingin and Whicher Scarps and in the coastal Quindalup Dune System. The Darling, Gingin and Blackwood Plateaux behind the scarps exhibit a range of steeper slopes characteristic of terrain deeply dissected by river and stream erosion. Level and very gently inclined slopes are generally found along the alluvial Pinjarra and Abba Plains and in the Bassendean Dune System, where low, degraded dunes are found.

Slope steepness is not the only factor that should be used in determining land use. When slope is integrated with other basic and thematic datasets, assessments can be made of other land qualities that, in turn, have a significant bearing on the assessment of land capability of an area (see section on Development potential).



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Figure 24. Residential development on steep slopes in Perth

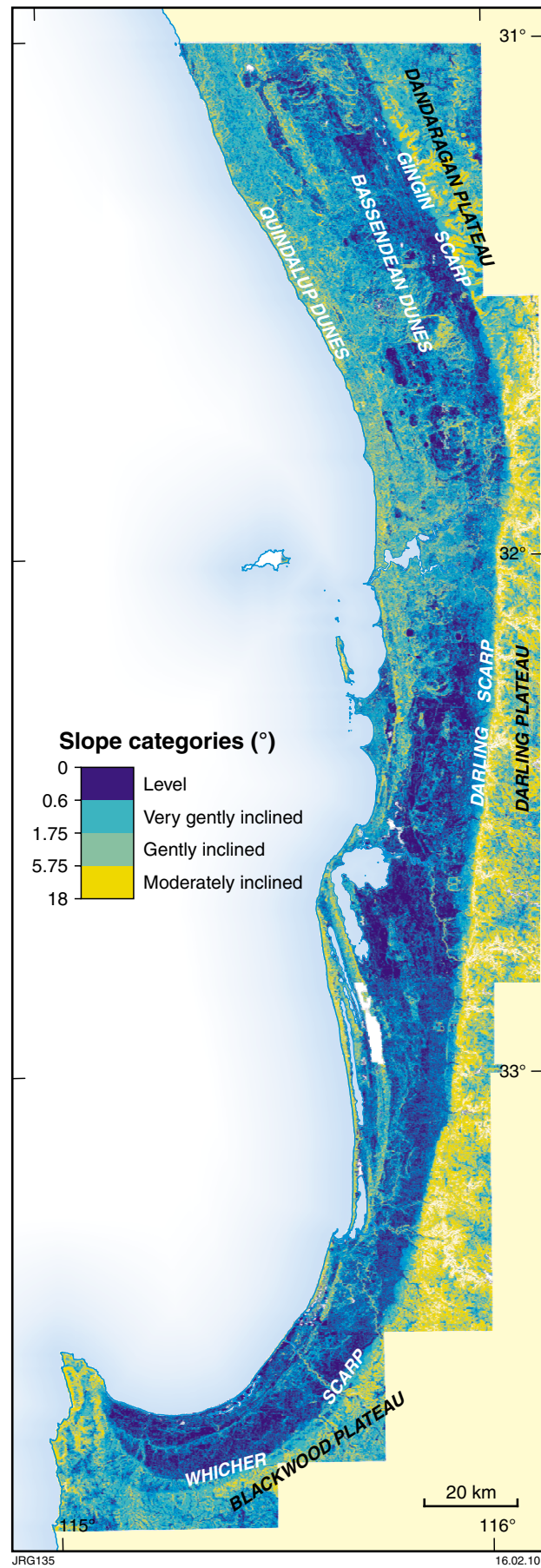


Figure 25. Slope categories

Hazards

Western Australia in general and the Swan Coastal Plain in particular is a geologically relatively stable area. Destructive earthquakes have taken place in Western Australia's Wheatbelt region, albeit infrequently, but their effects along the coastal plain have been limited. The risk to communities along the southern Swan Coastal Plain of a destructive earthquake is low. For further information on earthquake risk and other natural hazard risks in Perth, refer to Geoscience Australia's Cities Project Perth Report available at <<http://www.ga.gov.au/hazards/publications.jsp#perth>>.

A variety of geological hazards do, however, exist along the southern Swan Coastal Plain and its environs. They include landslides, shrinking or swelling of the ground, compressible or collapsible materials, flooding and soluble rocks.

Landslides occur as either slow slides or as rockfalls. Slides tend to occur in the more clayey soils along the Darling Scarp when the water content of the soil exceeds its capacity to be drained. Rockfalls have been documented on steeper slopes of the Tamala Limestone; the scarp at Mount Eliza in Kings Park has suffered many rock falls. The scale of available mapping and relative lack of research and engineering reports prevents a regional assessment of landslide potential being made.

Some clay soils increase (swell) or decrease (shrink) in volume as they absorb or lose water. The Guildford



JRG225

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Figure 26. Some coastal and disused quarry sections can be dangerous.



JRG198

22.02.10

Figure 27. Collapse of coastal cliffs at Cape Peron

Formation, in particular, is reactive in this way. It has caused cracking in several houses, but the variability of soils in the Guildford Formation precludes a detailed assessment of the hazard potential.

Compressible and collapsible materials are usually soft sediments, such as peat and other organic-rich materials, that are found in lakes, swamps and river valleys where the groundwater table is high and fluctuates seasonally.

The potential for flooding and ground subsidence is discussed in more detail later in this section.

All hazard themes are relevant to planners, developers and the general public who need to understand their nature, extent and significance and the risks that they may pose in order to incorporate the information into development plans.

The data presented here are only a basic assessment of hazards. The assessment of risk is outside the scope of this document because risk assessment requires detailed research and modelling of geological hazards. The maps in this section do, however, indicate where such detailed risk assessment is desirable or most necessary.



JRG199

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Figure 28. Hazard warning sign at Cape Peron

Geological indicators of flooding

Flooding includes both the inundation of floodplains by rivers and of coastal plains and estuaries.

Floodplains are flat or nearly flat land adjacent to a river or stream that can be flooded during higher than normal river flows when the main river channel is unable to contain the larger flow. Floodplains contain unconsolidated material that was deposited by the river during previous floods. In some cases older floodplains can be seen higher in the landscape as a series of river terraces. Good examples are to be seen along the middle reaches of the Swan River between Upper Swan and Guildford.

In contrast, coastal plains and estuaries are areas of flat, low-lying land adjacent to the coast that have a connection to the open sea. They are affected by marine influences such as tides, waves and storm surges. They are often characterized by silty and clayey sediments. The Leschenault Inlet and Vasse and Wonnerup Estuaries are typical examples.

The likelihood of flooding can be calculated statistically from hydrological data of known flood events. For example, a 1-in-100-year-flood is calculated to be the level of flood water expected to be equalled or exceeded every 100 years on average. Similar levels can be calculated for 1-in-50-year-floods or for any other frequency. This approach can lead to the delineation of many flood limits within a single river valley.

Based on the expected flood-water level, a predicted area of inundation can be mapped. These flood-prone area maps are very important in determining areas for potential future development, environmental regulations, and flood insurance.

However, the statistical approach to delineating floodplains based on arbitrary return periods can lead to disagreements about which 'floodplain' should be used in a given situation. A better approach might be to consider the natural floodplain as a whole.

Floodplains and coastal plains are natural features with distinctive morphologies that are easily mapped, either in the field or using remotely sensed imagery. Although geological maps do not explicitly identify floodplains and coastal plains, their characteristic geological deposits provide important information on the extent of flooding in the past. For example, on geological maps floodplains correspond to the extent of the alluvium related to the modern river channel. Geological maps are therefore an important source of information and highlight those areas in which flooding is likely to be an issue.

The map (Fig. 29) shows the location of floodplains and coastal plains that are at risk of flooding. It is based on the types of geological deposits present. Areas in which flooding may occur but where there are no geological indicators of past flooding have not been mapped.

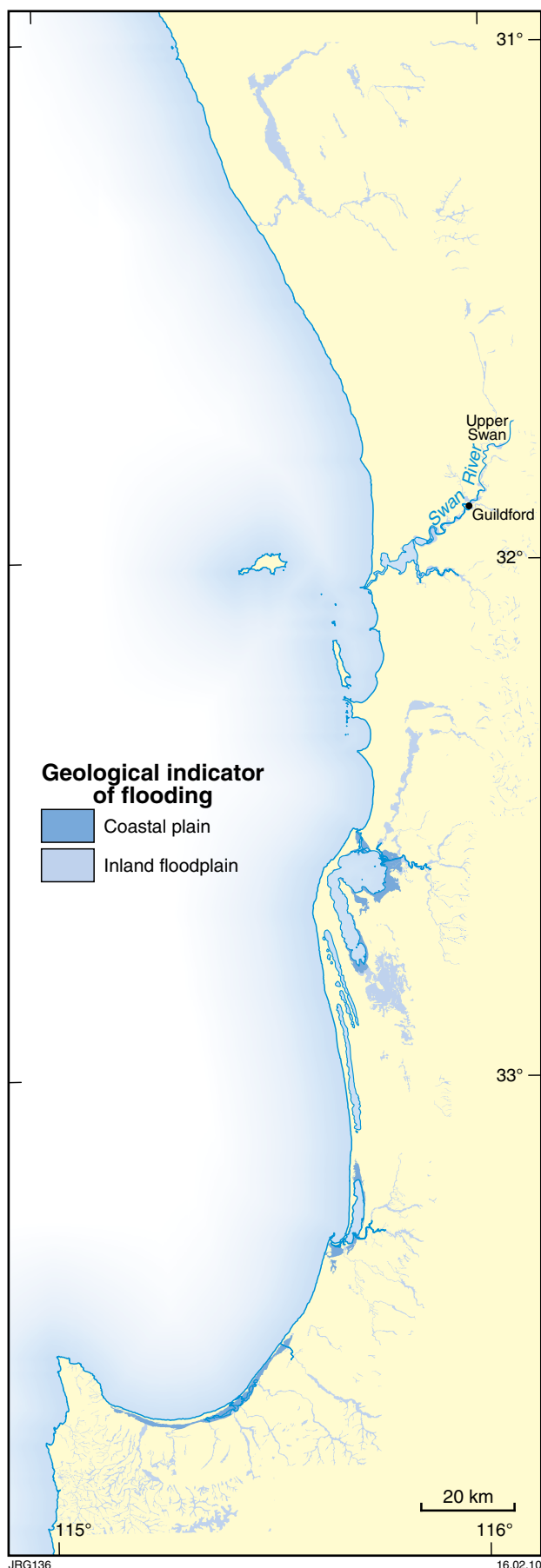


Figure 29. Geological indicators of flooding

Karst

Some rock types are soluble. Surface water, groundwater and rainfall can become weakly acidic as they react with atmospheric or soil carbon dioxide. The dissolution of soluble rocks by surface or groundwater produces landforms known collectively as karst. Karst landscapes mainly form in areas dominated by four rock types — limestone, chalk, gypsum and salt — although they have also been documented in other sedimentary rocks such as sandstone.

Rocks that dissolve readily may cause potential hazards. These hazards are related primarily to ground subsidence and are characterized by depressions such as sinkholes, caves, dry valleys, pinnacles and disappearing streams.

Although generally stable, underground cavities can collapse and the collapse may be triggered by a variety of causes such as human-induced disturbance of the ground, heavy rain, changes in drainage patterns, and water abstraction. An underground void must pre-exist for surface collapse to start, but when collapse occurs, roads and buildings can be severely damaged.

In Western Australia, karst generally occurs in limestone, which, along the southern Swan Coastal Plain, comprises the Tamala Limestone and its equivalents. These

limestones are very porous rocks that allow groundwater to circulate readily through cracks and pores and to remove the calcium carbonate by dissolution.

The map (Fig. 32) shows the location of known karstic features. It also identifies an area to the north of Perth, between Yanchep and Wanneroo, where there are large numbers of karstic features. Two areas have been historically prone to the development of karstic landscapes: Yanchep–Wanneroo and Leeuwin–Naturaliste Regions. However, it is important to realise that other areas underlain by limestone potentially contain significant numbers of karstic features.

In the Yanchep–Wanneroo area the karst belt runs in a northwest direction. It is associated with a chain of lakes in an interbarrier depression between the Yokine and Balcatta dune complexes of the Spearwood Dune System. Evidence from groundwater bores indicates that the karst belt is intimately associated with a marked steepening of the groundwater gradient along this interbarrier depression. At present, karstification is not active because of extremely low groundwater levels. However, karst features may still appear as a result of climate and environmental changes as well as changing land uses.



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Figure 30. Caves can be beautiful as well as hazardous.



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Figure 31. Damage to pool caused by ground collapse

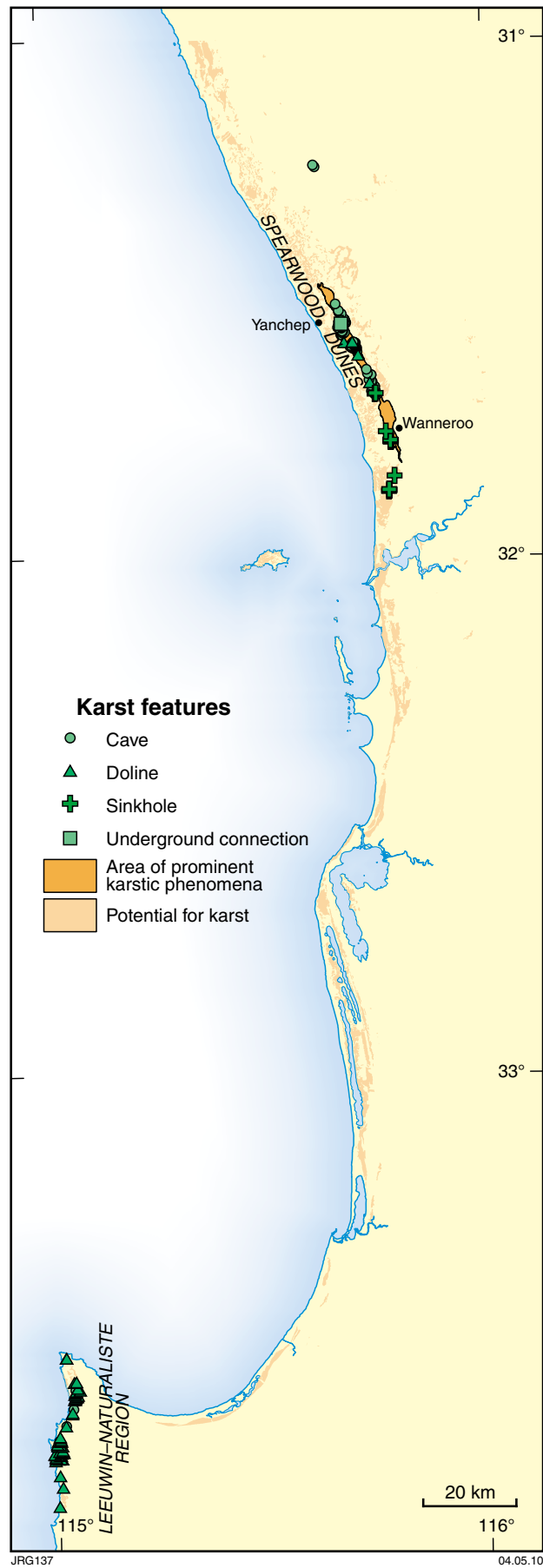


Figure 32. Karst features

Groundwater

Water is present underground across the whole of the southern Swan Coastal Plain as both superficial and confined aquifers. Aquifers are important natural underground reservoirs storing large amounts of water in pore spaces between sediment grains and in fractures. The superficial aquifer, which is contained in the surficial sediments, is the principal aquifer supplying potable water to southwest Western Australian communities. However, increased abstraction from the superficial aquifer is becoming less sustainable so, the deeper, confined aquifers (those that are sealed from the surface by overlying impermeable layers) and seawater desalinization are assuming greater importance as sources of domestic water. Groundwater is essential to the continuing development of southwest communities and to the survival of a healthy environment, but these limited resources are experiencing increased pressure from urban and industrial expansion.

Currently, groundwater supplies 50–60% of Perth's water supply as part of the Water Corporation's Integrated Water Supply System. Regional and local population centres, such as Lancelin, Guilderton, Bunbury, Busselton and Boyanup, source all water locally from bore fields in the unconfined aquifer.

The maps in this section focus on the quality of the superficial aquifer and an overall assessment of its vulnerability to contamination. The information comes from a large database of water boreholes and many research and scientific studies carried out by GSWA and other organizations. Although the GSWA has not played a role in the hydrogeological studies since 1995, most of this work is still relevant today. For more detail and up to date information, refer to the Department of Water website <<http://www.water.wa.gov.au/Tools/Monitoring+and+data/default.aspx>>. These data, when combined with geological map data, allow hydrogeologists to produce a range of thematic hydrogeological maps, some of which are included in this atlas.



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Figure 33. Jackadder Lake in Woodlands

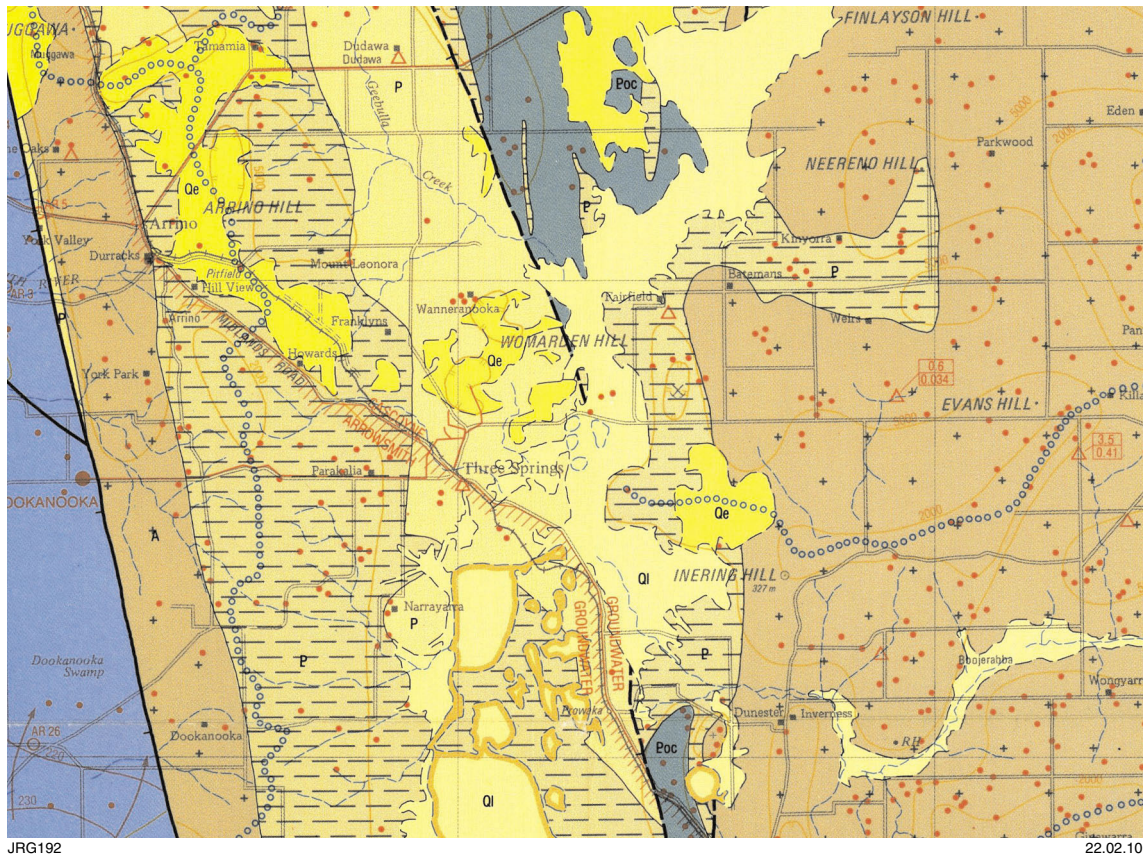


Figure 34. Part of a hydrogeological map



Figure 35. Water feature at Ellenbrook

Depth to groundwater

Information on the depth to the ground water table is essential in hydrogeological studies. For example, in investigations of groundwater contamination the thickness of the unsaturated zone (the zone where not all pore spaces are filled with water) is a major factor affecting the removal of contaminants. Knowing the depth to the groundwater table also helps engineers in construction design and hydrologists in the siting of boreholes for groundwater abstraction and monitoring.

Depth to groundwater is determined by calculating the vertical distance between the ground surface and the upper surface of the groundwater. In most cases depth to groundwater is very closely related to surface topography, characteristics of the geological materials, landforms, and the rates of recharge and discharge in the aquifer. In fact, a map of depth to groundwater, in a general way, replicates the shape and form of the land surface, albeit in a subdued form.

These governing factors generally do not change over time, except for the rates of recharge and discharge. Changes in the rates of recharge and discharge fluctuate naturally on a seasonal basis and this leads to rises and falls of groundwater levels over time. However, human-induced changes can have a more dramatic effect on groundwater levels. Increased levels of groundwater abstraction or widespread planting of exotic tree species can permanently

lower groundwater levels, whereas irrigation practices and the construction of settlement basins can cause higher rates of recharge.

The map (Fig. 37) was constructed mainly from two sources of information: land-surface elevation and existing water-level data from shallow boreholes. Land-surface elevation was derived from high-resolution digital elevation datasets with a horizontal ground resolution of 10 m and vertical resolution of ± 1.5 m. The water-level data were used to produce a digital elevation model (DEM) of the groundwater surface. The groundwater surface DEM was then subtracted from the land surface DEM to produce an image of the depth to the groundwater table below the land surface.

The map shows that depth to groundwater ranges from the surface along the major rivers and in some lakes to up to 130 m between Lancelin and the Moore River. There is a clear, close relationship between depth to groundwater and land-surface elevation. Depths to groundwater are greater in areas with high elevation and less in low-lying areas.

In general the groundwater level is close to the surface in the south and in the centre of the coastal plain, but is commonly deeper north of the Swan River. Below the crests of the Spearwood Dunes along the coast depth to groundwater is generally up to 50 m below the surface, but can also be in excess of 80 m below the highest dunes.



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Figure 36. Monitoring the groundwater level at Gnangara

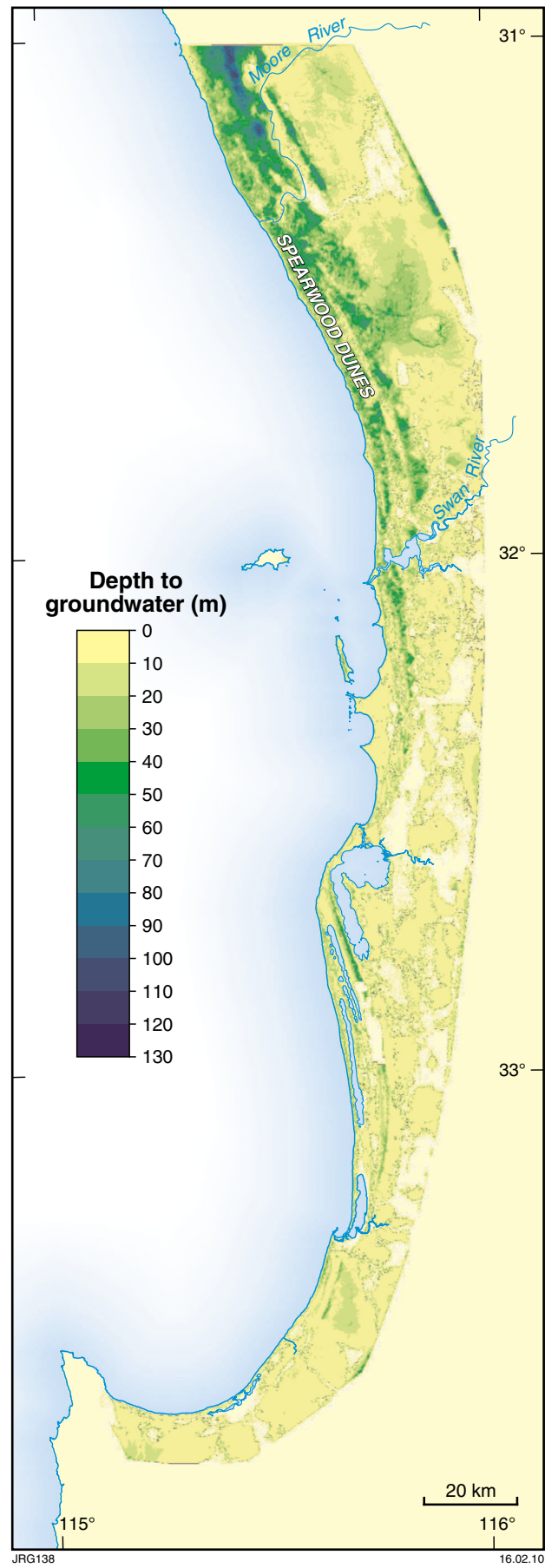


Figure 37. Depth to groundwater

Groundwater table salinity

Salinity is the measure of total dissolved solids (TDS) or salts within groundwater, and the salinity of the groundwater determines its potential uses. For example, potable water for human consumption should be less than 500 mg/L, whereas the salt tolerance of some plants and animals is much higher.

The map (Fig. 40) shows the salinity of the shallow groundwater aquifer in the surficial deposits at the groundwater table. The salinity of the groundwater ranges from about 100 to 12 000 mg/L TDS.

The unconfined aquifer is the most intensively used aquifer along the Swan Coastal Plain. Groundwater in this aquifer is separated into two large, distinct groundwater flow systems in the Perth region and into two smaller systems between Mandurah and Bunbury.

North of the Swan River, the lowest salinities, that is, the best quality water, are found on the crest of the Gnangara Mound. This is a major recharge area and the origin of the groundwater flow systems north of the Swan River. The

groundwater salinity is 250 mg/L TDS or less over a large part of the mound, with salinities of 250–500 mg/L TDS over the rest.

The Jandakot Mound south of the Swan River is also a major recharge area and has salinities as low as those of the Gnangara Mound.

Between Mandurah and Bunbury fresh groundwater with a salinity less than 500 mg/L TDS is restricted to two small groundwater mounds on the Harvey Flats — the Yanget and Mialla Mounds — and to a discontinuous zone adjacent to the Darling Scarp.

In most areas the salinity tends to be lower on the east of the coastal plain and rises towards the west and reflects the general direction of groundwater flow. Groundwater salinities are also higher in areas underlain by clayey sediments of the Guildford Formation, in areas of groundwater discharge, and down gradient from lakes. It is hypersaline (saltier than seawater) underneath the coastal lakes between Mandurah and Bunbury.



Figure 38. Desalination plant at Kwinana (courtesy Water Corporation)



Figure 39. An abstraction bore for Perth's water supply

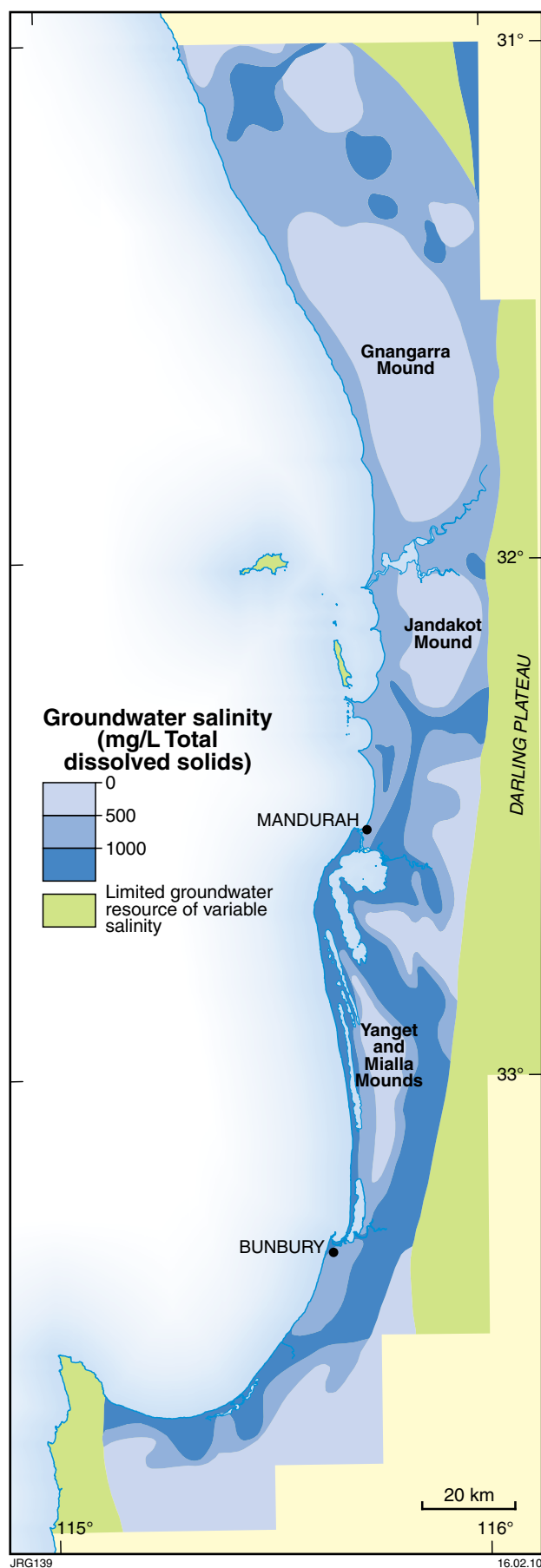


Figure 40. Groundwater table salinity

Recharge/discharge areas

There are a number of semi-confined and confined aquifers within the bedrock sediments of the Perth Basin. The most important are found in the Leederville and Yarragadee Formations. Although they are relatively deep aquifers, both are used to add potable water to Perth's water supply. The southern part of the Yarragadee aquifer, known as the South West Yarragadee aquifer, is the largest fresh body of groundwater in the State's southwest. It is considered a potential future source of high-quality drinking water for the southwest of Western Australia. It reaches the surface to form springs and seeps in parts of the Blackwood Plateau.

Every groundwater reservoir has a finite volume, and while this volume remains constant, the inflow (recharge) to and outflow (discharge) from the aquifer may vary over time. Managing a groundwater resource sustainably requires constant monitoring of the rates of recharge and discharge and the factors that affect them. Shallow unconfined aquifers can recharge very quickly after heavy widespread rain or flooding. However, deeper aquifers, with less exposure to the surface, recharge more slowly if at all.

The map (Fig. 42) shows the recharge/discharge areas for the confined aquifers. The uppermost bedrock aquifers, such as the Rockingham, Mirrabooka and Leederville aquifers, are recharged directly by downward leakage of groundwater from the surficial unconfined aquifer. However, this only happens where they are in direct hydraulic connection and where there is decreasing water pressure with depth. The unconfined aquifers of the surficial formations are recharged directly from rainfall.

The important Yarragadee aquifer is recharged by downward leakage of groundwater from the Leederville aquifer. In places, a confining bed (an aquifuge) between the Leederville and Yarragadee aquifers prevents recharge of the Yarragadee aquifer. Recharge also takes place from the surficial aquifer, but this is a minor component.

On the Gingin and Blackwood Plateaux the Leederville and Yarragadee aquifers are recharged directly by rainfall.

Because most of the groundwater flow in the bedrock aquifers is to the west the main discharge areas are along the west coast. The Rockingham and Kings Park aquifers discharge directly into the ocean over a saltwater interface along the coast. The Mirrabooka and Leederville aquifers also discharge offshore into the ocean, but mostly by upward leakage into the surficial aquifer. In addition the Leederville aquifer also discharges into the Yarragadee aquifer where the South Perth Shale is missing. The Yarragadee aquifer mostly discharges offshore over a series of saltwater wedges into the overlying strata, but there is also some discharge by upward leakage into the Leederville aquifer.

All major rivers south of the Moore River receive groundwater discharge from aquifers in the Perth Basin.

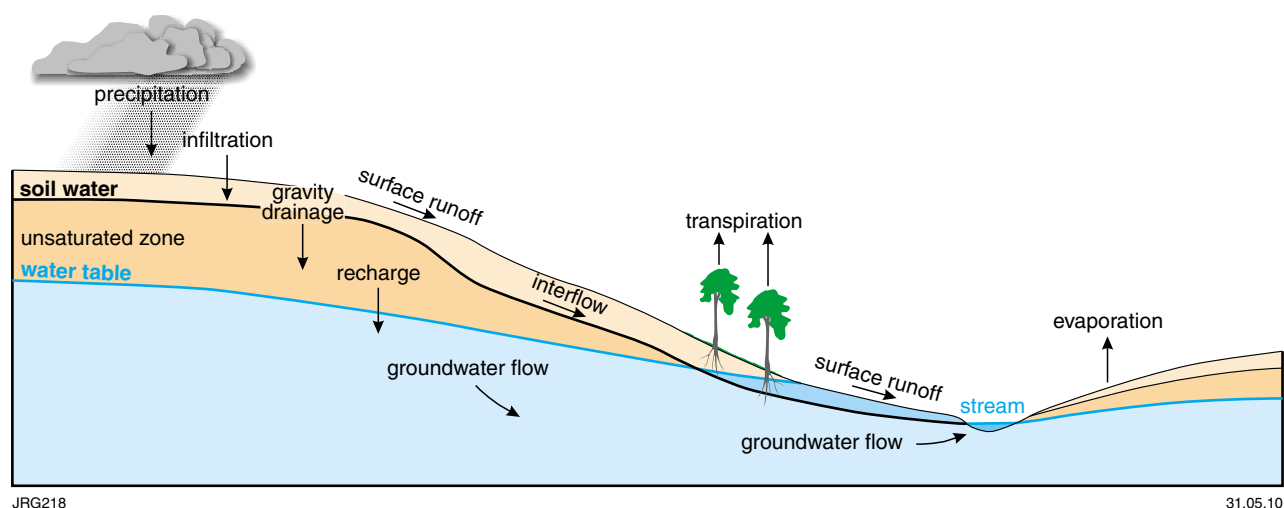


Figure 41. The hydrological cycle

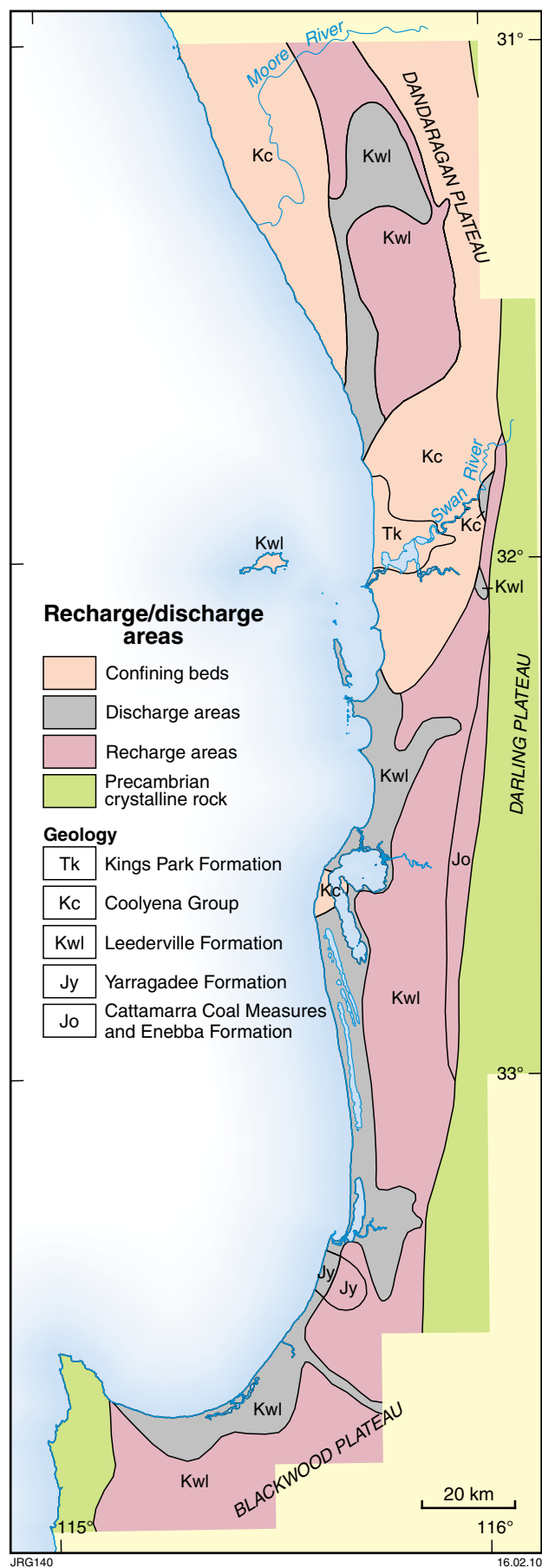


Figure 42. Groundwater recharge and discharge areas

Nitrogen and sulfate contamination

Contamination of groundwater is an important issue in the management of groundwater resources. Contamination is principally the result of urbanization and industrialization and may result from localized sources (see section on Point sources of pollution) or result from activities carried out over larger areas. These diffuse, or non-point sources of contamination are usually less severe than those derived from point sources, but may have a wider impact on the groundwater. For example, the widespread use of fertilizers can cause increased levels of nitrate and phosphate in the groundwater.

The map (Fig. 44) shows the distribution of three common indicators of groundwater contamination that are related to non-point sources of pollution: ammonia (as nitrogen); nitrate (as nitrogen); and the ratio of sulfate-to-chloride.

Ammonia is the most common form of nitrogen in groundwater where the level of oxygen in the groundwater is at extremely low levels. Low concentrations of ammonia can be produced naturally by, for example, the decay of animal and vegetable material. However, where levels of ammonia in the groundwater exceed about 0.25 mg/L the contamination is always the result of human activity. The areas where ammonia values are highest are in the market

gardening areas north and south of Perth and in the high-intensity agricultural districts of the Harvey–Waroona and Bunbury–Busselton regions. This is almost certainly related to the constant regular application of high nitrogen fertilizers.

Nitrate in groundwater can also be derived from natural sources, such as from the fixing of atmospheric nitrogen by leguminous plants like *Acacia* and *Casuarina*, but, as with ammonia, the main input is anthropogenic. The major sources of nitrate are septic sewage, fertilizers, and industrial and liquid waste. The map shows that elevated nitrate levels occur in only a few places, suggesting that the nitrate is being converted naturally to gaseous nitrogen by microbial activity in the surficial materials and groundwater.

The ratio of sulfate-to-chloride is a useful indicator of the impact of land use on groundwater quality, especially the impact of fertilizer use. Ratios greater than 0.25 generally indicate that groundwater contamination is related to the use of high-nitrogen fertilizers. The map shows that local high ratio values are found in the horticultural areas north and south of Perth and in the Harvey–Waroona and Bunbury–Busselton regions. This largely mirrors the pattern of ammonia distribution and confirms that the groundwater contamination is related to the widespread use of agricultural fertilizers.

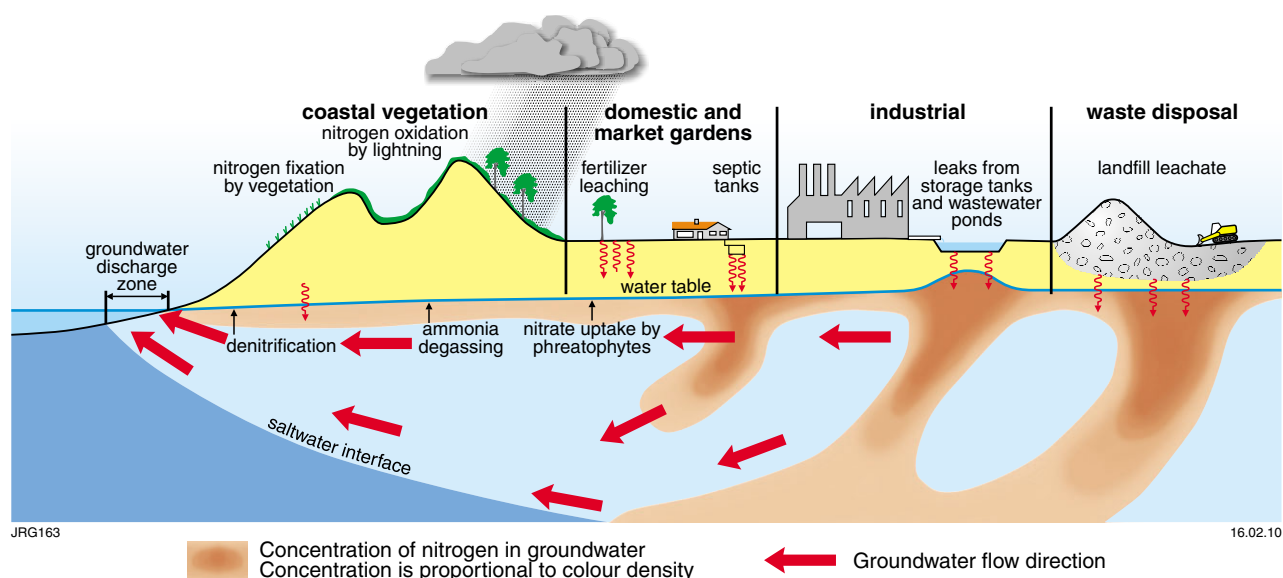


Figure 43. Sources of nitrogen and its movement in groundwater.

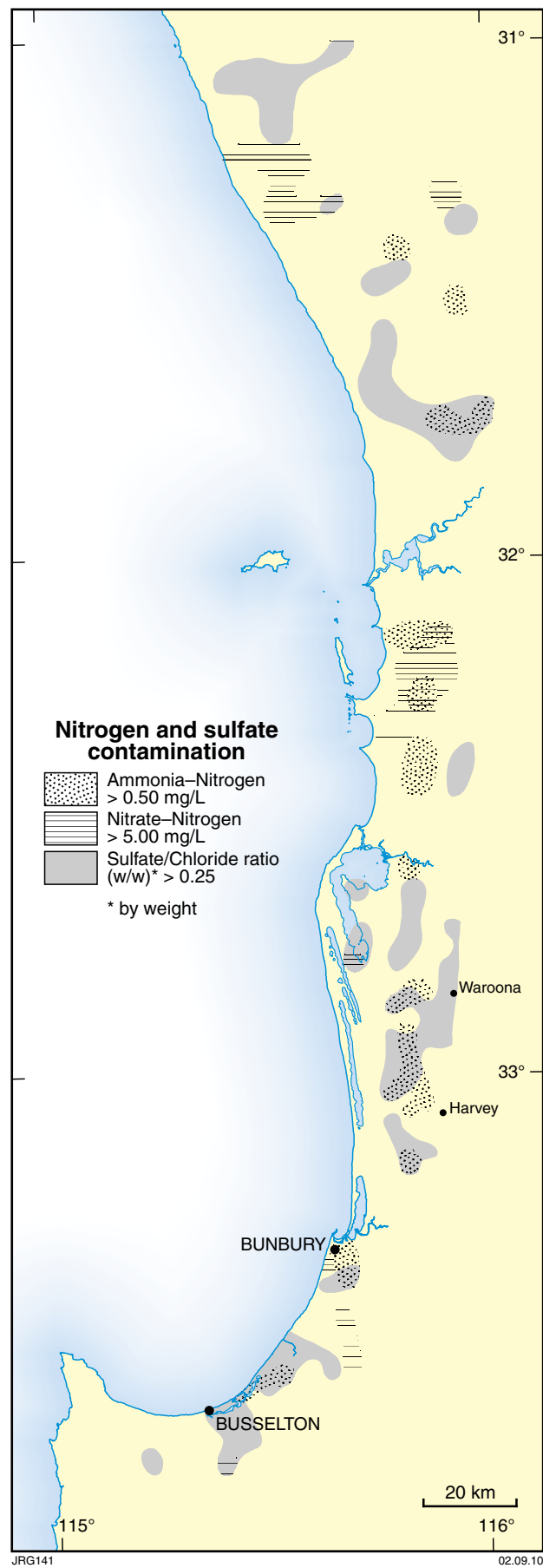


Figure 44. Nitrogen and sulfate contamination

Point sources of pollution

The groundwater in the surficial deposits of the Perth Basin is generally of excellent quality. For this reason a large percentage of the water requirements of the Perth metropolitan region and country and regional centres is met by these groundwater resources. Unfortunately, contamination by human activities can result in at least part of the groundwater resource being unusable for human consumption or can pose a threat to an otherwise healthy environment.

Point-source pollution comes from a variety of causes, including landfill and liquid-waste disposal sites, industrial effluent ponds, and burial sites. The pollutants from these include plant nutrients, bacteria and viruses, pesticides, hydrocarbons, heavy metals and other toxic chemicals. These pollutants enter the shallow groundwater, begin to move with the groundwater, and eventually spread out to form a pollution plume that moves in the same direction as the groundwater. Over time the pollution plume may extend a long distance from the source of the pollution.

Once groundwater has been polluted, it is virtually impossible to remove the pollutant. This means that the

groundwater may be unsuitable for drinking and other uses for decades or longer. It is also possible that pollution within the surficial aquifers could migrate into the deeper bedrock aquifers where the shallow groundwater recharges the deeper zones.

The map shows the location of identified and inferred point sources of groundwater contamination known to GSWA. The survey is not exhaustive and does not identify all sources of pollution. This is largely because many state and local government authorities hold their own data on sources of groundwater contamination.

An eight-fold grouping of pollution sites (Fig. 47) has been adopted, which reflect a specific range of activities. Each activity can be expected to produce a typical range of pollutants. For example, effluent from metal finishing has high values of cyanide, chromium and cadmium, whereas mechanical workshops produce oil, grease and detergents.

Most of the high-risk activities are restricted to areas zoned industrial such as Kwinana, Coogee, Osborne Park and Canning Vale.



Figure 45. Landfill site at Red Hill



Figure 46. Drainage basin in Perth's northern suburbs.

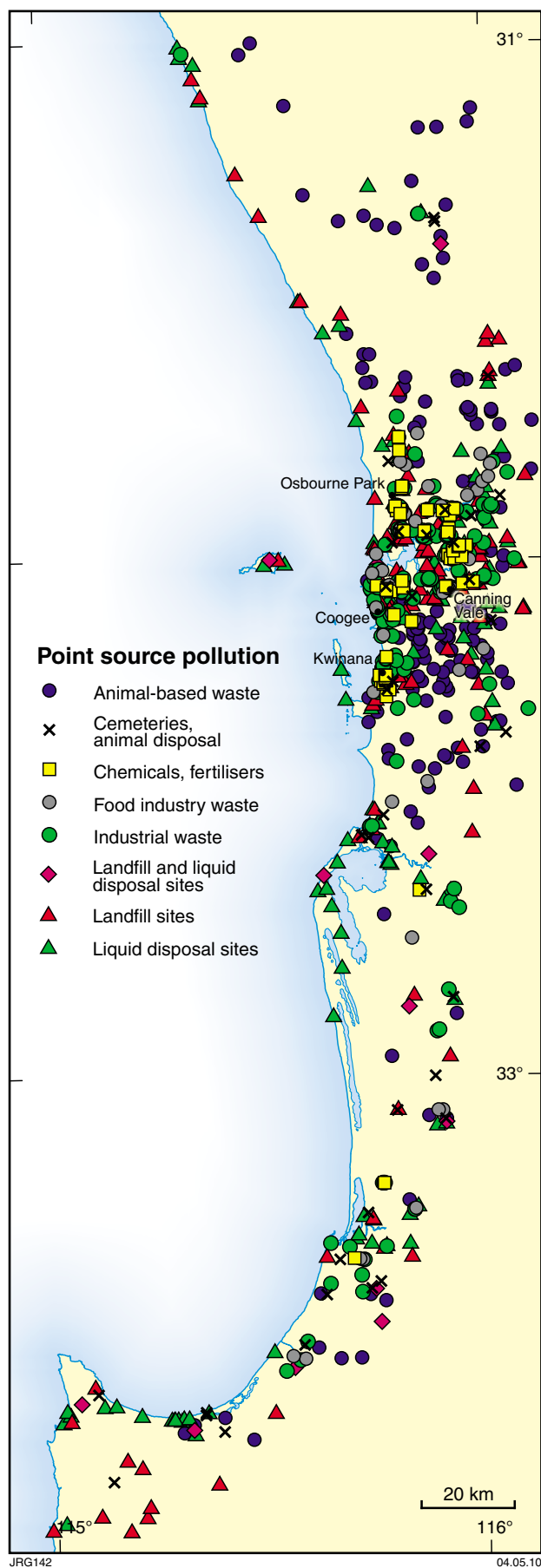


Figure 47. Locations of pollution point sources.

Groundwater vulnerability

Groundwater vulnerability is a measure of the risk of contaminants being able to reach the groundwater table from the ground surface. It is a function of the geological setting of an area and the climate. The principal factors governing groundwater vulnerability include the depth to the ground water table, the nature and characteristics of the materials above and below the ground water table, climatic factors, and the nature of the contaminants.

The depth of the groundwater table below ground level is the most important factor affecting the removal of contaminants, as it determines the thickness of the unsaturated zone through which contaminants must pass to reach the groundwater table. Thicker unsaturated zones allow more time for the removal of contaminants by their adsorption to organic matter or clay minerals or by microbial activity.

The characteristics of the materials through which the contaminants flow is also important. Porosity and permeability (the ability of a material to transmit fluids through its pore space) affect the rate of flow through the material to the groundwater. Flow through materials such as sand and gravel is easier and more rapid than in more fine-grained materials such as silt and clay. Furthermore, clay also has an ability to adsorb contaminants, whereas clean quartz sands have little such ability. The presence of karst features in limestone may even allow direct and rapid access of contaminants to the groundwater.

Climatic factors can determine how quickly contaminants are leached from materials and transported to the groundwater table. Higher rainfall and lower evaporation, combined with coarse-grained materials, can lead to increased recharge rates and therefore a greater potential for leaching and transport of contaminants.

The chemical composition of contaminants also determines how easily they are leached from the soil and transported to the groundwater table. The mobility of contaminants depends on their viscosity and solubility and to what degree they can become adsorbed by organic matter or clay minerals.

The map (Fig. 48) is based on an assessment of all these factors. Vulnerability has been ranked into five classes. 'High' to 'Very high' vulnerability is confined to the Swan Coastal Plain and the coastal limestone region of the Leeuwin–Naturaliste region. In these areas sandy materials with a generally shallow groundwater table predominate. Vulnerability is also high where karst development allows direct access to the watertable through sinkholes created by solution of the limestone.

There are areas of 'Low' to 'Very low' vulnerability on the Dandaragan, Blackwood and Darling Plateaux. In these areas the groundwater table is generally at a greater depth than on the coastal plain and the materials have a low permeability. Areas with predominantly clayey materials within the Guildford Formation also have low vulnerability because of their adsorbent properties and low permeability.

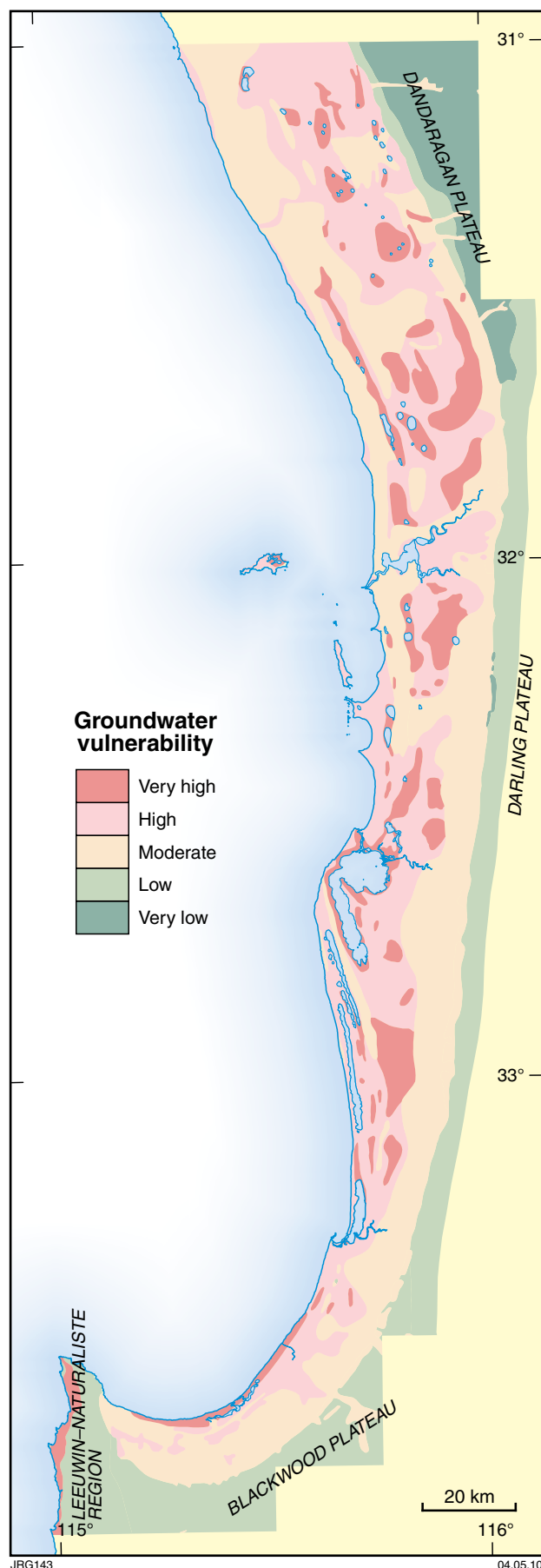


Figure 48. Groundwater vulnerability

Land properties

Conventional geological maps may group rocks that have markedly different engineering properties as a single unit or related units because they are of the same age. Such maps do not include information on the physical properties of the rocks and materials. For planning purposes, it is important to distinguish between adjacent rocks and soils that have similar compositions but are different in an engineering or environmental sense.

Once the nature and physical properties of geological units have been established, their capability to sustain different types of development can be assessed. When communicating information about land properties and capabilities, it is important to distinguish between two different kinds of activities: those that are undesirable because of their potentially damaging effects on the environment as opposed to the ones that are undesirable because of the effect the environment may have on the activity.

The themes of permeability and unified soil classification are two examples of thematic datasets that can easily be derived from primary geological mapping. They provide important information in helping engineers and planners to understand and assess the capability of the geological materials for various land uses.

In contrast, the development potential map takes a holistic view of the relative suitability for development based on natural factors. It is based on the integration of a number of natural factors that have an impact on development. This approach adds a new perspective to the geological data and forms an integral part of the total environmental planning strategy for engineering and land development.



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Figure 49. Kwinana Freeway south of Perth

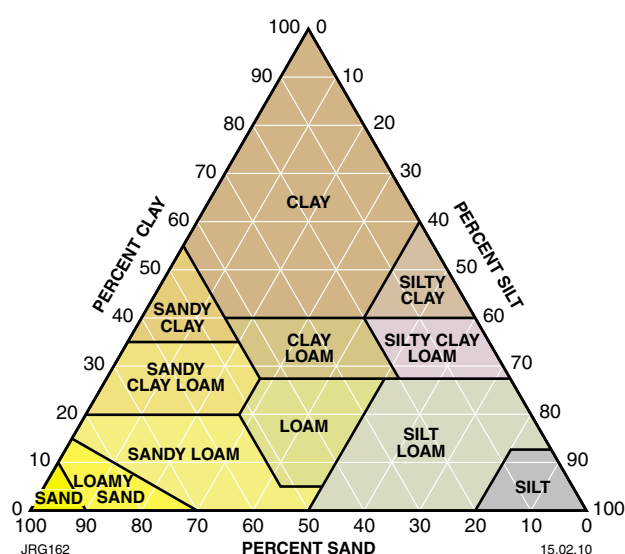


Figure 50. Material texture triangle



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Figure 51. A variety of surface material textures:
Top left: sand
Top right: shelly limestone
Bottom left: lateritic gravel
Bottom right: clay

Permeability

Permeability is the ability of a material to transmit fluids such as water. A highly permeable material is one in which there are few restrictions to the flow of water, whereas a material with low permeability slows down the movement of water. Permeability is closely related to the hydraulic conductivity of a material. It is a measure of the ease with which water can move through the material. Hydraulic conductivity in turn is inferred from attributes of the material, such as structure, texture, porosity, cracks and shrink-swell properties.

Because of their high hydraulic conductivity, sands and gravels have higher permeability ratings than clay sediments. The assessment of permeability is generally based on the hydraulic conductivity of the material being assessed.

Permeability is an important characteristic of a material because it provides empirical information on a number of land qualities, such as site drainage potential, erosion hazards and ease of excavation.

When the permeability of materials is considered in relation to their position in the landscape, an evaluation of the area's relative drainage conditions can be made. This measure of site drainage potential is, in effect, a measure of the ability of a material to drain excess water and reduce water logging. As such, it is a quality that can be assessed in the field independently of existing hydrological and climatic conditions.

The map (Fig. 54) shows a qualitative estimation of the permeability of materials in the southern Swan Coastal Plain assessed from field inspection of the physical attributes of the materials. A six-fold evaluation is used to identify the permeability classes. At this level of survey no physical measurements were taken, nor were external influences, such as internal and external drainage and underlying substrate taken into account.



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Figure 52. Clayey materials have low permeability.



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Figure 53. Sandy materials have high permeability.

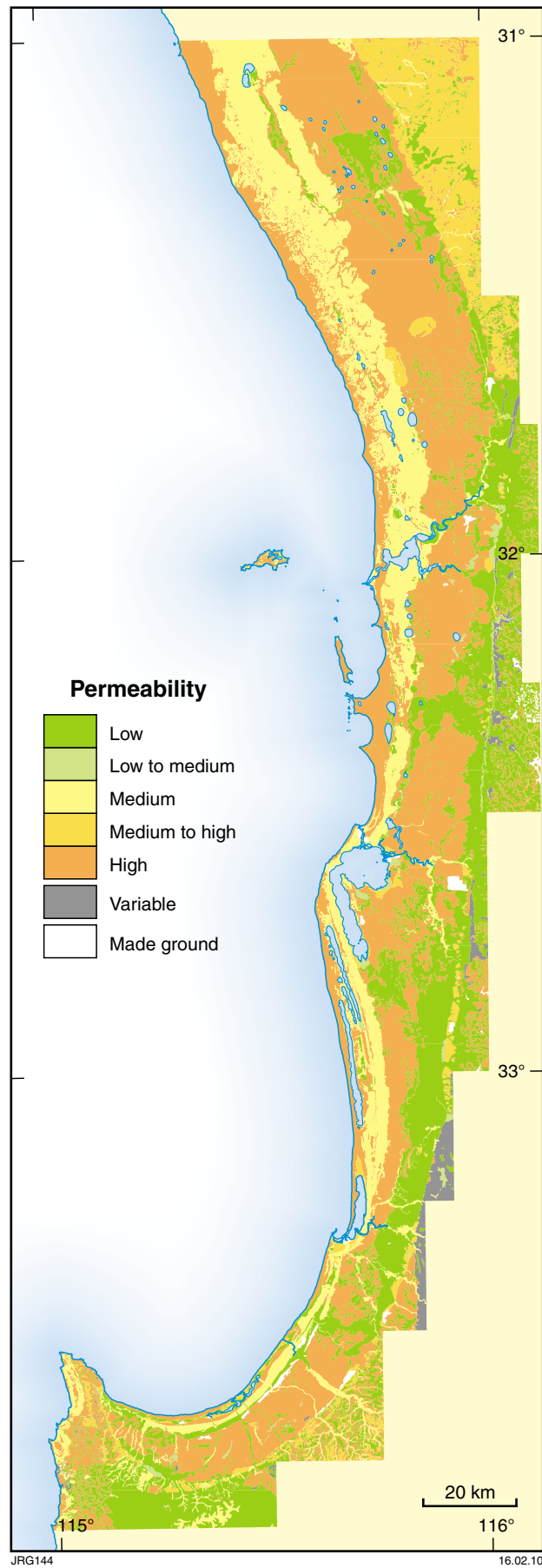


Figure 54. Surface substrate permeability

Unified soil classification

Most soils are an assorted mixture of loose, unconsolidated mineral grains and rock fragments. To geologists and engineers the term 'soil' also includes organic material such as peat. Knowing how soils behave under different conditions is important in helping to determine their development capabilities. The size and shape of grains and the amount of clay, organic material and water in the soil are all important factors in understanding the behaviour of soils.

To understand a complex material such as soil, it is useful to have a classification system that provides a standard method of identifying and characterizing them.

The Unified Soil Classification System (USCS) is a soil classification system used in engineering and geology to describe the texture and grain size of a soil (see table

Table 2. Categories of the Unified Soil Classification System

Symbol	Description
GW	Well graded gravels and gravel-sand mixtures, little or no fines
GP	Poorly graded gravels and gravel-sand mixtures, little or no fines
GM	Silty gravels, gravel-sand-silt mixtures
GC	Clayey gravels, gravel-sand-clay mixtures
SW	Well graded sands and gravelly sands, little or no fines
SP	Poorly graded sands and gravelly sands, little or no fines
SM	Silty sands, sand-silt mixtures
SC	Clayey sands, sand-clay mixtures
ML	Inorganic silts, very fine sands, rock flour, silty or clayey fine sands
CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays
OL	Organic silts and organic silty clays of low plasticity
MH	Inorganic silts, micaceous or diatomaceous fine sands or silts, elastic silts
CH	Inorganic clays of high plasticity, fat clays
OH	Organic clays of medium to high plasticity
Pt	Peat or other highly organic soils

below). The classification system can be applied to most unconsolidated materials, and is represented by a double-letter symbol. Each soil type is described in Table 2. The classification of soils is based on engineering properties: particle size, water holding capacity and plasticity, and organic content. The system has the advantage of being suitable for use in field conditions because a soil can be easily classified by visual and physical inspection.

The USCS classification is one of the primary datasets used in assessing the development capabilities of a soil because it is based on physical properties.

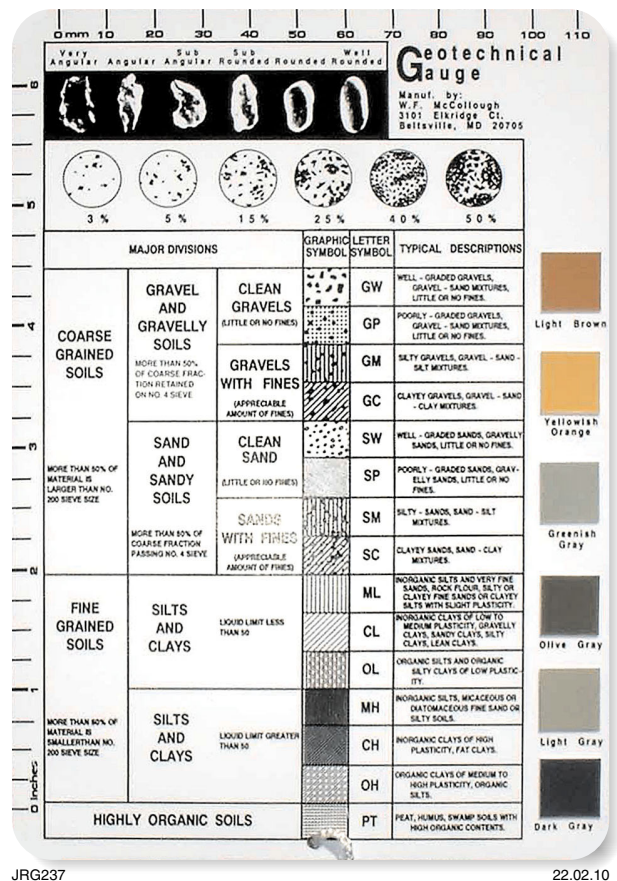


Figure 55. Data chart for engineering geology field work

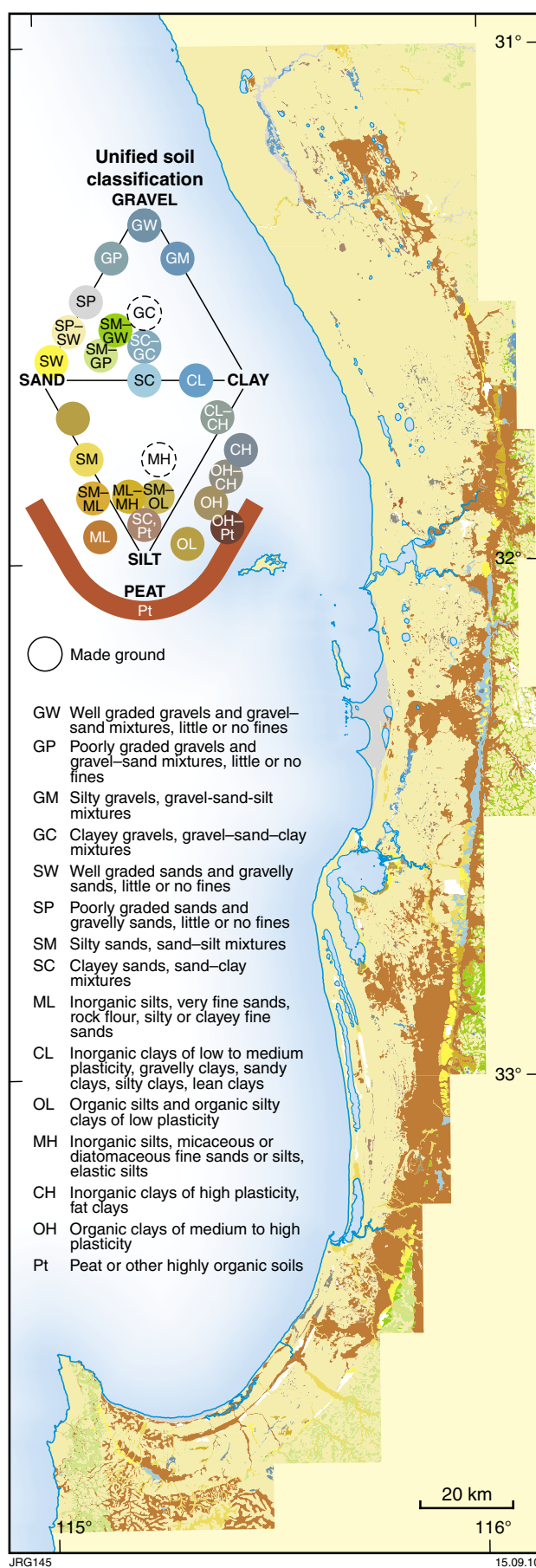


Figure 56. Soil types

Geological conservation

Geological conservation has a long history but, to date, has not received the level of interest traditionally given to biological conservation. Geological conservation involves the protection and management of sites of geological interest. It is an effort to conserve them for study and appreciation for future generations to come. Nevertheless, in these times of greater environmental awareness many people have become interested in all aspects of the landscape.

Geology underpins our ability to understand and explain the origin and evolution of the landscape. Many striking landforms and geological sections in the region provide insights into the geological history of the southern Swan Coastal Plain and to the evolution of the landscape as we see it today.

These natural features provide a scientific and educational resource that provides insights to geological processes in the past that have shaped the landscape. It also raises an awareness of how similar processes may shape our future. For example, understanding the effects of past sea-level changes will help us understand the possible effects of future sea-level changes as a result of climate change.

The single theme in this section — geoheritage — focuses on the diversity of geological features in the region. In contrast, geological conservation, increasingly called

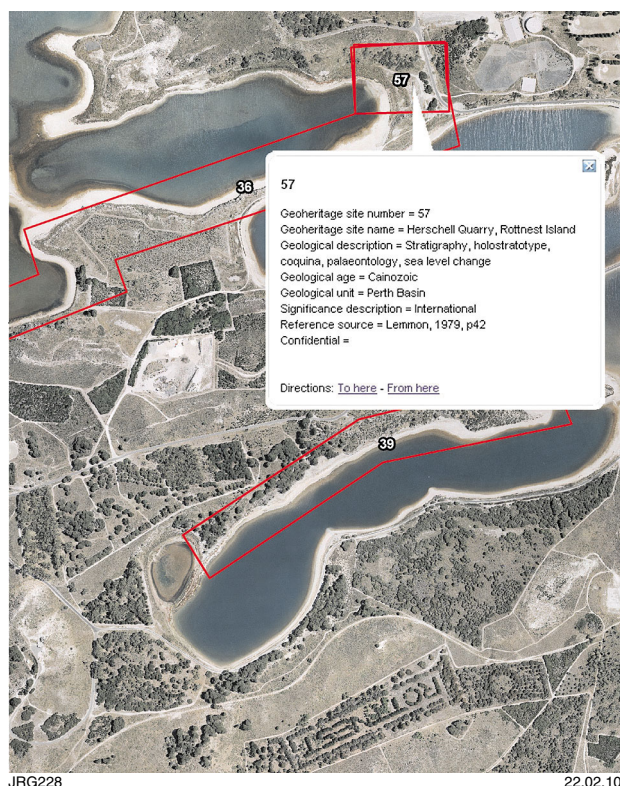


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Figure 58. Marine shell beds at Peppermint Grove

geoconservation, is the discipline concerned with the protection, management and interpretation of geodiversity. It is the role of the planning community to ensure that the diversity of Western Australia's unique geological heritage is recognized during the planning process and is maintained through careful planning.



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Figure 57. Geoheritage information for Herschell Quarry, Rottnest Island viewed in Google Earth



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Figure 59. Dolerite dykes intruding granite at Mountain Quarry

Geoheritage sites

Geoheritage is an emerging issue for land use geoscience in Western Australia. It relates to our responsibility to protect valuable geological features for the scientific and educational benefit of future generations.

Geoheritage sites are natural geological features that are considered to be unique within Western Australia and to have significant geoscientific and educational values. In Western Australia, sites of geological significance may include different aspects of geology and geomorphology. They include fossil localities, type sections, particular landforms or other geological features. Information on some of the more popular sites has been published by GSWA and provides details on accessibility and the main features to be seen.

A site of geological significance is one that displays special scientific or educational values for geological education, research and reference. The geological community therefore considers it to be worthy of management, protection or preservation.

The State Register of Geoheritage Sites is maintained by GSWA in collaboration with the Geological Society's Standing Committee for Geological Heritage on behalf of the community and made available to the public. The register is not a static document. New sites can be nominated and existing sites re-assessed or replaced as new geological concepts or priorities change the values of sites and features. Criteria used to select geoheritage sites include geological type, geological age, use, representative or outstanding nature, rarity, and current condition.

Low-key recreational use is unlikely to affect the geological values of geoheritage sites. However, it is important that potential impacts on Western Australian Sites of Geological Significance and other sites of geological importance are considered in planning for recreational use, tourism development, resource exploration, mining, and urban and industrial development. Before any activity or development is planned for a site on the Register, the Executive Director of GSWA should be consulted.

The map (Fig. 60) shows the location of the 33 sites listed in the register considered to have geoheritage values. While most sites have a low vulnerability rating, two sites on Rottnest Island have a high rating and one at Ridge Hill in Helena Valley has an extreme vulnerability rating.

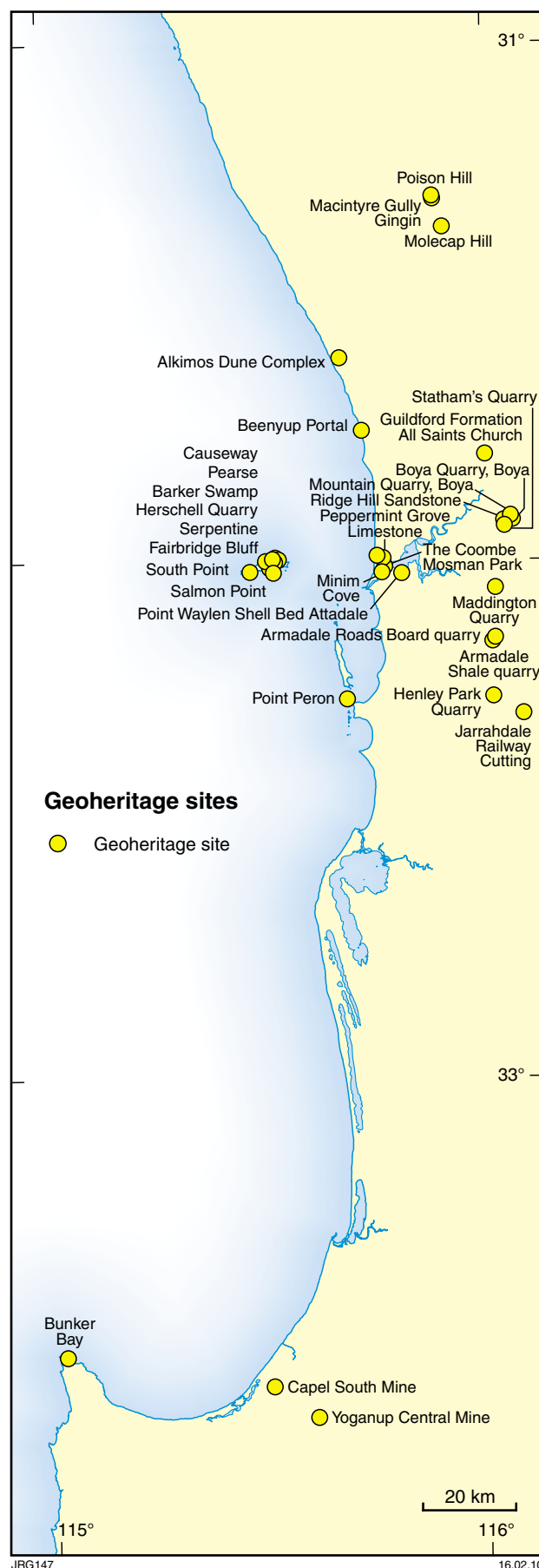


Figure 60. Geoheritage sites

Resources

Minerals are an essential part of our everyday life and our use of minerals continues to grow. Much of this growth is in those basic raw materials, also called construction materials, that go into building our urban and industrial infrastructure.

Until recently, supplies of our most important basic raw materials — hard rock, sand and limestone — have been quarried from deposits close to where they are needed. However, deposits close to urban areas are becoming exhausted, while demand for these materials continues to grow. New sources must be identified, but planning for the extraction of those basic raw materials is not coordinated or integrated at a regional level. Besides, there is an uncertainty about the lifetime of many key operations. Meanwhile, land that contains significant resources of construction materials is being sterilized by

urban expansion and by the creation of conservation parks and reserves.

Hence, integrated land use planning is essential. Such planning must recognize the necessity of protecting key areas of basic raw materials from developments that would otherwise sterilize resources that are needed to ensure long-term growth.

In this context, basic mineral resource information is critical. Knowledge of the extent, quality and importance of those resources is a key element in ensuring that sufficient resources are available to meet future demand.

The themes covered in this section include energy resources — coal, gas and geothermal. None of these resources is currently being exploited. However, considerable interest is being shown in the development of the gas and geothermal resources as new technologies are developed to extract them.

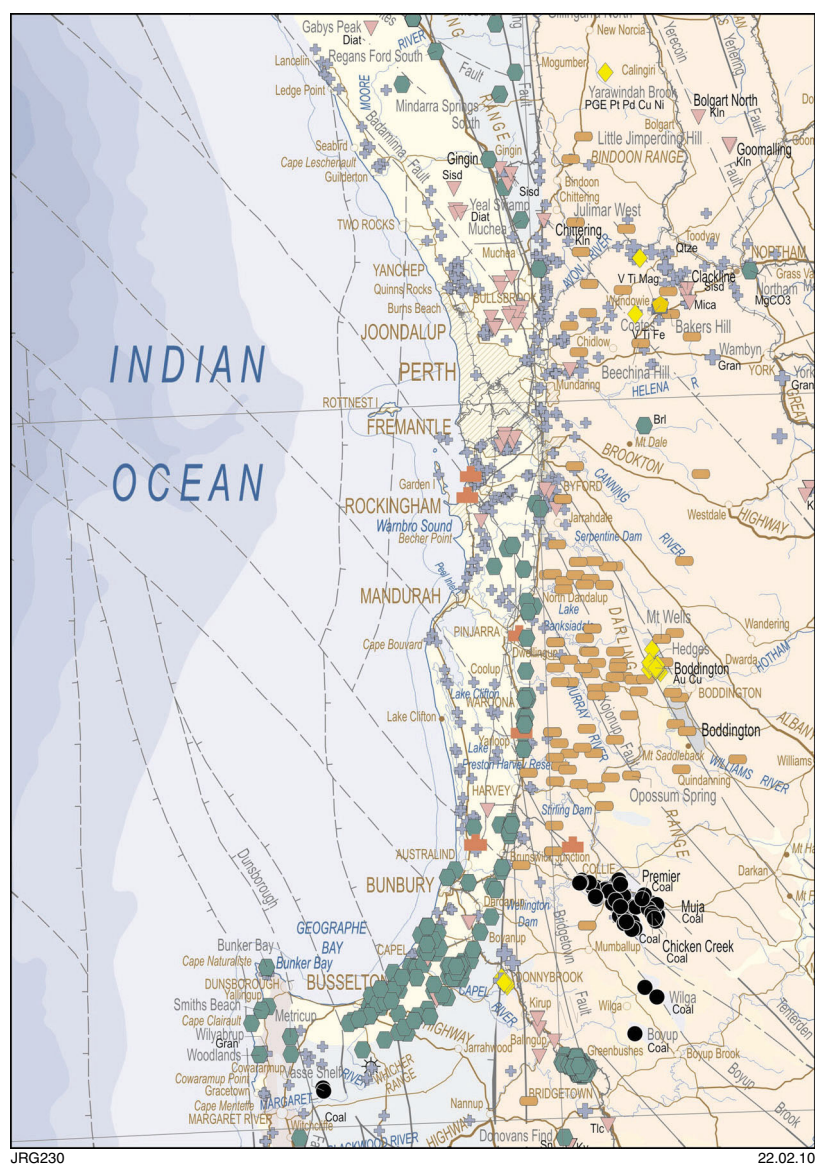


Figure 61. Mineral deposits and petroleum fields



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Figure 62. Dump trucks at a large mining centre.



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Figure 63. Cockburn Cement's processing plant

Mineral resources

The Department's Mines and Mineral Deposits database (MINEDEX) that provides information on the locations, operational status and estimated mineral resources and ore reserves of mines and mineral deposits in Western Australia. It includes the locations of historic mine sites and information on processing plants, tailings storage facilities, exploration sites, transportation sites and handling facilities. Other site types include tourist mines, ports, and power plants. MINEDEX is a knowledge base of geological information for metallic and other minerals that is essential for assessing the economic potential of an area as part of strategic planning.

The map (Fig. 66) shows the locations of MINEDEX sites by commodity group. A commodity group is a major mineral or combination of minerals, such as 'precious metal'. MINEDEX contains 10 commodity groups, plus a catch-all category of 'Other'. The 'Other' commodity group was created to cover non-minerals and non-petroleum, that is, chemicals and petrochemicals. Table 3 gives an indication of the types of minerals and materials contained in each commodity group.

Table 3. MINEDEX commodity groups and associated minerals and materials

<i>Commodity group</i>	<i>Typical minerals/materials</i>
Alumina	Aluminium, bauxite
Base metal	Copper, lead, zinc
Construction material	Limestone, limesand, sand, clay
Energy	Coal, petroleum, uranium
Industrial mineral	Silica sand, diatomite, greensand, gypsum
Iron	Iron ore
Other	Chemicals, petrochemicals
Precious metal	Gold, silver, platinum
Precious mineral	Diamond, semi-precious gemstones
Speciality metal	Tin, titanium minerals, rare earth elements
Steel alloy metal	Tungsten, molybdenum, nickel



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Figure 64. Exploring for mineral deposits



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Figure 65. Some industrial minerals

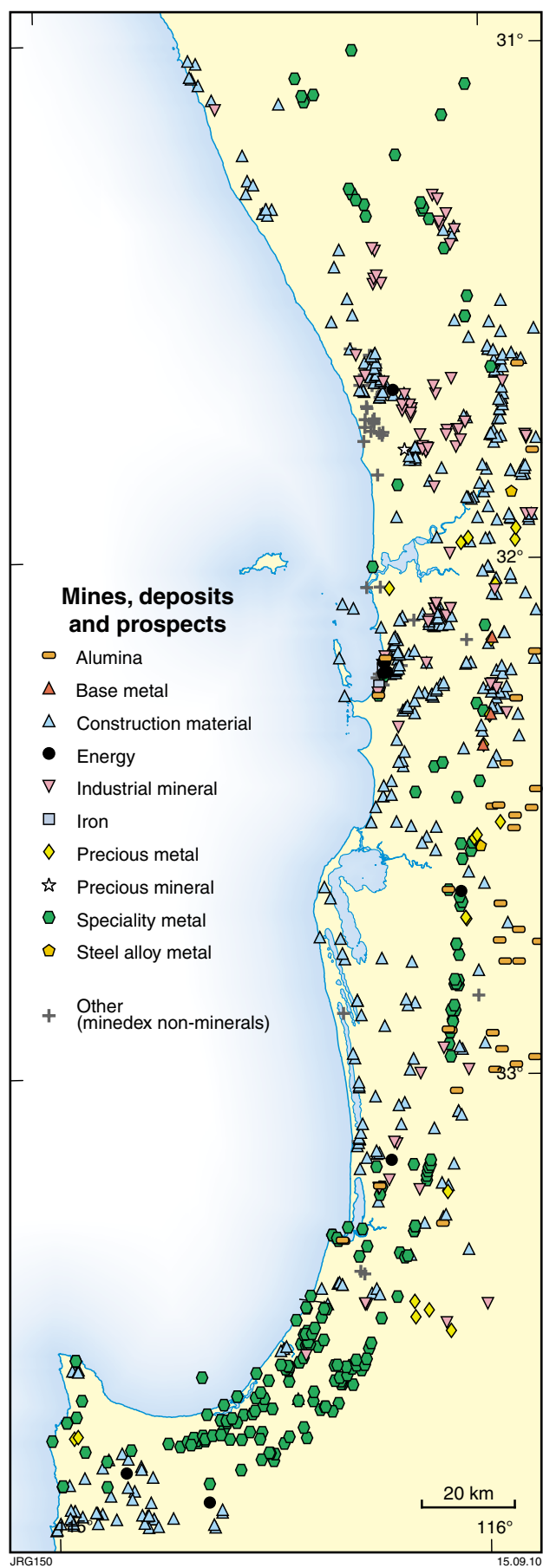


Figure 66. Locations of MINEDEX sites by commodity group

Titanium–zircon mineralization

Sand deposits containing the minerals ilmenite, rutile, zircon, monazite and xenotime have been mined in Western Australia since 1956. In the past, these minerals have been referred to as 'heavy minerals' and the deposits in which they are found as 'heavy mineral sands'. However, the preferred name for these minerals is now 'titanium–zircon minerals' and the deposits 'titanium–zircon mineral deposits', although in some deposits the value of zircon is greater than that of titanium minerals.

Western Australia is the dominant supplier of titanium and zircon minerals to world markets. The industry is the sixth-most valuable sector of Western Australia's mining industry. Some downstream processing of titanium–zircon minerals to produce white pigments takes place at three plants in the State. Titanium pigments are ultraviolet absorbing, non-toxic and inert. They are used in a wide variety of products including paints, sunscreens, plastics, paper and textiles.

The titanium mineral industry operates along almost the length of the Swan Coastal Plain, but is concentrated in two regions. In the southern Swan Coastal Plain the Bunbury–Capel region dominates production, and there are economic deposits of titanium–zircon minerals as far north as Mundijong.

The titanium–zircon minerals were deposited in three strandlines parallel to the present coast, each related to a time when sea level was higher. The Yoganup strandline is at the base of the Darling and Whicher Scarps; the Capel strandline is within the Spearwood Dune system; and the Quindalup strandline is confined to modern beaches and dunes.

Because the titanium–zircon minerals industry operates in areas where there are many competing alternative uses for land, land use planning initiatives have a major impact on access to resources. For example, rezoning from rural to urban and the creation of conservation areas can restrict or prohibit mining. A number of titanium–zircon mineral deposits have already been sterilized by competing land uses.

The map (Fig. 68) shows the distribution of the known titanium–zircon mineral deposits. The information displayed consists of the deposit strandlines and the associated mining footprint. These are referred to as Strategic Mineral Resource Protection Areas.

Many of the areas identified have been incorporated into Regional Planning Scheme policies by the Western Australia Planning Commission with a requirement that local government protect the areas in future planning documents.



Figure 67. Titanium dioxide powder

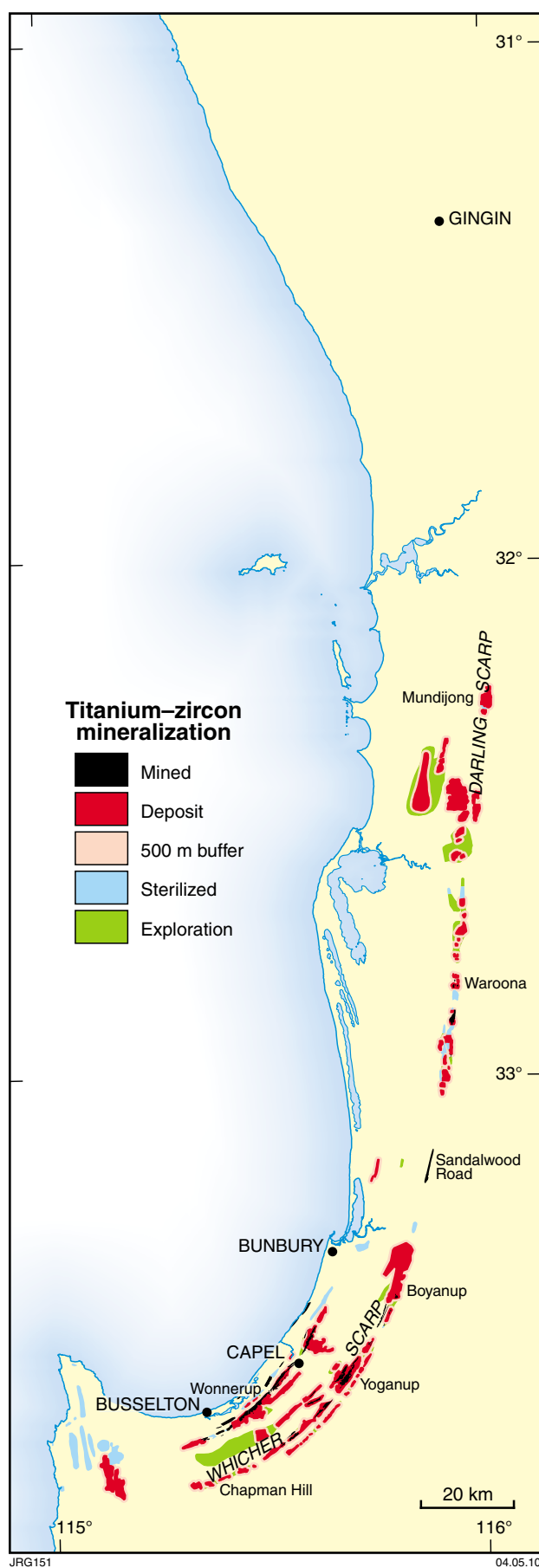


Figure 68. Locations of titanium-zircon mineral deposits

Dimension stone

Dimension stone is the term for any natural rock material quarried for blocks or slabs for interior or exterior uses. It includes traditional products such as building stone, ornamental stone and monumental stone.

Since earliest colonial times stone suitable for building was sought as close as possible to settlement sites. The principal rock types used were limestone from the extensive resources of the coastal Tamala Limestone and granite from the Darling Plateau.

Architects are once again turning to natural stone for use in new buildings and in innovative streetscape designs. This is leading to an increase in demand for natural stone and recognition of the value of local dimension stone resources.

The map (Fig. 71) shows the location of significant dimension stone quarries. The large number of quarries in the Tamala Limestone and its equivalents between Guilderton and Bunbury attest to the significance of the limestone building block industry. However, natural limestone blocks are only quarried from high-grade

limestone in the Carabooda–Nowergup and Guilderton areas. Elsewhere the limestone is too soft and in these areas crushed limestone is used in the manufacture of reconstituted limestone products.

As late as the 1970s three quarries east of Perth between Greenmount and Mundaring were quarried for use as dimension stone. Extensive stockpiles at the Mundaring quarry have been used in more recent times for rock armour and facing stone. Similar material has been quarried at Roelands east of Bunbury.

A dimension stone prospect has been identified in granitic gneissic rocks at Woodlands, 35 km west-southwest of Bunbury. The rock displays an attractive brown hue highlighted by a black linear texture.

The Bunbury Basalt near Bunbury has potential as cobbles and setts and as black, polished blocks.

In the Gingin area local diatomaceous clay known as Casuarina Stone was used in the past to construct a number of historic buildings in the town and has potential as a cut building stone.



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Figure 69. Limestone quarry producing natural building blocks



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Figure 70. Manufacture of reconstituted limestone blocks.

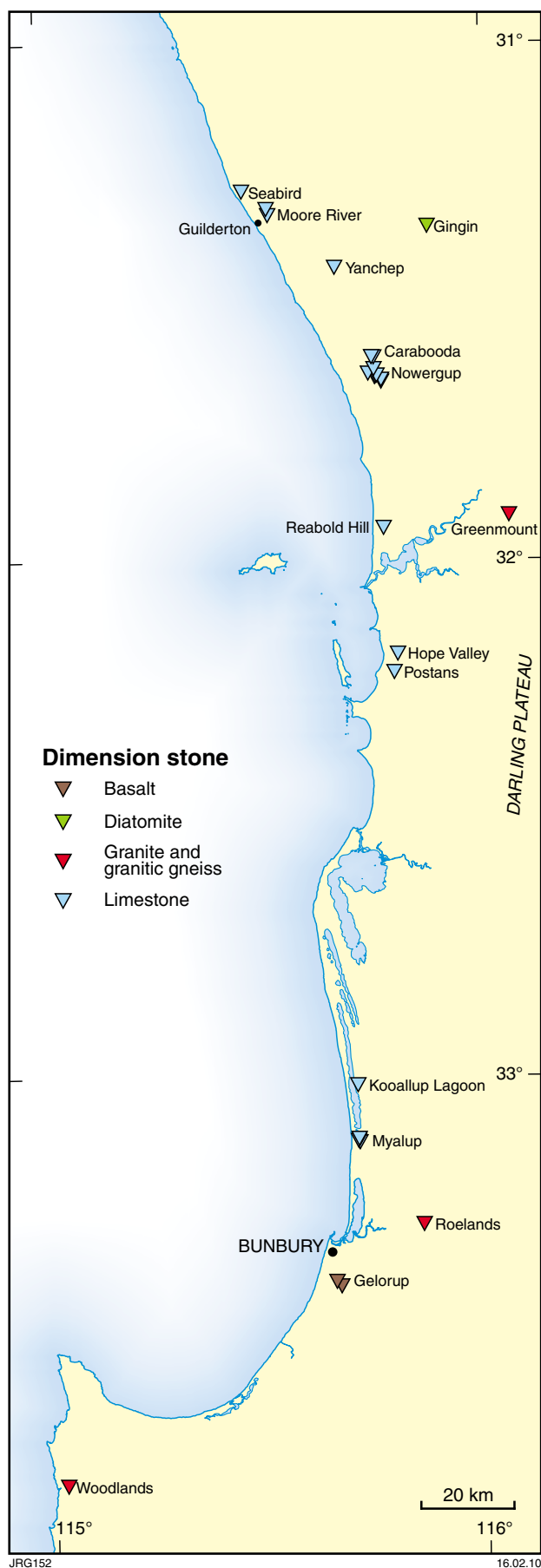


Figure 71. Dimension stone quarries

Hard rock

Hard rock is a general term covering various rock types, but mostly granite and dolerite. They are quarried mainly to supply aggregate in the form of crushed rock.

Two grades of aggregate are produced by most hard rock quarry operators. However, the difference is related more to the crushing and screening process than to the physical characteristics of the rock.

A-grade aggregate is screened to various size fractions and is used mainly for pre-mixed concrete (55%) and road surfacing (45%). Small amounts are used as railway ballast, as rock armour material in breakwater or dam construction, and as drainage aggregate.

B-grade aggregate is derived from the undersize material. It is used as base course material in road construction and in asphalt for road surfacing.

The map (Fig. 74) shows the large area of rock suitable for use as hard rock aggregate. In practice, however, access to material is influenced by environmental and economic issues. The bulk of the aggregate supply comes from quarries along the Darling Scarp from Herne Hill to Byford. Here overlying weathered layers are thin or absent. Further south at Roelands a quarry supplies rock armour for breakwaters in the Bunbury region.

In the Bunbury region the Bunbury Basalt is a valuable source of high-quality aggregate. Although the Bunbury Basalt is very extensive in subcrop it only comes close to the surface in a small number of locations, such as on the Bunbury foreshore. Only two areas contain basalt that can be economically extracted — Gelorup and Capel South. At present, basalt is extracted from only two operations at Gelorup. However, the Capel South area is considered to have the best prospects as a long-term resource of hard rock aggregate for the Bunbury region.



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Figure 72. Crushing and grading hard rock aggregate



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Figure 73. Hard rock quarry on the Darling Scarp

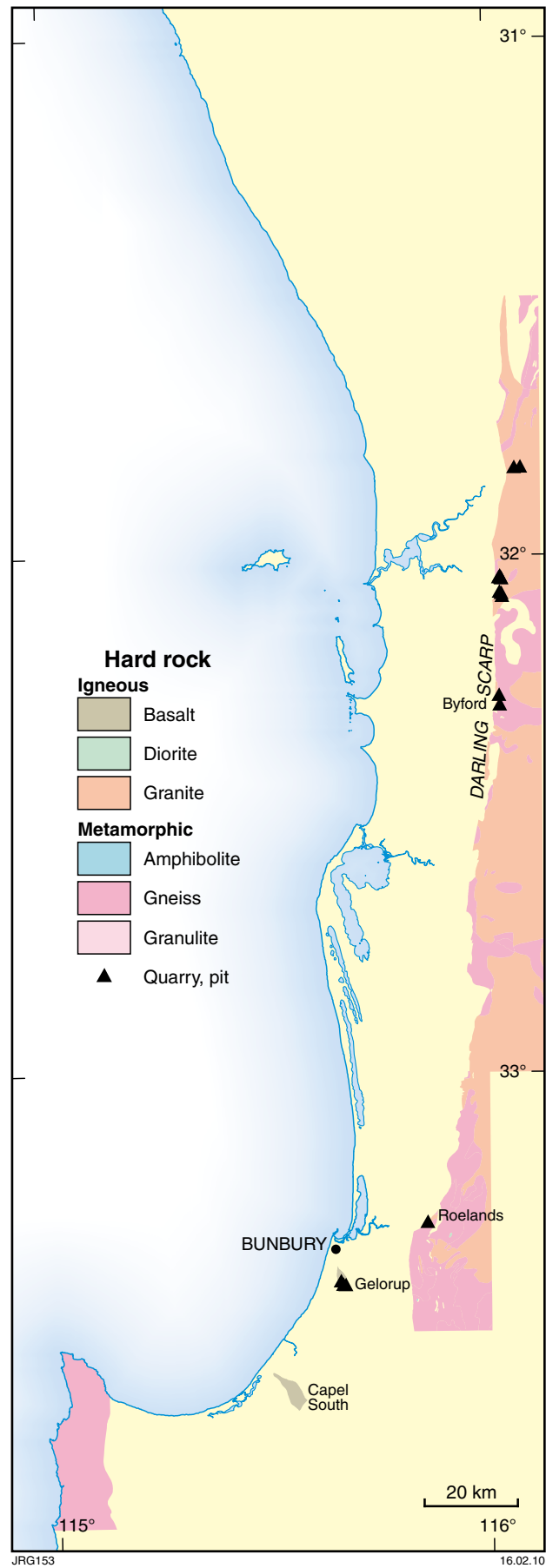


Figure 74. Distribution of hard rock

Gravel

Throughout southwest Western Australia the term 'gravel' is synonymous with lateritic gravel. Lateritic gravel consists of concentrations of loose, iron-rich clasts (nodules and pisoliths) and fragments commonly set in a clay-rich or sandy matrix. It is rarely more than one metre thick. Lateritic gravel forms by the natural mechanical disaggregation of the underlying lateritic duricrust. Lateritic duricrust is sometimes referred to as ferricrete or ironstone, or, incorrectly, as laterite. Together, lateritic gravel and lateritic duricrust form the uppermost part of the deep and extensively weathered layer that forms at the surface on the parent rock.

Although lateritic duricrust and gravel can develop in a variety of topographic positions, their distribution tends to coincide with uplands. They have also developed on a variety of rock types. In fact, the texture and composition of the lateritic duricrust and gravel is a useful indicator of the nature and composition of the parent rock.

Gravel is used mainly as road base and surfacing and for hard-stand surfaces. Quality controls for gravel are not stringent and tend to reflect the end use: a moderate proportion of clay is preferred where there is a need to bind the gravel. Well-graded gravel is preferred to reduce the number of voids in a completed road. A low proportion of boulders is required to reduce handling costs. The gravel must also be hard enough to withstand traffic.

The map (Fig. 77) shows that resources of gravel are abundant, especially on the Darling Plateau and in the Leeuwin–Naturaliste Region where lateritic duricrust and gravel have formed on ancient granitic rocks. They are less well-developed on the much younger, silica-rich sediments of the Perth Basin and the Blackwood and Dandaragan Plateaux.

There are minor deposits of gravelly material in alluvial deposits on the Swan Coastal Plain and in the Guildford Formation. However, extraction has not taken place at any of these sites.

In general, deposits of gravel of appropriate quality can be found within a relatively short distance of the location where it is to be used. Unfortunately, competing land use pressures commonly constrain access to these resources.

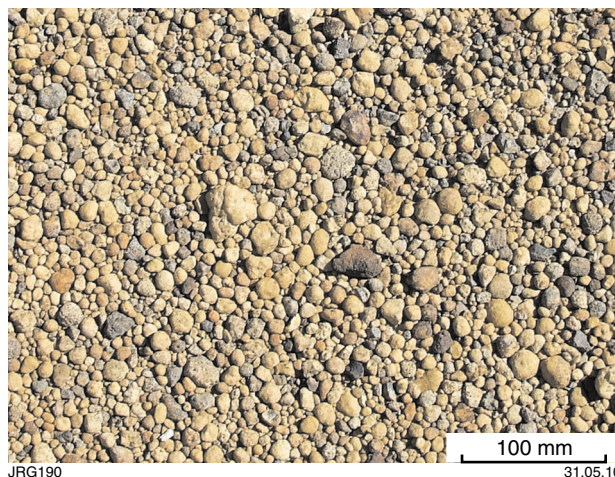


Figure 75. Lateritic gravel from the Darling Plateau



Figure 76. Screening and grading lateritic gravel

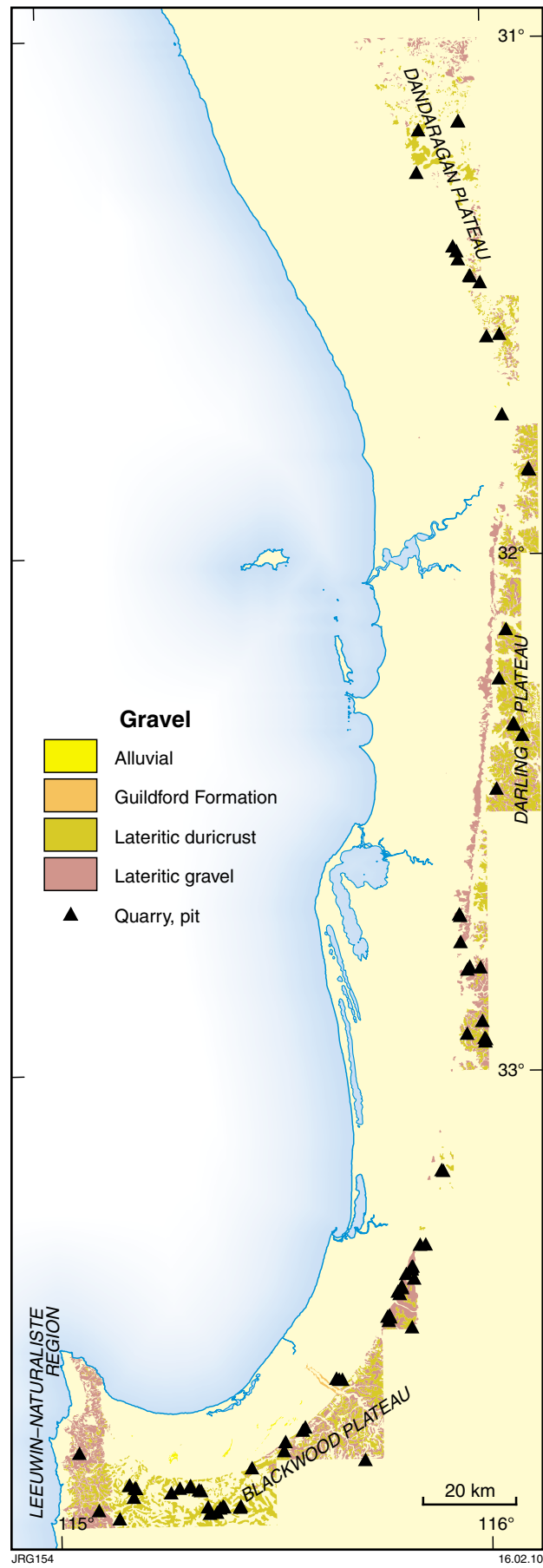


Figure 77. Distribution of gravel deposits

Clay

Clay plays a vital role in the building industry. Most of the clay extracted is used in the manufacture of bricks, pipes and tiles, walling blocks and pavers. Clay is also used as water-tight cores or linings for earth dams and ponds, especially for alumina refinery residue areas, and for sealing landfill sites.

Although clay is extracted from several geological units, no single clay is consistent in its properties. Variations in the amount of quartz, lime, carbon and salt all present problems, as do variations in particle size and hardness. Manufacturers must therefore blend various clays to achieve the mix they require. The industry must therefore have access to a number of different deposits.

A variety of ingredients can be used in manufacturing bricks, pipes and tiles. However, a portion of the ingredients must be strong, high-quality plastic clay. Brick manufacture needs about 20% and tile manufacture about 40% of plastic clay to impart strength and maintain the shape of the finished product.

The remaining portion of the mixture comes from other clays, schists or shales. These are usually non-plastic, poorer quality clays that are used to provide body to the final product. The type of material used depends on what is available close to the manufacturing plant.

In all manufacturing processes the quartz content of the blend must be controlled to avoid distortion and cracking in the final product. Small lumps of lime or shells can cause surface pitting, while high salt content can cause surface impurities to form.

The map (Fig. 80) shows the distribution of the various geological units and settings from which clay is extracted. Plastic clays are alluvial deposits found on the plains of former river valleys. North of Perth high-quality plastic clays are found along the Swan River and its tributaries. To the south of Perth the Serpentine River flood plain is a major source of clay. Further south, near Bunbury, clay is extracted from deposits in the Guildford Formation.

Semi-plastic clays have less plasticity than the alluvial clays but are an important ingredient in brick manufacture where they are useful for simple shapes. They are extracted from the sedimentary rocks of the Leederville Formation near Muchea and Bullsbrook.

Non-plastic clays include those derived from the weathering of granite and dolerite in the Darling Range, shales such as the Armadale Shales, and schists such as those found east of Bullsbrook.



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Figure 78. Display of clay bricks and tiles



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Figure 79. Restored brick kiln at Maylands

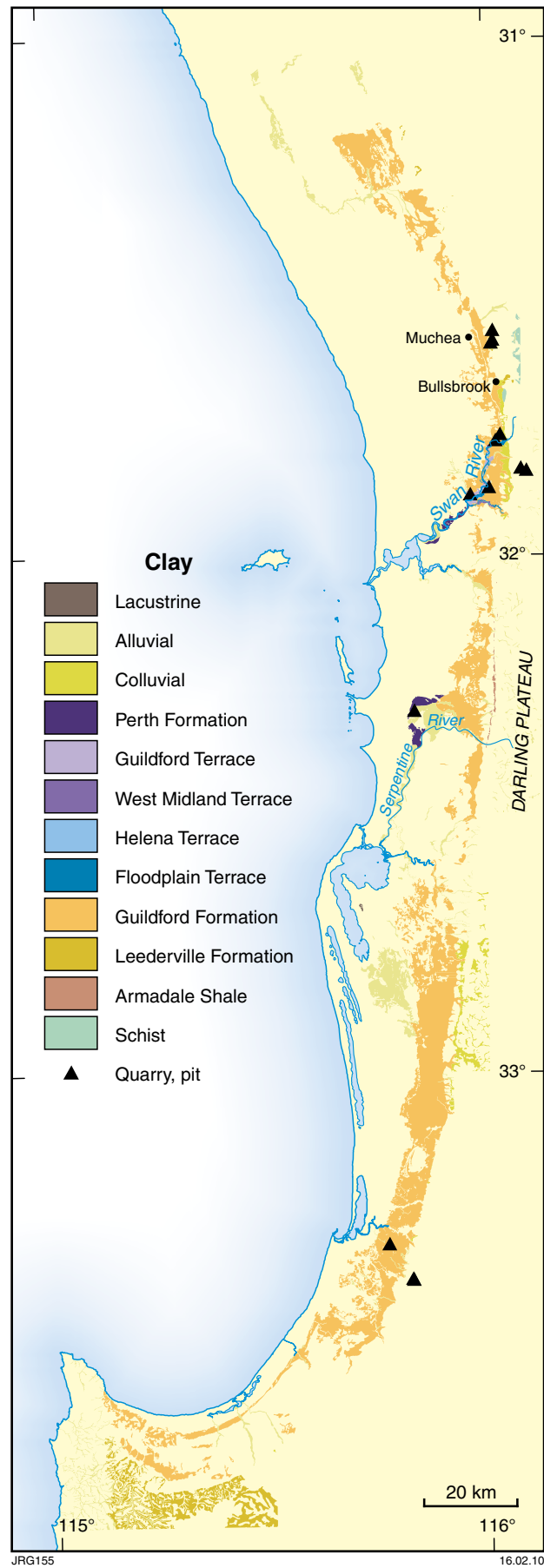


Figure 80. Geological units suitable for clay mining

Limesand

Limesand is a term used for sands rich in calcium carbonate. The Safety Bay Sand, which forms the more obvious dune landforms along the coast, is the principal source of limesand in the southern Swan Coastal Plain.

The limesand of the Safety Bay Sand consists of fragments of the shells of marine molluscs and quartz. The proportion of quartz is variable. The calcareous dunes were formed by the breaking up of marine shells by wave action in the nearshore environment and on the beach. Onshore winds mixed these fragments with quartz grains and heaped the particles into dunes immediately behind the beach. The calcium carbonate content of the limesand is usually greater than 50%, although there are higher grade deposits containing in excess of 85% calcium carbonate.

Limesand dredged from Cockburn Sound is a significant source of high-grade calcium carbonate for the manufacture of cement and lime. Limesand excavated onshore is primarily used as agricultural lime. Because of the low gate price of limesand and high transport costs the location of limesand mining is dictated by the close proximity of markets. However, the amount of magnesium

in limesand is an important consideration in cement manufacture. Irrespective of the transport costs, a limesand with appropriate levels of magnesium might therefore be transported a considerable distance.

The use of limesand as a soil conditioner is governed mainly by its ability to reduce soil acidity and to increase calcium and magnesium levels in the soil. Higher calcium and magnesium levels in soils increase the supply of other nutrients through stimulation of microbial activity.

The map (Fig. 82) shows the distribution of limesand. North of Perth the principal deposits of high-grade limesand are immediately south of Yanchep, south of Seabird, and between Ledge Point and Lancelin. Limesand extracted from a number of pits between Ledge Point and Lancelin is used mainly as a soil conditioner.

South of Perth, limesand extracted from pits south of Binningup is used for soil conditioning. However, the whole of the coastal strip between Mandurah and Bunbury is prospective for high-grade limesand.



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Figure 81. Bare limesand dunes

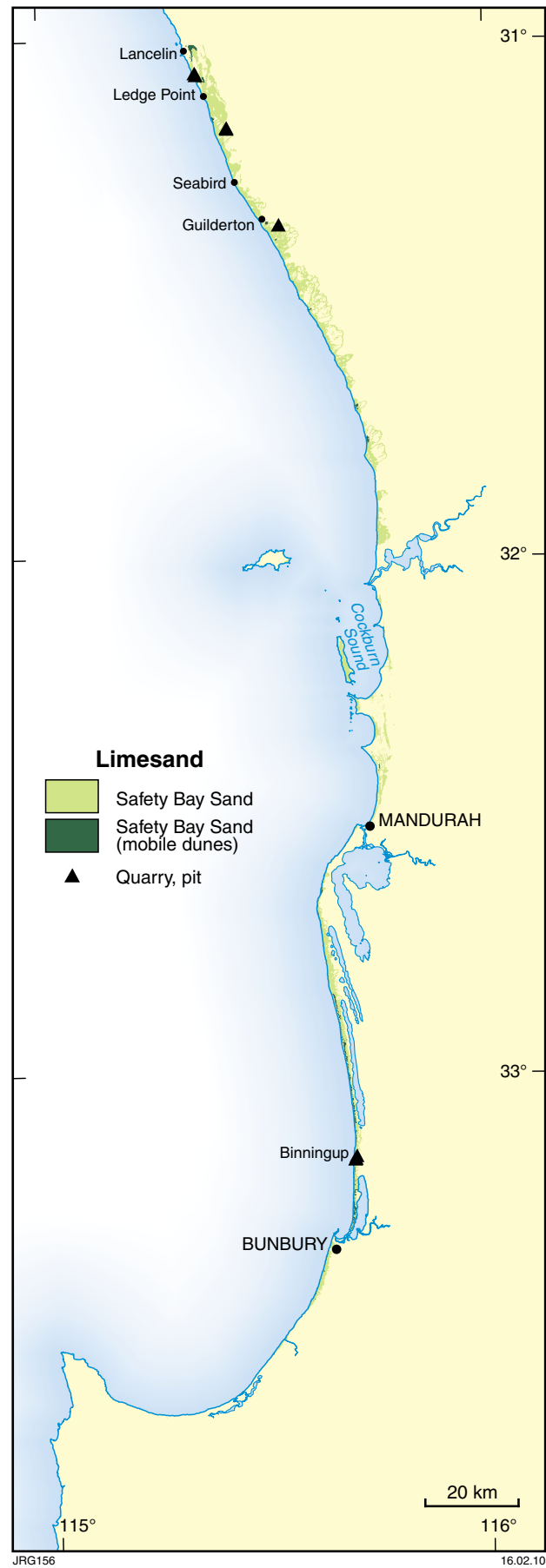


Figure 82. Distribution of limesand

Limestone

Limestone is an essential commodity for a wide range of industries and activities. The principal source of limestone is the Tamala Limestone, although two other limestone units contain important resources. These are the Kooallup Limestone and Tims Thicket Limestone between Mandurah and Bunbury. These limestone units are only a few hundred thousand years in age and are comprised mostly of calcarenite. Limestone units occur as a series of prominent ridges parallel to the coast. This proximity to the coast has put extra pressure on the limestone resources from competing land uses, particularly urban and residential development.

High-grade limestone is essential for cement manufacture and lime production. Cement manufacture requires limestone to have a calcium carbonate content of at least 85%, with low values for silica, iron, aluminium and magnesium. Locally, high-grade shell-sands dredged from Cockburn Sound are blended with lower grade limestone rock to produce a consistent feed to the lime kiln.

Currently there are no common specifications for lime because of the wide range of uses. Most lime is used locally as a neutralizing agent in alumina and gold refining processes as well as in the titanium mineral industry. Significant amounts of lime are also used in the manufacture of chemicals and in the building industry.

Low-grade limestone is primarily used as sub-base and base course material in road construction. Material suitable for roadbase should have a calcium carbonate content greater than 60%.

Limestone is also used as rock armour in breakwater construction, as a decorative building or dimension stone, and in the manufacture of reconstituted limestone blocks.

The map (Fig. 85) shows the distribution of limestone resources and those areas of high-grade limestone identified by GSWA. There are two main areas of limestone resources and production. In the north, most production occurs between Neerabup and Carabooda. Between Carabooda and Guilderton substantial areas of high-grade limestone have been identified but these are in State Forest, proposed extensions to industrial areas, and Yanchep National Park.

South of Perth, the main area for production of high-grade limestone is between Wattleup and Postans. Further south, there are several locations that contain substantial resources, especially the Baldivis, Singleton and Mandurah to Binningup areas.



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Figure 83. Disused limestone quarry at Joondalup



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Figure 84. Restored old lime kiln at Coogee

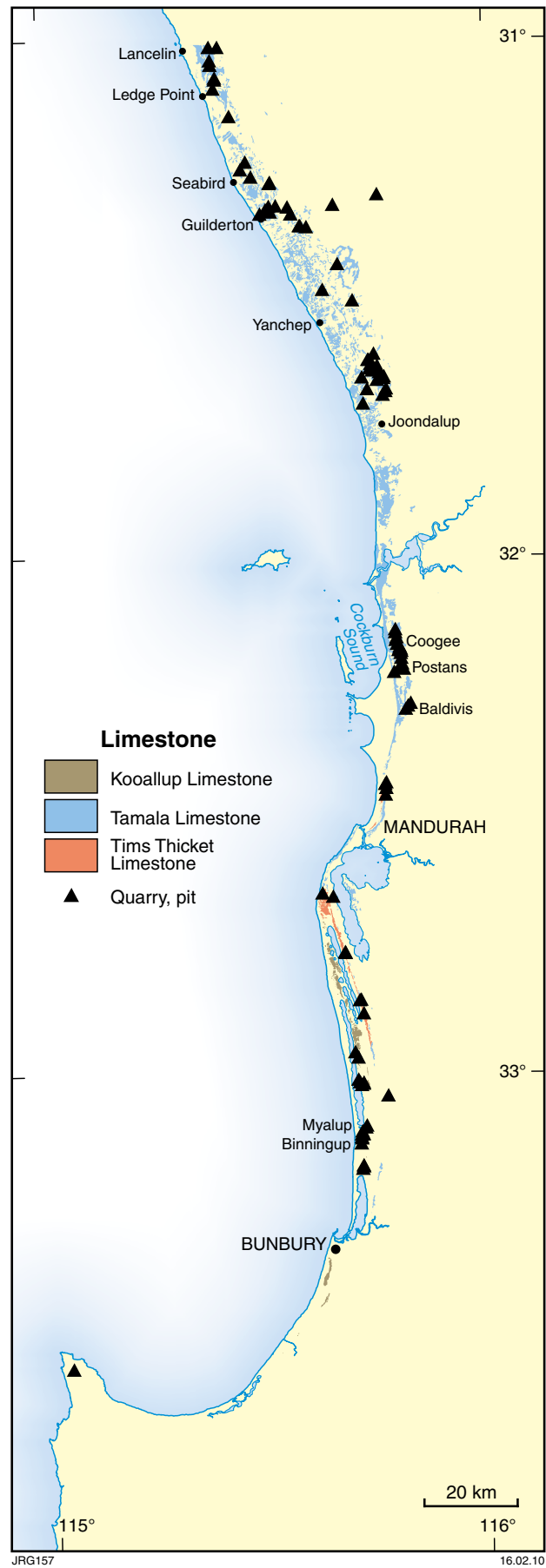


Figure 85. Locations of limestone resources

Sand

Sand is a low-cost, high-volume commodity that is essential to the construction industry. Several geological units contain sand but most supplies come from the Bassendean Sand, Yoganup Formation, and the informally named Tamala Sand. As it is uneconomic to transport sand over large distances the number of extraction sites is large and widespread.

The major use, by volume, of sand is for landfill, for the construction of roads, house pads, industrial-site development and sanitary landfill. Sand can also be used as bedding and protection for underground pipes and services to prevent damage. There are no formal specifications for these uses except that the sand must be free of organic matter. Furthermore, the clay content and grading characteristics must make the sand suitable for compaction.

Construction sands used in concrete and to produce mortar and plaster need to meet an appropriate set of standard specifications. Different specifications are required for each type of use. For example, concrete sand has to meet stringent criteria relating to size fraction and contained impurities. The sand available in the southern Swan Coastal Plain is generally finer than the ideal sand for concrete. However, a suitable end product can be obtained by mixing a variety of sands.

The most valuable sands are those with a high silica content, such as those found in the Bassendean Sand in the Gnangara, Jandakot and Kemerton areas. These sands are highly processed and are used as a raw material for glass manufacture, as foundry moulding sands, and for filtering and abrasive blasting. A large proportion of these high-grade silica sands are exported to Japan and other Southeast Asian countries.

Sand has historically been seen as an abundant resource and the availability of large deposits at cheap prices has been important in minimising the cost of residential and urban development. However, some types of sand are now in short supply because the development of urban areas has sterilized some valuable resources that could have been used for the continued development of those same urban areas.

The map (Fig. 88) shows the distribution of sand and sand extraction sites. The mapped extent of the sand resource has been determined by considering only those areas where sand is more than 2 m above the groundwater table.



Figure 86. Working sand pit at Baldvis



Figure 87. Sand is used extensively in construction.

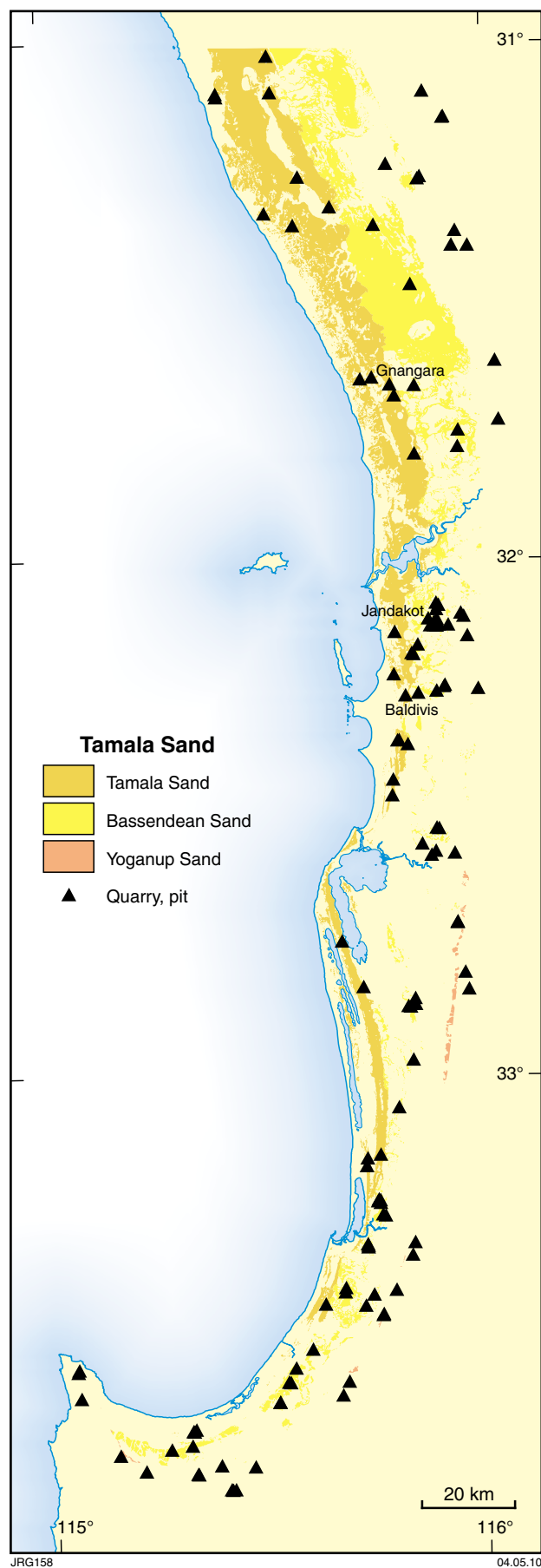


Figure 88. Distribution of sand and sand extraction sites

Vasse River Coalfield

In 1966–67, GSWA discovered coal in the Permian Sue Coal Measures near Dunsborough while undertaking a hydrogeological drilling program. Subsequent exploration by a number of companies has defined significant coal deposits in the Vasse River Coalfield (Fig. 91) between Busselton and Margaret River.

The Sue Coal Measures, which correlate with those at Collie, unconformably overlie crystalline Precambrian basement and underlie flat-lying Cretaceous sediments at depths between 100 and 250 m and extend down to a maximum depth of 3000 m.

There are up to 60 coal seams ranging in thickness from 0.1 to 4.5 m. The seams are too deep to be mined by open-cut methods, but many coal seams occur at depths accessible by underground mining methods. The Osmington seam is the thickest and most extensive seam in the coalfield and contains more than 30% of the coal resources of the coalfield, making it the main mining target.

In general, the coals are bituminous with low ash and sulfur contents but seams do show significant variation in their quality. Overall quality data suggest that the coal is export-grade steaming coal suitable for use in power generation and mineral processing.

Resources are estimated at 500 Mt.

Coal has not been mined from the Vasse River Coalfield, but a number of companies hold mining tenements over potentially economic areas.

Exploration is also taking place for coal seam methane within the Sue Coal Measures in the southwest.



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Figure 89. Coal is a primary source of power generation.



JRG169

31.05.10

Figure 90. Coal quality can vary depending on impurities.

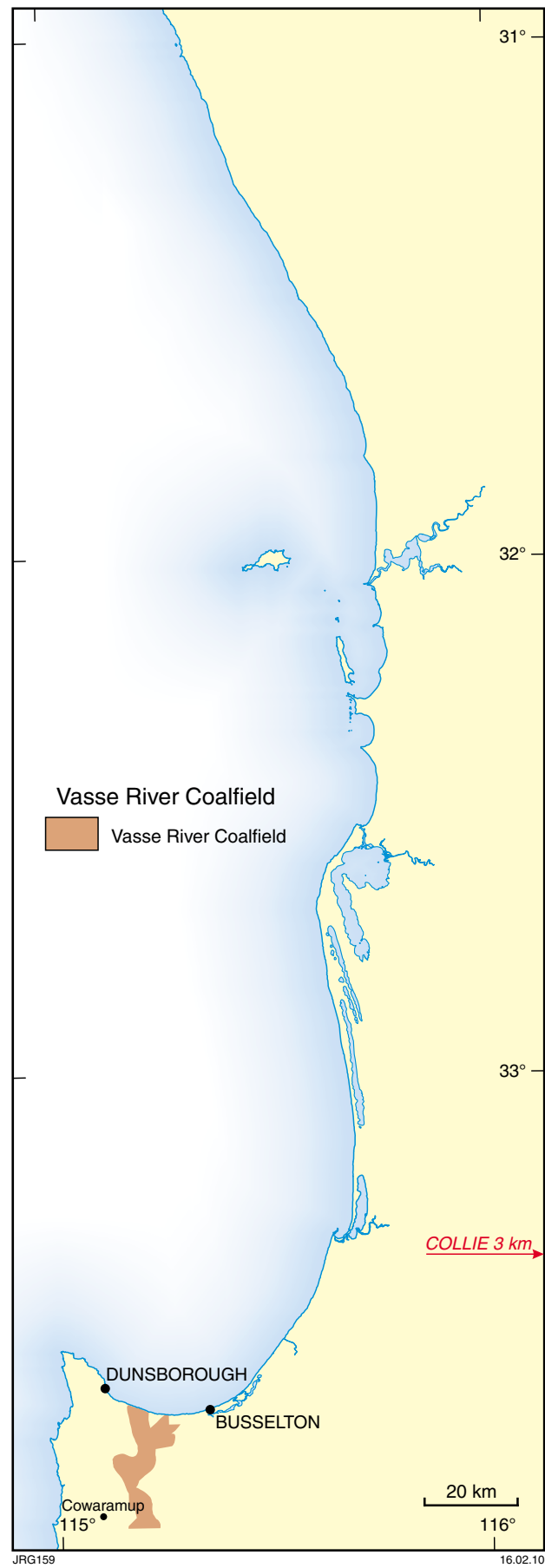


Figure 91. Location of Vasse River Coalfield

Gas fields

The map (Fig. 94) shows the location of the two onshore gas fields in the southern Perth Basin and the Dampier to Bunbury gas pipeline, including laterals, which brings domestic gas from the State's northwest.

Natural gas from the Whicher Range and Gingin gas fields is technically known as tight gas. This is because the reservoirs containing the gas have very low porosities and permeabilities. The key to extracting gas from tight gas fields is to induce fractures in the reservoirs to give the gas an easier pathway to the producing well.

The Whicher Range gas field was discovered in 1968. Between 1968 and 2005 five wells have been drilled in an attempt to extract gas from the field. Results in some cases were encouraging but proved to be not commercially viable because of the limited natural fracture pattern in the source rocks. More recently, a study has been proposed to determine the extent of fracture permeability and to investigate the potential for inclined or horizontal drilling and the merits of hydraulic fracture stimulation to increase productivity.

The Gingin gas field was discovered in 1965 and a total of four wells were eventually drilled. Production of gas started in March 1972 but lasted only until December 1972. Between June 1975 and January 1976 gas was produced at a reduced rate and piped to Perth. Nevertheless, production could not be sustained.

Although gas is no longer produced from either the Whicher Range or Gingin fields, interest continues in the potential for production from these tight gas reservoirs using existing and new production and drilling techniques.

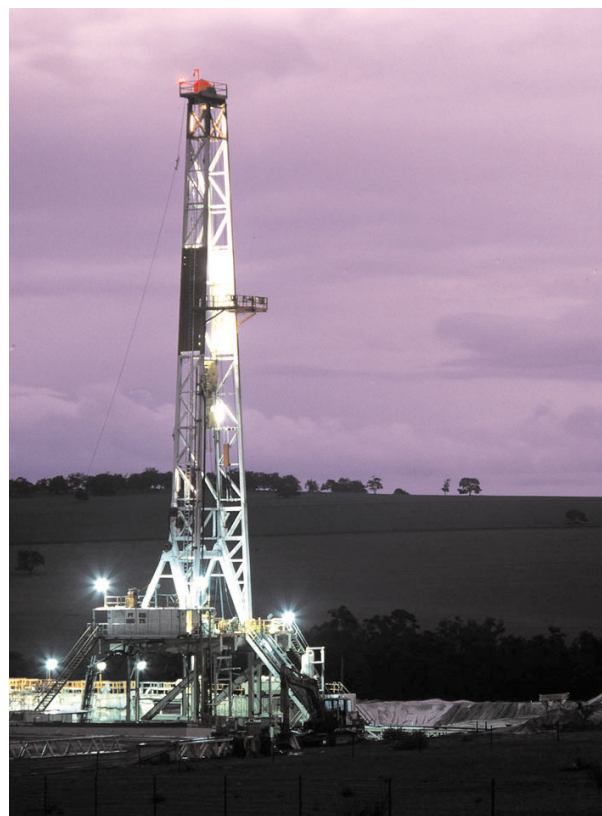
No commercial oil fields have been discovered in the onshore southern Perth Basin, although hydrocarbon deposits have been encountered in several wells.



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Figure 92. Gas is a major source of energy for homes and industry.



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Figure 93. Drilling for gas at Gingin

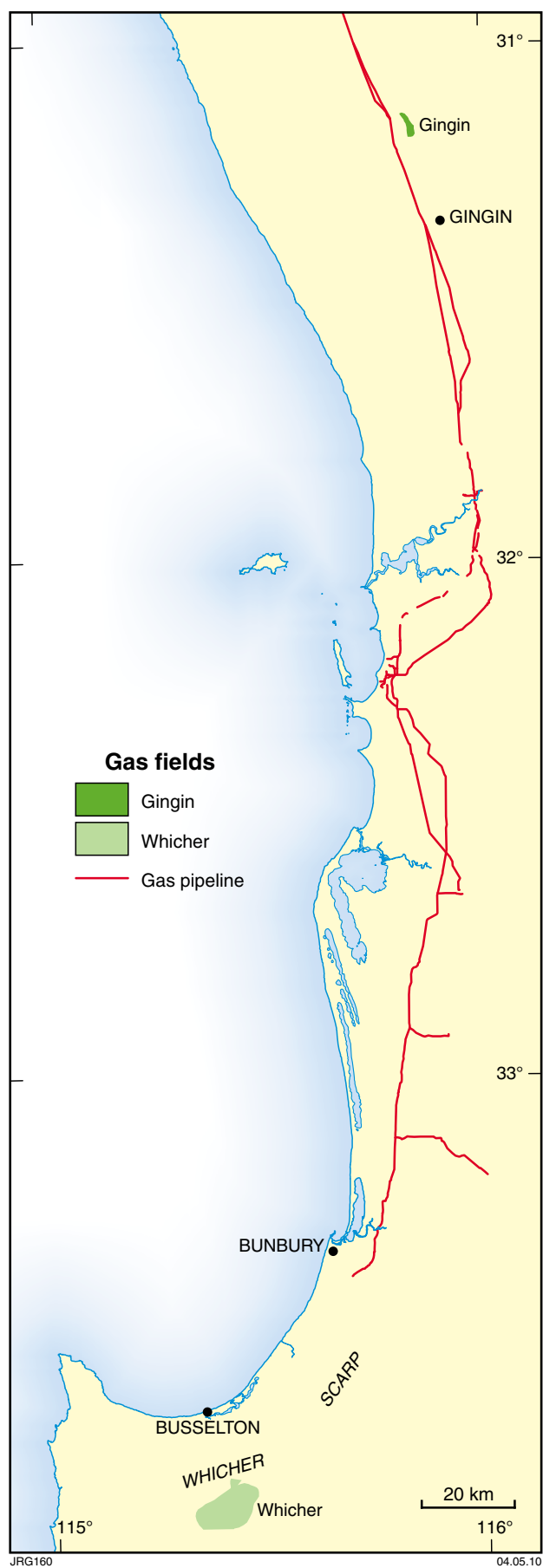


Figure 94. Locations of major gas fields and pipelines

Geothermal energy resources

The vast bulk of the Earth's energy resources consist of fossil fuels (i.e. coal, oil, gas). In one way or another, they consist of 'fossilized' radiant energy from the sun trapped in a suitable form that we can release by burning. The surface temperature of the Earth is primarily related to the amount of radiant energy received from the sun. However, a small amount of heat is generated from within the Earth itself from geological processes such as volcanic activity, mountain building and natural radioactivity.

In general, subsurface temperature increases with depth. The rate of increase can vary locally depending on the amount of heat generated in the subsurface, the nature of the rocks and their ability to conduct the heat to the surface. Understanding the factors that determine heat flow helps in assessing the amount of geothermal energy that can be generated from the heat contained in the Earth.

Although Western Australia is not characterized by geologically active areas similar to those in Iceland, New Zealand and California where subsurface temperatures are high, there is some potential for geothermal energy. Geothermal electricity generation requires a minimum temperature of 150°C to be commercial. However, lower temperature resources can be used for other purposes. In Perth, low-temperature resources are used at Challenge Stadium (Fig. 99) and Christ Church Grammar School for heating swimming pools.

In 2008 the then Department of Industry and Resources (now Department of Mines and Petroleum) commissioned a study to assess the geothermal potential of the Perth Basin. A total of 170 petroleum exploration wells were assessed for heat flow modelling and temperature prediction. Modelled surface heat-flow across much of the Perth Basin ranges from 30–140 mW/m², with a median of 76.5 mW/m² for the basin as a whole. The estimates of heat flow are based on bottom-of-well temperature data and rock thermal conductivities measured from a range of rock types encountered in those wells. Heat flow is lowest in the south near Margaret River and shows an apparent increase towards Lancelin in the north.

The map (Fig. 97) shows the depth of the inferred 200°C isotherm. A number of areas immediately north and south of Perth have the 200°C isotherm modelled at less than 5 km depth. They may therefore be of increased prospectivity for geothermal energy.



Figure 95. Challenge Stadium, Mount Claremont



Figure 96. Melville Aquatic Fitness Centre, Booragoon

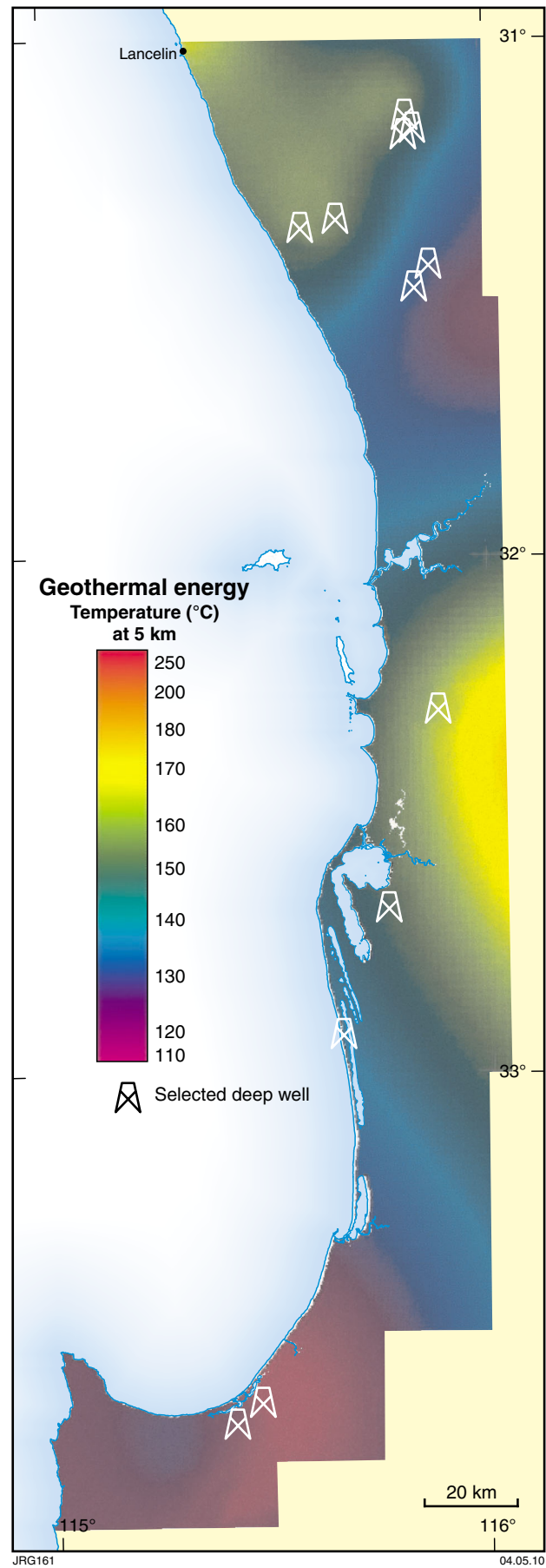


Figure 97. Geothermal energy at 5 km depth

Information sources and bibliography

Those seeking further information on aspects of the geology and mineral resources of the southern Swan Coastal Plain should contact the Geological Survey of Western Australia at:

Mineral House
100 Plain Street
East Perth WA 6004
☎ (08) 9222 3333
🌐 www.dmp.wa.gov.au/gswa

The following list of publications will also be of interest:

- Abeyasinghe, PB 1998, Limestone and limesand resources of Western Australia: Geological Survey of Western Australia, Mineral Resources Bulletin 18, 140p.
- Abeyasinghe, PB 2003, Silica resources of Western Australia: Geological Survey of Western Australia, Mineral Resources Bulletin 21, 228p.
- Archer, RA 1975, Clay resources of the Perth Region: Geological Survey of Western Australia, Record 1975/4, 26p.
- Archer, RA 1976, Aggregate and dimension stone in the Perth Region: Geological Survey of Western Australia, Record 1976/20, 25p.
- Biggs, ER 1979, Sand in the Perth Metropolitan Area: Geological Survey of Western Australia, Record 1979/6, 58p.
- Butkus, F 2001, Gravel search manual: Main Roads Western Australia, Perth, Pavements Engineering Report 2001-6M, 91p.
- Davidson, WA 1995, Hydrogeology and groundwater resources of the Perth Region, Western Australia: Geological Survey of Western Australia, Bulletin 142, 257p.
- Fetherston, JM 2007, Dimension stone in Western Australia: Volume 1 — Industry review and dimension stones of the Southwest Region: Geological Survey of Western Australia, Mineral Resources Bulletin 23, 181p.
- Freeman, MJ 1996, Bunbury Basalt as a basic raw material – preliminary assessment of possible future sources and requirements: Department of Minerals and Energy, Land Access Report EV 121, 27p. (unpublished).
- Freeman, MJ and Donaldson, MJ 2008, Mines and wines of southwestern Western Australia — a field guide: Geological Survey of Western Australia, Record 2008/10 (Adaptation of Record 2006/20 and 2004/17 with additions), 45p.
- Geological Survey of Western Australia 1990, Geology and mineral resources of Western Australia: Geological Survey of Western Australia, Memoir 3, 827p.
- Ghori, KAR 2008, The search for Western Australia's geothermal resources: Geological Survey of Western Australia, Annual Review, p. 25–31.
- Gozzard, JR 1987, Limesand and limestone resources between Lancelin and Bunbury, Western Australia: Geological Survey of Western Australia, Record 1987/5, 36p.
- Gozzard, JR 1989, A practical guide for interpreting the Environmental Geology map series: Geological Survey of Western Australia, Record 1989/10, 16p.
- Gozzard, JR 2007, Geology and landforms of the Perth Region: Geological Survey of Western Australia, 126p.
- Hassan, LY 1998, Mineral occurrences and exploration potential of southwest Western Australia: Geological Survey of Western Australia, Report 65, 38p.
- Hirschberg, K-JB 1989, Groundwater contamination in the Perth Metropolitan Region, in *Proceedings of the Swan Coastal Plain Groundwater Management Conference edited by G Lowe*: Western Australian Water Resources Council, Perth, p. 121–133.
- Hirschberg, K-JB and Appleyard, SJ 1996, A baseline survey of non-point source of groundwater contamination in the Perth Basin, Western Australia: Geological Survey of Western Australia, Record 1996/2, 57p.
- Le Blanc Smith, G and Kristensen, S 1998, Geology and Permian coal resources of the Vasse River Coalfield, Perth Basin, Western Australia: Geological Survey of Western Australia, Record 1998/7, 49p.
- Lemmon, TC, Gee, RD, Morgan, WR and Elkington CR, 1979, Important geological sites in the Perth and southwestern area of Western Australia: A report on their scientific significance and future protection: Geological Society of Australia (WA Division), 178p.
- Playford, PE 1988, Guidebook to the geology of Rottnest Island: Geological Society of Australia (WA Division), Perth, Excursion Guide No. 2, 67p.
- Sharif, A 2007, Tight gas resources in Western Australia: Petroleum in Western Australia, September 2007: Department of Industry and Resources, p. 28–31.
- van Gool, D, Tille, P and Moore, G 2005, Land evaluation standards for land resource mapping: assessing land qualities and determining land capability in south-western Australia: Department of Agriculture, Perth, Resource Management Technical Report 298, 137p.
- Western Australia Government, 1996, State gravel supply strategy: Government of Western Australia, Perth, Western Australia, 158p.

SEA TO SCARP
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