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

RECORD 2015/7

LIMESAND AND LIMESTONE RESOURCES OF SOUTHERN WESTERN AUSTRALIA

by
Geological Survey of Western Australia



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Limesand and limestone resources of southern Western Australia

by

Geological Survey of Western Australia

Abstract

This Record evaluates limesand and limestone resources along the south coast between Denmark and Point Culver, south of Balladonia. The quality of the limesand and limestone vary markedly and there are only a few high-quality sources along the south coast and inland of the coast. Seven surficial and five bedrock units have been identified that have the potential to supply limesand and limestone.

Within the surficial units, high-quality limesand is found near Denmark and Esperance and is used principally as a source of agricultural lime, but the large variability in carbonate content of the limesand makes it difficult to predict the location of potential high-grade deposits outside areas of known high-quality material. In contrast, the area between Denmark and Albany contains significant high-grade surficial limestone resources and should be the focus of future exploration. Inland of the south coast, the known deposits of dolomitic sand are a valuable source of agricultural lime. Other potential surficial resources are in remote locations and are suitable only for local markets.

Of the five bedrock limestone units, the Nanarup Limestone Member between Albany and Bremer Bay has the greatest potential as a source of lime. New mapping has extended the surface and interpreted subsurface extent of the Nanarup Limestone Member. Other bedrock limestone units are relatively unimportant as potential limestone resources except for local use.

KEYWORDS: aggregates, calcrete, construction materials, dolomite, lime, limestone, magnesite

Introduction

Resources of limesand and limestone for a wide variety of purposes are perceived to be widespread in Western Australia. While the geological units that contain these resources are extensive, the quality of the material varies widely and with no apparent consistent trend. Environmental and other competing land use constraints also play a significant role in determining the availability of land for resource extraction.

The west coast of Western Australia, from Bunbury to Geraldton, has significant limesand and limestone resources, some of which are of the highest quality (Gozzard, 1987b, 2014a,b). However, access to many of these is constrained by environmental and development considerations. In contrast, the south coast between Denmark and Esperance has fewer sources, with only a limited number of lower quality sources of limestone across its hinterland (Deparment of Agriculture and Food et al., 2006; Gazey and Gartner, 2009).

A desktop review by the Geological Survey of Western Australia (GSWA) showed that the available information on limesand and limestone resources of southern Western Australia lies scattered among a number of published and unpublished maps and reports produced by government departments and technical consultants acting on behalf of state and local government. The collation of these data would provide a valuable, single source of information for government, industry and the agricultural community on the location and quality of limesand and limestone in southern Western Australia.

This Record and the accompanying digital data package collates all available existing geological and analytical data and describes the limesand and limestone geology and resources of an area of 167 000 km^2 in southern Western Australia (Figs 1 and 2) extending from about Denmark to Point Culver, south of Balladonia. No fieldwork was carried out as part of the project to collect new information or validate existing information. While the Record and accompanying digital data package draw

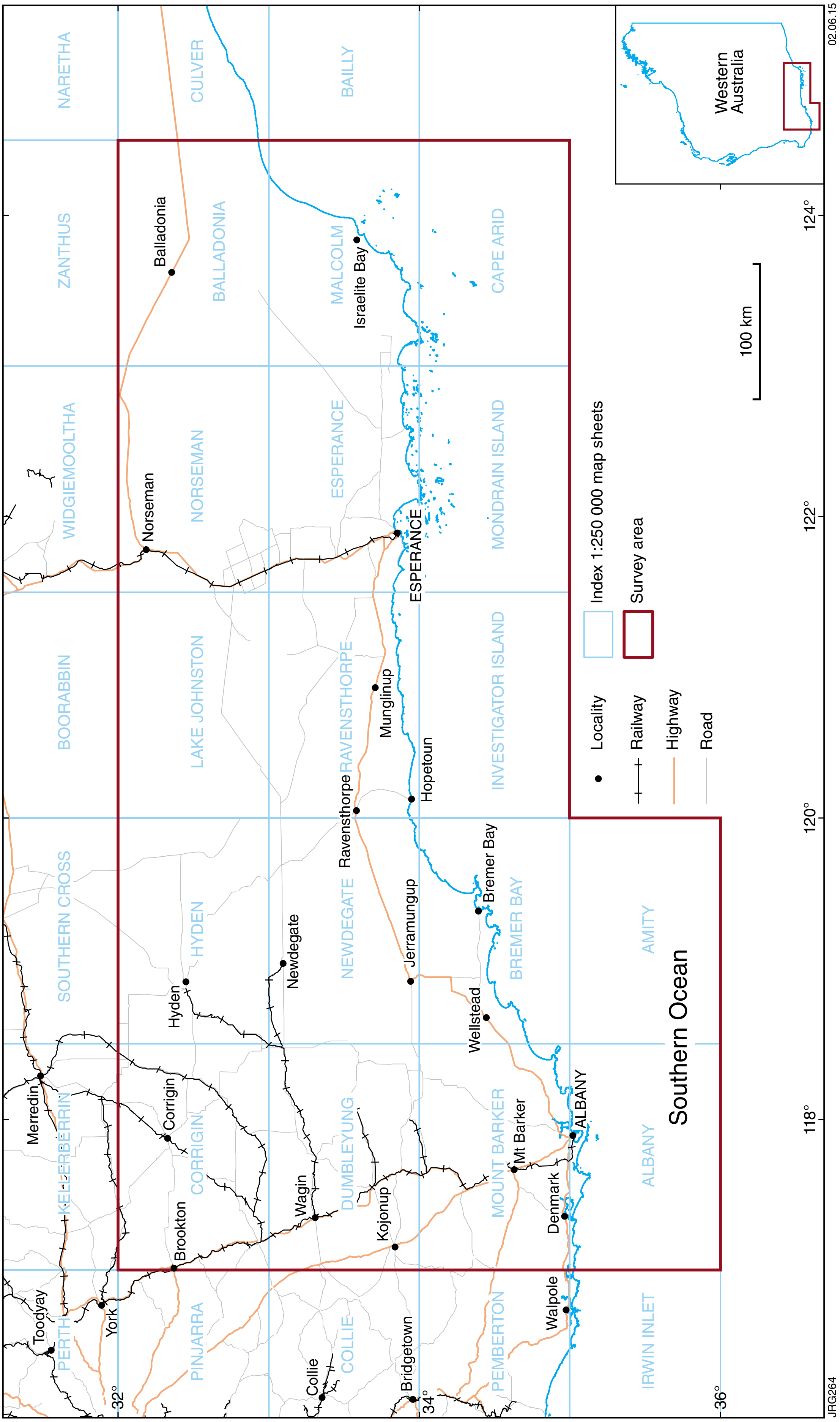

Figure 1. Area covered by the southern Western Australia limesand and limestone resource study

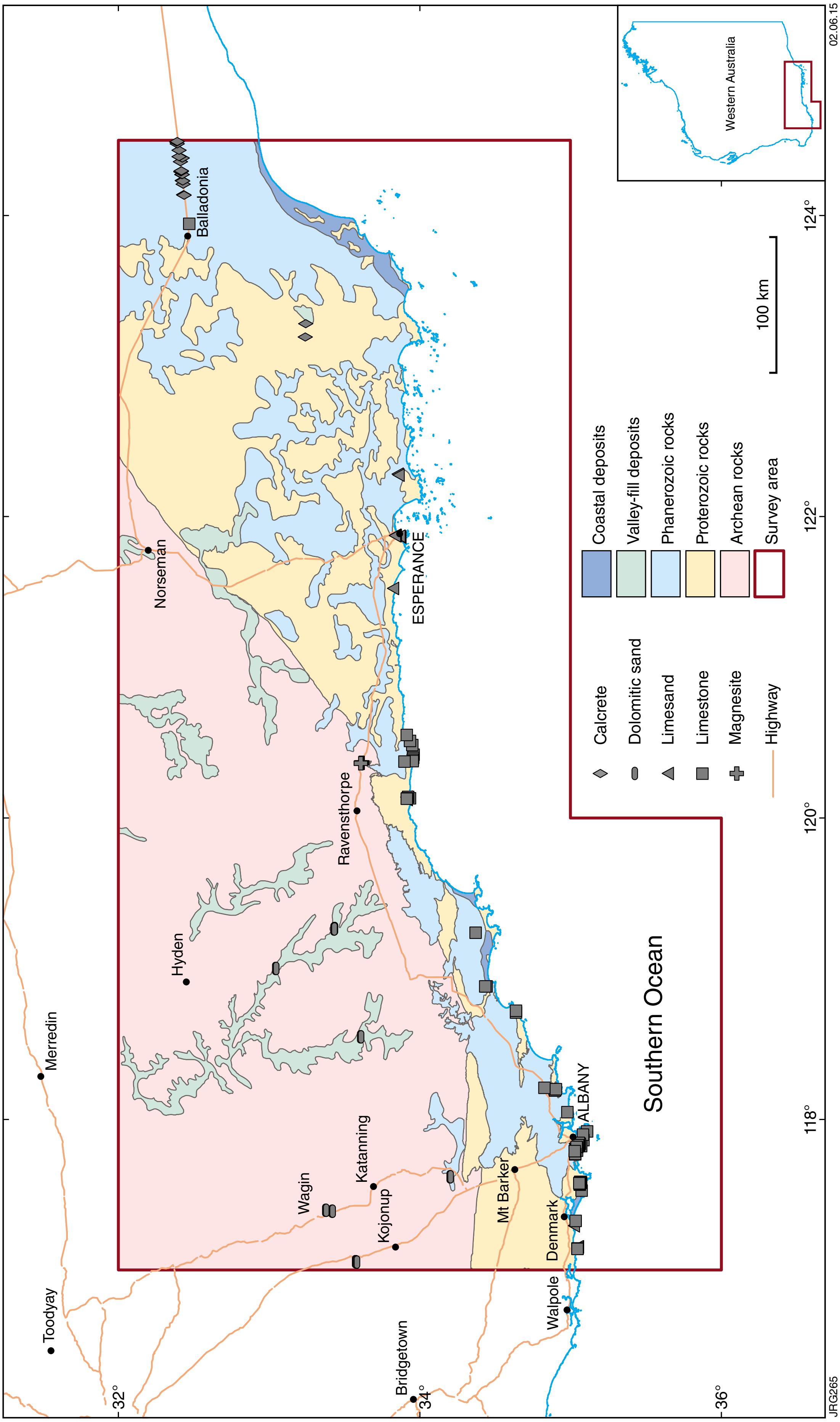

Figure 2. Limesand and limestone occurrences in southern Western Australia

exclusively on previous work, new interpretations of the available geological mapping are provided that highlight potential resource areas. A resource, in this Record, is defined as a deposit of material that is of potential economic interest such that there are reasonable prospects for eventual extraction.

The study area includes most of the Great Southern, much of the southern half of the Wheatbelt and the southern part of the Goldfields–Esperance State Development regions (Fig. 3). It also includes most of the South Coast, the eastern part of the South West, the southern half of the Avon and the southern fringe of the Rangelands Natural Resource Management regions (Fig. 4).

Uses of limesand and limestone

Limesand and limestone have a number of commercial applications (Abeysinghe, 1998). However, in Western Australia the three primary uses are as a cement raw material, as aggregate, including roadbase and armour rock, and as agricultural lime. In the Perth area in particular, limestone is also used as a dimension stone for retaining walls and sound barriers. Shell deposits are also used in cement manufacture; calcrete is used as roadbase aggregate; dolomite and magnesite are sources of lower quality agricultural lime. Abeysinghe (1998) provides details of the uses and specifications of materials containing lime.

As a cement raw material the calcium carbonate ($CaCO_3$) content of the material should be above 85%, magnesium oxide (MgO) should be less than 4% and acid insolubles less than 1.5%. The presence of other elements, compounds and impurities should be carefully controlled (Abeysinghe, 1998).

Low-grade limestone from the Tamala Limestone and its lateral geological equivalents is widely used as sub-base and basecourse material in road construction. Material used for road basecourse should have $CaCO_3$ content greater than 60%. Main Roads Western Australia has its own specifications for limestone and other materials to be used as road basecourse and sub-base (Main Roads Western Australia, 2003).

Rock of mean unit weight within the range of 2 tonnes to 20 tonnes is frequently used to protect or armour coastal structures such as breakwaters and sea walls. Historically, the only requirement for use was that the rock be judged 'hard and durable', but more stringent rock-quality tests are increasingly being used (Bradbury and Allsop, 1987).

Agricultural lime is applied for its neutralizing value, which is determined by chemical composition and purity, that is, the amount of calcium oxide (CaO) equivalent present. Particle size distribution (fineness) is also a significant factor in determining the amount and rate of pH change in the soil following liming (Gazey, 2011).

Sources of information

Data have been obtained from a number of sources for the preparation of this Record and the accompanying digital data package. Each is separately described with an explanation of its uses and limitations.

Base mapping

1:250 000-scale geological series maps

Primary 1:250 000-scale geological mapping by GSWA is available for the whole survey area (Fig. 5). The 12 individual geological maps are accompanied by a set of explanatory notes that describe in various levels of detail the rocks and regolith (that is, surficial weathered and transported materials) of the map sheet (Table 1). Most of the mapping was carried out in the 1970s, and it is the only existing geological mapping for which complete coverage of the survey area is available.

Mapping of the 1:250 000-scale map sheets was done at a reconnaissance level; each map sheet generally took only one field season to map. The rationale for the mapping program was to provide data and information that would be of direct benefit to the mining and exploration industries. Thus, the focus of the mapping was on the delineation, identification and description of the bedrock lithologies and their relationships. Mapping of the regolith was done at a very broad level that only identified units at the primary landform scale, for example, describing alluvium, colluvium, sandplain. Little emphasis was placed on delineating the individual materials within the regolith units.

Unfortunately, in this early mapping the boundaries of geological units and often, the geological units themselves, are mismatched at map sheet boundaries. This can cause significant problems when interpreting the mapping for derived or thematic products.

Table 1. Available 1:250 000-scale geological maps and notes

Map sheet name	*Author (s)*
Balladonia	Doepel and Lowry (1970a)
Bremer Bay	Thom and Chin (1984)
Corrigin	Chin (1986)
Dumbleyung	Chin and Brakel (1986)
Esperance – Mondrain Island	Morgan and Peers (1973)
Hyden	Chin et al. (1984)
Lake Johnston	Gower and Bunting (1972)
Malcolm – Cape Arid	Lowry and Doepel (1974)
Mount Barker – Albany	Muhling and Brakel (1985)
Newdegate	Thom et al. (1984)
Norseman	Doepel (1973)
Ravensthorpe	Thom et al. (1977)

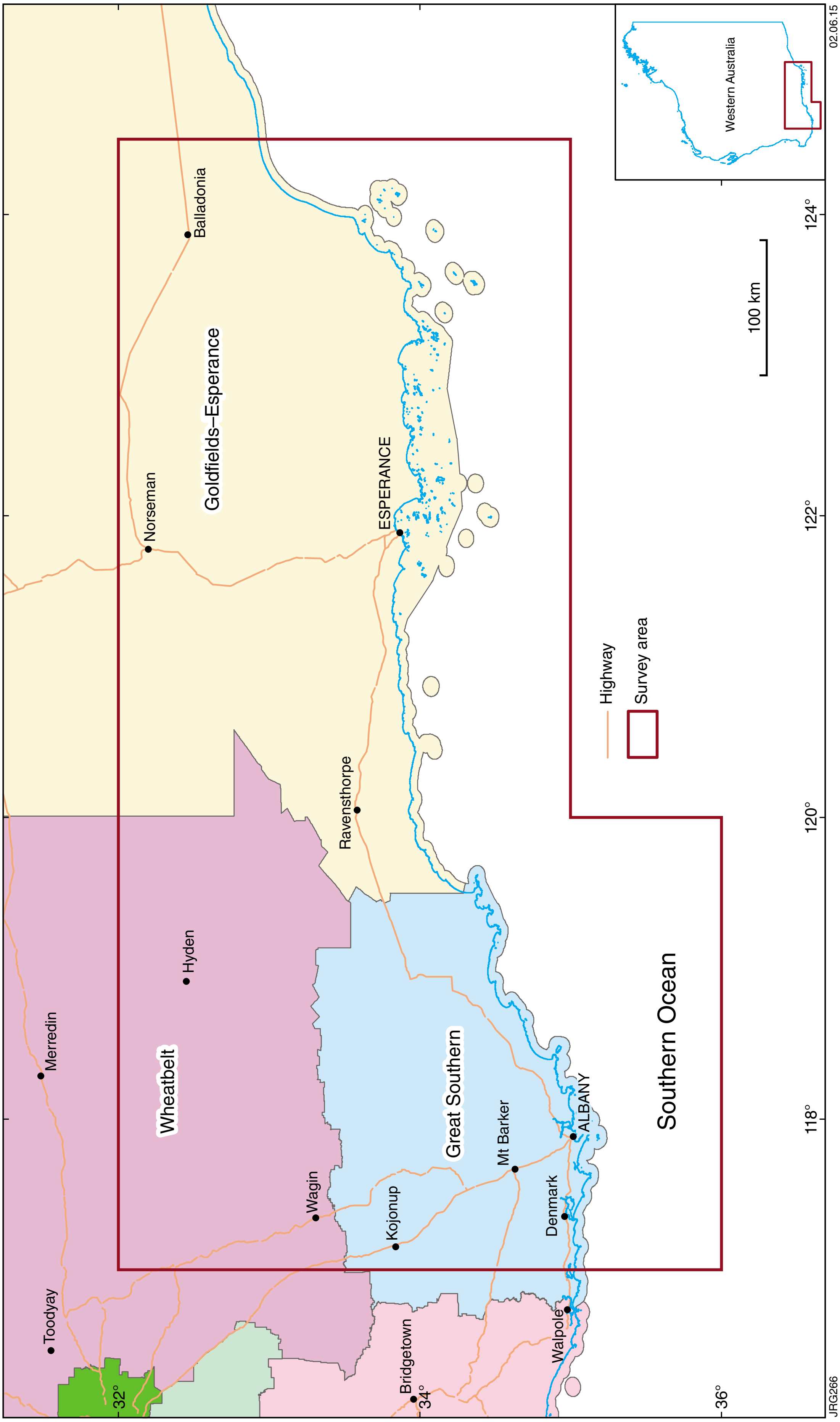

Figure 3. **State development areas in the study area**

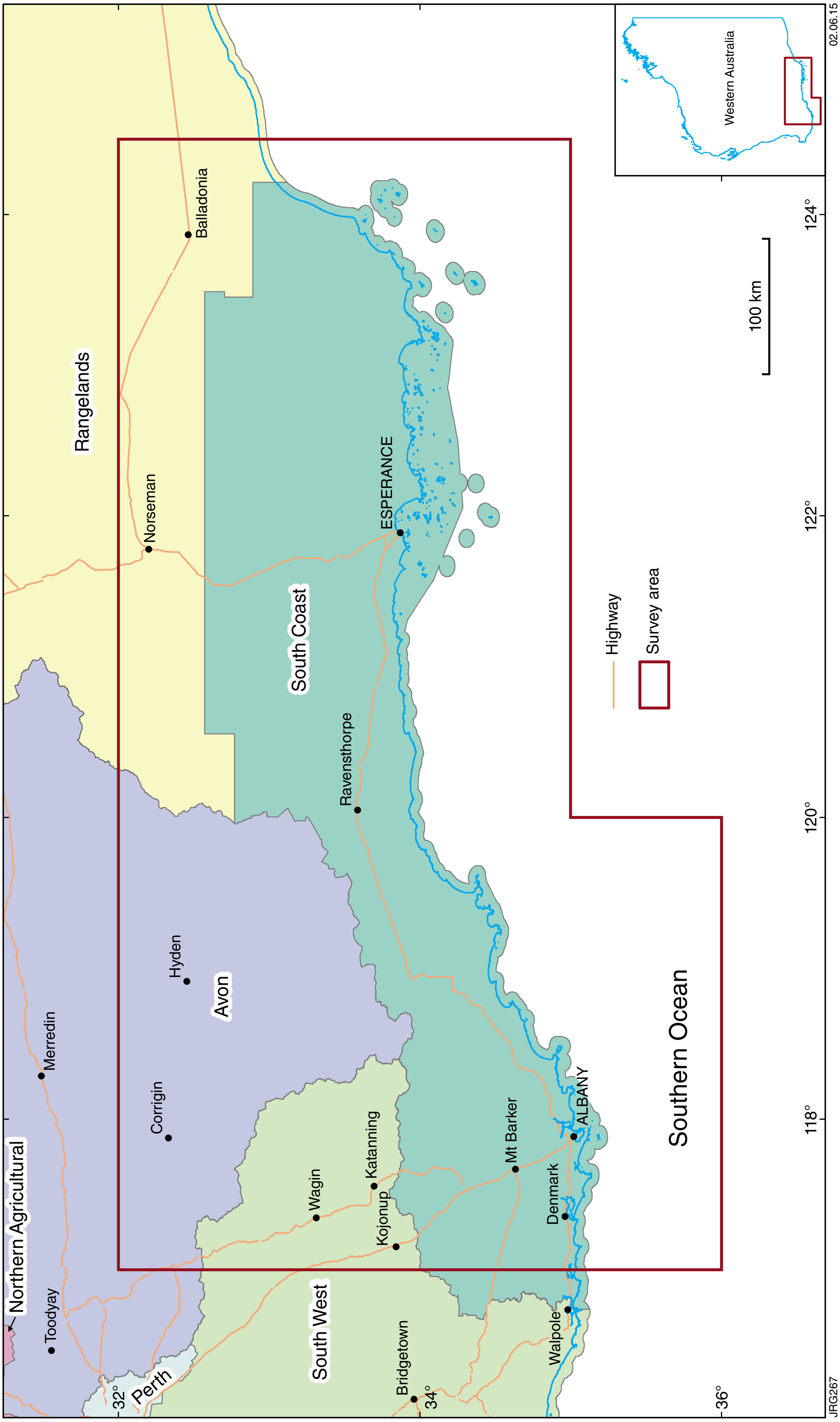

Figure 4. Natural resource management regions in the study area

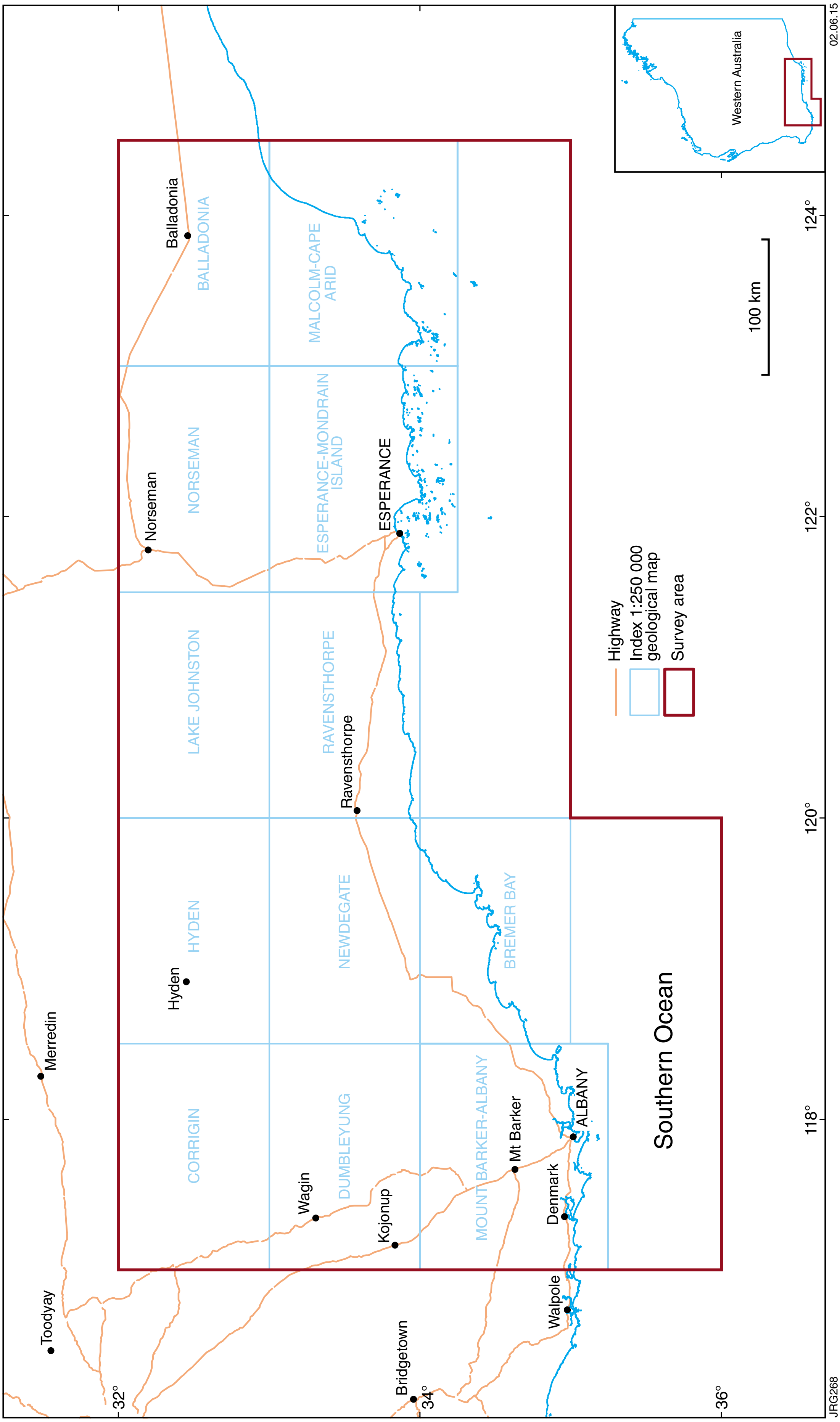

Figure 5. 1:250 000-scale geological map sheets in the study area

As the 1:250 000-scale geological mapping is the only complete dataset for the survey area, it was used as the primary dataset for the identification of the limesand and limestone resources. The identification of bedrock limestone units was straightforward, as was the identification of limesand and valley calcrete in the surficial units. Map sheet boundary problems, where they existed, were eliminated following a reinterpretation using large-scale orthophotography. However, because of the general lack of differentiation of materials in the mapped regolith units, identification of other potential calcareous material is not possible.

1:100 000-scale geological series maps

Between the mid-1990s and mid-2000s GSWA undertook a limited 1:100 000-scale geological mapping program in the survey area. Six of the 81 1:100 000-scale map sheets covering the study area were mapped, four in the Norseman area and two in the Ravensthorpe area (Table 2, Fig. 6). The mapping covers important mining centres and was carried out to gain an understanding of the controls of mineralization and the potential of the mapped areas to host other economic mineral deposits. Only the mapping in the Ravensthorpe area is accompanied by explanatory notes.

Geological mapping was carried out at a more detailed level than the 1:250 000-scale mapping. While the same emphasis on the delineation, identification and description of the bedrock lithologies and their relationships was foremost, more detail on the distribution and nature of the regolith was recognized. Unlike the 1:250 000-scale mapping, the 1:100 000-scale mapping does not suffer from the presence of boundary mismatches. However, as with the 1:250 000-scale mapping, the 1:100 000-scale mapping is still difficult to interpret by non-geologists.

The 1:100 000-scale mapping was used to help refine the extent of the various bedrock limestone units and to delineate and refine the extent of residual and valley calcrete and magnesite within the regolith materials.

One potentially significant issue arises when the 1:100 000-scale geological mapping is viewed in the regional context of the 1:250 000-scale mapping. There appears to be a lack of consistency between the maps of the same area at the two scales. Some of the inconsistency is related to the scale and accuracy of the topographic maps and aerial photography used as the basis of the mapping. Other issues relate to the use of updated and more relevant rock classification systems. However, much of the discrepancy can be explained by the more detailed and rigorous approach used during the 1:100 000-scale geological mapping program. The geology has not changed, but the way it is interpreted and mapped has.

1:50 000-scale environmental geology maps

In 1989 GSWA published the Albany and Torbay 1:50 000-scale environmental geology maps (Gozzard, 1989a,b) (Fig. 7). These two maps were specifically designed for non-specialists. The aim of the mapping was to present geological information in a form usable by planners, administrators, engineers and the general public for use in comprehensive resource planning.

The environmental geology maps are based on a thematic map approach, which identifies units on the basis of lithology, morphology, slope category, hydrogeology, hydrography and rock and regolith properties. The individual thematic maps were combined to delineate the final map units: these were then assigned attributes of environmental significance. These maps overcome the inadequacies that the 1:250 000-scale and 1:100 000-scale geological maps have for resource planning purposes. These two maps were used to further refine the extent of the limesand and limestone units of the Albany area.

1:250 000-scale hydrogeological maps

In the late 1990s the then Water and Rivers Commission (now Department of Water [DoW]) published six 1:250 000-scale hydrogeological maps in the study area (Table 3; Fig. 8). As salinization is a widespread problem in the southwest of Western Australia and is particularly severe on the south coast, the maps were produced to meet the need to better understand the hydrogeology of the region.

The maps show the distribution and types of aquifers, watertable levels, groundwater salinity and the location of water bores. The maps draw heavily on GSWA's 1:250 000-scale geological maps, bore data from the DoW's Water Information (WIN) water point database (Department of Water, 2014) and the Western Australian Mineral Exploration Index (WAMEX) mineral exploration drilling data and reports from the Department of Mines and Petroleum. These maps were used to refine the extent of the bedrock limestone units of the Albany to Bremer Bay area.

Table 2. Available 1:100 000-scale geological maps

Map sheet name	*Author (s)*
Buldania	Hall and Goscombe (2008)
Cocanarup	Witt (1996a)
Cowalinya	Hall and Jones (2008)
Dundas	Groenewald et al. (2008)
Norseman	McGoldrick (1993)
Ravensthorpe	Witt (1996b)

Table 3. Available 1:250 000-scale hydrogeological maps

Map sheet name	*Author (s)*
Bremer Bay	Dodson (1997)
Dumbleyung	Leonhard (2000)
Esperance – Mondrain Island	Johnson and Baddock (1998)
Mount Barker – Albany	Smith (1997)
Newdegate	Dodson (1999)
Ravensthorpe	Johnson (1998)

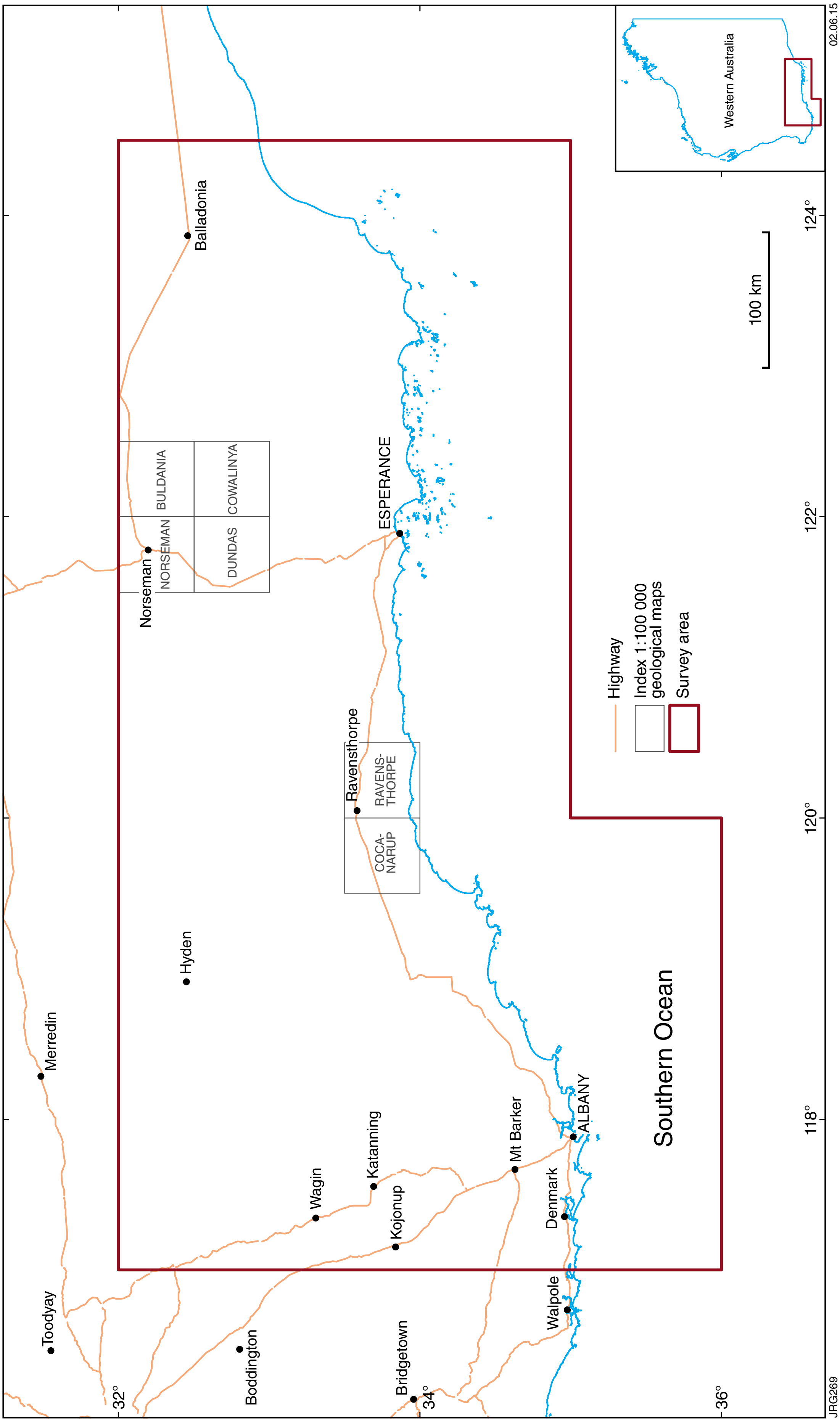

Figure 6. 1:100 000-scale geological map sheets in the study area

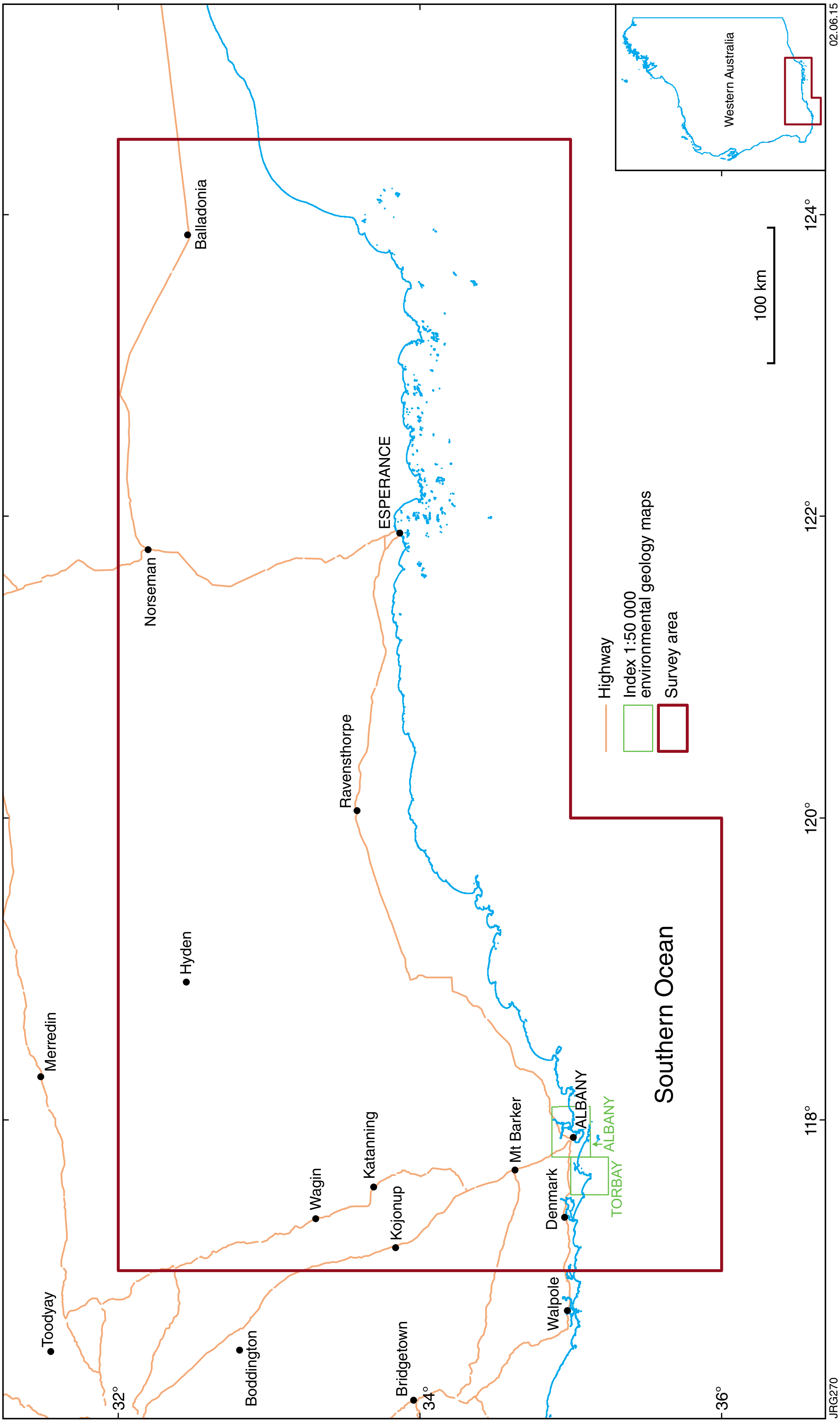

Figure 7. 1:50 000-scale environmental geology map sheets in the study area

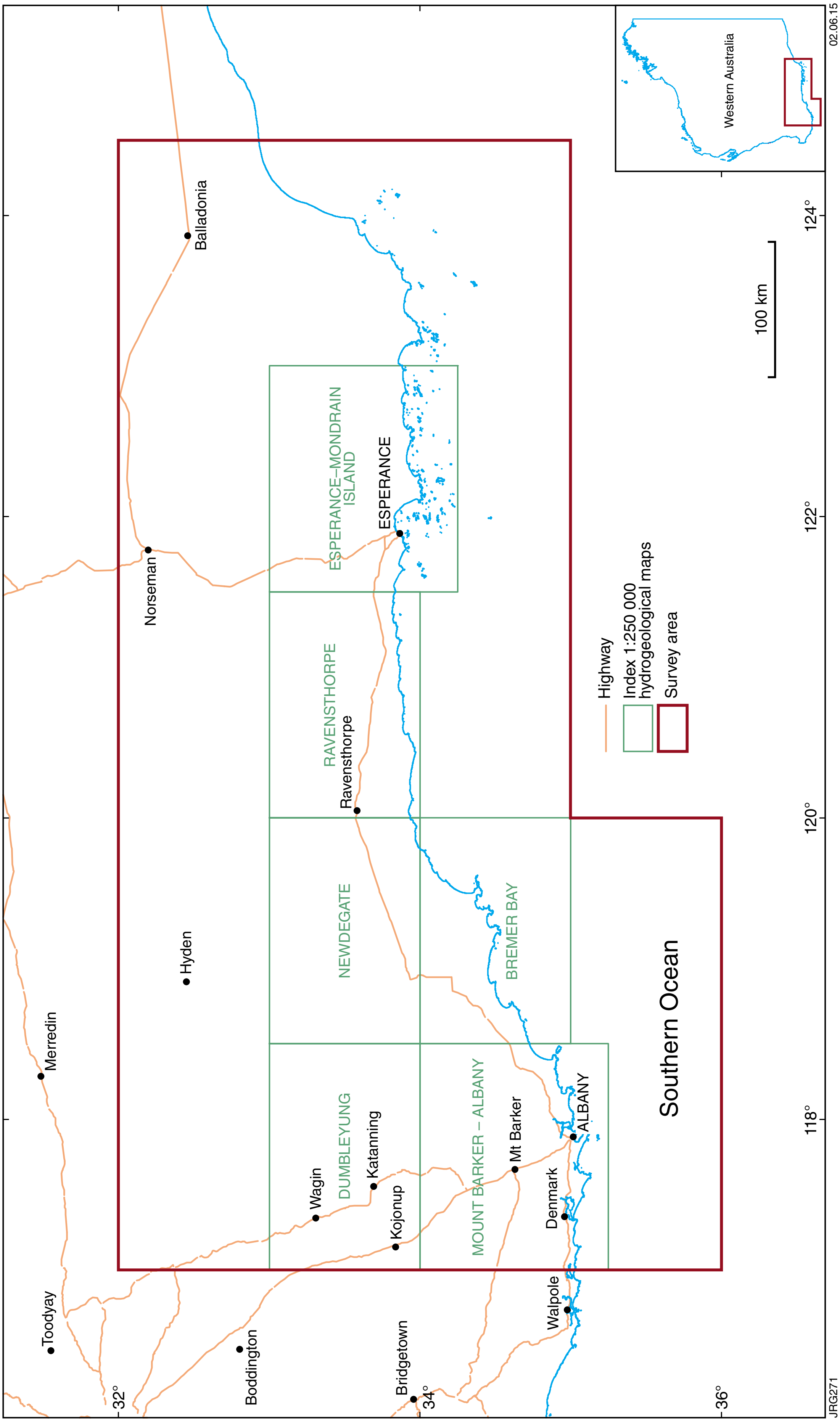

Figure 8. 1:250 000-scale hydrogeological map sheets in the study area

Soil–landscape maps

Soil–landscape, or land systems, mapping has been completed by the Western Australian Department of Agriculture and Food (DAFWA) for about 60% of the survey area (Table 4; Figs 9 and 10). The mapping is published at scales ranging from 1:50 000 to 1:250 000. All maps are accompanied by a report.

Soil–landscape mapping delineates repeating patterns of landscapes and associated soils. The mapping system is significantly influenced by landform and the effect of soil parent material — bedrock and regolith. Since the map units, which occur together naturally in the landscape, are combined into natural systems these associations can be used to predict the characteristics of the land surface. Although information on the regolith is not specifically referred to on a soil–landscape or land system map, the soil and landform information can be used to make detailed interpretations about the regolith. Soil–landscape and land systems maps are easy to interpret by non-specialists and are very useful in regolith mapping.

The ability to easily reinterpret soil–landscape mapping into derived or thematic products such as bedrock and regolith maps, from which basic raw materials maps can themselves be derived, makes this mapping system the preferred source of basic geological information. However, because of the lack of complete coverage over the study area only limited use could be made of these datasets to refine the extent of the limesand and limestone units.

Orthophotography

High-resolution digital orthophotography is available from Landgate for the whole survey area. The horizontal resolution of the dataset is 0.4 m. Dates of imagery of individual 1:100 000-scale map sheets vary from 2003 to 2009. This is an invaluable dataset and has been used to validate the interpretations of the spatial extent of the limesand and limestone units derived from other sources of mapping. It is also the major dataset used for locating pits and quarries and for determining the operating status of the pits and quarries, some of which may be out of date.

Table 4. Available soil–landscape maps

Map sheet name	*Author (s)*
Condingup	part of Salmon Gums – Esperance
Corrigin	Verboom and Galloway (2004)
Esperance	Overheu et al. (1993)
Tonebridge–Frankland	Stuart-Street (2005)
Jerramungup	Overheu (2005)
Katanning	Percy et al. (2000)
Nyabing–Kukerin	Percy et al. (2003)
Ravensthorpe	part of Salmon Gums-Esperance
South Coast and Hinterland	Churchward et al. (1988)
Southern Cross – Hyden	Frahmand (in prep.)
Salmon Gums – Esperance	Nicholas and Gee (in prep.)
Tambellup–Borden	Stuart-Street and Marold (2010)
Western Nullarbor	Waddell et al. (2010)

A derivative product of the process of generating orthophotographs from stereoscopic aerial photography is a digital elevation model (DEM). The DEM derived by Landgate for the survey area has a horizontal resolution of 10 m and a vertical resolution of 0.1 m. GSWA used this DEM to create a shaded relief digital terrain model illuminated from the northwest. The shaded relief model proved to be a very important and useful layer of information.

Topographic mapping

Series 3 Geodata Topo 250 000 contains a medium-scale vector representation of the topography of Australia current at 2006. It was produced by Geoscience Australia, the Australian federal government's national geoscience mapping agency. As its name suggests, the data are designed for use and viewing at the 1:250 000-scale. The data in the series includes ten themes containing 92 data layers.

Data from the cartography theme were used to help locate pits and quarries. The positions and status of these pits and quarries were verified by reference to the orthophotography discussed above.

Limesand and limestone data

Department of Agriculture and Food

In April and May 2008 DAFWA conducted a survey of agricultural lime availability and quality in southwest Western Australia (Gazey and Gartner, 2009). A total of 36 agricultural lime pits were sampled — 15 limesand pits, 12 limestone pits, and nine dolomite pits. The survey provided an opportunity to gather information from all suppliers of agricultural lime and has the potential to be a valuable source of information for farmers and government. Eleven of the 36 samples are from within the present survey area.

The survey was repeated in January and February 2011 when 24 agricultural lime pits were sampled, many of which had been sampled in the 2008 survey (Gazey, 2011). Six of these samples are from the present survey area.

The survey was also repeated in April 2013 when 19 agricultural lime pits were sampled — 10 limesand pits, six limestone pits, two dolomite pits and one pit in Nanarup Limestone Member (Gazey, 2013). Only two of these samples are from the present survey area.

Geological Survey of Western Australia

Until GSWA published a compilation of limesand and limestone resources in Western Australia (Abeysinghe, 1998), information on limesand and limestone resources was contained in a variety of published and unpublished reports. The primary sources of GSWA data for the survey area are Abeysinghe (1998), Gozzard (1987a), who compiled existing data and generated new analytical

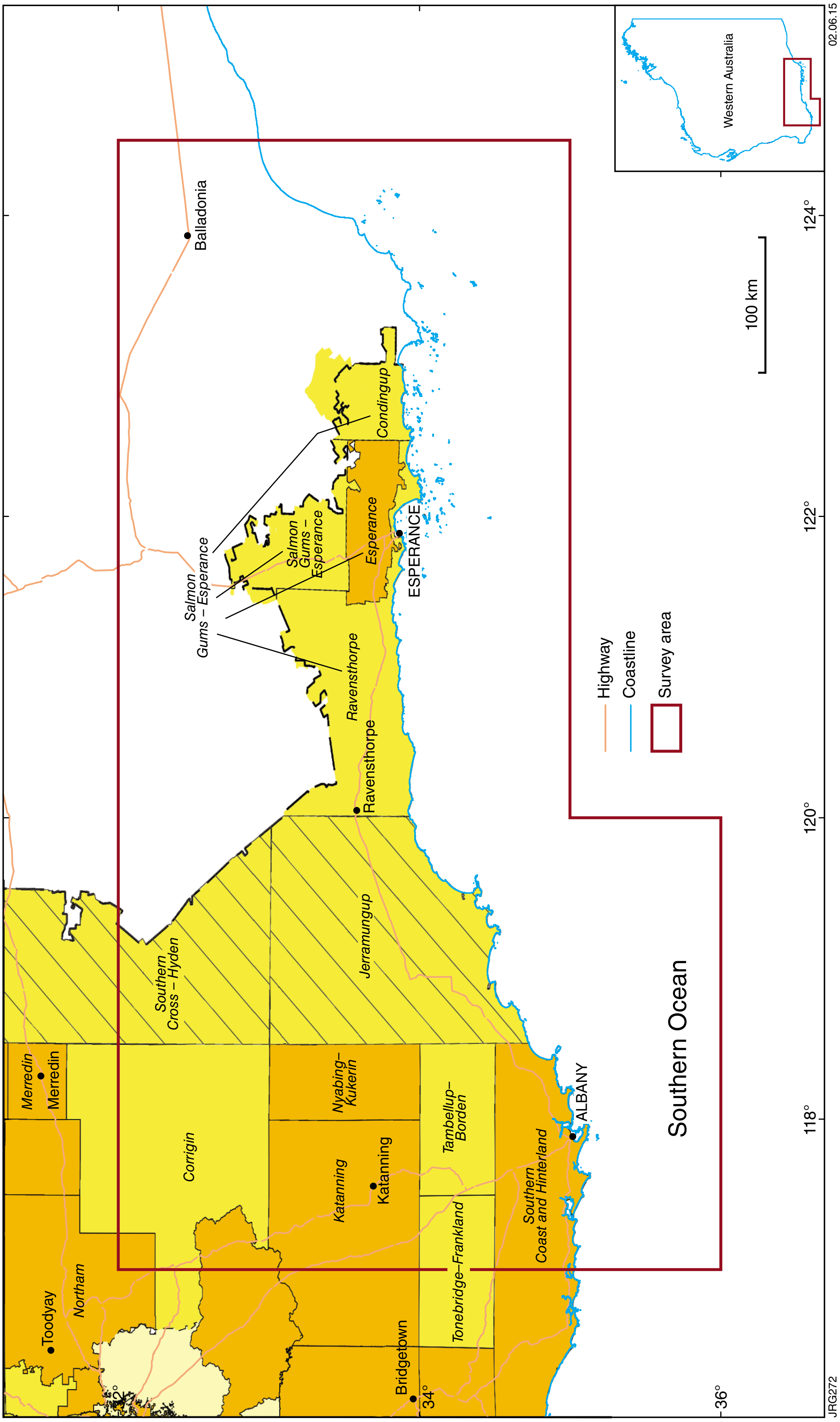

Figure 9. Soil–landscape surveys of the Southwest region in the study area

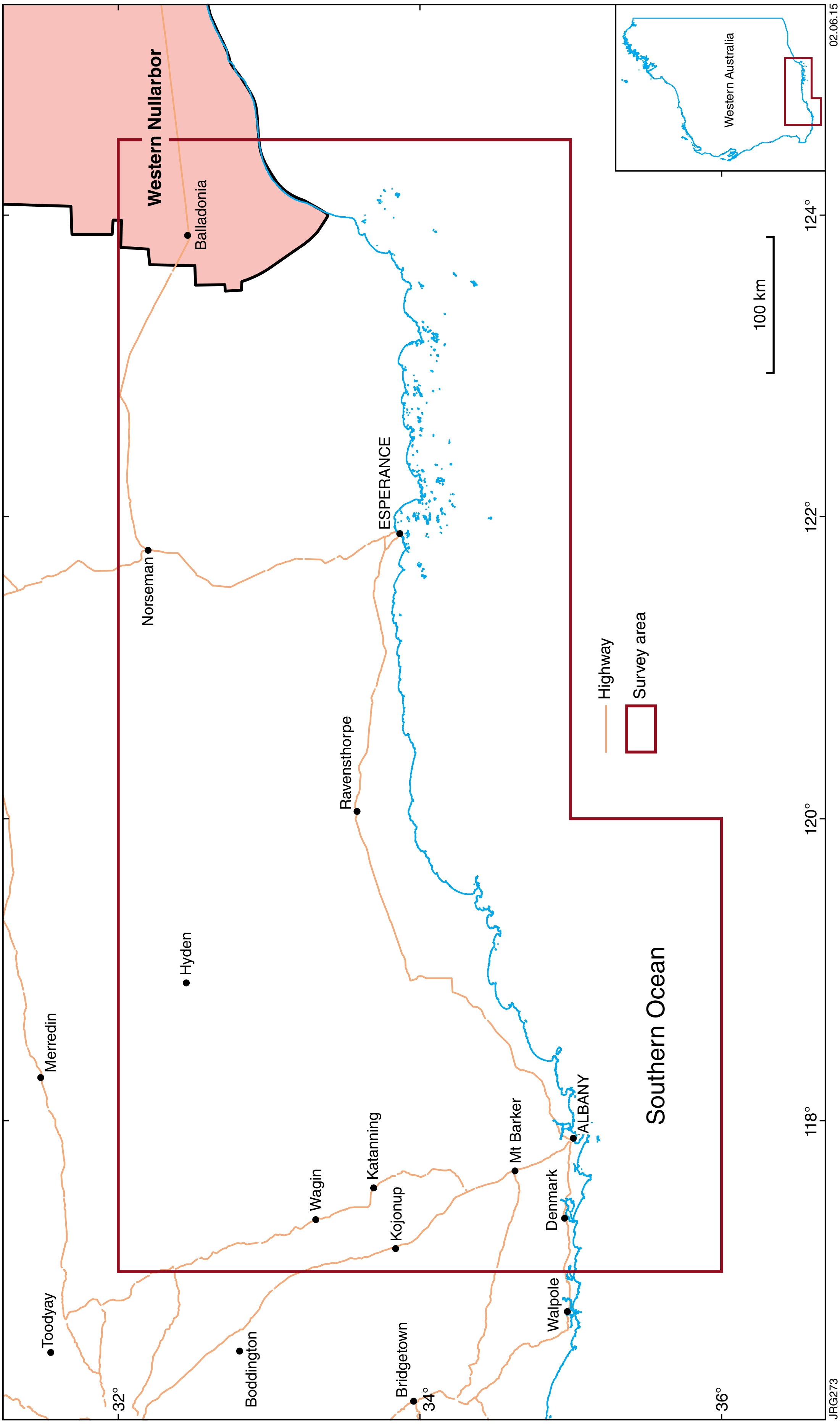

Figure 10. Soil–landscape surveys of the Rangelands region in the study area

data for the areas covered by the Albany and Torbay 1:50 000-scale environmental geology maps (see above), and Wyatt (1961) who undertook a reconnaissance survey of commercial lime deposits within a roughly 25 km radius of Albany. Other data sources for the survey area include Wilson (1924) and Woodward (1916).

Commercially exploitable deposits of magnesite are found in the Bandalup district, 25 km east of Ravensthorpe and at Kundup, 15 km southwest of Ravensthorpe. Abeysinghe (1996) provides comprehensive data and information on the quality and resources of the magnesite in these areas. Thirty analyses from Abeysinghe (1996) are from the present study area.

Consultants' technical reports

Two reports prepared by consultants include many analyses of limesand and limestone in the study area. Masters (1993) undertook a survey of the Shire of Denmark for agricultural lime. The survey aimed to identify and verify mineable deposits of first-grade agricultural lime, that is, those having an acid neutralizing value of at least 75%, with more than 80% passing through a 600 micron sieve. Following the results of the initial sampling and survey, a drilling program was conducted at five sites prospective for agricultural lime. The results of the drilling program showed that, within the Shire of Denmark, only the area to the immediate west of the existing Ocean Beach quarry has the potential to supply large tonnages of high-quality agricultural lime.

Industrial Mineral Services Pty Ltd et al. (2001) completed a study of basic raw materials (BRM) of the Esperance area for the then Department of Planning. The survey covered most of the agricultural area of the Shire of Esperance, with a more detailed assessment of the area around the town of Esperance. The BRM study included limesand and limestone and concluded that, while significant limesand and limestone resources exist in the Esperance region, the material is of generally lower grades that can only be used for construction material (fill) and road aggregate, although some limesand was used for agricultural lime.

Compilation of digital data layers

There are four major data layers in the accompanying digital data package — surficial resources, bedrock resources, quarries/pits, chemical analyses — and several other data layers relevant to an assessment of the resource potential for limesand and limestone in the study area. Table 5 lists the data sources that were used to create each of the four major data layers. All digital data were transformed or created in the geographical information systems software ArcMap v10.2.1. This allows their direct spatial comparison.

Surficial resources

The surficial resources data layer is based on all available geological and soil–landscape mapping, as well as orthophotography and digital elevation data (Table 5). The 1:250 000-scale geological mapping was used as the primary dataset for the identification of the surficial resources of limesand and limestone. The remaining five digital datasets were used to refine and validate the reinterpretation of the 1:250 000-scale geological mapping. The reinterpretation is based on the lithology of the surficial material as described on the published maps and accompanying explanatory notes. As a result, seven limesand and limestone BRM categories were identified: clay and calcrete; dolomitic sand; limesand; limestone; magnesite; residual calcrete; valley calcrete. These limesand and limestone BRM categories are described in a later section of this document.

Bedrock resources

Similar to the surficial resources data layer, the bedrock resources are based on various data sources (Table 5). The 1:250 000-scale geological mapping was used as the primary dataset for the identification of the bedrock resources of limesand and limestone; the remaining datasets were used to refine and validate the reinterpretation. From the geological mapping five bedrock resource categories were identified: dolomite; grey limestone; pale brown limestone; sandy limestone; white limestone.

The spatial extents of four of the bedrock resource categories are well constrained and accurately known. In contrast, the pale brown limestone (Nanarup Limestone Member) is found at the surface only as a few small sporadic outcrops. However, the geological development of the area between Albany and Bremer Bay (see references in Table 1 and Table 3) indicates that the subsurface extent of the Nanarup Limestone Member could be more extensive than its limited surface outcrop might indicate.

As part of this project a remapping exercise was undertaken to verify the subsurface extent of the Nanarup Limestone Member. In this regard the 1:250 000-scale hydrogeological maps (Table 3) were especially useful as features of the bedrock geology have been well defined from the extensive DoW WIN water point database (Department of Water, 2014) (see below).

Detailed information for each bedrock resource category is presented in a later section of this document.

Quarries/Pits

Very few of the data sources for the quarries/pits layer were available in a digital format and, therefore, locations of quarries and pits were digitized from information contained on maps and in reports (Table 5).

Table 5. Sources used in compiling major digital data layers

Data layer	*Data source*	*Comment*
Quarries/Pits	1:100 000-scale topographic maps	Locations digitized from raster map
	1:250 000-scale topographic maps	Locations digitized from raster map
	Crown reserves	Digital data filtered for limesand and limestone
	Extractive industry licences	Obtained from local authorities 2013 and digitized
	Gazey (2011)	Locations digitized from hardcopy report
	Gazey (2013)	Locations digitized from hardcopy report
	Gazey and Gartner (2009)	Locations digitized from hardcopy report
	Gozzard (1987a)	Locations digitized from hardcopy report
	GSWA 1:250 000-scale geological maps	Locations digitized from raster map
	GSWA 1:100 000-scale geological maps	Locations digitized from raster map
	GSWA 1:50 000-scale environmental geology maps	Locations digitized from raster map
	Industrial Mineral Services Pty Ltd et al. (2001)	Locations digitized from hardcopy report
	Landgate orthophotography	Locations digitized from orthophotography
	Masters (1993a)	Locations digitized from hardcopy report
	MINEDEX (Geological Survey of Western Australia, 2014)	Mines and mineral deposits point database
	Mining leases (Dept of Mines and Petroleum, 2014)	Digital data filtered for limesand and limestone
	Wyatt (1961)	Locations digitized from hardcopy map
Analyses	Abeysinghe (1996)	Data digitized from hardcopy report
	Abeysinghe (1998)	Data digitized from hardcopy report
	Gazey (2011)	Data digitized from hardcopy report
	Gazey (2013)	Data digitized from hardcopy report
	Gazey and Gartner (2009)	Data digitized from hardcopy report
	Gozzard (1987a)	Data digitized from hardcopy report
	Industrial Mineral Services Pty Ltd et al. (2001)	Data digitized from hardcopy report
	Masters (1993a)	Data digitized from hardcopy report
	Wyatt (1961)	Data digitized from hardcopy report
Surficial resources	DAFWA soil–landscape maps	Polygon dataset used to refine primary dataset
	GSWA 1:100 000-scale geological maps	Polygon dataset used to refine primary dataset
	GSWA 1:250 000-scale geological maps	Primary polygon dataset used
	GSWA 1:50 000-scale environmental geology maps	Polygon dataset used to refine primary dataset
	Landgate orthophotography	Raster dataset used to validate interpretations
	Shaded relief model	Raster dataset used to refine/validate interpretations
Bedrock resources	DoW WIN database	Water bores with stratigraphic logs digitized
	GSWA 1:50 000-scale environmental geology maps	Polygon dataset used to refine primary dataset
	GSWA 1:100 000-scale geological maps	Polygon dataset used to refine primary dataset
	GSWA 1:250 000-scale geological maps	Primary polygon dataset used
	Landgate orthophotography	Raster dataset used to validate interpretations
	Shaded relief model	Raster dataset used to refine/validate interpretations

Based on the information contained in the data sources, the quarries/pits layer was categorized according to the status of the operation, that is, active if currently working, and inactive if abandoned or in care and maintenance. The activity status of the quarries/pits was verified by reference to the available digital orthophotography and to GSWA's MINEDEX mines and mineral deposits database (Geological Survey of Western Australia, 2014). However, as stated above, the most recent digital orthophotography available is dated 2009. Hence, the locations of currently existing quarries and pits may not be up to date. The activity status of the quarries/pits may also be out of date.

Other attributes include the BRM being worked, the geological unit in which the quarry or pit is located and, if known, the owner of the operation.

Chemical analyses

No chemical analyses of samples of limesand and limestone were available digitally and therefore were digitized from information contained in available reports (Table 5). A total of 147 analyses of limesand and limestone was collated and digitized. The analyses were grouped into four categories — dolomitic sand (seven samples); limesand (30 samples); limestone (80 samples); magnesite (30 samples). All samples had been analysed for per cent calcium oxide (CaO), which was converted to per cent calcium carbonate ($CaCO_3$). Most samples were also analysed for magnesium oxide (MgO). Several samples were also analysed for per cent acid insoluble residue and neutralizing value. The neutralizing value of lime reflects its ability to change soil acidity. It takes into account the chemical composition of the acid-soluble forms of calcium and magnesium and the particle size distribution (percentage by weight) of the material. Higher neutralizing values indicate an increased capacity to change soil acidity.

Andreini and Dolling (2010) reported that the average neutralizing value of limesand sold in Western Australia (registered pits only) is 87% (range 64–95%); the average particle size is 90% less than 0.6 mm (range 57–100%) and it contains 33% and 1.5% calcium and magnesium, respectively. In comparison the average neutralizing value of limestone sold in Western Australia (registered pits only) is 78% (range 69–90%), the average particle size is 67% less than 0.6 mm (range 35–87%) and it contains 30% and 1.0% calcium and magnesium respectively. Dolomite sold in Western Australia (registered pits only) has an average neutralizing value of 69% (range 39–97%); the average particle size is 33% less than 0.6 mm (range 17–52%) and it contains 15% and 8.3% calcium and magnesium respectively.

A problem encountered while collating the analytical data from all the available sources is the lack of information in some reports of the method by which the analyses were determined. Only the DAFWA reports provide details of the laboratory methods, which used acid digestion and analysis using ICP-AES (inductively coupled plasma atomic emission spectrometry) to determine the CaO and MgO content of samples.

The GSWA publications provide little relevant detailed information but Abeysinghe (1998) suggests that many of the analyses quoted from pre-existing reports were probably obtained by a gravimetric method involving digestion of material by hydrochloric acid, and measurement of the mass of acid-insoluble material. This would provide total carbonate figures with $CaCO_3$ and $MgCO_3$ values probably representing total acid-soluble carbonate. Samples collected by Abeysinghe (1998) were chemically analysed in a specialist laboratory in Perth and so probably involved acid digestion and analysis using ICP-AES or ICP-OES (inductively coupled plasma optical emission spectrometry), but this is not stated.

Neither of the consultants' reports provides information on the analytical methods used.

As a variety of analytical methods have been used to determine the carbonate values presented in the accompanying digital data package, direct comparison of the chemistry of individual samples should proceed with caution. However, for practical purposes, the quoted values should be comparable.

Other relevant data layers

Four other data layers relate to the resource potential of the survey area. Three layers comprise mining leases, Crown reserves, extractive industry licences (EIL) and provide secure tenure, albeit of various durations, for operators. The fourth layer, MINEDEX, is GSWA's mines and mineral deposits database.

Mining leases are issued under the provisions of the *Mining Act 1978* where the commercial removal of BRM on Crown land has been applied for. Mining leases are issued for a term of 21 years with the option of renewal. Fourteen mining leases for the extraction of limesand and limestone are found in the survey area. However, only five are actively being worked and a further one includes an inactive limestone pit. This information has been verified against the MINEDEX database (GSWA, 2014).

EILs are issued by a local government authority under the *Planning and Development Act 2005* for the extraction of BRM on private (freehold) land as BRM on private (freehold) land is not a mineral under the *Mining Act 1978*. The issue of an EIL is usually considered in relation to a local government scheme and a region scheme, if there is one. Twenty-two of the 33 local authorities within the survey area were contacted with a request for information on extant EILs for lime and limestone. However, only nine replies were received. These contained information on 18 EILs, 11 of which are actively being worked, with a further one having an inactive working. The remaining EILs have no current or former workings. EILs for lime and limestone appear to be restricted mostly to the coastal local authorities.

Non-commercial extraction of BRM by local government authorities, Main Roads Western Australia and landowners on their own land for private use does not require a mining lease or EIL.

Eight Crown reserves for limestone are scattered sporadically across the survey area. Three are vested in local authorities, one in the Commissioner of Main Roads and four are unvested. Based on 2007 orthophotography only one, near Albany Regional Prison, is actively being worked.

MINEDEX was developed in 1984 by the then Western Australia Department of Minerals and Energy as a mineral resource inventory database (excluding petroleum), but has expanded to also serve as an administrative tool for parts of the *Mining Act 1978*, *Mines Safety and Inspection Act 1994*, *Mines Safety and Inspection Regulations 1995*, and their predecessors. MINEDEX provides a coordinated, project-based enquiry system for textual information on mine and site locations (coordinates etc.), notice of intent to mine, mineral resources, mine production, mining inspection data, and environmental reports. Increasingly, information relating to basic raw materials extracted from private land is being included. Data from this study have been entered into MINEDEX.

Surficial limesand and limestone resources

Overview

The principal sources of limesand and limestone in the survey area from surficial geological units are the extensive deposits that are found along the coastal belt and immediately inland of the coast. These respectively comprise unconsolidated coastal limesand dunes, which are irregular shaped dunes and ridges or east-northeast trending dunes, and calcarenite of the probable local equivalent of the Tamala Limestone of the west coast. Inland of the coast minor amounts of limestone are available as calcrete, dolomite and magnesite that are found in a variety of geological settings.

Production

Accurate statistics for limestone production in Western Australia are not available. This is because most production is not reported to the Department of Mines and Petroleum for the reason, as mentioned above, that limesand and limestone are not classed as minerals under the *Mining Act 1978* when they are mined on private (freehold) land.

Reported total production of limestone in the study area from 2005 to 2014 was 1.08 Mt and is only available for operations within the Shires of Denmark, Esperance and Ravensthorpe (Fig. 11). The production of magnesite since 2011 accounts for over 0.8 Mt of this total. This significant production is directly associated with the operation of the various nickel-related processes in the Ravensthorpe area (see below).

In contrast, both limesand and limestone have maintained relatively steady production rates of about 15 000 t per year each (Fig. 11). Most of this reported tonnage is used in the agricultural sector as a soil conditioner. However, significant production of limesand and limestone for agricultural purposes remains unreported as does the amount of agricultural lime being imported into the study area from west coast sources. Most of the unreported production of limestone in the study area is used as roadbase and in building construction.

Limesand

Geology

Limesand is found along much of the coastline from Denmark in the west to east of Esperance (Fig. 12). It occurs in a series of east–northeast trending parabolic and nested parabolic dunes and foredune plains. In the Esperance area these dunes extend up to 15 km inland. The dunes are generally stable, but foredunes and frontal dunes are susceptible to wave and wind erosion where they are exposed at the coast. Large areas of active dunes and blowouts occur along parts of the coast. The limesand dunes comprise the Quindalup Dune System and are equivalent to the Safety Bay Sand geological unit of Holocene age (11 700 years ago to the present) of the west coast (Gozzard, 1987b).

The limesand is composed of unconsolidated pale pinkish grey, fine- to medium-grained quartz sand and shell debris. The shell debris is the remains of marine organisms that had lived and died in the marine environment. After death, these shells were broken down and, with the quartz sand, were washed on to the beach by wave activity. From the beach, the material was transported onshore by wind action to form mobile dunes that moved farther inland from the beach to be later stabilized by vegetation.

Resource information

Limesand is a major resource commodity and is used almost exclusively in the study area as agricultural lime to neutralize the acidity in soils of agricultural areas. Currently, there are eight active limesand pits in the survey area, two near Albany, two at Hopetoun, south of Ravensthorpe and four near Esperance (Fig. 12). There are a further 13 inactive pits in the same three areas. The majority of the active workings are covered by mining leases or EILs. Two inactive workings are on a Crown reserve near Parry Beach vested in the Shire of Denmark for the purpose of a quarry site.

The neutralizing value of limesand is related to its total carbonate content (mostly $CaCO_3$) and its relatively fine grain size. Calcium carbonate values from 30 limesand samples range from 15.4% to 94.6%, although most values are between 40% and 75% (Appendix). Magnesium carbonate ($MgCO_3$) values are generally low and range from 0.7% to 6.0%. The measured neutralizing values available for only six limesand samples analysed range from 32.3 to 80.7, which reflect the variability of the total carbonate content. Neutralizing values for 14 of the 30 samples were calculated using the formula of Gazey (2013). These values range from 17.1 to 80.8, with most being less than 50 (Appendix).

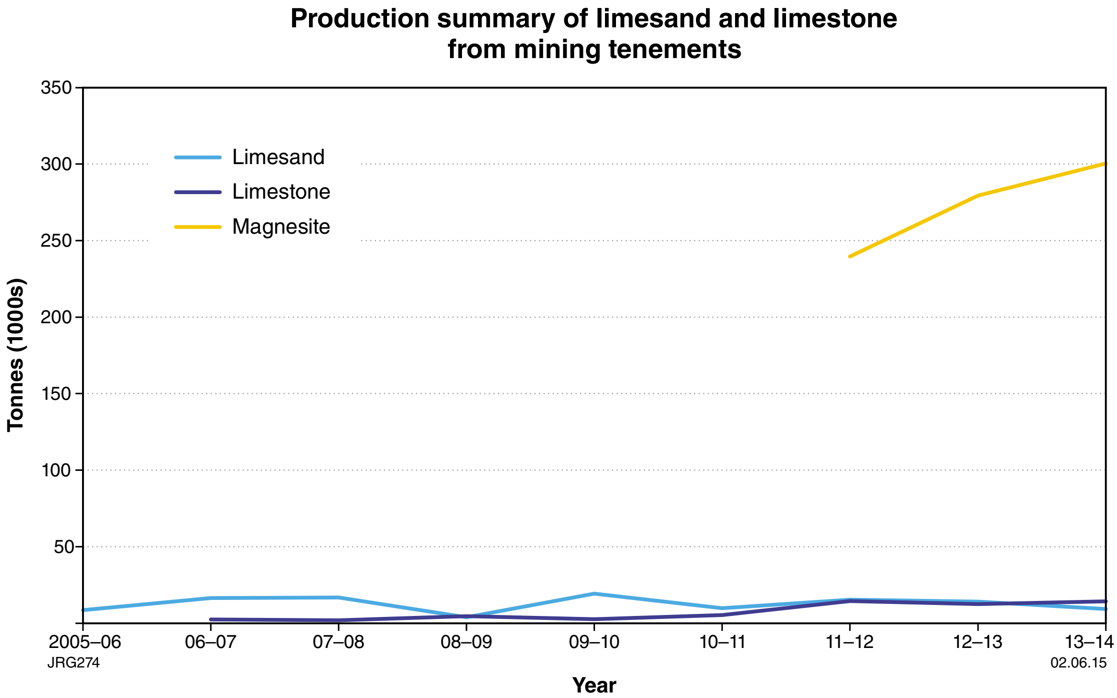

Figure 11. Production summary of limesand and limestone from mining tenements

The large variability in carbonate content of the coastal limesand dunes makes it difficult to predict the location of potential high-grade resources within the study area with any degree of accuracy. Compared to west coast limesand the south coast material is of an overall lower grade (Gazey and Gartner, 2009; Gazey, 2011; Gazey, 2013) and some Great Southern and Wheatbelt farmers find it more economical to import higher grade material from suppliers on the west coast. Notwithstanding, the limesand resources of the study area are considered to be an important resource. They are a valuable source of agricultural lime and have the potential for use in other industries. Currently, the highest quality material comes from a pit near Lights Beach, Denmark and from the Boyatup Lime Pit 37 km east of Esperance.

Chemical analyses of 26 samples from drillholes adjacent to the pit near Lights Beach range from 21.5% to 63.4% $CaCO_3$ with an average of 46.1% $CaCO_3$ (Fig. 13). The limesand is reported as averaging less than 5 m in thickness and is generally a pale grey and brown lime and quartz sand suitable only for second-grade agricultural lime (Masters, 1993). In contrast, three samples from the pit face average 76.6% $CaCO_3$.

Two samples taken from two small disused pits southwest of Parry Beach contain 20.5% and 31% $CaCO_3$, and a third sample from William Bay contained 54.8% $CaCO_3$ (Fig. 13).

In the Esperance area chemical analyses of 11 samples between Quallilup Lake and Mount Hannett range from 17.5% to 94.6% $CaCO_3$, with an average of 47.0% $CaCO_3$. Four samples from the Boyatup Pit average 73.6% $CaCO_3$ (Fig. 14), emphasizing the high quality of this deposit.

Limestone

Geology

Surficial limestone is found along the coast between Denmark and Esperance (Fig. 15) and the resource category includes two types of limestone. By far the more extensive resource category comprises a series of cemented former limesand dunes. A minor resource relates to estuarine limestone near Albany.

The cemented limesand dunes are large-scale, convex, asymmetric topographically irregular ridges. They comprise pale yellowish brown, friable, medium- to coarse-grained quartz and shell debris that has become variably cemented into a range of rock types varying from calcareous sandstone to sandy limestone. Their shape and composition suggests that they were formed as large-scale, bare, dune sheets that advanced over the land surface in a similar manner to the contemporary limesand dunes described above. Dissolution of the contained $CaCO_3$ by surface or groundwater and its precipitation at lower levels in the dunes cemented the unconsolidated material. These cemented dunes represent the probable south coast equivalent of the Pleistocene (2.5 million to 11 700 years ago) Tamala Limestone geological unit seen along the west coast.

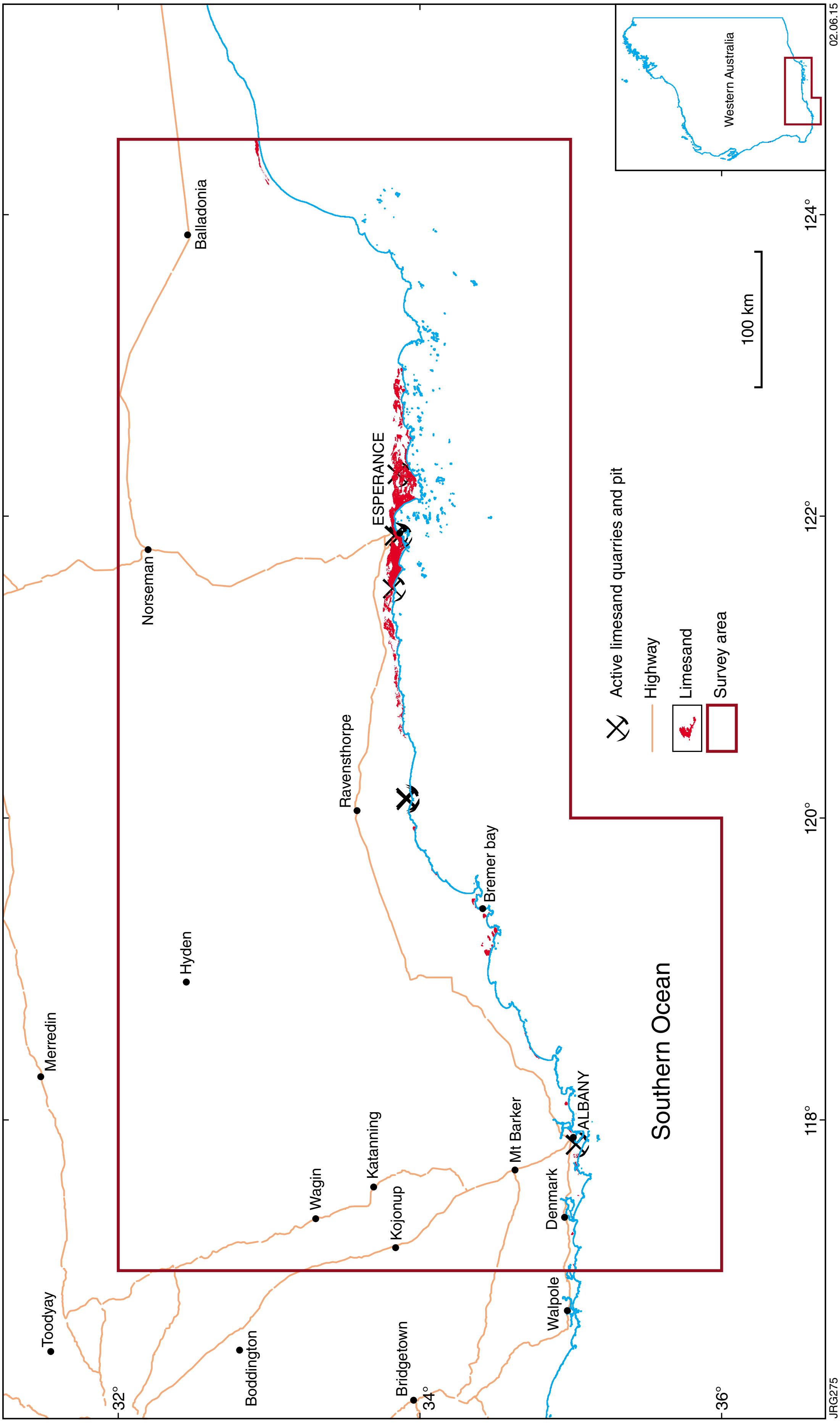

Figure 12. Extent of limesand resources

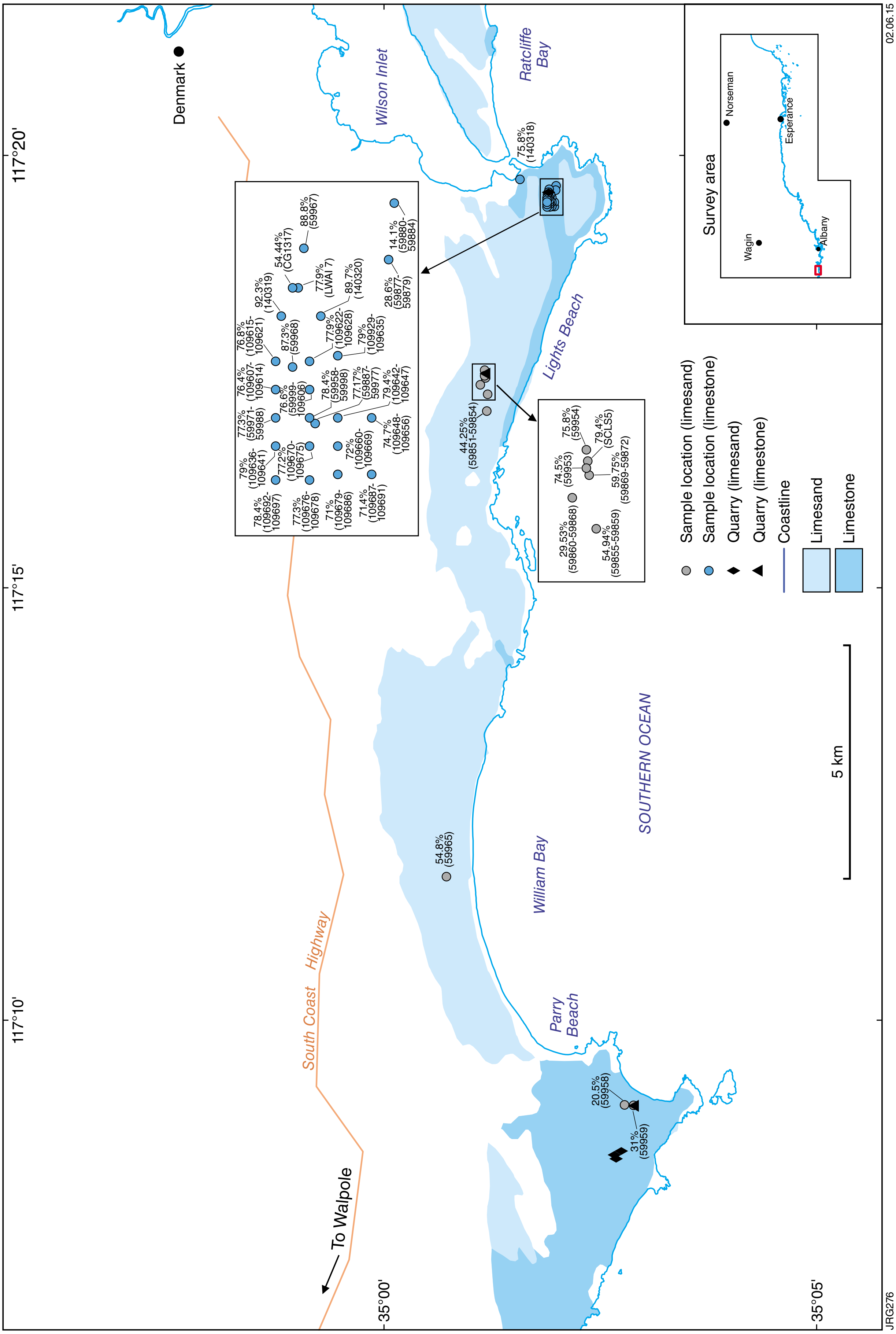

Figure 13. Extent of limesand and limestone resources southwest of Denmark

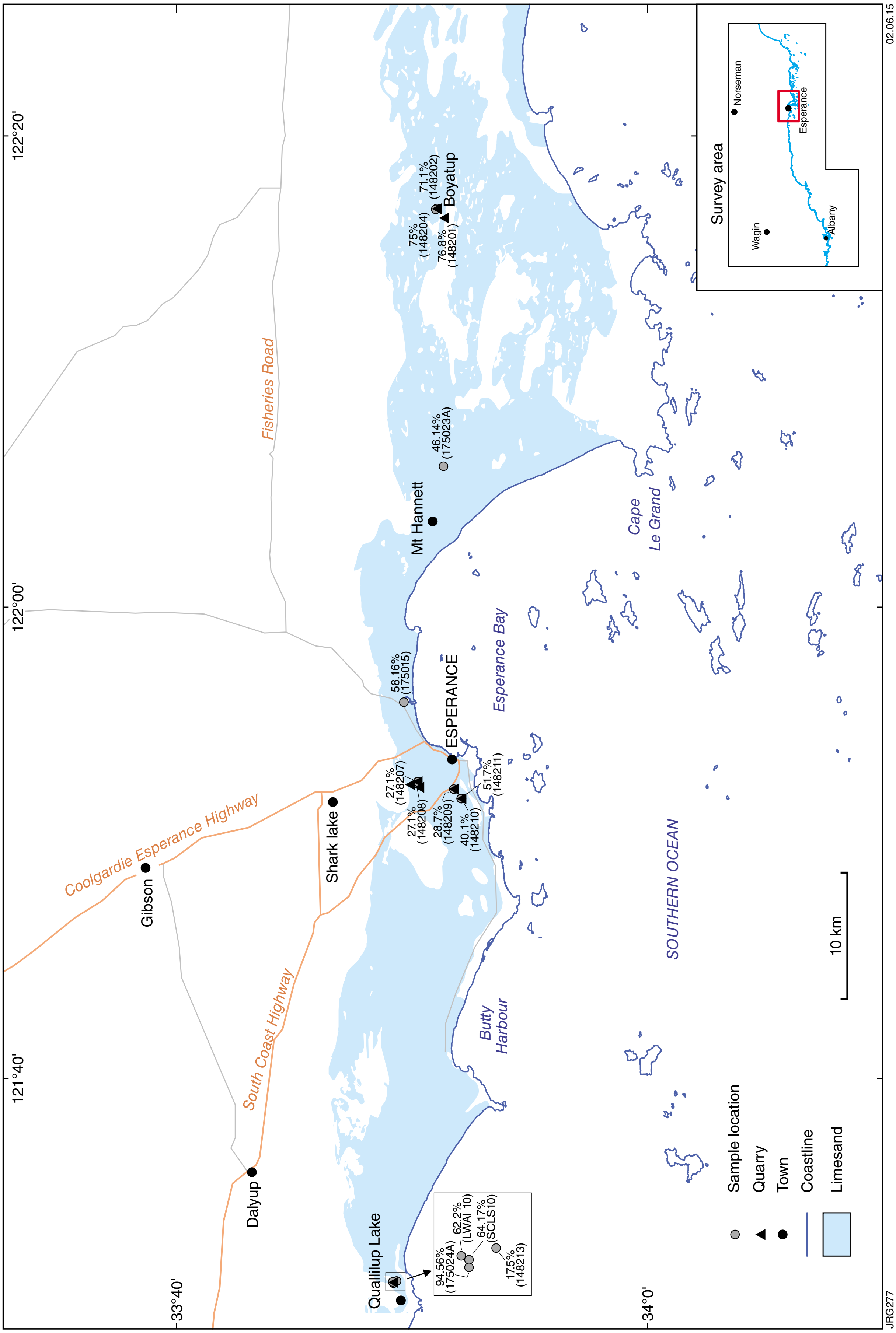

Figure 14. Extent of limesand resources near Esperance

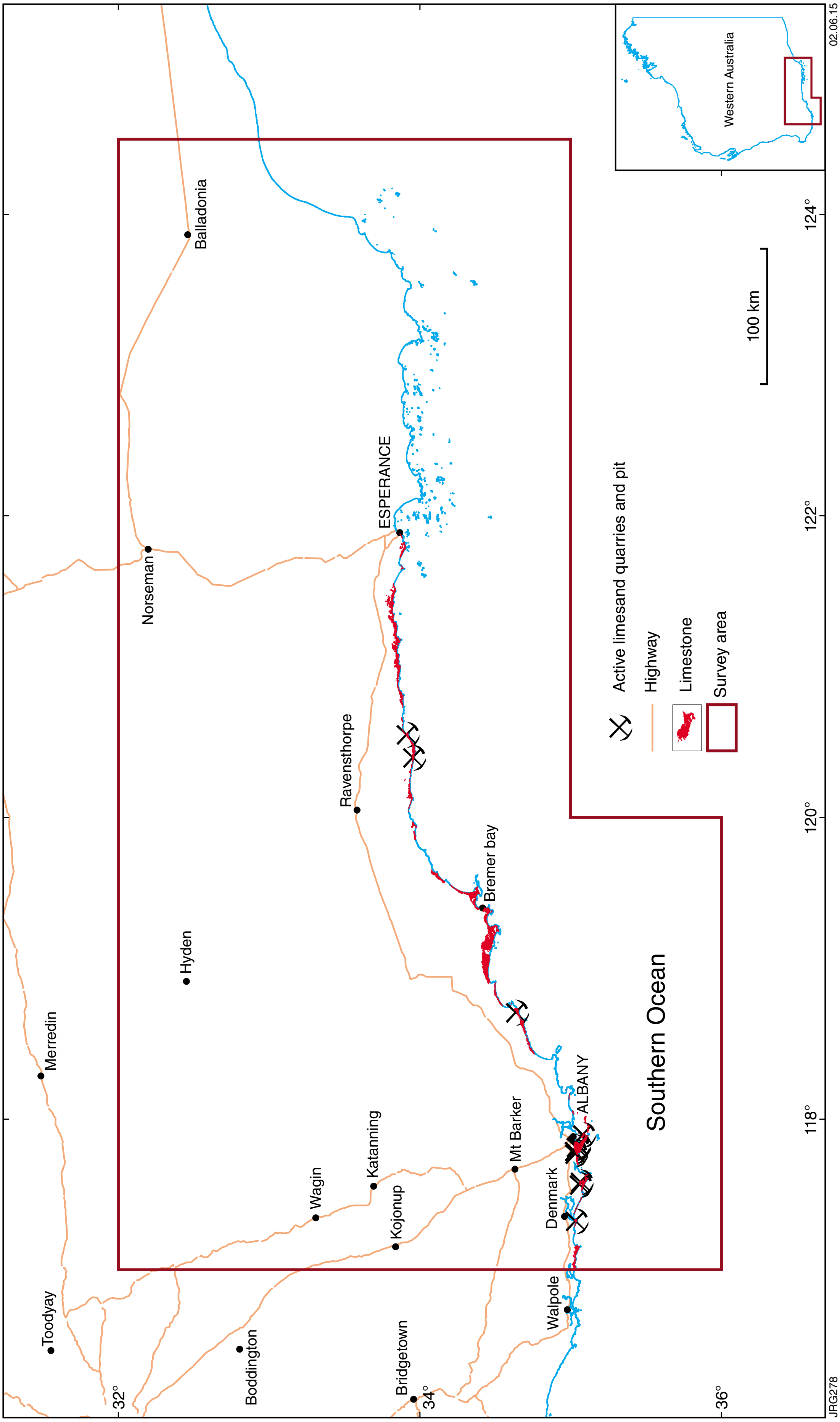

Figure 15. Extent of surficial limestone resources

At Little Grove on the southern shore of Princess Royal Harbour at Albany, limestone underlies a small, flat, level plain. This limestone is very pale brownish yellow, fine to medium grained, and contains subrounded shell debris with quartz sand. It was deposited on the floor of a protected, shallow embayment of Princess Royal Harbour approximately 6500 years ago when sea level was a few metres higher than at present. The environment of deposition was similar to the present day nearshore seagrass meadows where biogenic activity contributed most to the limestone with very little input of material from the land.

Resource information

Although the limestone is used primarily as a source of agricultural lime, significant amounts are used by Main Roads Western Australia and local authorities for road construction and maintenance. Thirteen active limestone pits are known, mostly in the southwest of the area between Denmark and Albany, with two near Mount Melville, 86 km northeast of Albany, and one near Jerdacuttup Lakes, 45 km southeast of Ravensthorpe (Fig. 15). A further 28 inactive limestone pits are found concentrated in the Denmark to Albany and Hopetoun areas. Of the 13 active limestone pits only six appear to have some kind of tenure — one on a Crown reserve, one on a mining lease and four on extractive industry licences. Nine of the 28 inactive pits also have tenure — one is on a Crown reserve and eight are within extractive industry licences.

Calcium carbonate values from 80 limestone samples range from 9.8% to 94.9%, although most values are between 60% and 90% (Appendix). Magnesium carbonate values are generally low and range from 0.1% to 14.6%, with the majority being less than 3%. The measured neutralizing values for four limestone samples analysed range from 60.1 to 79.7. Neutralizing values for 44 of the limestone samples were calculated using the formula of Gazey (2013). These values range from 10.2 to 96.7, with most in the range of 60–95.

As in the case of limesand, the origin and depositional history of the limestone has produced material with a significant variability in its carbonate content. This variability precludes being able to predict the location of high-grade resources without recourse to costly drilling and sampling programs. However, it is clear from the available analytical data that higher grade limestone (>70% $CaCO_3$ and >75 neutralizing value) is confined to the area between Denmark and Albany.

The Ocean Beach quarry, 8.5 km southwest of Denmark, is a large producer of agricultural lime from the Tamala Limestone (Fig. 13). Masters (1993) reported that $CaCO_3$ values of 126 samples from 17 drillholes consistently exceeded 70% with first-grade agricultural lime having an average of 78.4% and second-grade agricultural lime having an average of 75% (Fig. 16). Total in situ measured resources were estimated at 743,000 m^3. A further 15 surface samples from other surveys generally exceeded 75% $CaCO_3$.

Southwest of Torbay much of the limestone outcrop is within the West Cape Howe National Park (Fig. 17). Consequently, this limestone is unavailable for exploitation. Six samples from the limestone outcrop north of the West Cape Howe National Park have $CaCO_3$ values ranging between 54.2% and 64.9% with an average of 60.6%. These are significantly lower values than those from samples within the West Cape Howe National Park which have an average $CaCO_3$ content of 75.8%.

The limestone at Little Grove was used in the early years of the settlement of Albany as a high-quality source of lime for construction and agricultural purposes (Fig. 18). The limestone was extracted from a small quarry at Limeburner Point and fired in kilns at Limeburner Point and nearby Limekilns Point. Two samples of the limestone have $CaCO_3$ values of 82.3% and 90.6% with correspondingly high neutralizing values. This potential resource is no longer available because of the encroachment of residential and rural residential development at Big Grove and Little Grove.

In the Albany area (Fig. 18) $CaCO_3$ values from 25 samples range from 9.8% to 94.9% with an average of 63.2%. Magnesium carbonate values for these samples range from 0.8% to 2.7%; calculated neutralizing values are generally between 50 and 85. Much of the limestone outcrop lies within the Torndirrup National Park. Mapping of regionally significant basic raw materials in the Albany region (GSWA, in prep.) has identified the area between Albany Regional Prison and the Albany Wind Farm as containing the largest area of unconstrained limestone resources in the Albany region and is thus a strategically important limestone resource (Fig. 19).

Although many of the samples of high-grade limestone were taken from pits and quarries now in the West Cape Howe and Torndirrup National Parks, the Denmark to Albany area should be the focus of future exploration for high-grade limestone resources.

A continuous, narrow belt of limestone occurs along the coast between Hopetoun and Starvation Boat Harbour (Fig. 20). North of Southern Ocean Road access to the limestone is constrained by the Jerdacuttup Lakes Nature Reserve. All quarries along this stretch of coastline are currently inactive. There are no samples from this area. However, there is an active limestone quarry north of Twelve Mile Beach that had a $CaCO_3$ content of 54.9% with a neutralizing value of 73.1 (Gazey and Gartner, 2009).

Overall, the quality of the limestone is better than that of the limesand. The limestone can, therefore, be considered a strategic resource. Not only is it a valuable source of agricultural lime, but it has the potential for use in other industries where high-grade limestone is required.

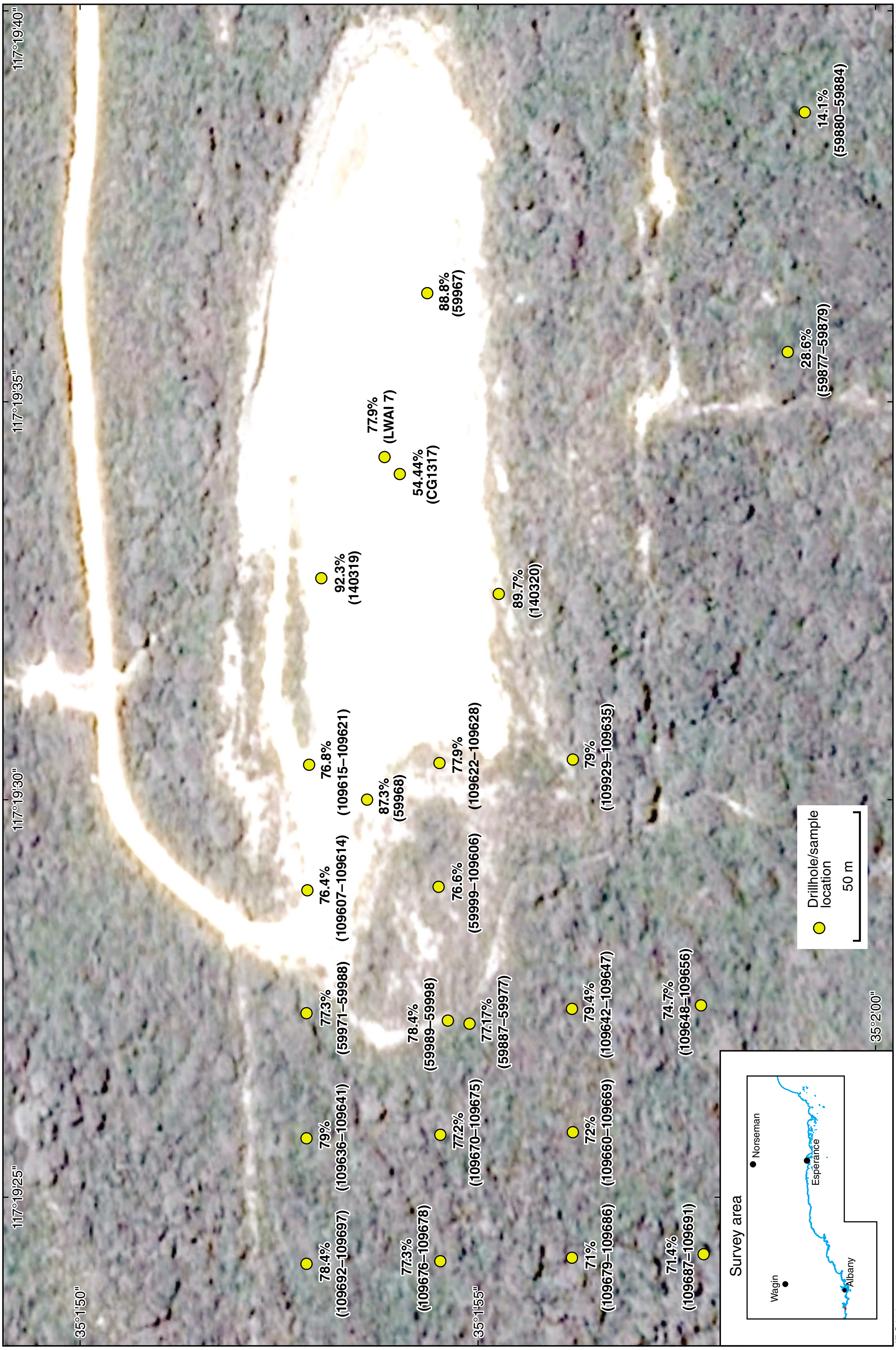

Figure 16. Drillhole and surface sampling at the Ocean Beach quarry, Denmark

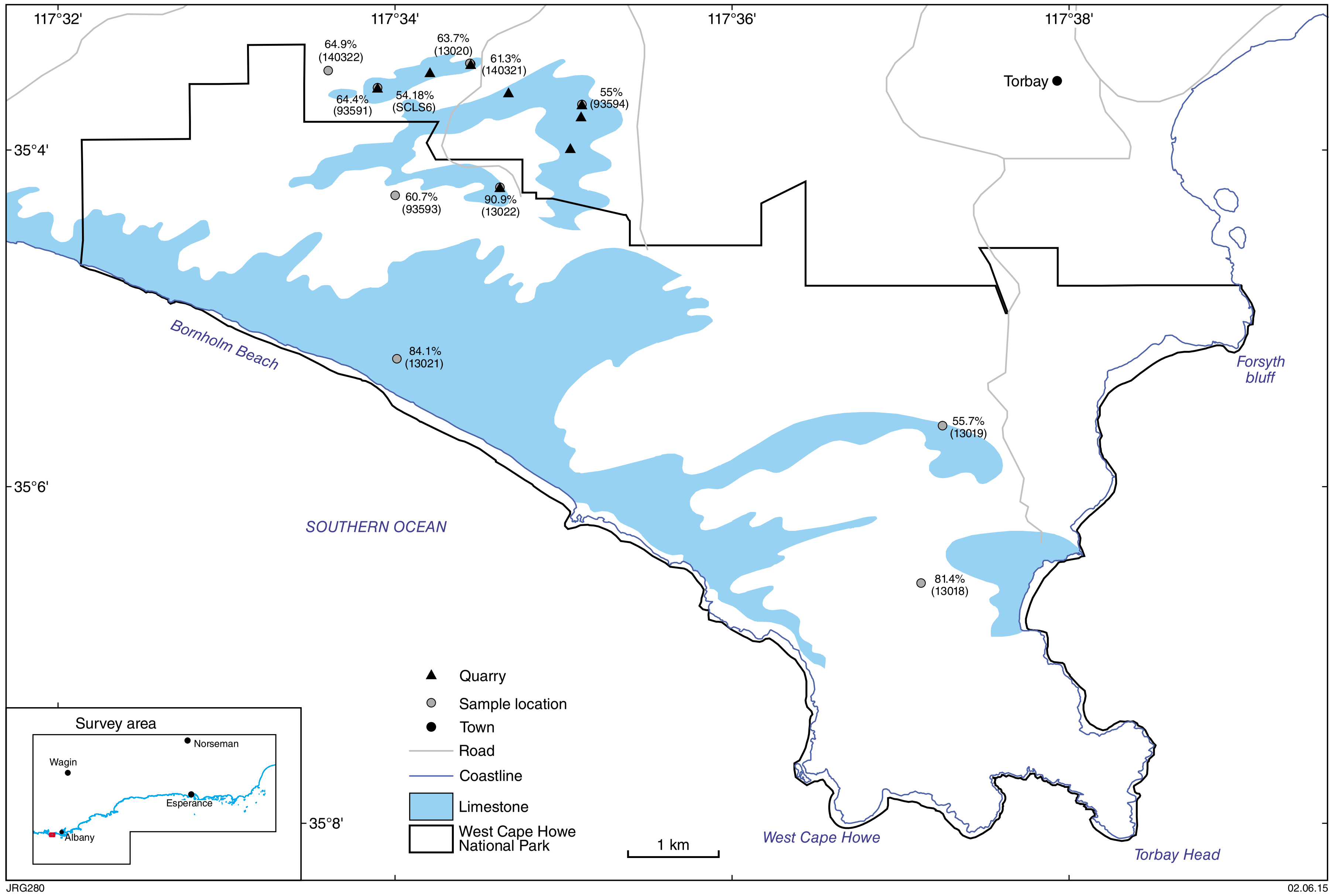

Figure 17. Extent of surficial limestone resources southwest of Torbay

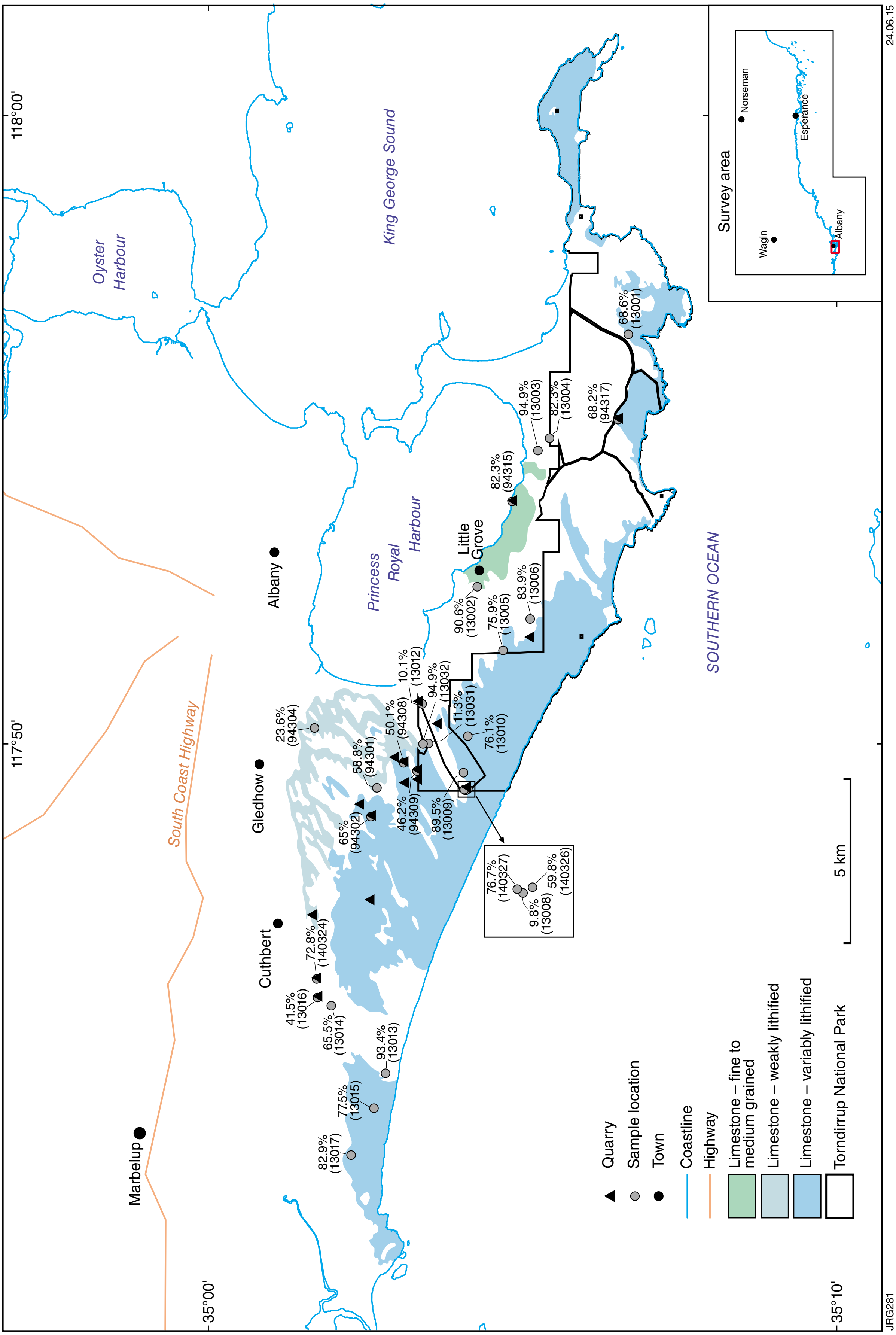

Figure 18. Extent of surficial limestone resources in the Albany area

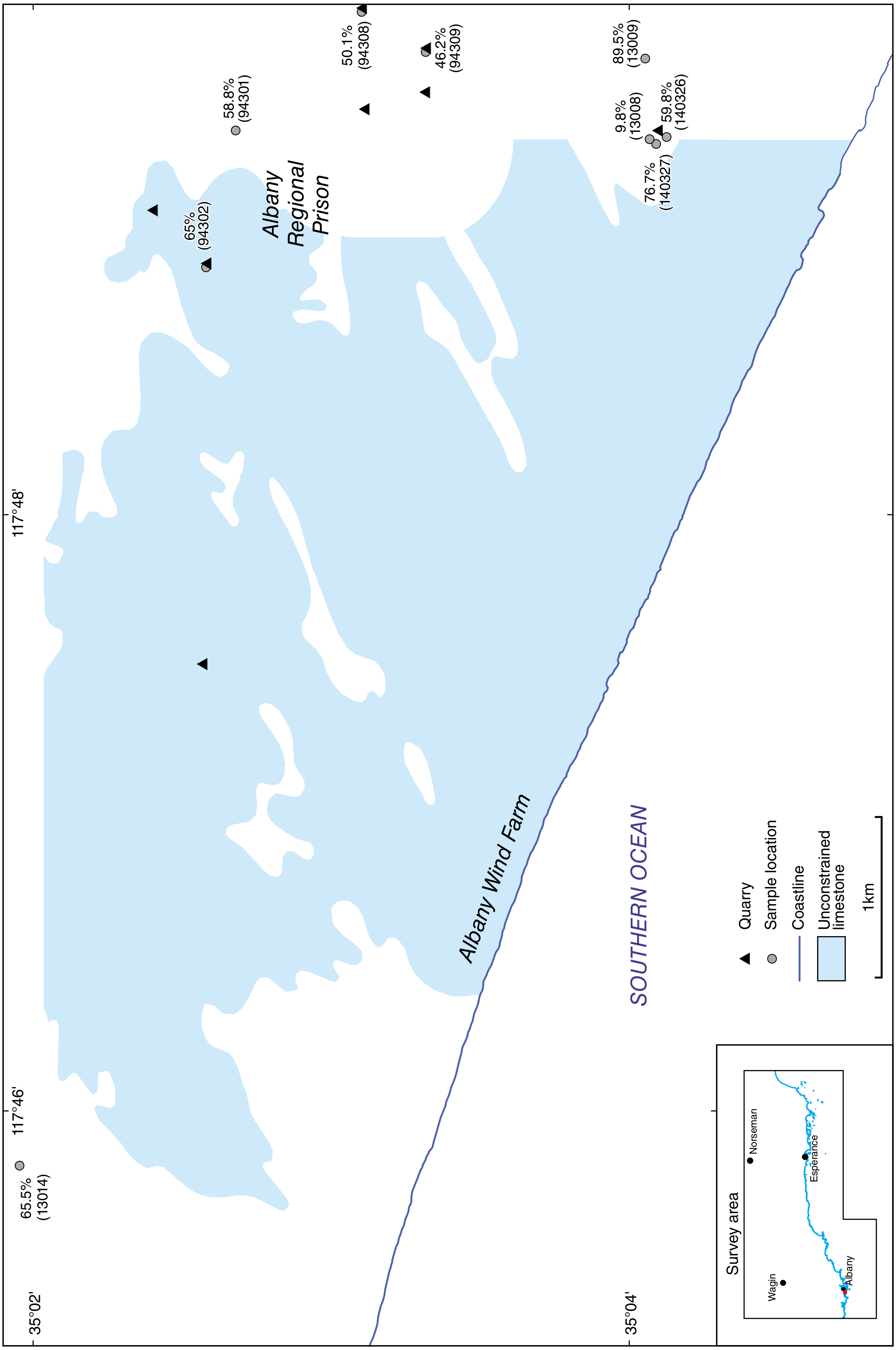

Figure 19. Unconstrained extent of surficial limestone resources near Albany Regional Prison

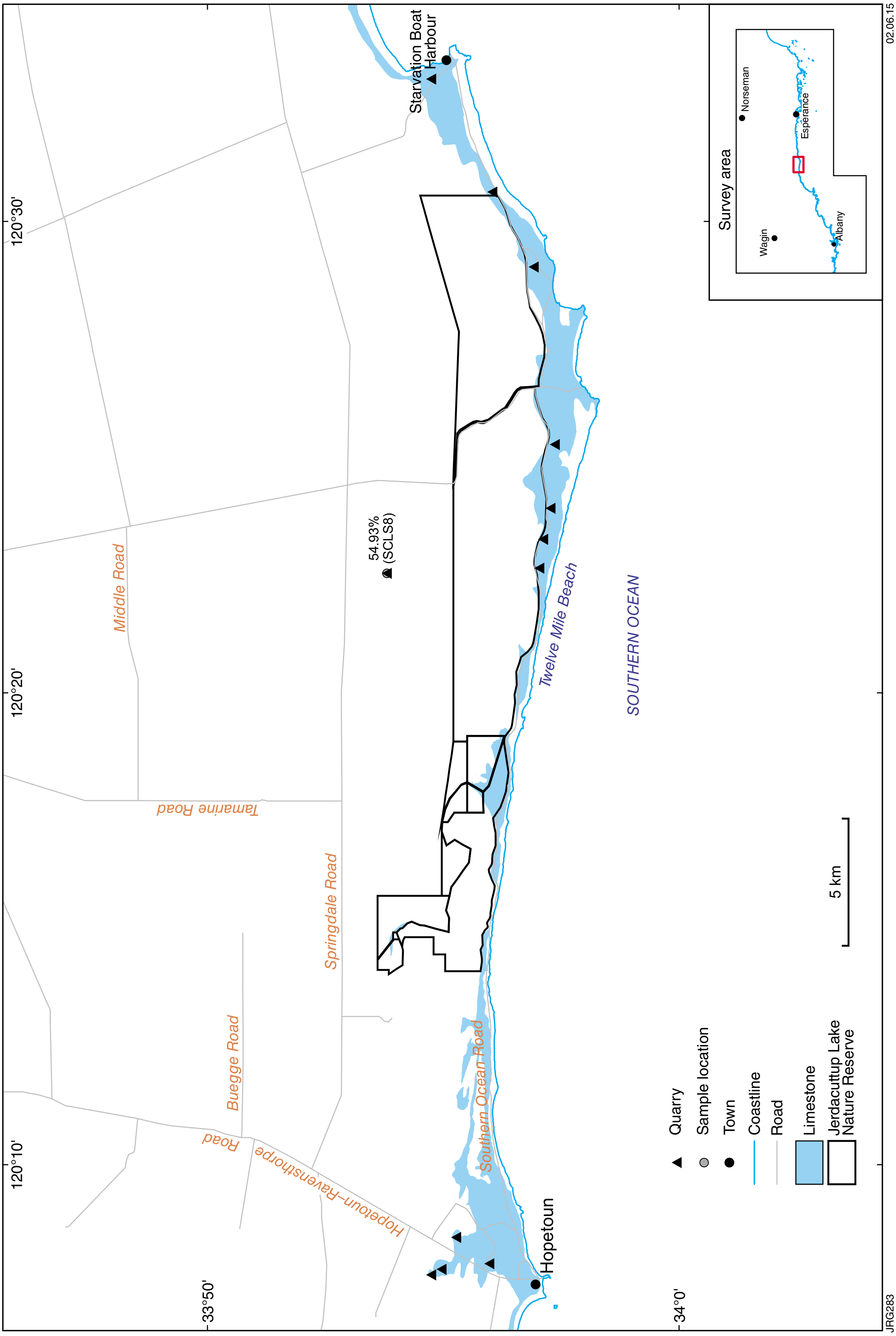

Figure 20. Extent of surficial limestone resources between Hopetoun and Starvation Boat Harbour

Dolomitic sand

Geology

Known active quarries and pits of dolomitic sand are restricted to the western part of the survey area and to west of Ravensthorpe where they are found as sporadic deposits in crescent-shaped dunes fringing claypans and lakes and ancient drainage flats linking the chains and claypans and lakes (Figs 21 and 22). The dunes were deposited from material that was blown from dry lake beds and alluvial surfaces of the valley-fill deposits and trapped by vegetation close to the lake shores.

The dolomitic sand is a loose mixture of calcium carbonate as calcite and magnesium carbonate as dolomite with varying amounts of clay, silt and quartz sand. No geological investigation has been undertaken on these deposits so the origin of the carbonates is unknown. However, the lake systems that contain the dolomitic sand also host deposits of valley calcrete (see below). Thus, there is an abundance of calcium carbonate in the lake systems that can contribute to the dolomitic sand. The origin of the dolomite is more problematic. Rosen and Coshell (1992) suggested that at Lake Hayward, in the Lake Clifton – Lake Preston system between Mandurah and Bunbury, the dolomite formed as a diagenetic replacement of calcite in the lake under the influence of bacterial activity. A similar origin may be suggested for the inland lakes of the study area given the absence of magnesium-rich rocks in most areas.

Resource information

Andreini and Dolling (2010) estimated that approximately 10% of the total lime used in Western Australia as agricultural lime is in the form of dolomitic sand (marketed as dolomite) and that it is used predominantly in the Great Southern region. In the study area there are five active workings and three inactive workings. The Department of Agriculture and Food, Western Australia has sampled the active pits on a number of occasions (Gazey and Gartner, 2009; Gazey, 2011; Gazey, 2013) and the analyses show that $CaCO_3$ values range from 26.5% to 46.2% and that $MgCO_3$ values range from 18.4% to 32.6% (Appendix). Measured neutralizing values range from 63.5 to 76.7.

The known resources of dolomitic sand are a valuable source of agricultural lime given their proximity to farmers in the Great Southern and southern Wheatbelt Development regions. As all known dolomitic sand deposits are found in the west of the study area, it is probable that future resources are to be found here rather than in the central and eastern parts of the study area.

Magnesite

Geology

Magnesite ($MgCO_3$) in the pure form is uncommon in nature and it usually consists of a mixture of $CaCO_3$ and $MgCO_3$. In the study area magnesite is found as a series of isolated deposits 35 km east and 35 km southeast of Ravensthorpe and at Munglinup (Fig. 23). The deposits are massive, structureless bodies that overlie many rock types. The known magnesite occurrences can be grouped into two broad categories based on their geological association: residual magnesite and sedimentary magnesite (Abeysinghe, 1996).

Residual magnesite is found in, and overlying, weathered high magnesian basalts and ultramafic rocks (serpentinite, amphibolite) of Archean age (>2.5 billion years ago) where subaerial weathering of the magnesium-rich minerals has altered them to magnesite. The magnesite, which usually does not form large deposits, is found in four main areas. At Carlingup, Kundip, Bandalup and Munglinup small occurrences of variable quality magnesite are commonly exposed along creek beds and tracks. At these localities magnesite forms lenticular, lumpy bodies varying from hard material to soft, chalky material. Thicknesses range from 0.5 m to 10.0 m (Abeysinghe, 1996).

In contrast, sedimentary magnesite is found as large replacement deposits in sandy sediments of the upper Eocene (33.9 to 56 million years ago) Pallinup Siltstone. The major sedimentary magnesite deposits are found at Bandalup as beds of nodular magnesite up to 7 m thick with an average mineable thickness of 4 m (Abeysinghe, 1996). The magnesite probably replaced originally poorly lithified green sands in the sedimentary sequence as magnesium-rich groundwater percolated through the sandy sediments.

Resource information

The magnesite deposits of the Ravensthorpe area have been extensively reviewed by Abeysinghe (1996) who collated all available chemical data (Appendix) and resource information (Fig. 24). Analytical data from 19 samples of residual magnesite show that $CaCO_3$ values range from 0.7% to 71%, although most values are less than 40%. Magnesium carbonate values range from 13.3% to 100%, with the majority being greater than 60%. Abeysinghe (1996) considered all deposits except those adjacent to Bandalup Creek to be subeconomic because of their small size and variable grade. He nonetheless estimated a total inferred resource of 300 000 t of magnesite with greater than 46% MgO to be present in the Bandalup Creek deposits. The Bandalup Creek residual magnesite deposits are being worked.

Analytical data for 11 samples of sedimentary magnesite show that sedimentary magnesite is overall of higher quality than the residual magnesite. Calcium carbonate values of sedimentary magnesite range from 0.8 to 3.2%, with $MgCO_3$ values ranging from 96.6 to 100%. Three active pits are located 4 km north-northwest of Bandalup Hill but the use of the magnesite is not known. The Bandalup Hill sedimentary magnesite deposits have in excess of 1 Mt indicated resources with grades ranging from 12.1% to 21.8% recoverable magnesite.

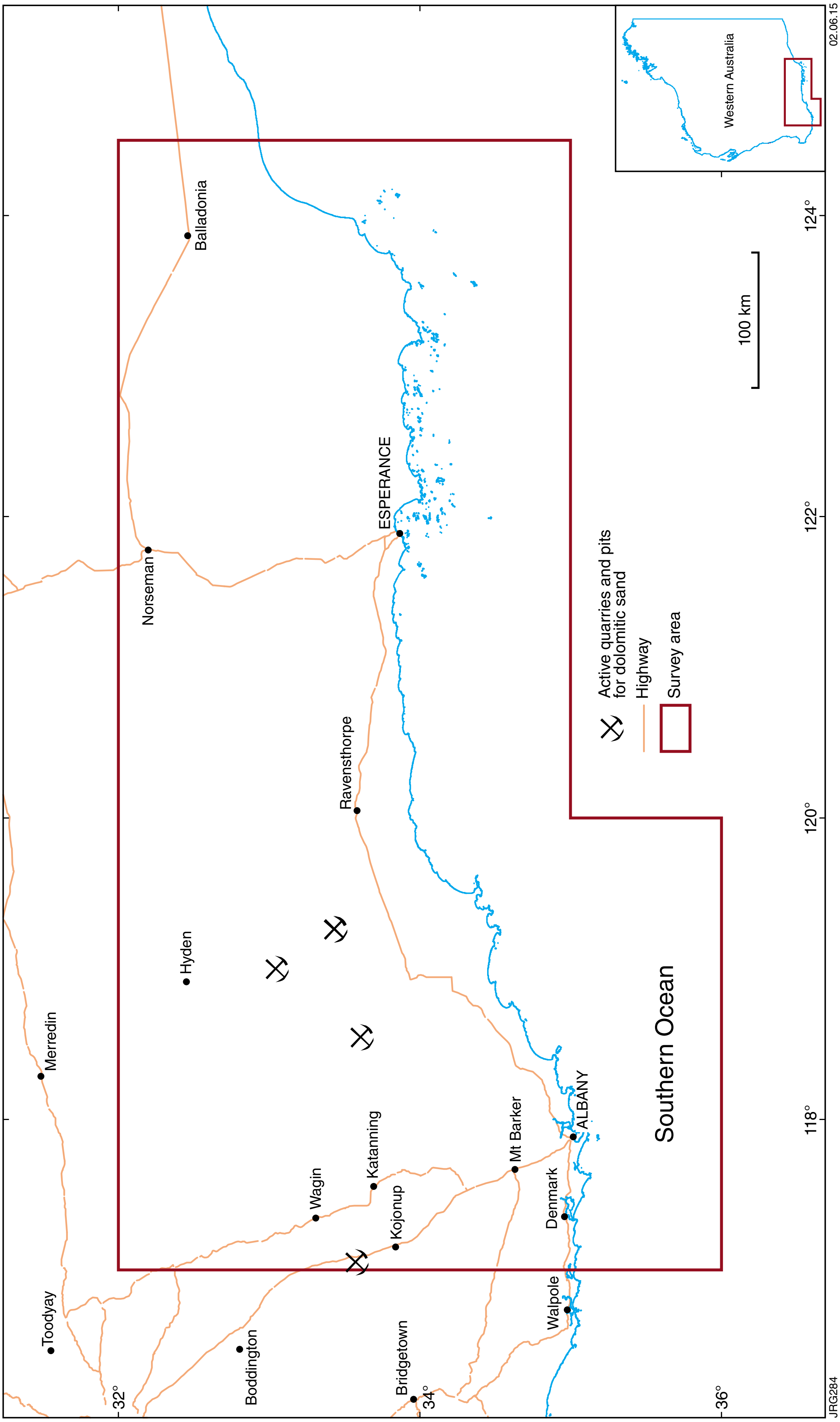

Figure 21. Location of active quarries and pits for dolomitic sand

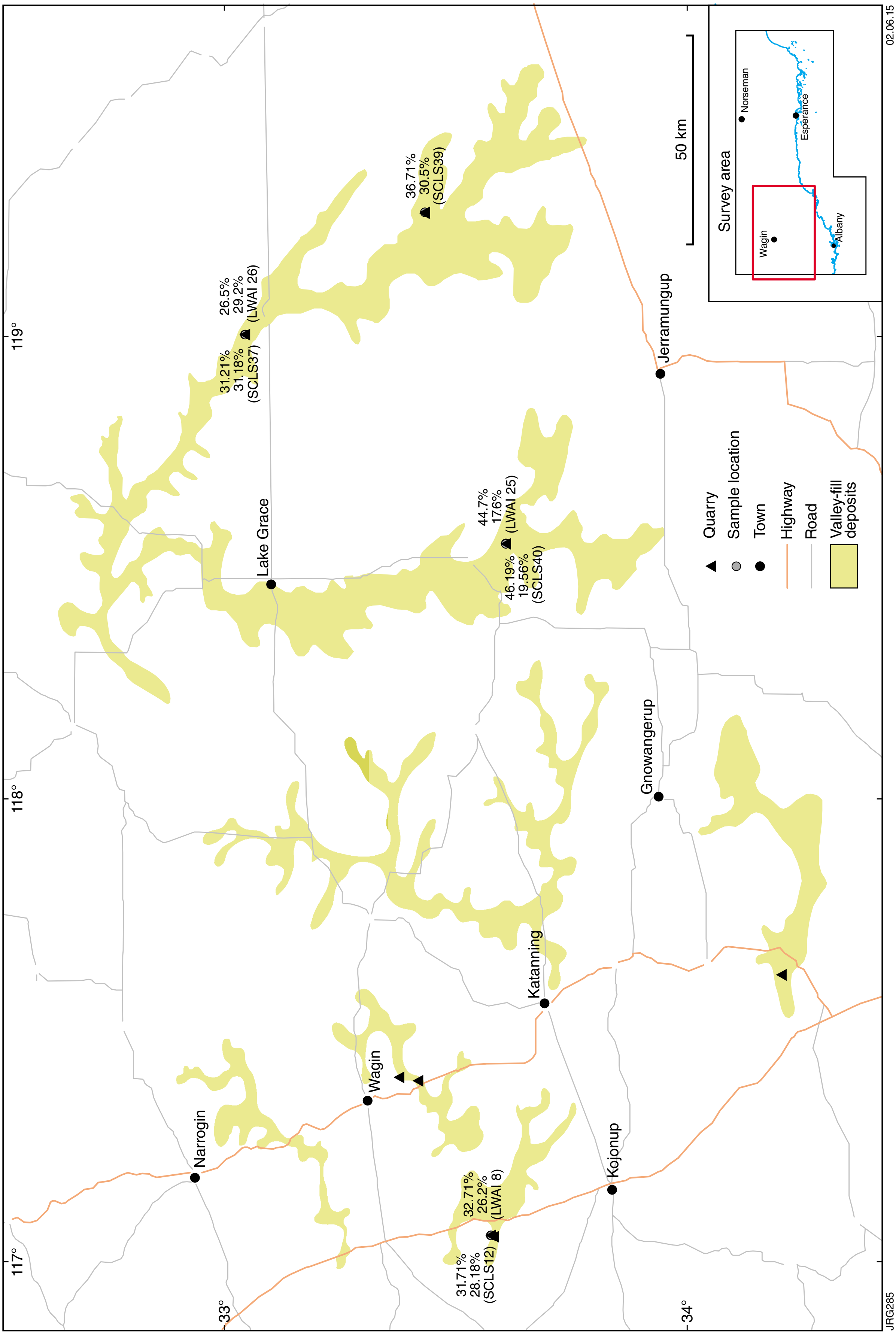

Figure 22. Location of dolomitic sand resources east of Kojonup

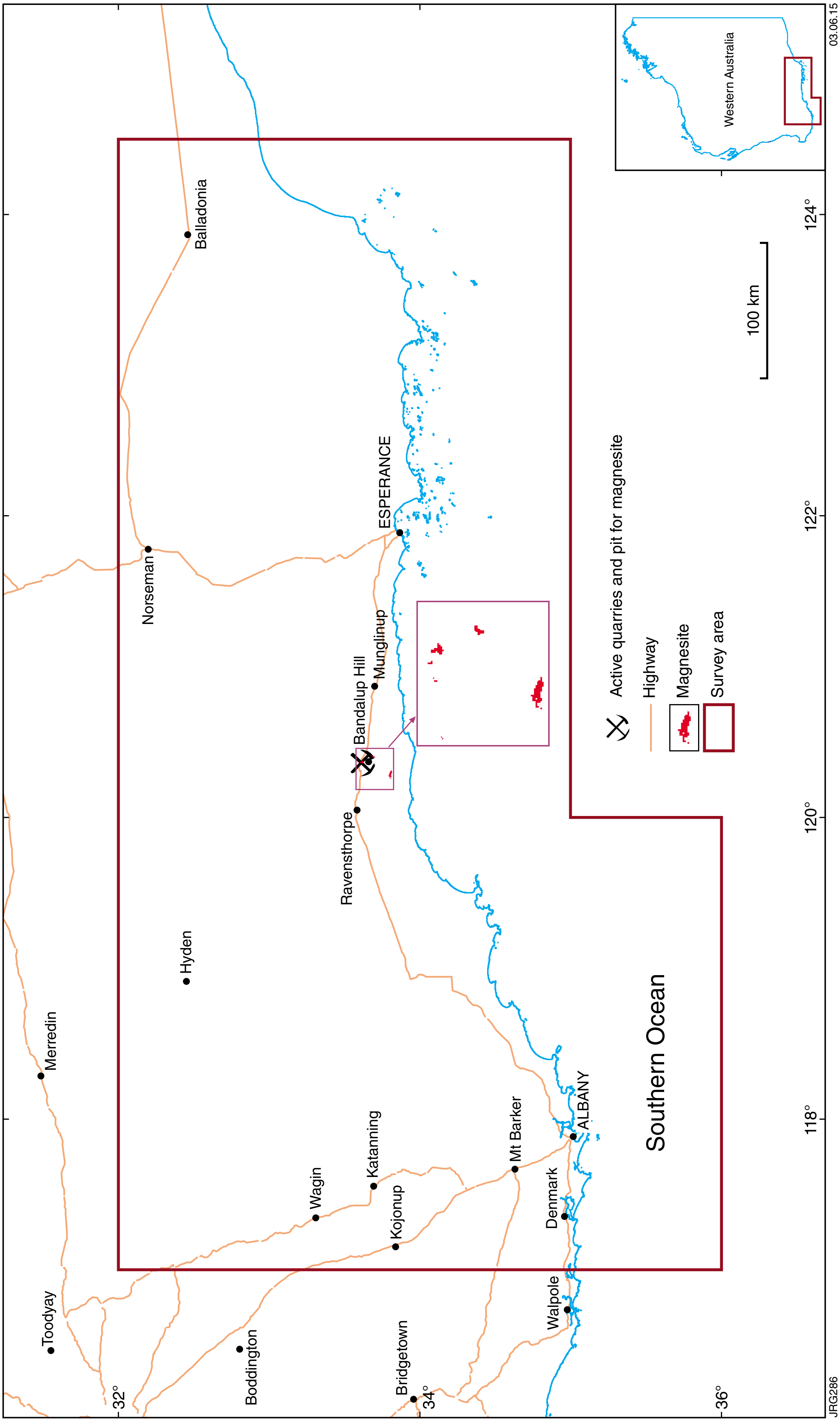

Figure 23. Extent of magnesite resources

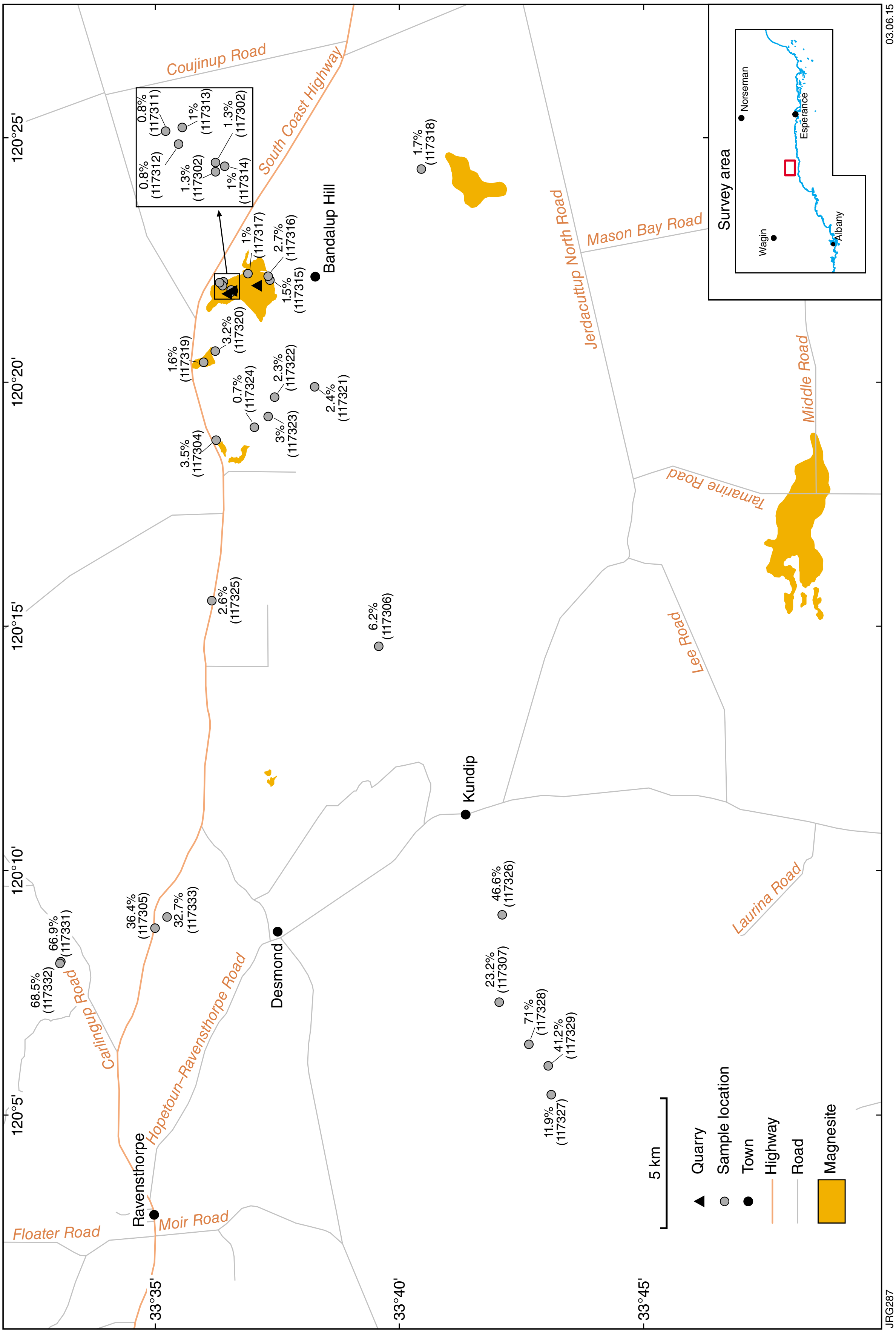

Figure 24. Extent of magnesite resources in the Ravensthorpe area

Although most of the magnesite deposits have security of tenure afforded by mining tenements, none of the tenements are specifically for BRM but are related to FQM Australia Nickel Pty Ltd's Ravensthorpe nickel operations. Several extractive industry licences have been taken out southeast of Bandalup Hill, which are held by Ravensthorpe Nickel Operations and Ashbridge Holdings Pty Ltd, and overlie granted mining tenements.

Historically, most magnesite of this area has gone into the production of dead-burned magnesia to produce refractory magnesia (Abeysinghe, 1996). In the 1980s production from Bandalup was shipped by Norseman Gold Mines NL to Queensland Alumina Ltd, presumably for the production of shaped refractory bricks. Magnesite from the Ravensthorpe area also has the potential to be used as a fertilizer to correct magnesium deficiencies in soil. Abeysinghe (1996) discusses other potential uses of magnesite.

Near Munglinup, approximately 75 km east of Ravensthorpe (Fig. 23), a small deposit of magnesite appears to be a weathering product of carbonated peridotite in gneissic host rocks (Abeysinghe, 1996). Two samples from this locality contained 47.2% and 48.0% MgO respectively.

Valley calcrete

Geology

Valley (groundwater) calcrete is found associated with present day and ancestral river valleys in the areas north of Jerramungup and Ravensthorpe and southeast of Norseman (Fig. 25). The deposits form level to very undulating raised platforms and low mounds up to several kilometres long and wide, and an elevation of less than 4 m above the surrounding valley-fill alluvial material (Fig. 26). The valley calcrete is a generally grey to white nodular and blocky limestone, which is friable and permeable in places, and occasionally shows some silicification. Karstic features such as sinkholes, cavities and solution pipes are common, especially in the more indurated material.

Development of valley calcrete appears to be related to the deposition of carbonates within channels or valleys by precipitation from carbonate-rich groundwater. The calcium and magnesium carbonates in the groundwater are largely derived from leaching of the surrounding bedrock. Anand and Paine (2002), Butt et al. (1977) and Sanders (1974) describe the origin, forms, mineralogy and chemistry of valley calcretes of the Yilgarn Craton.

Resource information

In general, the valley calcrete frequently reaches thicknesses of 10 m, with greater thicknesses known. There are no chemical analyses of the calcrete. The deposits in the Great Southern and Wheatbelt Development Regions in particular have the potential to be worked for agricultural lime, although contamination by deleterious material may pose problems in this regard.

Residual calcrete

Geology

Residual (pedogenic) calcrete has only been mapped in the area east and south of Norseman (Fig. 27). Figure 27 grossly underestimates the aerial extent of residual calcrete as it is derived solely from recent 1:100 000-scale geological mapping of the Buldania, Cowalinya and Dundas map sheets (Groenewald et al., 2008; Hall and Jones, 2008; Hall and Goscombe, 2008). Further detailed geological mapping of adjoining map sheets would undoubtedly extend the currently identified distribution of residual calcrete. However, the existing mapping does seem to indicate a general decrease in the extent of residual calcrete south from Norseman into the less arid parts of the survey area (Fig. 28).

Residual calcrete is generally grey to white and forms more- or less-well cemented aggregates composed mainly of $CaCO_3$. The residual calcrete generally forms as a massive calcareous duricrust at the ground surface, but may also be cavernous and have nodular and honeycomb textures. It may also contain sand, lateritic gravel and clay from adjoining units. The residual calcrete has developed in situ from the weathering of primarily mafic igneous rocks, and is therefore less abundant over granite and ultramafic rocks. Anand and Paine (2002) describe in detail the origin, forms, mineralogy and chemistry of residual calcretes of the Yilgarn Craton.

Resource information

Although the residual calcrete is a potentially large source for crushed limestone for use as roadbase, this is constrained by possible contamination from enclosed deleterious materials and by its remoteness from all but very local potential markets. Two small, inactive roadside scrapings in residual calcrete are found 145 km northeast of Esperance. The material from these scrapings appears to have been used for local road surfacing. The quality of the residual calcrete is unknown, but thicknesses are generally up to a maximum of 2 m.

Clay and calcrete

Geology

In the far northeast part of the survey area, near Balladonia, much of the region is underlain by a layer of residual calcareous clay 4.5 to 6 m thick, containing a layer of grey calcrete about 2 m thick (Doepel and Lowry, 1970b) (Fig. 29). The deposit overlies, and has been derived by prolonged weathering of, the Nullarbor Limestone (see bedrock limestone resources below). The calcrete is generally found up to 1.5 m below the surface, but where it is exposed it is seen to form slabs and cobbles with a characteristically rounded pebbly structure. Doepel and Lowry (1970b) suggested the calcrete was formed by lithification of the clay.

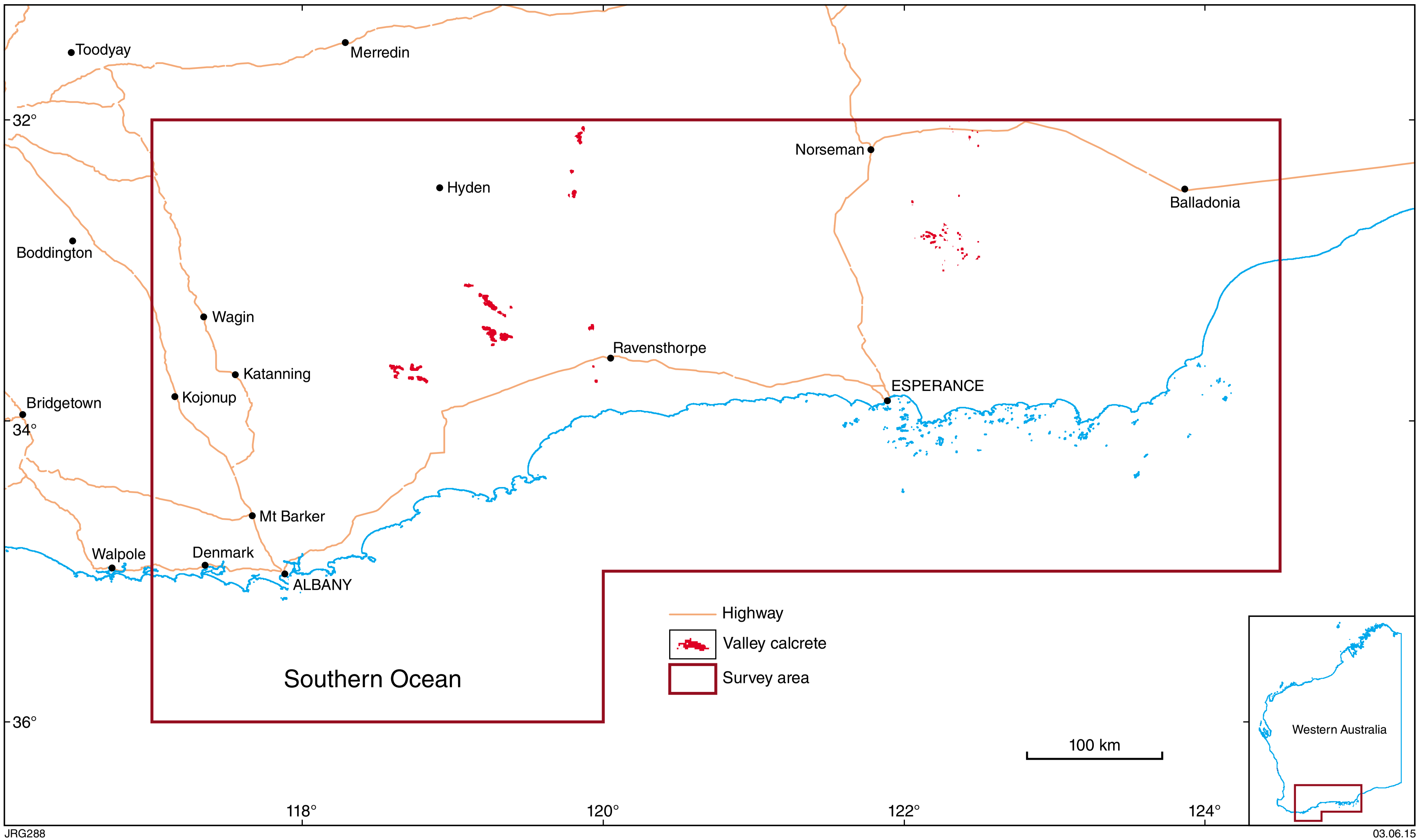

Figure 25. Extent of valley calcrete resources

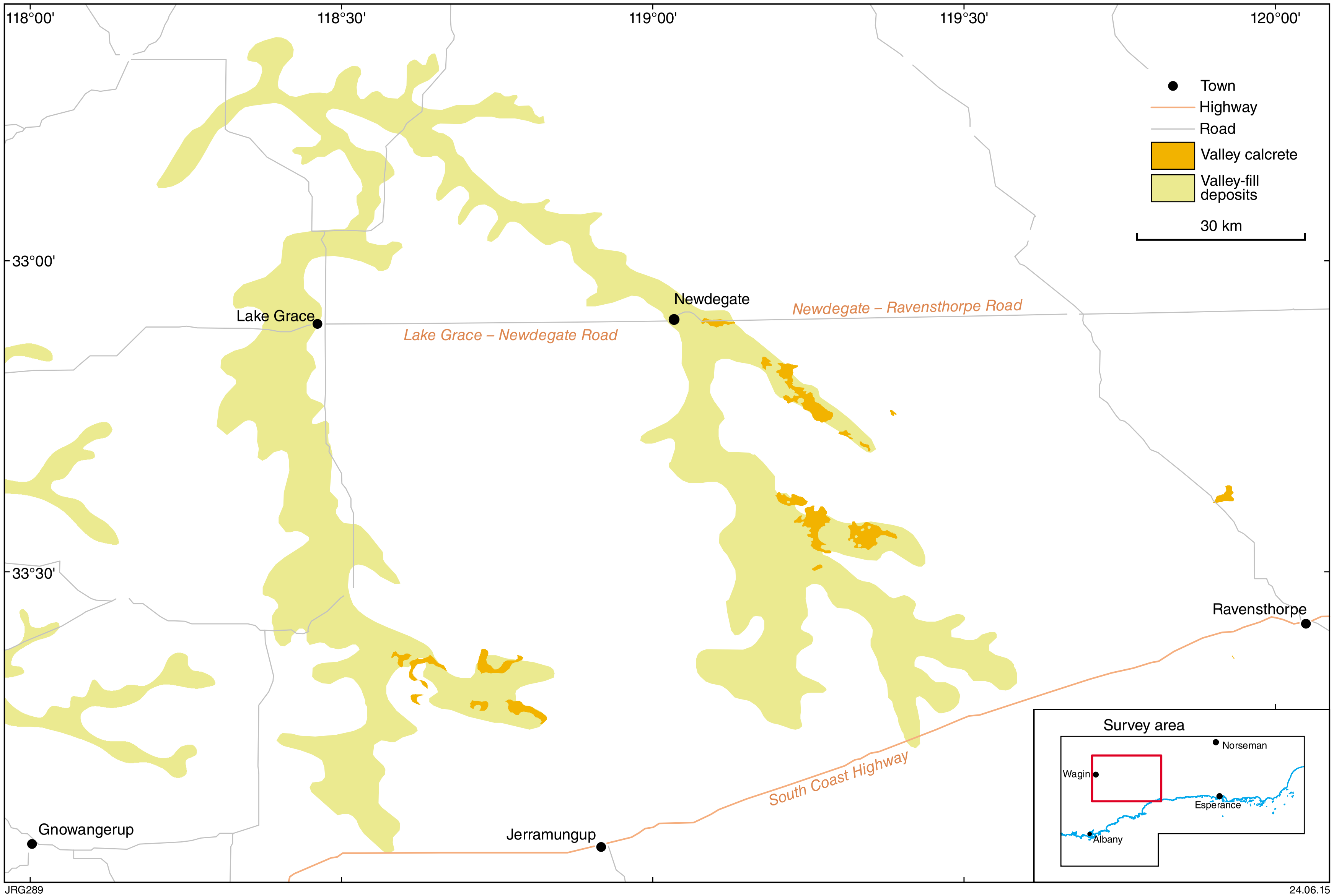

Figure 26. Extent of valley calcrete resources west of Ravensthorpe

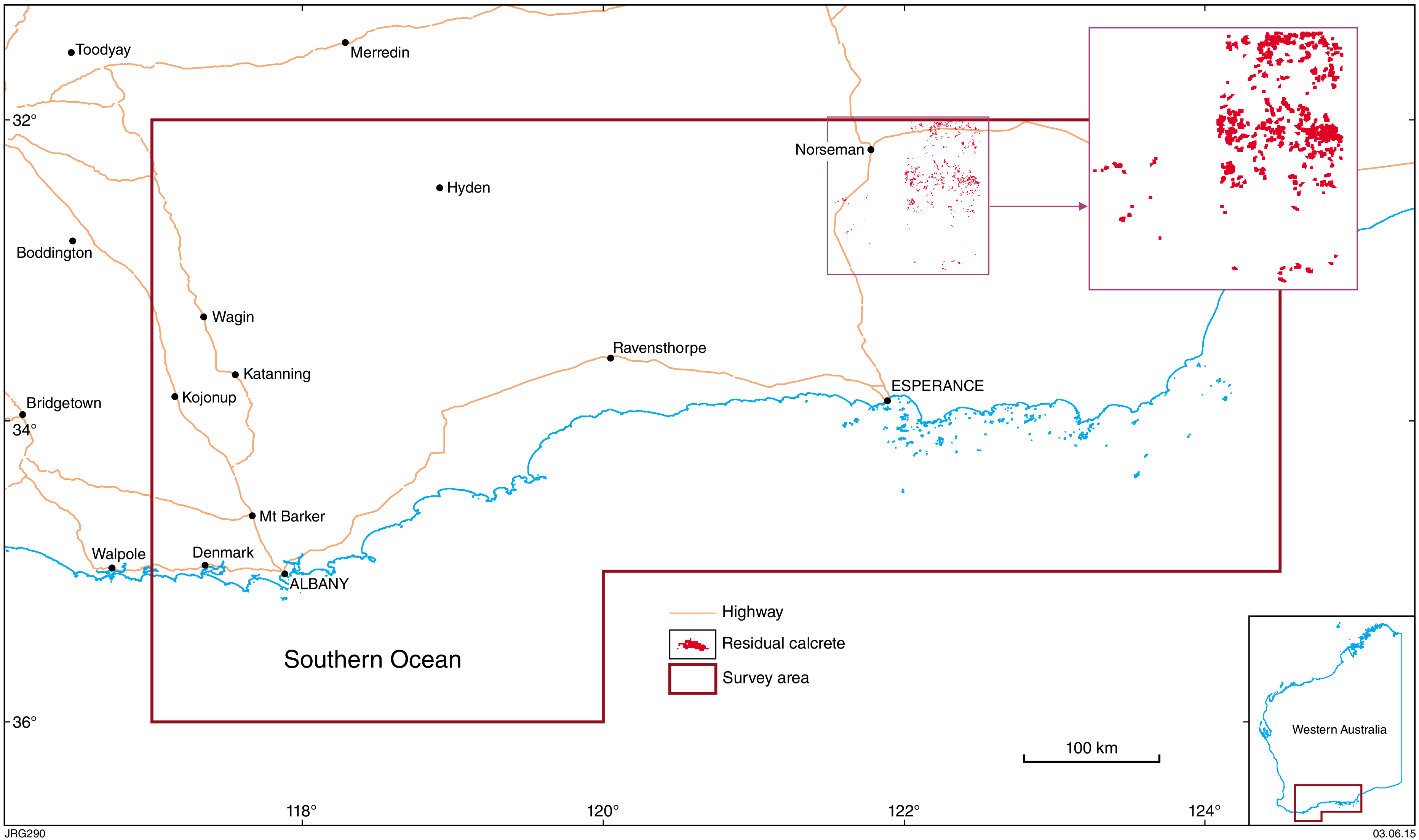

Figure 27. Extent of residual calcrete resources

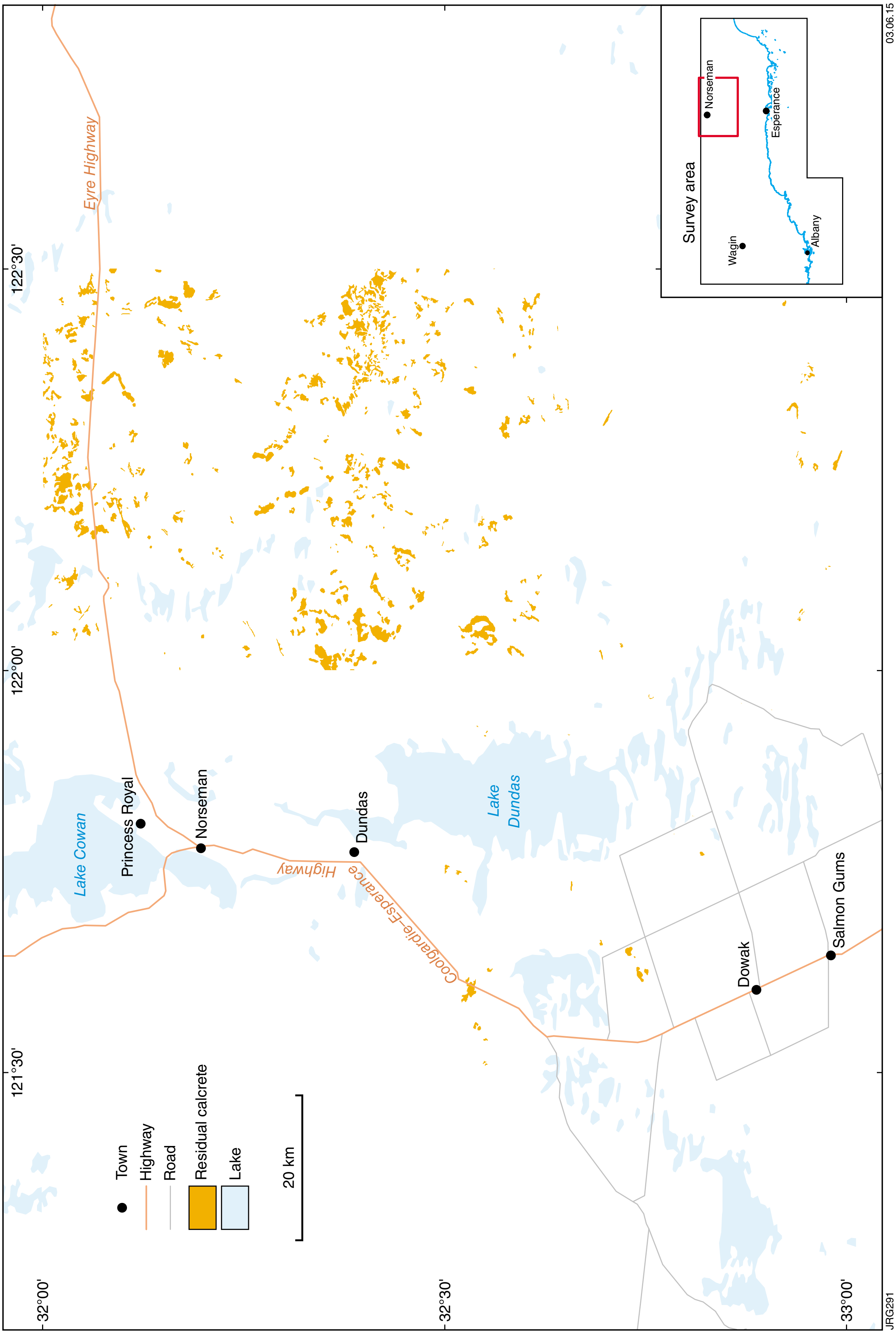

Figure 28. Extent of residual calcrete resources near Norseman

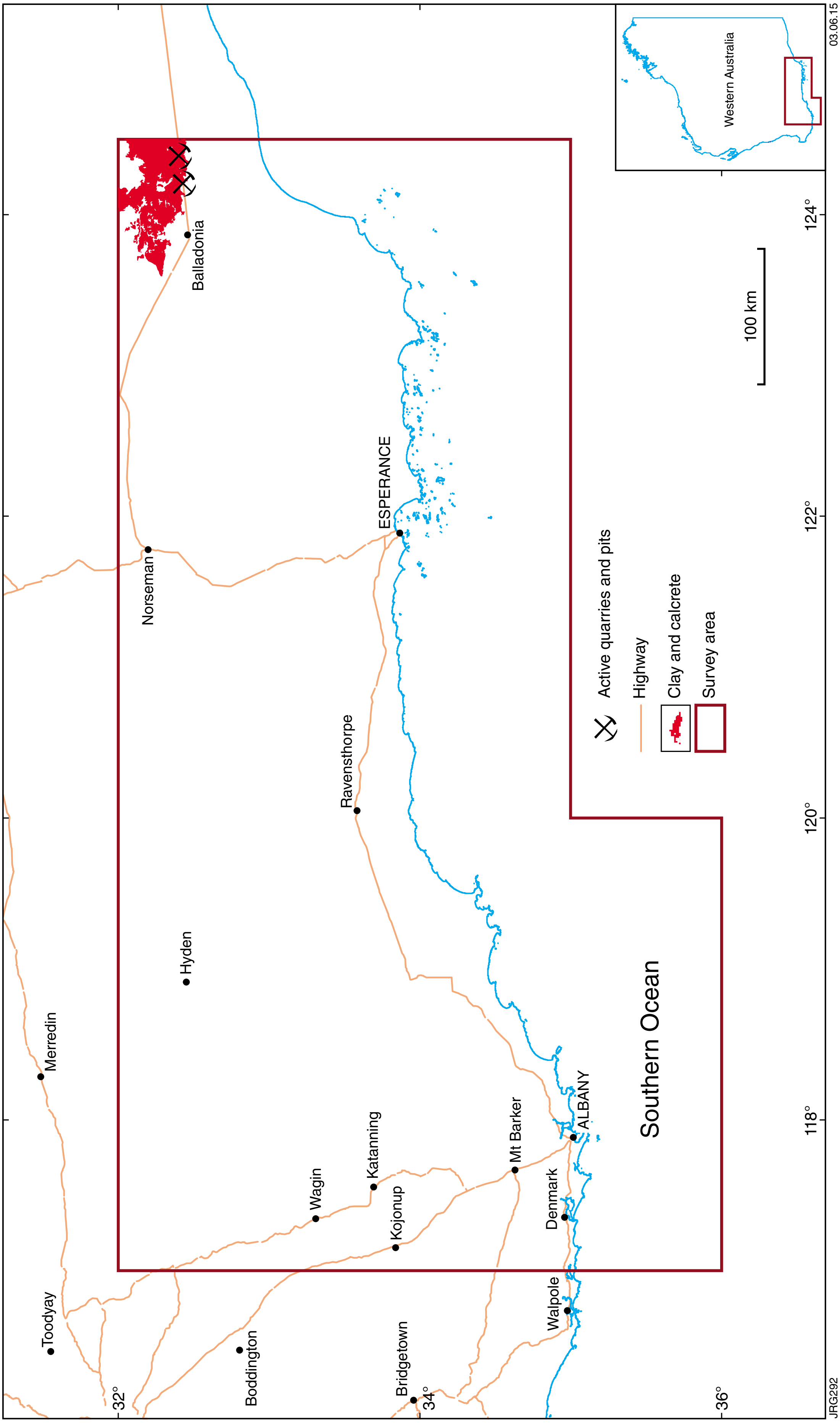

Figure 29. Extent of clay and calcrete resources

Resource information

Crushed calcrete from the clay and calcrete resource has been used extensively for roadbase for the Eyre Highway. Two pits along the highway are currently active with a further 18 known inactive pits also along the highway (Fig. 30). The clay and calcrete is a potentially large source of crushed limestone, but this potential is constrained to some extent by possible contamination from the enclosing clay and its remoteness from all but very local potential markets. The quality of the clay and calcrete resources is unknown.

Bedrock limestone resources

Overview

Within the survey area five geological units — Cowan Dolomite, Nanarup Limestone Member, Norseman Limestone, Nullarbor Limestone, Toolinna Limestone — have the potential to provide resources of limestone. However, only one of the geological units, the Nanarup Limestone Member, which is worked as a source of agricultural lime, is close to prospective markets. The two geological units in the Norseman area — Cowan Dolomite and Norseman Limestone — are of very limited extent. Further, the Nullarbor Limestone and Toolinna Limestone in the far east of the survey area have the potential to service only local markets.

Pale brown limestone

Geology

Six small, widely scattered outcrops of pale brown limestone are found in a belt between Nanarup, 14 km east of Albany and Bremer Bay (Fig. 31). In outcrop the limestone is very pale brown, friable, vuggy and fine to medium grained, principally contains subrounded quartz grains and shell debris and is generally highly fossiliferous (Gozzard, 1989a). The fossils in the pale brown limestone include foraminifera, echinoids, bryozoans, brachiopods and molluscs and indicate deposition in shallow, warm, marine conditions during the Late Eocene (33.9 to 38 million years ago (Cockbain, 1968b). The limestone belongs to the Nanarup Limestone Member of the Werillup Formation. Where it crops out, the pale brown limestone is at least 4.6 m thick, although the base and top are not exposed. However, detailed stratigraphic logs extracted from the DoW WIN database (Department of Water, 2014) show the pale brown limestone to have a maximum thickness of 27 m and, in combination with a desktop mapping exercise for this project, to be more extensive in the surface and subsurface than previously thought (Figs 31 and 32).

Resource information

The pale brown limestone is worked almost exclusively for high-quality agricultural lime (Gazey and Gartner, 2009; Gazey, 2011, 2013). Currently, there are four active pits in the survey area — Nanarup, Manypeaks, Pallinup and Bremer Bay (Fig. 31), with a further two inactive pits at Manypeaks and one at Pallinup. The active limestone pits at Nanarup, Manypeaks and Bremer Bay are covered by extractive industry licences. The pale brown limestone is a regionally significant limestone resource agricultural lime for the Great Southern Development and western South Coast Natural Resource Management regions. Analysis of five samples of the pale brown limestone show $CaCO_3$ values range from 47.7 to 85.9% with four being greater than 72% $CaCO_3$ (Appendix). Magnesium oxide values are consistently low, being less than 1%. Measured neutralizing values range from 70 to 90.

Although the surface extent of the outcrops of pale brown limestone is limited, its subsurface extent was poorly known prior to this project. To help refine the subsurface extent of the pale brown limestone (Nanarup Limestone Member) 33 boreholes with detailed stratigraphic logs were extracted from the DoW WIN database (Department of Water, 2014). These stratigraphic logs, which show depths to, thicknesses of, and lithologies of the pale brown limestone, were used in combination with remapped surface geological information to interpret the subsurface extent of the pale brown limestone. These data were used to recognize two further categories of the pale brown limestone (Nanarup Limestone Member). Limestone at depths of generally less than 20 m is identified as a potential resource, whereas limestone at depths of up to 40 m is categorized as a possible resource (Fig. 32).

Grey limestone

Geology

The Nullarbor Plain, in the far northeast of the survey area, is completely underlain by strongly cemented limestone (Fig. 33). The limestone is generally a hard, grey, poorly sorted, medium- to coarse-grained fossiliferous limestone. Foraminifera, coralline algae, bivalves and gastropods form the principal components of the grey limestone. The grey limestone constitutes the Nullarbor Limestone geological unit, which probably does not exceed 15 m in thickness in the study area (Doepel and Lowry, 1970a) although much further east recent drilling showed thicknesses of several tens of metres. The contained foraminifera indicate a Lower Miocene age (23 to 16 million years) for the grey limestone (Lowry, 1970; Doepel and Lowry, 1970a; O'Connell, 2011). O'Connell (2011) suggested that deposition of the grey limestone took place under subtropical conditions, principally on seagrass banks on the flat bottom of a wide shelf sea of normal salinity within the Eucla Basin.

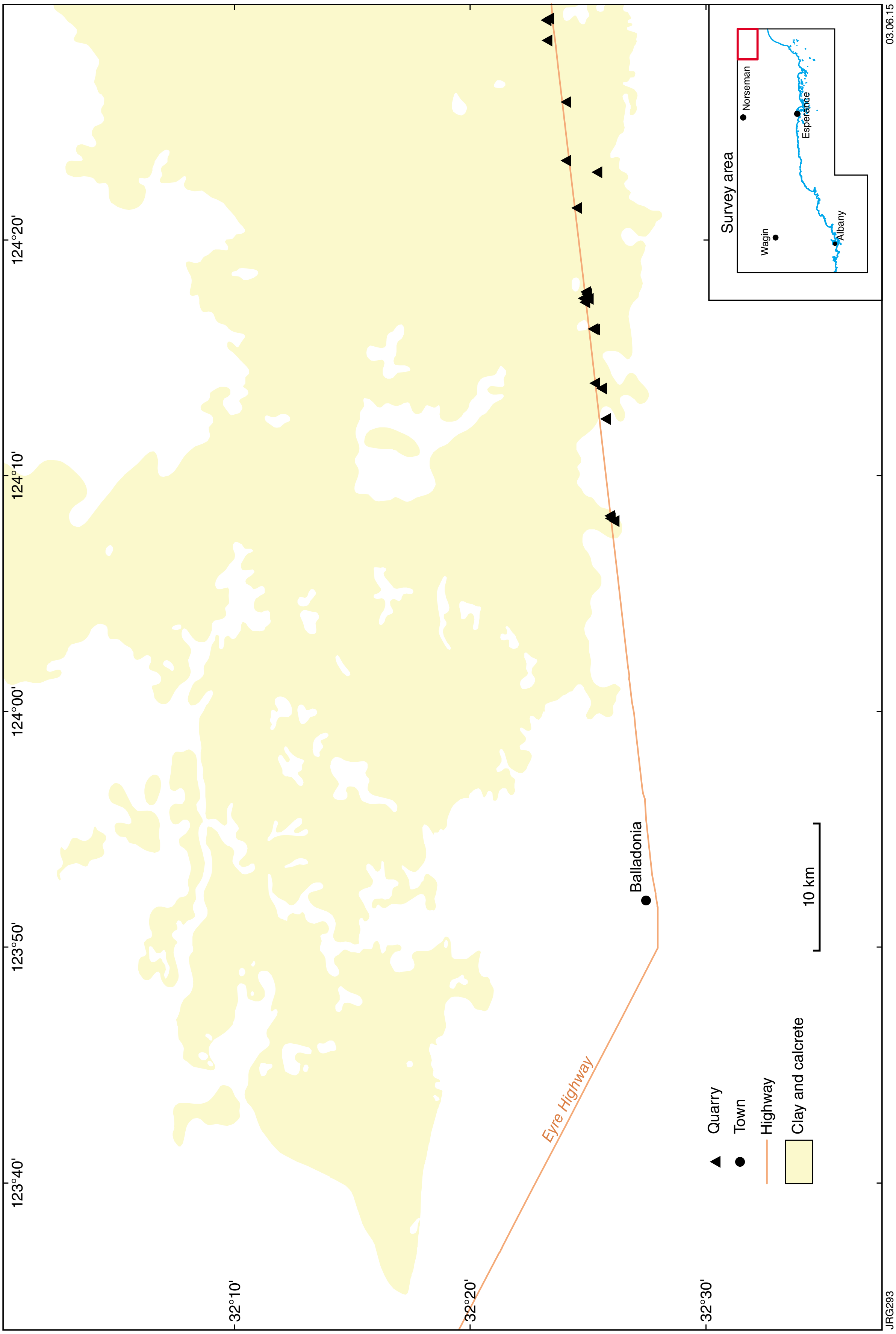

Figure 30. Extent of clay and calcrete resources near Balladonia

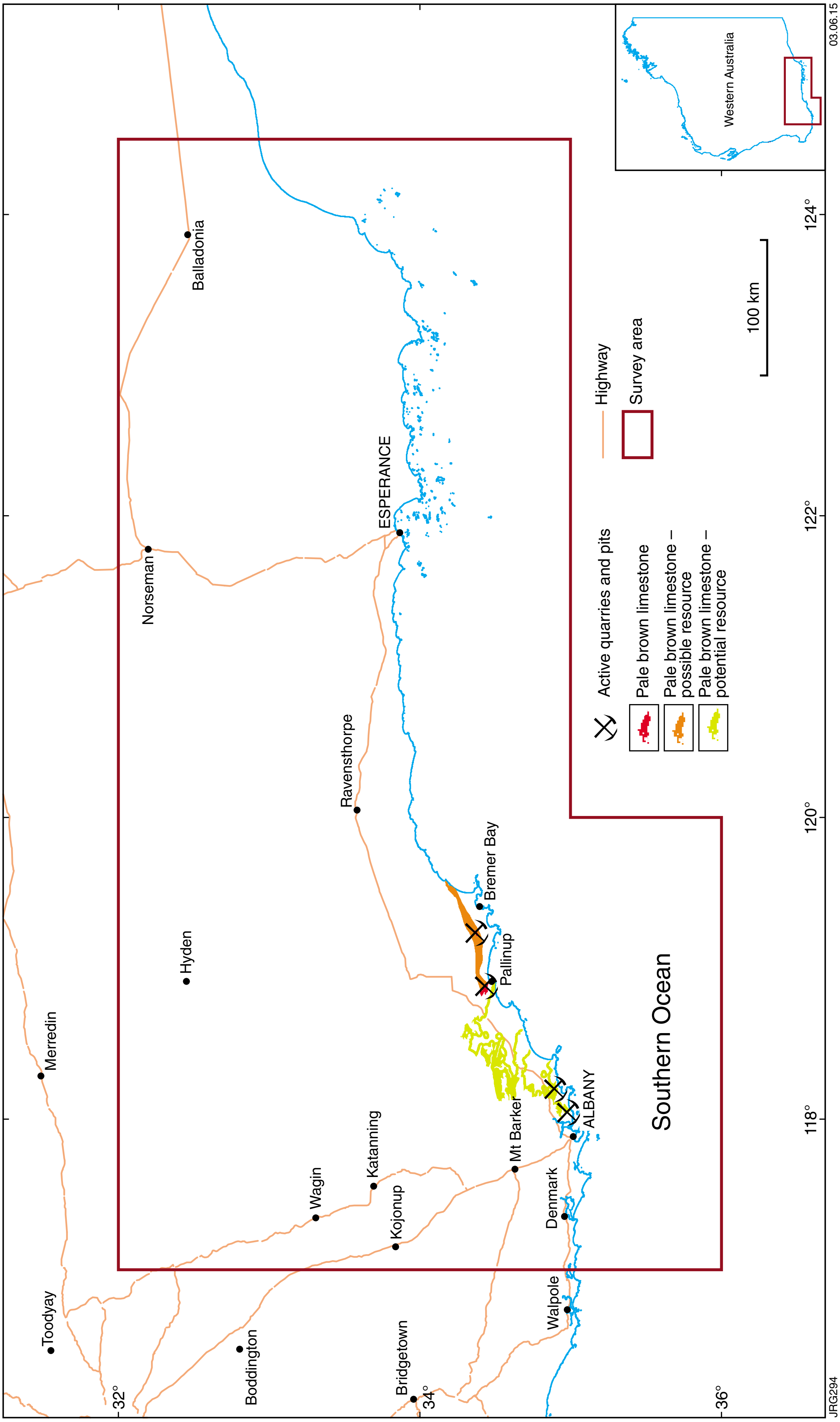

Figure 31. Extent of pale brown limestone resources

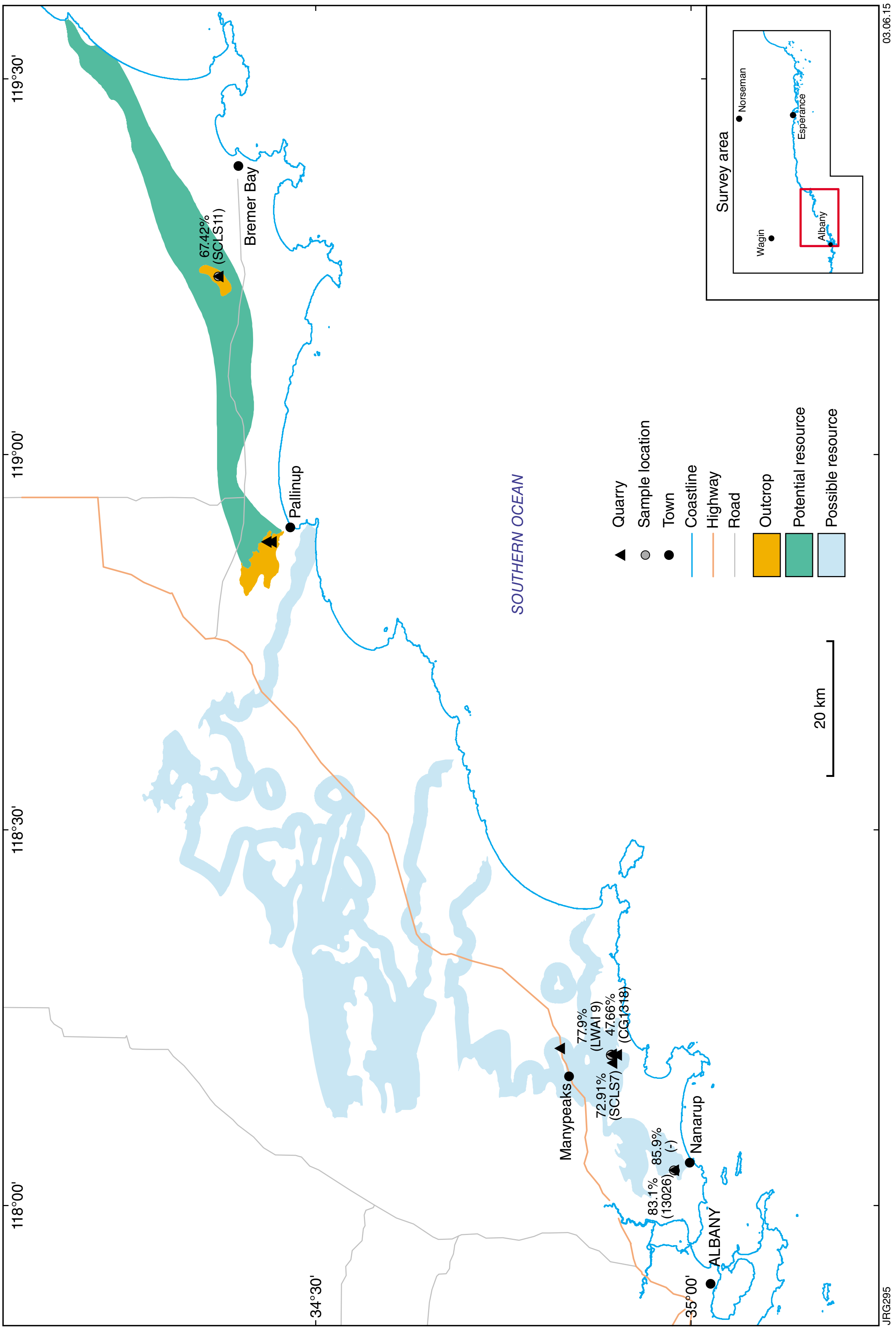

Figure 32. Pale brown limestone resources between Albany and Bremer Bay

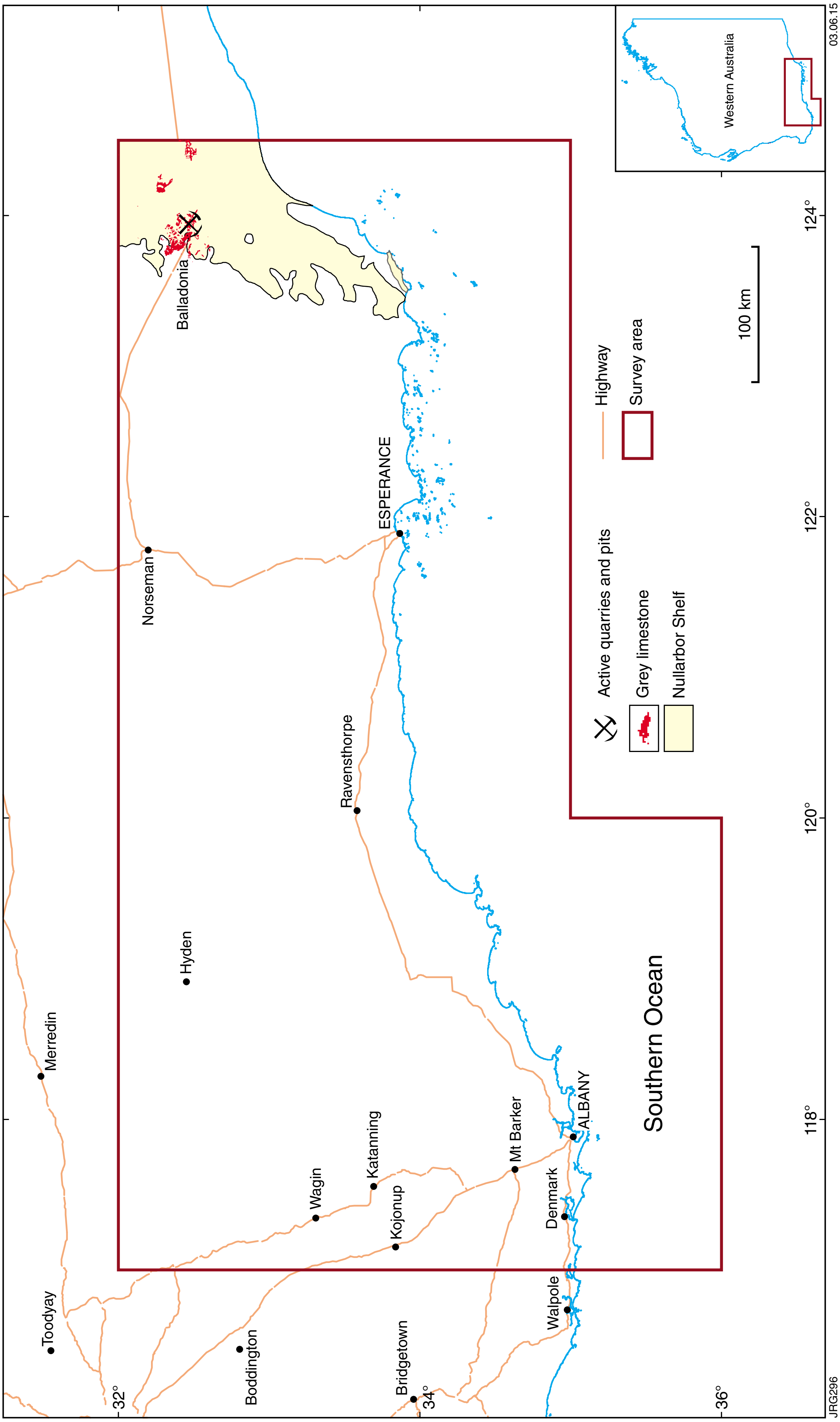

Figure 33. Extent of grey limestone resources

Resource information

There is a single known active limestone pit 7.5 km east of Balladonia homestead that is intermittently worked for road aggregate (Figs 33 and 34). The quality of the grey limestone is unknown. The subsurface extent of the limestone is constrained by the extent of the Nullarbor Shelf sub-basin of the Eucla Basin (Figs 33 and 34). Because of its remoteness, the grey limestone is considered to be of significance as a limestone resource for local purposes only.

White limestone

Geology

White limestone outcrops in the far east of the survey area where it is well exposed in a long but very narrow belt along the Wylie Scarp from Bilbunya on the survey area's eastern boundary to Israelite Bay to the southwest (Fig. 35). The limestone continues to the west under an extensive cover of younger rocks and surficial material but its extent, depth and thickness in the subsurface is unknown. The subsurface extent of the limestone is constrained by the extent of the Nullarbor Shelf sub-basin of the Eucla Basin (Fig. 35). The limestone is part of the Abrakurrie Limestone and ranges from white to orange brown, the latter colour being partly related to staining by clay produced by weathering. It is typically a medium- to very coarse-grained, porous to indurated limestone largely composed of rod-like segments of bryozoa. Other fossils include echinoids, molluscs and foraminifera (Lowry, 1970; Lowry and Doepel, 1974; O'Connell, 2011). Known thicknesses of the white limestone range from 55 m to 67 m at Point Culver, 19 km east of the survey area (Lowry, 1970). The fossil assemblage is indicative of an Upper Eocene age (33.9 to 38 million years ago) for the limestone with deposition taking place along the inner part of a wide cool-water continental shelf comparable with modern sediments of the Great Australian Bight (Lowry, 1970; O'Connell, 2011).

Resource information

There are no known workings in the white limestone and no analyses. However, almost the whole extent of the outcrop of the white limestone is within the Nuytsland Class 'A' Nature Reserve and is therefore effectively unavailable for exploitation (Fig. 36). Notwithstanding this impediment, because of its remoteness, limited surface extent and unknown subsurface extent the white limestone is considered to be of relative insignificance as a limestone resource for all except very local purposes.

Sandy limestone

Geology

Sandy limestone resources are found as a group of five very small outcrops close to the eastern end of the Lake Cowan causeway at Norseman (Figs 37 and 38). Two further small isolated outcrops are found 10.5 km east of Buldania Rocks and on the western margin of a claypan 5 km northeast of Lake Gilmore respectively (Fig. 37). All outcrops are part of the Norseman Formation geological unit (Clarke et al., 2003). The Norseman Formation forms knolls and low rises and is a variably cemented, massive to weakly bedded fossiliferous sandy limestone to fine-grained sandstone. The sandy limestone is commonly silicified and patchy dolomitization has been recognized (Doepel, 1973). The fossils identified within the formation include molluscs, gastropods, bryozoans, echinoids, corals and foraminifera. The sandy limestone in the survey area is relatively thin. A maximum known thickness of 9.1 m is found outside the survey area near Binneringie homestead, 70 km northeast of Norseman. Based on the contained foraminifera, Cockbain (1968b) considered the Norseman Formation to be Upper Eocene (33.9 to 38 million years ago) and suggested that it is probably laterally equivalent to the Cowan Dolomite (described below) and was deposited in more nearshore conditions in the same arm of the sea that extended northwards from Esperance towards Kalgoorlie. Also based on the contained foraminifera Cockbain (1968a) suggested that the Norseman Formation correlates with the pale brown limestone (Nanarup Limestone Member, see above).

Resource information

There are no known workings of the sandy limestone resource and, within the survey area there are no analyses. However, in the mid-1970s Western Mining Corporation drilled 11 boreholes in the Binneringie limestone outcrop at the northern end of Lake Cowan (Western Mining Corporation Ltd, 1976). Reported analyses indicate an average of 53.5% $CaCO_3$ for the material with some pockets of higher grade material. Considering the remoteness and size of the individual deposits of sandy limestone in the survey area, this material is considered to have insufficient potential to be commercially exploitable.

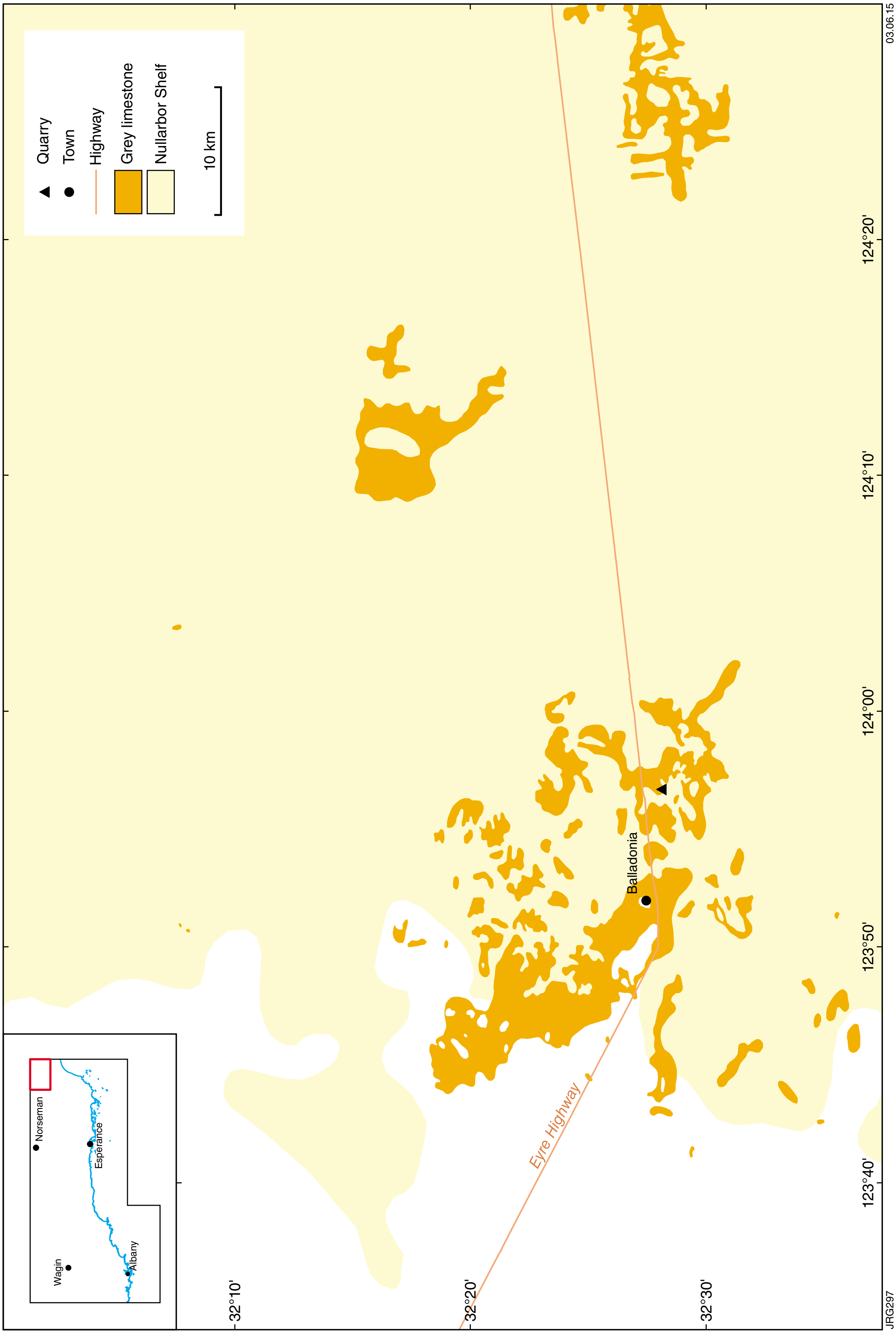

Figure 34. Extent of grey limestone resources near Balladonia

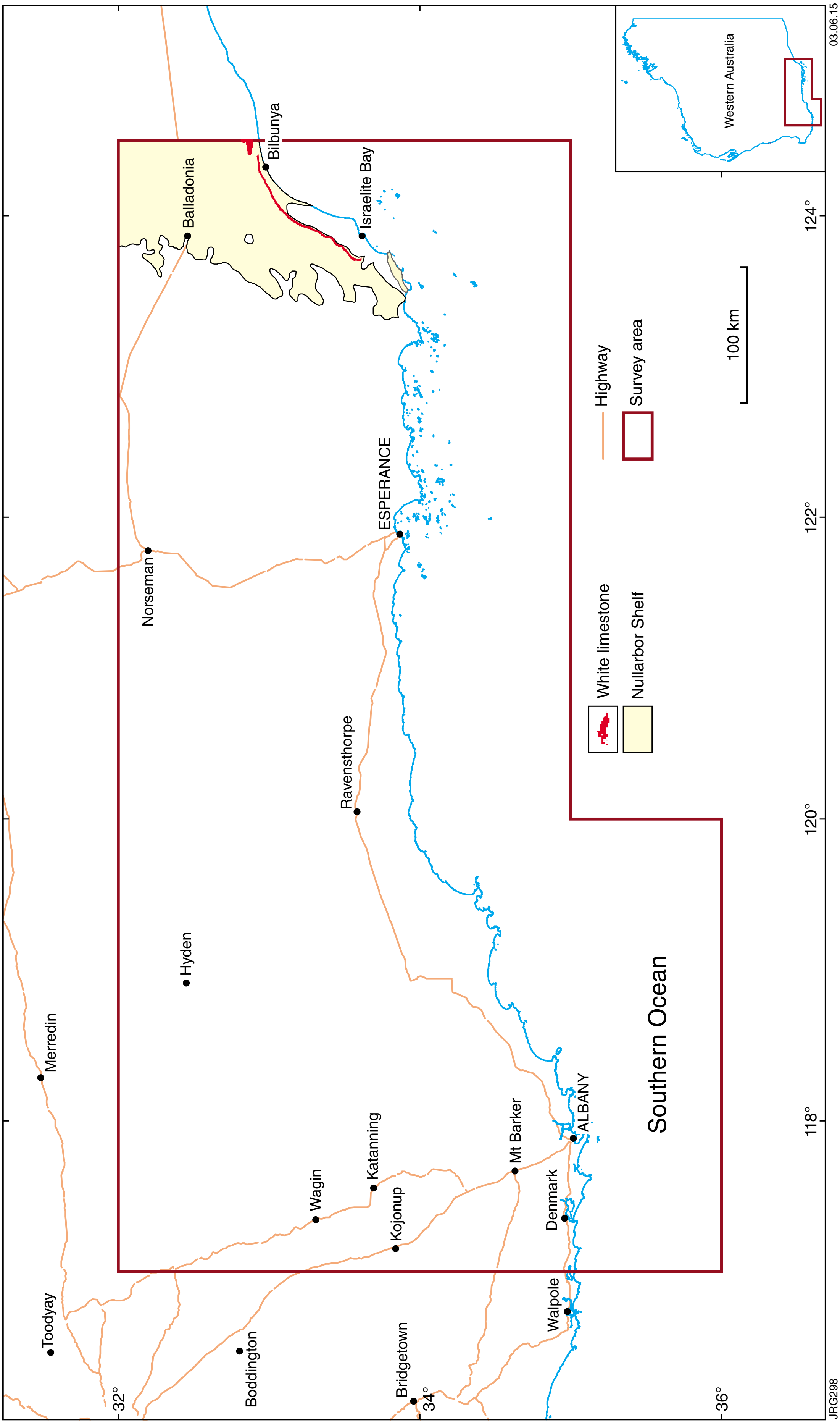

Figure 35. Extent of white limestone resources

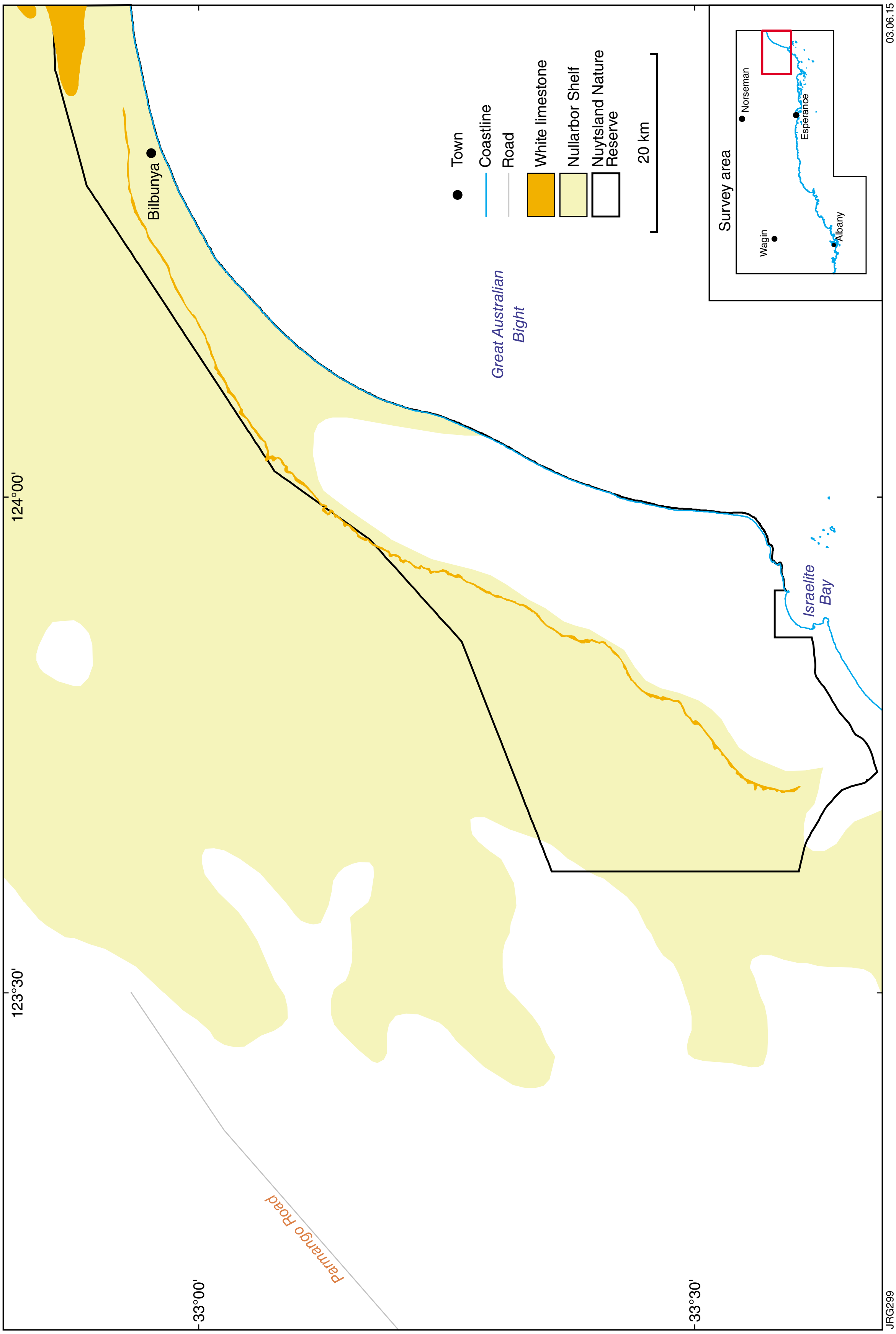

Figure 36. White limestone resources between Bilbunya and Israelite Bay

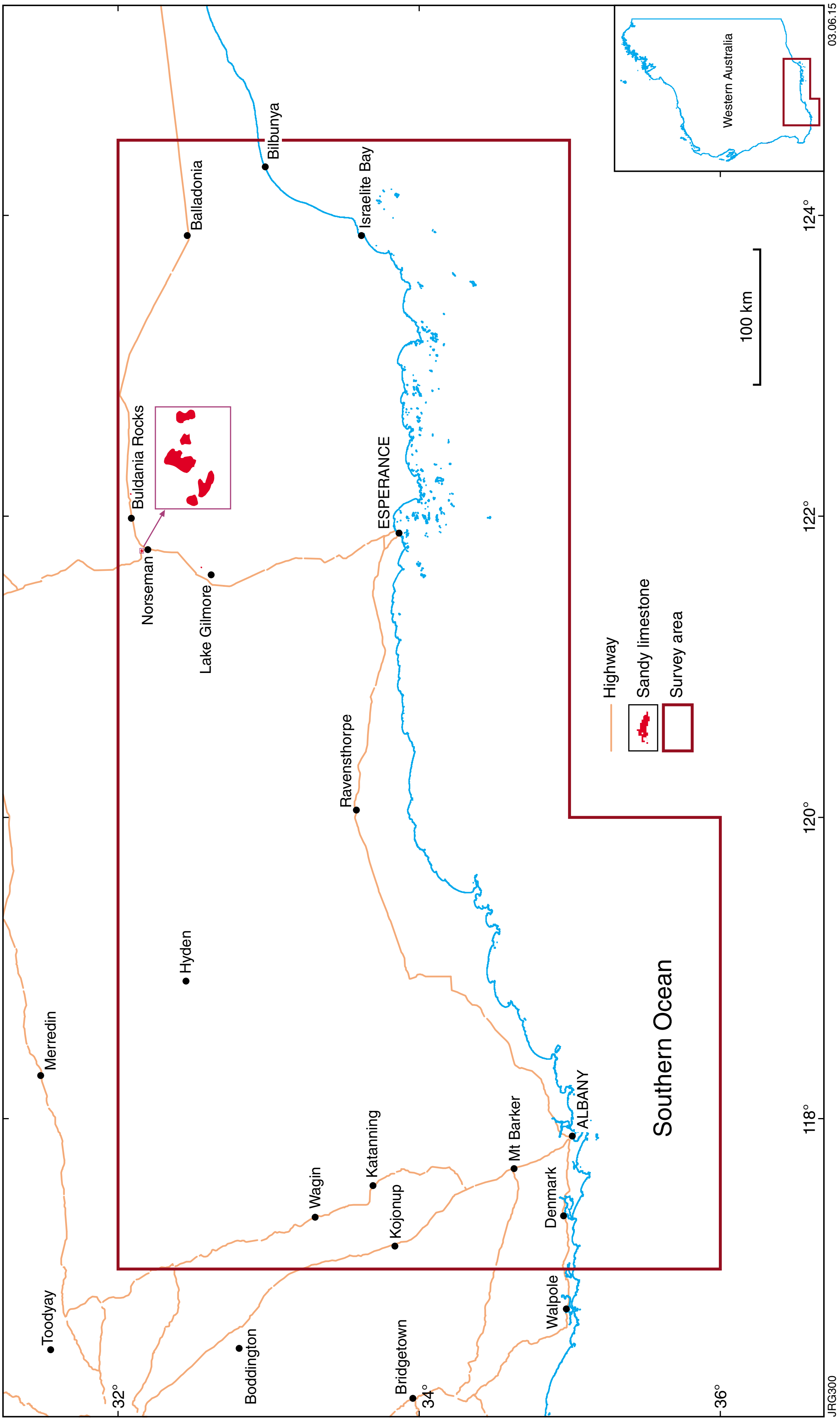

Figure 37. Extent of sandy limestone resources

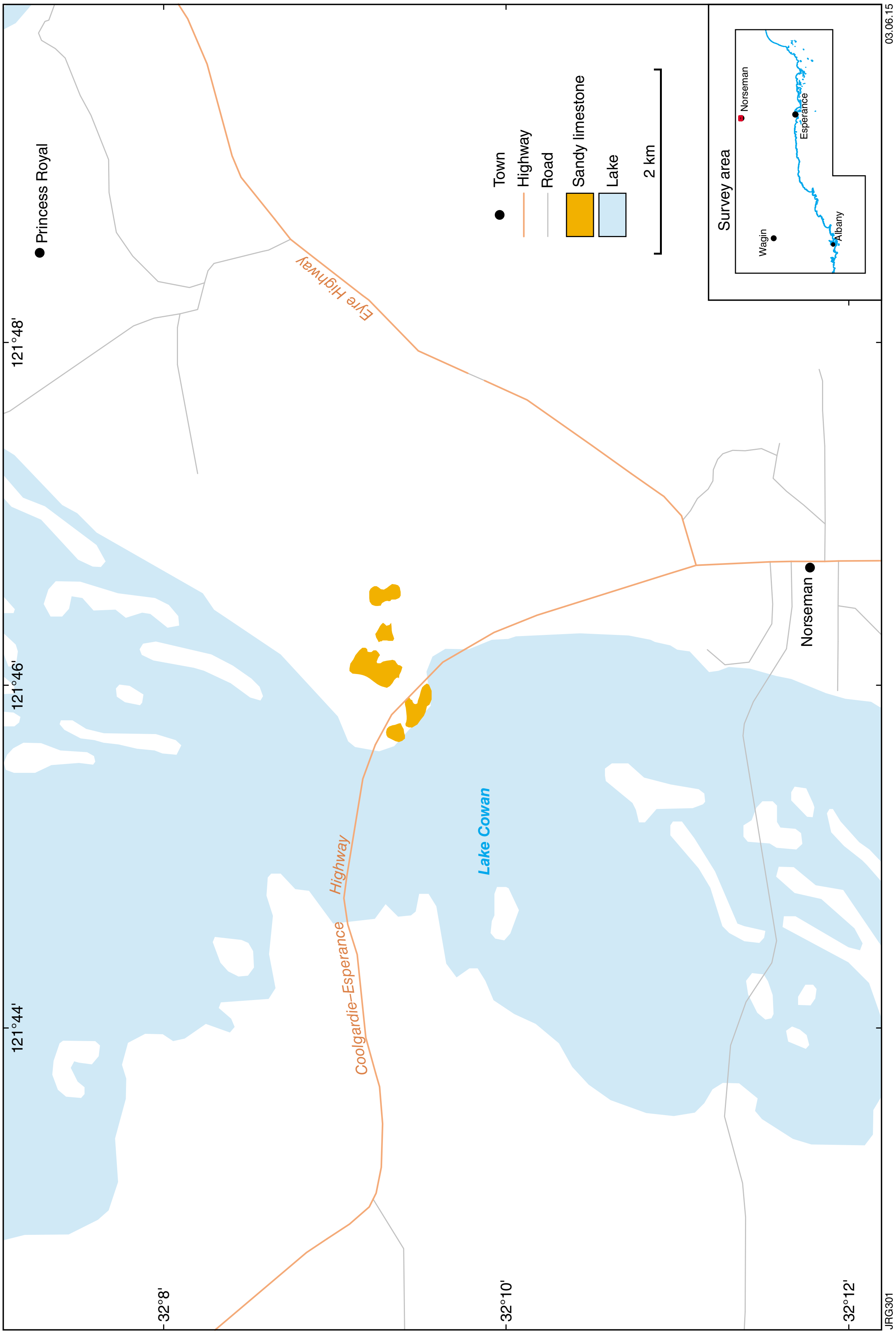

Figure 38. Sandy limestone resources near Norseman

Dolomite

Geology

Dolomite is found as relatively small, widely scattered outcrops in knolls and low rises immediately north of Norseman, 10 km northeast and 27 km east of Norseman (Figs 39 and 40). The dolomite is part of the Cowan Dolomite geological unit and consists of unfossiliferous, massive, very fine-grained white to grey dolomite to dolomitic carbonate mudstone, which locally can contain fragments of quartz and ferruginous chert nodules. It reaches its maximum thickness of approximately 12 m at Lake Brazier (Fig. 40). Because of its association with the Norseman Limestone (see sandy limestone above), the Cowan Dolomite is thought to have been deposited during the Late Eocene (33.9 to 38 million years ago) in a shallow water, possibly hypersaline, arm of the sea that extended northwards from Esperance towards Kalgoorlie when the sea level was about 400 m above present day levels (Cockbain, 1968b; Doepel, 1973).

Resource information

There are no known workings in the dolomite and no analyses. Because of its limited extent the dolomite is considered to be of relative insignificance as a limestone resource for all except local purposes.

Summary

Resources of limesand and limestone are perceived to be widespread in Western Australia. While the geological units that contain these resources are extensive, the quality of the material varies widely, with no apparent consistent trend. In contrast to the west coast of Western Australia, the south coast has fewer sources of high-grade limesand and limestone, with the south coast hinterland having only a limited number of lower quality sources of lime.

This Record and its accompanying digital dataset consolidate all existing published and unpublished base mapping and resource quality information and identify seven surficial and five bedrock limesand and limestone resource units. Of the seven surficial units, limesand and limestone are the only ones that contain strategic resources. While the south coast limesand is a major agricultural lime resource, it is of overall lower quality than the west coast resources. The large variability in carbonate content of the limesand makes it difficult to predict the location of potential high-grade deposits outside the areas of known high-quality material near Denmark and Esperance.

In contrast, the quality of the limestone of the lateral equivalents of the Tamala Limestone geological unit is better overall than that of the limesand. Not only is it a valuable source of agricultural lime and road aggregate, it has the potential for use in other industries where high-grade limestone is required. The area between Denmark and Albany contains significant high-grade limestone resources and should be the focus of future exploration.

The known deposits of dolomitic sand are concentrated in the west of the study area and are a valuable source of agricultural lime given their proximity to farmers in the Great Southern and southern Wheatbelt Development regions. Although further exploration should be concentrated in the west of the study area, it is not possible to predict the location of similar deposits other than those found in dunes and lunettes fringing lakes and ancient drainage flats.

The remaining potential surficial resources — clay and calcrete, magnesite, residual calcrete, valley calcrete — generally consist of small, isolated outcrops in remote locations suitable only for local potential markets. Quality information for these potential resources is lacking.

Of the five bedrock limestone units, the pale brown limestone of the Nanarup Limestone Member geological unit has the greatest potential as a readily available source of lime. It is worked almost exclusively for high-quality agricultural lime between Albany and Bremer Bay where it is considered to be a strategic limestone resource for the Great Southern Development and western South Coast Natural Resource Management regions. New mapping as part of this project has extended the known surface and interpreted subsurface extent of the Nanarup Limestone Member.

The remaining four bedrock limestone units — grey limestone, white limestone, sandy limestone, and dolomite — are only found in remote locations. This would make them relatively unimportant as potential limestone resources for agricultural markets. However, they may have the potential to supply industrial markets, for example, the mining industry in the Eastern Goldfields.

Acknowledgements

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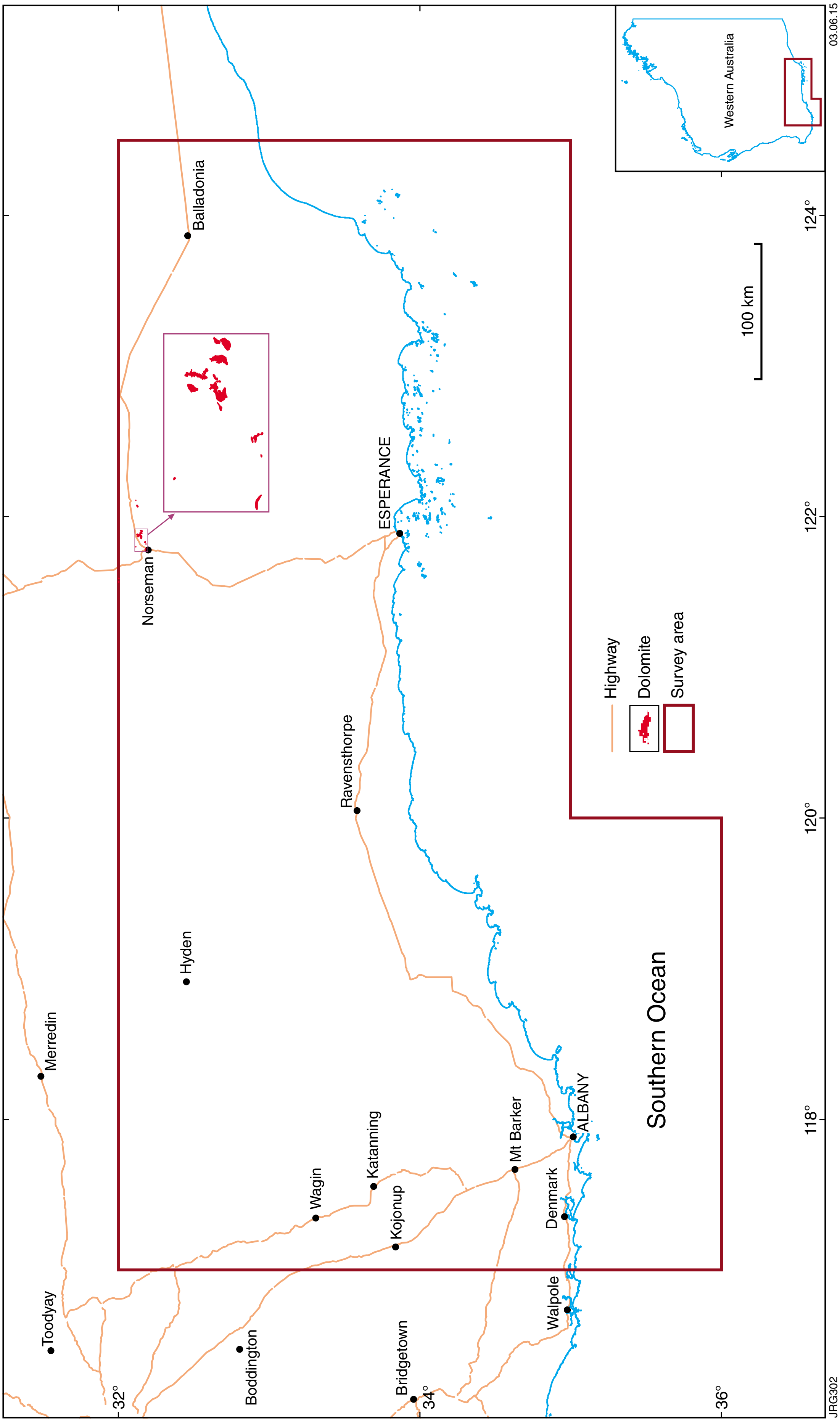

Figure 39. Extent of dolomite resources

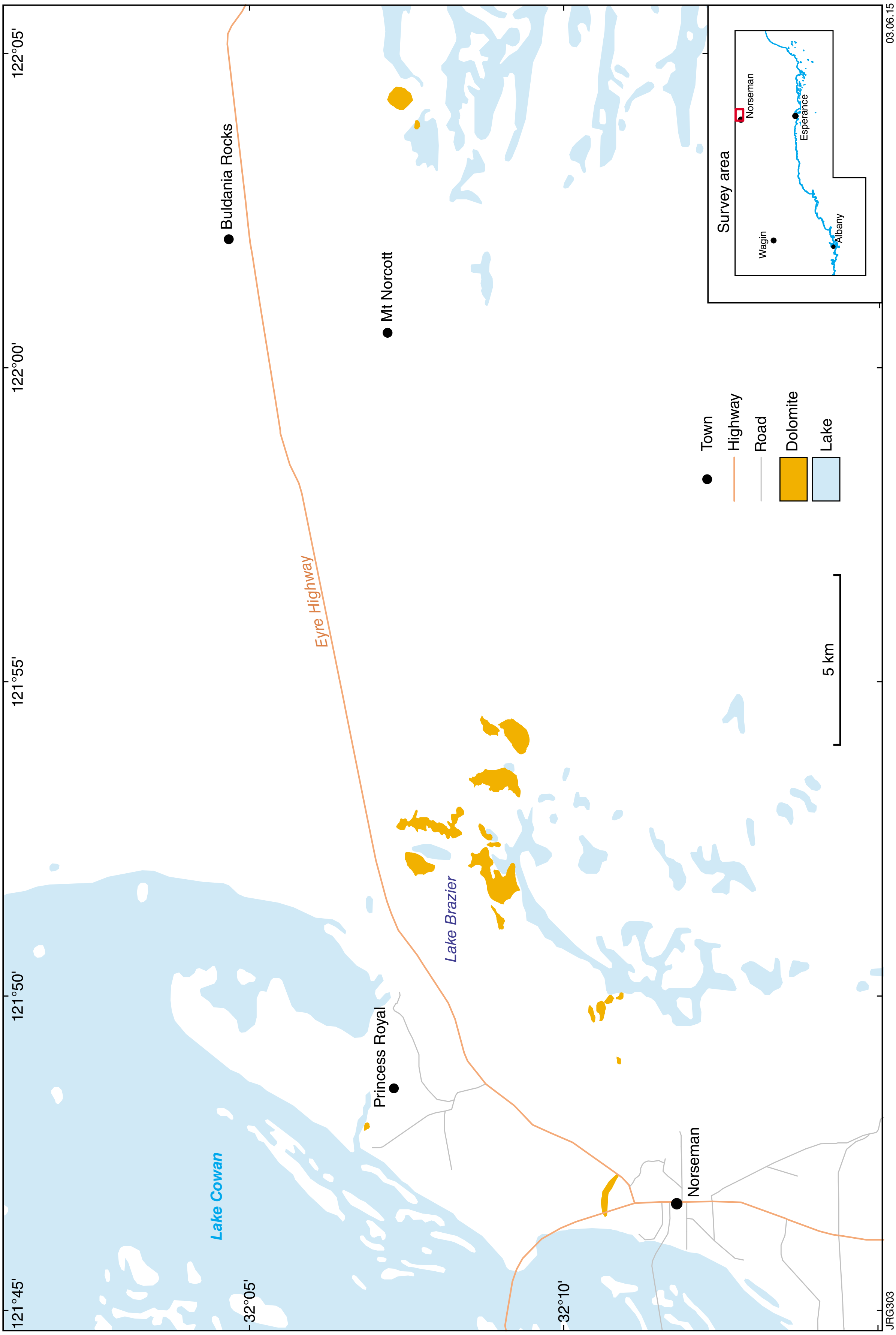

Figure 40. Extent of dolomite resources near Norseman

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Appendix

Chemical analyses of limesand and limestone

Site ID	*Basic raw material type*	*Sample no.*	*$CaCO_3$*	*CaO*	*MgO*	*Acid insoluble residue*	*Neutralizing value (measured)*	*Neutralizing value (calculated)*	*Geology*
				Percentage					
LWAI 26	Dolomitic sand	LWAI 26	26.5	18.8	14.6		63.5		Alluvium
SCLS37	Dolomitic sand	SCLS37	31.2	17.5	15.6		71.9		Alluvium
LWAI 25	Dolomitic sand	LWAI 25	44.7	25.0	8.8		67.2		Ancient drainage flats
SCLS40	Dolomitic sand	SCLS40	46.2	25.9	9.8		72.9		Ancient drainage flats
SCLS39	Dolomitic sand	SCLS39	36.7	20.6	15.3		76.7		Calcrete
LWAI 8	Dolomitic sand	LWAI 8	32.7	18.3	13.1		65.0		Older alluvium
SCLS12	Dolomitic sand	SCLS12	31.7	17.8	14.1		67.8		Older alluvium
24271NW16	Limesand	13011	22.7	12.7	0.7	47.7		24.5	Estuarine sand
24271NW17	Limesand	13007	15.4	8.6	0.8	82.1		17.1	Estuarine sand
24282SE7	Limesand	13023	46.7	26.1	0.8	47.8		48.7	Estuarine sand
59851-59854	Limesand	59851-59854	44.3	24.9					Coastal dune sand
59855-59859	Limesand	59855-59859	54.9	30.8					Coastal dune sand
59860-59868	Limesand	59860-59868	29.5	16.6					Coastal dune sand
59869-59872	Limesand	59869-59872	59.8	33.5					Coastal dune sand
59873-59876	Limesand	59873-59876	60.3	33.8					Coastal dune sand
59953	Limesand	59953	74.5	41.7					Coastal dune sand
59954	Limesand	59954	75.8	42.5					Coastal dune sand
59958	Limesand	59958	20.5	11.5					Coastal dune sand
59959	Limesand	59959	31.0	17.4					Coastal dune sand
59965	Limesand	59965	54.8	30.7					Coastal dune sand
Bandy Creek	Limesand	175015	58.2	32.6	1.5			61.9	Coastal dune sand
Boyatup Lime Pit	Limesand	148202	71.1	39.8	2.8	17.6		78.3	Coastal dune sand
Boyatup Lime Pit	Limesand	148203	71.5	40.1	2.8	16.6		78.4	Coastal dune sand
Boyatup Lime Pit	Limesand	148201	76.8	43.0	1.4	12.5		80.2	Coastal dune sand

Site ID	*Basic raw material type*	*Sample no.*	*$CaCO_3$*	*CaO*	*MgO*	*Acid insoluble residue*	*Neutralizing value (measured)*	*Neutralizing value (calculated)*	*Geology*
Boyatup Lime Pit	Limesand	148204	75.0	42.0	2.3	13.6		80.8	Coastal dune sand
Freeman Road Pit	Limesand	148209	28.7	16.1	1.1	61.1		31.5	Coastal dune sand
Kipping Road Pit	Limesand	148207	27.1	15.2	0.9	63.2		29.5	Coastal dune sand
Kipping Road Pit	Limesand	148208	27.1	15.2	0.9	6.3		29.6	Coastal dune sand
Lake Quallilup	Limesand	175024A	94.6	37.9	2.9		72.7		Coastal dune sand
Lake Quallilup	Limesand	148213	17.5	9.8	0.7	78.6		19.2	Coastal dune sand
LWAI 10	Limesand	LWAI 10	62.2	34.8	2.3		70.7		Coastal dune sand
SCLS10	Limesand	SCLS10	64.2	35.9	2.5		71.5		Coastal dune sand
SCLS5	Limesand	SCLS5	79.4	44.5	1.0		80.7		Coastal dune sand
SCLS9	Limesand	SCLS9	39.5	22.1	0.3		41.5		Coastal dune sand
Stockyard Road	Limesand	175023A	46.1	25.9	0.8		32.3		Coastal dune sand
Thompson Street	Limesand	148210	40.1	22.5	1.3	49.9		43.5	Coastal dune sand
Thompson Street	Limesand	148211	51.7	29.0	1.2	45.6		54.7	Coastal dune sand
Tamarine Road	Limestone	117330	88.6	49.6	1.6			92.8	Calcrete
24271NE10	Limestone	94315	82.3	46.0	0.6	14.3		83.6	Estuarine limestone
25283SW11	Limestone	13027	13.4	7.5	0.4	84.3		14.5	Estuarine limestone
25283SW8	Limestone	13026	83.1	46.4	1.1	12.0		85.9	Nanarup Limestone Member
CG1318	Limestone	CG1318	47.7	26.7	1.0		69.4	52.3	Nanarup Limestone Member
LWAI 9	Limestone	LWAI 9	77.9	43.7	0.7		76.4		Nanarup Limestone Member
Nanarup Lime	Limestone		85.9	48.1	0.8		90.1		Nanarup Limestone Member
SCLS7	Limestone	SCLS7	72.9	40.9	0.8		76.2		Nanarup Limestone Member
25283SW10	Limestone	13025	11.3	6.3	0.5	85.9		12.4	Coastal dune sand
SCLS11	Limestone	SCLS11	67.4	37.8	2.7		74.2		Sandplain
13006	Limestone	13006	83.9	47.7	0.9	10.3		87.4	Coastal limestone
140318	Limestone	140318	75.8	42.5	0.9	19.1		78.0	Coastal limestone
140319	Limestone	140319	92.3	51.9	0.9	6.0		95.1	Coastal limestone
140320	Limestone	140320	89.7	50.2	0.8	6.5		91.9	Coastal limestone
140321	Limestone	140321	61.3	34.3	0.9	36.0		63.7	Coastal limestone
140322	Limestone	140322	64.9	36.4	1.0	31.4		67.3	Coastal limestone
140324	Limestone	140324	72.8	40.8	1.2	21.3		75.8	Coastal limestone
140326	Limestone	140326	59.8	33.5	0.4	38.4		60.8	Coastal limestone
140327	Limestone	140327	76.7	43.0	0.6	18.9		78.3	Coastal limestone
24271NE11	Limestone	94317	68.2	38.1	1.1	25.7		70.7	Coastal limestone

Site ID	*Basic raw material type*	*Sample no.*	*$CaCO_3$*	*CaO*	*MgO*	*Acid insoluble residue*	*Neutralizing value (measured)*	*Neutralizing value (calculated)*	*Geology*
24271NE7	Limestone	13003	94.9	53.0	0.4	2.4		95.7	Coastal limestone
24271NE8	Limestone	13004	82.3	46.0	1.1	12.9		85.0	Coastal limestone
24271NE9	Limestone	13001	68.6	38.3	0.8	27.3		70.5	Coastal limestone
24271NW11	Limestone	13014	65.5	36.6	0.0	33.9		65.6	Coastal limestone
24271NW12	Limestone	13016	41.5	23.2	0.0	56.7		41.6	Coastal limestone
24271NW13	Limestone	13032	94.9	53.0	0.5	1.4		96.1	Coastal limestone
24271NW14	Limestone	13031	11.3	6.3	0.5	86.3		12.7	Coastal limestone
24271NW15	Limestone	13012	10.1	5.6	0.1	88.3		10.2	Coastal limestone
24271NW18	Limestone	13008	9.8	5.4	0.3	87.8		10.4	Coastal limestone
24271NW19	Limestone	13009	89.5	50.0	0.7	5.3		91.0	Coastal limestone
24271NW20	Limestone	13010	76.1	42.5	0.9	19.0		78.3	Coastal limestone
24271NW21	Limestone	13005	75.9	42.4	0.6	20.6		77.2	Coastal limestone
24271NW22	Limestone	13002	90.6	50.6	0.6	6.4		92.0	Coastal limestone
24271NW23	Limestone	94301	58.8	32.7	0.1	39.6		58.6	Coastal limestone
24271NW24	Limestone	94302	65.0	36.3	0.4	34.3		65.9	Coastal limestone
24271NW25	Limestone	94304	23.6	13.2	0.1	75.8		23.9	Coastal limestone
24271NW26	Limestone	94308	50.1	28.0	0.4	49.6		51.1	Coastal limestone
24271NW27	Limestone	94309	46.2	25.8	0.5	52.0		47.4	Coastal limestone
24274NE3	Limestone	13017	82.9	46.3	1.1	12.3		85.5	Coastal limestone
24274NE4	Limestone	13015	77.5	43.3	1.3	16.5		80.8	Coastal limestone
24274NE5	Limestone	13013	93.4	52.2	0.7	1.7		95.0	Coastal limestone
24274NW10	Limestone	93593	60.7	33.9	1.5	34.6		64.4	Coastal limestone
24274NW11	Limestone	93594	55.0	30.7	1.0	42.9		57.3	Coastal limestone
24274NW3	Limestone	13020	63.7	35.6	1.7	30.8		68.0	Coastal limestone
24274NW4	Limestone	13022	90.9	50.8	1.1	3.85		93.6	Coastal limestone
24274NW5	Limestone	13021	84.1	47.0	2.3	9.6		89.7	Coastal limestone
24274NW6	Limestone	13019	55.7	31.1	0.5	41.3		56.9	Coastal limestone
24274NW7	Limestone	13018	81.4	45.5	0.9	13.8		83.6	Coastal limestone
24274NW8	Limestone	93589	78.2	43.7	0.8	18.1		80.0	Coastal limestone
24274NW9	Limestone	93591	64.4	36.0	1.2	32.7		67.4	Coastal limestone
25274NW2	Limestone	13024	93.4	52.2	1.4	0.8		96.7	Coastal limestone
25283SE1	Limestone	13030	14.7	8.24	0.3	82.4		15.4	Coastal limestone
25283SW9	Limestone	13028	11.7	6.55	0.3	85.8		12.6	Coastal limestone

Site ID	*Basic raw material type*	*Sample no.*	*$CaCO_3$*	*CaO*	*MgO*	*Acid insoluble residue*	*Neutralizing value (measured)*	*Neutralizing value (calculated)*	*Geology*
59877-59879	Limestone	59877-59879	28.6	16.0					Coastal limestone
59880-59884	Limestone	59880-59884	14.1	7.9					Coastal limestone
59887-59977	Limestone	59887-59977	77.2	43.2					Coastal limestone
59956	Limestone	59956	77.5	43.4					Coastal limestone
59967	Limestone	59967	88.8	49.8					Coastal limestone
59968	Limestone	59968	87.3	48.9					Coastal limestone
CG1317	Limestone	CG1317	54.4	30.5	1.0		75.6	43.5	Coastal limestone
LWAI 7	Limestone	LWAI 7	77.9	43.6	1.0		79.7		Coastal limestone
Ocean Beach Quarry BH1	Limestone	59971-59988	77.3	43.3					Coastal limestone
Ocean Beach Quarry BH2	Limestone	59989-59998	78.4	43.9					Coastal limestone
Ocean Beach Quarry BH3	Limestone	59999-109606	76.6	42.9					Coastal limestone
Ocean Beach Quarry BH4	Limestone	109607-109614	76.4	42.8					Coastal limestone
Ocean Beach Quarry BH5	Limestone	109615-109621	76.8	43.0					Coastal limestone
Ocean Beach Quarry BH6	Limestone	109622-109628	77.9	43.6					Coastal limestone
Ocean Beach Quarry BH7	Limestone	109929-109635	79.0	44.3					Coastal limestone
Ocean Beach Quarry BH8	Limestone	109636-109641	79.0	44.3					Coastal limestone
Ocean Beach Quarry BH9	Limestone	109642-109647	79.4	44.5					Coastal limestone
Ocean Beach Quarry BH10	Limestone	109648-109656	74.7	41.9					Coastal limestone
Ocean Beach Quarry BH12	Limestone	109660-109669	72.0	40.3					Coastal limestone
Ocean Beach Quarry BH13	Limestone	109670-109675	77.2	43.3					Coastal limestone
Ocean Beach Quarry BH14	Limestone	109676-109678	77.3	43.3					Coastal limestone
Ocean Beach Quarry BH15	Limestone	109679-109686	71.0	39.8					Coastal limestone
Ocean Beach Quarry BH16	Limestone	109687-109691	71.4	40.0					Coastal limestone
Ocean Beach Quarry BH17	Limestone	109692-109697	78.4	43.9					Coastal limestone
Quagi Headland	Limestone	148214	68.6	38.4	1.2	17.7		71.8	Coastal limestone
SCLS6	Limestone	SCLS6	54.2	30.4	1.3		60.1		Coastal limestone
SCLS8	Limestone	SCLS8	54.9	30.8	7.0		74.7		Coastal limestone
117301	Magnesite	117301	1.3	0.73	47.7			121.2	Sedimentary magnesite
117302	Magnesite	117302	1.3	0.74	48.1			122.2	Sedimentary magnesite
117304	Magnesite	117304	3.5	2.0	46.1			119.4	Residual magnesite
117305	Magnesite	117305	36.4	20.4	25.1			99.5	Residual magnesite
117306	Magnesite	117306	6.2	3.5	44.2			117.3	Residual magnesite
117307	Magnesite	117307	23.2	13.0	33.3			106.9	Residual magnesite

Site ID	Basic raw material type	Sample no.	$CaCO_3$	CaO	MgO	Acid insoluble residue	Neutralizing value (measured)	Neutralizing value (calculated)	Geology
117311	Magnesite	117311	0.8	0.5	48.0			121.4	Sedimentary magnesite
117312	Magnesite	117312	0.8	0.4	48.0			121.4	Sedimentary magnesite
117313	Magnesite	117313	1.0	0.6	47.8			121.1	Sedimentary magnesite
117314	Magnesite	117314	1.0	0.5	48.3			122.3	Sedimentary magnesite
117315	Magnesite	117315	1.5	0.9	47.2			120.2	Sedimentary magnesite
117316	Magnesite	117316	2.7	1.5	47.7			122.6	Sedimentary magnesite
117317	Magnesite	117317	1.0	0.5	48.2			122.1	Sedimentary magnesite
117318	Magnesite	117318	1.7	1.0	47.3			120.6	Residual magnesite
117319	Magnesite	117319	1.6	0.9	48.2			122.7	Sedimentary magnesite
117320	Magnesite	117320	3.2	1.8	46.2			119.4	Sedimentary magnesite
117321	Magnesite	117321	2.4	1.4	47.1			120.8	Residual magnesite
117322	Magnesite	117322	2.3	1.3	47.4			121.4	Residual magnesite
117323	Magnesite	117323	3.0	1.7	46.2			119.1	Residual magnesite
117324	Magnesite	177324	0.7	0.4	48.6			122.9	Residual magnesite
117325	Magnesite	117325	2.6	1.5	47.6			122.3	Residual magnesite
117326	Magnesite	117326	46.6	26.1	20.2			97.4	Residual magnesite
117327	Magnesite	117327	11.9	6.6	39.0			109.9	Residual magnesite
117328	Magnesite	117328	71.0	39.8	8.8			93.3	Residual magnesite
117329	Magnesite	117329	41.2	23.1	25.6			105.6	Residual magnesite
117331	Magnesite	117331	66.9	37.5	6.4			83.0	Residual magnesite
117332	Magnesite	117332	68.5	38.4	7.7			88.0	Residual magnesite
117333	Magnesite	117333	32.7	18.3	29.9			107.8	Residual magnesite
117337	Magnesite	117317	0.7	0.4	47.2			119.3	Residual magnesite
117338	Magnesite	117338	0.8	0.5	48.0			121.4	Residual magnesite

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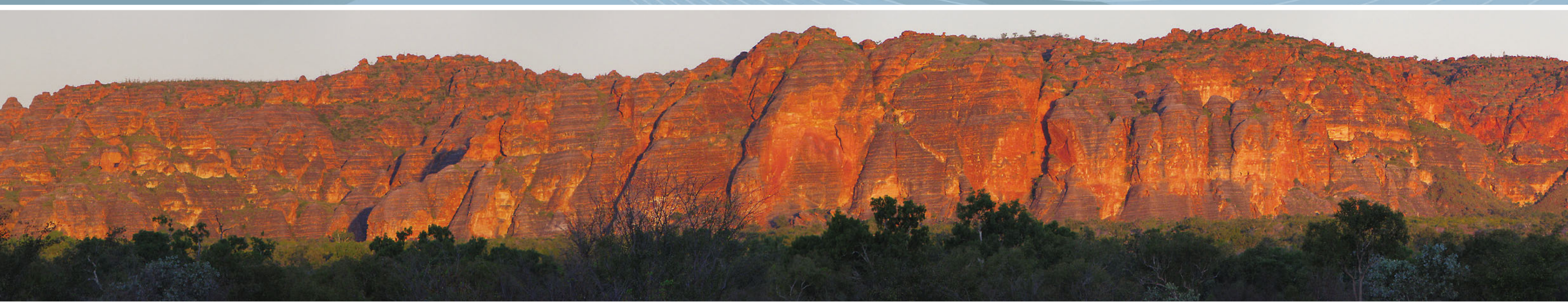
LIMESAND AND LIMESTONE RESOURCES OF SOUTHERN WESTERN AUSTRALIA



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