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Peter Harris, Andrew Heap, Vicki Passlow, Laura Sbaffi, Melissa Fellows, Rick Porter-Smith, Cameron Buchanan and James Daniell

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Geomorphic Features of the Continental Margin of Australia

Report to the National Oceans Office on the production of a consistent, high-quality bathymetric data grid and definition and description of geomorphic units for part of Australia's marine jurisdiction

Seabed Mapping and Characterisation Project Team:

Peter Harris, Andrew Heap, Vicki Passlow, Laura Sbaffi, Melissa Fellows, Rick Porter-Smith, Cameron Buchanan and James Daniell

Petroleum and Marine Division

Geoscience Australia

GPO Box 378

Canberra, ACT 2601

Department of Industry, Tourism & Resources
Minister for Industry, Tourism & Resources: Senator The Hon. Ian Macfarlane, MP
Parliamentary Secretary: The Hon. Warren Entsch, MP
Secretary: Mark Paterson

Geoscience Australia
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Correspondence for feedback:
Peter Harris
Geoscience Australia
GPO Box 378
Canberra
ACT 2601

Peter.Harris@ga.gov.au

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Chapter 1. INTRODUCTION

In July 2002, Geoscience Australia and the National Oceans Office agreed to carry out a jointly-funded project to produce a consistent, high-quality bathymetric data grid from the coastline of Australia out to the 200 nautical mile limit (i.e., covering the coastal waters, the territorial sea, and the exclusive economic zone (EEZ[1]) - by far the largest of the jurisdictions), and to use the grid to identify and map geomorphic features of the seabed. The area selected to be mapped covered the contiguous portion of continental Australia's 200 nautical mile zone, as well as the same zone around Macquarie Island (part of Tasmania), and the Australian Territories of Norfolk Island, Christmas Island, and Cocos-Keeling Islands. Australia's marine jurisdiction off Heard and McDonald Islands and the Australian Antarctic Territory was not included in the present project.

The methods section of this report provides a list of data used and the computational procedures employed to reduce the data to a 250 m resolution bathymetric grid. The techniques and definitions used to produce the geomorphic feature map are also described.

In the results section of the report, the key geomorphic features of the Australian continental margin are described, drawing extensively on work published in the scientific literature. Specific geomorphic features that have been named or that have been reported in scientific investigations are reviewed and the overall geomorphic make-up of the margin is summarised in the form of a geographic information system (GIS).

An understanding of the shape of the seabed (bathymetry) and the type of seabed forms (geomorphic features) is considered fundamental information needed for ocean planning and management. This is partly because the nature of the seabed can be an important determinant of the diversity and dynamics of marine biological communities. In addition, bathymetry data is available over extensive areas of Australian waters where very little else is known about the ocean environment.

The work undertaken for this report will contribute to the National Oceans Office National Work Program for regional marine planning and will provide input to the national marine bioregionalisation. In particular, this work falls under the work program themes of ‘building on the existing knowledge base’ and ‘mapping Australia’s EEZ’. Moreover, the objectives in undertaking this work specific to Geoscience Australia are as follows:

1. To add new bathymetry data points generated by the Royal Australian Navy (RAN) Hydrographic Office to the Geoscience Australia bathymetry database for the continental shelf to supplement data already entered from the shelf, slope and rise to develop a consistent, high quality bathymetric data grid for Australia’s EEZ.

[1] Generally in this report, where the term “EEZ” has been used it includes all of Australia’s marine jurisdictional zones lying within 200 nautical miles of Australia’s territorial sea baseline (i.e., the Coastal Waters, Territorial Sea and the Exclusive Economic Zone), except in the northwest, north and northeast, where the outer limit of the mapped area corresponds to treaty boundaries with Indonesia, Papua New Guinea, Solomon Islands and France.

2. To prepare the bathymetric data grid so that it is available to be used for oceanographic models and in developing a bioregionalisation of Australia's EEZ.
3. To define geomorphic features on the basis of expert interpretation of seabed morphology and geological origins.
4. To prepare the geomorphic features and associated descriptions so that they are available to be used in the bioregionalisation of the Australia's EEZ.

The main outcomes of the project are:

1. An improved understanding of the continental shelf and slope bathymetry to assist in development of regional marine plans and the general management of Australia's oceans.
2. Enhanced availability of geological information for use in marine planning and management.
3. Improved data accessibility, by making the bathymetry grid and geomorphic units widely available, in particular, contributing to development of fundamental marine datasets for Australia.
4. To build a national capacity for data integration (e.g., working toward related national data-management initiatives)

1.1. Australia's Oceans Policy and the National Work Program

The Government's commitment to an integrated ecosystem-based approach to planning and management of all ocean uses is at the core of Australia's Oceans Policy, launched in December 1998. Regional marine planning is one of the tools by which this ecosystem-based approach will be delivered.

As part of its ongoing work, the National Oceans Office is currently implementing a National Work Program to provide strategic scientific support for the development and implementation of regional marine plans. The National Work Program includes biophysical and socio-economic projects, as well as efforts aimed at improving the use of information in regional marine plans.

The national marine bioregionalisation is a major area of work under the National Work Program. The national marine bioregionalisation aims to contribute to the continual improvement of Australia's ecologically-based regional planning framework and underlying information base. The work program will produce a series of bioregions in a hierarchical structure that reflect ecosystem processes and biogeography throughout Australia's EEZ. It will build on previous regionalisations and result in a comprehensive, fully integrated and agreed set of bioregions.

The planned outcomes of this work include an improved information base on biological and physical characteristics of Australia's oceans and improved use of that information in planning and management of human uses of the marine environment, particularly through regional marine planning.

This work will focus on the mid and outer continental shelf, the continental slope and deep sea areas, recognising that these areas are the most poorly defined and therefore the priority for enhancement. Particular emphasis will also be given to the next area for regional marine planning - the Northern Region, which encompasses the eastern Arafura Sea, the Gulf of Carpentaria and Torres Strait.

The end product of this work program will be a comprehensive, fully integrated and agreed set of benthic and pelagic regions in a hierarchical structure (smaller regions nested within larger regions) covering Australia's EEZ. These regions will reflect biogeography and ecosystem processes and will incorporate finer-scale information where it is available (e.g., Great Barrier Reef, Southeast Marine Region) or where it is necessary to support regional marine planning (initially northern Australia). It is envisaged that the results will be used to update, extend and refine the current national ecologically-based planning framework, the Interim Marine and Coastal Regionalisation of Australia (IMCRA), with particular emphasis on waters greater than 3 nautical miles offshore.

This project is one of a series planned by the National Oceans Office over the next few years, to provide baseline information that will be eventually integrated into a national marine bioregionalisation. Further information about the other projects and the derivation of the national marine bioregionalisation are available at the National Oceans Office web page: www.oceans.gov.au

Chapter 2. METHODS

2.1. Database Population

In this project the existing Geoscience Australia bathymetry database was updated and expanded by adding several new sources of data. The content and status of Geoscience Australia's bathymetry database as of January 2002 was reviewed by Petkovic and Buchanan (2002; Fig. 2.1). The database at that time contained data from a total of 931 surveys, extending from 34°N—79°S and 90°—180°E. The typical point data spacing is 25-200 m and the database contained a total of 202,072,810 points. Geoscience Australia acquired approximately 20% of these surveys.

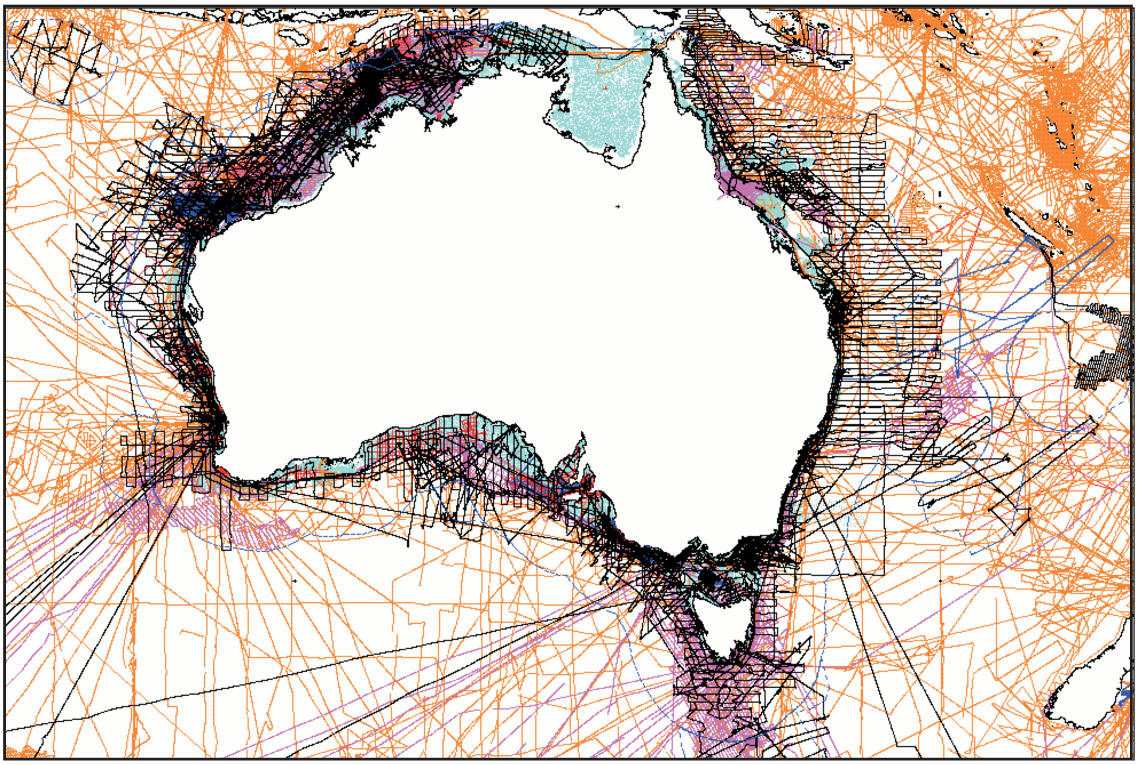

Figure 2.1. Geoscience Australia ship-track database (Mardat) showing bathymetric coverage prior to January 2002 (fPetkovic and Buchanan, 2002). Black = Geoscience Australia research surveys; Dark blue = Geoscience Australia contract surveys; Purple = other Geoscience Australia surveys; Red = private company seismic surveys; Light blue = RAN Australian Hydrographic Service charts; Orange = Foreign sources, mainly National Geophysical Data Centre. Also included in the database but not highlighted in this figure are digital data obtained from NATMAP bathymetric 1:250,000 series.

Data used in this study included the addition of a further 87,502,588 points to the database derived from the following sources (see Appendix A for a full listing of data):

- Royal Australian Navy (RAN) Fairsheet data (4,383,177 points);
- RAN Laser Airborne Depth Sounder (LADS) survey data (18,720,814 points);
- Swath Surveys (64,238,920 points); and
- CSIRO Division of Marine Research Franklin and *Southern Surveyor* surveys 1991-2002 (~50 surveys, ~160,000 points).

Altogether, the above sources represent an increase to the database of approximately 43%. In the following sections, the information provided by each of these four sources is described and their integration into the database is explained.

2.1.1. Royal Australian Navy Hydrographic Service Fairsheet Data

Data from Royal Australian Navy (RAN) Australian Hydrographic Service (AHS) fairsheets on the shelf were digitised using a combination of optical character recognition and hand digitising techniques. The point depth readings are adjusted for sea level (tides) during each of the surveys. Surveys conducted after the mid-1960's used miniranger radio navigation around a surveyed transmission point. Vertical and horizontal accuracy is good to excellent. The collation and correction of digitally entered Fairsheet data provided by the RAN Hydrographic Office required the application of filters and visualisation tools to "clean" the data of spurious points and other errors. Fairsheets to be included in the analysis were identified by comparing sheet distribution with existing digital coverage. Fairsheets were excluded if there were two or more sheets that overlapped each other or if a sheet was not needed because other, more accurate, survey data were available (e.g., LADS or swath bathymetry data; see below).

The procedure carried out by the RAN for capturing the analogue hydrographic data digitally was undertaken as follows: Spot depths represented in the images were digitised using a manual screen-based system and output as an ASCII file of x, y, and z coordinates. Data from each chart were then passed through a range checking program, and gridded for inspection and error detection. Finally, individual sheet files were concatenated and the coordinates were converted to WGS84 positional datum, the equivalent of the new Australian AGD94 datum.

2.1.2. RAN Laser Airborne Depth Sounding (LADS) Data

Laser Airborne Depth Sounding (LADS) surveys are used by the RAN only for reef surveys in the Great Barrier Reef and limited parts of the Timor Sea, because of the limited depth penetration and water quality restrictions of optical depth sounding methods. LADS data are of excellent quality and extremely high resolution, but are limited to waters <20 m deep. This depth limit is due to the inability of laser light to penetrate through water of greater depth and be reflected back to the sensor. Waters that are highly turbid present a problem for LADS, which is not reliable in some coastal regions for this reason. All LADS data received from the RAN by Geoscience Australia were used in the present study.

2.1.3. Multibeam Surveys and CSIRO Ship Track Data

Since January, 2002, data from six swath mapping surveys carried out in Australia's EEZ have become available and were added to the database for the current project (Table 2.1):

- R/V *Maurice Ewing* Australian transit legs 2000-2001. Data quality was poor due to the lack of sound velocity corrections but processed accordingly and incorporated where possible (Fig. 2.2).
- R/V *Sonne* Australian transit legs, in 1999 and 2002.

SONNE 136 (South Tasman Rise/ Macquarie Ridge): Data quality was poor due to the lack of sound velocity casts but processed accordingly and incorporated where possible.

SONNE 168: Data quality was good due to system upgrades in 2000 although ping data was not indexed, and thus no quality control could be carried out.

- N/O *L'Atalante*: Transit survey 2001. Gridded data received from Ray Wood (NZ) over Norfolk Island EEZ. Two grids were provided for these data at 500 m and 150 m resolution. Data density was variable (Fig. 2.2D).
- BHP/Billiton survey using S/V *Petr Kotzov* 2002, received under industry PSLA requirements (see western side of Fig. 2.2F). These data are ping-based and supplied as x,y,z triplets. No quality control or reprocessing was possible due to lack of indexing although data set is internally consistent and of good quality.
- Data acquired by R/V *Marion Dufresne* January-March 2003 during the AUSCAN survey program was not received before gridding commenced for this project.

Table 2.1. Multibeam bathymetry data collected between April 1999 and March 2003 added to the Geoscience Australia database.

Survey Name	Platform	Year	Institution	Area	No. of Points
SONNE136	R/V *Sonne*	1999	GEOMAR	South Tasman Rise/Macquarie Ridge	15,649,941
AUSTREA 3	R/V *L'atalante*	2000	GA/IFREMER	Norfolk Ridge	1,057,372
EWINGEW0113	R/V *Maurice Ewing*	2001	LDGO	Exmouth Plateau	14,477,979
EWINGEW0114	R/V *Maurice Ewing*	2001	LDGO	South Tasman rise	1,293,655
EWINGEW0201	R/V *Maurice Ewing*	2002	LDGO	Tasman sea East coast	2,337,566
BHP3300C1	R/V *Petr Kottsov*	2002	BHP/Billeton	Outer Browse basin	15,985,715
SONNE168	R/V *Sonne*	2002	GEOMAR	Tasman sea East coast	10,574,537
AUSCAN 1	R/V *Marion Dufresne II*	2003	GA/IPEV	Great Australian Bight	0*
Total					**61,376,765**

Single-beam echosounder (ship-track) data recorded during R/V *Franklin* and R/V *Southern Surveyor* surveys completed between 1990 and 2001 were added to the database. Whilst navigational accuracy was generally assumed to be <10 m, vertical accuracy showed datum shifts of 3–5 m when compared to the Fairsheet data. For this reason the continental shelf data were not used. Data acquired in water depths >300 m might exhibit this vertical error but were retained due to the reduced relative error and lack of conflicting datasets.

The distribution of newly acquired bathymetry data added to the Geoscience Australia database as part of this project is shown in Figures 2.2 (A-F). The areas that have had the most new data added are the western margin, and parts of the northern and Torres Strait margins (Fig. 2.2).

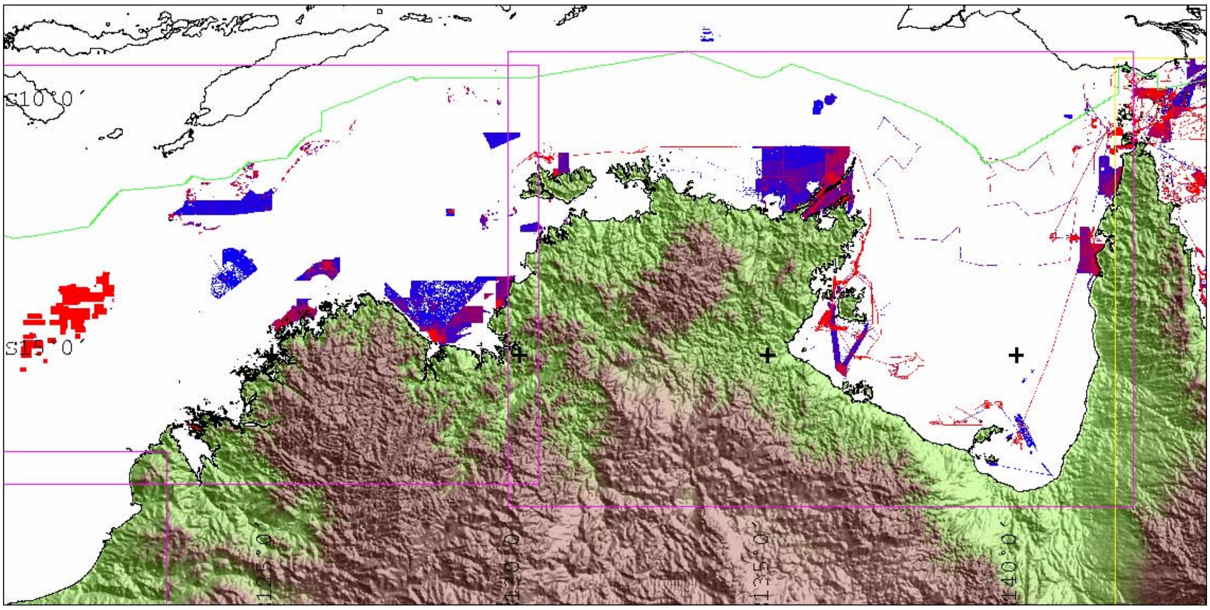

Figure 2.2. Bathymetric data added to the Geoscience Australia database. (A) Northern margin. Red >200 data points km^{-2} (LADS, Multibeam sonar datasets and high density vertical soundings); Purple 20-200 data points km^{-2}; Blue <20 data points km^{-2} (Vertical soundings and digitised fairsheets).

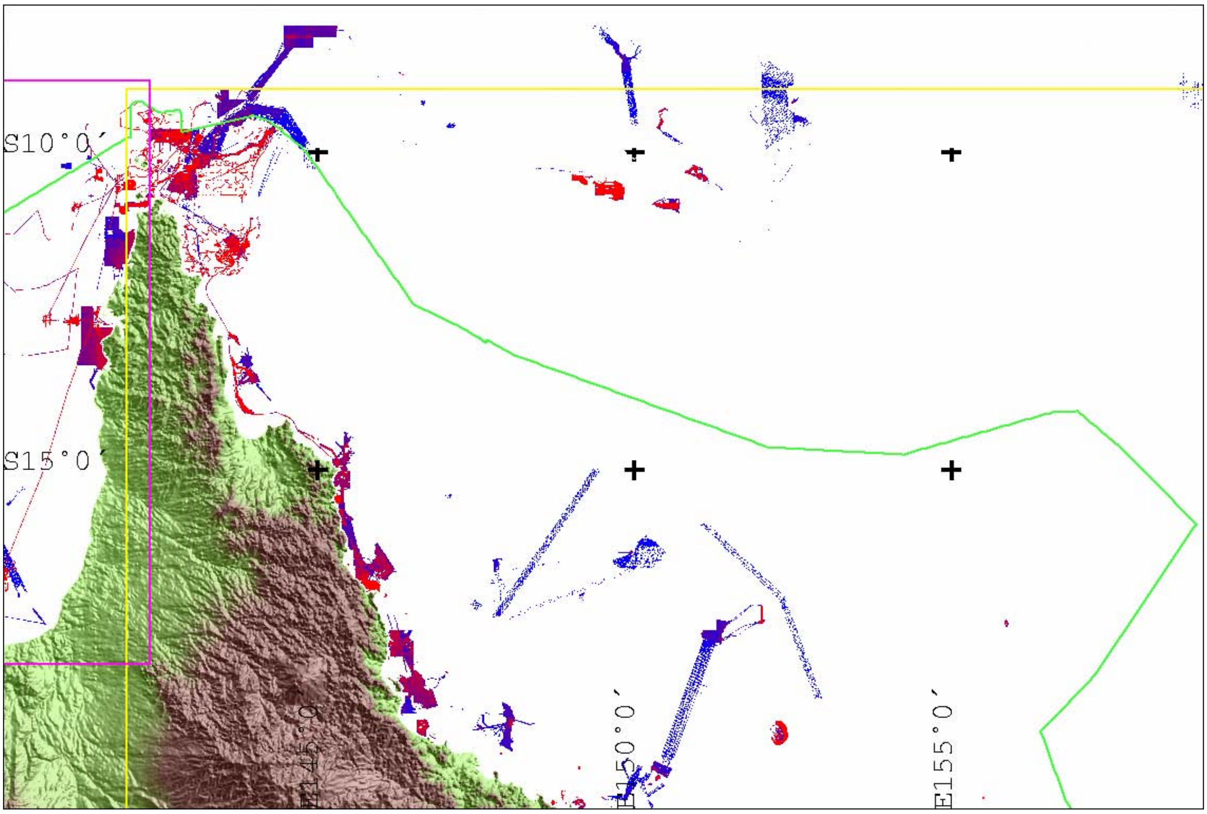

Figure 2.2– Con't. (B) Northeast margin.

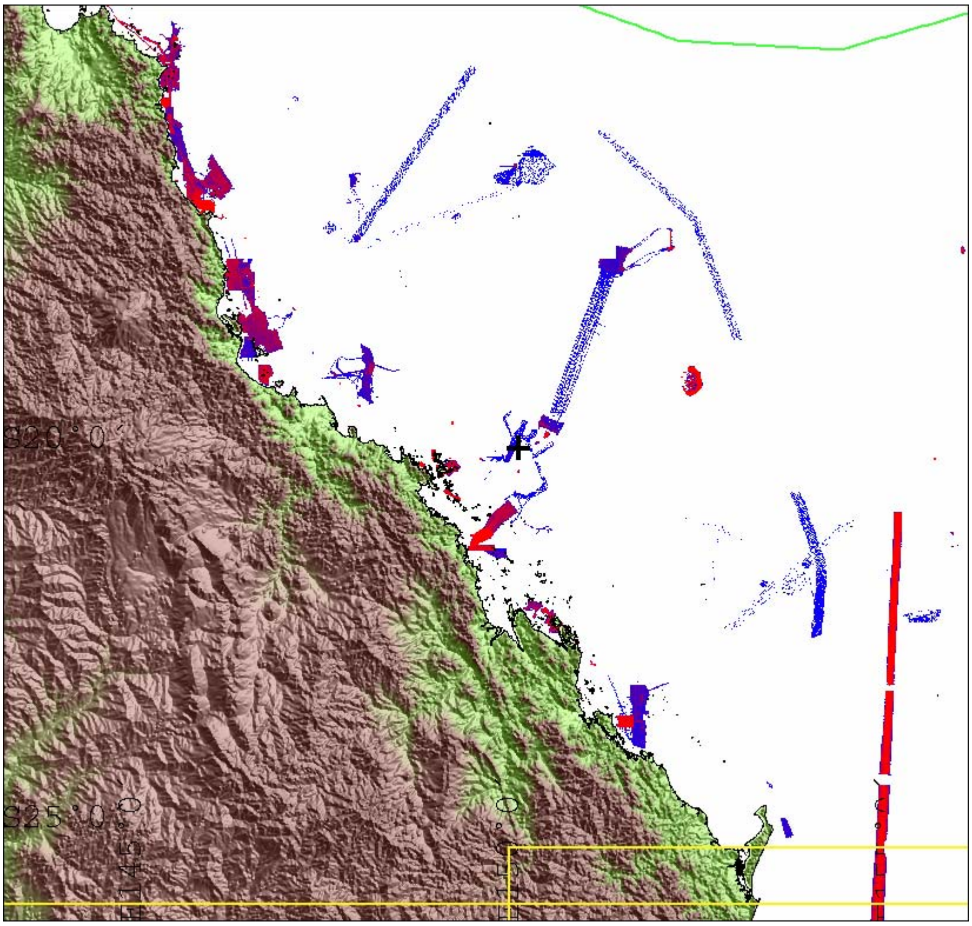

Figure 2.2– Con't. (C) Northeast margin.

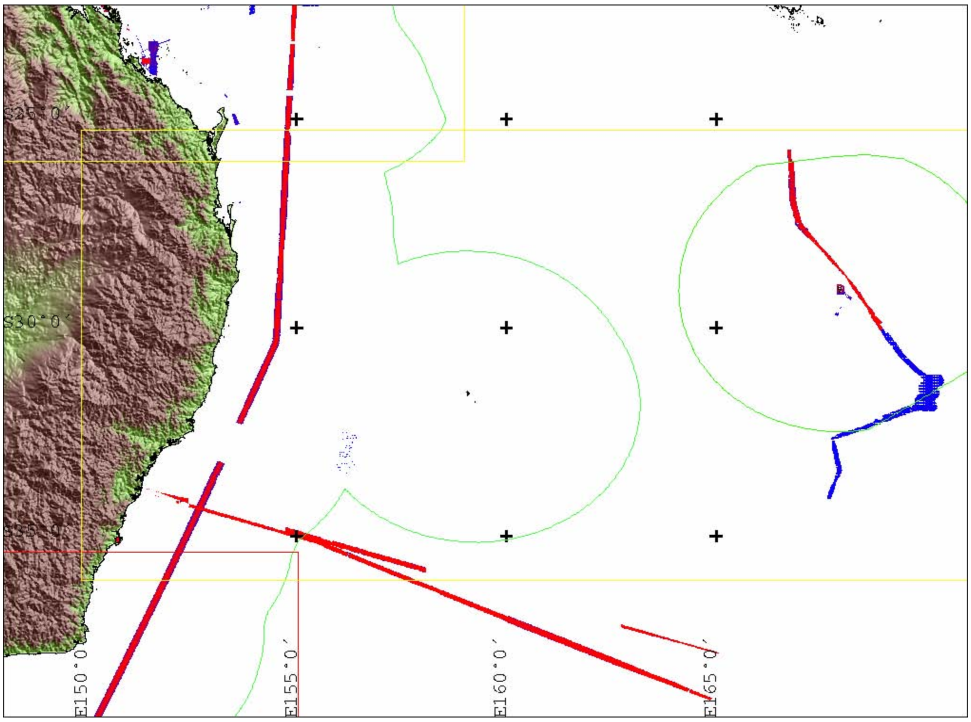

Figure 2.2– Con't. (D) Eastern margin

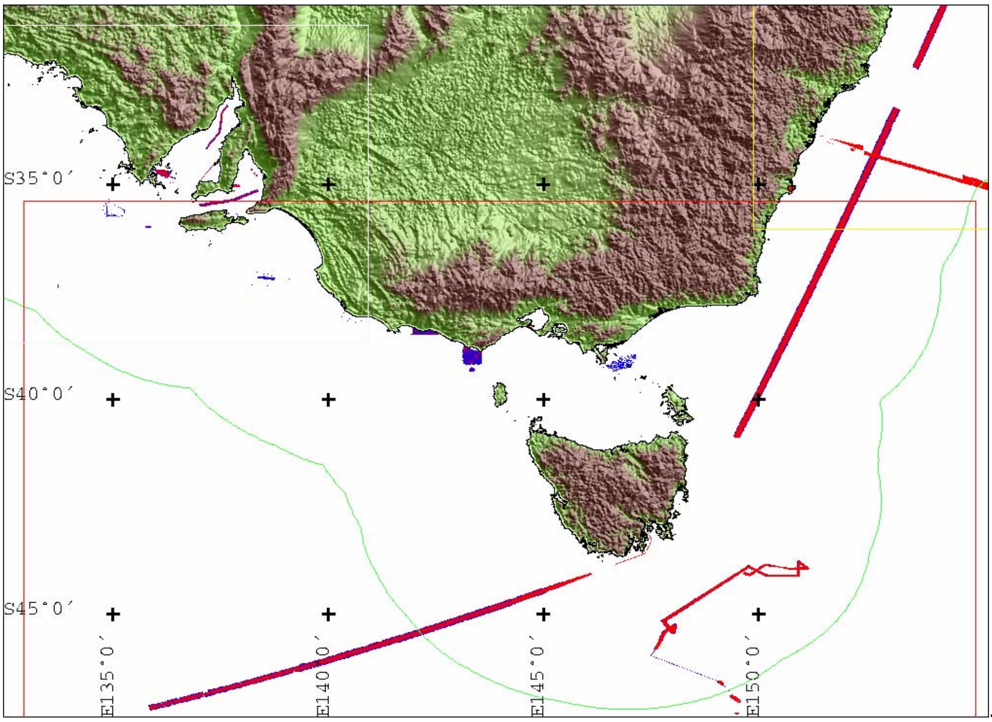

Figure 2.2– Con't. (E) Southeast margin.

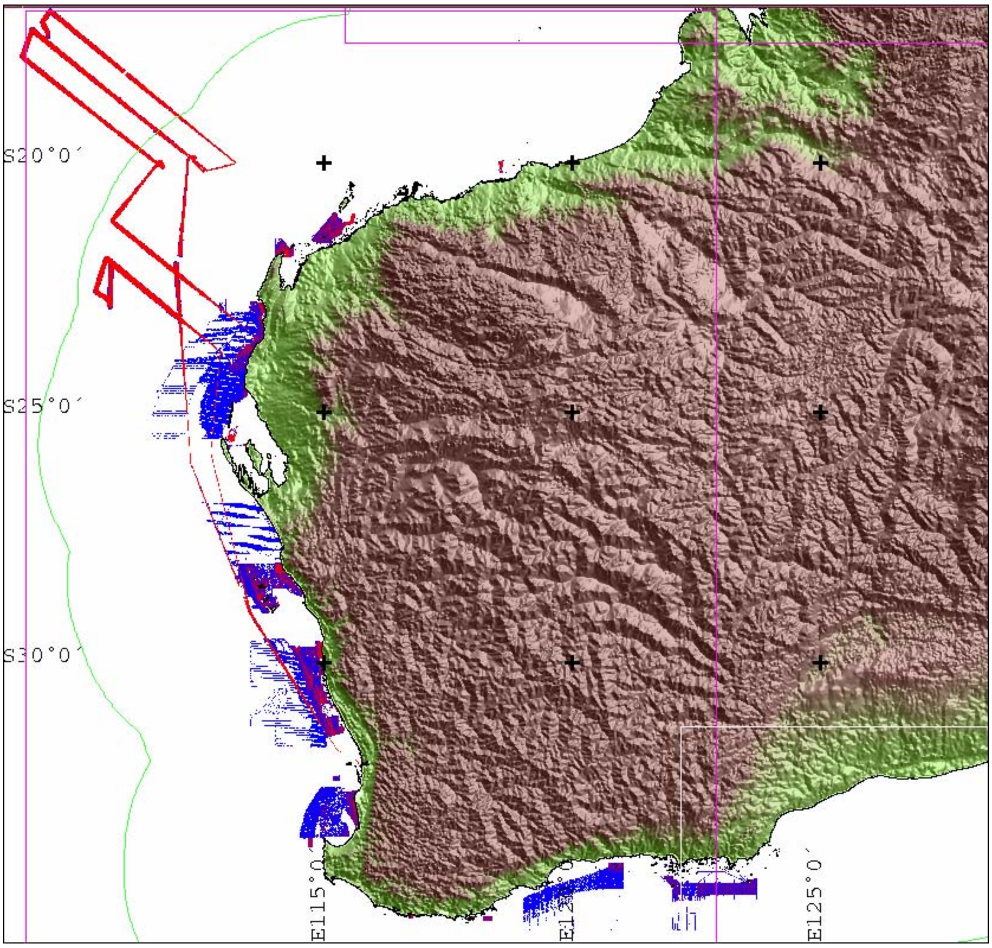

Figure 2.2.–Con't. (F) Western margin.

2.2. Creating bathymetric grids from the database

The primary aim of this compilation was to produce a topographic grid of the seabed for Australia's continental margins for the purposes of geological interpretation, and to provide a fundamental layer for an integrated GIS. The grid is not intended as a navigation aid, or to replace hydrographic products produced by the Australian Hydrographic Service. In order to produce a reasonably consistent grid, the ship-track data have been “levelled” to overcome the artefacts that would otherwise be generated at intersections.

Accuracy of water depth measurements depends on several factors, including the speed of sound used to convert echo sounder times to depth, and whether tidal and datum corrections have been applied. Sound speed varies depending on temperature and salinity of seawater. The sound speed used to calculate water depth and other processing parameters was not always recorded, but where available these corrections were used.

Processing included checking for data spikes and other noise. The effectiveness of the method was assessed by visual inspection. Regions of surveys that contained extensive noise were omitted.

The software program Intrepid™ was used to perform multi-pass gridding of datasets. The data used in this study contained a high variation in data distribution, which warranted the application of this multi-pass technique. The first pass grid was created at a coarse cell size of 0.0045° (500 m), and the values obtained are used as part of the dataset for the subsequent grid. The data density in many parts of the Australian continental margin is very low, and these areas have been supplemented with data from the grid of predicted bathymetry from satellite altimetry, which has a cell size of about ~0.03° or 3.7 km (Smith and Sandwell, 1997). The following grids were supplemented with predicted bathymetry: Christmas Island, Cocos Island, and the region between Norfolk Ridge and Lord Howe Rise.

The grids were computed from the processed data at a cell size of 0.00225° or ~252 m (Table 2.2). The minimum curvature tension parameter (Ct) is set at 0.5. This is a compromise between minimum curvature (Ct = 0) and minimum potential (Ct = 1). This is significant in areas of poor control, where minimum curvature generates a grid that smoothly "over-shoots" the data, and minimum potential produces cusps at data points. For gridding bathymetry, a Ct = 0.5 is sufficiently smooth yet retains some of the characteristic roughness of topographic data. Datum used for all grids is WGS84, Geodetic projection.

2.3. Generation of bathymetric and drainage maps

Bathymetric contour maps were generated from each grid at a scale of 1:5,000,000 using the ARCInfo *CONTOUR* program. This scale was selected in order to set a minimum size for the geomorphic features to be mapped (~10 km) in view of the overall quality of the available data and the selected grid size of 250 m (see section 2.4 below for rationale used in determining map scale and resolution).

Before contouring, the grid was smoothed using the *FOCALMEAN* program in ARCInfo. This routine was set to examine each cell location on an input grid of nine points, find the mean of the values, and assign this value to the middle cell location on the output grid. This process was applied twice to each grid before contouring. Hence, the first smoothing is averaged over a length scale of 750 m and the second smoothing over 2,250 m.

Table 2.2. Gridding parameters.

Parameter	Value
Longitude W	102°E
Longitude E	172°E
Latitude N	8°S
Latitude S	52°S
Grid cell size	0.00225°
Coarse cell size	0.00450°
Minimum curvature tension	0.5
Maximum iterations	100
Maximum residual	1 m
Masking of no-data areas	Off
Additional smoothing	Off

The identification of shelf valleys and submarine canyons on the continental slope was aided by the use of predicted drainage maps. In order to predict a drainage pattern for each area using the ARCInfo drainage analysis program, each of the 250 m bathymetry grids was combined with a 250 m resolution topographic map of the onshore areas. Analysis of the combined bathymetric and topographic grids followed a set procedure, as follows:

1. Fill the bathymetric model to remove sinks and peaks (see below).
2. Calculate flow direction from bathymetric grid.
3. Calculate flow accumulation from above.
4. Eliminate excessive channels beyond required resolution.
5. Calculate stream order (STRAHLER or SHREVE); and
6. Convert results into a Arc/Info coverage.

Errors in data due to resolution or rounding errors create “sinks” or “peaks”, which must be removed to ensure proper delineation of drainage. The *FILL* command uses several ARCGrid functions including: *FLOWDIRECTION*, *FLOWACCUMULATION*, *SINK*, *WATERSHED*, and *ZONALFILL* to locate and remove sinks. The program iterates until all errors within the specified {z limit} are removed (e.g., Tarboton et al., 1991).

The direction of flow is determined by finding the direction of steepest descent from each cell. This is calculated as *drop = change in z value / distance * 100*, where the distance is determined between cell centres (Jenson and Domingue, 1988). Therefore, if the cell size is 1, the distance between two orthogonal cells is 1 and the distance between two diagonal cells is 1.414. If the descent to all adjacent cells is the same, the neighbourhood is enlarged until a steepest descent is found. If all neighbours are higher than the processing cell, it is treated as noise and be filled to the lowest value of its neighbours and have a flow direction towards this cell. However, if a one-cell sink is next to the physical edge of the grid or has at least one *NODATA* cell as a neighbour, then it is not filled due to insufficient neighbour information. To be considered a true one-cell sink, all neighbour information must be present. If two cells flow to each other, they are sinks, and have an undefined flow direction.

As streams flow down-slope they may accumulate into a larger flow. This processes results in a stream network that is used as input to the *STREAMORDER*, *STREAMLINE*, and *STREAMLINK* functions (Jenson and Domingue, 1988), which use an appropriate threshold value for stream network delineation (Tarboton et al., 1991).

2.4. Geomorphic Feature Identification and Mapping

Geomorphic features were identified using the 250 m spatial resolution bathymetry maps with reference to previously published geological studies. As noted above, a scale of 1:5,000,000 was selected in order to set a minimum size for the geomorphic features to be mapped; hence a feature 10 km in size appears as 5 mm on the maps. This scale is reasonable, given the pixel size of the grid (i.e., 40 pixels x 250 m for a 10 km size object) and is consistent with the smoothing carried out for contour mapping (smoothed over 2,250 m; see above).

The vertical spacing of contours was set for 5 m on the shelf (0 - 500 m) and at 100 m for greater depths. The contour maps were supplemented by false-colour, azimuth illuminated, bathymetric images, generated by assigning a gradational colour value to each (un-smoothed) depth pixel. These false-colour images were generated for the shelf (colour ramped from 0-500 m) and for the entire margin (colour ramped from 0 m to the maximum depth occurring in the mapped area). The false colour images were useful for detecting some smaller, low relief features as the eye can discern subtle colour variations that might otherwise be missed on a contour map.

Terms and nomenclature used in this report to describe geomorphic features of the seabed are based on definitions endorsed by the International Hydrographic Organisation (IHO, 2001). Further details of these terms and documentation underlying their adoption by IHO may be found at the following internet address: http://www.iho.shom.fr/publicat/free/files/B6efEd3.pdf for complete IHO documentation (IHO, 2001).

For the purposes of this study, we selected 21 separate categories of geomorphic feature for mapping (Table 2.3) from the 53 feature types given by IHO (2001). The fewer number of features used here grouped similar geomorphic units (that might have different names) into single categories (e.g., "bank" and "shoal" are number 5; "deep", "hole" and "valley" are number 6; etc.). This decision was made to reduce the amount of time required to classify features. We also added a category for sandwaves (subaqueous dunes of Ashley et al., 1990) and sand banks (number 21) as we considered these features to be important geomorphic features on the shelf, even though they are not included in the list published by IHO (2001).

Table 2.3. List of geomorphic features. Definitions are from IHO (2001), except for sandwaves and sand banks, which are defined in Ashley et al. (1990).

No.	Name	Definition
1	Shelf	Zone adjacent to a continent (or around an island) and extending from the low water line to a depth at which there is usually a marked increase of slope towards oceanic depths.
2	Slope	Slope seaward from the shelf edge to the upper edge of a continental rise or the point where there is a general reduction in slope.
3	Rise	Gentle slope rising from the oceanic depths towards the foot of a continental slope.
4	Abyssal Plain	Extensive, flat, gently sloping or nearly level region at abyssal depths.
5	Bank	Elevation over which the depth of water is relatively shallow but normally sufficient for safe surface navigation.
	Shoal	Offshore hazard to surface navigation that is composed of unconsolidated material.
6	Deep	In oceanography, an obsolete term which was generally restricted to depths greater than 6,000 m.
	Hole	Local depression, often steep sided, of the sea floor.
	Valley	Relatively shallow, wide depression, the bottom of which usually has a continuous gradient. This term is generally not used for features that have canyon-like characteristics for a significant portion of their extent.
7	Trench	Long narrow, characteristically very deep and asymmetrical depression of the sea floor, with relatively steep sides.
	Trough	Long depression of the sea floor characteristically flat bottomed and steep sided and normally shallower than a trench.
8	Basin	Depression, characteristically in the deep sea floor, more or less equidimensional in plan and of variable extent.
9	Reef	Rock lying at or near the sea surface that may constitute a hazard to surface navigation.
10	Canyon	A relatively narrow, deep depression with steep sides, the bottom of which generally has a continuous slope, developed characteristically on some continental slopes.
11	Knoll	Relatively small isolated elevation of a rounded shape.
	Abyssal Hills	Tract, on occasion extensive, of low (100-500 m) elevations on the deep sea floor.
	Hill	Small isolated elevation.
	Mountains	Large and complex grouping of ridges and seamounts.
	Peak	Prominent elevation either pointed or of a very limited extent across the summit.
12	Ridge	(a) Long, narrow elevation with steep sides. (b) Long, narrow elevation often separating ocean basins. (c) Linked major mid-oceanic mountain systems of global extent.
13	Seamount	Large isolated elevation, greater than 1000 m in relief above the sea floor, characteristically of conical form.
	Guyot	Seamount having a comparatively smooth flat top.
14	Pinnacle	High tower or spire-shaped pillar of rock or coral, alone or cresting a summit. It may extend above the surface of the water. It may or may not be a hazard to surface navigation.
15	Plateau	Flat or nearly flat area of considerable extent, dropping off abruptly on one or more sides.
16	Saddle	Broad pass, resembling in shape a riding saddle, in a ridge or between contiguous seamounts.
17	Apron	Gently dipping featureless surface, underlain primarily by sediment, at the base of any steeper slope.
	Fan	Relatively smooth, fan-like, depositional feature normally sloping away from the outer termination of a canyon or canyon system.
18	Escarpment	Elongated and comparatively steep slope separating or gently sloping areas.
19	Sill	Sea floor barrier of relatively shallow depth restricting water movement between basins.
20	Terrace	Relatively flat horizontal or gently inclined surface, sometimes long and narrow, which is bounded by a steeper ascending slope on one side and by a steeper descending slope on the opposite side.

21	Sandwave Sand Bank	Wave-like bed form made of sand on the sea floor. Submerged bank of sand in a sea or river that may be exposed at low tide.

2.5. Procedure of Feature Identification and Mapping

Features listed in Table 2.3 were identified on the contour and false colour maps and drawn by hand onto transparent compilation maps. The identification of shelf valleys, basins and submarine canyons was aided by the results of a drainage analysis of the bathymetric model (Section 2.3). Any features described in previously published articles that we found in our literature search were also added to the compilation maps. Also available to aid in the interpretation were slope and aspect maps for each region, although in practice such maps were not found to be particularly helpful since the spacing of isobaths on the contour maps clearly represent information on relative changes in slope.

When completed, the compilation maps were scanned, georeferenced and the separate polygons were digitised. Each polygon was attributed to one of the 21 categories of geomorphic feature (Table 2.3) and stored as an ARC/GIS shape file. Care was taken where separate maps sheets joined to ensure that features were correctly identified and retained their identity across the boundaries. The final product was a single GIS layer of geomorphic features for Australia’s EEZ.

2.5.1. Defining the Shelf Break and Foot of Slope

Two of the fundamental boundaries marked on the geomorphic features maps are the shelf break and foot of slope. The shelf break was picked by hand, by the identification of the sudden change in seabed gradient (highlighted by closely spaced contours) that occurs at the boundary between the outer shelf and upper slope. This is typically a simple and obvious choice for the interpreter to make, although there are some areas where the identification of the shelf break is not apparent. Examples include parts of the Timor Sea, the Arafura Sea and Rowley Shoals region, which are described in more detail in the results section (Chapter 3).

By contrast with the shelf break, identifying and mapping the foot of slope is a complex and non-trivial exercise. In the areas where Geoscience Australia has undertaken an analysis of the continental margin using the provisions set out in Article 76 of the UN Convention on the Law of the Sea, the foot of slope was picked from ship-recorded, bathymetric profiles extracted from Geoscience Australia's Ozmar2 database. This was accomplished by choosing the point of maximum change of gradient at the base of the continental slope on the particular profile. Profiles were selected on the basis of their orientation with respect to the margin, the quality (generally related to the age) of the navigation system, and location around the margin. Where a continental rise is present (defined in the scientific and technical guidelines to UNCLOS as “a wedge of sediment at the base of the continental slope”), the foot of slope usually corresponds to the slope/rise boundary. Two geographic areas around the Australian margin are named “rises” (i.e., South Tasman Rise and Lord Howe Rise), even though they are not part of the continental rise. These are elevated flat areas of seafloor classified here as “plateaus” (Table 2.3).

Determination of the point of maximum change of gradient was made with the assistance of a special extension written for ArcView, which identifies the changes in gradient down the profile between adjacent sample points. Several potential foot-of-slope positions (inner, intermediate, outer) were selected within the basal continental slope zone and then one was subsequently chosen as the 'preferred' pick, taking into account adjacent profiles

Elsewhere, a decision as to the location of the foot of slope was made by examining the change in gradient using the 250 m bathymetric model. We selected the foot of slope by eye, where the contour spacing increases from the slope to the abyssal plain regions. Abyssal plains are generally below 4,000 m water depth and are characterised by a low-gradient surface with a slope of <1:1,000.

Chapter 3. RESULTS

In this chapter, the results of the interpretation of the bathymetric maps are presented area by area, starting from the southeast and working clockwise around the continent. For each area, the key geomorphic features of the continental margin are described, drawing on work published in the scientific literature where available. The features were mapped and defined as described in Section 2.4.

3.1. Southeast Margin (Cape Howe to Kangaroo Island)

The southeast continental margin of Australia covers nearly 1.1 million km^2, extending from Kangaroo Island in the west to slightly north of Cape Howe on the south coast of New South Wales. The area encompasses Bass Strait and the continental margins adjacent to Tasmania (Fig. 3.1). Geomorphic features that have been named or that have been reported in scientific investigations are listed in Table 3.1 and the geomorphic make-up of the margin is provided in Table 3.2.

3.1.1. Continental Shelf

The geomorphology of the southeast margin and the origins and development of its geomorphic features can be directly attributed to the rifting of Australia and Antarctica and the opening of the Tasman Sea during the late Cretaceous and early Tertiary periods (Norvick and Smith, 2001).

The continental shelf including Bass Strait covers an area of about 215,000 km^2 (Table 3.2). In the SE region, the shelf extends from the coast to the shelf break at approximately 200 m water depth. Bass Strait, a seaway separating Tasmania from the mainland, is approximately 350 km wide and 500 km long, with an average depth of 60 m (Fig. 3.2). A comprehensive study of the submarine topography of Bass Strait was published by Jennings in 1958. He reported that the bathymetric Bass Basin, a shallow depression approximately 120 km wide and 400 km long in the centre of Bass Strait, occupies an area of >65,000 km^2 with a maximum depth near its geographic centre of 83 m. Two plateaus, the Bassian Rise and King Island Rise located on the eastern and western margins of Bass Strait, respectively, are composed of a basement of Palaeozoic granite. These features form sills separating Bass Basin from the adjacent ocean basins. Associated with the <50 m deep Bassian Rise is the Furneaux Islands, the largest of which is Flinders Island (max. elevation 760 m). The surface of the King Island Rise also occurs in water depths of <50 m, and includes the shallow (40 m) Tail Bank at its northern margin as well as King Island itself.

Subaqueous dunes (sandwaves) and tidal current ridges occur on the seabed over the Bassian and King Island Rises. Malikides (1988) estimated that subaqueous dunes cover approximately 6,000 km^2 of the seabed in Bass Strait (Table 3.2). Slater (1969) reported that Banks Strait exhibits a number of erosional (deep rocky channels) and depositional (tidal sand ridges and dunes) features. The largest of the tidal sand ridges, Moriarty Bank, lies east of Clarke Island and is approximately 20 km long and 4 km wide, orientated east-west, sub-parallel to the flow of tidal currents (Fig. 3.3).

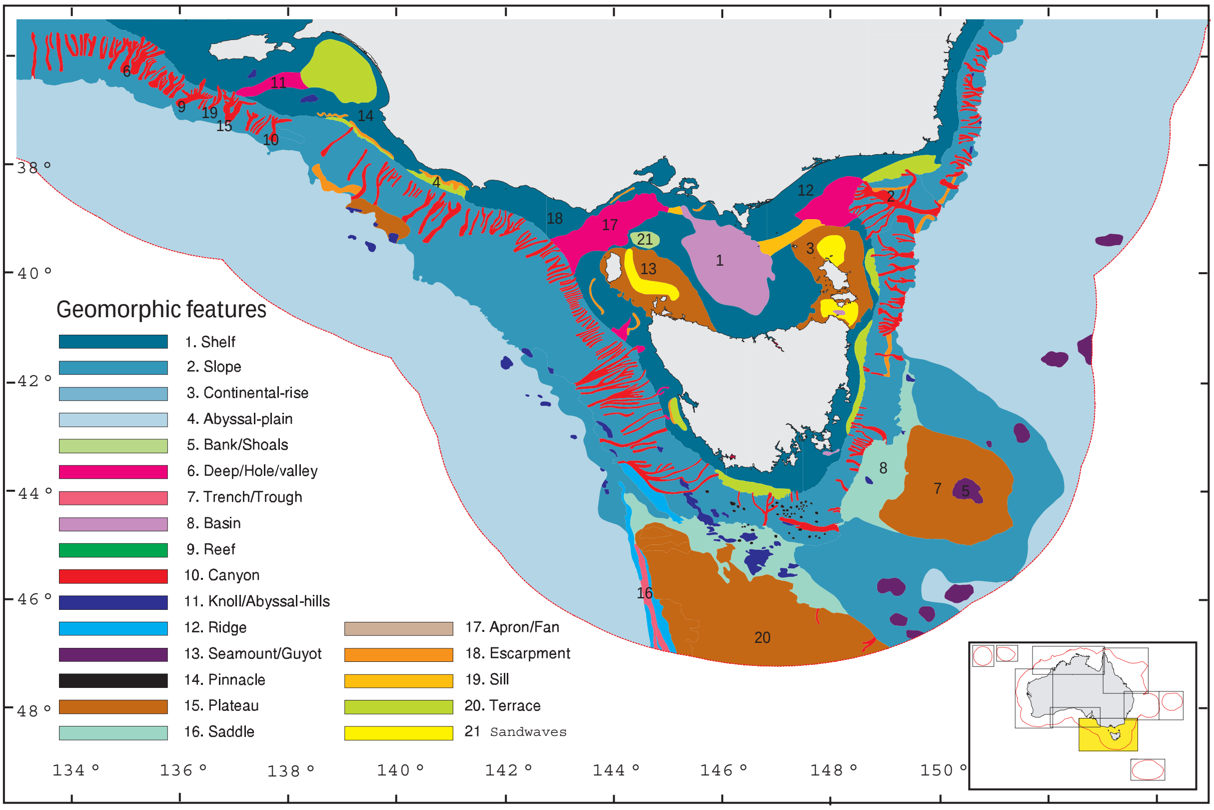

Figure 3.1. Geomorphic features on the southeast margin. See Table 3.1 for key to place names and Table 3.2 for surface areas of features.

A study of the Quaternary history of the Bass Basin was undertaken by Blom and Alsop (1988). They concluded that sea level fluctuations over the last 65,000 years isolated the basin from the sea. From prior to 60,000 to 26,000 yr BP and from 11,800 to 8,700 yr BP, Bass Basin existed as a freshwater lake or embayment.

These phases occurred when sea level fell below the western (Otway Depression) sill depth of ~67 m. During the last glacial maximum ~18,000 years ago, the basin was completely isolated and formed a brackish lake. Sea level rose rapidly during the post-glacial transgression and by 10,000 yr BP the basin was open to the Great Australian Bight on the northwest side, giving rise to a large marine embayment. Sea level continued to rise and the Bass Strait seaway was formed by about 8,000 yr BP.

On the Otway Shelf, Jennings (1958) mentions a submarine scarp between Barwon Head and Cape Otway, and Gill *et al.*, (1980) reported a submerged cliff, located in about 45 m water depth and extending for approximately 20 km between Point Roadnight and Sugarloaf Creek. In eastern Bass Strait, the main feature is the Flinders Depression, which is the shelf-ward continuation of Bass Canyon.

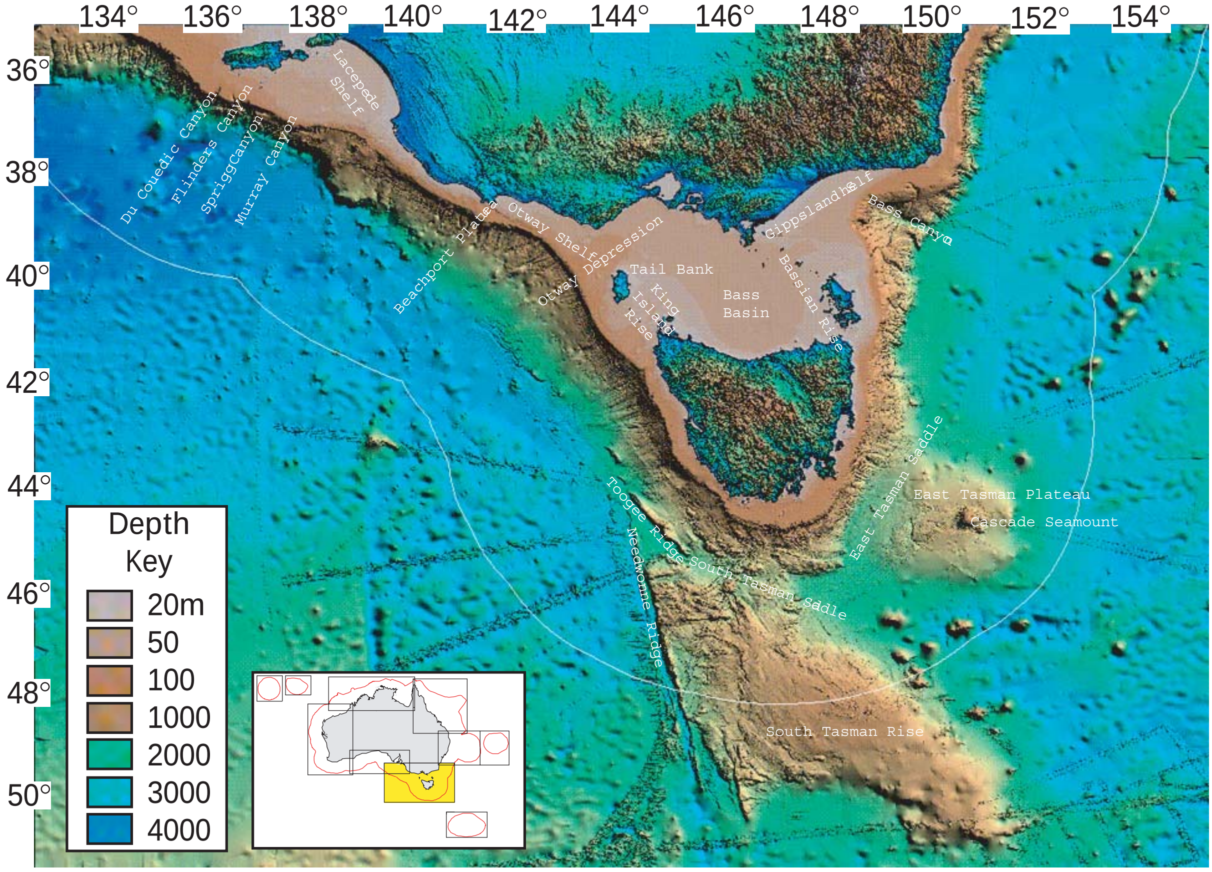

Figure 3.2. False-colour bathymetric image of the southeast margin.

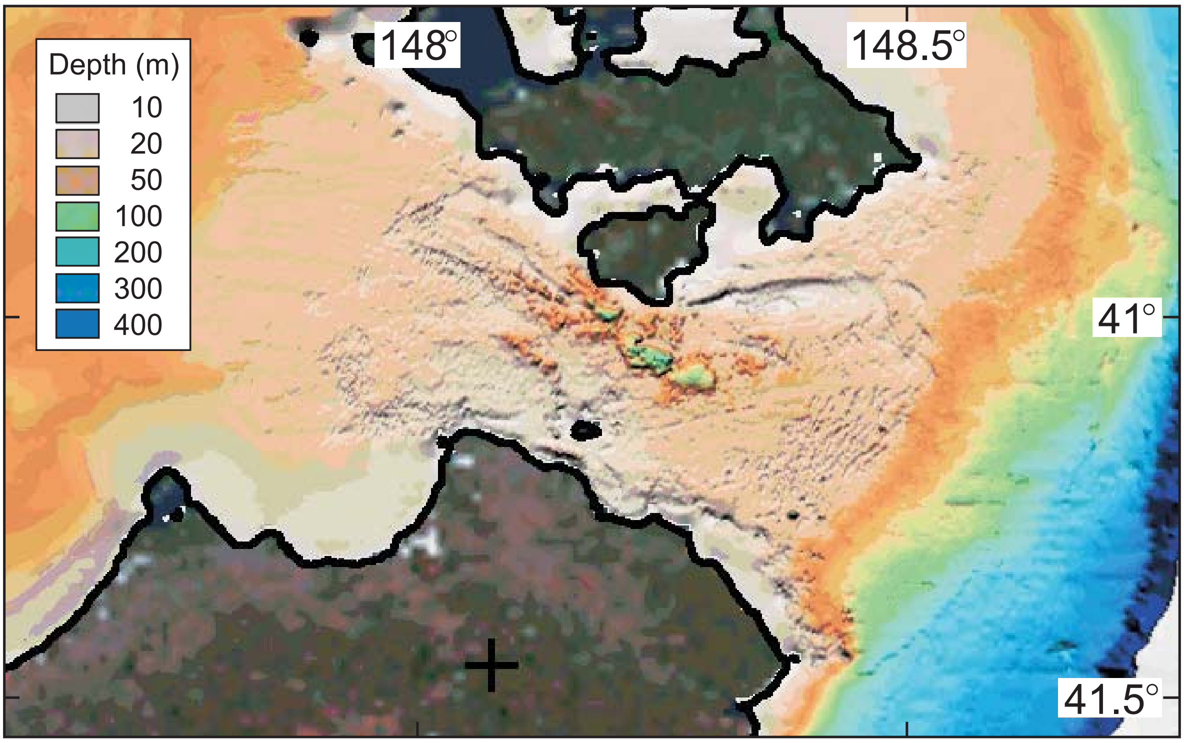

Figure 3.3. False-colour bathymetric image of the Banks Strait area of eastern Bass Strait, illuminated from the south, showing tidal current ridges, large-scale dunes (sandwaves) and tidally-scoured depressions on the seabed.

Other notable geomorphic features on the Tasmanian shelf include a channel (or basin) up to 120 m deep adjacent to Cape Pillar and elongate terraces, generally located on the outer shelf in water depths of 150-170 m, which trend parallel to the shelf break. Off Macquarie Harbour on the western coast of Tasmania, there is an inner shelf terrace located in water depths of 30-50 m bounded by an escarpment on its seaward side (Jones and Holdgate, 1980).

Further to the west, the Lacepede Shelf contains a single, broad terrace (70 km x 120 km) located between the 40 and 60 m isobaths (Bone et al., 1993). Seaward of this terrace is a broad local depression that leads to the upper part of the Murray Canyon system. This area includes the outlet of the Murray River (at the northern end of the Coorong). The Lacepede Shelf includes Pleistocene Murray River deposits corresponding to more active phases of the river system (Willcox et al., 1988).

3.1.2. Continental Slope and Rise

Recent swath mapping studies (e.g., Hill et al., 1995; Exon et al., 1997; Muller et al., 1997) have revealed that at moderate water depths (~3,500 m) the seabed of the continental margin south of Tasmania is characterised by gentle to moderate relief. At abyssal water depths, the seabed is characterised by gently undulating relief associated with irregular and faulted basement blocks and seamounts. To the east of Tasmania, numerous rounded to elongate seamounts rise as much as 1,300 m above the surrounding flat seabed of the abyssal plain. To the west of Tasmania, south of Cape Sorell, ~40% of the seabed is exposed bedrock, which forms extensive WSW-trending canyons, escarpments and basement blocks with moderate to steep relief.

East and northeast of Tasmania, mapping studies (e.g., Exon et al., 1994, 1997; Hill et al., 1998) reveal a steep and rugged continental slope and a narrow, shallow-gradient rise. Both the slope and rise are incised with numerous submarine canyons that are up to 30 km long and >500 m deep and connect directly to the abyssal plain (Conolly, 1968; Fig. 3.3). The largest of these submarine canyons is Bass Canyon, an ESE-trending funnel-shaped chasm 60 km long and 10-15 km wide at its mouth, located east of Bass Strait. The canyon has incised the margin to a depth of more than 2 km and is bounded to the north and south by steep bedrock walls that attain 1000 m in height. Bass Canyon drops away from the shelf break located at 100-150 m water depth to 1,500 m water depth over a distance of ~22 km (Keene and Hubble, 1985), giving an average slope of ~4°. Further east, the canyon floor depth increases from 1,500 m to 4,000 m over a distance of ~80 km (average slope of ~1.8°) where it debouches onto the abyssal plain in the Tasman Sea. The main canyon floor, located in water depths of >4,000 m, is connected to the continental shelf by three large, deeply incised tributary canyons and numerous smaller valleys. One of these, the Everard Canyon forms a tributary system, entering from the north. Numerous, mostly un-named submarine canyons dissect other parts of the slope, many of which are only poorly mapped using the available data (Hill et al., 2000; Fig. 3.4). Southwest of Tasmania, an extensive network of linear to curvilinear submarine canyons extend >60 km from the shelf edge to the base of the slope. In total, submarine canyons are extensive and cover >35,000 km^2 of the margin (Table 3.2). Also, small (<5 km width) perched basins have been described on the slope in some areas (e.g., seawards of

Cape Pillar; Harris et al., 1999) that are below the resolution of the mapping conducted for this study.

The continental slope on the southern and eastern margins of Tasmania extends offshore to encompass the East Tasman Plateau (on which the Cascade Seamount is perched) and the South Tasman Rise. The East Tasman Plateau, located approximately 100 km southeast of Tasmania, is a roughly circular broad dome of approximately 40,000 km^2 that rises from water depths of >3,300 m. Near the crest is the younger volcanic cone of the Cascade Seamount, which rises to almost 700 m water depth at the summit (Lanyon et al., 1993; Hill and Moore, 2001). The eastern flank of the East Tasman Plateau forms a steep (14°) 1,400 m high scarp that gives way to a gently rising terrace that intersects the base of the steeply sided Soela Seamount. The East Tasman Plateau also contains several smaller parasitic cones, both on the flanks of the seamount and along the terrace.

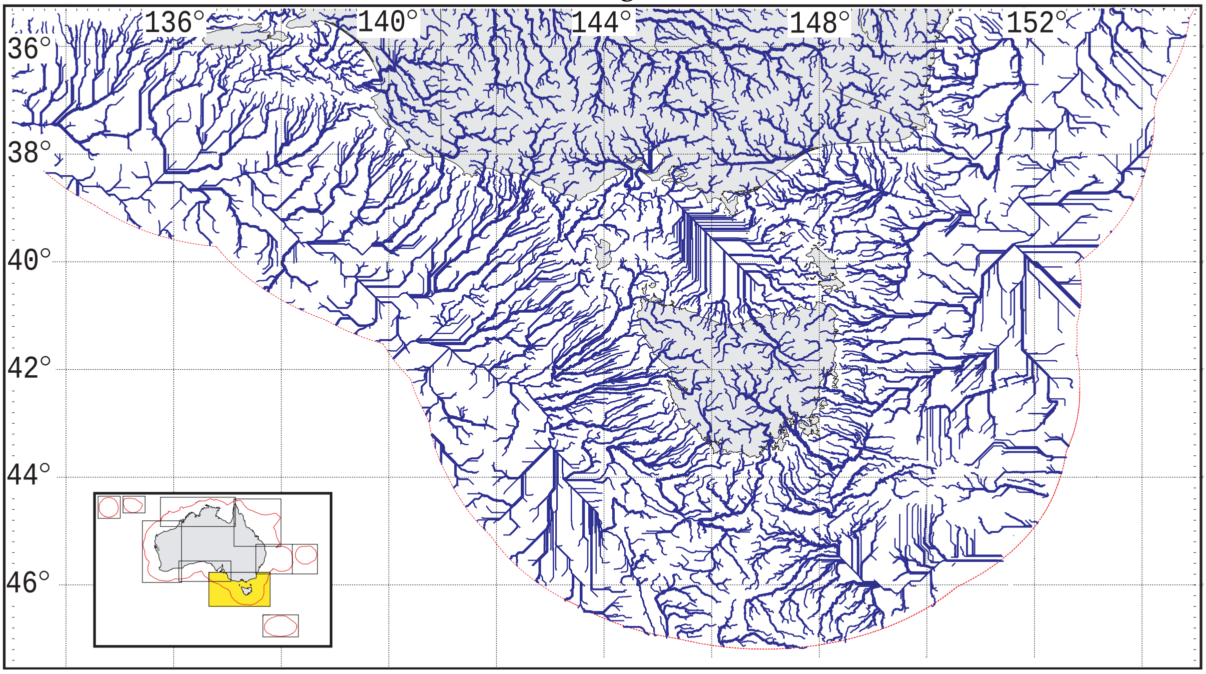

Figure 3.4. Predicted drainage system for the southeast margin, showing the positions of major submarine canyons on the continental slope.

The South Tasman Rise forms a NW-trending broad plateau approximately 1,000 km long and 500 km wide that is characterised by a rough, irregular surface surrounded by gentle slopes. It covers an area of approximately 200,000 km^2 and rises from water depths of >4,000 m to an elevation of 800 m (Royer and Rollet, 1997; Hill and Moore, 2001). At its southern limit, this fragment of continental crust extends the continental slope more than 200 nautical miles (>370 km) from the coast of Tasmania. On its western margin, the South Tasman Rise is flanked by the Tasman Fracture Zone, an extensive ridge-trench complex comprised of a series of high relief ridges and troughs (Fig. 3.1), with escarpments up to 2-3 km high.

The East Tasman and South Tasman Saddles, located in 3,000 m water depth, connect the East Tasman Plateau and South Tasman Rise to Tasmania (Hill and Moore, 2001). The morphology of the East Tasman Saddle starts out flat but then becomes more rugged with increasing water depth, containing extensive rock exposures on the lower part of the slope. The South Tasman Saddle is characterised by rugged topography, with extensive rock exposure on the upper part of the slope, including jagged canyons (up to 250 m deep) and volcanic cones (up to 600 m high), which is also the location of the Tasman Seamounts marine protected area. Elsewhere small, localised areas containing ridges, pinnacles and valleys with relief of >100 m occur between extensive areas of moderately-graded, rough slopes and numerous (>70) volcanic cones.

Notable features along the continental slop of the Otway margin include the Beachport Plateau (Von der Borch et al., 1970), which is actually a terrace perched on the lower continental slope, surrounded by several hills. It lies in 900 to 2,700 m water depth. To the west of the Beachport Plateau there are two sizeable escarpments on the continental slope that were first described by Von der Borch and Clarke (1993) based on a GLORIA swath mapping survey of this area. Still further to the west, the Sprigg, Murray and Du Couedic Canyon systems dissect the continental slope over its full width (from the shelf break to foot of slope).

Table 3.1. List of previously described geomorphic features on the southeast margin. Features are numbered (left hand column) on Fig. 3.1.

No.	Geomorphic Feature	Feature Type	References
1	Bass Basin	Basin (8)	Jones and Holdgate (1980)
2	Bass Canyon	Canyon (20)	Keene and Hubble (1985)
3	Bassian Rise	Plateau (15)	Jennings (1958)
4	Beachport Plateau	Terrace (20)	Von der Borch et al. (1970)
5	Cascade Seamount	Seamount (13)	Bernardel et al. (2000)
6	Couedic Canyon	Canyon (20)	Von der Borch et al. (1970)
7	East Tasman Plateau	Plateau (15)	Exon et al. (1997), Bernardel et al. (2000)
8	East Tasman Saddle	Saddle (16)	Hill et al. (2000)
9	Everard Canyon	Canyon (20)	Conolly (1968)
10	Flinders Canyon	Canyon (20)	Conolly (1968)
11	Flinders Depression	Valley (6)	Jennings (1958)
12	Gippsland Shelf	Shelf (1)	Lavering (1994a)
13	King Island Rise	Plateau (15)	Jennings (1958)
14	Lacepede Shelf	Shelf (1)	Bone et al. (1993)
15	Murray Canyon	Canyon (20)	Von der Borch et al. (1970)
16	Needwonne Ridge	Ridge (12)	Exon et al. (1997)
17	Otway Depression	Valley (6)	Jennings (1958)
18	Otway Shelf	Shelf (1)	Boreen et al. (1993)
19	Sprigg Canyon	Canyon (20)	Von der Borch and Clarke (1993)
20	South Tasman Rise	Plateau (15)	Royer and Rollet (1997)
21	South Tasman Saddle	Saddle (16)	Hill et al. (2000)
22	Tail Bank	Bank (5)	Jennings (1958)
23	Toogee Ridge	Ridge (12)	Exon et al. (1997)

Table 3.2. Geomorphic make-up of the southeast margin. Code refers to the geomorphic feature type listed in Total area

Code	Geomorphic Feature	Km^2	Percent
1	Shelf*	219,349	18.36
2	Slope*	430,436	36.02
4	Abyssal plain*	545,226	45.63
	Total	**1,195,011**	100
1	Shelf*	116,893	10.92
2	Slope*	243,925	22.79
4	Abyssal plain*	428,749	40.06
5	Bank/Shoal	1,348	0.13
6	Deep/Hole/Valley	19,021	1.78
7	Trench/Trough	2,087	0.20
8	Basin	24,141	2.26
9	Reef	4	0.0004
10	Canyons	36,968	3.45
11	Knoll/Abyssal Hills/Hill/Peak	7,084	0.66
12	Ridge	5,845	0.55
13	Seamount/Guyot	9,087	0.85
14	Pinnacle	732	0.07
15	Plateau	106,026	9.91
16	Saddle	30,442	2.84
17	Apron/Fan	-	0.00
18	Escarpment	5,499	0.51
19	Sill	2,790	0.26
20	Terrace	22,469	2.10
21	Sandwaves/sand bank	7,837	0.73

***** First listing of continental shelf, slope, and abyssal plain areas are total, mutually exclusive areas. Second listing of continental shelf, slope, and abyssal plain areas are less the surface areas of superimposed features (e.g., shelf area is total shelf area minus superimposed basin area, sill area, terrace area, etc.).

3.2. Southern Margin (Great Australian Bight)

The continental margin in Southern Australia extends approximately 1,700 km from Esperance, Western Australia, across the Great Australian Bight (GAB) to Kangaroo Island in South Australia (Figs. 3.5, 3.6). It covers an area of 692,670 km^2. The margin is a divergent, passive, continental margin that formed during the protracted period of extension and rifting (mainly during the Cretaceous) leading to the separation of Australia from Antarctica and Australia's subsequent northward drift (Willcox and Stagg, 1990; Norvick and Smith, 2001). Geomorphic features that have been named or that have been reported in scientific investigations are listed in Table 3.3 and the geomorphic make-up of the margin is provided in Table 3.4.

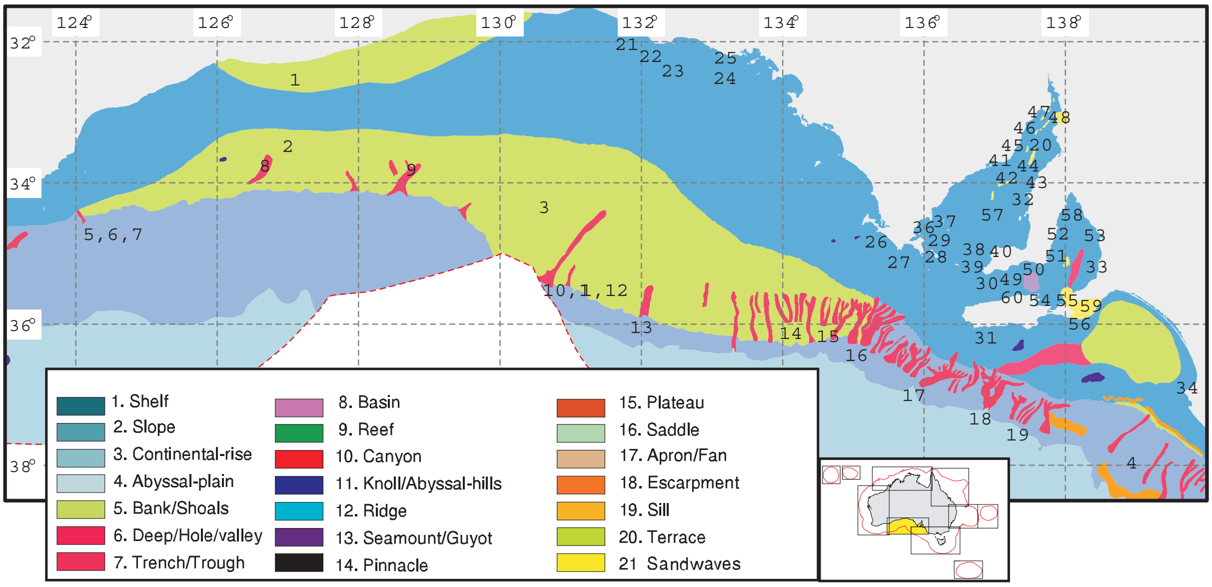

Figure 3.5. Geomorphic features on the southern margin. See Table 3.3 for key to place names and Table 3.4 for surface areas of features.

3.2.1. Continental Shelf

The continental shelf in this region is broad and arcuate in shape, with the GAB forming the dominant feature of the area. The GAB shelf is an immense, relatively flat, submarine plain 80 km wide at either end, expanding to 260 km in width at the head of the Bight. The shelf can be divided into the lower shoreface-inner shelf (<50 m water depth), middle shelf (50 to 120 m) and outer shelf, which extends to the shelf break (125 to 170 m). Along the margin, the outer shelf is 10 to 30 km wide, except in the west where the whole shelf narrows to <30 km (James et al., 2001).

The shelf is underlain by deep continental margin basins (Bradshaw et al., 2003) filled with Mesozoic terrigenous sediment and capped by approximately 800 m thick, largely cool water, Cenozoic, carbonate sediments (James et al., 2001). The GAB is bounded to the west by Archean and Palaeo-proterozoic crystalline rocks of the Yilgarn Craton and in the east by Palaeo-proterozoic rocks of the Gawler Craton (Bradshaw et al., 2003).

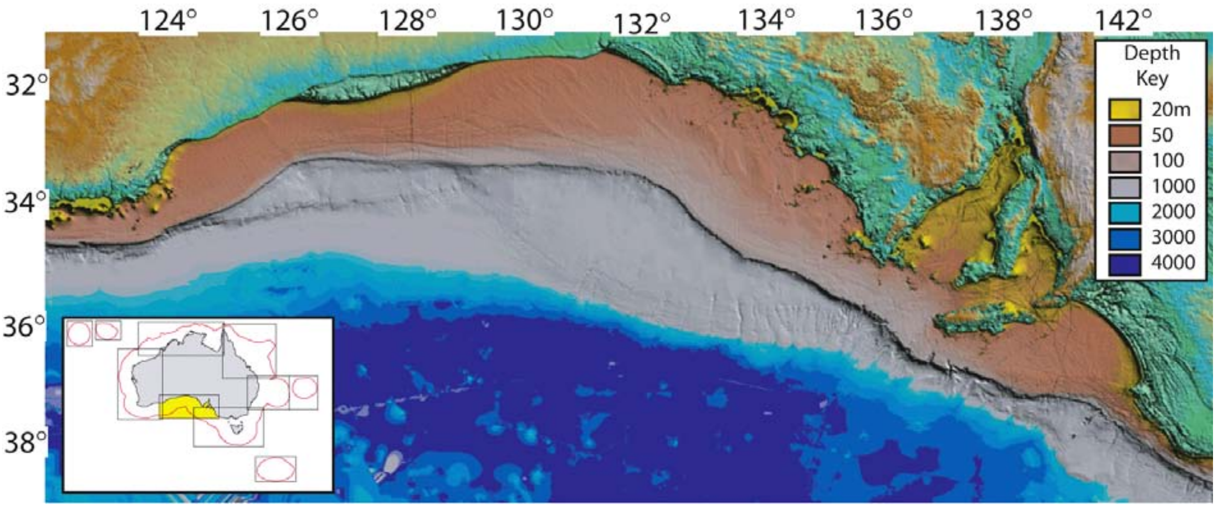

Figure 3.6. False-colour bathymetric image illuminated from the north of the southern margin.

The shelf in the GAB exhibits NW-SE trending features that are oblique to the coast. These features are possibly subaqueous dunes deposited by the eastern flowing oceanic currents such as the Leeuwin and South Australian Currents (Rollet et al., 2001). The oceanography of the shelf is dominated by storms, with the wave trains approaching mostly from the southwest (James et al., 2001). James et al. (1994) coined the term "shaved shelf" to describe the situation in the GAB, where biogenic sediment production is balanced by surface-wave erosion processes to yield zero net sedimentation. Sediments found in <100 m water depth contain mainly coarse-grained sand and gravel containing significant (>50%) relict and palimpsest fractions that attest to wave reworking and slow accumulation rates (James et al., 2001). Significant spiculitic carbonate mud deposition occurs on the upper slope (below storm wave base) where a 500 m thick prograding sediment wedge has been deposited in the Quaternary (Feary and James, 1998).

Spencer Gulf and Gulf of St. Vincent.– To the east of the GAB, the continental shelf narrows from around 100 km wide to 30 km adjacent to Kangaroo Island, and incorporates the Spencer and St. Vincent Gulfs. These Gulfs have a similar bathymetry, both being shallow and triangular in shape (Fig. 3.7). Spencer Gulf is the larger, 325 km long and about 100 km wide, and is 79 km wide at the mouth (Gostin et al., 1984; Noye, 1984). The entrance to Spencer Gulf is partially blocked by several small islands and has a maximum water depth of 50 m. It is connected to the Southern Ocean by channels that have average depths of 40 m. The depth of the Gulf is 40 m for 100 km northwards but then gradually shallows over the next 200 km towards the head. Three quarters of the area of the Gulf is less than 30 m deep. The Gulf is divided into two parts at a constriction, from Lowly Point across to Ward Spit, which limits the amount of water exchanged between the shallow upper regions and deeper lower regions (Noye, 1984, Gostin et al., 1988).

The Gulf of St. Vincent is about 130 km long and 70 km wide at the mouth, (Bye, 1976). It has a maximum depth of 41 m. Both the Investigator Strait and Backstairs Passage form a shallow sill to the Gulf and contain tidal current sand ridges stabilised by seagrasses (Harris, 1994a). The beds of both of these passages are

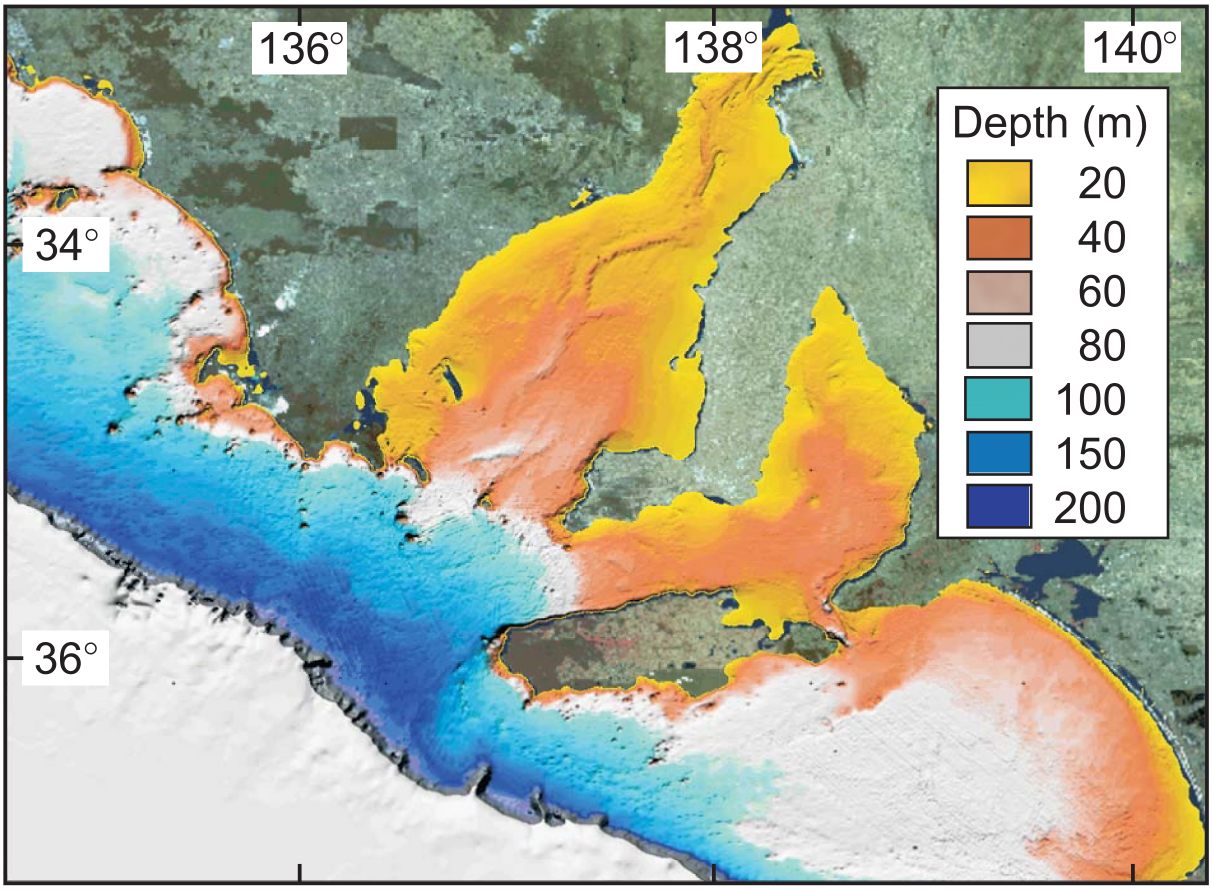

Figure 3.7. False-colour bathymetric image illuminated from the northeast, showing a close-up view of the Spencer Gulf–Kangaroo Island area. The upper regions of the Spencer Gulf contain tidal sand ridges that are partially stabilised by seagrasses (Harris, 1994a).

scoured by tidal currents, which have exposed the underlying bedrock in localised depressions (Gostin et al., 1988).

3.2.2. Continental Slope

Beyond the shelf, the GAB region contains a broad (up to 250 km wide) continental slope that includes several terraces (Wilcox et al., 1988). In the central and eastern regions, is the 700 km long Ceduna Terrace, which extends to water depths of 2,000 m. The Eyre Terrace (Conolly et al., 1970) extends from 200 to 1,000 m and borders part of the western margin (Wilcox et al., 1988). Along the western and central parts of the GAB, the lower continental slope forms a broad, low-gradient feature, the Recherche Lower Slope. This has been incorrectly termed a continental rise by some previous workers.

3.2.2.1. Terraces

Processes such as eustatic sea level rise, tectonic subsidence, and/or climatic change have been used to explain the formation of the terraces on the southern margin. The terraces are thought to correspond to a Late Cretaceous (Albian-Cenomanian) shelf that formed during the deposition of deltaic sediments derived from the erosion of the uplifted eastern Australia highlands (Totterdell et al., 2000, Norvick and Smith, 2000, Rollet et al., 2001). Since the beginning of the Tertiary the southern margin has been sediment starved and dominated by cool-water carbonates. The Late Cretaceous shelf margin continued to subside throughout the Tertiary at a greater rate than the accumulation of carbonates. This resulted in the Tertiary shelf margin being inboard of the Late Cretaceous margin (Rollet et al., 2001). The terraces form a regional intermediate topography between the continental shelf and deep ocean, and probably consist of a sequence of former shelf sediments (Conolly and Von der Borch, 1967).

Eyre Terrace.– The Eyre Terrace is located in the west, and has a width of 200 km. It occurs in water depths of between 200 and 2,000 m (Rollet et al., 2001, James et al., 1994).

Roe Terrace.– The Roe Terrace is an area of shallow, smooth seabed 75 km wide off Eucla on the inner shelf, and occurs in water depths of between 30 and 50 m (James et al., 2001). The terrace was probably formed by marine erosion and cliff retreat throughout the Pleistocene and is veneered with a metre thick blanket of sediment (James et al., 2001).

Ceduna Terrace.– The Ceduna Terrace is located between 130 and 134˚ E, in the east. The terrace is up to 200 km wide and occurs in water depths of between 200 and 3,000 m (Rollet et al., 2001, James et al., 2001, Von der Borch, 1967a). The vertical relief on the terrace locally attains 150 m (Von der Borch, 1967a). The seabed gradient increases to 1:600 seaward of the incipient slope that separates the shelf from the terrace (Von der Borch, 1967a). The smooth surface of the Ceduna Plateau might be a relict depositional surface that has rough topography in areas where there has been subsequent erosion (Conolly and Von der Borch, 1967). It is a relict late Cretaceous shelf margin (Rollet et al., 2001).

3.2.2.2. Submarine Canyons

The continental slope of the southern margin contains numerous submarine canyons. The larger canyons were mapped from the bathymetric contours and drainage analysis (Fig. 3.8). The axes of the submarine canyons are generally oriented perpendicular to the shelf break, and the majority of them occur at considerable distances (up to 80 km) from the nearest landmass which suggests that they are probably inactive at present. The relative aridity of southern Australia, and absence of rivers in the region suggests that there has been little significant fluvial erosion or terrigenous sediment input to the margin during the Quaternary, although carbonate sedimentation on the margin has been prolific through this time.

Albany Group.– The Albany Group includes approximate 32 submarine canyons between Broke Canyon in the west and Malcolm Canyon in the east (Rollet et al., 2001). The Albany Group begins in its western extremity opposite the seaward extent of the Darling Fault, separating Perth Basin sediments from crystalline basement rocks. Offshore of Albany, the continental shelf is narrow and contains several indentations associated with slumps up to 50 km wide with a displacement of about 10 km down dip.

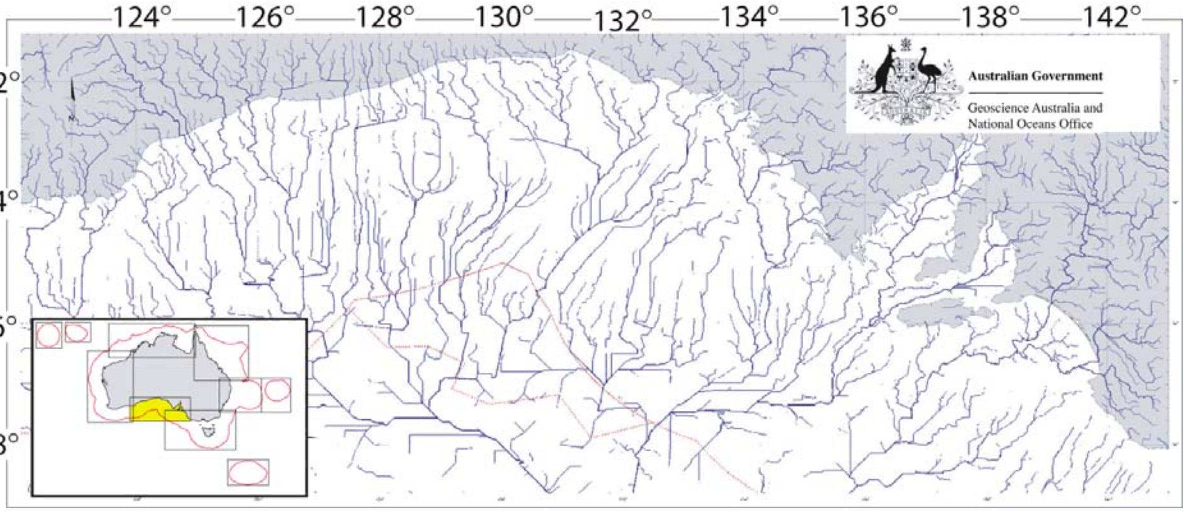

Figure 3.8. Predicted drainage system of the southern margin, showing the positions of major submarine canyons on the continental slope.

Esperance Canyon.– Esperance Canyon heads in about 100 m water depth about 30 km offshore from Esperance at the edge of the continental shelf. Upper reaches of the canyon are 16 km west of Termination Island in the Recherche Archipelago. A sediment-filled channel extending from Esperance may extend out to the head of the Esperance Canyon (Von der Borch, 1968).

Pasley Canyon.– Pasley Canyon is located at longitude 124˚ E. It lies opposite the eastern end of shallow basement rocks that crop out on the continental shelf and comprise the islets of the Recherche Archipelago (Von der Borch, 1968). East of Malcolm Canyon the trend of the margin changes from E–W to NE–SW. This change in orientation corresponds with the eastern edge of the Yilgarn Block and the western boundary of the Tertiary Eucla Basin onshore and a break between the Eyre and Bremer Basins (Rollet et al., 2001).

Eyre and Eucla Canyons.– Two large canyons, Eyre and Eucla Canyons, occur down-slope from the Eyre Terrace. A fault zone or structural boundary probably guides their locations (Rollet et al., 2001).

Nullarbor and Ceduna Canyons.– The eastern part of the Ceduna Terrace is incised by at least six canyons, including Nullarbor and Ceduna Canyons.Nullarbor Canyon is the largest and deepest in the area and is composed of a series of deep holes (Rollet et al., 2001). Ceduna Canyon is located at longitude 133˚ E and consists of a small V-shaped canyon with flat floor, lying opposite the boundary between the Eucla Basin and basement rocks (Von der Borch, 1968).

Murray Group.– The Murray Group of canyons is located between longitudes 135 and 138˚ E. The topography of the canyon slopes is extremely rough, and is characterized by small steep furrows and several large deep canyons. *Youngs Rocks*, 25 km north of the Murray Group, corresponds to areas of pre-Tertiary rocks of Upper Proterozoic to Cambrian ages, and intrusives of the Adelaide Syncline (Von der Borch, 1968). Murray and Sprigg Canyons are particularly large features each with vertical relief in excess of 2,000 m. The heads of the submarine canyons in this group contain both amphitheatre and branching dendritic types (Conolly and Von der Borch, 1967).

Bridgewater Group.– The Bridgewater Group of canyons includes four, well-defined, steep, narrow V-shaped submarine canyons. The canyons are located opposite the Otway Basin and are formed in Tertiary and older sediments (Von der Borch, 1968).

3.2.3. Abyssal Plain

The foot of the continental slope was determined from UNCLOS positions and were used to define the boundary marking the edge of the abyssal plain. Picks were available from the west to longitude 134° E. In the east, the boundary was determined based on bathymetric contours. Bathymetry in this area was of insufficient spatial resolution to discriminate features confidently on the abyssal plain.

Table 3.3. List of previously described geomorphic features on the southern margin. Features are numbered (left hand column) on Fig. 3.5.

No.	Geomorphic Feature	Feature Type	References
1	Roe Terrace	Terrace (20)	James et al. (2001)
2	Eyre Terrace	Terrace (20)	James et al. (1994)
3	Ceduna Terrace	Terrace (20)	Von der Borch (1967b); Rollet et al. (2001)
4	Beachport Plateau	Terrace (20)	Von der Borch et al. (1970)
5	Cooper Canyon	Canyon (10)	Rollet et al. (2001)
6	Pasley Canyon	Canyon (10)	Von der Borch (1968)
7	Malcome Canyon	Canyon (10)	Rollet et al. (2001)
8	Eyre Canyon	Canyon (10)	Rollet et al. (2001)
9	Eucla Canyon	Canyon (10)	Rollet et al. (2001)
10	Nullarbor Canyon	Canyon (10)	Rollet et al. (2001)
11	Yatala Canyon	Canyon (10)	Rollet et al. (2001)
12	Adieu Canyon	Canyon (10)	Rollet et al. (2001)
13	Ceduna Canyon	Canyon (10)	Von der Borch (1968)
14	Fowlers Canyon	Canyon (10)	Rollet et al. (2001)
15	Topgallant Canyon	Canyon (10)	Rollet et al. (2001)
16	Lincoln Canyon	Canyon (10)	Rollet et al. (2001)
17	De Couedic Canyon	Canyon (10)	Rollet et al. (2001)
18	Murray Canyon	Canyon (10)	Von der Borch (1968)
19	Sprigg Canyon	Canyon (10)	Rollet et al. (2001)
20	Spencer Gulf Sand Banks	Sand Banks (21)	Gostin et al. (1984)
21	D'Entrecasteaux Reef	Reef (9)	R. A. N. (1997a)
22	Nuyts Reefs	Reef (9)	R. A. N. (1997a)
23	Yatala Reef	Reef (9)	R. A. N. (1997a)
24	Cannan Reefs	Reef (9)	R. A. N. (1997a)

25	Lounds Reef	Reef (9)	R. A. N. (1997a)
26	Stuart Reef	Reef (9)	R. A. N. (1997b)
27	The Cabbage Patch	Reef (9)	R. A. N. (1990)
28	Dangerous Reef	Reef (9)	R. A. N. (1990)
29	Buffalo Reef	Reef (9)	R. A. N. (1990)
30	Emmes Reef	Reef (9)	R. A. N. (1990)
31	Lipson Reef	Reef (9)	R. A. N. (1990)
32	Tiparra Reef	Reef (9)	R. A. N. (1992a)
33	Horseshoe Reef	Reef (9)	R. A. N. (1992b)
34	Margaret Brock Reef	Reef (9)	R. A. N. (1992c)
35	Breaksea Reef	Reef (9)	R. A. N. (1969)
36	Jane & Nicolette Shoals	Bank/Shoal (5)	R. A. N. (1990)
37	Rosalind Shoal	Bank/Shoal (5)	R. A. N. (1990)
38	Louise & Suzanne Shoals	Bank/Shoal (5)	R. A. N. (1990)
39	Lake Macquarie Bank	Bank/Shoal (5)	R. A. N. (1990)
40	Waller, Lawrey, Iron Wyalla, Brook & Packman Shoals	Bank/Shoal (5)	R. A. N. (1990)
41	Dillon Shoals	Bank/Shoal (5)	R. A. N. (1992a)
42	Clan Macdougall Shoal	Bank/Shoal (5)	R. A. N. (1992a)
43	Riley & Moonta Shoals	Bank/Shoal (5)	R. A. N. (1992a)
44	Middle Bank	Bank/Shoal (5)	R. A. N. (1992a)
45	Plank Shoal	Bank/Shoal (5)	R. A. N. (1992a)
46	Yarraville & Musgrave Shoals	Bank/Shoal (5)	R. A. N. (1992a)
47	Western & Eastern Shoals, Fairway Bank	Bank/Shoal (5)	R. A. N. (1992a)
48	Douglas Bank	Bank/Shoal (5)	R. A. N. (1992a)
49	Orcades Bank	Bank/Shoal (5)	R. A. N. (1992b)
50	Pt Davenport Shoal	Bank/Shoal (5)	R. A. N. (1992b)
51	Troubridge & Tapley Shoals, McIntosh Bank	Bank/Shoal (5)	R. A. N. (1992b)
52	Orontes Bank	Bank/Shoal (5)	R. A. N. (1992b)
53	Wonga Shoal	Bank/Shoal (5)	R. A. N. (1992b)
54	Landing & Hardstaff Shoal	Bank/Shoal (5)	R. A. N. (1992b)
55	Yatala Shoal	Bank/Shoal (5)	R. A. N. (1992b)
56	Sanders Bank	Bank/Shoal (5)	R. A. N. (1992c)

Table 3.4. Geomorphic make-up of the southern margin. Code refers to the geomorphic feature type listed in Table 2.2.

Code	**Geomorphic Feature**	**Km^2**	**Percent**
1	Shelf*	251,430	36.30
2	Slope*	257,670	37.20
4	Abyssal plain*	183,570	26.50

	Total	**692,670**	**100.00**
1	Shelf*	226,590	32.71
2	Slope*	114,460	16.52
4	Abyssal plain*	183,560	26.50
5	Bank/Shoal	340	0.05
6	Deep/Hole/Valley	2,010	0.29
8	Basin	510	0.07
10	Reef	30	0.00
11	Canyons	16,890	2.44
15	Knoll/Abyssal Hills/Hill/Peak	290	0.04
18	Escarpment	380	0.05
20	Terrace	147,150	21.24
21	Sandwave/Sand bank	460	0.07

***** First listing of continental shelf, slope, and abyssal plain areas are total, mutually exclusive areas. Second listing of continental shelf, slope, and abyssal plain areas are less the surface areas of superimposed features (e.g., shelf area is total shelf area minus superimposed basin area, sill area, terrace area, etc.).

3.3. Western Margin (Cape Leuwin to Northwest Shelf)

The western margin of Australia (Figs. 3.9, 3.10) is an Atlantic-type passive margin, where the Australian continent is moving away from the spreading centre in the Indian Ocean (Falvey and Veevers, 1974). The margin extends from Cape Leuwin in the south to the Northwest Shelf in the north, and represents an area of approximately 1,239,690 km^2. The geomorphic features of the margin owe their origins to the rifting of Australia and the opening of the Indian Ocean after the initial break-up of the Gondwana supercontinent between 95 and 83 Ma ago (Veevers, 1986). Major geomorphic features that have been named or that have been reported in scientific investigations are listed in Table 3.5 and the geomorphic make-up of the margin is provided in Table 3.6.

3.3.1. Continental Shelf

Recherche Shelf.– The Recherche Shelf borders the southern coast of Western Australia and extends from Israelite Bay located at the western edge of the Great Australian Bight to Cape Leeuwin (Carrigy and Fairbridge, 1954). The Recherche Shelf is 25 to 65 km wide and covers an area of nearly 65,000 km^2. Four main reefs, South West, Maude, Brown and Warren Reefs occur on the shelf (Royal Australian Navy, 1991; 1994), which is studded with islands of crystalline rock such as the Archipelago of the Recherche (Conolly, 1970; Conolly and Von der Borch, 1967). Bird (1979) describes the Recherche Shelf as having an inner zone of scoured rock platforms dotted with islands, and further towards the shelf edge there is a cover of shelly sand. The major portion of the shelf is a 20 to 50 km wide plain, to a water depth of 100 m. Further seawards, the shelf drops off rapidly to the shelf break at water depths of 110 to 150 m (Conolly and Von der Borch, 1967).

Rottnest Shelf.– The Rottnest Shelf extends from Cape Leeuwin to Geraldton (Carrigy and Fairbridge, 1954). The Shelf ranges in width from 45 to 100 km (Playford et al., 1976) and covers an area of approximately 52,000 km^2. The southern Rottnest Shelf is a distally steepened ramp-like surface, 43 to 93 km in width (Collins, 1988). Several large reefs are located along this sector of the continental shelf, and from south to north are named Geographe, Naturaliste, Bouvard, Murray, Coventry, and Horseshoe Reefs (Royal Australian Navy, 1988).

North of Cockburn Sound (Perth) the Rottnest shelf is characterised by luxuriant seagrasses growing on coralline-encrusted hardgrounds (James et al., 1999). An incipient rim on the outer shelf is capped further north by the Houtman Abrolhos reef platforms, which are the highest latitude reefs in the Indian Ocean. The reefs exhibit complex karst topography, with numerous doline "blue holes" as noted by Teichert (1947) and Fairbridge (1946). The reefs are not completely relict; there is widespread modern coral growth, and bore-holes from the reef's landward (eastern) side penetrated 25 m of Holocene reefal carbonate (Collins et al., 1996). On the outer shelf offshore of the Houtman Abrolhas reefs, Harris et al. (1991) described shore parallel ridge system backed by depressions. The ridges are defined by the shape of the 50 m contour, which delimits several shore-parallel ridges located seawards of the main reef complex. Ridges and depressions at about 90-95 m can be traced along the outer shelf for over 100 km along the shelf. Inshore of the 50 m isobath, the mid-to inner-shelf is a broad planar surface, upon which the Houtman Abrolhos Reefs rest. Elsewhere, high-quality data are limited for the southern margin with the result that much of the physiography of the margin is still poorly known.

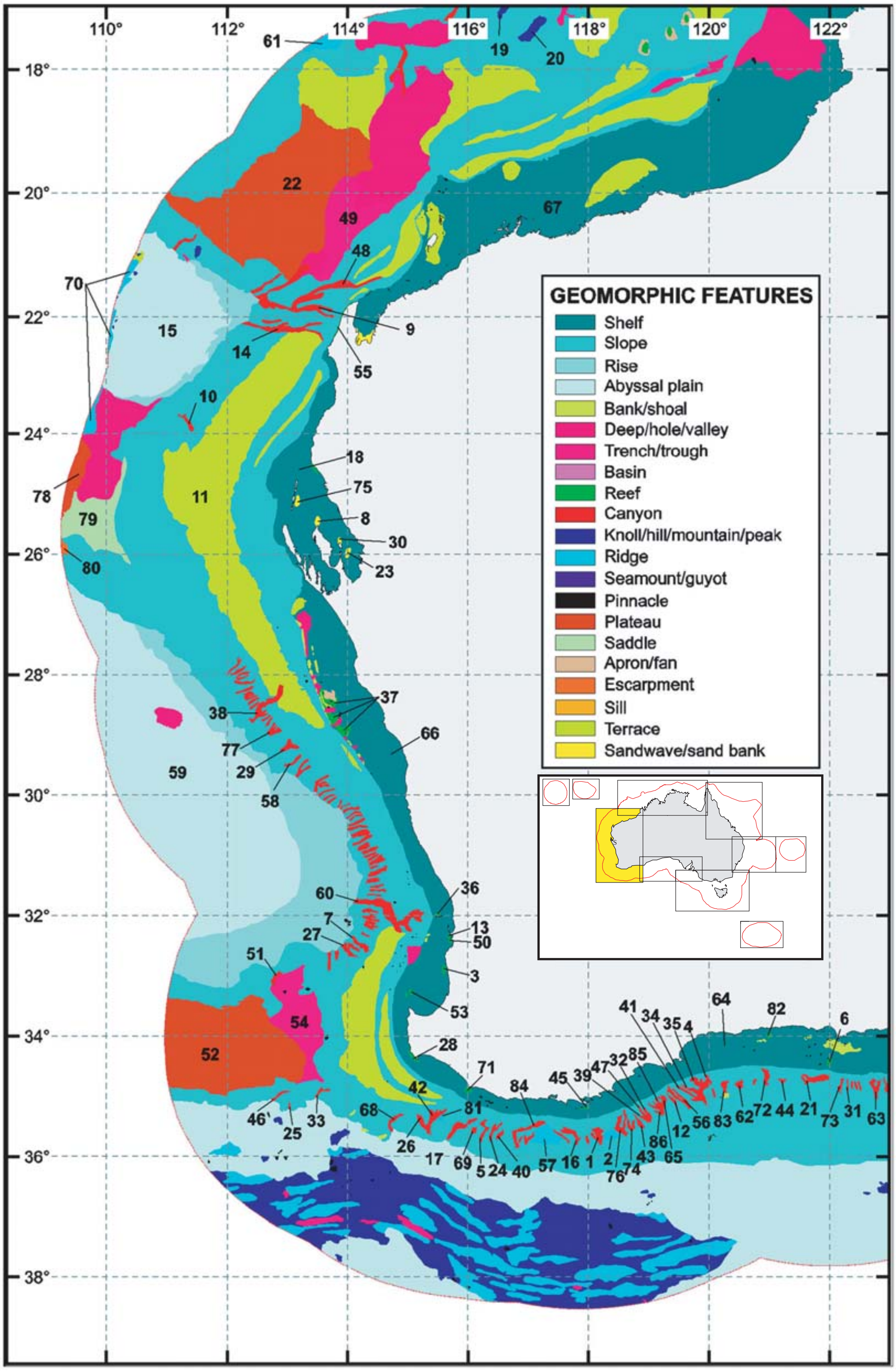

Figure 3.9. Geomorphic features on the western margin. See Table 3.5 for key to place names and Table 3.6 for surface areas of features.

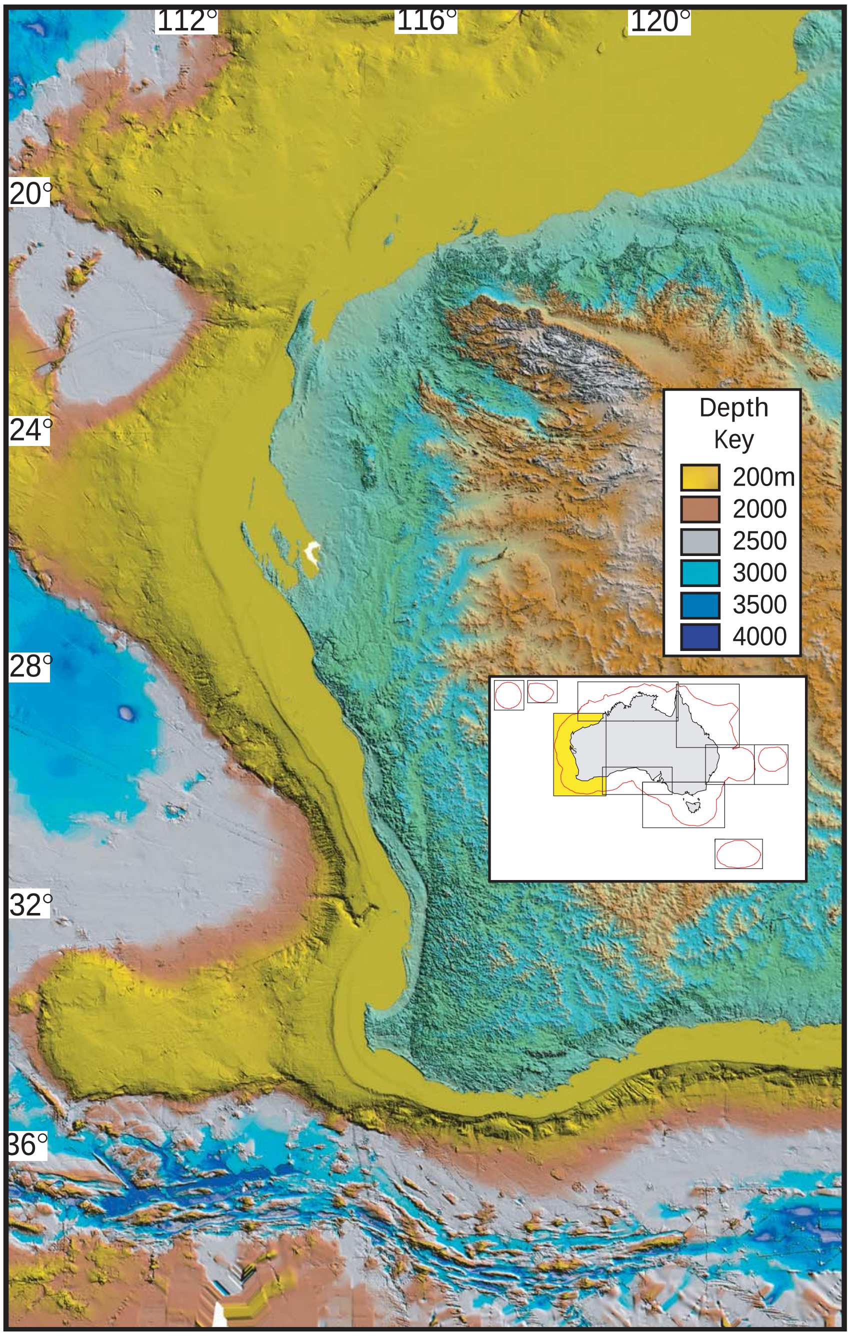

Figure 3.10. False-colour bathymetric image illuminated from the north showing the western margin.

Dirk Hartog Shelf.– The Dirk Hartog Shelf, also known as the Carnarvon ramp (James et al., 1999), extends from Shoal Point in the south to North West Cape in the north (Carrigy and Fairbridge, 1954). The shelf covers an area of approximately 77,000 km^2 and is about 70 km wide. A major geomorphic feature on this part of the shelf is Shark Bay, a shallow marine embayment of approximately 12,950 km^2 (Logan and Cebulski, 1970), which includes several sandbanks and low-gradient tidal flats (Faure, Cape Peron, Green Turtle Flats, and Uranie Bank). Shelf sediments offshore of Shark Bay are mostly relict, and are either sorted planktonic foraminiferal sands under strong bottom currents, or spiculitic mud. James et al. (1999) suggest that relict sediments here are due to arrested carbonate sedimentation caused by downwelling and episodic outflows of saline, Shark-bay waters onto the outer shelf and upper slope. In the north, located between 20° and 22°S, is Ningaloo Reef, a 260 km long fringing reef that extends northeast along the shelf edge (Collins, 2002). Further to the south, the Perth Basin is a N-S trending feature that extends about 1,000 km beneath the coastal region and continental margin of southwest Australia (Marshall et al., 1989) and covers an area of approximately 45,000 km^2 off shore (Playford et al., 1976).

North West Shelf.– A major marine province of Western Australia is the North West Shelf, which extends for about 2,400 km along the northwest margin of the continent, between Exmouth Gulf in the south and Melville Island in the north. The continental shelf covers an area of approximately 720,000 km^2 (Exon, 1994), and the margin contains several large mid-slope marginal plateaus (Exmouth and Wallaby Plateaus) that occur in water depths of over 2,000 m (Exon, 1994). The southern region of the North West Shelf includes the Browse, Bonaparte, Canning, Roebuckand and Carnarvon Basins (Purcell and Purcell, 1988). The shelf width ranges from 16 km off North West Cape to 200 km near the Rowley Shoals (Jones, 1971, 1973; Purcell and Purcell, 1988).

Rowley Shelf.– The Rowley Shelf is located between the Leveque Rise in the north and North West Cape in the south (Carrigy and Fairbridge 1954). The shelf covers an area of about 246,000 km^2. Within the Rowley Shelf, smaller segments of the continental shelf have been identified (e.g., Peedamullah Shelf, Preston Shelf). However, such shelf segments are generally related to more complex features than the shelf proper, because they can be traced onshore and their limits are based on fault zones. The shelf contains the Rowley Shoals, a chain of coral atolls that are of similar dimensions, shape, and orientation. The atolls are oriented N-S and are pear-shaped, with the narrow end towards the north. The Shoals rise with nearly vertical sides from water depths of up to 440 m (Jones 1973).

3.3.2. Continental Slope

Falvey and Veevers (1974) divided the continental slope into an upper slope (with a gradient of 2°-20°) and lower slope (with a gradient of 1°-2°). The slope is variable both in width and gradient, and is on average narrower in the southwest. Submarine canyons are abundant on the upper slope, and commonly occur in groups rather than as single incisions. South of the Carnarvon Basin, the upper slope is smooth and canyons are rare (Marshall et al., 1993). The lower slope incorporates several large marginal plateaus; from south to north these are the Naturaliste, Wallaby and Exmouth Plateaus (Symonds and Willcox, 1988). The base of the lower slope is distinguished by an abrupt reduction in gradient, with the rise (where developed) extending from the base of the lower slope to the abyssal plain.

West of Rottnest Island, about 50 km offshore from the Swan River Estuary is the Perth Canyon, a large submarine canyon of similar dimensions to Bass Canyon on the southeast margin (Fig. 3.11). The canyon is about 160 km long and debouches on to the abyssal plain north of the Naturaliste Plateau, but the head of the canyon does not extend eastward onto the continental shelf (Playford et al., 1976). Along its upper course, smaller feeder canyons divided by terraces, enter the main canyon from the southeast (Fig. 3.11).

Submarine canyons are very well developed all along the southwestern continental margin, particularly west of 122° E (Fig. 3.9). Von der Borch (1968) mapped, named and grouped a large number of these canyons. The canyon morphology is described in section 3.2. However, 40 of the main canyons in the Albany Group that occur on the western margin are listed in Table 1. Other canyons also appear in the Offshore Resource Map Series (Jongsma et al., 1990; 1991; Jongsma and Johnston, 1993), in the nautical charts of the Royal Australian Navy (1994) and in the seabed character mapping of the Great Australian Bight by Rollet et al. (2001). In the north, two large canyons occur west of Cape Exmouth and west of the Rowley Shoals (Figs. 3.9 and 3.12).

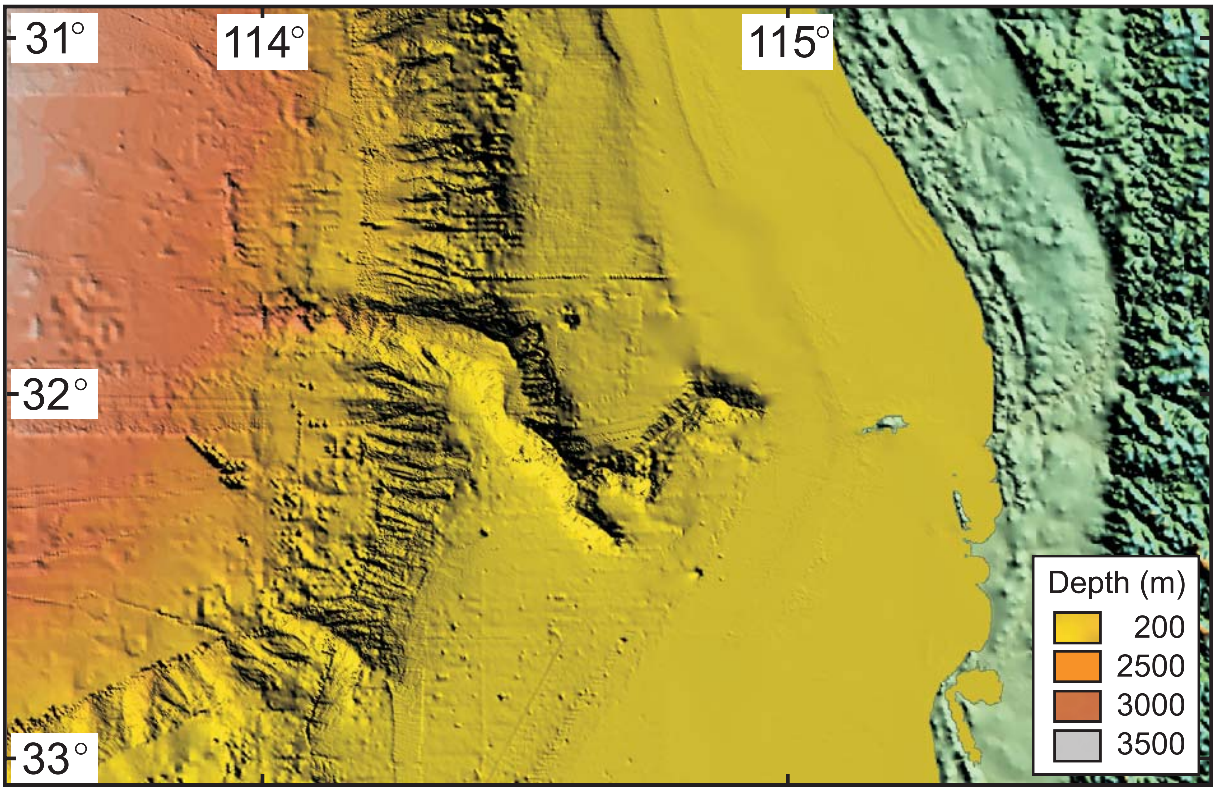

Figure 3.11. False-colour bathymetric image illuminated from the north showing the Perth Canyon.

Naturaliste Plateau.– The Naturaliste Plateau is located approximately 260 km west of Cape Leeuwin and Cape Naturaliste in water depths of approximately 2,000 to 5,000 m. It covers an area of approximately 90,000 km² and is up to 400 km wide and 250 km long. To the north, it borders the Perth Abyssal Plain and to the east is separated from the shelf by the N-S trending Naturaliste Trough (Borissova, 2002).

Carnarvon Terrace.– The Carnarvon Terrace is located east of the Wallaby Plateau and Wallaby Saddle and forms an arcuate shallow zone in the upper continental slope. It covers an area of about 80,000 km² and extends for 800 km between Geraldton and North West Cape (Symonds and Cameron, 1977). It extends between the 400 m and the 1,600 m isobaths and is widest about 115 km west of Carnarvon.

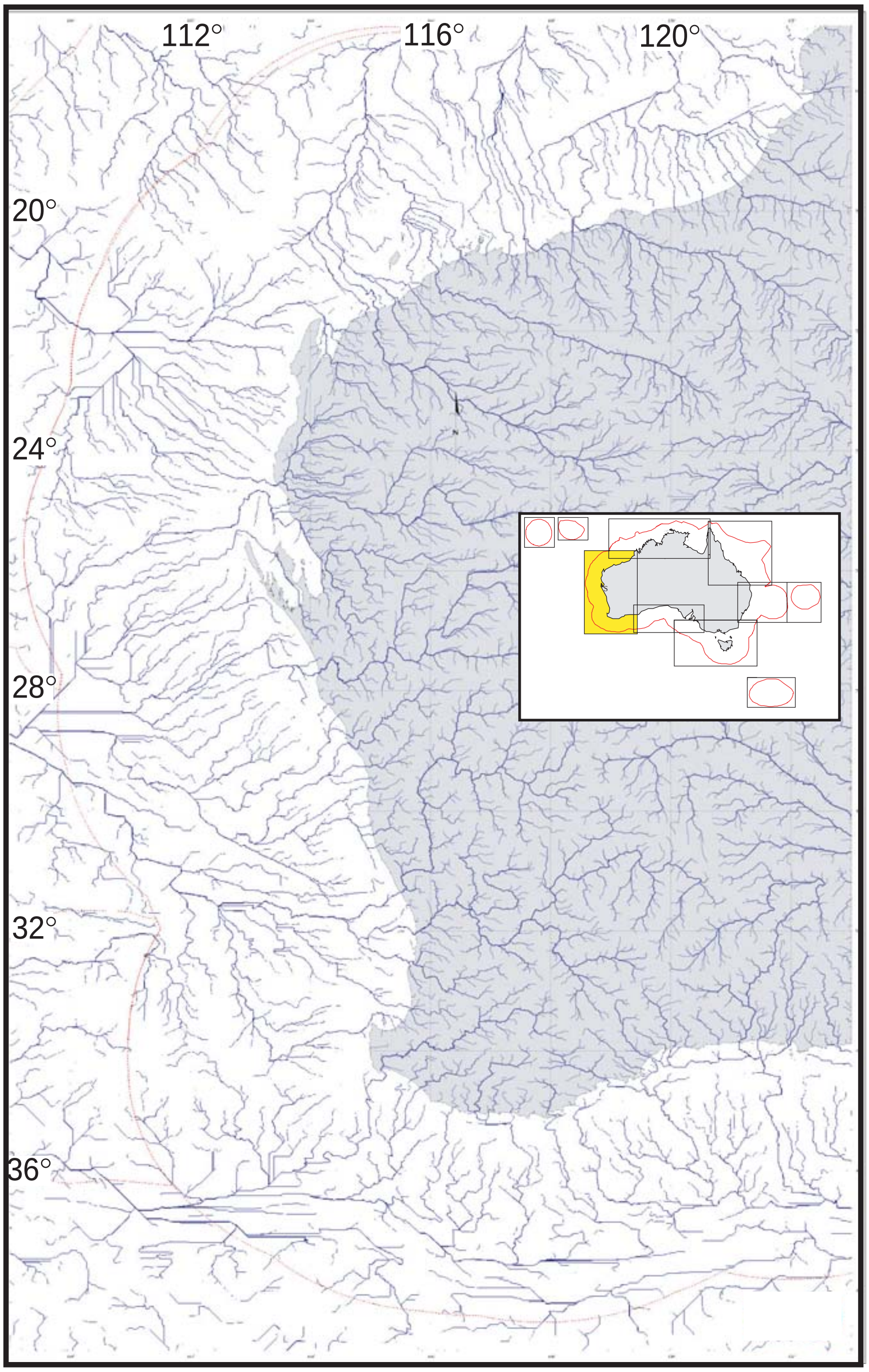

Figure 3.12. Predicted drainage system of the western margin, showing the positions of major submarine canyons on the continental slope.

Wallaby Plateau.– The Wallaby Plateau is located southwest of the Cuvier Abyssal Plain at a regional depth of 2,500 m. It comprises an asymmetric, dome-shaped, bathymetric high that tilts down towards the south. The Plateau covers an area of about 70,000 km² (Sayers et al., 2002), and is separated from the lower continental slope by the 100 km wide Wallaby Saddle, a deep northerly trending trough (Symonds and Cameron, 1977). Two N-NE trending ridges extend from the northern margin of the Plateau. In the west, the Sonja Ridge is about 40 km wide, 200 km long and commonly rises to water depths of around 2,600 m. In the east, the Sonne Ridge is up to 40 km wide, 230 km long and is located in water depths of 3,800 m. The Wallaby Plateau is bordered to the south by the NW-trending Wallaby-Perth Scarp (the Wallaby-Zenith Fracture Zone).

Exmouth Plateau.– The Exmouth Plateau is an extensive marginal plateau that represents a large block of continental crust that subsided after rifting and sea-floor spreading in the Indian Ocean. The Exmouth Plateau trends NE-SW, parallel to the coast and the area shallower than 2,000 m is approximately 150,000 km^2 (Exon and Willcox, 1980). Geologically, the Plateau forms part of the northern Carnarvon Basin (Hocking et al., 1987; Cockbain, 1989). The Plateau surface has a gradient <0.5° and is bounded by the 800 m isobath to the southeast, and by the lower continental slope to the north, northwest, and southwest where water depths range from 2,000-4,000 m (Stagg et al., 2003). The surface of the Plateau is rough and undulating and is between 900 and 1,000 m water depth. The western margin has a gradient of up to 3°. The Montebello Trough is a broad valley that separates the Exmouth Plateau from the upper slope (Falvey and Veevers, 1974). The major features along the northern margin of the Plateau, apart from the Montebello Trough, are the Platypus Spur, Wombat Plateau, Echidna Spur, Emu Spur and Swan Canyon with relief of >500 m (Exon and Willcox 1980). The largest canyons on the Exmouth Plateau are located along the northern margin, where their orientations are strongly controlled by major faults (Ramsay and Exon, 1994). Emu Spur is a N-trending broad ridge up to 350 m in height. The neighbouring Swan Canyon is a steep-sided submarine valley >500 m deep, that opens out on the Argo Abyssal Plain in water depths of >5,000 m. Smaller canyons also occur on the southern margin. The northern region of the plateau is characterised by northerly trending spurs and valleys.

3.3.3. Foot of Slope and Rise

The foot of slope in Western Australia forms a broad, seaward arc along the seaward margin of the Naturaliste Plateau that turns landward north of the Plateau into the Perth Canyon, before turning seawards again further north. A second major seaward excursion of the foot of slope occurs in association with the Exmouth Plateau.

The rise is generally a smooth sediment apron (e.g., south of the Exmouth Plateau), apart from northwest of the Exmouth Plateau where the surface is rough and undulating. South of 26° S, a NW-aligned escarpment bordering the Perth Abyssal Plain disrupts the rise. The rise bordering parts of the Scott and Exmouth Plateaus is narrow and has a rough surface. Along the Wallaby-Perth Scarp, the rise is located in water depths of between the 4,500 and 5,500 m and is of variable width. South of 28°S the width increases considerably (Marshall et al., 1989).

3.3.4. Abyssal Plain

Diamantina Zone.– The Diamantina Zone is an elongated area of the seabed that is characterized by very rough topography that has formed as a result of very slow seafloor spreading at the Southeast Indian Ridge axis (Mutter et al., 1985) The zone extends from the eastern edge of Broken Ridge in the Indian Ocean to 120-125° E (Talwani et al., 1978). South of Western Australia, the Diamantina Zone is about 200 km wide and consists of closely spaced E-W trending basement ridges and troughs with relief of up to 4,000 m. The southern edge of the Diamantina Zone corresponds to a scar left in the topography by the rifting that separated Antarctica and Australia (Mammerickx and Sandwell 1986). The boundary between the Diamantina Zone and the Australia-Antarctica Basin further to the south is marked by a rapid shallowing of bathymetry from 6,500 m to 4,500-5,000 m and a change to smooth topography.

Perth Abyssal Plain.– The Perth Abyssal Plain is located in water depths of over 5,600 m. Along the Wallaby-Perth Scarp and the continental slope to the south, numerous canyons have acted as conduits for sediment the abyssal plain (Falvey and Veevers, 1974). Abyssal hills occur to the west and occur as low hills, blanketed with pelagic sediments, and sharp ridges. They trend NNE-NE and terminate abruptly along boundaries, which form northwesterly lineations, interpreted by Stagg and Exon, (1981) as possible fracture zones.

Cuvier Abyssal Plain.– The Cuvier Abyssal Plain is located in water depths of over 5000 m. It receives a large amount of terrigenous sediment from the continent. It deepens to the northwest to form a possible drainage system into the deeper Wharton Basin through a gap at 20° S and 108.5° E.

Table 3.5. List of previously described geomorphic features on the western margin. Features are numbered (left hand column) on Fig. 3.9.

No.	Geomorphic Feature	Feature Type	References
1	Albany Canyon	Canyon (10)	Von der Borch (1968)
2	Albany Spur	Ridge (12)	Jongsma and Johnston (1993a)
3	Bouvard Reef	Reef (9)	Royal Australian Navy (1988)
4	Bremer Canyon	Canyon (10)	Von der Borch (1968)
5	Broke Canyon	Canyon (10)	Von der Borch (1968)
6	Brown Reef	Reef (9)	Royal Australian Navy (1991)
7	Busselton Canyon	Canyon (10)	Jongsma and Johnston (1993a)
8	Cape Peron Flats	Sandbank (21)	Royal Australian Navy (1968)
9	Cape Range Canyon	Canyon (10)	Jongsma et al. (1990)
10	Carnarvon Canyon	Canyon (10)	Jongsma et al. (1990)
11	Carnarvon Terrace	Terrace (20)	Symonds and Cameron (1977)
12	Cheyne Canyon	Canyon (10)	Jongsma and Johnston (1993a)
13	Coventry Reef	Reef (9)	Royal Australian Navy (1988)
14	Cloates Canyon	Canyon (10)	Jongsma et al. (1990)
15	Cuvier Abyssal Plain	Abyssal Plain (4)	Falvey and Veevers (1974)
16	Denmark Canyon	Canyon (10)	Rollet et al. (2001)
17	D'Entrecasteaux Canyon	Canyon (10)	Von der Borch (1968)
18	Dirk Hartog Shelf	Shelf (1)	Carrigy and Fairbridge (1954)
19	Echidna Spur	Ridge (12)	Exon and Willcox (1980)
20	Emu Spur	Ridge (12)	Exon and Willcox (1980)
21	Esperance Canyon	Canyon (10)	Von der Borch (1968)
22	Exmouth Plateau	Plateau (15)	Exon and Willcox (1980)
23	Faure Flat	Sandbank (21)	Royal Australian Navy (1968)
24	Frankland Canyon	Canyon (10)	Jongsma and Johnston (1993a)

25	Freycinet Canyon	Canyon (10)	Jongsma and Johnston (1993c)
26	Gardner Canyon	Canyon (10)	Jongsma and Johnston (1993a)
27	Geographe Canyon	Canyon (10)	Rollet et al. (2001)
28	Geographe Reef	Reef (9)	Royal Australian Navy (1988)
29	Geraldton Canyon	Canyon (10)	Rollet et al. (2001)
30	Green Turtle Flat	Sandbank (21)	Royal Australian Navy (1968)
31	Hammer Canyon	Canyon (10)	Jongsma and Johnston, 1993b
32	Hassell Canyon	Canyon (10)	Jongsma and Johnston (1993a)
33	Hemelin Canyon	Canyon (10)	Jongsma and Johnston (1993c)
34	Henry Canyon	Canyon (10)	Royal Australian Navy (1994)
35	Hood Canyon	Canyon (10)	Royal Australian Navy (1994)
36	Horseshoe Reef	Reef (9)	Royal Australian Navy (1988)
37	Houtman Abrolhos	Reef (9)	Collins et al. (1997)
38	Houtman Canyon	Canyon (10)	Rollet et al. (2001)
39	Ichtyologist Canyon	Canyon (10)	Jongsma and Johnston (1993c)
40	Kargan Canyon	Canyon (10)	Jongsma and Johnston (1993a)
41	Kent Canyon	Canyon (10)	Jongsma and Johnston (1993a)
42	Knob Canyon	Canyon (10)	Royal Australian Navy (1994)
43	Leeuwin Canyon	Canyon (10)	Von der Borch (1968)
44	Manypeaks Canyon	Canyon (10)	Jongsma and Johnston (1993a)
45	Marlay Canyon	Canyon (10)	Jongsma and Johnston (1993b)
46	Maude Reef	Reef (9)	Royal Australian Navy (1984)
47	Mentelle Canyon	Canyon (10)	Jongsma and Johnston (1993c)
48	Mermaid Canyon	Canyon (10)	Jongsma and Johnston (1993a)
49	Montebello Trough	Trough (7)	Falvey and Veevers (1974)
50	Murray Reef	Reef (9)	Royal Australian Navy (1988)
51	Naturaliste Knoll	Knoll (11)	Jongsma and Johnston (1993c)
52	Naturaliste Plateau	Plateau (15)	Borissova (2002)
53	Naturaliste Reef	Reef (9)	Royal Australian Navy (1988)
54	Naturaliste Trough	Trough (7)	Borissova (2002)
55	Ningaloo Reef	Reef (9)	Collins (2002)
56	Pallinup Canyon	Canyon (10)	Jongsma and Johnston (1993a)
57	Parryville Spur	Ridge (12)	Jongsma and Johnston (1993a)
58	Pelsaert Canyon	Canyon (10)	Jongsma et al. (1991)
59	Perth Abyssal Plain	Abyssal Plain (4)	Falvey and Veevers (1974)
60	Perth Canyon	Canyon (10)	Playford et al. (1976)
61	Platypus Spur	Ridge (12)	Exon and Willcox (1980)
62	Powell Canyon	Canyon (10)	Rollet et al. (2001)
63	Recherche Canyon	Canyon (10)	Jongsma and Johnston (1993b)
64	Recherche Shelf	Shelf (1)	Carrigy and Fairbridge (1954)
65	Riche Canyon	Canyon (10)	Jongsma and Johnston (1993a)
66	Rottnest Shelf	Shelf (1)	Carrigy and Fairbridge (1954)

67	Rowley Shelf	Shelf (1)	Carrigy and Fairbridge (1954)
68	Scott Canyon	Canyon (10)	Rollet et al. (2001)
69	Shannon Canyon	Canyon (10)	Jongsma and Johnston (1993a)
70	Sonne Ridge	Ridge (12)	Sayers et al. (2002)
71	South West Reef	Reef (9)	Royal Australian Navy (1994)
72	Swan Canyon	Canyon (10)	Stagg and Exon (1981)
73	Termination Canyon	Canyon (10)	Jongsma and Johnston (1993b)
74	Tokes Canyon	Canyon (10)	Von der Borch (1968)
75	Uranie Bank	Sandbank (21)	Royal Australian Navy (1968)
76	Vancouver Canyon	Canyon (10)	Von der Borch (1968)
77	Wallaby Canyon	Canyon (10)	Jongsma et al. (1991)
78	Wallaby Plateau	Plateau (15)	Falvey and Veevers (1974)
79	Wallaby Saddle	Saddle (16)	Symonds and Cameron (1977)
80	Wallaby-Perth Scarp	Escarpment (18)	Symonds and Cameron (1977)
81	Walpole Spur	Ridge (12)	Jongsma and Johnston (1993a)
82	Warreen Reef	Reef (9)	Royal Australian Navy (1994)
83	Whale Canyon	Canyon (10)	Royal Australian Navy (1994)
84	Wilson Canyon	Canyon (10)	Von der Borch (1968)
85	Wilyunup Canyon	Canyon (10)	Royal Australian Navy (1994)
86	Wongerup Canyon	Canyon (10)	Jongsma and Johnston (1993a)

Table 3.6. Geomorphic make-up of the western margin. Code refers to the geomorphic feature type listed in Table 2.2.

Code	Geomorphic Feature	Km^2	Percent
1	Shelf*	195,270	15.75
2	Slope*	589,280	47.53
3	Rise*	59,750	4.80
4	Abyssal plain*	395,390	31.89
	Total	**1,239,690**	**100.00**
1	Shelf*	180,190	14.54
2	Slope*	356,200	28.73
3	Rise*	59,700	4.82
4	Abyssal plain*	285,600	23.04
9	Reef	1610	0.13
10	Canyons	22,630	1.83
11	Knoll/Abyssal Hills/Hill/Peak	66,990	5.40
12	Ridge	41,540	3.35
14	Pinnacle	800	0.06
15	Plateau	74,320	6.00

16	Saddle	7,880	0.64
17	Apron/Fan	240	0.02
18	Escarpment	240	0.02
20	Terrace	91,610	7.39
21	Sandwave/Sand bank	820	0.07

***** First listing of continental shelf, slope, rise and abyssal plain areas are total, mutually exclusive areas. Second listing of continental shelf, slope, rise and abyssal plain areas are less the surface areas of superimposed features (e.g., shelf area is total shelf area minus superimposed basin area, sill area, terrace area, etc.).

3.4. Northern Margin (Northwest Shelf to Cape York)

The northern continental margin of Australia extends for more than 3,000 km from the Rowley Shoals in the west to Torres Strait in the east. A seafloor area of 1,537,010 km^2 lies between the coast and limit of the EEZ. The geomorphology of the margins and the origins and development of their geomorphic features can be directly attributed to the convergence of the Australian platform with Papua New Guinea and Indonesian archipelago, and associated down-warping and uplifting of different sections of the continental crust in the north, and the opening of the Indian Ocean and associated rifting and subsidence in the northwest. Major geomorphic features that have been named or that have been reported in scientific investigations are listed in Table 3.7 and the geomorphic make-up of the margins is provided in Table 3.8 and Figure 3.13.

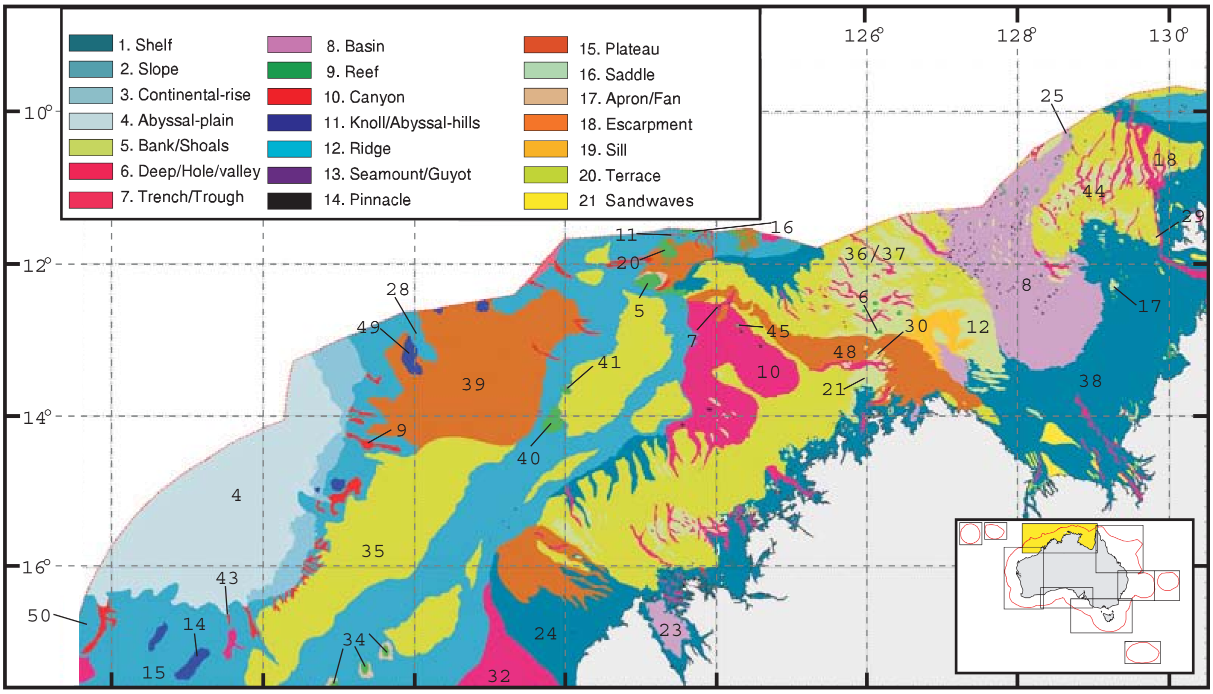

Figure 3.13. (A) Geomorphic features on the northwest margin. See Table 3.7 for key to place names and Table 3.8 for surface areas of features

3.4.1. Continental Shelf

The continental shelf of northern Australia covers an area of approximately 1,005,500 km^2 (Table 3.8). The shelf can be divided into several distinct geomorphic provinces: the Gulf of Carpentaria, Arafura Shelf, Sahul Shelf, and Rowley Shelf, all of which were drowned less than 18,000 years ago by the latest post-glacial marine transgression. The continental shelf is continuous between Australia and Papua New Guinea which formed an emergent land bridge during the last ice age (Harris, 1994b).

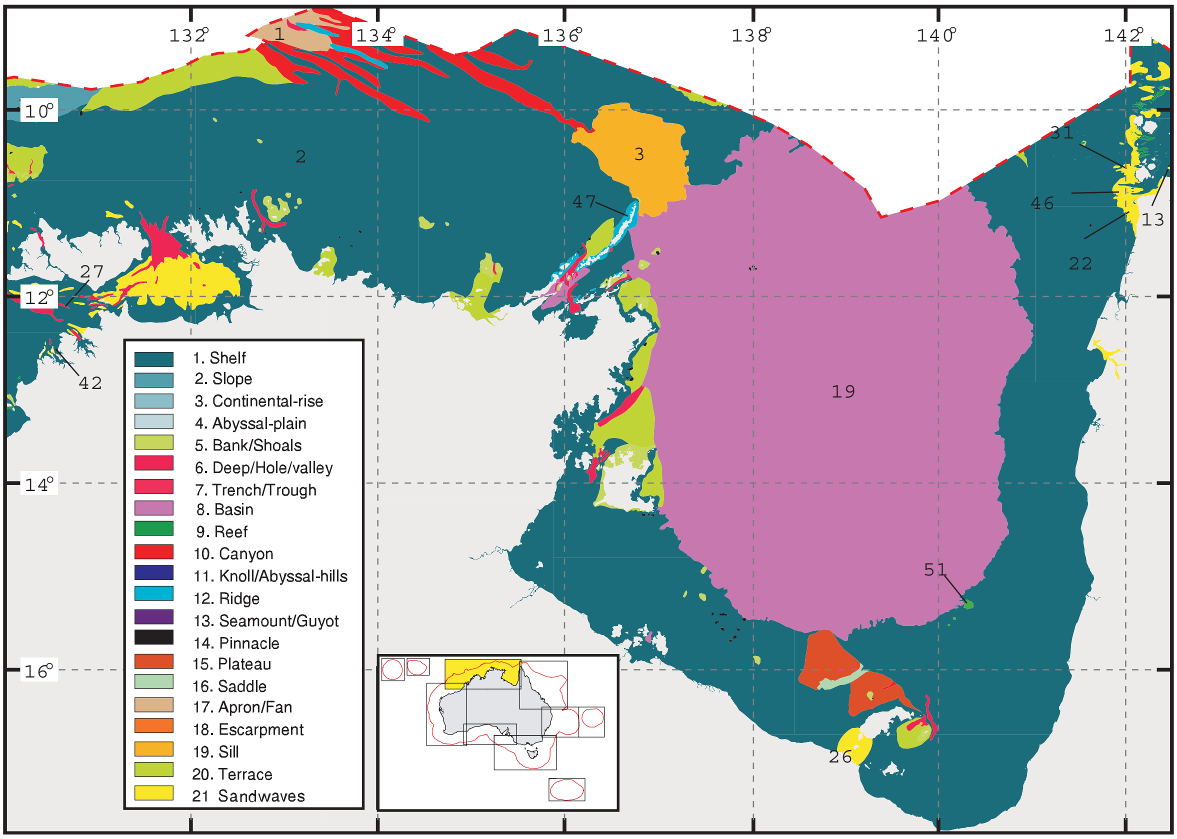

Figure 3.13–cont. (B) Geomorphic features on the northern margin. See Table 3.7 for key to place names and Table 3.8 for surface areas of features.

Rowley Shelf.– The Rowley Shelf is a low-gradient platform that covers an area of approximately 25,000 km² (Carrigy and Fairbridge, 1954; Fig. 3.14). The shelf break is almost indiscernible, with the profile of the shelf merging with the upper slope, in water depths of 300 m. Seawards of this is then the Rowley Terrace, which extends into water depths of >3500 m. Despite the difficulty in defining the shelf break, Jones (1973) suggested that the shelf width varies considerably, from >170 km in the north to <30 km in the south. The Leveque Rise separates the shelf from the Sahul Shelf to the northeast. Only the very northern part of the shelf is located in this region, and it is characterised by a broad seaward-sloping valley that extends beyond the shelf edge at about 200 m water depth and abuts the Leveque Rise to the northeast. Reefs, depressions and sand waves ranging in height from 5-10 m are locally present on the smooth shelf surface (Jones, 1973; Mcloughlin et al., 1988).

Sahul Shelf.– The Sahul Shelf is a shallow platform of complex topography. Broadly, it has a low relief, bowl-shape that is over 500 km wide at its widest point, and covers an area of approximately 415,000 km² (Carrigy and Fairbridge, 1954). Important geomorphic features of the shelf include the Sahul Banks, an extensive complex of algal banks on the outer shelf, and the Bonaparte Depression, a broad central depression on the inner to middle shelf regions. The shelf is bounded to the SW by the Leveque Rise, to the east by the Van Diemen Rise, and to the NW by the Timor Trough. The shelf break occurs at approximately 120 to 150 m water depth, and is shallower in the NE than SW.

An extensive system of reefs occurs at the shelf edge. North of Ashmore Reef, the reefs are made mostly of the coralline algae *Halimeda* as well as the skeletons of foraminifers and molluscs in lesser amounts. South of (and including) Ashmore Reef, the reefs are mostly constructed from the skeletons of hard corals. This zonation is caused by up-welling of cooler, nutrient-rich water from the Indian Ocean, providing ideal conditions for the development of hard corals. North of this latitude, water temperatures are too high due to the shallow shelf water depths and through-flow of warm equatorial water associated with the global ocean circulation through the Indonesian Archipelago (Heyward et al., 1997). The outer shelf regions are characterised by a nearly continuous chain of submerged carbonate banks that rise from water depths of 150 m, with some banks rising from depths of as much as 300 m. The banks are generally <10 km^2 in area with flat tops, and contain steep slopes of up to 33°, with an average of 20° (van Andel and Veevers, 1967).

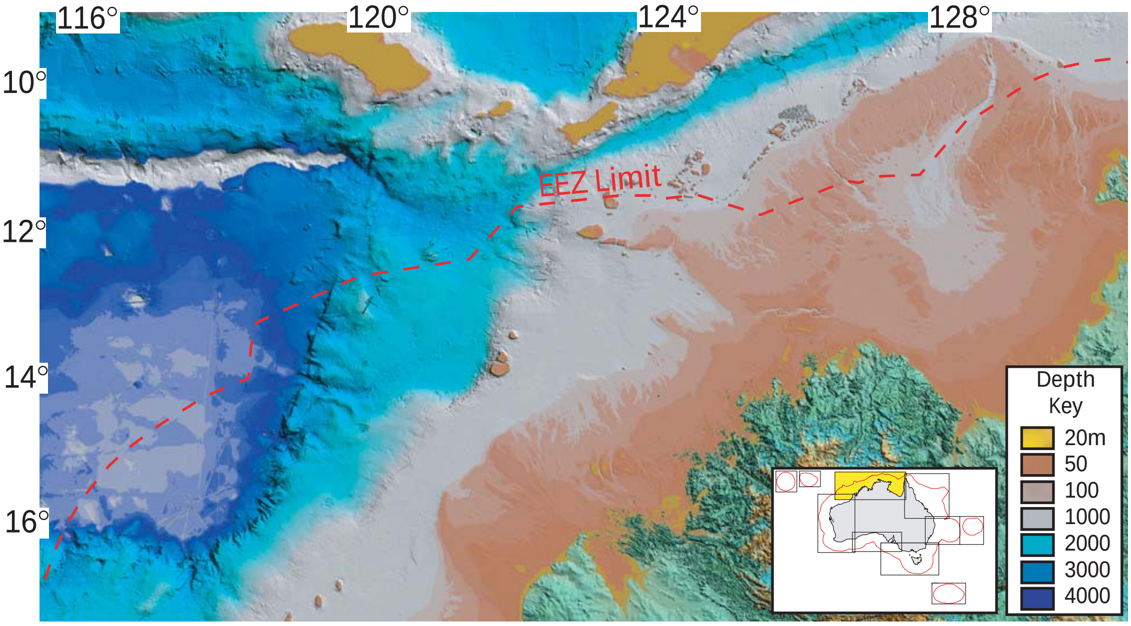

Figure 3.14. False-colour bathymetric image illuminated from the north showing the Timor Sea and Joseph Bonaparte Gulf.

Individual banks are separated from each other by narrow channels with sinuous profiles that are up to 150 m in depth. The channels shoal towards the shelf edge and terminate at about 90 m water depth. A broad deeper water terrace of regional extent surrounds the banks, and probably represents a wave-cut platform (e.g., van Andel and Veevers, 1967; Jones, 1973; Jongsma, 1974). Two major theories exist for the formation of the banks: 1) that they are drowned carbonate platforms that have been unable to keep up with sea level rise (e.g., Lavering, 1993, 1994b); and 2) that they are carbonate accumulations that have developed along hydrocarbon seeps, associated with microbial utilisation of hydrocarbons which promotes the precipitation of carbonate (Roberts, 1992).

On the inner and middle shelf is the Bonaparte Depression, a 45,000 km^2 shelf depression that forms an epicontinental sea with a maximum water depth of 155 m (Lees, 1992). The Londonderry, Sahul, and Van Diemen Rises bound the Depression. Small, steep-sided banks similar to those on the outer shelf fringe the valley on both sides, rising from water depths of more than 100 m. Broad, stepped, level terraces bounded by steep scarps occur on the wester and eastern flanks. The floor is relatively flat but is punctuated by numerous pinnacles and subaqueous banks of variable dimensions. Geological sampling (e.g., van Andel and Veevers, 1967; Marshall et al., 1994) has revealed that many of the pinnacles and banks are the remnants of calcareous shelf and coastal deposits that have been eroded to their present elevations.

In the north, the Malita Valley connects the depression to the Timor Trough. This valley exhibits a narrow, arcuate profile with steep sides that attains a maximum depth of >240 m between the Sahul and Van Diemen Rises. On the Londonderry Rise, west of the Depression, are numerous broad flat-topped banks that are separated by relatively wide, shallow channels. There is a well developed channel oriented east-west that crosses the eastern branch of the rise, dissecting the Penguin Shoals and Holothuria Banks, and connects the Bonaparte Depression with the Browse Depression to the west. Given its depth and connection with the shelf edge, the Bonaparte Depression would have been an estuarine embayment or shallow lake when the shelf was subaerially exposed. The topography of entire SE region of the shelf is subdued. Banks and hills are rare and channels and tidal sand banks occur next to the entrances of large estuaries and rivers.

Van Diemen Gulf.– Van Diemen Gulf is linked to the Arafura Sea by the Dundas Strait scoured to a depth of up to 140 m by strong tidal currents (Fig. 3.15). Inspection of nautical charts of the area (AUS 720) reveals the presence of tidal sandbanks in Clarence Strait the southern part of Dundas Strait and in Van Diemen Gulf. The banks are up to 20 km in length and 4 km in width and have formed probably in response to the strong tidal currents which may reach speeds of up to 200 cm sec^{-1} in Dundas Strait. Subtidal dunes with a wavelength of about 90 m and height of up to 8 m were noted by Harris (1994b) in southern Dundas Strait; the central section is probably a lag gravel surface, scoured clear of surficial sediments. The tidal sand banks are separated by steep-sided channels, the most distinct of which are the North and South Gutters in Beagle Gulf which have depths of up to 50 m, and Clarence Strait in Van Diemen Gulf which is over-deepened attaining 100 m. The depression forming Clarence Strait swings north around Bathurst Island to run approximately 120 km across the shelf (Fairbridge, 1953).

Arafura Shelf.– The Arafura shelf is the northern extension of the Australian continental platform. It is a gently seaward sloping plain (up to 350 km wide) with subdued topography that covers an area of approximately 630,000 km^2 (Nicol, 1970). Because of its shallow elevation, the geomorphology of the Arafura Shelf is probably largely the product of low sea level erosional processes (Jongsma, 1974; Fig. 3.16). The shelf is separated from the Sahul Shelf in the west by the Van Diemen Rise, which consists of a series of shallow algal banks separated by narrow channels, similar in morphology and origin to those on the Sahul Shelf. Seaward of these banks, the shelf edge occurs at water depths of 120 to 180 m (Jongsma, 1974). East of these submerged banks, the shelf break trends towards the north and follows the interfluve of the Arafura Depression, and thus does not extend between Australia and Papua New Guinea. Instead, in the east, the shelf is bounded by the Wessel Rise, which separates it from the Gulf of Carpentaria. In the northwest, the shelf slopes down to the Arafura Depression and Timor Trough. The algal banks that make up the Van Diemen Rise are oriented across-shelf and have broad flat tops that locally rise up to 50 m water depth (Jongsma, 1974), and are surrounded by a terrace of regional extent. Narrow, deep channels dissect the banks and exhibit orientations that appear to have exploited weaknesses in the underlying geology. The channels probably formed from fluvial incision of the algal banks during periods of sea level lowstand when the shelf was subaerially exposed (van Andel and Veevers, 1967, van der Kaars, 1991), although it is likely that tidal currents have also acted to preserve these channels.

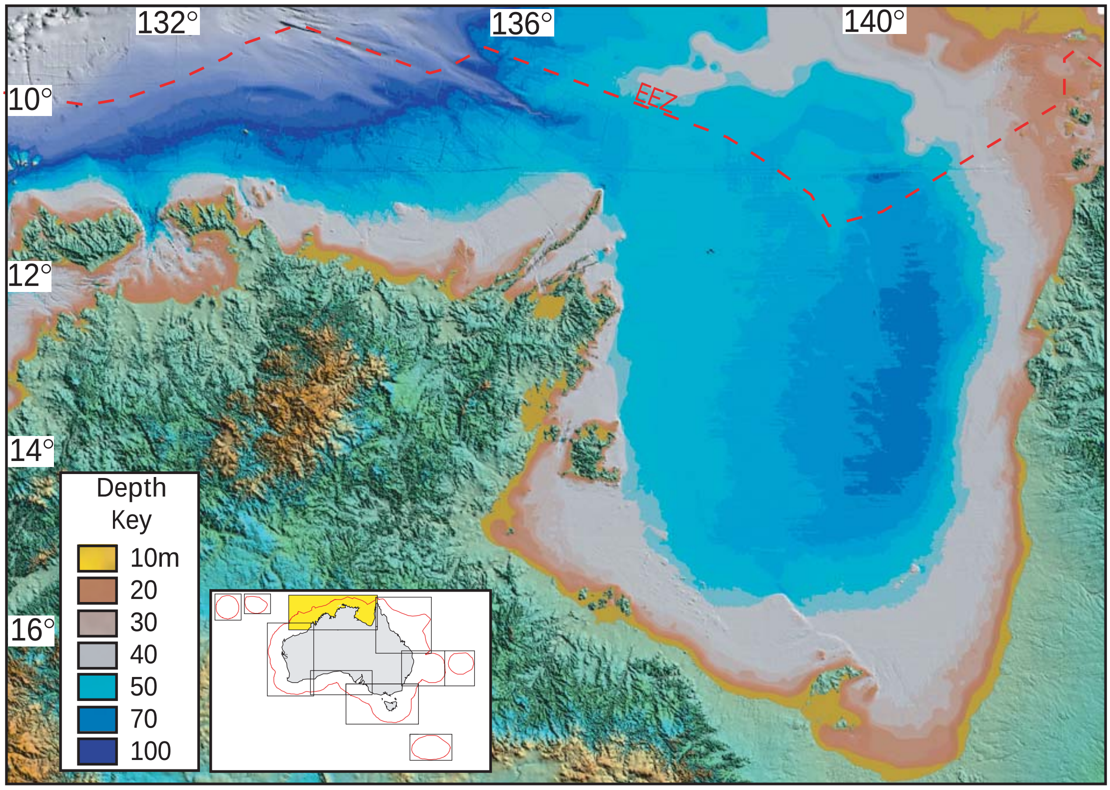

Figure 3.15. False-colour bathymetric image illuminated from the north showing the channels leading into Van Diemen Gulf (Dundas Strait and Clarence Strait).

Gulf of Carpentaria.– The Gulf of Carpentaria extends from the Wessel Rise in the west, where it joins the Arafura Shelf and Arafura Depression across a sill at 53 m water depth, and to Torres Strait in the east, where it joins the Coral Sea Depression across a sill at 12 m water depth. The Gulf is a shallow epicontinental sea that covers an area of more than 510,000 km^2 and has an approximate volume of nearly 2,500 x 10^9 m^3 (Torgersen et al., 1983). The floor of the Gulf is a low-gradient (<1:18,000) plain of relatively low relief. The deepest parts are located in the east, where water depths attain 70 m, but over most of the Gulf water depths are between 50 and 60 m, with deviations of less than 2 m (Chivas et al., 2001). The margins of the Gulf generally have shallow gradients 1:750-1:1,500 in the east, 1:3,000 in the south, and 1:250-1:125 in the west, with the steepest from Groote Eylandt north to Cape Wessel (Jones and Torgersen, 1988). In 2003, a group of three submerged patch coral reefs was discovered in the southeastern corner of the Gulf of Carpentaria in about 30 m water depth; reefs may be much more extensive in that region (Harris et al., 2004). A broad ridge of <13 m relief trends ENE-WSW and terminates at the Arafura Sill, a 10,000 km^2 area of shelf with a relief of less than 2 m (Torgersen et al., 1983), and forms the northern drainage boundary for the Gulf. Immediately to the west of the sill is a prominent submarine channel that extends across the Arafura Shelf to the edge of the continental shelf, which would have connected the Gulf with the Arafura Depression during times of low sea level.

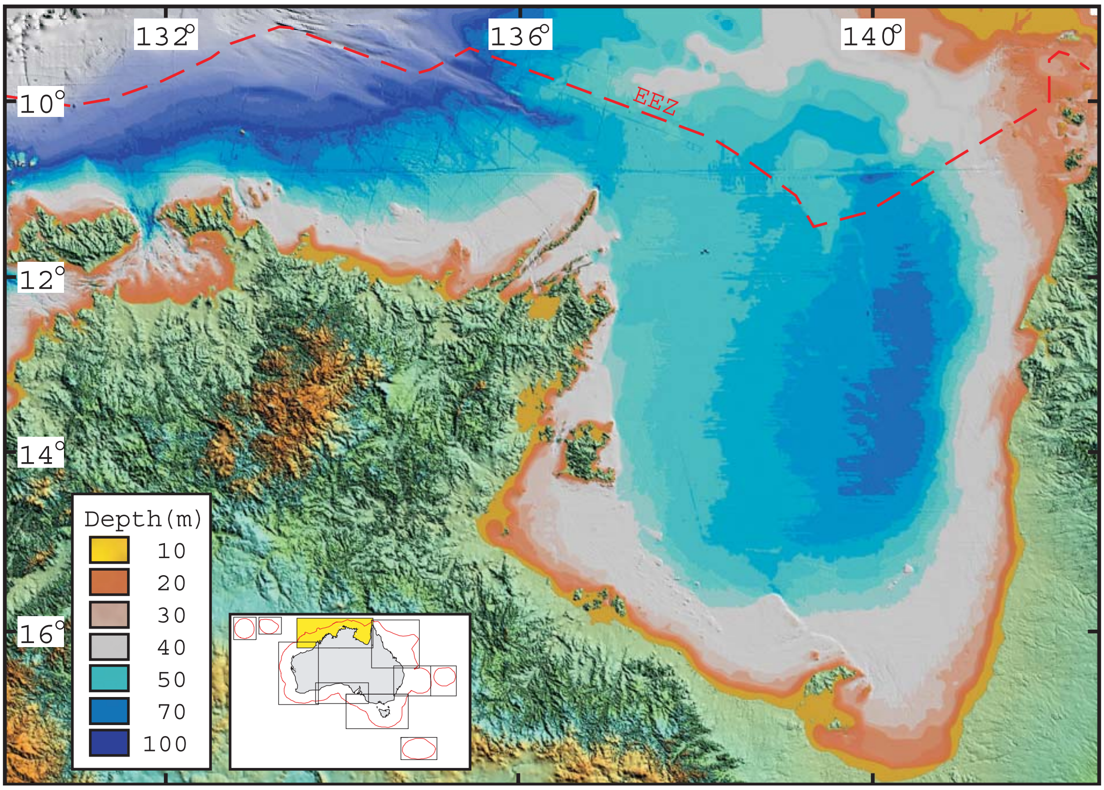

Figure 3.16. False-colour bathymetric image illuminated from the north showing the Arafura Sea and Gulf of Carpentaria.

In the northeast, a broad, low-relief terrace in water depths of 40-45 m extends into the Gulf from Torres Strait. In the south of the Gulf, the seabed topography is more variable and contains a number of small, rounded pinnacles and several broad, flat-topped terraces that are locally capped by coral reefs. The pinnacles are probably high points of submerged continental rocks, protruding through nearshore and pelagic sediments on the seabed. The terraces are bounded to the northeast by steep-slopes that strike northwest, and are separated from each other by shallow submarine valleys. These terraces are the surface expression of submerged fragments of continental rock that are located northwest of Mornington Island. Tidal sand banks and subaqueous dunes with wavelengths of between 80 and 200 m occur over a wide area north of Groote Eylandt in water depths of 15 to 20 m (Harris et al., 1991). Tidal sand banks also locally occur in Endeavour Channel in Torres Strait (Harris, 1988), between islands and the coast, including a well developed dune field around Mornington Island in the southeast, and at the entrances to harbours, estuaries and rivers.

Recent geologic studies have revealed that the Gulf was an isolated basin during times of low sea level and formed a lake (Lake Carpentaria) that had an outlet channel to the Arafura Sea over the sill (Chivas et al., 2001). At its greatest extent, Lake Carpentaria may have covered an area of 165,000 km^2 (Fig. 3.17) and attained maximum water depths of more than 15 m (Jones and Torgersen, 1988). Inter-bedded marine, coastal and lacustrine deposits have been recovered in shallow cores from the Gulf floor (e.g., Phipps, 1980; Torgersen et al., 1988; Chivas et al., 2001), and incised channels, and erosional unconformities of regional extent interpreted as previous shorelines have been recognised in shallow seismic profiles (Edgar et al., 1994). Seismic profiles from the Arafura Sill exhibit incised channels of up to 10-15 m relief extending to a maximum of 75 m below present sea level (Jones and Torgersen, 1988). The channels likely were formed by fluvial incision during lows in sea level and then partially filled during the subsequent transgressions.

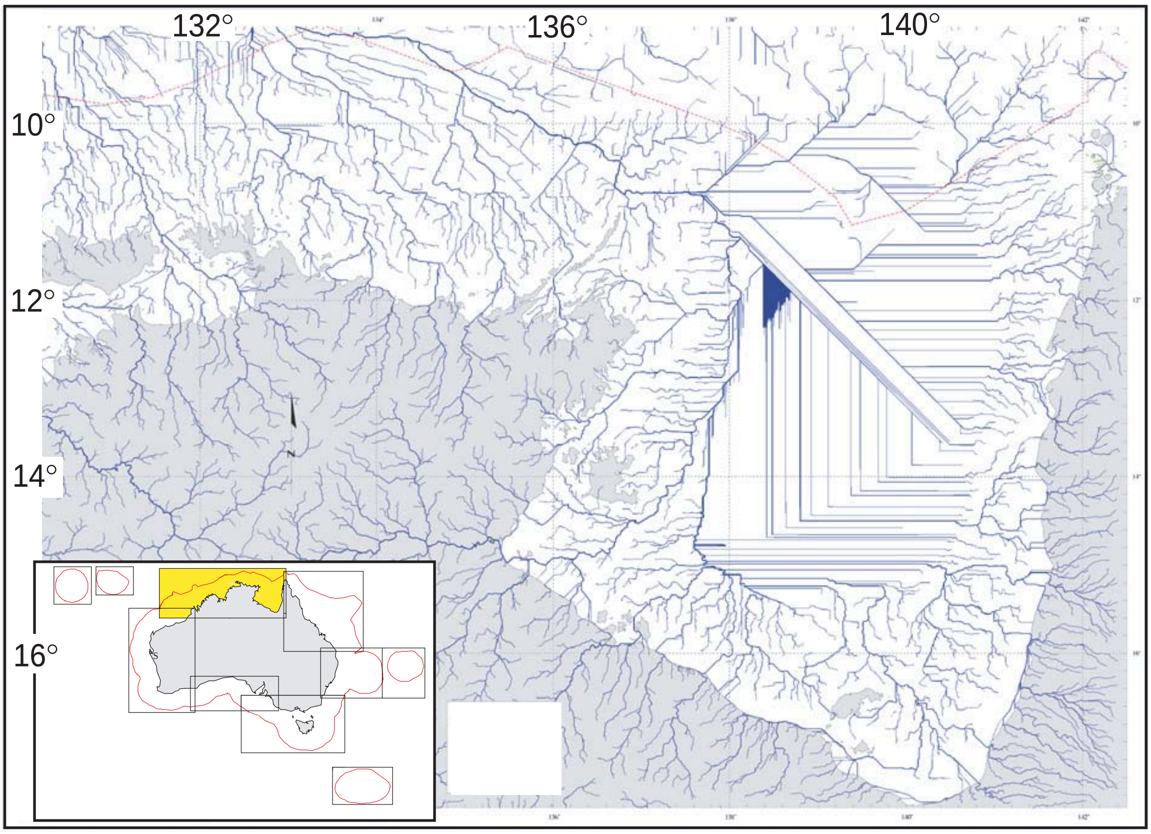

Figure 3.17. Predicted drainage system of the Arafura Sea, showing the positions of major shelf valleys and submarine canyons on the continental slope. Note the straight flow lines that delimit the Carpentaria basin and the drainage exiting the basin to the west through the Arafura Sea.

3.4.2. Continental Slope, Rise and Abyssal Plain

Because the continental shelf is continuous between Australia and Papua New Guinea, only the northwest margin of Australia contains slope, rise and abyssal elements. Falvey and Veevers (1974) conveniently divided this region into upper slope, marginal plateaus and terraces, lower slope, rise, and slope foothills. Apart from the slope, rise and abyssal plain, the major geomorphic features of the margin are the Arafura Depression, Timor Trough, Scott and Exmouth Plateaus, and the Rowley Terrace.

Continental Slope.– The slope is a composite feature comprised of an upper slope surface, which has a gradient of between 1-2° and a maximum gradient of 5°, and a lower slope surface which has a gradient of between 2-20° (Falvey and Veevers, 1974). Off the Arafura Shelf region, the upper slope contains the Arafura Depression, a marginal depression that extends into the Timor Trough and is connected to the shelf by a series of submarine valleys (Fig. 3.18). Off the Sahul Shelf region, the shelf edge and upper continental slope are marked by a series of submarine terraces that occur at depths between 120 to 250 m (van Andel and Veevers, 1967). From these terraces, the slope extends down into the Timor Trough to a depth of 2,000 m and joins the volcanic Banda Arc complex, the location of an active convergent plate margin (Smith and Ross, 1986).

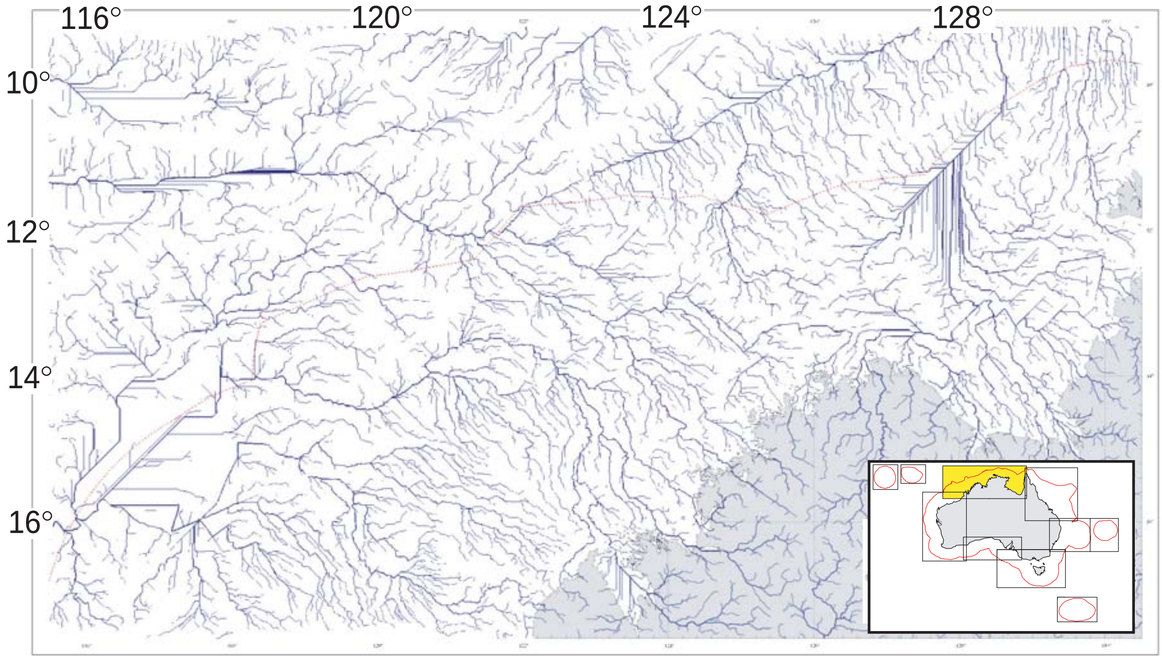

Figure 3.18. Predicted drainage system of the Timor Sea, showing the positions of major shelf valleys and submarine canyons on the continental slope. Note the straight flow lines that delimit the Bonaparte basin and the drainage exiting the basin to the north into the Timor Sea

In the southwest, away from the Scott and Exmouth Plateaus, the upper slope has a smooth profile with nearly uniform gradients. Above the Plateaus, however, the upper slope has a convex profile, increasing in gradient with depth down to plateau level (Falvey and Veevers, 1974). North of Scott Reef the upper slope has a concave profile. Two extensive submarine canyon provinces occur on the upper slope north and south of Scott Reef. Between Ashmore and Scott Reefs, in water depths of 400-600 m, the slope gradient is markedly reduced forming an upper-slope terrace known as Ashmore Terrace.

Timor Trough.– The Timor Trough is an NE-SW trending elongate depression with a maximum depth of 3,200 m that extends for 850 km between the island of

Timor and the Sahul Shelf. The trough is asymmetric in profile and includes a flat axial bottom, between 2 and 15 km wide and locally v-shaped. The Australian flank is generally smooth with local relief of 200 m in valleys and scarps. In contrast, the Timor flank is generally hummocky with local relief of 400 m (Veevers et al., 1978). On the Australian flank, between the shelf edge and approximately 550 m water depth, lies a discontinuous chain of reefs, including major reefal accumulations of Hibernia Reef, Fantome Shoal, the Big Bank Shoals, and Echo Shoal. Sediment lobes occur on this section of the slope and extend a short distance downslope (Veevers et al., 1978). Submarine canyons are rare, but locally occur at the base of large reef accumulations.

Scott Plateau.– The Scott Plateau covers an area of approximately 80,000 km^2 (Stagg and Exon, 1981) and occurs at approximately mid-slope elevations on the northwest margin. The surface of the Plateau is principally in water depths of between 2,000 and 3,000 m, and its maximum depth of roughly 3,600 m occurs on the western edge (Falvey and Veevers, 1974). The plateau forms a broad dome (Scott Plateau Dome) with water depths of <2,000 m over the dome crest, and water depths of <1,800 m over Wilson Spur (Stagg, 1978). Numerous spurs and valleys of varying orientations characterise the top of the dome. South of the dome, Bowers Canyon, a large east-west trending trough, separates the Plateau from the Rowley Terrace. The Scott Plateau Saddle, a local NNE-SSW trending depression (~2,000 m water depth), with low-gradient flanks, connects the Scott Plateau to the adjacent upper slope in the east.

Rowley Terrace.– The Rowley Terrace covers an area of approximately 50,000 km^2 (Stagg and Exon, 1981) and forms a smooth, seaward-sloping surface on the upper to middle slope. The terrace is shallowest in the east, where the surface joins the upper slope in approximately 2,000 m water depth and slopes downwards to the west to 3,000-4,000 m water depth. The surface of the terrace seems to be a low-relief platform that is cut in the south by erosional channels of >300 m relief (Jones, 1973). A large submarine canyon system (including the Swan Canyon; Section 3.3.2), with tributaries that extend onto the Rowley Terrace into water depths of <2,000 m, separates the terrace from the northeastern flank of the Exmouth Plateau.

Large reefal accumulations have grown on the terrace, including Ashmore, Seringapatan, and Scott Reefs. Scott and Seringapatam Reefs rise from approximately 400 m water depth. The flanks of the atolls are steep, and are almost vertical within 200-300 m of the surface. Scott Reef is made up of two atolls, separated by a 400 m deep channel (Jones, 1973). In the south, Mermaid, Clerke, and Imperieuse Reefs (i.e., the Rowley Shoals) rise from approximately 350 m water depth. Approximately 50 km southwest of Imperieuse Reef, a submerged reef rises up to 100 m above the sea floor and terminates in 287 m water depth (Jones, 1973).

The lower slope occurs below the marginal plateaus of Scott Plateau and the mid- and upper-slope terraces of Rowley and Ashmore Terraces and terminates at the rise or abyssal plain. The top of the lower slope occurs in water depths of 1,300-3,600 m and extends down to 4,200-5,300 m (Falvey and Veevers, 1974). Where present, the lower slope is incised by the distal ends of submarine canyons on the upper slope. On the northwest side of the Scott Plateau, slope gradients are <5° and convex in profile. Below crest of Scott Plateau, several small terraces occur, and deep submarine canyons are incised into the continental slope. The Bowers and Oates Canyons are the largest, cutting deeply into the western plateau margin and debouching on to the Argo Abyssal Plain in water depths of >5,500 m (Stagg, 1978; Stagg and Exon, 1981). Adjacent to these terraces, and Scott Plateau and Rowley Terrace further south, the lower slope terminates at a NNE-SSW trending escarpment that represents the edge of the continental crust and the boundary with the rise. Here, numerous submarine canyons that have cut into the underlying rock dissect the lower slope and upper regions of the rise. Further to the south and west of the Rowley Shoals, the escarpment representing the base of slope then trends E-W along the northern margin of the Exmouth Plateau.

Continental Rise.– Where it is developed, the Continental Rise extends from the base of the lower slope to the Argo Abyssal Plain. The rise bounds the western edge of the Scott Plateau and Rowley Terrace.

Argo Abyssal Plain.– The Argo Abyssal Plain is an area of seabed at abyssal depths that has very low relief. The water depth over the plain is >5,000 m. While having virtually no relief, the surface tilts gently up to the north and forms an outer ridge to the Java Trench (Falvey and Veevers, 1974). Swales have been recognised in the SW regions of the plain, while the western margin contains small hills.

Arafura Depression.– The western regions of the Arafura Depression form a drowned fluvial system comprised of a complex series of ridges and valleys which existed during sea level lowstand (Jongsma, 1974). At the base of the Arafura Depression is a fan deposit (Arafura Fan?). Only the most southern edge of the fan is located in Australian waters. The Arafura Depression is bordered on the south by submarine valleys and ridges that extend onto the Arafura Shelf and westward to a sill that separates it from the Gulf of Carpentaria basin. The surface of the fan is hummocky, and given its location in 200-300 m water depth (below the shelf break) deposition in the Arafura Depression would have been continuous throughout the Late Quaternary. It is possible that fan deposits contain a record of the environmental changes in the Gulf of Carpentaria associated with eustatic sea level cycles.

Table 3.7. List of previously described geomorphic features on the northern margin. Features are numbered (left hand column) on Figs. 3.13 (A) and (B).

No.	Geomorphic Feature	Feature Type	References
1	Arafura Depression	Valley (6)	Jongsma (1974)
2	Arafura Shelf	Shelf (1)	Carrigy & Fairbridge (1954)
3	Arafura Sill	Sill (19)	Jones & Torgersen (1988)
4	Argo Abyssal Plain	Abyssal Plain (4)	Falvey & Veevers (1974)
5	Ashmore Reef	Reef (9)	van Andel & Veevers (1967)
6	Baldwin Bank	Bank (5)	van Andel & Veevers (1967)
7	Barracouta Shoal	Reef (9)	van Andel & Veevers (1967)
8	Bonaparte Depression	Valley (6)	Lees (1992); van Andel & Veevers (1967)
9	Bowers Canyon	Canyon (10)	Stagg (1978)
10	Browse Depression	Valley (6)	Carrigy & Fairbridge (1954)
11	Cartier Trough	Canyon (10)	van Andel & Veevers (1967)

12	East Londonderry Rise	Bank (5)	van Andel & Veevers (1967)
13	Endeavour Strait	Hole (6)	Admiralty Chart 301
14	Emu Spur	Bank (5)	Falvey & Veevers (1974)
15	Exmouth Plateau	Plateau (15)	Falvey & Veevers (1974)
16	Fantome Shoal	Reef (9)	van Andel & Veevers (1967)
17	Flattop Bank	Bank (5)	Admiralty Chart
18	Flinders-Evans Shoals	Bank (5)	van Andel & Veevers (1967)
19	Gulf of Carpentaria	Basin (8)	Torgersen et al. (1988); Chivas et al. (2001)
20	Hibernia Reef	Reef (9)	van Andel & Veevers (1967)
21	Holothuria Banks	Bank (5)	van Andel & Veevers (1967)
22	Inskip Banks	Sandbank (21)	Admiralty Chart
23	King Sound	Basin (8)	Carrigy & Fairbridge (1954)
24	Leveque Rise	Bank (5)	Carrigy & Fairbridge (1954)
25	Malita Shelf Valley	Valley (6)	van Andel & Veevers (1967); Lees (1992)
26	Mornington I. Tide Delta	Sandbank (21)	Admiralty Chart
27	North Gutter	Hole (6)	Admiralty Chart
28	Oates Canyon	Canyon (10)	Falvey & Veevers (1974); Stagg (1978)
29	Parry Shoal	Shoal (5)	van Andel & Veevers (1967)
30	Penguin Shoal	Bank (5)	van Andel & Veevers (1967)
31	Rothsay Banks	Sandbank (21)	Admiralty Chart
32	Rowley Depression	Valley (6)	Carrigy & Fairbridge (1954)
33	Rowley Shelf	Shelf (1)	Jones (1973); Stagg (1978)
34	Rowley Shoals	Reef (9)	Carrigy & Fairbridge (1954)
35	Rowley Terrace	Terrace (20)	Falvey & Veevers (1974); Stagg (1978)
36	Sahul Banks	Bank (5)	van Andel & Veevers (1967)
37	Sahul Rise	Bank (5)	van Andel & Veevers (1967)
38	Sahul Shelf	Shelf (1)	Fairbridge (1953); van Andel & Veevers (1967)
39	Scott Plateau	Plateau (15)	Falvey & Veevers (1974); Stagg (1978)
40	Scott Reef	Reef (9)	Jones (1973)
41	Seringapatam Reef	Reef (9)	Jones (1973)
42	South Gutter	Hole (6)	Admiralty Chart
43	Swan Canyon	Canyon (10)	Falvey & Veevers (1974); Stagg (1978)
44	Van Diemen Rise	Bank (5)	van Andel & Veevers (1967)
45	Vulcan Shoal	Bank (5)	van Andel & Veevers (1967)
46	Wallis Banks	Sandbank (21)	Admiralty Chart
47	Wessel Rise	Bank (5)	Torgersen et al. (1983); Jones & Torgersen (1988)
48	West Londonderry Rise	Bank (5)	van Andel & Veevers (1967)
49	Wilson Spur	Bank (5)	Falvey & Veevers (1974)
50	Wombat Plateau	Plateau (15)	Falvey & Veevers (1974)
51	Carpentaria Reefs	Reef (9)	Harris et al. (2004)

Table 3.8. Geomorphic make-up of the northern margin. Code refers to the geomorphic feature type listed in Table 2.2.

Code	Geomorphic Feature	Km^2	Percent
1	Shelf*	1,005,500	65.42
2	Slope*	460,950	29.99
3	Rise*	11,590	0.75
4	Abyssal plain*	58,970	3.84
	Total	**1,537,010**	**100.00**
1	Shelf*	506,030	32.92
2	Slope*	221,560	14.42
3	Rise*	11,590	0.75
4	Abyssal plain*	58,980	3.84
5	Bank/Shoal	43,720	2.84
6	Deep/Hole/Valley	78,730	5.12
7	Trench/Trough	650	0.04
8	Basin	249,120	16.21
9	Reef	4,970	0.32
10	Canyons	16,580	1.08
11	Knoll/Abyssal Hills/Hill/Peak	3,100	0.20
12	Ridge	5,700	0.37
14	Pinnacle	1,320	0.09
15	Plateau	84,110	5.47
16	Saddle	610	0.04
17	Apron/Fan	3,670	0.24
18	Escarpment	20,690	1.35
20	Terrace	218,540	14.22
21	Sandwave/Sand bank	13,470	0.88

***** First listing of continental shelf, slope, rise and abyssal plain areas are total, mutually exclusive areas. Second listing of continental shelf, slope, rise and abyssal plain areas are less the surface areas of superimposed features (e.g., shelf area is total shelf area minus superimposed basin area, sill area, terrace area, etc.).

3.5. Northeast Margin (Great Barrier Reef Province)

The northeast continental margin of Australia extends for more than 2,000 km from the Gulf of Papua in the north to Fraser Island in the south. The area included in this study extends from the coast to the limit of the EEZ and covers an area of 1,324,540 km^2. The margin includes the Eastern, Queensland, and Marion Plateaus, which are carbonate-dominated plateaus located offshore from the continent. The Great Barrier Reef (GBR), which extends for nearly 2,000 km along the middle to outer continental shelf, is the largest tropical, mixed siliciclastic-carbonate reef system on Earth. The GBR and offshore plateaus are separated from each other by the Pandora, Bligh, Queensland, and Townsville Troughs. Other major features include: the Kenn Plateau, Cato Trough, Coral Sea Basin, and Osprey Embayment (Figs. 3.19, 3.20).

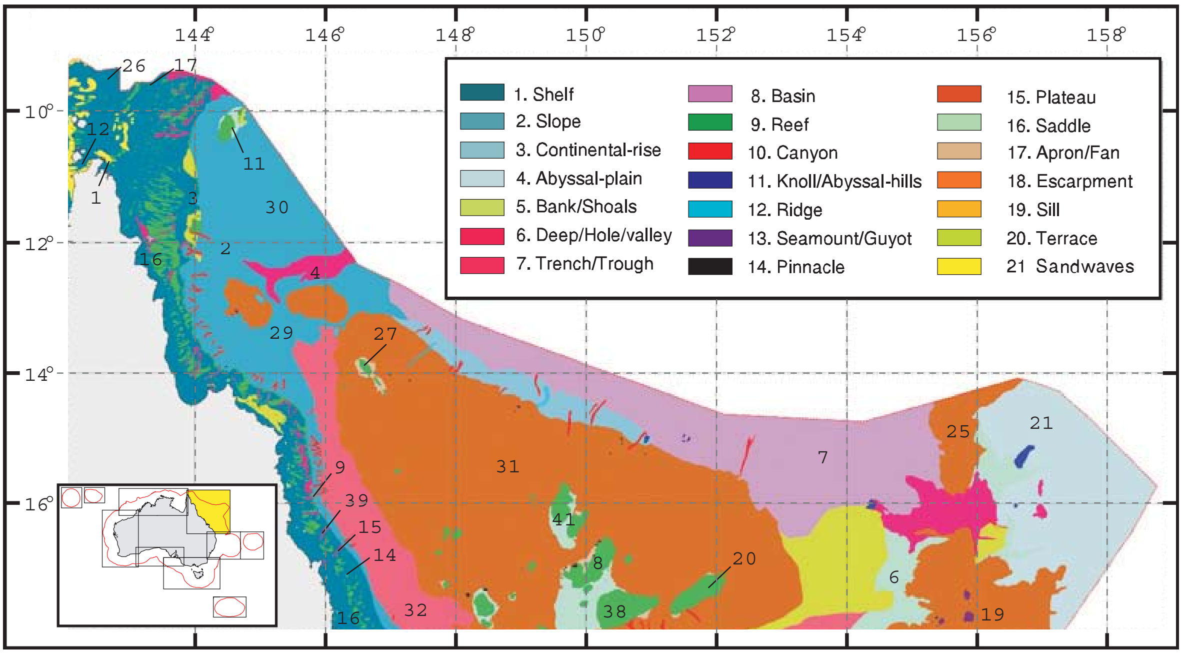

Figure 3.19. (A) Geomorphic features on the northeast margin adjacent to the Great Barrier Reef. See Table 3.9 for key to place names and Table 3.10 for surface areas of features.

The origin and development of the geomorphic features of the northeast margin are a result of the fragmentation of the margin following late-Cretaceous to early Tertiary rifting, associated largely with the opening of the Tasman Sea (Davies et al., 1989, 1993). This rifting influenced margin evolution by producing large, shallow-water plateaus suitable for the development of coral complexes and permitting individual reefs to grow on the corners of rotated fault blocks. Geomorphic features that have been named or that have been reported in scientific investigations are listed in Table 3.9 and the geomorphic make-up of the margin is provided in Table 3.10.

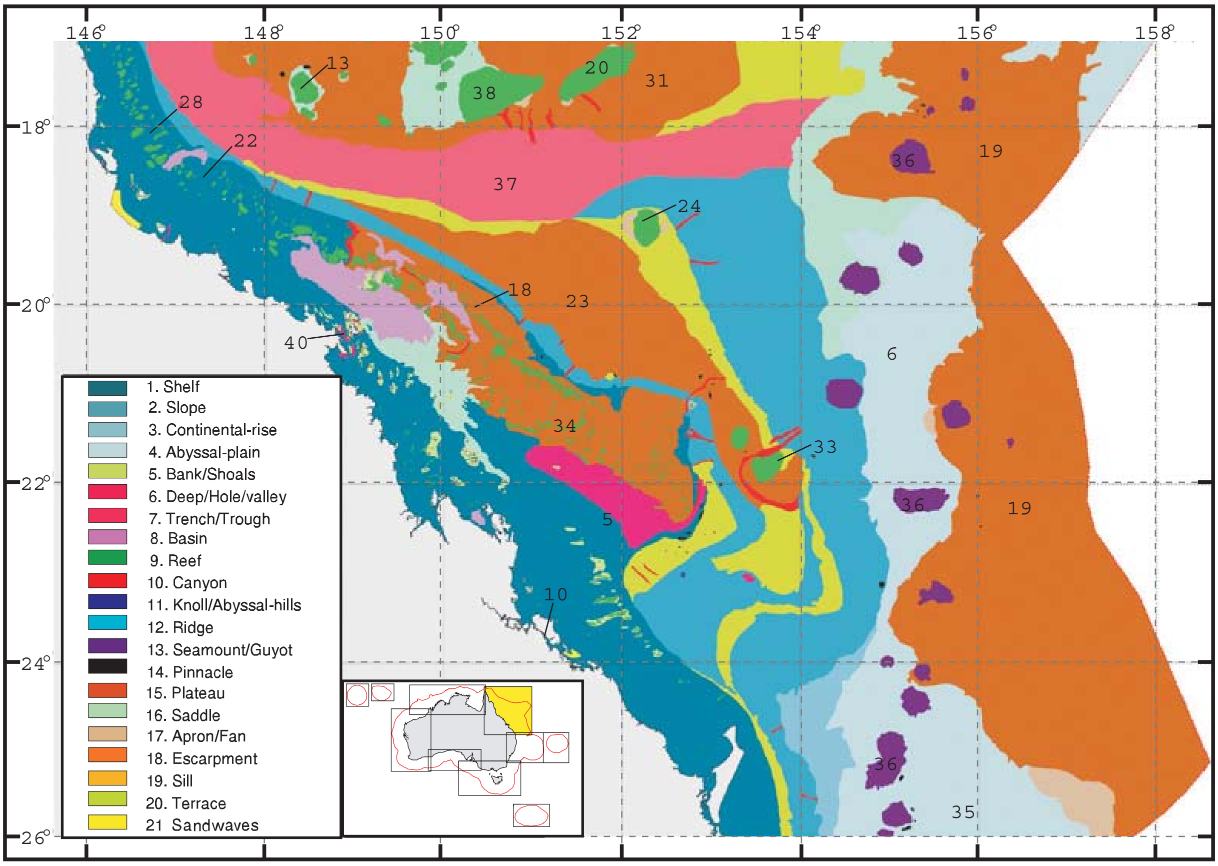

Figure 3.19–Cont. (B) Geomorphic features on the northeast margin adjacent to the Great Barrier Reef. See Table 3.9 for key to place names and Table 3.10 for surface areas of features.

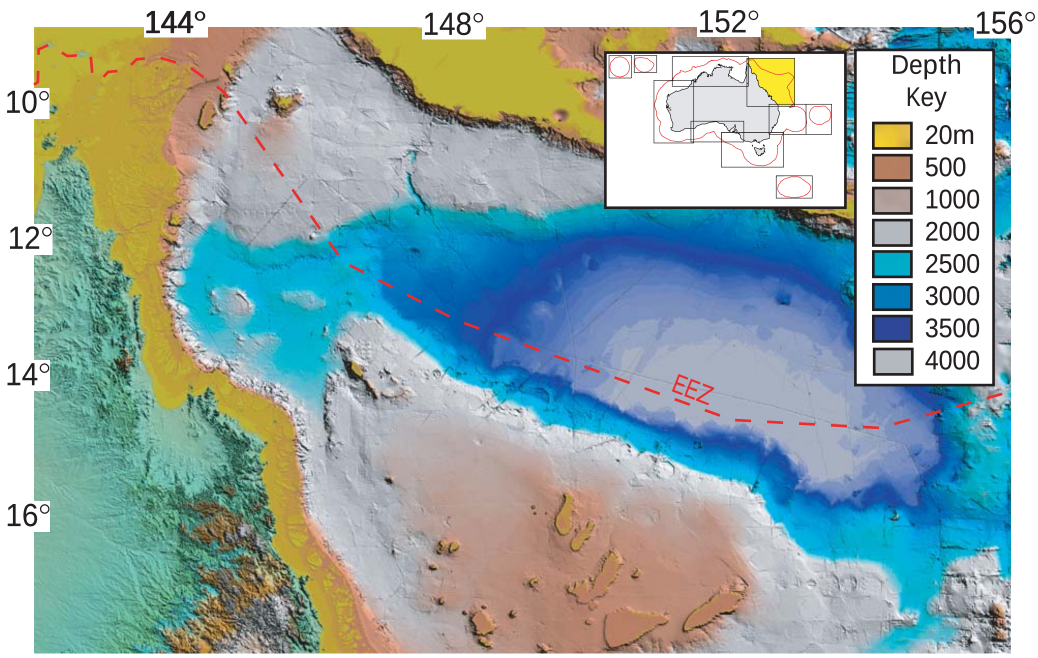

Figure 3.20. False-colour bathymetric image illuminated from the north showing the northeast margin with the Coral Sea basin and marginal plateaus.

3.5.1. Marginal Plateaus

Eastern Plateau.– The Eastern Plateau is the most northern marginal plateau in on the margin and is bounded by the Pandora and Bligh Troughs to the west, Moresby Trough to the east, and Coral Sea Basin to the south. The surface of the plateau is approximately 31,000 km^2 and is gently convex in shape. Water depths over the plateau are >1,500 m on average. The topography of the southern margin is controlled by normal faults and thus it has significant and dramatic relief, sloping steeply downwards into the Coral Sea Basin. The western margin has a more complex topography, formed probably by thrusting (Davies et al., 1989). Towards the crest of the plateau surface lies Eastern Fields Reef, a steep-sided modern coral platform 45 km wide.

Queensland Plateau.– The Queensland Plateau is the largest marginal plateau on the margin. It is bounded to the northeast by the Coral Sea Basin, to the west by the Queensland Trough, and to the south by the Townsville Trough. The plateau covers an area of approximately 165,000 km^2. Geological studies (e.g., Mutter and Karner 1980) reveal that the surface of the plateau is mostly smooth and slopes gently downward towards the north. Approximately 50% of the plateau surface occurs in water depths of less than 1,000 m resulting in living reefs that are at or near present sea level and which occur over about 10-15% of the surface (Davies et al., 1989). The largest of these reefs are the Tregrosse and Lihou reef complexes, with smaller complexes of the Willis, Diana, and Coringa Reefs. In the west, steep-sided pinnacles, 1-2 km across, rise from water depths of >1,200 m to within 10 m of the surface. These pinnacles have formed on raised corners of underlying fault blocks and form the Flinders, Bougainville, Holmes, and Osprey Reefs (Davies et al., 1989).

The surface of the plateau contains two distinct terraces at water depths of approximately 500-600 m between Tregrosse, Lihou, and Coringa Reefs, and also between Willis and Diana Reefs, that represent the remnant surfaces of previous carbonate platforms. Another terrace representing a younger, but less extensive, carbonate platform surface occurs at 50 m. Modern reefs have grown on this terrace to present elevations. Two further, less distinct, deep-water terraces occur in the east and northeast of the plateau in water depths of >2,000 m. Submarine canyons with relief of up to 500 m, spaced 40 km apart, occur on the northern slopes (Winterer, 1970), but they are less well developed in the western and southern slopes. A major submarine canyon complex occurs to the south of Lihou Reef, where slopes at canyon heads are locally >20°. An extensive area of continental rise is located on the northern margin that slopes gently into the Coral Sea Basin and is dissected by numerous small submarine canyons (Symonds and Willcox 1988).

Marion Plateau.– The Marion Plateau is located east of the GBR and bounded to the north by the Townsville Trough and to the east by the Cato Trough (Fig. 3.21). Seismic studies (e.g., Davies et al., 1989) reveal that the plateau is separated from the continent to the west by several north–south oriented half-grabens that were filled with siliciclastic sediment prograding eastwards across the continental shelf during the Tertiary. As a result, the modern surface of the plateau forms a deep-water extension to the continental shelf. The plateau is broadly triangular in shape and approximately 77,000 km^2. Water depths over the surface range from 100 m in the west to >500 m in the east. The eastern slopes are steeper than the northern slopes, with upper slopes attaining 0.3° between water depths of 200 and 600 m and 4.5° in water depths of 500-1,000 m. Submarine canyons are better developed on the eastern slopes (Mutter and Karner 1980). Despite the shallow water depths, reef growth on the plateau is limited to Marion Reef to the northeast and Saumarez Reef to the southeast. Because the half-grabens separating the platform from the continent in the west cease at the confluence of the Townsville and Queensland Troughs, it is thought that the Marion Plateau was originally a separate marginal plateau. The Swains Reef high, a NW-trending basement ridge, separates the plateau from the Capricorn Basin to the south. Like the Queensland Plateau, the Marion Plateau contains two terraces at water depths of 2,600-2,000 m and 1,500-500 m that represent the remnant surfaces of carbonate platforms (Davies et al., 1989).

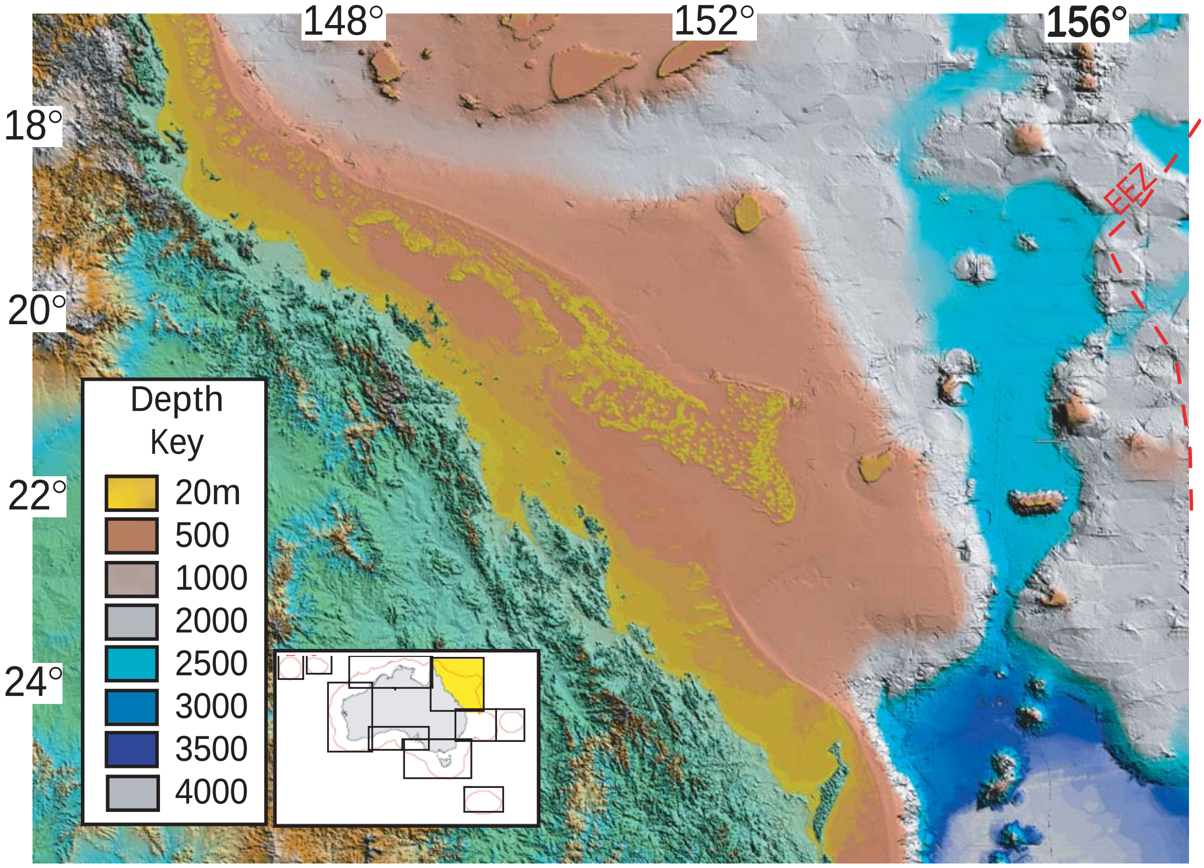

Figure 3.21. False-colour bathymetric image illuminated from the north showing the northeast margin with the northern Tasman Sea basin and marginal plateaus.

3.5.2. The Great Barrier Reef Continental Shelf

The Great Barrier Reef (GBR) extends for about 2,000 km along the northeast margin of Australia and contains approximately 2,500 individual reefs (Hopley, 1982). Collectively, the modern reefs of the GBR, which rise from the shelf surface to present sea-level elevations, are the single most extensive geomorphic feature on the Australian continental shelf. The continental shelf is narrowest and shallowest in the north where reefs and *Halimeda* banks occupy the entire shelf. The shelf widens and deepens to the south, where reefs occupy only the mid to outer shelf regions. At the extreme southern margin the shelf narrows considerably and contains several reef complexes next to the shelf break that are separated from the mainland by Curtis Channel.

The continental slope is steepest (10°-60°) and extends to greater depths in the north. Numerous submerged reefs, and small (<1 km^2) terraces and knickpoints interpreted to be old shorelines and erosional coastal cliffs, occur along the upper continental slope in water depths of <170 m (Carter et al., 1986; Harris and Davies, 1989). The upper slope is commonly characterised by a reefal limestone escarpment, extending from the shelf break to a depth of >300 m (Harris and Davies, 1989). Extensive submarine canyon systems are conspicuously absent on the upper slope and corridors for sediment transport are limited to deep-sea troughs (Fig. 3.22).

Torres Strait, in the most northern regions, is an extremely shallow seaway that connects the northeast margin with the Gulf of Carpentaria on the northern continental margin of Australia (see section 3.4). Torres Strait contains large continental islands with extensive E-W oriented reefs between them. Intervening passages are generally <12 m deep and characterised by strong tidal currents, although some larger channels have been exhumed up to 120 m (Harris et al., 1996). The strong tidal currents have produced extensive areas containing sandwaves and sandbanks (Harris, 1988, 1991, 1995, 2001).

In the south, the reefs are elevated on the *Swain Reefs High*, forming a shallow platform. An extensive area of tidal sand banks also occurs in and around Broad Sound, where tidal ranges attain 8 m (Cook and Mayo, 1978). Next to this platform, the head of the Capricorn Channel (Marshall, 1977) forms a shallow shelf valley that slopes gently downwards towards the southeast but is deflected around the southern GBR and debouches to the northeast onto the upper slope. Beyond the shelf break in the Capricorn Channel, the slope steepens from about 0.9° in water depths of <600 m to 1.6° in water depths of between 500 to 1,000 m (Harris and Baker, 1988).

Inter-reef channels figure prominently on the shelf (Figs. 3.22 and 3.23). They are generally steep-sided, deep, exhibit winding, dendritic, and meandering courses, and are swept clean of sediment by strong tidal currents (Hopley, 1982). Some channels also exhibit enclosed contours, where submerged reefal shoals either partially or completely block the ends. The largest of the reef passes are exploited as shipping channels (see Table 3.10).

Tidal current shoals, rising as much as 30 m from the level of surrounding seabed, are located adjacent to continental islands in the GBR lagoon (e.g., Heap et al., 1999, 2001, 2002). Depressions up to 120 m deep, scoured by locally accelerated tidal currents, occur in the passages between the islands (e.g., Heap et al., 2002).

3.5.3. Marginal Depressions

Pandora Trough.– The Pandora Trough is an elongate basin 250 km long and 50 km wide on the western margin on the Eastern Plateau that trends northeast with its axis being parallel to the shelf break (Fig. 3.20). Profiles across the trough are asymmetric with the deepest parts abutting the steepest slopes of Eastern Fields Reef (Winterer, 1970). Several submarine canyons occur on the western margin, but it is unknown whether these canyons directly connect the shelf to the trough (see also Brunskill et al., 1995).

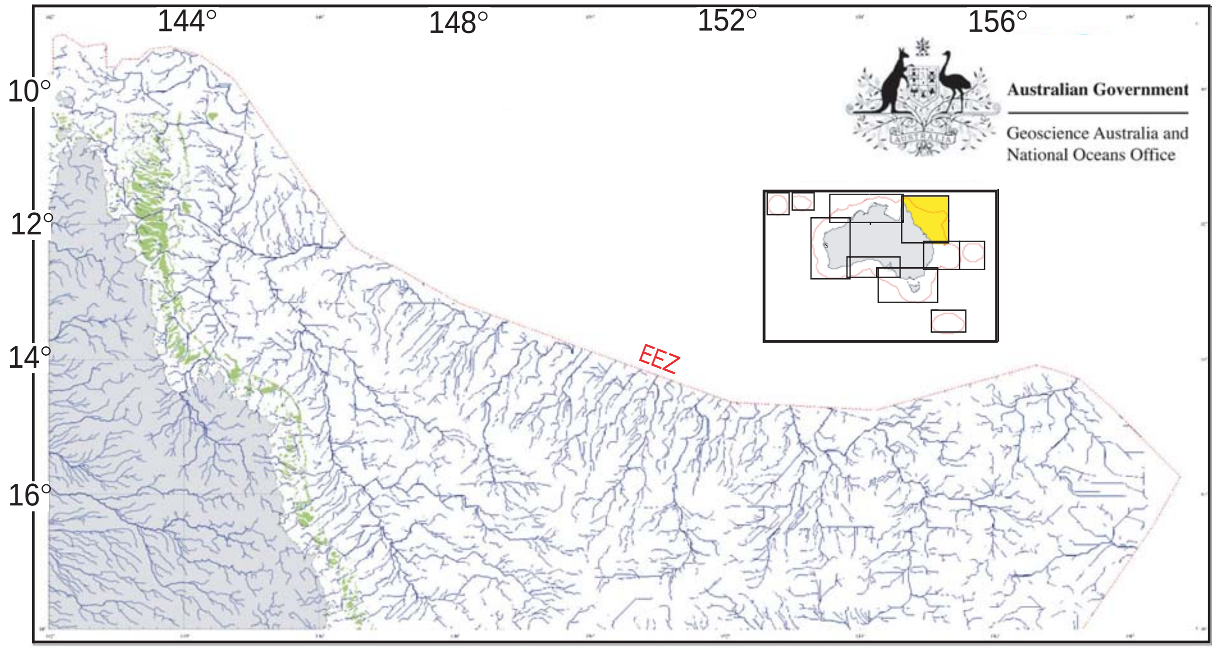

Figure 3.22. Predicted drainage system of the northeast margin, showing the positions of major shelf valleys and submarine canyons on the continental slope.

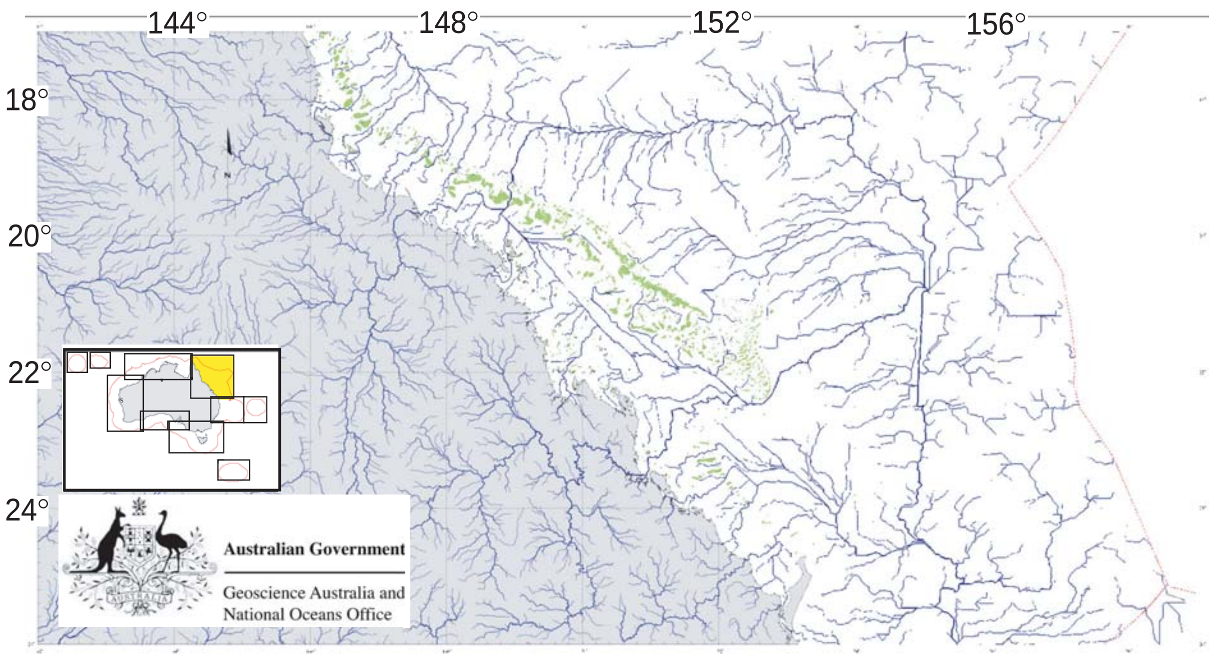

Figure 3.23. Predicted drainage system of the northeast margin, showing the positions of major shelf valleys and submarine canyons on the continental slope.

Bligh Trough.– The Bligh Trough is a N-S trending, elongate depression of the sea floor, that lies adjacent to the continental shelf on the southwest slopes of the Eastern Plateau. The axis of the trough is parallel to the shelf break and is approximately 200 km long, and may form a southern extension to the Pandora Trough to the north. Submarine canyons occur on the western margin of the trough where the slope is steep, but it is unknown whether these canyons connect the continental shelf with the Coral Sea Basin. The trough opens out into Osprey Embayment where it connects with the larger Bligh Canyon.

Bligh Canyon.– Bligh Canyon is an E-W trending relatively straight depression in the sea floor situated in Osprey Embayment at the mouths of the Queensland and Bligh Troughs. Drainage from both of these troughs is funnelled through Bligh Canyon eastward into the Coral Sea Basin. Seismic surveys (e.g., Winterer, 1970) have revealed that the valley floor is up to 10 km wide, mostly flat, but also entrenched about 100 m in places The valley sides have gradients of between 3^{o} and 20^{o}.

Queensland Trough.– The Queensland Trough is a broad NW-SE trending depression of the seabed that formed as a rift basin from the parting of the Queensland Plateau and the Australian plate as the Coral Sea Basin opened (Symonds et al., 1983; Scott, 1993). As the Coral Sea Basin opened, the Queensland Plateau lost marginal support, tilted northward and subsided directly toward the Coral Sea Basin thus forming the Queensland Trough. The trough stretches more than 550 km and covers an area of approximately 80,000 km^2. In the north, the trough opens out into the Osprey Embayment and Coral Sea basin, where it has a maximum width of 200 km and depth of 2,800 m. In the south, the trough narrows to 90 km and shoals to 900 m where it terminates at a sill that separates it from the Townsville Trough to the south.

Profiles across the trough are asymmetric, with slopes on the western margin much steeper than those of the eastern margin. Slopes on western margin attain gradients of between 10-60^{o} particularly in the north, while those on the eastern margin are generally <2^{o} but do attain as much as 10^{o} in the north. The majority of the seabed of the trough lies at water depths between 1,000 and 2,000 m and the longitudinal profile of the bed slopes gently towards the north at a gradient of <1^{o}. In the north, a bathymetric high presumed to be a basement fault block, divides the trough into two northward trending channels (Dunbar et al., 2001).

Previous acoustic mapping of the trough using GLORIA sidescan sonar (D.P. Johnson, unpublished data) reveals that, south of 16^{o} S, the seabed is comprised of exposed bedrock but north of this latitude, lobate and digitate features, interpreted as proximal gravity flows, extend down slope. Dunbar et al. (2001) named the four largest flows: Lark, Trinity, Grafton, and Flora (from north to south), after adjacent reef passages. Elongate features along the trough axis, parallel to the shelf break, represent distal gravity flows that define an axial down slope sediment transport pathway to the north. Despite numerous reef passages on the continental shelf, there are no reported submarine fans on the western margin and little evidence for gravity flows adjacent to the central GBR shelf (Dunbar et al., 2001).

Townsville Trough.– The Townsville Trough is a broad E-W trending depression of the seabed that formed as a rift basin from the parting of the Queensland and

Marion Plateaus as the Coral Sea Basin opened (Symonds et al., 1983; Scott, 1993; Struckmeyer et al., 1994). The trough is more than 590 km in length. To the east, the tough opens out into the Cato Trough, where it has a maximum width of 120 km and depth of approximately 3,500 m. In the west, the trough narrows to 90 km and shoals to 900 m where it terminates at a sill that separates it from the Queensland Trough to the north. Profiles across the trough are broadly asymmetric, with slopes on the northern margin generally steeper than those of the southern margin. Submarine canyons dissect the northern margin and connect the Queensland Plateau with the Townsville Trough.

Coral Sea Basin.– The Coral Sea Basin is a broad, flat depression of the seabed that is bounded to the south by the Queensland Plateau, to the west by the GBR and Torres Strait Platforms, to the north by the Eastern and Papuan Plateaus, and to the east by the Louisiade Plateau and Mellish Rise. The Coral Sea Basin is a northwest extension of the Louisiade Triple junction that also includes the Cato Trough and Tasman Basin (Gaina et al., 1999). Only a small area of the basin occurs in Australian waters, where water depths are more than 4,000 m.

The basin floor is characterised by subdued topography, with gentle slopes (<2^{o}) rising to the Queensland Plateau to the south, although more dramatic slopes rise to the Eastern Plateau and GBR in the north and west, respectively. Submarine canyons extend to the floor of the basin along the southern and western margins, dissecting the continental rise of the Queensland Plateau. Although there are no reported submarine fans reported in along the southern margin, a large fan occurs near the western margin at the mouths of the Moresby and Bligh Canyons (Winterer, 1970).

3.5.4. Tasman Sea (including Kenn Plateau, Cato Trough and Tasman Basin)

Distal regions of the NE margin contain a collection of prominent, although poorly defined, very large geomorphic features, including the Kenn Plateau, Cato Trough, Middleton Basin, Louisiade Plateau, and Mellish Rise. Collectively, these features have an area of more than 400,000 km^2, and are located in water depths of <1,000 m to >3,000 m (N.F. Exon, *written communication*). The largest of these features, the Kenn Plateau (Kroenke et al., 1983), lies at the junction between the Coral and Tasman Seas and is separated from the Marion Plateau to the west by the N-trending Cato Trough, a broad relatively flat-floor depression which reaches water depths of >3,000 m. Although poorly mapped, the Kenn Plateau is considered to be a large submerged continental block that is contiguous with the Bellona Plateau to the northeast and the Middleton Basin to the southeast (Weissel and Hayes, 1977). Only about 100,000 km^2 of the Kenn Plateau occurs in Australian waters, of which about 40,000 km^2 is in water depths <2,000 m. The surface is most shallow along its northwestern margin and slopes gently downwards to the southeast. The few seismic studies of the features in this region (Mutter, 1973, Symonds, 1973) reveal a rugged surface, with numerous seamounts, pinnacles, reefs, and submerged basement highs. The seamounts of Kenn Reef, and Bird and Cato Islands probably have volcanic origins, as they appear to form a northerly extension of the Tasmantid Seamount Chain, a prominent north-south trending chain of submarine volcanoes extending into the Tasman Basin (McDougall and Duncan, 1988).

Table 3.9. List of previously described geomorphic features on the northeast margin. Features are numbered (left hand column) on Figs. 3.19 (A) and (B).

No.	Geomorphic Feature	Feature Type	References
1	Adolphus Channel	Channel (10)	Harris (1991)
2	Bligh Canyon	Trough (7)	Winterer (1970)
3	Bligh Entrance	Channel (10)	Hopley (1982)
4	Bligh Trough	Trough (7)	Winterer (1970)
5	Capricorn Channel	Channel (10)	Hopley (1982)
6	Cato Trough	Trough (7)	Hill (1994)
7	Coral Sea Basin	Basin (8)	Winterer (1970)
8	Coringa Reef	Reef (9)	Davies et al. (1989)
9	Cruiser Pass	Channel (10)	Harris & Baker (1988)
10	Curtis Channel	Channel (10)	Hopley (1982)
11	East Fields Reef	Reef (9)	Hopley (1982)
12	Endeavour Strait	Channel (10)	Harris (2001)
13	Flinders Reef	Channel (10)	Harris & Baker (1988)
14	Flora Passage	Channel (10)	Dunbar et al. (2000)
15	Grafton Passage	Channel (10)	Harris & Baker (1988)
16	Great Barrier Reef	Plateau (15)	Davies et al. (1989)
17	Great North East Channel	Channel (10)	Harris (2001)
18	Hydrographers Passage	Channel (10)	Harris & Baker (1988)
19	Kenn Plateau	Plateau (15)	Wilcox (1981)
20	Lihou Reef	Reef (9)	Davies et al. (1989)
21	Louisiade Plateau	Plateau (15)	Gaina et al. (1999)
22	Magnetic Passage	Channel (10)	Harris & Baker (1988)
23	Marion Plateau	Plateau (15)	Davies et al. (1989)
24	Marion Reef	Reef (9)	Hopley (1982)
25	Mellish Rise	Plateau (15)	Gaina et al. (1999)
26	Missionary Passage	Channel (10)	Harris (2001)
27	Osprey Reef	Reef (9)	Davies et al. (1989)
28	Palm Passage	Channel (10)	Harris & Baker (1988)
29	Pandora Trough	Trough (7)	Winterer (1970)
30	Papuan Plateau	Plateau (15)	Davies et al. (1989)
31	Queensland Plateau	Plateau (15)	Davies et al. (1989)
32	Queensland Trough	Trough (7)	Winterer (1970)
33	Saumarez Reef	Reef (9)	Hopley (1982)
34	Swains Reef High	Plateau (15)	Hopley (1982)
35	Tasman Basin	Basin (8)	Hill (1994)
36	Tasmantid Seamounts	Seamount (13)	McDougall & Duncan (1988)
37	Townsville Trough	Trough (7)	Struckmeyer et al. (1994)
38	Tregrosse Reef	Reef (9)	Davies et al. (1989)
39	Trinity Opening	Channel (10)	Harris & Baker (1988)

40	Whitsunday Passage	Channel (10)	Hopley (1982)
41	Willis Reef	Reef (9)	Hopley (1982)

Table 3.10. Geomorphic make-up of the northeast margin. Code refers to the geomorphic feature type listed in Table 2.2.

Code	Geomorphic Feature	Km^2	Percent
1	Shelf*	242,250	18.29
2	Slope*	974,610	73.58
3	Rise*	15,940	1.20
4	Abyssal plain*	91,740	6.93
	Total	**1,324,540**	**100.00**
1	Shelf*	151,390	11.43
2	Slope*	187,190	14.13
3	Rise*	14,700	1.11
4	Abyssal plain*	66,440	5.02
5	Bank/Shoal	3,280	0.25
6	Deep/Hole/Valley	31,280	2.36
7	Trench/Trough	86,890	6.56
8	Basin	144,240	10.89
9	Reef	41,200	3.11
10	Canyons	6,180	0.47
11	Knoll/Abyssal Hills/Hill/Peak	970	0.07
12	Ridge	680	0.05
13	Seamount/Guyot	8,860	0.67
14	Pinnacle	690	0.05
15	Plateau	466,140	35.19
16	Saddle	48,000	3.62
17	Apron/Fan	2,700	0.21
20	Terrace	62,500	4.72
21	Sandwave/Sand bank	1,210	0.09

***** First row of continental shelf, slope, rise and abyssal plain areas are total, mutually exclusive areas. Second row continental shelf, slope, rise and abyssal plain areas are less the surface areas of superimposed features (e.g., shelf area is total minus superimposed basin area, sill area, terrace area, etc.).

3.6. Eastern Margin (Fraser Island to Cape Howe)

The east Australian continental margin extends for more than 1,400 km from Fraser Island in the north to the south coast of New South Wales. The area included in this study extends from the coast to the limit of the EEZ and covers and area of 1,066,630 km^2 (Table 3.11). The geomorphology of the margin (Fig. 3.24) and the origins and development of its geomorphic features can be directly attributed to rifting and break-up between Australia and the Lord Howe Rise/Dampier Ridge in the Late Cretaceous and Paleogene (Hayes and Ringis, 1973; Weissel and Hayes, 1977; Shaw, 1978, 1979). The narrow shelf and steep continental slope are the products of asymmetric plate rifting between 60 and 80 million years ago (Veevers et al., 1991). The eastern margin may be contrasted with the typical "Atlantic type" passive margin by way of its narrowness, the relatively thin sequence of post-rift sediments and the steepness of the slope (Marshall, 1979). Geomorphic features that have been named or that have been reported in scientific investigations are listed in Table 3.11 and the geomorphic make-up of the margin is provided in Table 3.12.

3.6.1. Continental Shelf

The continental shelf covers an area of 58,920 km^2 (Table 3.11). The shelf is relatively narrow in comparison with other parts of Australia, having an average width of about 25 km (Fig. 3.25). It is 10 km in width adjacent to Montague Island (36°15'S) and widens between Moreton and Fraser Islands to nearly 75 km (26°-27°). The coastline generally trends NE-SW between Cape Howe and Cape Byron, before turning N-S between Cape Byron and Fraser Island.

Shelf Break.– The shelf break is defined by a change in gradient from <0.5° on the shelf to >1.0° on the upper slope. This occurs at a water depth of 120 m at Tweed Heads and at 155 m off Sugarloaf Point (Roy and Thom, 1981). The depth of the shelf break is fairly uniform at between 145 to 165 m along the southern to middle parts of the NSW shelf (Davies, 1979). Northwards, however, the shelf break becomes progressively shallower, reaching a minimum depth of about 70 m adjacent to Fraser Island (Marshall, 1979). In general, the shelf gradient is steepest between the shoreline and the 60-100 m isobath. In the water depths of 100-150 m there is typically a flat (<0.2°) planar surface, termed the middle shelf plain by Phipps (1963). The depth and morphology of the shelf break are probably controlled by the underlying bedrock geometry and by the prograding sediment wedge and its differential compaction (Jones et al., 1975; Davies, 1979).

Shelf Terraces.– Terraces, "knick points", and other breaks in slope occur along all sections of the shelf, but are particularly well developed in profiles between Sugarloaf Point and Jervis Bay (Davies, 1979). In this area, histograms of terrace depths show three "peaks" centred around water depths of 40-60 m, 80-100 m and 120-140 m. The depths at which the terraces occur suggest their formation is related to earlier Pleistocene sea levels, when they were cut by erosional processes.

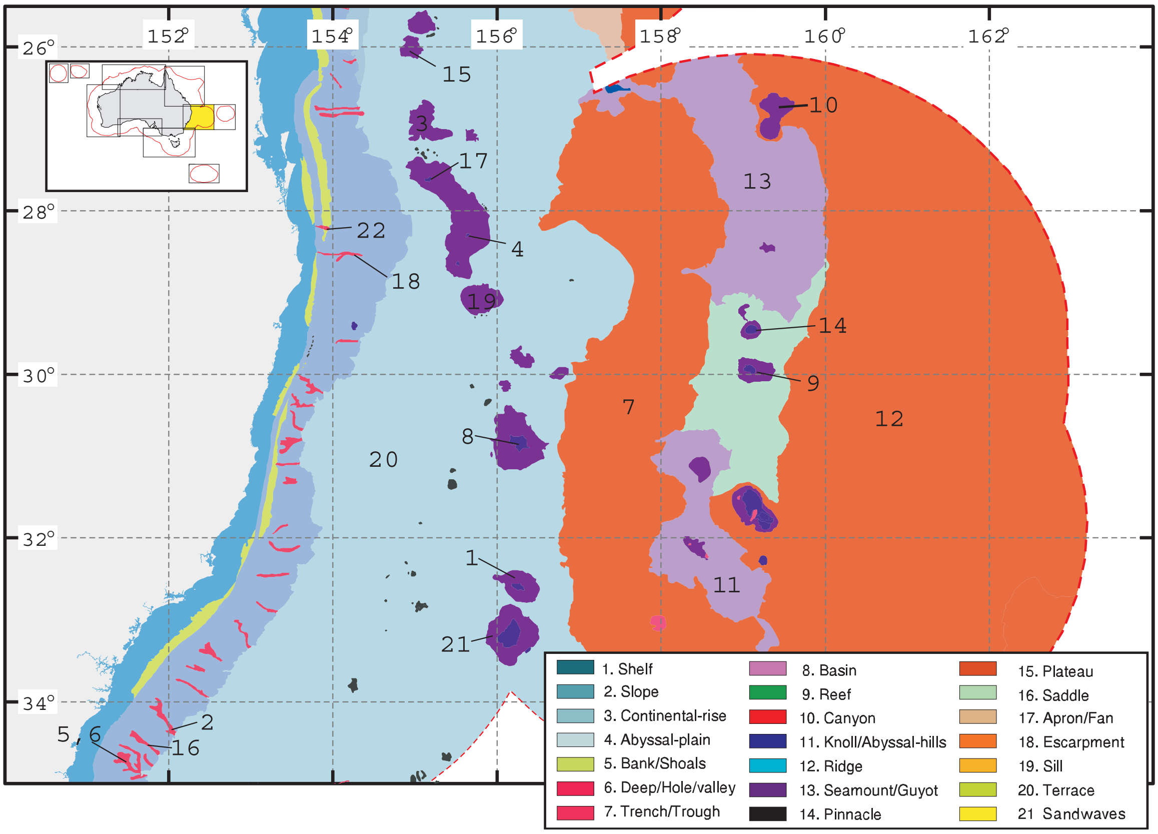

Figure 3.24. Geomorphic features on the eastern margin. See Table 3.11 for key to place names and Table 3.12 for surface areas of features.

Middle Shelf Banks.– In the northern part of the area there are several banks of notable size on the middle shelf. These include Barwon Bank (26° 30' S) and Windarra Bank, located to the south of Tweed Heads (28° 28' S, 153° 42' E). These banks rise from water depths of 50 to 60 m on the middle shelf to within 22-30 m of the surface. Other smaller, un-named banks are located at water depths of 50-60 m on the shelf between North Stradbroke Island and Fraser Island. The banks are thought to be the partly-cemented remains of drowned coastal sand bars (Jones and Kudras, 1982).

Bedrock Outcrop.– In the region 29-30° S the inner shelf undulates to 50 m. This rugged topography is associated with outcrop of basement rock (Marshall, 1972). From 30° S to Coffs Harbour, a number of islands, such as North Solitary Island, occur some 5-11 km offshore. Numerous shoals and pinnacles also occur, some of these being exposed above sea level. These appear to be outcrops of bedrock and are associated with the rough topography on the inner shelf (Marshall, 1972). Similar rough topography at depths of 170-260 m in the region south of 31° S is also attributed to bedrock outcrop (Marshall, 1972).

3.6.2. Continental Slope and Rise

The morphology of the continental slope is dominated by basement structure. The slope is generally broadly concave, especially in the south. The gradient varies from less than 1° on the mid-slope, where sediments are trapped behind basement ridges, to 20° where basement is exposed on the seabed (Colwell et al., 1993). North of 28° S, the upper slope is a sloping platform, while the lower slope steepens to 11° (Marshall, 1972). The angle of the upper continental slope is generally less than 2° in the area north of Jervis Bay, except near latitude 34°10′ S where it is more than 4°. South of Jervis Bay the inclination of the slope progressively increases, so that slopes of more than 10° are common (Davies, 1979).

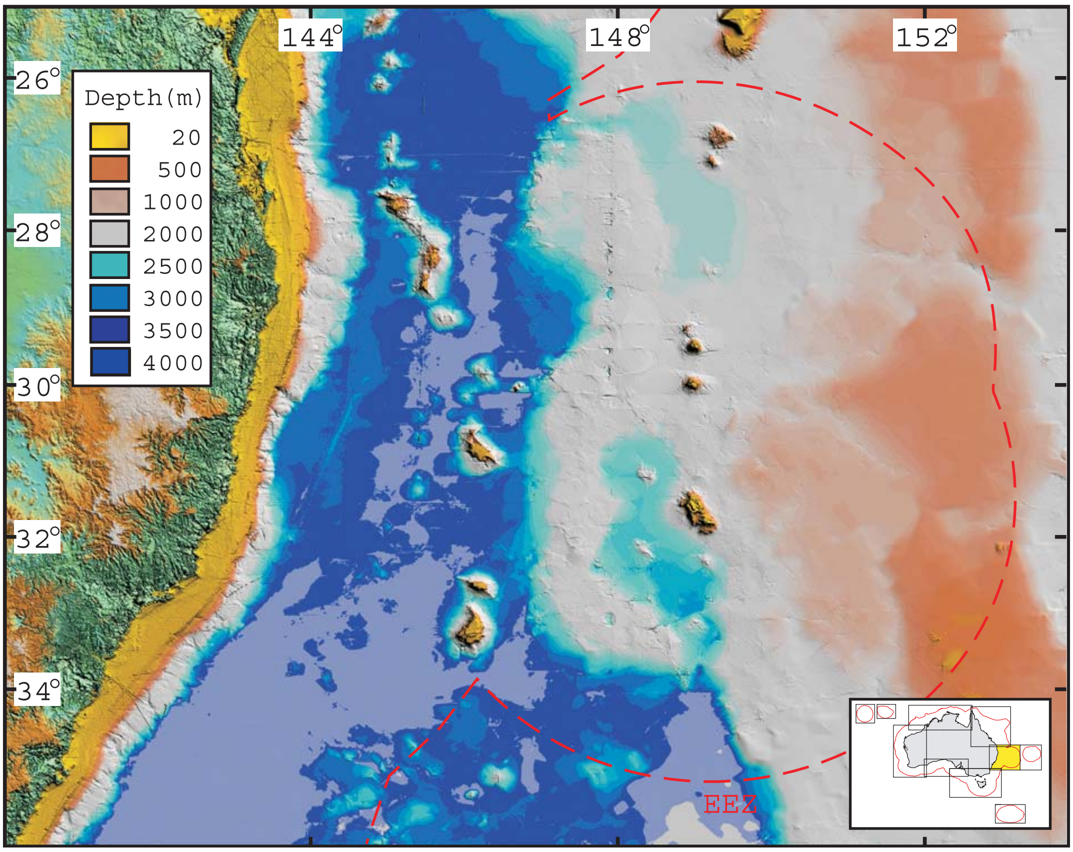

Figure 3.25. False-colour bathymetric image illuminated from the north showing the eastern margin with the Tasman Sea basin and marginal plateaus

The depth at which the upper and lower slope is divided varies from 200-270 m along the slope, although in some areas the steepest slopes are below 500 m (Marshall, 1972). Bedrock outcrop is present on the eastern edge of the upper slope in the region north of 28° S (Marshall, 1972). Jenkins (1992) observed long ridges (>200 m) of exposed bedrock in water depths of 2,500-4,000 m in the region of 34°-36° S. These represent the edges of blocks tilted in the rifted structure (Jenkins, 1992). Jenkins also observed raised volcanic/igneous ring complexes at mid-slope depths (3,000 m), which are related to volcanic activity during rifting of the Lord Howe Rise (Hubble et al., 1992; Section 3.7).

Submarine Canyons.– Canyon systems are common on the slope of this region (Figs. 3.25 and 3.26). Davies (1979) and Packham (1983) noted the presence of several submarine canyons in the upper slope interpreted from bathymetric data. Marshall (1972) identified two canyons on the continental slope in northern NSW, between 28° and 29° S; the Tweed and Richmond Canyons (Table 3.11). At 200 m water depth the

Tweed Canyon has a width of 6.5 km, with an axial depth of 75 m and wall height of 480 m. Rugged topography on the southern edge of the canyon probably reflects exposed bedrock on the walls and seabed (Marshall, 1972). The width of the Richmond Canyon is 13.5 km, with axial depth >800 m. Rough topography and pinnacles on the southern margin similarly reflect exposed bedrock, which together with a tributary canyon, contribute to relief of 150 m (Marshall, 1972).

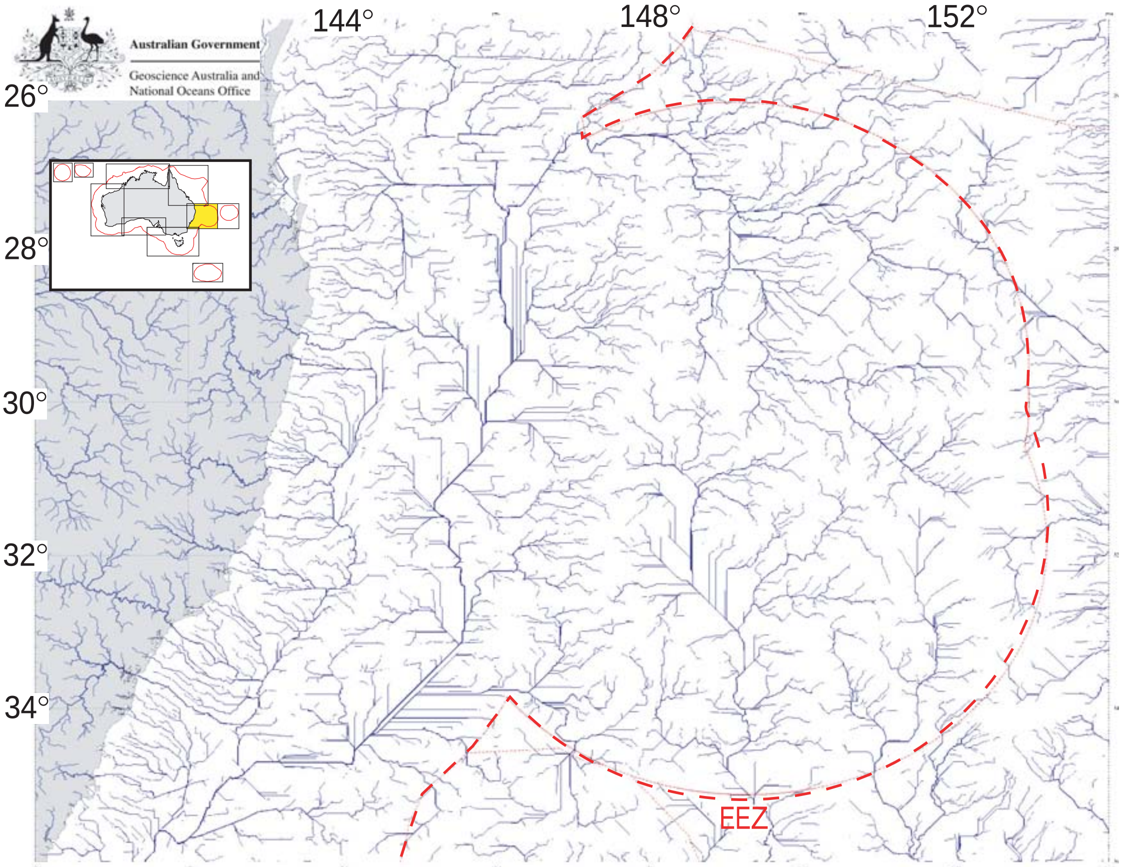

Figure 3.26. Predicted drainage system of the eastern margin, showing the positions of major shelf valleys and submarine canyons on the continental slope.

Between 30° and 31° S the continental slope is strongly dissected by numerous canyons and tributaries, which merge into at least five canyons further downslope (Marshall, 1972). A survey using GLORIA sidescan sonar over the slope between 34° and 36° S revealed numerous submarine canyons of differing scale (Jenkins and Lawrence, 1990). Davies (1979) identified ten canyons or canyon-like features (some of which may be tributaries of the same canyon system) on the upper slope in the area between Jervis Bay and Bermagui. Canyons north of Batemans Bay are included in Table 3.12. The remaining canyons are listed in Section 3.1.

Beecroft Canyon has a wide upper portion and a V-shaped profile from water depths of 530-728 m. The two sections are separated by a broad terrace on the north and a narrower terrace on the southern side (Davies, 1979). Perpendicular Canyon has a similar profile, with shoulders at water depths of 379 and 366 m. The canyon is 1 km wide across the shoulders. The flat floor occurs at a water depth of 596 m and is 0.25 km wide (Davies, 1979). St George Canyon is a much smaller feature, lacking the typical V-shaped profile. It is 1 km wide, with a floor at a water depth of 448 m

(Davies, 1979). Conjola Canyons are also smaller features; Conjola A, which lacks a V-shaped profile, is about 2 km wide, while Conjola B is 0.5 km wide (Davies, 1979).

It is evident that a high degree of slope erosion and canyon formation has occurred along certain sections of the NSW and southern Queensland shelf over various time scales. However, none of the canyons intrude onto the shelf, or into water depths shallower than the shelf break. Marshall (1979) noted that even though the Tweed and Richmond Canyons occur off river mouths, there is no evidence of channels on the shelf. Both canyons appear to head in water depths of 160-180 m. Geological studies (e.g., Marshall, 1972; Davies, 1979) have inferred from this that canyon formation occurred during times of lower relative sea level and that they are inactive under the present high sea-level conditions.

3.6.3. Continental Rise and Abyssal Plain

A continental rise (and wider slope) is present in the area between Cape Morton and Coffs Harbour, with the rise extending to the Britannia Guyots (Marshall, 1972). There is no development of a continental rise off southern NSW (Colwell et al., 1993). This reflects a low level of sediment input, probably caused by sediment trapping on the shelf or slope, low terrigenous input to the coast and sediment bypassing in canyon systems (Colwell et al., 1993).

The foot of the slope generally occurs in water depths of between 4,600 m and 4,850 m (Jenkins, 1992; Colwell et al., 1993). The upper surface of the abyssal plain is generally smooth, although in places at the base of slope, current scour has produced a small channel or moat (Colwell et al., 1993). Jenkins (1992) noted patches of reflective sediment that appear to be ribbons of silt, winnowed by currents at abyssal depths.

Tasman Sea.– Between the Australian continent and the Dampier Ridge (discussed in Section 3.7) lie the volcanic seamounts of the Tasmantid Seamount Chain, created by hotspot activity. Included in this region of the coastline are, from north to south: Moreton Seamount, Brisbane Guyot, Brittania Guyots, incorporating Queensland Guyot, Stradbroke Seamount, Derwent-Hunter Guyot, Barcoo Bank and Taupo Bank (Table 3.11), as well as several un-named structures. These seamounts vary in size and complexity from the complex of major seamounts forming Brittania Guyots to smaller structures, such as Barcoo Bank. All the features are flat-topped. The northern seamounts rise from the seabed to summit at water depths of 150-400 m (Marshall, 1972). The southern seamounts are deeper: Stradbroke Seamount rises to 900 m water depth (Marshall, 1972), while Barcoo Bank rises to less than 1,400 m water depth (Hill et al., 2000).

Table 3.11. List of previously described geomorphic features on the eastern margin. Features are numbered (left hand column) on Fig. 3.24.

No.	Geomorphic Feature	Feature Type	References
1	Barcoo Bank	Seamount (13)	Ringis and Hayes (1972)
2	Beecroft Canyon	Canyon (10)	Davies (1979)
3	Brisbane Guyot	Seamount (13)	Ringis and Hayes (1972)
4	Brittania Guyots	Seamount (13)	Ringis and Hayes (1972)
5	Conjola Canyon A	Canyon (10)	Davies (1979)
6	Conjola Canyon B	Canyon (10)	Davies (1979)
7	Dampier Ridge	Ridge (12)	McDougall et al. (1994)
8	Derwent-Hunter Guyot	Seamount (13)	Ringis and Hayes (1972)
9	Elizabeth Reef	Seamount (13)	Mammerickx et al. (1971)
10	Gifford Guyot	Seamount (13)	Mammerickx et al. (1971)
11	Lord Howe Basin	Basin (8)	Stagg et al. (2002)
12	Lord Howe Rise	Ridge (12)	Stagg et al. (2002)
13	Middleton Basin	Basin (8)	Stagg et al. (2002)
14	Middleton Reef	Seamount (13)	Mammerickx et al. (1971)
15	Moreton Seamount	Seamount (13)	Ringis and Hayes (1972)
16	Perpendicular Canyon	Canyon (10)	Davies (1979)
17	Queensland Guyot	Seamount (13)	Ringis and Hayes (1972)
18	Richmond Canyon	Canyon (10)	Marshall (1972)
19	Stradbroke Seamount	Seamount (13)	Ringis and Hayes (1972)
20	Tasman Basin	Basin (8)	Hill (1994)
21	Taupo Bank	Seamount (13)	Ringis and Hayes (1972)
22	Tweed Canyon	Canyon (10)	Marshall (1972)

Table 3.12. Geomorphic make-up of the eastern margin. Code refers to the geomorphic feature type listed in Table 2.2.

Code	Geomorphic Feature	Km^2	Percent
1	Shelf*	58,920	5.52
2	Slope*	618,310	57.97
3	Rise*	9,780	0.92
4	Abyssal plain*	379,620	35.59
	Total	**1,066,630**	**100.00**
1	Shelf*	54,980	5.16
2	Slope*	78,660	7.38
3	Rise*	9,780	0.92
4	Abyssal plain*	354,480	33.23
6	Deep/Hole/Valley	410	0.04

8	Basin	65,100	6.10
9	Reef	40	0.004
10	Canyons	4,460	0.42
11	Knoll/Abyssal Hills/Hill/Peak	2,440	0.23
12	Ridge	220	0.02
13	Seamount/Guyot	28,720	2.69
14	Pinnacle	1,160	0.11
15	Plateau	428,030	40.13
16	Saddle	23,470	2.20
17	Apron/Fan	5,120	0.48
20	Terrace	9,560	0.90

***** First row of continental shelf, slope, rise and abyssal plain areas are total, mutually exclusive areas. Second row continental shelf, slope, rise and abyssal plain areas are less the surface areas of superimposed features (e.g., shelf area is total minus superimposed basin area, sill area, terrace area, etc.).

3.7. Lord Howe Rise and Norfolk Rise Margin

The seafloor within the limits of the Australian EEZ surrounding Lord Howe Rise and Norfolk Rise covers an area of 431,170 km² (Table 3.13; Fig. 3.27). The development of the geomorphic features comprising the Lord Howe Rise and Norfolk Ridge is related to seafloor spreading, following late-Cretaceous initiation of rifting between the Challenger Plateau and the middle Lord Howe Rise, associated with the opening of the Tasman Sea (Gaina et al., 1998). The breakup of the Tasman Sea is interpreted as a complex history of events (Jongsma and Mutter, 1978; Gaina et al., 1998). As a result, much of the morphology of the region is complex with the region east of Norfolk Ridge, in particular, interpreted as an area of complex depressions and plateaus (Bernardel et al., 2002). For this reason, the morphology of this area is discussed in terms of the major provinces identified by Bernardel et al. (2002) and Stagg et al. (2002). Geomorphic features (Fig. 3.27) that have been named or that have been reported in scientific investigations are listed in Table 3.13 and the geomorphic make-up of the region is provided in Table 3.14. Bathymetric data are particularly sparse in the region (Fig. 3.28), and hence the details of features are only poorly defined. The reliability of the geomorphic features map is thus not as good here as for other parts of Australia.

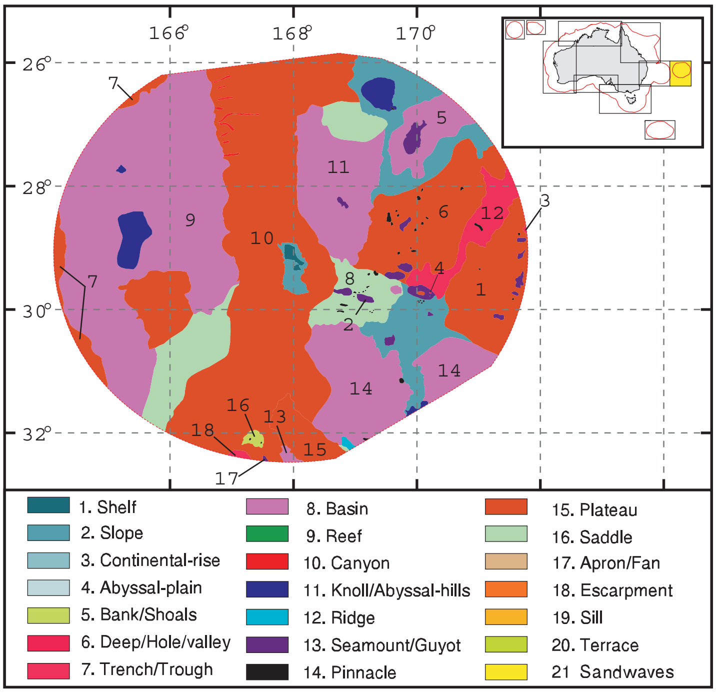

Figure 3.27. Geomorphic features on the Norfolk Ridge margin. See Table 3.13 for key to place names and Table 3.14 for surface areas of features.

3.7.1. Dampier Ridge-Lord Howe Rise Region

Dampier Ridge.– The Dampier Ridge extends over 800 km on a northerly trend between 34° S and 26° S, averaging about 100 km in width. The western margin consists of steep NNW-trending sections and more gently sloping NW-trending sections (McDougall et al., 1994). The western margin appears to be underlain by *en* *echelon* N-S oriented fault blocks (Hill et al., 2000). Heights of the crests range from 2,000-2,500 m (Stagg et al., 2002).

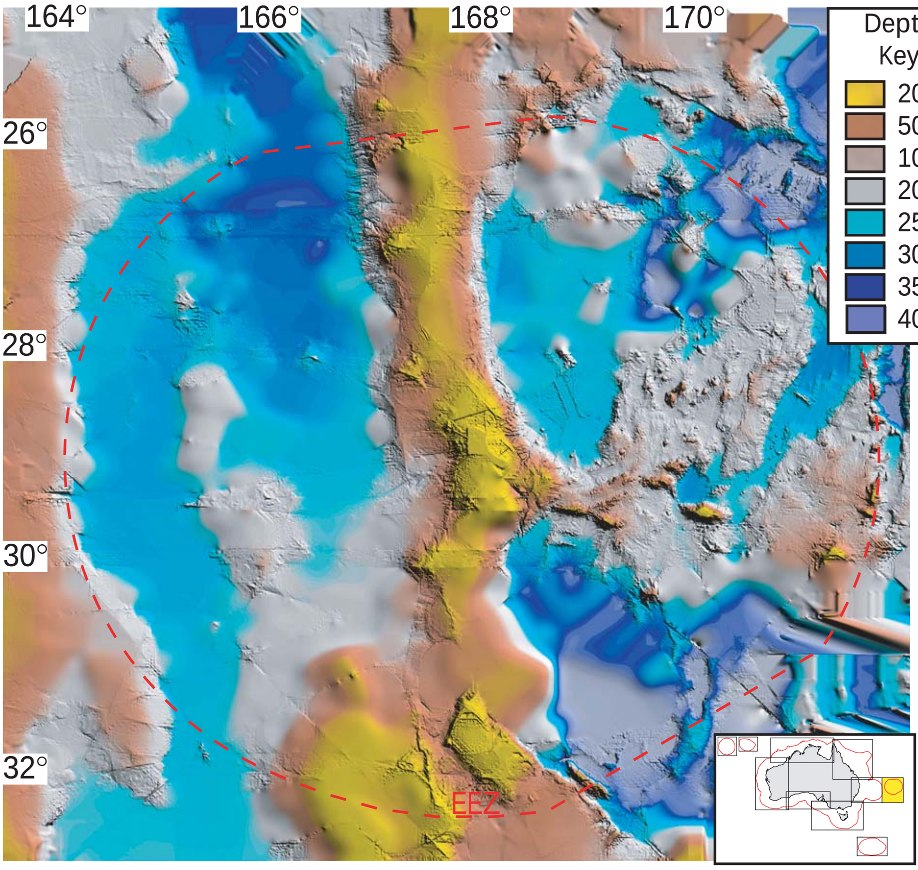

Figure 3.28. False-colour bathymetric image illuminated from the north of the Norfolk Ridge margin. Data coverage is very sparse in this region, causing the image to contain numerous ship-track and extrapolation artefacts.

Lord Howe Basin.– The Lord Howe Basin lies between Lord Howe Rise and the Dampier Ridge. It is 4,050 m deep and generally flat-bottomed, except for a large seamount that rises steeply from the centre of the basin to water depths of at least 2,800 m (Hill et al., 2000). Collectively, the basins of the Norfolk Ridge area account for nearly 40% of the surface area (Table 3.13), comprising the single most important geomorphic feature of the region.

Middleton Basin.– The Middleton Basin lies between Lord Howe Rise and the Dampier Ridge to the north of the Lord Howe Basin (Willcox et al., 1980; Stagg et al., 2002). The mean water depths in the basin are 3,000 m (McDougall et al., 1994).

Lord Howe Rise.– The Lord Howe Rise is the largest feature in the region, extending from the eastern Coral Sea in the north to the Bellonia Trough in the south. It is about 2,500 km in length and has a width of 450-650 km. The Lord Howe Rise covers an area of about 1,100,000 km^2 (Bernardel et al., 2002). The NW-trending northern segment of the Lord Howe Rise merges with a region of complex topography, which includes the Kenn Plateau and Mellish Rise. The central segment, which occurs over the region 24°-34° S, has a N-S trend and extends for some 1,100 km. The southern segment again trends NW-SE. Excluding the islands and banks of the Lord Howe seamount chain on the western flanks of the chain, the rise is shallowest in the east occur in water depths that range from 1,000-1,500 m (Stagg et al., 2002).

On the western flanks of the rise is the N-trending Lord Howe seamount chain, which includes isolated islands and banks, such as Elizabeth and Middleton Reefs and Gifford Guyot (Table 3.13). Lord Howe Island and Ball's Pyramid, which are also part of this chain, are the eroded, subaerial remains of volcanic edifices (McDougall et al., 1981). This complex is 90 km (NNW-SSE) by 50 km (WSW-ENE) and lies in water depths of between 1,800 m (ENE) and 3,500 m (WSW). Swath bathymetry data from Hill et al. (2000) shows the submarine flanks of the islands to be rugged and steep, commonly 10°-20° or steeper. The structure includes flow structures, canyons and numerous volcanic cones and pinnacles. At least one cone 200 m high occurs on the adjacent rise.

New Caledonia Basin.– The New Caledonia Basin lies to the east of the Lord Howe Rise. It extends for about 2,000 km from the North Island of New Zealand to the SW of New Caledonia. The northern and southern segments trend NW while the central segment lies N-S. The basin has a strong linearity, with an average width of about 150 km. The bed of the basin is generally flat-lying and occurs in water depths of 3,000 m (Stagg et al., 2002).

Norfolk Ridge.– The Norfolk Ridge is a major feature in this region, comprising a complex system of ridges and basins, extending from New Caledonia in the north to New Zealand in the south (Eade, 1988; Bernardel et al., 2002). The northern section is a steep-sided, narrow submerged continental ridge, approximately 70 km wide, with water depths at the crest of between 500-1,500 m (Hill, 1993). The only exposed parts on the central section are Norfolk and Phillip Islands, which were formed by volcanic activity (Jones and McDougall, 1973).

3.7.2. West Norfolk Ridge System

The West Norfolk Ridge system forms the southward continuation of the Norfolk Ridge (Stagg et al., 2002; Bernardel et al., 2002). It comprises a series of NW-trending ridges and basins; from southwest to northeast these include the West Norfolk Ridge, Wanganella Trough, Wanganella Ridge, Wanganella Bank, Reinga Basin and Taranui Block (Table 3.13). The Wanganella Bank (Table 3.13) forms the northern extension of the Wanganella Ridge (P. Symonds, *pers. comm.*). Water depths in this system range from 300-1,000 m on the ridges to 1,500-2,000 m in the intervening basins (Bernardel et al., 2002).

Norfolk Province.– The Norfolk Province comprises the North Norfolk Basin, which is bounded to the north by a plateau area (Bernardel et al., 2002). The southern margin of the province has gentle slopes of 2°-4°, punctuated by several volcanoes. The western margin with the Norfolk ridge is irregular, with deep NE-trending linear canyons. The margin appears to be stepped with slopes averaging 8°-13° and attaining 13°-22° in places. A central seamount occurs at 28°14′ S, 168°45′ E.

Nepean Province.– The Nepean Province includes the Nepean Saddle, a spur of the Norfolk Ridge, located to the east of Norfolk Island, and a portion of the South Norfolk Basin (Bernardel et al., 2002). The province is characterised by an irregular surface, with several large seamounts, ridges and basins.

Nepean Saddle.– The Nepean Saddle separates the North and South Norfolk Basins. It is approximately 39 km wide adjacent to the Norfolk Ridge and widens eastwards along two distinct broad ridges, trending ESE and ENE, respectively. The saddle is undulating with gentle 4°-8° slopes to the northeast and east, descending into the North Norfolk Basin and is dotted by seamounts. The southern margin of the saddle has a distinct E-W oriented seamount, Blackbourne Seamount (Table 3.13), which peaks at about 800 m (Bernardel et al., 2002). The surrounding slopes average 8°-18° with some steepening to 18°-27° where they descend into the South Norfolk Basin. Several smaller volcanic peaks punctuate the seamount. East of the seamount, the ridge broadens and forms an irregular surface with several small volcanic peaks and a small oval-shaped basin. The summit of the main ridge ranges in water depths from 2,100 to 2,600 m. The ridge dips gently (0°-4°) towards the South Norfolk Basin. At the eastern edge of the province is the Faust Guyot, which rises to about 600 m from the surrounding seabed which occurs in water depths of between 3,000 and 3,500 m. The slopes circling the seamount are 18°-27° near the summit and 8°-18° in the lower reaches. The northern ridge of the Nepean Saddle is characterised by three parallel NE-trending ridges, with volcanic peaks and seamounts, and two moderately-sized seamounts. The northeast corner of the province contains two irregularly-shaped seamounts, centred at 29°26′ S, 169°40′ E and 29°18′ S, 169°46′ E. The seamounts, which peak at water depths of 900 m and 1000 m, respectively are separated by a saddle at a depth of about 2,200 m. The slopes, which range from 8°-18° to 18°-27° in areas, show numerous volcanoes on the lower reaches.

South Norfolk Basin.– A portion of this basin occurs in the southern part of the Nepean Province. It is bounded to the north by the Nepean Saddle. The western margin is defined by the NNE-trending escarpment of the Norfolk Ridge. The basin floor in this area, which occurs in water depths ranging from 2,700 to 3,700 m, is undulating and increases gradually in depth to the south. A central high region is defined by two east-trending ridges at water depths of 2,500-3,000 m, dotted by small volcanoes, and a group of NE-trending volcanoes (Bernardel et al., 2002).

Forster Basin.– The Forster Basin, which comprises the Forster Province, lies to the east of the Kingston Province. Its western and southern margins border the Norfolk Province. It comprises an oval-shaped basin characterised by deeper bathymetry, relative to the North Norfolk Basin. A distinct feature is a large seamount centred at 27°10′ S, 169°58′ E (Bernardel et al., 2002).

Kingston Province.– The Kingston Province is a triangular-shaped province characterised by a north-east-trending trough, the Phillip Trough, which separates the Bates Plateau in the south east from the Kingston Plateau in the west (Bernardel et al., 2002).

Bates Plateau.– The Bates Plateau is a wedge-shaped plateau, which extends northwards from the high separating the North and South Norfolk Basins (Bernardel et al., 2002). The western margin of the plateau is irregular with numerous embayments. It slopes gently (2°-8°) towards the north and west, descending into the adjacent broad depression. The eastern flanks are rugged with NE to SE-dipping slopes of 13°-18° and several spurs protrude into the adjacent Cagou Trough. The surface of the plateau is undulating and rippled. Depths along the main plateau range from 2100-2600 m. A distinct ESE-trending saddle traverses the plateau at latitude 28°51′ S. Small seamounts punctuate the central and western areas.

Kingston Plateau.– The Kingston Plateau lies directly east of the North Norfolk Basin and north of the Nepean Province (Bernardel et al., 2002). The plateau has an irregular, undulating surface, marked by depressions, seamounts and volcanic edifices. Bathymetry is variable, ranging between 2,200-2,900 m, with seamounts rising to 2,100 m depth. The south-western margin is characterised by 8°-18° south-west to north-west-dipping slopes that descend into the adjacent, deeper floor of the North Norfolk Basin. The slopes along the eastern margin generally dip 2°-8° towards the north east and south. Areas in the central region are marked by escarpments with slopes of 13°-22°. Seamounts and volcanoes dominate in the southern half of the plateau. Two larger seamounts are centred at 28°41′ S, 169°46′ E and 28°33′ S, 169°51′ E, with summits of 1600 m and 1200 m respectively. The south-western margin has a series of discontinuous ridges, while the northern half of the plateau is characterised by a further series of discontinuous ridges, trending N, NE and NNE, with scattered volcanic edifices.

Phillip Trough.– The Phillip Trough separates the two plateau regions of the province (Bernardel et al., 2002). It has an irregular shape that trends northeast in the south and swings more to a north-south orientation in the north. The trough is arc-shaped at the northern extent and rectangular in the central region. In the south it is narrow initially, broadening to the south, with a distinct circular basin in the southwest. The basin floor lies at a depth of around 3400-3500 m in the north and central regions, rising to 3000-3300 m in the south. The southeast margin of the central trough is irregular and characterised by numerous embayments. In the northeast, the trough is separated from the Cagou Trough by a narrow sinuous escarpment-bounded ridge with 18°-27° NE to E-dipping slopes and 0°-8° N to NW-dipping slopes. The western flanks of the trough are well defined with slopes ranging from 2°-13° to the east and south. The margin is irregular in the south, being linear in the central region and curved in the north. Overall the trough floor is broadly undulating with prominent northwest dips. Small seamounts with peaks of 2700-2900 m occur in the northern and central areas. Between latitudes 28°34′ S and 28°44′ S there is a series of well-defined south-easterly-trending series of volcanoes lying at about 2700 m water depth. The trough floor in this region is rough with irregular rises and volcanoes. The southern region is gently undulating with a scattering of small seamounts.

Cagou Trough.– The Cagou Trough is a well-defined N-S oriented feature which is centred approximately along latitude 171°52′ E (Bernardel et al., 2002). The trough consists of a series of basins that can be broadly divided into three main regions: northern, central and southern. Overall the trough shallows to the south, with the minimum depth of 2940 m reached in the southern region. The deepest part of the trough occurs in a central smooth-floored basin with a maximum depth of about 4260

m. The western margin of the trough is a series of well-defined steep, arcuate slopes that become more irregular in the south. These western slopes range from 18°-27° in the north, becoming progressively more variable in the south and ranging from 4°-13°. The eastern margin is relatively linear with slopes of 8°-13°, decreasing to 4°-8° in the south.

Table 3.13. List of previously described geomorphic features on the Lord Howe Rise/Norfolk Ridge margin. Features are numbered (left hand column) on Fig. 3.27.

No.	Geomorphic Feature	Feature Type	References
1	Bates Plateau	Plateau (15)	Bernardel et al. (2002)
2	Blackbourne Seamount	Seamount (13)	Bernardel et al. (2002)
3	Cagou Trough	Trough (7)	Bernardel et al. (2002)
4	Faust Guyot	Seamount (13)	Bernardel et al. (2002)
5	Forster Basin	Basin (8)	Bernardel et al. (2002)
6	Kingston Plateau	Ridge (12)	Bernardel et al. (2002)
7	Lord Howe Rise	Plateau/Rise (15)	Stagg et al. (2002)
8	Nepean Saddle	Saddle (16)	Bernardel et al. (2002)
9	New Caledonia Basin	Basin (8)	Stagg et al. (2002)
10	Norfolk Ridge	Ridge (12)	Bernardel et al. (2002)
11	North Norfolk Basin	Basin (8)	Bernardel et al. (2002)
12	Phillip Trough	Trough (7)	Bernardel et al. (2002)
13	Reinga Basin	Basin (8)	Bernardel et al. (2002)
14	South Norfolk Basin	Basin (8)	Bernardel et al. (2002)
15	Taranui Block	Plateau (15)	Bernardel et al. (2002)
16	Wanganella Bank	Bank (5)	Bernardel et al. (2002)
17	Wanganella Ridge	Ridge (12)	Bernardel et al. (2002)
18	Wanganella Trough	Trough (7)	Bernardel et al. (2002)

Table 3.14. Geomorphic make-up of the Lord Howe Rise/Norfolk Ridge margin. Code refers to the geomorphic feature type listed in Table 2.2.

Code	Geomorphic Feature	Km^2	Percent
1	Shelf*	680	0.16
2	Slope*	430,490	99.84
4	Abyssal plain	-	-
	Total	**431,170**	**100**
1	Shelf*	680	0.16
2	Slope*	31,300	7.26
5	Bank/Shoal	710	0.17
6	Deep/Hole/Valley	10	0.002
7	Trench/Trough	9,820	2.28

8	Basin	167,610	38.87
10	Canyons	620	0.14
11	Knoll/Abyssal Hills/Hill/Peak	6,800	1.58
12	Ridge	280	0.07
13	Seamount/Guyot	4,580	1.06
14	Pinnacle	800	0.19
15	Plateau	178,160	41.32
16	Saddle	29,800	6.91

***** First row of continental shelf, slope, rise and abyssal plain areas are total, mutually exclusive areas. Second row continental shelf, slope, rise and abyssal plain areas are less the surface areas of superimposed features (e.g., shelf area is total minus superimposed basin area, sill area, terrace area, etc.).

3.8. Cocos-Keeling and Christmas Island Margins

The seafloor within the limits of the Australian EEZ surrounding Cocos-Keeling and Christmas Island margins cover areas of 467,250 km^2 and 328,150 km^2, respectively (Table 3.16; Fig. 3.29 A and B). The geomorphology of the region and development of the geomorphic features can be directly attributed to the rifting of India and Australia, and associated volcanism along fracture zones developed during the opening of the Indian Ocean and subsequent fusing of the Indo-Australian plate. Major geomorphic features that have been named or that have been reported in scientific investigations are listed in Table 3.15 and the geomorphic make-up of the region is provided in Table 3.16.

3.8.1. Cocos-Keeling Island Margin

The Cocos-Keeling Islands are a group of low-lying coral atolls in the northeast Indian Ocean. The islands have formed on a steep-sided seamount, which rises from a depth of 5,000 m. The seamounts on which the atolls have formed are the largest in an easterly trending chain of seamounts that are geologically related to the Christmas Islands further to the east. The Cocos-Keeling Islands are situated on a steep-sided irregularly shaped uplifted block called the Cocos Rise that contains numerous volcanic cones and seamounts. The seamounts are of variable shape and size and have summits that attain 1,000 m water depth. The surface of the rise is thus very rugged, and is dissected by numerous narrow valleys that criss-cross the surface and contain sediment up to 200 m thick (Jongsma 1976). To the south of the Cocos Islands is the Umitalea Mary Seamount, which rises from abyssal depths to within 16 m of the water surface. A distinct north-south trending ridge of variable height and width dissects the region and separates the Cocos Island seamounts from the Christmas Island seamounts. This steep-sided linear ridge is up to 2,000 m high, and contains rounded summits that have a similar appearance to the seamounts located on the plateaus either side of it. In the south, the ridge is bounded on both sides by linear depressions in the seafloor that have similar north-south trending axes.

The trench-ridge complex is probably similar in origin to the Ninetyeast Ridge, which lies west of the Cocos-Keeling Islands and represents a fault-related/hot-spot structure associated with a the northward movement of the Indian continent (Kashintsev et al. 2000). To the northwest and southeast of the Cocos-Keeling Islands, the Cocos and Wharton basins are abyssal plains with undulating seafloor topography. Numerous steep-sided seamounts and basement ridges cut the plains and produce a very rugged topography. Shallow basins of variable depth occur between the seamounts and ridges.

3.8.2. Christmas Island Margin

Java Trench.– The seabed morphology of the Java Trench is characterised by well-developed trench, fore-arc ridge, fore-arc basin, and volcanic arc elements. The trench is flanked to north by the fore-arc ridge, which has a rough surface and rises to water depths of 2,500 to 2,000 m. The slope rises steadily but irregularly to form two distinct parts; a very steep and rough lower slope that extends from the bottom

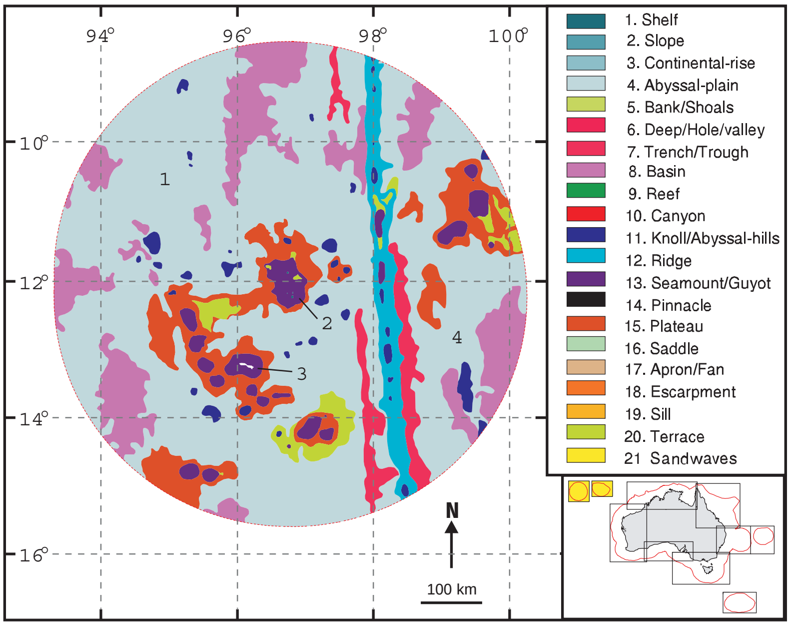

Figure 3.29. (A) Geomorphic features of the Cocos-Keeling Island margin. See Table 3.15 for key to place names and Table 3.16 for surface areas of features

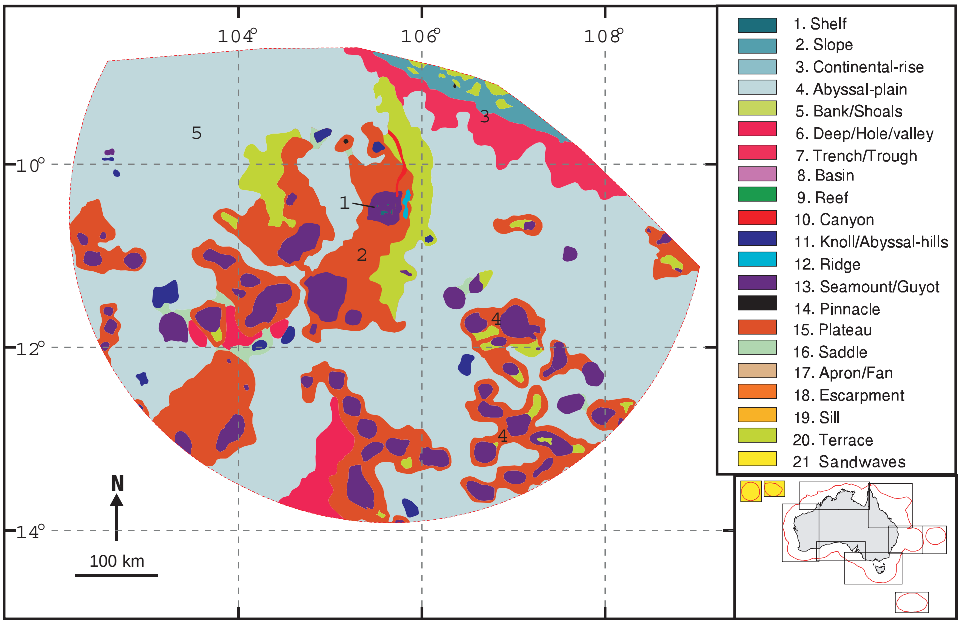

Figure 3.29–Cont. (B) Geomorphic features of the Christmas Island margin. See Table 3.15 for key to place names and Table 3.16 for surface areas of features.

of the trench to about 3,500 m and an upper slope that rises more gradually to the ridge crest (Borissova 1994). The upper slope also contains a series of steps defined by basement outcrops (Borissova 1994). The trench itself trends NW-SE and increases in depth from approximately 6,500 m in the west to more than 7,000 m in the east (Borissova 1994). The floor of the trench is generally flat or dips gently towards the axis. The depth of the trench correlates directly with the thickness of sediment in the trough, being shallower where the sediment is thicker. On the southern flank, the seabed deflects gently downwards, and descends approximately 1,000 m over a 70-100 km wide region.

Throughout its length the trench forms distinct morphological segments between 70 and 100 km long. The segments are widest and deepest in the middle and narrow and shallow towards the edges (Exon et al., 1993). The edges represent transition zones that lie close to seamounts or submarine ridges approaching the trench. Local deeps are a result of seamounts being carried into the trench and causing down warping of the seafloor in the vicinity of the plate boundary. A major deviation in the trench axis occurs at about 106° E due to the influence of the Christmas Island Rise.

Christmas Island and Roo Rises.– Christmas Island resides on a steep-sided irregularly shaped elevated block called the Christmas Island Rise (Exon et al., 1993). The rise is between 800-1,000 m higher in places than the surrounding seabed and its surface is studded with numerous seamounts of variable heights, which produce both a rugged and undulating morphology. The seamounts are a continuation of the Vening-Meinesz seamounts. They form a NE-SW trending chain of densely spaced seamounts up to 50 km in diameter whose summits mostly attain 2,000 m water depth, although the largest seamount rises more than 5,000 m and forms Christmas Island (Rivereau, 1965). Where the rise abuts the Java Trench, the trench floor becomes very shallow and narrows considerably to approximately 40 km wide. This change in morphology is due to the impact of the Christmas Island rise on the trench, with the shallowing representing the presence of part of the rise in the trench (Borissova, 1994). In the eastern most regions, a similar effect on trench structure occurs with the impact of the Roo Rise where it deflects the strike of the Java Trench between 50-60 km to the north (Masson et al., 1990). The Roo Rise also forms an irregularly shaped elevated block that locally attains heights of 500 m above the surrounding seabed. It also contains seamounts.

Wharton Basin.– The seabed morphology of the Wharton Basin is quite diverse, but is most strikingly characterised by numerous seamounts that rise up from the abyssal plain in water depths of over 5,500 m. The seamounts, which attain heights of between 1,000 and 3,000 m, are generally grouped into clusters of large and small irregularly spaced volcanoes (Borissova, 1994). Most of the seamounts have very steep slopes and are circular and conical in shape. The seamounts form two distinct provinces that are related to the tectonic history of the region. In the west and centre, the seamounts are located on a large irregularly shaped block (Christmas Island Rise) and are described above. In the east, the seamounts trend NE-SW but are not associated with any uplifted region and they are smaller in size, with their summits occurring at about 3,000 m water depth (Borissova, 1994). Flat areas occur mostly in the northwest in water depths of about 5,400 m. Between the flat areas and seamount provinces, the seabed is characterised by abyssal hills that form an undulating topography of 30-40 m to 200 m relief. The hills typically coincide with outcropping basement ridges.

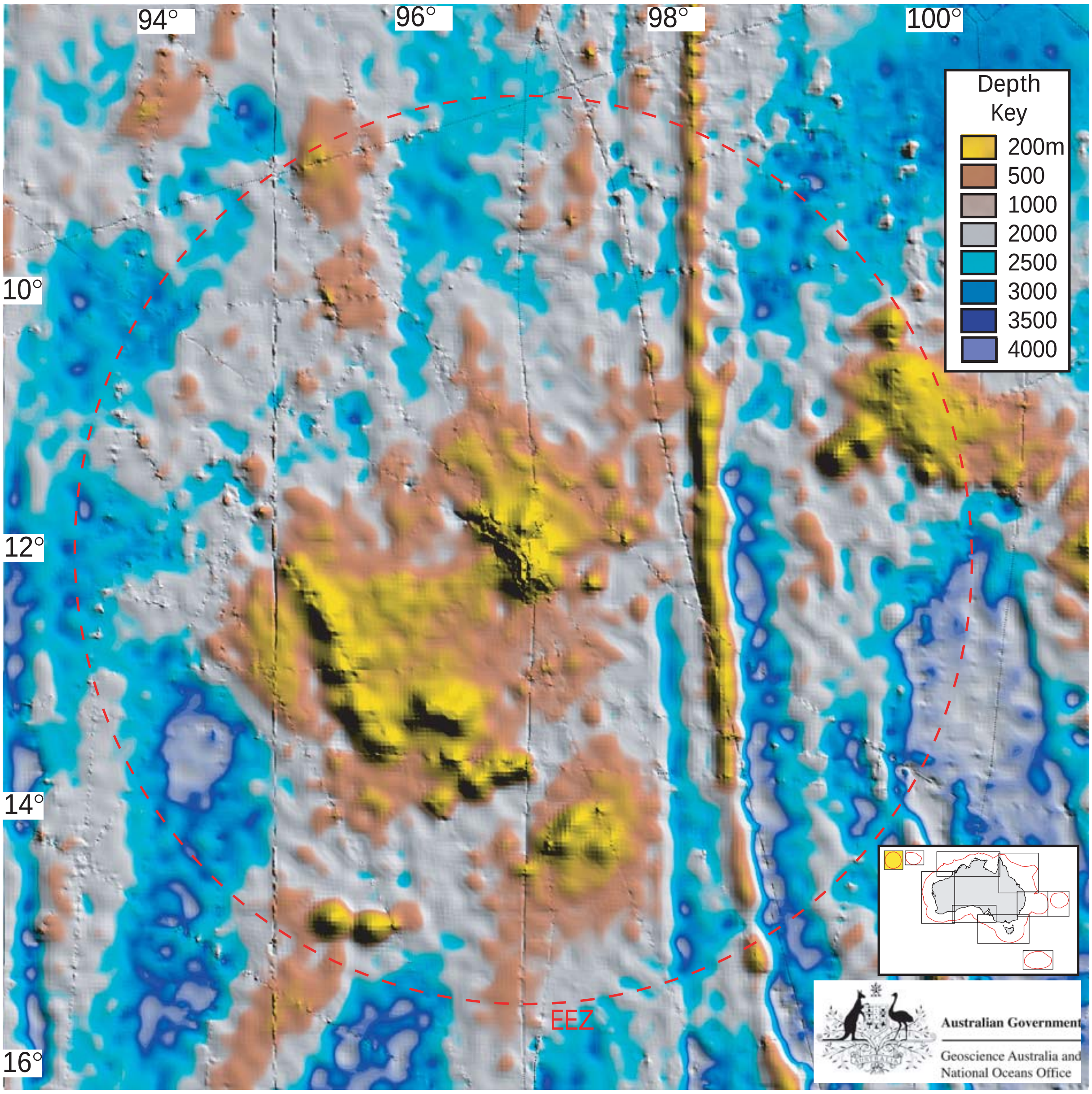

Figure 3.30. False-colour bathymetric image illuminated from the north of the Cocos-Keeling Island margin. Data coverage is very sparse in this region, causing the image to contain numerous ship-track and extrapolation artefacts.

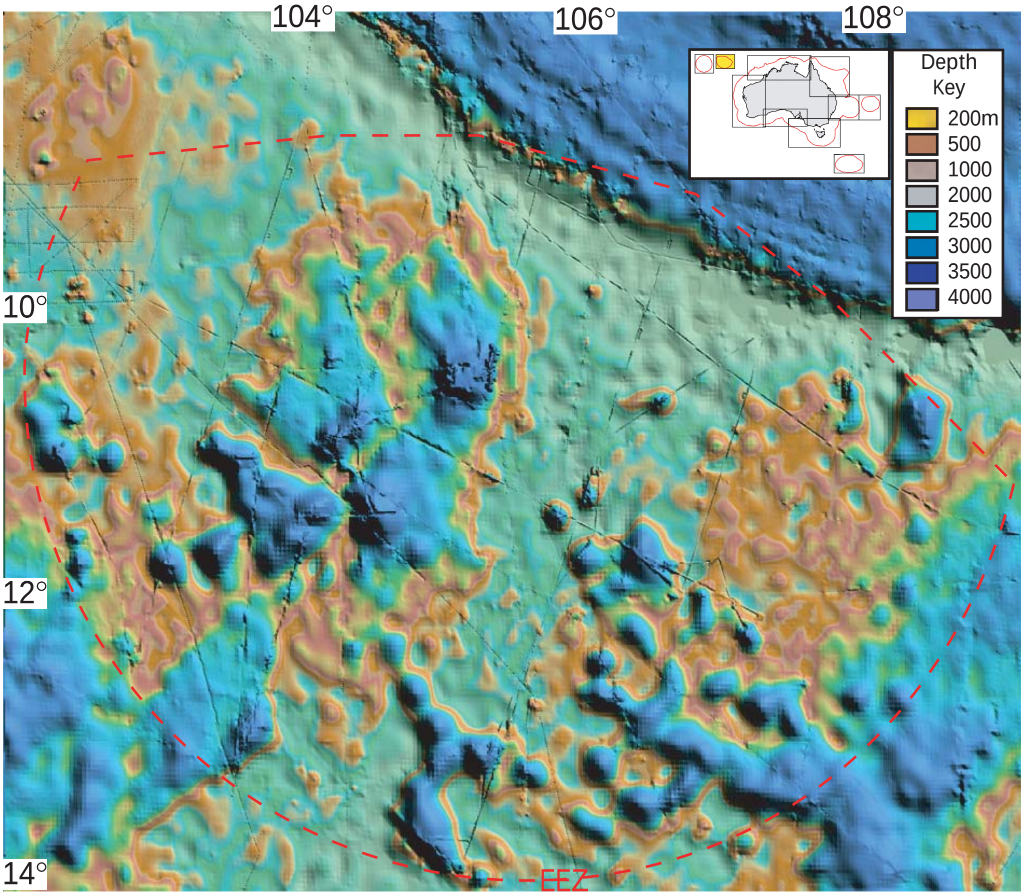

Figure 3.31. False-colour bathymetric image illuminated from the north of the Christmas Island margin. The Java Trench, up to 7,000 m deep, extends across the northern part of the image. Data coverage is very sparse in this region, causing the image to contain numerous ship-track and extrapolation artefacts.

Table 3.15A. List of previously described geomorphic features on the Cocos-Keeling Island margin. Feature are numbered (left hand column) on Fig. 3.29(A).

No.	Geomorphic Feature	Feature Type	References
1	Cocos Basin	Abyssal Plain (4)	Jongsma (1976)
2	Cocos Island Rise	Plateau (15)	Jongsma (1976)
3	Umitaka Mary Seamount	Seamount (13)	Jongsma (1976)
4	Wharton Basin	Abyssal Plain (4)	Jongsma (1976)

Table 3.15B. List of previously described geomorphic features on the Christmas Island margin. Features are numbered (left hand column) on Fig. 3.29(B).

No.	Geomorphic Feature	Feature Type	References
1	Christmas Island	Seamount (13)	Rivereau (1965)
2	Christmas Island Rise	Plateau (15)	Exon et al. (1993)
3	Java Trench	Trench (7)	Borissova (1994)
4	Roo Rise	Plateau (15)	Exon et al. (1993)
5	Wharton Basin	Abyssal Plain (4)	Borissova (1994)

Table 3.16. Geomorphic make-up of the Cocos-Keeling and Christmas Island margins. Code refers to the geomorphic feature type listed in Table 2.2.

Code	Geomorphic Feature	Km^2	Percent
Cocos-Keeling Islands			
1	Shelf	100	0.02
2	Slope	35,130	7.52
4	Abyssal plain	432,020	92.46
7	Trench/Trough	16,100	3.45
8	Basin	62,420	13.36
11	Knoll/Abyssal Hills/Hill/Peak	8,010	1.71
12	Ridge	18,310	3.92
13	Seamount/Guyot	14,800	3.17
20	Terrace	10,070	2.16
	Total	**467,250**	**100**
Christmas Island			
1	Shelf	60	0.02
2	Slope	17,090	5.21
4	Abyssal plain	297,960	90.80
6	Deep/Hole/Valley	6,380	1.94
7	Trench/Trough	10,890	3.32
10	Canyons	340	0.10
11	Knoll/Abyssal Hills/Hill/Peak	2,570	0.78
12	Ridge	190	0.06
13	Seamount/Guyot	26,610	8.11
14	Pinnacle	40	0.01
15	Plateau	49,950	15.22
16	Saddle	1,930	0.59
20	Terrace	15,840	4.83
	Total	**328,150**	**100**

3.9. Macquarie Island Margin

The seafloor within the limits of the Australian EEZ (plus extended continental shelf) surrounding Macquarie Island margin covers an area of 588,610 km^2. The geomorphology of this region is dominated by the Macquarie Ridge complex, which consists of a kinked-linear system of ridges and adjoining trenches. The complex consists of three segments: the McDougall, Macquarie, and Hjort provinces. Major geomorphic features that have been named or that have been reported in scientific investigations are listed in Table 3.17 and the geomorphic make-up of the region is shown in Figure 3.32 and the areas of features are listed in Table 3.18.

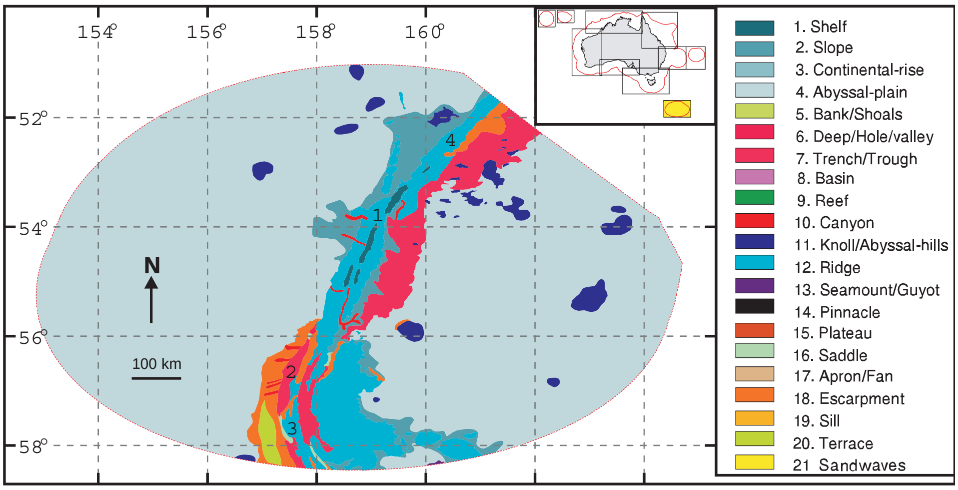

Figure 3.32. Geomorphic features of the Macquarie Island margin. See Table 3.17 for key to place names and Table 3.18 for surface areas of features.

The McDougall and Macquarie provinces are characterised by a western ridge flanked by an eastern trench. In contrast, the broader, arcuate Hjort province consists of a westerly trough flanked by an easterly ridge (Bernardel and Symonds, 2001). Shallow depths (<50 m) and flat-topped morphology suggest some 140 km of the Macquarie segment was previously above sea level (Massell et al., 2000). This forms a shelf geomorphic feature, which has been extrapolated to other similar shallow, flat-topped sections of the ridge that lie above 200 m water depth.

Ridge systems form an extensive kinked-linear to arcuate complex incorporating three main sections (from north to south): the McDougall segment, (~410 km long), the Macquarie segment (~350 km long) and the arcuate southern ridge system of the Hjorst segment. A narrow, linear, NE-trending discontinuous ridge (maximum relief 1,500 m) associated with the Jurru fracture zone meets the junction of the McDougall and Macquarie segments in the north. The uplifted ocean ridge is steep-sided with an uneven bisected surface. Relative relief of the valley bisecting the ridges is up to 700 m.

All crust in this region is believed to be oceanic in origin (Weissel *et al.*, 1977). Pervasive tectonic spreading fabric, typically trending orthogonally to fracture zones,

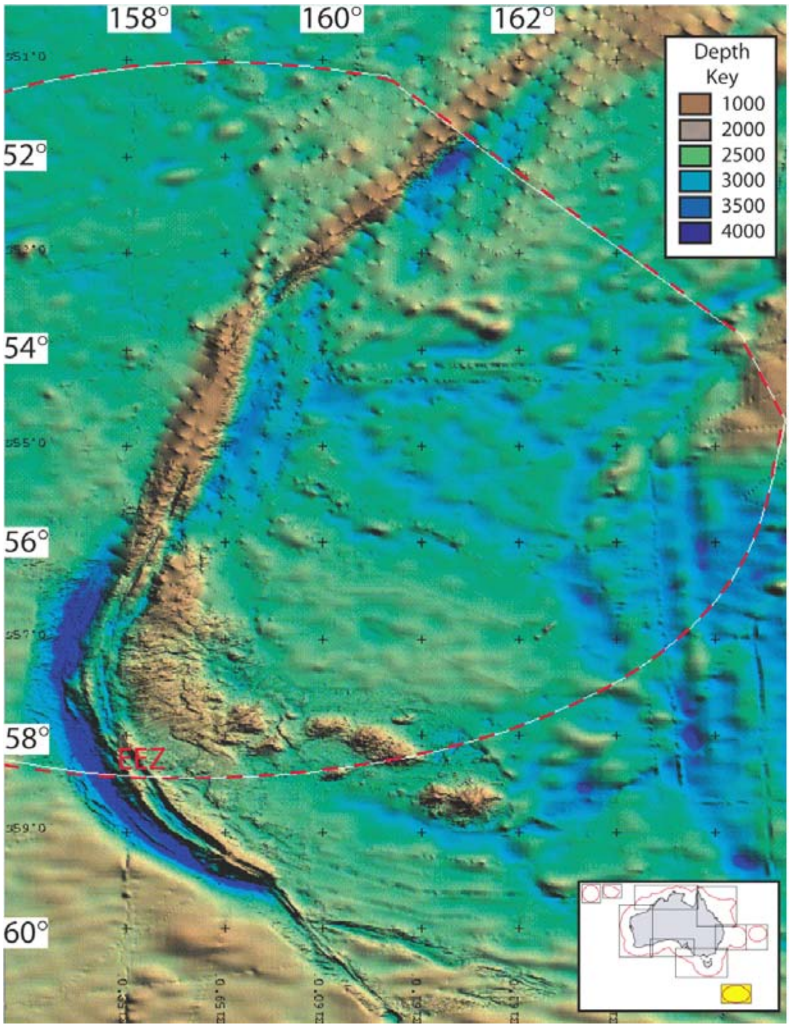

Figure 3.33. False-colour bathymetric image illuminated from the north of the Macquarie Island margin. The Hjort Trench, up to 6,000 m deep, extends across the southwestern part of the image.

is visible throughout the region (Massell *et al*., 2000). Continuous lineaments up to 60 km long have been observed, but are more commonly in the order of 10–30 km (Massell *et al*., 2000).

Seamounts and volcanic cones are well developed on the eastern side of the Macquarie Ridge, rising from abyssal depths to about 2,000 m. This chain of SE-trending seamounts forms the continuation of the Hjort Ridge and can be subdivided into a northern group of three and a southern group of two. There are fewer large seamounts to the west, although there are a number of low-relief (<1,000m elevation above the level of surrounding seabed) abyssal hills in this area. A large seamount located to the south of the Hjort Trench (60° S, 158° 30′ E) rises to within 1,300 m of the sea surface (Fig. 3.33).

A major feature is the Hjort Trench, which is formed by a disconnected series of flat-bottomed trenches, lying in water depths of about 6,000 m, and joined by saddles ridge (Bernardel and Symonds, 2001). The Hjort Trench is arcuate in plan view, extending along a length of about 450 km in the southeastern part of the EEZ, between 56° S and 59° 30′ S latitude. It is bordered by steep escarpments and ridges on the eastern side that rise to within 2,000 m of the surface. To the west, the Trench is bordered by flat abyssal plain at around 3,500 m water depth (Fig. 3.33).

Separation between trenches and ridges was based on a combination of bathymetry and change in slope. Trench floors are included in the area delineated as trench. Ridges include tops and flanks, although steep flanks were classed as escarpments, where the isobaths are so closely spaced that they bunched together.

Table 3.17. List of previously described geomorphic features on the Macquarie Island margin. Features are numbered (left hand column) on Fig. 3.32.

No.	Geomorphic Feature	Feature Type	References
1	Macquarie Ridge	Ridge (13)	Massell et al. (2000)
2	Hjort Trench	Trench (7)	Bernardel & Symonds (2001)
3	Hjort Ridge	Ridge (13)	Massell et al. (2000)
4	MacDougall Ridge	Ridge (13)	Massell et al. (2000)

Table 3.18. Geomorphic make-up of the Macquarie Island margin. Code refers to the geomorphic feature type listed in Table 2.2.

Code	Geomorphic Feature	Km^2	Percent
1	Shelf	1,506	0.32
2	Slope	19,652	4.12
4	Abyssal plain	373,655	78.26
6	Deep/Hole/Valley	86	0.02
7	Trench/Trough	24,533	5.14
10	Canyons	1,422	0.30
11	Knoll/Abyssal Hills/Hill/Peak	10,214	2.14
12	Ridge	36,693	7.69
13	Seamount/Guyot	75	0.02
15	Plateau	780	0.13
16	Saddle	335	0.07
18	Escarpment	9,234	1.93
	Total	**477,430**	**100**

Chapter 4. DISCUSSION AND CONCLUSIONS

The geomorphology of the Australian continental margin has been described previously by several authors (e.g., Bird, 1979; Falvey and Mutter, 1981; Veevers, 1984). These studies noted the relatively large expanse of continental shelves in the north in comparison with the south, the close proximity of vast abyssal plains to the southern margin and the deep troughs off Queensland and in the Timor Sea. The papers cited in Chapter 3 regarding individual features such as submarine canyon systems, marginal plateaus, trenches and ridges, etc. (listed in tables at the end of each section) points to an extensive body of literature on the subject.

This study has collated such information and, for the first time, systematically measured the surface area and distribution of geomorphic features (i.e., those listed in Table 2.3) around the Australian continent within the limits of the EEZ (Fig. 4.1). The results provide the basis for a new assessment of the geomorphology of the Australian continental margin and its regional variation.

In the following discussion, we describe the distribution of geomorphic features on the Australian margin in order to characterise it in terms of differences and similarities in geomorphic composition. Our approach will be an attempt to quantify regional differences, based on surface areas and distribution patterns of different features.

4.1. Regional Variation in the Area of Continental Shelf, Slope, Rise and Abyssal Plain

The surface areas of continental shelf, slope, rise and abyssal plain vary regionally within the Australian EEZ (Fig. 4.1). On average, the shelf, slope, and abyssal plain each cover about a third of the total area, with the rise making up just over one percent of the area (Table 4.1). Two regions around the Australian continent, however, exhibit a significant departure from this average pattern. Firstly, the northern margin is dominated by continental shelf, which comprises >70% of the overall area. Secondly, the eastern margin is dominated by abyssal plain, which comprises >85% of that area. The other main difference between the margins of continental Australia is the absence of any significant continental rise in the southeast and southern margins (Fig. 4.1).

The four island margins included in this study (Macquarie Island, Norfolk Island, Cocos-Keeling Island, Christmas Island) differ from the continental regions in that their EEZ's are all dominated by abyssal plains (typically 80 to 90% of the area) and very small shelf areas (<1%). This makes them similar to the eastern margin in overall area distribution. The island regions are all about the same size in total area, about 500,000 km^2 (Fig. 4.1).

4.2. Regional Trends in the Distribution of Geomorphic Features

The surface areas of the continental shelf, slope, rise and abyssal plain occurring on the Australian margin (not including the Australian Antarctic Territory and Heard Island) add up to a total area of just under 8.6 million km^2 (Table 4.1). Superimposed upon this area are the 17 other categories of geomorphic feature that we have recognised in this study. Their combined areas add up to less than 44% of the total surface area (Table 4.1), and so there are continental shelf, slope, rise and abyssal plain areas that do not have any other geomorphic feature present or could not be resolved at our mapping scale.

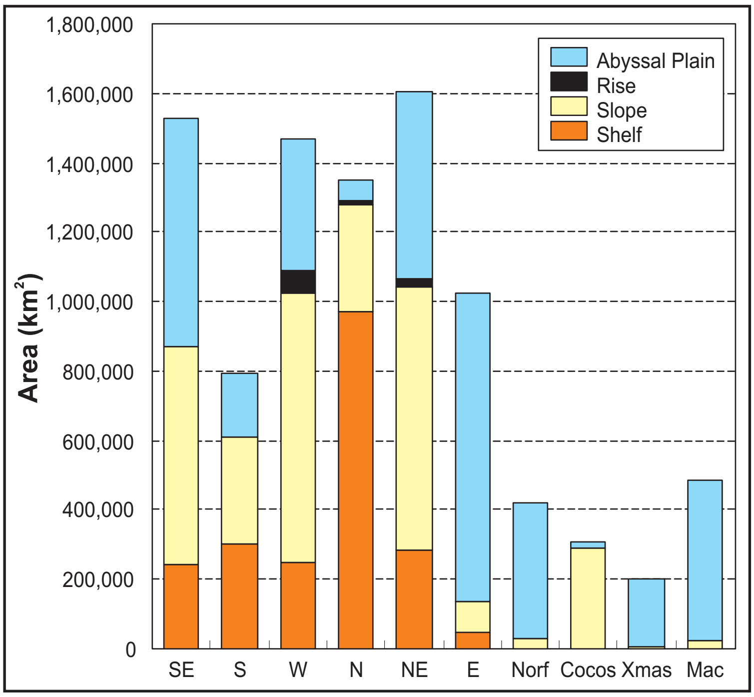

Figure 4.1. Areas (km^2) of continental shelf, slope, rise and abyssal plain for different margins of Australia. SE = southeast margin, S = southern margin, W = western margin, N = northern margin, NE = northeast margin, E = eastern margin, Norf = Norfolk Island, Cocos = Cocos-Keeling Island, Xmas = Christmas Island, Mac = Macquarie Island.

It is important to recognise that, whereas the shelf, slope, rise or abyssal plain environments are mutually exclusive, other types of geomorphic feature are not. For example, submarine canyons can extend across shelf, slope, rise or abyssal plain environments. Reefs occur on the shelf but also upon marginal plateaus and as atolls on top of seamounts that extend from the abyssal plain.

The distribution of geomorphic features on a regional basis (Fig. 4.2) is not uniform and exhibits wide variation. The summation of the feature surface areas in each margin (Fig. 4.3) demonstrates that, after the shelf, slope and abyssal plain, *Plateaus* cover the largest area of seabed. Their total area is over 1.4 million km^2 and plateaus are found on all margins. They are most extensive on the northeast margin, where they cover an area of 466,140 km^2, followed by the eastern margin, where they cover an area of 428,030 km^2.

Basin.– Basins are the second most extensive feature (Table 4.1 and Fig. 42.) covering a total area of 713,136 km^2. They are found most extensively on the northern (249,120 km^2), the Norfolk Island (167,610 km^2), and the northeast (144,240 km^2) margins. Basins perched on continental shelves are most common on the northern margin, whereas basins on the Norfolk Island and northeast margins are mostly located in the deep ocean (>2,000 m water depth).

Table 4.1. Surface areas of geomorphic features around the Australian margin.

Code	Geomorphic Feature	Km^2	Percent
1	Shelf*	1,976,109	1.13
2	Slope*	3,817,165	23.04
3	Rise*	97,072	44.51
4	Abyssal plain*	2,685,235	31.31
	Total	**8,575,581**	**100**
1	Shelf*	1,242,740	14.49
2	Slope*	1,294,189	15.09
3	Rise*	97,072	1.18
4	Abyssal plain*	2,174,365	25.36
5	Bank/Shoal	51,207	0.60
6	Deep/Hole/Valley	165,227	1.93
7	Trench/Trough	171,608	2.00
8	Basin	713,136	8.32
9	Reef	47,980	0.56
10	Canyons	106,096	1.24
11	Knoll/Abyssal Hills/Hill/Peak	108,471	1.27
12	Ridge	109,459	1.28
13	Seamount/Guyot	92,722	1.08
14	Pinnacle	5,514	0.06
15	Plateau	1,408,628	16.43
16	Saddle	142,463	1.66
17	Apron/Fan	6.611	0.08
18	Escarpment	15,352	0.18
19	Sill	17,351	0.20
20	Terrace	577,741	6.74
21	Sandwave/Sand bank	23,822	0.28

***** First row of continental shelf, slope, rise and abyssal plain areas are total, mutually exclusive areas. Second row continental shelf, slope, rise and abyssal plain areas are less the surface areas of superimposed features (e.g., shelf area is total minus superimposed basin area, sill area, terrace area, etc.).

Terrace.– Terraces are the third most extensive type of geomorphic feature, covering a total area of 577,741 km^2. Terraces are found on all margins except for the Norfolk Island margin, and are particularly widespread on the northern (218,540 km^2), southern (147,150 km^2) and western (91,610 km^2) margins.

Trench/trough.– Trench/troughs cover a total area of 171,608 km^2 and are found on all margins except the southern and adjacent to the eastern margin. Their greatest extent is in the northeast and Macquarie Island margins, where they cover 86,890 km^2 and 24,533 km^2 respectively.

Deep/hole/valley.– Deep/hole/valleys cover a total area of 165,227 km^2 and are found extensively on the northern (78,730 km^2), western (26,800 km^2), and southeast (19,021 km^2) margins.

Saddle.– Saddles cover a total area of 142,463 km² and are found on all except the southern and Cocos-Keeling Island margins. The margin having the largest spatial coverage is the northeast (48,000 km²), followed by the southeast (30,442 km²), margins.

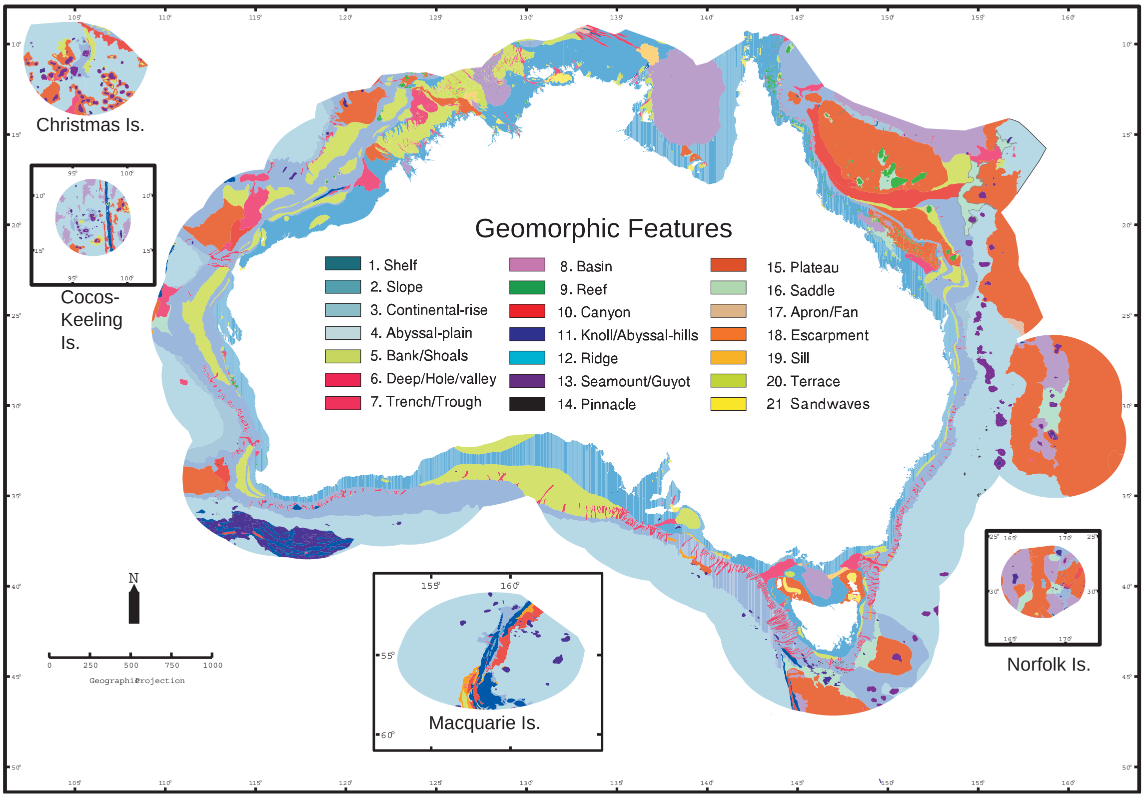

Figure 4.2. Distribution of geomorphic features around the Australian continental margin

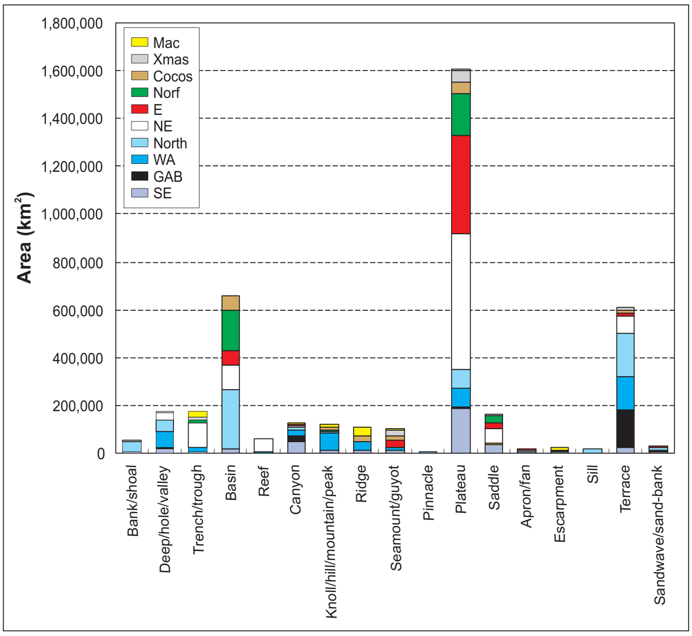

Figure 4.3. Histogram showing the cumulative surface area of different geomorphic features (excluding the shelf, slope, rise and abyssal plain) in relation to their geographic distribution.

Canyon.– Canyons cover a total area of 106,096 km^2 and are found on all margins, except for the Cocos-Keeling Islands margin. Canyons cover the largest area on the southeast margin (36,968 km^2), followed by the western (22,630 km^2), southern (16,890 km^2) and northern (16,580 km^2) margins. Canyons are less common on the northeast (6,180 km^2), and eastern (4,460 km^2) margins. There is not a simple relationship between canyon occurrence and onshore drainage and regional rainfall patterns (river discharge). The area of greatest sediment discharge to the coast (the northeast margin) has fewer canyons (in terms of surface area) than does the southern margin, which receives virtually zero fluvial sediment load. Another factor may be that the maps are biased by data richness, and hence canyons are only seen where there is sufficient bathymetric data. However, since the southern and eastern margins (for example) have comparable data densities, the difference in canyon development between these areas appears to be a real phenomenon.

Submarine canyons serve as major conduits of terrigenous (land-derived) sediment from the continents to the deep ocean basins, particularly during ice ages when sea level was lower and rivers flowed across the continental shelf to discharge their loads at or near to the shelf break. Most large canyons commence on the continental shelf, commonly at the mouths of large rivers, and are incised into the continental slope. Canyons that originate on the shelf at the mouths of rivers usually contain terrigenous sediments, whereas those which originate on the slope, and not in association with rivers, contain mainly biogenic-hemipelagic sediments. Canyon lengths typically range from 50 to 300 km, sloping seawards at between 58 to 8 m/km. Canyon axes are generally aligned normal to the coastline, although they may be deflected along-slope by structural features. Canyons may occur as single channels or involve complex tributary systems. At their seaward terminations, submarine canyons commonly empty onto the abyssal plain where sediments accumulate to form large, wedge-shaped, submarine fan deposits (Clarke et al., 1992). These observations suggest a classification scheme for submarine canyons, as follows:

- 1 Commences on shelf
  - 1A Associated with terrestrial river drainage system
    - 1Ax Single channel
    - 1Ay multiple (dendritic) channels
  - 1B Not associated with terrestrial river drainage system
    - 1Bx Single channel
    - 1By multiple (dendritic) channels
- 2 Commence on slope
  - 2A Associated with terrestrial river drainage system
    - 2Ax Single channel
    - 2Ay multiple (dendritic) channels
  - 2B Not associated with terrestrial river drainage system
    - 2Bx Single channel
    - 2By multiple (dendritic) channels

An assessment of canyons on the southern margin of Australia illustrates the spatial heterogeneity of canyon types in this region (Fig. 4.4). This information may be useful for further ecological studies of submarine canyons, to test whether the different pathways of geological evolution of canyons gives rise to different assemblages of benthic communities.

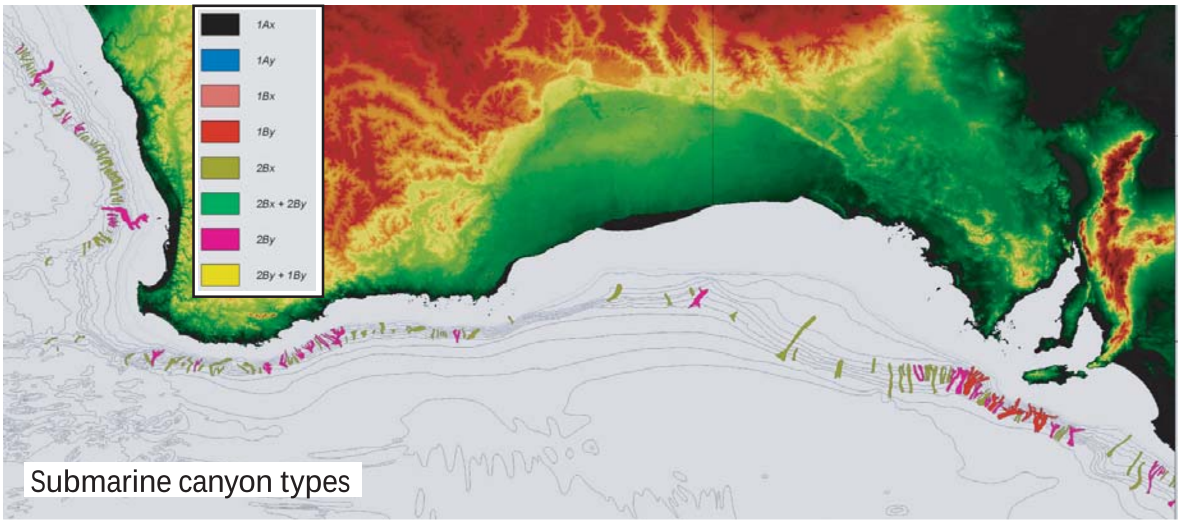

Figure 4.4. Map showing the distribution of different submarine canyon types along the southern margin.

Knoll/hill/peak/mountain.– Knoll/hill/peak/mountains cover a total area of 108,471 km² and are found on all margins, but are most extensive on the western margin (66,990 km²). They are common in all of the offshore island territories (e.g., Macquarie Island has 11,710 km², Cocos-Keeling has 8,010 km² and Norfolk Island has 6,800 km²), where volcanism, tectonism and crustal deformation processes are most active. Knoll/hill/peak/mountain features along with seamounts, guyots and pinnacles may have important biological associations, as they tend to be the preferred habitat for a range of filter-feeding species (often endemic species) and demersal fish. This is due to the affect the topography has on currents and nutrient upwelling processes.

Ridge.– Ridges cover a total area of 109,459 km² and are most extensive on the eastern margin offshore of New South Wales (i.e., the Lord Howe Rise), where they make up nearly 40% of the area.

Seamount/guyot.– Seamount/guyots cover a total area of 92,722 km² and are found most commonly on the eastern margin (28,720 km²), and in association with the offshore islands of Christmas Island and Cocos-Keeling Islands, which are themselves large seamounts that rise above sea level. Seamounts were not found on the southern, western, or northern margins.

Bank/shoal.– Bank/shoals cover a total area of 51,207 km² and occur mainly on then margin (43,885 km²). They were found on all margins apart from the offshore island territories.

Reef.– Reefs cover a total area of 47,980 km² and are found most extensively on the northeast (41,200 km²), northern (4,970 km²), and western (1,610 km²) margins. They do not occur on any of the other margins, although reefs are of local importance in most coastal environments. The total reef area in our estimate is close to that provided by the "Reefbase" online GIS (http://reefgis.reefbase.org), which estimates Australia's coral reef area as 48,960 km². These values ignore submerged reefs, which cannot be observed from satellite images, such as occur in the Great Barrier Reef (Harris and Davies (1989) and the Gulf of Carpentaria (Harris et al., 2004).

Sandwave/sand bank.– Sandwave/sand banks cover a total area of 23,822 km^2 and are found on most margins (Harris 1994), particularly the northern (13,470 km^2) and southeast (7,840 km^2) margins.

Sill.– Sills cover a total area of 17,351 km^2 and are found on the northern (14,581 km^2) and northeast (2,970 km^2) margins. These are at continental shelf depths and join shelf basins to the adjacent ocean.

Escarpment.– Escarpments cover a total area of 15,352 km^2 and are found most extensively on the Macquarie Island margin, where they cover 9,234 km^2.

Apron/fan.– Apron/fans cover a total area of 6,611 km^2 and are found around continental Australia on the western, northern, northeast, and eastern margins. The east margin has the largest area of Apron/fans covering 5,120 km^2.

Pinnacle.– Pinnacles cover a total area of 5,514 km^2, the smallest surface area of features mapped. They are found on all margins, except for the southern, Macquarie Island, and Cocos-Keeling Islands margins.

4.3. Conclusions

Using a new 250 m resolution bathymetric model, the surface area and distribution of geomorphic features located around the Australian continental margin have been mapped systematically for the first time. This work is supported by the numerous case-studies of geomorphic features that have been published in the literature. The results provide the basis for a new assessment of the geomorphology of the Australian continental margin and its regional variation. The information allows for the characterisation of different regions around the Australian EEZ in terms the types and surface areas of the geomorphic features which occur there. Furthermore, this information provides the basis for deriving a new regionalisation of the EEZ.

A geomorphic-based regionalisation of the seafloor within Australia's EEZ will provide a useful starting point for the derivation of a bioregionalisation which will summarise multiple-layers of environmental data (e.g., Kostleyev et al., 2000). For example, geomorphology was a key input parameter for devising the bioregionalisation for the southeast region of Australia (Butler et al., 2002) and for later selecting boundaries of candidate marine protected areas (MPAs).

As more swath bathymetry data become available, there is no doubt that new features will be discovered and the true extent and shape of known features will need to be revised. Hence, the maps of geomorphic features and their areas presented here will need to be regularly updated.

The definition of terms is also of key importance. Future work may inform us that the categories of features mapped in this study should be merged or subdivided. The largest categories in terms of percentage of surface area (abyssal plains, plateaus, basins and terraces) might be subdivided on the basis of roughness or slope. In particular, the application of the geomorphic feature maps produced here to predict the occurrence and distribution of specific biological communities or general associations may require the merging or subdivision of geomorphic classes. For example, it is not immediately obvious what ecological distinction there is between a "saddle" and a "slope" in the context of the geomorphology of immediately surrounding seafloor. The relationship between benthic assemblages and geomorphic features is generally poorly understood, but it is especially so in deep oceanic (slope and abyssal) realms.

The results presented here provide a starting point for future research into these and other research fields for Australia. For the first time, it is possible for managers to discuss quantitatively the conservation values of specific habitats in terms of their overall areal extent or in terms of their relative percentage coverage of the EEZ. We do not suggest any relationship between the relative area of a class of geomorphic feature and its conservation value, but we consider it to be a positive (and significant) step forward that the area and distribution of features can now at least be discussed quantitatively within the spatial framework that our geomorphic feature maps provide.

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Appendix A: Data digitised from charts

1:250,000 scale bathymetric charts digitised by GA						2,568		
Long. W (dec. deg.)	Long. E (dec. deg.)	Lat. S (dec. deg.)	Lat. N (dec. deg.)	Min. Depth (m)	Max. Depth (m)	No. of Points	Source	Identifier
150.1671	151.0981	-36.0010	-35.0007	13	328	2,568	A	si5613_a

Fair sheets digitised by Australian Hydrographic Service						4,380,609		
Long. W (dec. deg.)	Long. E (dec. deg.)	Lat. S (dec. deg.)	Lat. N (dec. deg.)	Min. Depth (m)	Max. Depth (m)	No. of Points	Source	Identifier
165.0191	166.5000	-12.2979	-10.6681	12	4658	2,145	D	01826_2
166.3338	167.8356	-12.5492	-10.6663	41	4031	4,067	D	01827_2
166.3342	167.8505	-10.8208	-9.2469	13	4289	3,753	D	01828_2
164.8344	166.5006	-10.8323	-8.7448	7	5253	4,486	D	01829_2
163.3343	164.9994	-11.0718	-9.1815	644	5253	2,160	D	01830_2
161.8473	163.5000	-11.1661	-9.2492	67	5615	2,110	D	01831_2
150.6924	150.7544	-35.1390	-35.0913	-1	78	4,729	D	01832_2
150.6705	150.8071	-35.1732	-34.9924	-1	68	14,434	D	01836_2
171.4707	172.7102	-20.7074	-19.9989	2754	3488	408	D	01839_2
170.6743	171.9992	-19.9963	-17.9991	2323	3948	1,470	D	01840_2
172.0004	173.5076	-19.9933	-18.0002	1509	3418	2,147	D	01841_2
170.3497	171.9990	-17.9992	-16.0104	1783	3887	2,878	D	01842_2
172.0004	173.2664	-17.9961	-16.1320	1118	3404	1,073	D	01843_2
170.1078	171.4994	-15.9978	-14.2070	2674	3792	1,489	D	01844_2
171.5009	171.9502	-15.9968	-14.9290	2532	3609	309	D	01845_2
167.5473	167.9944	-18.7167	-18.0370	2253	5404	97	D	01846_2
167.3340	168.4178	-17.9987	-16.1904	60	4548	2,458	D	01847_2
165.9430	167.3327	-16.7207	-15.0771	1	5435	1,557	D	01848_2
167.9161	168.3999	-9.9997	-9.4993	14	3960	196	D	01855_2
167.7501	169.4162	-11.9999	-9.9986	362	3996	2,827	D	01856_2
169.4163	170.5377	-13.9983	-11.9982	1000	4106	898	D	01857_2
171.0830	173.0056	-12.7923	-11.4933	17	3695	2,316	D	01858_2
165.0988	166.4964	-11.4026	-10.8365	199	3496	321	D	01859_2
166.5031	168.1604	-12.4581	-10.8347	42	3858	471	D	01860_2
166.5129	167.8877	-10.4933	-10.4750	1276	3685	83	D	01861_2
164.8858	166.4852	-10.8319	-10.4660	245	4120	129	D	01862_2
163.5022	165.1656	-10.6940	-10.4372	1113	4237	317	D	01863_2
161.9995	163.4953	-10.5640	-9.9354	163	4164	348	D	01864_2
167.7520	169.4161	-13.6670	-11.9981	390	4254	1,617	D	01865_2
169.4164	171.0813	-11.9994	-10.1898	14	3963	2,670	D	01866_2
138.2927	138.3438	-34.7980	-34.7578	15	19	1,209	D	01867_2
138.2536	138.2964	-34.7413	-34.7067	15	19	687	D	01868_2
138.1867	138.2290	-34.6544	-34.6202	15	20	785	D	01869_2
142.7340	142.8749	-10.3627	-10.2238	8	24	1,020	D	03857_6
142.8697	142.9989	-10.2911	-10.2197	14	24	135	D	03858_6

142.9844	143.2329	-10.2505	-10.0389	18	29	598	D	03859_6
143.2372	143.3976	-10.1760	-9.9992	15	43	3,248	D	03860_6
142.8750	142.9447	-10.2904	-10.2500	17	23	434	D	03861_6
142.9133	143.0737	-10.7558	-10.2370	17	25	163	D	03862_6
136.4035	136.5536	-11.5499	-11.4099	-2	75	8,596	D	03864_6
136.0564	136.4849	-11.9834	-11.6117	1	31	17,951	D	03865_6
136.3758	136.5356	-11.9428	-11.8638	7	44	2,615	D	03866_6
136.2919	136.3890	-11.9723	-11.8738	7	26	2,419	D	03867_6
136.3457	136.4902	-11.9703	-11.8966	0	46	5,943	D	03868_6
136.3877	136.4487	-11.6455	-11.5853	22	28	1,184	D	03870_6
136.5166	136.7041	-11.5968	-11.2718	21	48	4,580	D	03871_6
145.6888	145.7720	-16.6886	-16.6080	17	26	1,312	D	03872_6
146.0222	146.0913	-16.9884	-16.9187	25	38	1,185	D	03873_6
145.5683	145.6014	-16.5661	-16.5339	16	18	414	D	03874_6
145.3830	145.5531	-15.7778	-15.5949	2	41	3,860	D	03876_6
149.1028	149.2207	-17.0330	-16.9061	16	555	295	D	03878_6
147.8008	147.9307	-17.2849	-17.1764	21	950	564	D	03880_6
148.0001	148.5163	-17.4051	-17.0763	917	1174	388	D	03881_6
148.4996	149.0146	-17.1405	-16.8842	781	959	366	D	03882_6
149.0003	149.5136	-16.9477	-16.6918	627	853	365	D	03883_6
149.4966	150.0081	-16.7538	-16.5289	422	676	340	D	03884_6
149.8825	150.0172	-16.5439	-16.4598	549	640	72	D	03885_6
149.7462	150.0177	-16.5284	-16.2034	20	695	838	D	03886_6
149.9927	150.3258	-16.5160	-16.4784	261	815	207	D	03887_6
149.9970	150.4997	-16.4793	-16.0091	147	1031	3,385	D	03888_6
145.3460	145.3941	-15.7108	-15.5936	13	24	683	D	03889_6
145.3460	145.3941	-15.7108	-15.5936	13	24	683	D	03890_6
145.3310	145.4073	-15.7511	-15.6290	5	21	327	D	03893_6
145.4132	145.5308	-15.9875	-15.7619	18	33	1,573	D	03894_6
117.9190	117.9871	-35.0695	-35.0436	1	35	1,376	D	06313_6
117.9864	118.0466	-35.0690	-35.0447	7	41	1,608	D	06314_6
145.3196	145.4603	-15.8513	-15.5967	-1	24	1,978	D	06315_6
145.3603	145.4598	-15.8526	-15.7407	6	24	994	D	06316_6
144.4665	144.6327	-8.1833	-7.9854	7	67	5,759	D	06317_6
144.6332	144.7992	-8.1833	-7.9920	16	97	5,337	D	06318_6
144.7997	144.9159	-8.1834	-7.9833	29	101	4,246	D	06319_6
144.4664	144.6325	-8.3406	-8.1497	22	265	6,404	D	06320_6
144.6332	144.7993	-8.3408	-8.1499	56	101	5,202	D	07029_6
144.7997	144.9159	-8.3434	-8.1500	70	103	4,138	D	07030_6
144.4628	144.6497	-8.1804	-8.0435	9	68	185	D	07034_6
144.6168	144.8162	-8.1805	-8.0443	23	81	131	D	07035_6
144.7844	144.9819	-8.0933	-8.0463	52	88	123	D	07036_6
144.4604	144.6426	-8.3161	-8.1790	27	89	223	D	07037_6
136.2288	136.4028	-34.9418	-34.9285	41	136	3,008	D	07038_6
145.3209	145.4603	-15.8514	-15.5967	-3	24	1,978	D	07041_6
150.9167	151.0565	-10.3334	-10.2160	0	473	4,109	D	07149_6

150.7857	150.9168	-10.3280	-10.2295	9	446	2,974	D	07150_6
150.9214	151.0591	-10.4199	-10.3333	-1	300	4,094	D	07151_6
147.0207	147.1641	-9.6047	-9.5334	25	1528	305	D	07152_6
133.6133	134.0321	-8.6922	-8.4124	149	179	394	D	07153_2
133.6664	133.8549	-8.5511	-8.4121	145	181	808	D	07154_2
135.9856	136.2915	-11.7172	-11.4001	0	59	9,028	D	07157_2
136.2928	136.5423	-11.4472	-11.3328	5	28	3,009	D	07158_2
136.1251	136.4201	-11.5989	-11.3284	0	41	11,048	D	07159_2
136.1344	136.5296	-11.3969	-11.1318	18	39	23,576	D	07173_2
136.1348	136.3839	-11.1348	-10.7942	31	47	23,310	D	07174_2
136.3822	136.6260	-11.1337	-10.7924	25	52	24,626	D	07175_2
136.4528	136.5867	-11.9506	-11.7854	-3	47	6,226	D	07176_2
136.3273	136.4892	-11.9394	-11.7674	-3	35	2,947	D	07177_2
136.0920	136.4022	-12.0429	-11.8892	-3	40	4,978	D	07178_2
115.1675	115.3011	-32.3380	-32.2411	49	160	2,095	D	07180_2
118.1834	118.3820	-35.1537	-35.0497	64	77	4,111	D	07181_2
114.6629	114.7665	-33.6714	-33.4903	46	131	5,387	D	07182_2
136.1252	136.4201	-11.5989	-11.3282	0	41	11,049	D	07199_2
135.9423	136.1231	-11.8550	-11.6454	-1	77	3,726	D	07200_2
135.9421	136.1467	-11.8550	-11.6219	-2	77	5,043	D	07201_2
135.9609	136.0279	-11.8373	-11.7130	-2	43	604	D	07202_2
135.9428	136.5411	-11.8548	-11.3281	-1	68	8,459	D	07203_2
147.1562	149.7987	-10.6798	-9.6128	598	2036	69	D	07204_2
148.2058	148.3141	-4.7888	-4.6756	423	1730	30	D	07205_2
147.8919	148.2195	-7.4159	-6.6396	291	4412	290	D	07206_2
151.2485	152.4550	-10.2272	-4.3172	405	8078	165	D	07208_2
130.7664	130.9994	-11.3696	-10.9250	-1	45	16,737	D	07211_2
130.6500	130.7667	-11.4545	-11.2498	-2	30	13,254	D	07214_2
150.6314	150.6732	-10.3638	-10.3351	3	112	59	D	07215_2
154.5012	154.7996	-5.9992	-5.5009	0	1872	6,448	D	09298_2
154.5011	154.9989	-6.4982	-6.0004	1	5082	10,891	D	09299_2
127.2650	127.4993	-13.7498	-13.5281	58	97	2,549	D	09300_2
127.2677	127.4995	-13.9888	-13.7503	27	81	3,839	D	09301_2
127.7504	127.9993	-14.2497	-14.0003	27	62	3,973	D	09302_2
127.7780	127.9995	-14.4526	-14.2502	23	47	3,306	D	09303_2
127.5117	127.7494	-14.2238	-14.0001	8	61	4,656	D	09304_2
127.7508	127.7887	-13.9996	-13.9656	59	63	40	D	09305_2
127.5002	127.7496	-13.9998	-13.7504	1	90	6,573	D	09306_2
127.5005	127.5168	-13.7496	-13.7338	74	82	28	D	09307_2
128.2506	128.4994	-14.2496	-14.0903	34	46	1,156	D	09308_2
128.2504	128.4993	-14.4995	-14.2503	15	49	8,311	D	09309_2
128.0004	128.2496	-14.4957	-14.2504	13	46	8,508	D	09310_2
128.0008	128.2493	-14.2495	-14.1439	34	52	895	D	09311_2
128.7505	128.8599	-14.1298	-14.0004	28	40	387	D	09312_2
128.5006	128.6439	-14.4142	-14.2504	25	36	1,040	D	09313_2
128.5005	128.7492	-14.2495	-14.0003	29	96	2,765	D	09314_2

123.2841	123.3748	-16.4467	-16.3751	-3	124	3,008	D	09315_2
123.2802	123.3747	-16.3748	-16.2963	-3	118	2,699	D	09316_2
123.3749	123.4998	-16.4843	-16.3725	-6	96	9,883	D	09317_2
123.5320	123.6194	-16.5264	-16.5001	-4	22	1,203	D	09318_2
123.5001	123.6247	-16.4999	-16.4202	-4	41	8,804	D	09319_2
123.6252	123.6618	-16.4977	-16.4683	-6	8	747	D	09320_2
143.7427	143.9999	-13.7349	-13.5000	-2	83	7,807	D	09321_2
143.8145	144.0012	-13.5053	-13.3242	0	100	5,185	D	09322_2
144.1263	144.2496	-13.8738	-13.7499	18	33	121	D	09323_2
144.0000	144.1248	-13.7488	-13.4997	20	55	1,914	D	09324_2
144.0003	144.0661	-13.4998	-13.4534	2	1050	368	D	09325_2
114.8937	114.9995	-33.2496	-33.0007	45	58	1,902	D	09326_2
114.8881	114.9993	-33.4995	-33.2504	18	54	2,296	D	09327_2
114.8991	115.0002	-33.0001	-32.8075	36	102	2,055	D	09328_2
115.2505	115.4995	-33.2492	-33.0003	27	45	1,954	D	09329_2
115.2506	115.4996	-33.4671	-33.2502	8	40	5,402	D	09330_2
115.0000	115.2502	-33.4672	-33.2496	10	51	3,476	D	09331_2
115.0002	115.2497	-33.2500	-33.0005	0	59	4,462	D	09332_2
115.2496	115.5003	-32.7501	-32.5579	22	46	5,039	D	09333_2
115.2504	115.5002	-33.0004	-32.7504	2	43	4,496	D	09334_2
114.9998	115.2497	-33.0000	-32.7985	31	59	3,780	D	09335_2
115.6209	115.6713	-33.2997	-33.2505	8	18	327	D	09336_2
115.5006	115.6868	-33.2501	-32.9997	1	31	8,342	D	09337_2
115.4998	115.6691	-33.0000	-32.7500	0	31	9,981	D	09338_2
115.4999	115.6880	-32.7504	-32.5368	0	30	7,168	D	09339_2
114.4999	114.9395	-33.4979	-32.9999	25	470	8,740	D	09340_2
114.5956	114.9999	-32.9978	-32.5006	36	5656	5,849	D	09341_2
114.9020	114.9989	-32.4976	-32.4749	162	322	121	D	09342_2
115.0008	115.3587	-32.7984	-32.5002	36	532	4,108	D	09343_2
115.0002	115.4054	-32.4991	-32.4742	37	169	523	D	09344_2
149.8062	149.9999	-20.9874	-20.5622	28	55	622	D	09345_2
149.4925	149.9598	-20.4125	-20.0001	1	64	1,946	D	09346_2
149.7894	150.0001	-20.0004	-19.5045	0	81	1,773	D	09347_2
150.0001	150.3785	-20.8686	-20.4999	24	68	972	D	09348_2
150.1024	150.3803	-20.4996	-20.0005	20	77	918	D	09349_2
149.9999	150.4585	-19.9999	-19.6300	0	88	1,778	D	09350_2
127.7846	128.0001	-14.1653	-13.9998	48	66	2,026	D	09351_2
127.7497	128.0001	-13.9996	-13.8335	55	86	5,812	D	09352_2
127.6390	127.7500	-13.9667	-13.8331	46	73	1,052	D	09353_2
128.2499	128.5000	-14.2003	-13.9998	36	85	3,891	D	09354_2
128.2500	128.5002	-14.5015	-14.4181	8	30	3,568	D	09355_2
127.9816	128.2501	-14.5039	-14.4336	3	28	3,466	D	09356_2
127.9998	128.2501	-14.2582	-13.9993	38	61	3,814	D	09357_2
128.2494	128.5004	-14.0004	-13.8330	24	63	3,732	D	09358_2
127.9999	128.2497	-13.9997	-13.8323	28	66	4,529	D	09359_2
128.7504	128.8673	-14.0150	-14.0000	29	41	220	D	09360_2

128.4999	128.7498	-14.0899	-14.0001	34	45	408	D	10450
128.8255	129.0001	-13.7501	-13.5691	38	60	1,022	D	10451
128.7501	128.9998	-13.9997	-13.7497	25	56	4,364	D	10452
128.4998	128.7503	-14.0003	-13.8306	37	57	2,129	D	10453
129.2502	129.3317	-13.5880	-13.5002	39	49	362	D	10454
129.0004	129.1008	-13.8567	-13.7503	27	40	920	D	10455
129.0000	129.2501	-13.7501	-13.4997	31	61	4,286	D	10456
128.3748	128.3866	-14.7164	-14.6707	3	15	247	D	10457
128.2499	128.3751	-14.7277	-14.6249	3	74	12,390	D	10458
128.2501	128.3482	-14.6251	-14.4999	2	50	10,348	D	10459
128.1248	128.2502	-14.6251	-14.4996	-2	214	14,172	D	10460
128.1811	128.2503	-14.7273	-14.6247	-3	39	4,233	D	10461
128.1185	128.1252	-14.5127	-14.5000	4	24	98	D	10462
145.7497	145.9945	-16.7502	-16.4999	0	43	10,451	D	10463
145.7499	145.8347	-16.8518	-16.7497	2	19	2,796	D	10464
145.6727	145.7504	-16.8239	-16.7499	0	14	1,503	D	10465
145.5935	145.7497	-16.7495	-16.5003	0	31	14,390	D	10466
145.7496	145.9854	-16.4999	-16.3648	0	61	4,584	D	10467
145.5533	145.7502	-16.5000	-16.2493	-1	49	11,434	D	10468
145.5592	145.6494	-16.2505	-16.1821	24	47	1,494	D	10469
113.3728	113.4999	-28.6575	-28.4999	165	730	1,231	D	10470
113.2472	113.5004	-28.2524	-27.9994	10	530	8,872	D	10471
113.2498	113.5001	-28.4973	-28.2501	40	680	4,581	D	10472
113.1775	113.2493	-28.3004	-28.2503	457	615	281	D	10473
113.7496	114.0004	-28.7502	-28.4998	-1	80	7,080	D	10474
113.7496	114.0003	-29.0006	-28.7497	0	560	10,031	D	10475
113.5028	113.7501	-28.9998	-28.7500	3	1080	3,847	D	10476
113.4994	113.7506	-28.7502	-28.4989	0	610	12,980	D	10477
113.7497	114.0010	-28.2496	-28.0000	33	51	5,008	D	10478
113.7496	114.0001	-28.5002	-28.2503	0	50	11,876	D	10479
113.4997	113.7503	-28.5012	-28.2495	0	165	13,044	D	10480
113.4995	113.8708	-28.3232	-28.0004	15	65	7,907	D	10481
114.2498	114.5002	-28.6586	-28.4996	21	59	4,144	D	10482
113.9997	114.0850	-28.9151	-28.7501	1	51	2,397	D	10483
113.9991	114.2499	-28.7501	-28.5003	9	41	672	D	10484
114.2499	114.4835	-28.5000	-28.2553	18	43	8,004	D	10485
113.9999	114.2500	-28.5003	-28.2499	17	42	14,399	D	10486
114.0000	114.2506	-28.2510	-28.1928	11	38	2,463	D	10487
114.4998	114.5760	-28.6684	-28.5146	14	38	1,245	D	10488
142.7943	143.8627	-11.6239	-10.7452	0	54	1,057	D	10489
142.7495	143.0004	-10.7500	-10.4996	-2	30	14,483	D	10490
142.6069	142.7499	-10.6736	-10.5000	7	24	4,247	D	10491
142.7498	143.0004	-10.5002	-10.2500	-1	31	18,683	D	10492
142.6476	142.7501	-10.5001	-10.3541	14	22	3,094	D	10493
142.9999	143.1220	-10.7488	-10.4998	0	28	5,533	D	10494
143.0000	143.0872	-10.4997	-10.2500	18	30	5,204	D	10495

142.9877	143.0833	-10.2504	-10.1392	18	28	773	D	10496
142.8433	143.0032	-10.7499	-10.7201	16	23	682	D	10497
142.7977	142.9997	-10.9235	-10.8316	20	28	484	D	10498
143.2497	143.5000	-11.2171	-11.1025	27	39	366	D	10499
143.1121	143.2504	-11.1058	-10.9998	23	32	231	D	10500
142.9998	143.1170	-11.0001	-10.9203	21	28	185	D	10501
143.7495	143.8488	-11.6701	-11.4997	12	43	2,870	D	10502
143.6422	143.7549	-11.7501	-11.4998	11	46	2,903	D	10503
143.7493	143.8345	-11.5005	-11.3603	13	343	1,139	D	10504
143.5000	143.7506	-11.5001	-11.2496	5	57	16,108	D	10505
143.4994	143.6012	-11.2502	-11.2155	15	42	131	D	10506
127.7926	127.9994	-13.8325	-13.4996	58	88	5,466	D	10507
128.2739	128.5002	-14.7503	-14.4996	-1	37	13,793	D	10508
128.3626	128.4999	-14.8039	-14.7500	-2	15	1,076	D	11629
128.1915	128.4997	-14.4998	-14.0031	16	42	668	D	11630
128.0000	128.4966	-13.8332	-13.5001	56	80	8,438	D	11631
128.7501	128.9996	-14.6731	-14.5000	-1	25	1,991	D	11632
128.4997	128.7503	-14.7504	-14.4999	-1	30	9,652	D	11634
128.7491	129.0006	-14.2503	-14.0002	16	78	15,342	D	11635
128.7489	129.0005	-14.5036	-14.2503	9	46	10,069	D	11636
128.4997	128.7505	-14.5003	-14.2497	13	34	10,847	D	11637
128.4996	128.7506	-14.2501	-14.0003	22	47	2,511	D	11638
128.4988	129.0009	-13.8334	-13.5006	39	74	7,481	D	11639
129.2497	129.4006	-14.2492	-14.0024	9	34	582	D	11640
129.0000	129.2504	-14.4160	-14.2505	14	77	6,074	D	11641
128.9999	129.2502	-14.2505	-14.0002	18	88	17,743	D	11642
146.3542	146.5053	-18.1812	-17.9995	-1	49	4,131	D	11644
146.2491	146.5041	-17.7503	-17.4976	-1	64	14,767	D	11645
146.2497	146.5026	-18.0002	-17.7495	0	57	15,652	D	11646
146.1183	146.2500	-17.9261	-17.7491	0	28	6,783	D	11647
146.1036	146.2504	-17.7502	-17.4984	-1	30	12,353	D	11648
146.2499	146.4754	-17.5000	-17.4014	28	50	284	D	11649
146.0949	146.2501	-17.4999	-17.2503	20	33	734	D	11650
113.4979	114.0000	-30.4755	-30.0095	1908	4907	1,644	D	11657
113.4951	114.0068	-29.9773	-29.4988	640	4635	2,609	D	11658
114.0767	114.5003	-30.9814	-30.5043	829	4559	1,525	D	11659
114.0009	114.5005	-30.4983	-30.0009	181	4692	3,568	D	11660
114.4780	114.5004	-30.0557	-29.9999	185	280	85	D	11661
114.2501	114.5001	-29.7502	-29.5951	28	611	5,245	D	11662
114.2498	114.5002	-30.0000	-29.7500	33	964	6,586	D	11663
114.0004	114.2498	-29.9993	-29.7498	603	1650	2,949	D	11664
114.0004	114.2497	-29.7502	-29.5001	176	959	4,129	D	11665
114.7687	114.8714	-30.6500	-30.4999	36	56	83	D	11666
114.7498	114.7579	-30.9955	-30.7933	189	735	63	D	11667
114.5002	114.7505	-30.9953	-30.7506	187	2333	2,609	D	11668
114.5000	114.7448	-30.7492	-30.5002	171	1065	2,721	D	11669

114.7499	114.9171	-30.2500	-30.0000	33	62	3,505	D	11670
114.7502	114.9298	-30.4998	-30.2502	34	77	4,583	D	11671
114.5006	114.7499	-30.5001	-30.2501	33	808	11,734	D	11672
114.4996	115.0327	-30.2501	-29.9889	38	671	11,654	D	11673
114.7500	114.9745	-29.7504	-29.5376	0	45	13,056	D	11674
114.7496	114.9798	-30.0000	-29.7494	0	54	14,566	D	11675
114.4986	114.7513	-30.0009	-29.7484	37	188	9,868	D	11676
114.4999	114.7501	-29.7501	-29.6536	35	60	3,639	D	11677
141.7499	142.0002	-11.7503	-11.4998	-1	21	19,305	D	11678
141.7501	142.0004	-11.9999	-11.7498	-2	22	3,599	D	11679
141.6202	141.7498	-11.7743	-11.7498	20	27	619	D	11680
141.6221	141.7502	-11.7500	-11.4999	16	29	6,572	D	11681
141.7499	141.9940	-11.2504	-11.0000	10	17	4,524	D	11682
141.7502	142.0002	-11.5000	-11.2500	11	20	12,369	D	11683
141.6259	141.7503	-11.5001	-11.2501	15	23	4,273	D	11684
141.6332	141.7504	-11.2503	-10.9999	12	178	3,291	D	11685
141.8645	141.8752	-10.9450	-10.8750	5	13	783	D	11686
141.8658	141.8750	-10.8751	-10.8300	4	13	550	D	11687
141.8750	142.0000	-10.8752	-10.8284	0	15	8,127	D	11688
141.8750	142.0001	-10.9676	-10.8750	0	17	12,987	D	11689
142.0000	142.0724	-11.7350	-11.5000	-2	13	2,905	D	11690
141.9998	142.1268	-11.5001	-11.2499	-2	21	9,533	D	11691
142.0012	142.1240	-11.2503	-11.1971	-1	13	1,483	D	11692
142.0001	142.0096	-10.8751	-10.8598	6	13	111	D	12357
142.0000	142.0177	-10.9169	-10.8752	0	14	698	D	12358
159.8707	160.3353	-8.3338	-7.8331	15	3070	1,722	D	12359
160.3319	160.7958	-8.3333	-7.8333	10	3278	2,919	D	12360
159.8527	160.3340	-8.8336	-8.3330	11	1975	3,772	D	12361
160.3324	160.7186	-8.8332	-8.3330	6	1988	1,731	D	12362
159.8563	160.3325	-9.3330	-8.8326	8	1706	1,444	D	12363
160.3340	160.8349	-9.3336	-8.8332	20	1943	1,563	D	12364
160.8332	161.0858	-9.3333	-9.1208	12	1248	285	D	12365
160.3614	160.8338	-9.7643	-9.3334	41	1451	1,190	D	12366
160.8176	161.3329	-9.8328	-9.3337	52	1863	2,010	D	12367
161.3334	161.8303	-9.8331	-9.4626	8	2235	1,244	D	12368
160.8319	161.3327	-10.3318	-9.8326	21	2861	1,887	D	12369
161.3356	161.7758	-10.3056	-9.8342	63	2557	1,049	D	12370
161.6398	162.0623	-10.4410	-9.6326	32	2565	485	D	12371
159.5621	160.8573	-10.0132	-9.5447	-5	1407	367	D	12372
161.2507	162.4307	-10.8969	-10.3163	4	965	289	D	12373
160.8253	161.2836	-9.0010	-8.2358	38	1620	390	D	12374
161.1997	161.6347	-9.5743	-8.9894	9	2188	536	D	12375
114.7717	115.0008	-31.2500	-30.9997	42	710	4,245	D	12376
114.9429	115.0001	-31.2943	-31.2504	117	180	43	D	12377
114.7502	114.9999	-30.7500	-30.4999	24	177	18,409	D	12378
114.7498	114.9999	-31.0000	-30.7500	27	793	12,265	D	12379

114.7234	114.7493	-30.8094	-30.7507	180	234	83	D	12380
114.5011	114.7496	-30.7494	-30.5005	77	868	2,469	D	12381
114.7499	115.0028	-30.2498	-30.0000	-4	52	7,517	D	12382
114.7500	114.9967	-30.5001	-30.2499	4	76	3,342	D	12383
114.7503	114.9798	-29.9998	-29.8916	0	45	3,411	D	12384
114.9914	115.0416	-31.6617	-31.5550	170	236	388	D	12385
115.2494	115.3988	-31.4148	-31.2484	2	44	5,272	D	12386
115.2496	115.2961	-31.2500	-31.0422	25	271	1,663	D	12387
114.9899	115.2626	-31.4997	-31.2496	25	194	13,428	D	12388
115.0004	115.2500	-31.2502	-31.0003	25	112	11,213	D	12389
115.2498	115.2922	-30.9689	-30.8797	-5	28	2,455	D	12390
115.0003	115.1636	-30.9995	-30.7503	23	42	2,799	D	12391
115.1976	115.2502	-30.9592	-30.8747	2	29	3,065	D	12392
115.1889	115.2472	-30.8753	-30.8599	3	25	377	D	12393
115.0003	115.1000	-30.7498	-30.5629	24	43	1,759	D	12394
113.4950	113.9997	-31.2513	-31.0002	4151	4999	1,151	D	12395
113.5777	114.0002	-31.0053	-30.5326	4497	4876	727	D	12396
113.9996	114.4987	-31.6563	-31.5089	2854	9925	450	D	12397
113.9991	114.5012	-31.4746	-31.0090	2094	4959	1,448	D	12398
114.0018	114.4974	-30.9990	-30.5005	863	4615	762	D	12399
114.5009	115.0091	-31.6760	-31.4997	181	3630	1,583	D	12400
114.5000	115.0007	-31.4986	-30.9997	113	3350	3,886	D	12401
145.8813	146.0005	-16.7077	-16.5000	-1	47	5,721	D	12402
145.9012	145.9997	-16.2499	-16.1297	15	650	2,256	D	12403
145.8860	146.0003	-16.4999	-16.2498	-1	175	6,595	D	12404
145.9998	146.2448	-16.7281	-16.4998	-1	567	11,432	D	12405
146.0000	146.1794	-16.5001	-16.2517	0	566	8,588	D	12406
146.0000	146.0193	-16.2499	-16.2309	228	508	42	D	12407
150.3113	150.4056	-19.8691	-19.7772	13	81	5,417	D	12408
150.2498	150.5000	-19.7501	-19.5597	48	307	5,913	D	12412
150.2500	150.5000	-19.9353	-19.7499	-1	233	1,076	D	12413
150.2045	150.2501	-19.9458	-19.9099	0	67	384	D	12414
150.4998	150.5392	-19.8215	-19.7501	97	256	287	D	12415
150.5000	150.5902	-19.7502	-19.6512	234	313	780	D	12416
121.7629	122.0003	-34.4477	-34.2497	9	183	3,969	D	12417
122.0000	122.4552	-35.3411	-35.0002	446	4484	1,347	D	12418
121.9957	122.4532	-35.0018	-34.5007	85	3923	1,552	D	12419
122.2496	122.4999	-34.7498	-34.5009	79	1642	4,341	D	12420
114.1543	114.2502	-21.8753	-21.7499	-1	33	11,428	D	12421
114.2498	114.3627	-21.7503	-21.5948	-3	55	3,615	D	12422
113.9998	114.2385	-21.8776	-21.7497	0	102	5,137	D	12423
114.2499	114.3711	-21.8792	-21.7497	4	27	4,625	D	12424
114.0000	114.2503	-21.7500	-21.4997	14	2243	12,585	D	12425
121.9983	122.2505	-34.7497	-34.5002	85	2129	6,832	D	12428
122.2503	122.4995	-34.5001	-34.3304	20	96	3,240	D	12429
121.9996	122.2504	-34.5001	-34.2517	0	98	3,817	D	12430

122.4998	122.6368	-34.7497	-34.4999	76	1895	4,033	D	12431
122.5006	122.6367	-34.5000	-34.3967	75	84	144	D	12432
150.7499	150.7633	-22.5742	-22.5391	-2	19	347	D	12433
150.7203	150.7501	-22.6251	-22.5291	-2	16	1,950	D	12434
150.7114	150.7327	-22.6381	-22.6251	-2	13	123	D	12435
150.2500	150.3055	-22.1270	-22.0182	12	29	941	D	12436
150.0462	150.2500	-22.1623	-22.0182	4	26	5,549	D	12437
149.3749	149.5001	-21.2500	-21.1248	13	24	21,563	D	12438
149.3494	149.3750	-21.2499	-21.1350	13	19	1,180	D	12439
149.4137	149.5001	-21.1250	-21.0661	19	28	3,898	D	12440
149.3752	149.4701	-21.2950	-21.2499	4	148	3,171	D	12441
149.3446	149.3750	-21.2989	-21.2500	12	16	1,865	D	12442
149.5523	149.7478	-21.1186	-20.9998	29	40	4,981	D	12443
149.6248	149.6616	-21.1252	-21.0891	29	32	984	D	12444
149.6249	149.6563	-21.1642	-21.1251	28	31	818	D	12445
149.5000	149.6249	-21.1251	-21.0285	23	41	13,023	D	12446
149.4999	149.6249	-21.2354	-21.1249	18	30	13,533	D	12447
149.7823	149.9050	-20.7500	-20.6868	42	49	1,360	D	12448
149.7496	149.9794	-20.9971	-20.7500	1	474	13,452	D	12449
149.5648	149.7497	-20.9999	-20.7735	-1	51	9,923	D	12450
150.2503	150.4438	-21.1087	-21.0286	3	57	439	D	12451
150.0639	150.2500	-21.1210	-21.0001	10	56	177	D	12452
112.4493	112.5009	-23.4985	-23.4351	971	1117	39	D	12453
112.4995	113.0010	-23.5004	-23.0006	316	1093	2,111	D	12454
112.8524	113.0020	-22.9986	-22.7003	866	1053	991	D	12455
112.9994	113.5004	-23.4997	-22.9990	60	880	5,951	D	12456
112.9990	113.5227	-23.0015	-22.7130	93	1040	702	D	12457
113.4990	113.7224	-23.4923	-22.9982	34	105	3,013	D	12458
113.7498	113.8253	-23.2439	-23.0000	0	40	868	D	12459
113.5057	113.7503	-23.2500	-23.0000	2	102	4,621	D	12460
113.7494	113.8267	-23.0003	-22.7592	0	41	3,803	D	12461
113.4991	113.7511	-23.0001	-22.7500	0	147	13,290	D	12462
111.9631	112.0008	-24.0040	-23.9346	0	1028	46	D	12463
112.0016	112.5016	-24.3981	-23.9987	170	965	286	D	12464
111.9964	112.5098	-24.0046	-23.5008	441	1130	1,890	D	12465
112.6588	112.9963	-24.9863	-24.5009	66	110	247	D	12466
112.4984	113.0018	-24.4998	-23.9986	65	442	5,564	D	12467
112.4989	113.0004	-24.0009	-23.5210	109	899	3,758	D	12468
112.9982	113.4528	-24.3918	-23.9999	7	108	5,514	D	12469
113.2502	113.4571	-24.2497	-24.0000	6	60	3,250	D	12470
113.0712	113.2503	-24.2499	-23.9998	40	93	4,802	D	12471
112.9976	113.5001	-24.0011	-23.4994	31	291	4,543	D	12472
113.2506	113.5003	-23.7507	-23.5302	30	94	6,048	D	12473
113.2493	113.5018	-24.0004	-23.7492	3	94	10,821	D	13437
113.0861	113.2503	-24.0001	-23.9654	41	98	986	D	13438
113.4994	113.5939	-23.6313	-23.5051	46	61	162	D	13439

113.4990	113.5619	-23.8586	-23.7495	2	41	390	D	13440
113.4966	113.7589	-23.7547	-23.4996	0	61	7,889	D	13441
113.7495	113.7713	-23.4998	-23.2500	4	42	979	D	13442
113.5065	113.7503	-23.5003	-23.2495	25	66	6,194	D	13443
142.3683	142.4665	-10.5342	-10.5275	13	19	753	D	13444
141.3942	141.4816	-13.7234	-13.5003	3	16	1,302	D	13445
141.2497	141.5002	-13.2503	-12.9995	8	32	17,001	D	13446
141.2504	141.5001	-13.4994	-13.2499	6	26	6,286	D	13447
141.1877	141.2502	-13.3393	-13.2501	21	29	909	D	13448
141.2095	141.2502	-13.2502	-13.1050	23	30	676	D	13449
141.2597	141.4989	-12.7497	-12.4999	19	45	13,137	D	13450
141.2593	141.5001	-13.0003	-12.7495	20	40	18,036	D	13451
141.2597	141.4624	-12.5004	-12.4055	29	45	5,028	D	13452
141.4998	141.6907	-13.4457	-13.2498	-1	13	10,117	D	13453
141.5000	141.6901	-13.2502	-12.9997	-1	22	13,984	D	13454
141.5000	141.7607	-13.0004	-12.7468	-1	216	19,529	D	13455
146.9263	147.0076	-18.2502	-18.2048	15	64	161	D	13456
147.0868	147.2854	-18.7606	-18.6831	4	44	65	D	13457
146.3646	146.5002	-18.5882	-18.5003	-1	44	1,935	D	13459
146.2877	146.4998	-18.2501	-18.1008	-1	44	1,998	D	13460
146.2737	146.4999	-18.4996	-18.2497	-3	33	14,618	D	13461
146.7501	146.8787	-18.7302	-18.5002	31	49	6,473	D	13462
146.4998	146.7502	-18.7425	-18.4996	0	50	13,376	D	13463
146.7497	146.9803	-18.5014	-18.2448	5	72	1,749	D	13464
146.4998	146.7499	-18.5004	-18.2497	3	61	15,524	D	13465
146.5000	146.6368	-18.2502	-18.1319	8	54	4,330	D	13466
146.9976	147.0674	-18.1874	-18.1515	18	73	332	D	13467
111.5051	111.9995	-25.5011	-24.9994	536	1097	1,400	D	13468
111.5336	112.0003	-25.0011	-24.4998	588	1040	969	D	13469
111.7063	112.0000	-24.5013	-24.0510	765	1040	642	D	13470
112.0012	112.4984	-25.4509	-24.9998	116	609	556	D	13471
112.0003	112.5009	-25.0006	-24.4997	114	763	961	D	13472
111.9995	112.5013	-24.4990	-24.0497	203	960	956	D	13473
112.4990	113.0007	-25.5009	-25.0000	56	131	7,398	D	13474
112.4987	113.0009	-25.0004	-24.4994	60	132	8,806	D	13475_3
112.5004	112.9999	-24.5000	-24.0500	63	410	1,333	D	13476_3
113.0447	113.1312	-25.7137	-25.6371	0	21	943	D	13477_3
113.1248	113.1802	-25.5724	-25.5000	7	19	2,882	D	13478_3
113.0355	113.1252	-25.5784	-25.4999	3	25	5,076	D	13479_3
112.9998	113.1027	-25.2219	-25.0037	31	77	754	D	13480_3
113.2498	113.2684	-25.2803	-25.2612	7	13	603	D	13481_3
113.0633	113.1253	-25.3751	-25.3243	3	41	1,002	D	13482_3
113.1250	113.2347	-25.5002	-25.3747	6	20	4,439	D	13483_3
113.0406	113.1253	-25.5001	-25.3749	10	37	8,599	D	13484_3
113.1250	113.2501	-25.3751	-25.2570	5	27	3,067	D	13485_3
112.9994	113.3904	-24.9960	-24.4998	3	74	6,428	D	13486_3

113.3335	113.4583	-24.7105	-24.5000	0	49	3,647	D	13487_3
113.0014	113.3769	-24.4998	-24.3918	46	67	2,036	D	13488_3
113.3585	113.4177	-24.5000	-24.3867	0	58	1,100	D	13489_3
112.8798	113.0011	-27.6936	-27.5062	205	460	171	D	13495_3
112.6172	113.0006	-27.4808	-26.9995	133	575	1,128	D	13496_3
112.5165	113.0005	-26.9997	-26.7204	134	502	914	D	13497_3
113.1273	113.2803	-28.1469	-28.0008	181	528	191	D	13498_3
112.9990	113.5008	-27.9983	-27.4999	33	548	2,219	D	13499_3
113.0012	113.5006	-27.5006	-27.0088	63	196	2,393	D	13500_3
112.9998	113.5004	-26.9984	-26.7188	46	148	1,474	D	13501_3
113.4998	114.0008	-27.9917	-27.5014	41	70	2,047	D	13502_3
113.4999	113.9992	-27.4976	-27.0026	22	90	2,882	D	13503_3
113.4994	113.7951	-26.9887	-26.7642	26	88	875	D	13504_3
113.9990	114.1424	-27.9945	-27.5013	22	50	897	D	13505_3
113.9992	114.0885	-27.4991	-27.3247	22	49	151	D	13506_3
114.1248	114.2426	-28.2317	-28.1250	5	26	4,007	D	13507_3
113.9997	114.1254	-28.2363	-28.1247	11	39	8,448	D	13508_3
113.9998	114.1254	-28.1250	-28.0000	4	181	9,035	D	13509_3
114.1245	114.1593	-28.1255	-27.9997	9	30	1,439	D	13510_3
129.2760	129.5002	-13.8758	-13.7499	-1	29	3,898	D	13525_3
129.1066	129.2498	-13.7496	-13.5979	27	40	612	D	13526_3
129.0586	129.4989	-13.5001	-13.4049	30	62	2,510	D	13527_3
129.5001	129.6249	-14.1249	-14.0000	-5	22	9,896	D	13528_3
129.7501	129.8288	-13.7500	-13.5003	-4	18	3,948	D	13529_3
129.7504	129.7860	-13.8092	-13.7504	-3	6	304	D	13530_3
129.4997	129.7501	-14.0004	-13.7499	-5	47	11,247	D	13531_3
129.4997	129.6254	-14.0003	-13.8747	-3	35	17,006	D	13532_3
129.5000	129.7504	-13.7500	-13.4998	1	36	14,730	D	13533_3
129.7498	129.9104	-13.5002	-13.3905	-2	24	3,347	D	13534
129.5005	129.7501	-13.5005	-13.4043	16	37	6,171	D	13535
121.7630	121.9990	-34.2498	-34.0045	21	83	280	D	13537
121.8816	122.0005	-34.4368	-34.2498	8	87	719	D	13538
122.2512	122.4986	-34.1651	-34.0612	42	54	158	D	13539
122.3399	122.5003	-34.4999	-34.3834	45	86	291	D	13540
121.9997	122.0620	-34.4749	-34.3157	9	97	1,956	D	13541
122.0005	122.2488	-34.0637	-34.0000	28	47	152	D	13542
122.7504	123.0002	-34.6461	-34.4998	84	447	5,481	D	13543
122.6125	122.7491	-34.7282	-34.5000	80	1402	2,988	D	13544
122.7505	122.9996	-34.2041	-34.1671	77	90	289	D	13545
122.7504	123.0001	-34.4999	-34.2916	64	93	5,106	D	13546
122.5013	122.7502	-34.4999	-34.2503	72	86	5,072	D	13547
122.5002	122.7498	-34.2495	-34.1665	40	83	177	D	13548
123.2501	123.4991	-34.6359	-34.4997	84	349	5,455	D	13549
123.0044	123.2488	-34.7208	-34.5001	84	1296	5,374	D	13550
123.2508	123.3779	-34.2493	-34.1070	62	84	125	D	13551
123.2496	123.4999	-34.4997	-34.2505	49	94	6,091	D	13552

151.2828	151.5331	-17.4999	-17.3322	21	659	4,636	D	14140
151.2829	151.5327	-17.7391	-17.5002	2	565	4,114	D	14141
151.0383	151.2836	-17.7556	-17.5001	14	690	7,009	D	14142
150.7725	151.2473	-18.4990	-17.7505	584	1575	4,283	D	14143
150.4969	150.9753	-19.2492	-18.5004	460	1570	2,910	D	14144
150.4148	150.7012	-19.6993	-19.2510	263	473	1,638	D	14145
151.5330	151.9853	-17.5949	-17.0958	3	610	642	D	14146
151.9858	152.0159	-17.2499	-17.1099	0	145	2,791	D	14147
151.9338	152.0543	-17.3972	-17.2500	0	69	4,550	D	14148
152.2151	152.3313	-19.0497	-18.9652	44	68	491	D	14149
152.2607	152.3733	-19.2166	-19.0503	-1	60	2,762	D	14150
152.2230	152.3029	-19.3020	-19.2169	17	100	683	D	14151
147.7535	147.8962	-16.5878	-16.3761	15	1160	1,609	D	14153
149.7177	149.9882	-16.3066	-16.2429	10	603	901	D	14154
147.6954	147.8982	-16.7682	-16.7127	23	1058	170	D	14156
145.2483	145.4995	-14.7501	-14.5427	-1	41	4,938	D	14159
145.2499	145.5004	-15.0000	-14.7499	0	60	13,290	D	14160
145.2185	145.2497	-14.9041	-14.8144	0	20	517	D	14161
145.5005	145.5440	-14.7676	-14.7496	0	43	215	D	14162
145.5003	145.5791	-14.7505	-14.6403	0	39	697	D	14163
145.3356	145.4317	-15.2501	-15.1676	5	28	1,686	D	14164
145.3170	145.5006	-15.1880	-14.9999	5	41	8,949	D	14165
145.3575	145.4324	-14.9998	-14.9698	7	44	292	D	14166
149.3253	149.8288	-8.2706	-7.9861	728	3700	798	D	14168
149.7849	149.9687	-8.9993	-8.6902	351	558	1,592	D	14169
149.8491	150.0497	-9.5778	-9.0004	441	947	2,057	D	14170
149.8418	150.1068	-8.5313	-8.1769	18	2760	374	D	14171
149.7595	149.9976	-8.7161	-8.4665	0	499	4,505	D	14172
149.5691	149.8999	-8.4999	-8.2031	0	1470	3,271	D	14173
125.7503	125.8488	-14.2501	-14.1250	-6	56	1,716	D	14174
125.7500	125.8764	-14.1249	-14.0469	-6	336	2,335	D	14175
122.9963	123.5006	-12.1673	-11.8745	14	288	8,636	D	14176
123.4997	124.1673	-12.0001	-11.8747	94	262	7,508	D	14177
123.4996	124.1649	-12.1668	-12.0002	92	295	9,984	D	14178
124.1692	124.8333	-12.0001	-11.6615	17	347	12,508	D	14179_3
124.1663	124.8338	-12.1669	-11.9998	89	127	8,393	D	14180_3
124.8350	124.9944	-11.9992	-11.6512	99	328	4,154	D	14181_3
124.8364	124.9939	-12.0992	-12.0011	94	122	1,235	D	14182_3
122.9686	123.0137	-12.2078	-12.1751	8	81	294	D	14183_3
124.7433	124.9723	-11.8519	-11.7461	11	343	1,226	D	14184_3
124.9996	125.1199	-11.7434	-11.6216	10	315	942	D	14185_3
125.7498	125.9126	-14.2502	-14.0018	-8	226	7,675	D	14186_3
125.7500	125.8764	-14.1249	-14.0470	-6	41	2,337	D	14187_3
125.7503	125.8488	-14.2502	-14.1250	-6	237	1,719	D	14188_3
125.7897	125.8513	-14.2873	-14.2502	-3	50	438	D	14189_3
125.5961	125.6064	-14.2614	-14.2501	-5	4	29	D	14190_3

125.4997	125.7501	-14.2503	-13.9998	-7	51	18,272	D	14191_3
125.6366	125.7335	-14.1076	-14.0815	2	31	343	D	14192_3
125.6248	125.7499	-14.2365	-14.1267	-3	55	969	D	14193_3
125.4998	125.7488	-14.0000	-13.8417	-11	57	6,167	D	14194_3
144.6843	144.8499	-14.4390	-14.3599	14	36	1,994	D	14963_3
144.8502	145.0120	-14.5116	-14.4237	8	27	2,419	D	14964_3
118.4751	118.5997	-20.0417	-19.9281	3	20	5,857	D	14967_3
118.4829	118.5764	-20.1586	-20.0417	7	19	3,308	D	14968_3
118.5269	118.5833	-20.1928	-20.1585	7	17	1,694	D	14969_3
166.8022	167.2567	-14.8989	-14.3162	360	2128	1,843	D	14970_3
168.0955	169.9965	-17.5250	-15.8530	176	3343	2,424	D	14971_3
170.0042	170.5038	-17.0018	-15.9124	2518	3465	763	D	14972_3
168.0618	169.9961	-15.9469	-13.9361	110	3867	4,667	D	14973_3
170.0040	170.5148	-15.9141	-14.1668	329	3727	1,162	D	14974_3
166.2889	168.0005	-13.9526	-12.2635	22	4692	7,807	D	14975_3
168.0024	169.6337	-13.9392	-12.5028	662	7780	1,919	D	14976_3
166.3143	167.8894	-15.3354	-13.8125	54	4917	2,924	D	14977_3
167.5442	168.5670	-15.2969	-13.9500	80	3783	1,667	D	14978_3
145.0205	145.0835	-14.6252	-14.5733	11	15	1,121	D	14979_3
145.0832	145.2502	-14.7481	-14.5950	3	74	3,755	D	14980_3
145.2501	145.3209	-14.8297	-14.7035	9	33	2,473	D	14981_3
124.8365	124.9936	-12.0990	-12.0010	94	122	1,235	D	14982_3
122.9686	123.0136	-12.2078	-12.1752	8	81	294	D	14983_3
124.7431	124.9723	-11.8520	-11.7461	11	343	1,223	D	14984_3
124.0012	124.4316	-13.3329	-13.0921	101	210	1,391	D	14985_3
123.9998	124.5069	-13.8120	-13.3334	14	154	4,846	D	14986_3
123.7670	123.9994	-13.4994	-12.9679	72	230	1,093	D	14987_3
123.7657	123.9995	-13.8789	-13.5006	86	210	1,656	D	14988_3
137.7623	137.9272	-35.0527	-34.9907	0	77	6,586	D	14990_3
143.1077	143.5575	-39.0333	-38.7600	9	88	16,572	D	14993_3
143.1107	143.5495	-39.3396	-39.0332	29	102	9,285	D	14994_3
145.2524	145.5069	-15.2504	-15.0001	0	43	9,324	D	14997_3
145.3162	145.5003	-15.5003	-15.2496	2	37	5,792	D	14998_3
145.3413	145.3941	-14.7496	-14.7240	3	30	222	D	14999_3
62.7726	62.9033	-67.4582	-67.4065	22	545	905	D	15000_3
62.8031	62.9108	-67.5503	-67.4501	-1	769	1,878	D	15001_3
126.0195	126.1666	-13.2501	-13.1079	12	65	12,273	D	15003_3
126.2494	126.3759	-13.3446	-13.0345	42	78	1,106	D	15004_3
126.0221	126.1668	-13.3725	-13.2500	16	59	3,782	D	15005_2
125.4339	125.6675	-13.5018	-13.3277	40	145	1,689	D	15006_2
125.7110	125.7857	-13.3448	-13.2818	5	113	1,708	D	15007_2
126.0003	126.3330	-13.4166	-13.0834	17	165	21,770	D	15008_2
126.1358	126.2743	-13.4920	-13.4165	19	78	1,367	D	15009_2
125.6664	125.8113	-13.5001	-13.4165	16	62	2,058	D	15010_2
125.6670	125.9997	-13.4164	-13.1192	19	166	13,999	D	15011_2
126.1666	126.2446	-13.2503	-13.1432	18	113	3,220	D	15012_2

126.1665	126.3204	-13.3834	-13.2499	9	75	4,031	D	15013_2
125.2848	125.5212	-14.1667	-13.9928	25	65	8,280	D	15015_2
125.2500	125.5864	-14.4226	-14.1665	-3	53	19,734	D	15016_2
124.9737	125.2504	-14.5029	-14.2043	-4	54	17,563	D	15017_2
136.4497	136.7305	-11.6836	-11.4454	10	46	10,170	D	15018_2
136.4500	136.7316	-11.9669	-11.6832	-2	52	10,593	D	15019_2
123.5007	123.6929	-34.7210	-34.4999	46	1294	4,193	D	15968_2
123.0010	123.2495	-34.4999	-34.2503	79	94	4,829	D	15969_2
123.4998	123.6925	-34.4999	-34.2879	5	94	6,678	D	15970_2
123.0010	123.2497	-34.2500	-34.0380	2	91	1,642	D	15971_2
136.5790	136.6919	-12.1612	-11.9666	3	29	2,020	D	15972_2
136.4652	136.4997	-11.5036	-11.4564	-1	66	856	D	15974_2
136.4666	136.6328	-11.9102	-11.7666	-1	58	13,015	D	15975_2
124.5468	124.6223	-13.1221	-13.0449	10	174	2,017	D	15978_2
124.0043	124.0660	-13.4809	-13.4164	11	92	2,859	D	15979_2
123.9995	124.1669	-13.1937	-12.8445	189	231	1,875	D	15980_2
124.3243	124.3614	-12.8986	-12.8673	18	361	895	D	15981_2
124.1680	124.7204	-13.4159	-12.8385	90	208	8,355	D	15982_2
155.9102	156.4193	-33.4764	-32.4912	122	4263	1,455	D	15983_2
141.8351	142.0001	-10.5678	-10.4166	0	13	12,314	D	15984_2
141.9999	142.1257	-10.5586	-10.4164	0	15	24,416	D	15985_2
141.8238	142.0187	-10.5543	-10.5313	9	13	299	D	15993_2
141.9930	142.1278	-10.5620	-10.5446	10	14	85	D	15994_2
141.8019	141.8935	-10.6536	-10.5247	8	22	9,483	D	15996_2
141.9120	142.0002	-10.5832	-10.5028	9	13	5,211	D	15997_2
141.9996	142.1336	-10.5785	-10.4463	9	15	9,720	D	15998_2
143.8751	143.9932	-14.0960	-14.0010	3	33	6,786	D	16002_2
143.7884	143.8750	-14.0806	-14.0000	5	21	5,855	D	16003_2
143.7091	143.7389	-13.7990	-13.7497	10	24	2,077	D	16004_2
143.7280	143.7502	-13.9170	-13.8749	7	17	936	D	16005_2
143.6799	143.7154	-13.6317	-13.4928	8	23	4,397	D	16006_2
143.7499	143.8749	-14.0001	-13.8750	7	23	11,739	D	16007_2
143.7499	143.7933	-13.8750	-13.8194	8	26	2,474	D	16008_2
143.6923	143.7449	-13.7499	-13.6251	0	33	5,530	D	16009_2
143.7124	143.7501	-13.8751	-13.7927	10	27	3,770	D	16010_2
143.6668	143.7136	-13.5045	-13.3986	4	28	3,558	D	16011_2
150.6705	150.8070	-35.1732	-34.9924	-1	334	14,422	D	16012_3
145.0019	145.4987	-4.4986	-4.0010	1	8433	2,024	D	16013_3
145.5005	145.6617	-4.4999	-4.3582	172	1000	365	D	16014_3
144.4999	144.9989	-4.0003	-3.5006	2	1596	2,415	D	16015_3
144.7029	144.9988	-4.2443	-4.0001	11	1210	671	D	16016_3
146.3074	146.3302	-4.5510	-4.4875	54	1290	20	D	16017_3
143.7518	143.9999	-3.6964	-3.5007	7	613	978	D	16018_3
144.0000	144.5003	-3.7886	-3.5262	6	733	2,933	D	16019_3
145.4728	145.4978	-4.5306	-4.4999	121	275	17	D	16020_3
145.5003	145.9999	-4.9998	-4.4999	1	1420	3,010	D	16021_3

142.8699	142.9763	-10.3046	-10.2507	15	24	432	D	16022_3
142.7500	142.8804	-10.3543	-10.2804	-1	24	2,970	D	16023_3
142.9468	142.9995	-10.2502	-10.2143	18	23	158	D	16024_3
122.9198	123.0448	-12.2283	-12.1664	-1	252	6,202	D	16026_3
143.0004	143.0199	-10.2346	-10.2119	19	25	50	D	16027_3
146.4387	146.5005	-39.2542	-39.1725	66	75	127	D	16028_3
146.4948	146.7494	-39.3431	-39.2496	67	76	339	D	16029_3
146.4993	146.7508	-39.2509	-38.9995	28	75	1,412	D	16030_3
146.7505	147.0000	-39.0002	-38.9479	49	57	192	D	16031_3
146.7487	147.0017	-39.2505	-38.9994	11	68	1,908	D	16032_3
147.0006	147.1357	-39.0000	-38.9200	54	61	324	D	16033_3
146.7506	146.9559	-39.2983	-39.2502	58	69	148	D	16034_3
146.9998	147.1262	-39.2149	-39.0001	12	61	904	D	16035_3
143.2496	143.2912	-10.2236	-9.9979	19	39	1,492	D	16036_3
142.9956	143.2507	-10.3329	-9.9957	-10	43	17,635	D	16037_3
143.3760	143.5000	-9.2498	-9.0133	-2	58	3,933	D	16038_3
143.4157	143.4999	-9.4635	-9.2500	13	44	3,039	D	16039_3
143.5003	143.7497	-9.2498	-9.0143	0	45	6,681	D	16040_3
143.7500	143.8654	-9.2413	-9.1647	32	56	856	D	16041_3
143.5000	143.7366	-9.4070	-9.2500	21	48	3,528	D	16042_3
119.9952	120.4976	-34.5925	-34.5004	73	398	773	D	16043_3
119.9846	120.5015	-34.4997	-34.1532	56	86	4,595	D	16044_3
120.5003	120.9981	-34.5211	-34.4997	86	464	251	D	16045_3
120.4978	121.0074	-34.5002	-34.0863	16	398	9,670	D	16046_3
120.6978	121.0090	-34.1691	-33.9936	0	86	9,959	D	16047_3
115.1537	115.2402	-21.0005	-20.9645	9	56	475	D	16048_3
114.8905	115.0005	-21.3337	-21.2005	7	64	1,922	D	16049_3
114.9993	115.3338	-21.3340	-20.9997	-1	68	21,457	D	16050_3
115.3321	115.6355	-21.3334	-21.0022	4	17	3,024	D	16051_3
114.7317	115.0005	-21.5951	-21.3330	-1	58	12,380	D	16052_3
114.9997	115.3336	-21.6399	-21.3330	-1	19	17,333	D	16053_3
115.3332	115.3535	-21.4183	-21.3332	7	14	218	D	16054_3
115.5000	115.6078	-21.1668	-20.9959	0	15	11,430	D	16055_3
115.3635	115.5031	-21.2383	-21.1560	0	16	4,667	D	16056_3
115.4998	115.6070	-21.2249	-21.1665	8	14	2,794	D	16057_3
138.3409	138.7486	-37.2205	-37.1193	221	763	1,978	D	16058_3
137.6239	138.6178	-37.5055	-37.1463	910	4932	127	D	16059_3
118.6541	138.7543	-37.3502	-35.1879	77	2809	562	D	16060_3
152.5002	152.7313	-9.5167	-9.3539	8	1636	1,502	D	16069_3
152.4967	152.7657	-9.6682	-9.4974	59	1811	367	D	16070_3
151.9939	152.5079	-9.9309	-9.4912	30	2914	2,290	D	16071_3
151.9935	152.5328	-9.5063	-8.9849	19	2366	4,458	D	16072_3
151.8207	152.0715	-9.5423	-9.2614	43	649	221	D	16073_3
151.9790	152.5179	-9.0286	-8.5465	39	2445	3,709	D	16074_3
152.4619	152.5896	-9.2252	-9.1336	1	87	868	D	16075_3
146.6294	146.7447	-19.0509	-18.8981	0	23	5,932	D	16077_3

146.5449	146.6485	-19.0508	-18.9045	0	21	6,051	D	16078
146.6292	146.7325	-19.1703	-19.0283	0	19	3,661	D	16079
146.5456	146.6485	-19.1613	-19.0279	0	19	4,243	D	16080_3
146.3072	146.5592	-18.8553	-18.5402	1	40	5,625	D	16081
135.0086	135.6664	-11.8211	-10.8004	19	54	412	D	17563_3
135.6671	135.9162	-10.9994	-10.7732	43	52	1,788	D	17564_3
135.6692	135.9167	-11.2492	-10.9997	36	48	2,808	D	17565_3
135.5973	135.6890	-12.0782	-12.0097	-3	14	1,704	D	17566_3
135.4965	135.5973	-12.1030	-11.9867	-3	27	2,746	D	17567_3
135.6892	135.7807	-12.0268	-11.9798	-2	34	950	D	17568
135.7811	135.8996	-11.9871	-11.8926	-3	9	2,433	D	17569_3
135.9165	136.1527	-11.5164	-11.2493	22	37	9,367	D	17570_3
135.9165	136.1440	-11.2499	-10.9995	32	47	7,733	D	17571_3
135.9170	136.1512	-10.9998	-10.7613	39	49	4,250	D	17572_3
135.6685	135.9168	-11.5165	-11.2496	28	40	4,165	D	17573_3
147.5002	147.5893	-19.0655	-18.9784	10	48	788	D	17575_3
153.8590	154.0001	-22.4969	-22.0002	323	459	2,620	D	17576_3
153.3883	154.0001	-21.9995	-21.4169	-1	1761	3,208	D	17577_3
154.0002	154.6014	-21.9998	-21.4185	406	2774	979	D	17578_3
153.5806	153.8084	-20.8334	-20.5814	1634	2159	785	D	17579_3
151.9598	152.1468	-20.9088	-20.8530	25	299	39	D	17580_3
152.1617	152.7665	-21.4090	-20.8947	-1	276	209	D	17581_3
152.7675	153.3802	-21.3306	-21.0770	18	402	287	D	17582_3
153.4700	154.0003	-21.4150	-20.8342	447	1983	1,972	D	17583_3
154.0013	154.6147	-21.4148	-20.9092	9	2781	525	D	17584_3
152.5446	152.7612	-21.8009	-21.4165	9	99	95	D	17585_3
152.7701	153.3829	-21.9992	-21.6961	99	469	607	D	17586_3
152.7697	153.2630	-22.3908	-22.0019	30	277	568	D	17587_3
154.0002	154.0244	-22.2539	-22.0009	414	526	199	D	17588_3
154.6263	155.4388	-22.1451	-21.3835	218	3250	171	D	17589_3
146.2561	146.5652	-18.0135	-17.7277	10	45	2,279	D	17590_3
146.2553	146.4562	-18.2334	-18.1340	3	35	2,106	D	17591_3
142.4459	142.6165	-10.4864	-10.3971	11	28	3,669	D	17592
142.6167	142.8168	-10.4147	-10.3101	10	22	4,340	D	17593_3
142.8167	143.0025	-10.3292	-10.2306	8	25	1,356	D	17594_3
143.2003	143.4164	-10.1414	-10.0008	13	47	721	D	17595_3
143.3089	143.6662	-10.0001	-9.5426	12	49	1,494	D	17596_3
146.7595	146.8418	-19.2084	-19.1415	3	7	599	D	17597_3
143.6674	144.0530	-9.9066	-9.8329	7	104	320	D	17598_3
135.6667	135.8586	-11.2500	-10.9999	36	49	4,690	D	17603_3
135.6669	135.8413	-11.0000	-10.7785	45	52	3,304	D	17604_3
135.6662	135.9187	-11.5000	-11.2496	30	41	7,511	D	17605_3
135.4170	135.6662	-11.4997	-11.2496	31	44	7,239	D	17606_3
135.4188	135.6731	-11.7496	-11.4996	19	37	4,540	D	17607_3
135.6661	135.9212	-11.7296	-11.4998	17	34	2,287	D	17608
135.0223	135.5182	-11.5343	-10.7808	31	55	398	D	17609_3

135.4287	135.7898	-11.8621	-11.6235	17	34	535	D	17610
135.4168	135.6658	-10.9998	-10.7782	46	54	3,238	D	17611
135.4166	135.6666	-11.2498	-10.9997	38	51	4,096	D	17612_3
135.8343	136.0997	-11.8478	-11.5589	-4	35	2,507	D	17614_3
135.6079	135.8353	-11.9489	-11.7146	-3	17	2,752	D	17615_3
145.1755	146.6759	-9.2484	-8.1700	7	767	2,361	D	17616
145.1668	145.4164	-8.1764	-7.9999	28	128	4,555	D	17617
145.1670	145.4151	-8.0001	-7.8557	0	80	2,506	D	17618
144.9176	145.1662	-8.1777	-7.9998	61	106	8,323	D	17619
144.9169	145.1665	-8.0001	-7.7916	0	74	5,626	D	17620
144.6669	144.9169	-8.0000	-7.7508	0	65	3,008	D	17621
144.4664	144.6669	-8.0001	-7.7499	-1	19	2,848	D	17622
144.4734	144.6636	-7.7496	-7.5952	-1	9	337	D	17623
144.6682	144.8485	-7.7478	-7.6068	-1	8	96	D	17624
145.6688	147.0231	-9.6971	-8.3878	56	2059	857	D	17625
144.1684	145.6660	-9.4340	-8.0419	14	1513	856	D	17626
143.6787	143.9835	-13.5277	-13.2694	10	51	171	D	17633
143.9454	144.1892	-13.8149	-13.4754	18	77	155	D	17634
130.8195	130.8263	-12.4648	-12.4615	-5	12	2,287	D	17636
151.4958	151.7351	-23.6064	-23.2473	5	58	6,454	D	17637
136.8231	136.8668	-12.1582	-12.0553	2	25	100	D	17644
141.3720	141.4541	-10.6769	-10.6764	15	20	43	D	17645
141.3485	141.4520	-10.1611	-9.9168	0	20	380	D	17646_3
136.5438	136.6064	-12.1981	-11.9146	0	31	113	D	17647
147.8560	148.0002	-19.3740	-19.2499	39	60	1,586	D	17648_3
148.0001	148.0716	-19.4307	-19.2500	4	63	968	D	17649
147.7501	148.0003	-19.2501	-18.9999	9	72	4,090	D	17650
148.0001	148.0742	-19.2498	-19.0001	2	65	1,862	D	17651
147.7515	148.0002	-18.9998	-18.7501	0	126	2,926	D	17652
148.0001	148.2499	-18.9987	-18.7501	-1	94	3,772	D	17653
147.9036	148.0000	-18.7501	-18.6259	26	101	1,294	D	17654
148.0001	148.0501	-18.7499	-18.6854	67	109	305	D	17655
147.3976	147.4996	-19.0809	-19.0002	32	42	176	D	17656
147.5005	147.7501	-19.0831	-19.0003	37	55	910	D	17657
147.5007	147.7353	-18.9998	-18.7961	13	73	451	D	17658
148.2505	148.4156	-18.9865	-18.9510	30	71	274	D	17659
148.0067	148.1014	-19.0255	-18.8899	2	73	1,749	D	17660
151.1719	151.4478	-23.3321	-22.9908	25	34	194	D	17661
151.4501	151.7169	-23.4166	-23.0538	24	62	8,359	D	17662
151.7177	151.9916	-23.1884	-23.0766	43	86	591	D	17663
151.2737	151.4501	-23.7326	-23.3333	12	43	611	D	17664
151.4506	151.6760	-23.7333	-23.4174	6	42	3,974	D	17665
151.3704	151.7258	-23.9523	-23.7331	10	34	4,378	D	17666
151.6006	151.6431	-23.7073	-23.6621	6	31	256	D	17667
167.9334	168.0269	-29.0667	-28.9470	18	383	2,239	D	17671
167.8550	167.9335	-29.0667	-28.9432	13	53	3,245	D	17672

167.8295	167.9332	-29.1846	-29.0666	28	112	3,093	D	17673
167.9339	168.0668	-29.1912	-29.0666	21	67	3,137	D	17674
168.0677	168.2145	-29.3145	-29.1741	57	279	1,115	D	17675
167.8009	167.9785	-29.7217	-29.4677	48	895	431	D	17676
135.6167	135.8308	-11.7499	-11.6192	14	29	2,595	D	21092
135.6167	135.8154	-11.9044	-11.7499	6	21	2,396	D	21093
135.3669	135.6157	-11.7497	-11.4949	20	40	5,989	D	21094
135.3669	135.6169	-12.0162	-11.7498	13	35	4,757	D	21095
135.1169	135.3666	-11.7499	-11.4838	-19	37	3,197	D	21096
135.1170	135.3661	-12.0160	-11.7498	1	28	1,269	D	21097
134.8686	135.1163	-11.7499	-11.4839	6	36	1,918	D	21098
135.0042	135.1168	-11.7840	-11.7499	6	19	86	D	21099
134.5033	135.7460	-12.1987	-11.1086	1	55	684	D	21100
136.1631	136.3088	-34.6999	-34.6417	6	31	1,245	D	21101
136.1613	136.3301	-34.8391	-34.6965	1	40	5,071	D	21102
135.9702	136.2342	-34.7632	-34.6566	17	27	1,105	D	21103
136.1725	136.4411	-34.8548	-34.7392	17	49	1,551	D	21104
135.8692	135.9830	-34.7274	-34.6584	12	22	224	D	21105
152.8243	157.9895	-27.4669	-23.0032	182	4806	228	D	21106
158.0104	163.9991	-28.8066	-25.1164	1120	3437	273	D	21107
164.0188	167.8165	-29.6367	-27.5600	810	3511	177	D	21108
138.1438	138.3706	-35.2172	-35.0940	28	41	3,513	D	21109
137.9403	138.1860	-35.2912	-35.1693	33	43	3,916	D	21110
137.7786	138.0181	-35.3727	-35.2512	29	38	3,816	D	21111
131.4795	131.5339	-11.8415	-11.8103	6	28	628	D	21112
135.4503	135.6676	-12.1126	-11.8977	-2	18	3,125	D	21113
135.2365	135.4595	-12.1622	-11.9609	-3	24	4,003	D	21114
135.3351	135.4362	-12.0008	-11.7436	13	35	4,059	D	21115
134.9885	135.2728	-11.1249	-10.7978	47	57	446	D	21118
135.0102	135.2743	-11.4698	-11.1093	35	51	486	D	21119
135.0240	135.0253	-11.5134	-11.4546	31	39	23	D	21120
135.2569	135.5196	-11.1265	-10.7785	45	59	6,291	D	21121
135.2576	135.5201	-11.4703	-11.1083	32	52	11,094	D	21122
135.3233	135.5196	-11.6933	-11.4521	29	39	3,225	D	21123
134.9905	135.2737	-11.1266	-10.8213	47	58	708	D	21124
134.9945	135.2742	-11.4703	-11.1086	35	52	684	D	21125
135.0199	135.2747	-11.5005	-11.4529	27	39	65	D	21126
135.2574	135.5231	-11.1262	-10.7984	47	57	1,103	D	21127
135.2572	135.5474	-11.4621	-11.1082	32	52	1,105	D	21128
135.2589	135.5292	-11.5010	-11.4522	30	40	158	D	21129
143.7149	143.9173	-9.3716	-9.2880	6	81	259	D	21131
143.2705	143.6993	-9.6667	-9.4203	-3	92	3,845	D	21132
143.0221	143.3168	-10.0330	-9.6802	-2	43	6,512	D	21133
143.3167	143.5752	-10.0332	-9.6664	-3	68	8,035	D	21134
142.7603	143.0489	-10.3488	-10.0325	6	30	1,971	D	21135
143.0502	143.4252	-10.2358	-10.0335	-1	47	1,100	D	21136

140.2220	140.9291	-38.4563	-37.9720	22	683	253	D	21139
140.8858	141.5519	-38.6357	-38.2406	39	177	167	D	21140
143.7784	143.9565	-13.2500	-13.0677	5	42	1,873	D	21141
143.6610	143.7497	-13.3736	-13.2890	6	25	132	D	21142
143.7507	143.9975	-13.4991	-13.2499	1	48	3,015	D	21143
143.7023	143.7501	-13.5368	-13.5147	11	26	30	D	21144
143.7503	144.0002	-13.5949	-13.5004	17	62	110	D	21145
144.0002	144.1362	-13.7489	-13.5696	22	62	274	D	21146
144.1275	144.2562	-13.9049	-13.7499	19	33	249	D	21147
144.3173	144.5990	-8.5500	-8.2674	40	98	4,841	D	22586
144.2334	144.4409	-8.8198	-8.5499	27	75	3,472	D	22587
143.9789	144.2334	-8.9333	-8.6536	37	81	4,417	D	22588
143.8668	144.1459	-9.2163	-8.9334	11	98	6,031	D	22589
143.5020	143.7833	-9.6162	-9.3337	0	98	5,434	D	22590
143.7833	144.0667	-9.4995	-9.2169	0	127	4,811	D	22591
144.0666	144.3500	-9.4998	-9.2420	9	148	2,872	D	22592
144.3502	144.5026	-9.4999	-9.2991	56	109	1,297	D	22593
144.4238	144.7271	-9.7497	-9.3671	71	633	555	D	22594
144.6800	144.9798	-10.2491	-9.7525	90	1728	634	D	22595
144.1918	144.3715	-9.7726	-9.5000	7	208	283	D	22596
144.2661	144.8513	-9.9955	-9.3019	16	1571	4,613	D	22597
144.0095	144.5173	-10.7715	-9.9935	356	789	561	D	22598
143.6931	143.9976	-9.5530	-9.1594	6	129	827	D	22600
143.9951	144.3009	-9.5315	-9.2460	40	155	878	D	22601
144.2922	144.6005	-9.6014	-9.2687	44	178	325	D	22602
143.6603	143.8528	-9.6081	-9.4678	0	84	1,733	D	22603
146.0026	147.1087	-9.9509	-9.5538	614	2187	207	D	22604
145.0050	145.9929	-10.0141	-9.7405	632	2069	162	D	22605
142.9323	147.1452	-11.0413	-9.5208	0	56	589	D	22606
143.0837	143.2660	-9.2671	-9.2193	4	68	115	D	22607
143.2679	143.3826	-9.3634	-9.2193	10	42	126	D	22608
143.3712	143.5668	-10.1030	-9.9921	4	62	5,591	D	22609
143.5667	143.7531	-10.0491	-9.9675	4	67	3,173	D	22610
141.0088	141.1115	-10.2437	-10.1742	22	33	173	D	22614
141.3548	141.8021	-10.5680	-9.9096	9	20	316	D	22615
141.6898	142.1335	-10.5775	-10.1563	9	14	148	D	22616
129.2528	129.5048	-10.8495	-10.5246	22	170	4,966	D	22617
129.5028	129.7380	-10.8148	-10.5286	25	169	4,908	D	22618
129.7360	130.0078	-10.7138	-10.5308	21	140	3,184	D	22619
126.5614	129.3217	-11.8031	-10.4614	21	231	587	D	22621
129.2643	130.5378	-12.2339	-10.7746	19	188	430	D	22622
129.4660	129.5407	-12.2823	-12.2622	16	71	249	D	22625
129.5390	129.5796	-11.9195	-11.8858	41	60	143	D	22626
129.7660	129.8656	-12.1952	-12.1537	30	56	300	D	22627
146.5476	146.7631	-2.3548	-2.1858	8	776	4,947	D	22628
146.0152	146.2667	-2.4522	-1.9978	7	918	949	D	22629

146.2677	147.0996	-2.5732	-2.1960	15	1063	3,044	D	22630
147.1002	147.1840	-2.5730	-2.2394	212	916	191	D	22631
146.5473	146.7376	-2.3555	-2.1858	7	297	5,692	D	22632
146.0711	149.9942	-4.9855	-2.1255	84	2505	1,039	D	22633
147.1287	149.7240	-8.3024	-6.8040	722	4502	122	D	22634
155.4101	155.9977	-7.3167	-7.1365	882	1631	31	D	22635
147.4499	147.5449	-3.0848	-2.9968	331	1663	426	D	22636
146.6497	146.7555	-4.9669	-4.8692	36	1716	250	D	22637
148.4993	148.6360	-7.8288	-7.7801	1874	3611	53	D	22638
142.8701	142.8935	-9.9177	-9.8400	9	20	989	D	22639
159.9895	160.1188	-8.9899	-8.8725	40	191	493	D	22641
145.7986	145.8549	-5.2220	-5.1955	22	440	131	D	22642
147.7273	147.7807	-3.0325	-2.9711	559	956	103	D	22643
145.7327	145.9302	-2.1792	-2.0303	204	892	234	D	22644
146.1566	146.2792	-2.6385	-2.5289	556	880	221	D	22645
142.3337	142.4856	-9.7695	-9.6241	-3	12	4,483	D	22646
142.4850	142.6450	-9.7696	-9.6096	-3	24	4,443	D	22647
142.6445	142.8047	-9.8095	-9.6171	-3	19	3,546	D	22648
142.8040	142.9640	-9.8093	-9.6079	0	22	3,280	D	22649
142.9633	143.1164	-9.8096	-9.6072	-5	26	2,981	D	22650
147.2751	147.4875	-2.4869	-2.4115	14	583	62	D	22651
141.7904	141.8667	-10.8480	-10.7792	0	15	2,127	D	22652
141.9500	142.0834	-10.8482	-10.7771	2	18	5,493	D	22655
142.0834	142.2168	-10.8441	-10.7509	2	18	4,978	D	22656
142.2168	142.3372	-10.8439	-10.7806	8	17	629	D	22657
136.1128	136.3216	-9.9734	-9.7604	50	61	1,838	D	22658
137.5188	137.6625	-33.2966	-33.1422	15	26	1,975	D	22659
137.4833	137.6066	-33.3881	-33.2047	15	28	2,394	D	22660
137.4759	137.5354	-33.5146	-33.3312	1	30	2,383	D	22661
137.4572	137.5330	-33.6415	-33.4583	2	278	2,385	D	22662
137.4165	137.4996	-33.8039	-33.6308	9	30	2,118	D	22663
137.3480	137.4777	-33.9379	-33.7612	17	32	1,993	D	22664
137.2059	137.3568	-34.0510	-33.8734	16	34	2,057	D	22665
137.1346	137.2738	-34.1616	-33.9958	16	26	1,987	D	22666
146.0187	149.9782	-10.7892	-9.7168	610	2374	177	D	22667
136.1050	136.3660	-9.9749	-9.7414	50	61	2,305	D	22668
135.8710	136.1213	-10.1723	-9.8444	53	99	2,940	D	22669
135.9954	136.1728	-34.7999	-34.6379	7	29	7,885	D	22670
143.7256	143.7324	-11.7846	-11.7782	27	39	2,219	D	22674
147.9667	147.9828	-37.9031	-37.8894	-1	19	1,656	D	22684
158.6559	158.9965	-55.1339	-54.3389	20	273	112	D	22689
147.6345	147.6395	-19.1556	-19.1339	5	40	818	D	22690
136.2079	136.3522	-13.9265	-13.7116	0	46	4,728	D	22693
136.2525	136.3331	-13.7124	-13.5736	0	28	2,653	D	22694
136.3512	136.5028	-13.8357	-13.7107	-1	46	3,486	D	22695
136.3589	136.4903	-13.7117	-13.6102	0	40	2,631	D	22696

136.5019	136.5248	-13.8275	-13.7879	0	5	372	D	22697
134.6562	134.9267	-11.0543	-10.7986	45	62	2,188	D	24915
134.6524	134.9259	-11.4069	-11.0453	11	55	4,372	D	24916
134.7547	134.9259	-11.7227	-11.3981	0	41	3,600	D	24917
134.9179	135.1916	-11.0545	-10.7939	44	60	5,775	D	24918
134.9176	135.1923	-11.4073	-11.0453	37	56	14,887	D	24919
134.9177	135.1925	-11.7568	-11.3980	-2	44	11,560	D	24920
135.1842	135.3514	-11.0544	-10.7826	40	60	2,915	D	24921
135.1836	135.4341	-11.4072	-11.0454	34	54	6,912	D	24922
135.1836	135.4417	-11.7555	-11.3980	-2	43	6,968	D	24923
142.3250	142.4245	-10.7333	-10.6209	2	23	4,410	D	24924
142.2122	142.3251	-10.7331	-10.6097	2	24	1,042	D	24925
142.2003	142.3251	-10.8577	-10.7333	2	19	5,326	D	24926
142.3250	142.3842	-10.8434	-10.7333	0	17	1,950	D	24927
137.3443	140.8058	-11.8163	-10.3137	39	62	209	D	24930
140.9382	141.4356	-10.6918	-10.1578	15	42	1,177	D	24931
123.5339	123.5505	-12.5347	-12.5230	-9	34	5,967	D	24932
123.5504	123.5670	-12.5347	-12.5227	-15	35	5,761	D	24933
123.5670	123.5830	-12.5347	-12.5233	-2	41	5,217	D	24934
123.5504	123.5670	-12.5347	-12.5227	-16	40	6,548	D	24935
122.9254	122.9356	-12.2527	-12.2382	-19	39	1,620	D	24936
129.2931	129.3050	-12.1839	-12.1486	31	116	87	D	24940
123.1517	123.1609	-12.2545	-12.2364	-5	18	4,360	D	24943
135.7168	137.9385	-15.5161	-13.5818	4	56	686	D	24947
135.7142	137.8782	-15.5224	-13.7993	3	55	813	D	24948
135.6455	137.9963	-15.7108	-13.9108	5	52	497	D	24949
145.4583	145.6210	-16.2540	-16.0085	6	39	5,162	D	24950
145.3765	145.5789	-16.0137	-15.7786	-2	37	3,912	D	24951
145.3168	145.4291	-15.7176	-15.4933	-2	30	2,406	D	24952
152.1492	152.1847	-4.2594	-4.2002	0	6743	5,414	D	24954
152.1561	152.1631	-4.2972	-4.2798	0	64	61	D	24956
152.1632	152.2173	-4.3097	-4.2594	0	323	2,149	D	24957
147.0915	152.4230	-5.1419	-4.2647	280	1215	275	D	24958
146.9433	147.0958	-15.5315	-15.3465	1202	1630	141	D	24959
151.9095	152.5619	-7.6236	-4.2442	208	8042	179	D	24960
151.9173	153.2135	-8.4780	-4.2313	350	8071	120	D	24961
152.1467	153.5306	-10.4522	-8.6899	435	4173	299	D	24962
150.5251	152.4918	-11.4177	-9.8332	120	3000	286	D	24963
145.0319	153.1234	-11.6705	-9.3650	120	3291	225	D	24964
137.9718	141.2923	-11.7181	-11.6136	297	2781	74	D	24965
136.8167	136.9976	-14.6033	-14.3286	32	46	3,559	D	24966
136.7464	136.9405	-14.9155	-14.5965	3	38	4,751	D	24967
136.6098	136.7534	-14.9532	-14.6846	23	33	2,948	D	24968
136.4736	136.7516	-15.2417	-14.9466	18	31	5,349	D	24969
136.1690	136.3486	-14.2532	-13.9179	3	30	7,406	D	24970
136.2141	136.3706	-14.6033	-14.2465	0	26	6,117	D	24971

136.2609	136.4246	-14.9533	-14.5972	17	27	6,339	D	24972
136.3073	136.4667	-15.3000	-14.9466	0	25	6,406	D	24973
136.3500	136.5184	-15.3183	-15.1467	0	21	8,672	D	24974
136.5150	136.6237	-15.3183	-15.1949	13	190	2,145	D	24975
136.5150	136.5879	-15.4294	-15.3149	9	18	2,109	D	24976
136.3847	136.5184	-15.4016	-15.3148	0	16	2,410	D	24977
149.0486	149.1084	-20.2794	-20.2299	-3	132	3,312	D	24979
149.0373	149.0959	-20.3168	-20.2793	-4	135	1,964	D	24980
148.9087	148.9663	-20.3272	-20.2807	-3	50	3,979	D	24981
148.9667	149.0056	-20.3812	-20.3272	-2	43	2,846	D	24982
148.9748	149.1222	-20.3753	-20.2195	1	132	2,616	D	24984
148.9801	149.1222	-20.2197	-20.1453	3	61	2,189	D	24985
149.1221	149.2205	-20.3218	-20.1562	6	64	4,254	D	24986
130.4029	130.4981	-12.5419	-12.4166	-3	356	1,352	D	24987
130.8590	130.9887	-12.3320	-12.1790	-2	16	1,512	D	24988
139.9239	140.2765	-16.6319	-16.1595	19	38	3,155	D	24989
140.1231	140.4080	-16.9857	-16.6317	17	31	1,344	D	24990
139.7695	139.9167	-16.6947	-16.5522	-4	30	1,326	D	24991
140.0840	140.3773	-15.5468	-15.2392	17	48	298	D	24992
130.5640	130.6849	-11.8445	-11.7309	-5	18	2,532	D	24993
130.5522	130.6416	-11.9267	-11.8410	-2	25	1,956	D	24994
145.4026	145.4998	-14.6619	-14.5261	0	45	1,195	D	24995
145.3986	145.5505	-14.5267	-14.3821	0	957	1,751	D	24996
153.2577	153.3396	-24.4773	-24.3811	45	200	154	D	24998
153.6205	153.6548	-27.0022	-26.9703	156	189	94	D	24999
135.7417	135.8748	-36.0006	-35.9480	127	195	1,212	D	25000
150.3871	150.5325	-22.4222	-22.2716	-6	22	6,541	D	25008
150.3871	150.4778	-22.2716	-22.1300	-3	45	3,201	D	25009
150.3219	150.3871	-22.3311	-22.2251	4	43	1,357	D	25010
142.3337	142.4818	-9.8338	-9.7679	-2	13	1,235	D	25014
142.4816	142.6414	-9.9613	-9.7579	2	17	2,218	D	25015
142.6413	142.8013	-9.9598	-9.7570	0	19	3,722	D	25016
142.8008	142.9611	-9.9595	-9.7563	-3	31	3,777	D	25017
142.9602	143.1166	-9.9586	-9.7557	-4	39	3,051	D	25018
142.8321	142.9615	-10.0217	-9.9589	-10	24	826	D	25019
142.9613	143.1164	-10.0218	-9.9581	-3	28	1,763	D	25020
142.9600	143.0060	-9.8322	-9.7680	-4	36	1,184	D	25021
128.5351	128.6714	-12.1415	-12.0732	66	101	3,379	D	25022
128.4970	128.6730	-12.1957	-12.0481	66	129	2,259	D	25023
143.5170	143.7833	-9.5972	-9.3886	0	100	1,744	D	25024
143.7834	144.0667	-9.4998	-9.3171	-1	139	3,710	D	25025
144.0667	144.3500	-9.4789	-9.3154	-1	149	2,828	D	25026
144.3500	144.4192	-9.4588	-9.3537	63	106	478	D	25027
129.1871	129.3391	-12.2762	-12.1681	22	67	2,790	D	25028
129.1802	129.3663	-12.3684	-12.2598	19	68	2,648	D	25029
129.3362	129.4018	-12.1464	-12.0665	19	69	808	D	25030

150.3381	150.4387	-9.6261	-9.5162	167	1076	3,147	D	25638
150.3817	150.4714	-9.5187	-9.3964	18	629	3,864	D	25639
150.3645	150.5112	-9.3990	-9.2993	0	116	5,227	D	25640
150.3688	150.7561	-9.8577	-9.6068	0	1198	592	D	25641
133.6868	133.7234	-37.3992	-37.3054	28	91	262	D	25642
155.8354	155.8677	-17.3699	-17.3435	0	70	206	D	25643
155.8298	155.8833	-17.4412	-17.3701	-1	866	3,817	D	25644
128.8732	128.9736	-9.7492	-9.6032	10	48	843	D	25645
129.0298	129.1065	-9.8131	-9.6966	8	48	254	D	25646
129.2761	129.3222	-9.8948	-9.8674	8	47	162	D	25648
129.4103	129.4207	-9.8918	-9.8780	14	45	32	D	25649
137.0122	137.0990	-34.8902	-34.7936	2	34	2,647	D	25650
137.0900	137.1863	-34.8012	-34.6903	26	34	2,905	D	25651
137.1774	137.2735	-34.6977	-34.5871	8	28	3,048	D	25652
137.2644	137.3320	-34.5943	-34.5085	5	19	1,946	D	25653
135.6723	135.9619	-12.3170	-12.0119	-2	19	9,071	D	25654
135.8290	136.1734	-12.1445	-11.8268	-1	64	12,813	D	25655
135.9976	136.3727	-11.8553	-11.6023	0	84	5,061	D	25656
128.1316	128.1570	-14.6367	-14.6113	-2	23	913	D	25658
142.8643	142.9482	-10.2383	-10.1872	1	25	2,538	D	25659
142.9408	143.0113	-10.2379	-10.1838	16	25	2,320	D	25660
142.8361	142.9494	-10.4254	-10.3133	2	25	7,638	D	25661
142.9409	142.9993	-10.3378	-10.2339	15	25	3,678	D	25662
143.0045	143.0378	-10.1546	-10.0903	10	27	934	D	25663
142.4413	142.4855	-10.2923	-10.2490	4	16	242	D	25664
142.6205	142.7228	-10.2944	-10.1916	12	18	1,359	D	25665
142.4634	142.5422	-10.1621	-10.0959	15	18	2,404	D	25666
143.4350	143.5862	-10.0539	-10.0215	30	57	478	D	25667
143.5817	143.7328	-10.0310	-9.9959	46	67	488	D	25668
143.7282	143.8670	-10.0169	-9.9046	0	6363	2,562	D	25669
143.8248	143.9634	-9.9609	-9.8390	0	115	3,538	D	25670
143.9591	144.0986	-9.9043	-9.8121	0	109	3,956	D	25671
144.0661	144.2082	-9.9155	-9.7934	0	262	4,047	D	25672
144.1104	144.2337	-9.7996	-9.6767	4	114	4,576	D	25673
144.1670	144.3155	-9.7021	-9.5881	2	145	4,119	D	25674
129.3302	129.3547	-12.1739	-12.1499	24	64	193	D	25675
129.3563	129.3861	-12.1906	-12.1611	27	66	372	D	25676
129.4154	129.4534	-12.1701	-12.1289	21	65	387	D	25677
129.5012	129.5312	-12.1454	-12.1201	21	68	287	D	25678
129.2204	129.2824	-12.4034	-12.3677	25	66	429	D	25679
129.2650	129.3211	-12.4228	-12.3965	36	63	285	D	25680
129.3109	129.3501	-12.4627	-12.4233	50	70	334	D	25681
129.2282	129.2865	-12.4679	-12.4328	26	63	729	D	25682
129.8594	129.9291	-12.1478	-12.0246	13	56	377	D	25683
128.0451	131.9271	-8.1150	-3.6646	198	7260	169	D	25684
129.2138	129.6179	-10.0226	-8.0102	119	2294	118	D	25685

129.6152	129.9304	-11.7718	-10.0110	20	174	119	D	25686
132.0946	133.4709	-9.4350	-6.7354	128	1457	57	D	25687
133.5003	134.6751	-11.2542	-9.4952	37	120	75	D	25688
133.8836	134.4480	-11.7108	-11.1682	22	51	137	D	25689
133.3426	133.9163	-11.4654	-10.9441	21	59	191	D	25690
132.7853	133.3721	-11.3193	-10.8490	16	60	164	D	25691
132.4860	132.8463	-11.3167	-10.8643	9	64	163	D	25692
129.9931	130.2507	-12.5191	-12.3398	14	38	4,676	D	25693
130.2248	130.4374	-12.5483	-12.3166	0	167	4,810	D	25694
129.5314	129.5975	-9.9571	-9.8779	12	86	895	D	25695
126.3360	126.4252	-10.7149	-10.6672	19	44	44	D	25696
126.1824	126.3362	-10.7604	-10.6954	12	45	219	D	25697
126.0254	126.1624	-10.7614	-10.6634	20	49	769	D	25698
126.0232	126.1661	-10.8204	-10.7615	21	49	133	D	25699
125.8580	126.0160	-10.8466	-10.6966	14	355	705	D	25700
125.8586	125.9687	-10.9686	-10.8460	18	42	251	D	25701
125.6971	125.8580	-10.8481	-10.6913	13	49	908	D	25702
125.6981	125.8575	-10.9730	-10.8469	18	47	705	D	25703
125.5632	125.6981	-10.8982	-10.7376	17	50	1,868	D	25704
125.5400	125.6989	-11.0950	-10.8981	13	46	275	D	25705
125.5038	125.5115	-11.1403	-11.1151	21	34	45	D	25706
125.4741	125.5403	-11.1030	-11.0392	20	45	488	D	25707
125.3450	125.5040	-11.2866	-11.1029	15	127	801	D	25708
125.2974	125.3368	-11.3417	-11.3075	15	49	107	D	25709
125.3052	125.3450	-11.3076	-11.2599	18	50	151	D	25710
125.1931	125.2974	-11.5112	-11.3254	14	50	703	D	25711
125.2730	125.2803	-11.5135	-11.5112	19	39	7	D	25712
124.6694	124.7341	-11.3753	-11.2920	19	48	965	D	25713
124.6700	124.7278	-11.4339	-11.3749	19	47	567	D	25714
124.6231	124.6697	-11.3754	-11.2969	20	50	663	D	25715
124.5106	124.6700	-11.5796	-11.3754	13	49	1,263	D	25716
124.5120	124.5613	-11.7145	-11.5796	18	47	126	D	25717
124.5001	124.5104	-11.4238	-11.4069	18	49	35	D	25718
124.3521	124.5068	-11.6839	-11.5241	19	50	872	D	25719
124.3529	124.4974	-11.8815	-11.7230	15	48	502	D	25720
124.3097	124.3523	-11.6903	-11.6366	21	48	359	D	25721
134.7321	135.0321	-11.6665	-11.3180	20	39	3,841	D	25722
134.4440	134.7497	-11.8321	-11.4357	15	39	909	D	25723
134.7184	135.0587	-11.8916	-11.6333	14	29	3,155	D	25724
134.8181	134.9335	-12.0201	-11.8586	0	23	1,525	D	25725
155.6946	155.7386	-21.1614	-21.1087	24	64	520	D	25726
155.0733	155.3219	-22.2888	-22.1436	0	3125	571	D	25727
155.3084	155.5683	-22.2863	-22.1298	0	2932	831	D	25728
113.1880	113.1972	-25.3610	-25.3472	9	18	949	D	25729
113.1831	113.1939	-25.4333	-25.4181	0	16	1,203	D	25730
152.6690	152.9428	-18.5911	-18.1214	2091	2379	925	D	25731

158.5382	159.1363	-9.3013	-8.7481	53	1788	2,204	D	25732
159.0166	159.1163	-9.2087	-9.0602	3	590	1,475	D	25733
145.4659	159.6279	-14.3921	-10.5311	51	4545	326	D	25734
160.1283	161.0200	-10.2954	-9.3609	34	5298	144	D	25735
159.0187	159.9229	-9.3794	-8.8583	175	1588	62	D	25736
159.6139	159.6634	-10.5614	-10.4522	47	5154	1,078	D	25737
129.8514	129.9368	-12.1308	-12.0177	14	55	1,982	D	25738
146.6592	146.6991	-38.7859	-38.7427	0	21	1,416	D	25739
149.3217	149.5052	-21.3464	-21.2657	1	18	8,222	D	25740
149.4921	149.6913	-21.3467	-21.2736	1	28	7,837	D	25741
149.4962	149.7547	-21.4660	-21.3242	3	27	2,634	D	25742
149.7470	149.8624	-21.4635	-21.3212	4	30	1,477	D	25743
141.4858	141.4961	-10.2578	-10.2247	0	17	431	D	25744
124.2737	124.3528	-11.7965	-11.6903	17	47	458	D	25745
151.0078	151.6234	-16.2878	-15.8181	991	1187	1,003	D	25746
151.4985	152.1230	-16.7528	-16.2808	783	1028	1,023	D	25747
151.9921	152.4468	-17.2014	-16.7496	786	1349	926	D	25748
152.3423	152.6111	-17.6665	-17.1970	1169	1603	904	D	25749
152.5055	152.7745	-18.1324	-17.6642	1554	2224	932	D	25750
135.8127	136.1223	-12.0965	-11.7323	-3	75	11,819	D	26288
151.2181	151.3660	-10.5910	-10.4852	25	601	193	D	26423
151.1653	151.2143	-10.5052	-10.4841	256	359	50	D	26424
151.3670	151.3861	-10.5965	-10.5610	42	58	25	D	26425
150.7683	150.9167	-10.3333	-10.1907	-1	469	3,061	D	26426
150.8661	150.9164	-10.3546	-10.3333	130	264	487	D	26427
150.8701	150.9005	-10.2392	-10.2091	0	378	5,008	D	26428
150.9174	151.0667	-10.4457	-10.3333	13	349	429	D	26429
151.0666	151.1679	-10.4824	-10.3334	11	362	3,813	D	26430
150.9166	151.0648	-10.3333	-10.1833	1	602	3,473	D	26431
119.5590	120.0936	-34.8993	-34.3168	57	3718	7,176	D	26433
120.1598	121.1271	-35.4569	-34.1629	65	4946	476	D	26434
118.9742	119.5695	-34.9105	-34.3913	10	1952	7,884	D	26435
118.9857	119.5721	-35.4654	-34.9004	67	4219	2,889	D	26436
119.5737	120.1133	-35.4644	-34.8901	925	4941	918	D	26437
146.2655	150.4206	-18.1827	-15.2615	28	1663	326	D	26439
143.9135	148.5691	-13.4877	-9.1900	42	4372	162	D	26440
148.5879	152.8626	-18.4957	-13.5043	799	4547	166	D	26441
152.8693	154.0015	-23.0043	-18.5155	365	2315	122	D	26442
149.6472	149.9856	-16.5384	-16.2912	11	570	1,404	D	26443
147.6376	148.0629	-17.3059	-16.9998	33	1146	819	D	26444
147.8843	148.4159	-16.9995	-16.4997	800	1047	1,571	D	26445
148.2985	148.8237	-16.4986	-16.0001	96	1033	1,380	D	26446
148.6301	149.0904	-15.9982	-15.4999	965	1075	1,279	D	26447
148.9829	149.4392	-15.4989	-14.9604	953	1594	1,371	D	26448
147.4032	147.5914	-17.1860	-17.0071	1094	1355	372	D	26449
147.7667	147.8833	-16.9982	-16.4766	416	1184	235	D	26450

113.0865	113.0988	-25.5357	-25.5295	10	17	544	D	26451
113.0889	113.1018	-25.6786	-25.6645	5	20	1,520	D	26452
113.3425	113.3524	-25.4257	-25.4124	14	16	1,096	D	26453
113.3822	113.3927	-25.6184	-25.6045	5	8	1,123	D	26454
113.3559	113.3936	-25.6535	-25.6397	4	11	324	D	26455
113.3560	113.3840	-25.6354	-25.6170	1	11	355	D	26456
113.2053	113.5051	-25.6544	-25.5025	0	18	66	D	26457
112.9942	113.1867	-25.6522	-25.3427	1	50	228	D	26458
135.9076	136.0330	-34.6725	-34.6528	1	24	2,338	D	26459
136.0226	136.1565	-34.6712	-34.6528	21	27	2,462	D	26460
136.1454	136.2278	-34.7447	-34.6523	20	29	3,084	D	26461
136.1984	136.2719	-34.8228	-34.7306	20	36	2,873	D	26462
139.0821	141.2214	-38.5797	-37.1795	137	645	79	D	26463
141.1706	144.4398	-39.0579	-38.5617	61	284	82	D	26464
144.3420	147.0962	-39.5636	-38.9648	35	78	82	D	26465
147.5777	148.4628	-41.7445	-40.1705	25	103	83	D	26466
137.8586	137.8899	-35.6884	-35.6675	6	16	582	D	26467
147.9517	147.9997	-42.7726	-42.7255	26	49	330	D	26468
136.9977	137.1944	-35.5004	-35.4118	35	46	3,721	D	26469
137.1822	137.4092	-35.4735	-35.3765	22	39	4,550	D	26470
137.3969	137.6237	-35.4382	-35.3436	22	36	4,396	D	26471
137.6117	137.8085	-35.4048	-35.3165	29	36	3,569	D	26472
128.9176	128.9452	-9.7524	-9.7181	12	44	189	D	26473
129.1002	129.1283	-9.8728	-9.8013	11	47	105	D	26474
129.2232	129.2357	-9.9873	-9.9730	10	44	39	D	26475
126.5808	126.6835	-10.4060	-10.2757	23	49	338	D	26476
126.5610	126.6191	-10.5795	-10.4058	23	49	427	D	26477
128.5253	128.5360	-9.7582	-9.7075	43	48	12	D	26478
128.5362	128.6466	-9.7943	-9.6380	17	49	327	D	26479
128.5381	128.6653	-9.9348	-9.7942	10	48	678	D	26481
129.5385	129.5591	-10.1581	-10.1262	11	49	118	D	26484
130.8025	130.8125	-10.0363	-10.0204	11	44	39	D	26485
124.4037	124.4255	-11.2720	-11.2386	13	36	109	D	26486
124.4254	124.5855	-11.2757	-11.1223	19	2735	1,210	D	26487
124.5850	124.6460	-11.2645	-11.1246	19	48	716	D	26488
124.2712	124.3575	-11.4814	-11.3796	21	46	270	D	26489
124.3577	124.5177	-11.4797	-11.2795	20	48	904	D	26490
124.5178	124.5301	-11.4029	-11.3880	23	45	25	D	26491
124.1583	124.2888	-11.6069	-11.5030	18	48	1,269	D	26492
124.2886	124.3805	-11.6091	-11.4997	19	46	561	D	26493
124.2953	124.3542	-11.7960	-11.7726	21	46	198	D	26494
125.0751	125.1149	-11.6748	-11.6482	10	49	47	D	26496
124.7489	124.8406	-11.8432	-11.7512	13	45	73	D	26497
124.9113	125.0253	-11.7910	-11.7060	12	46	144	D	26498
125.0757	125.1436	-11.7118	-11.7051	25	44	18	D	26499
125.2221	125.2839	-11.5128	-11.4650	17	45	92	D	26500

123.6970	123.7014	-11.5490	-11.5451	28	31	618	D	26503
124.3033	124.3085	-11.5985	-11.5947	20	23	802	D	26504
124.0216	124.0272	-12.5480	-12.5442	16	23	931	D	26505
122.9810	123.0071	-12.2384	-12.2157	0	31	130	D	26506
122.9172	122.9494	-12.2449	-12.2240	-4	47	609	D	26508
123.0511	123.0785	-12.1802	-12.1706	-4	47	426	D	26509
123.0784	123.1106	-12.1878	-12.1758	-4	36	600	D	26510
123.1106	123.1379	-12.2000	-12.1759	-4	45	666	D	26511
123.1378	123.1637	-12.2294	-12.1886	-4	34	1,257	D	26512
123.1507	123.1701	-12.2610	-12.2293	-4	30	995	D	26513
123.6896	123.7913	-11.5723	-11.5218	3	290	401	D	26514
123.5687	123.6897	-11.5771	-11.5194	11	48	791	D	26515
123.5448	123.5644	-11.6871	-11.6716	24	47	50	D	26516
123.3898	123.5219	-11.7414	-11.5669	14	46	153	D	26517
123.3690	123.4755	-11.9025	-11.7413	0	51	1,162	D	26518
123.2776	123.3687	-11.7642	-11.6529	28	50	1,057	D	26519
123.2813	123.3692	-11.8979	-11.7641	12	50	1,342	D	26520
123.8202	123.8367	-11.8086	-11.7932	14	46	56	D	26521
123.1612	123.2825	-12.3828	-12.2635	8	49	572	D	26522
123.2824	123.4371	-12.3881	-12.3062	9	50	1,971	D	26523
123.4582	123.5827	-12.4147	-12.3359	11	54	1,692	D	26524
123.6251	123.7656	-12.4676	-12.4220	21	50	548	D	26525
123.7656	123.9264	-12.4730	-12.4046	4	49	827	D	26526
123.9268	123.9647	-12.4128	-12.4015	28	49	87	D	26527
125.1031	125.1150	-11.6584	-11.6480	9	48	30	D	26528
124.9398	125.0246	-11.7833	-11.7070	10	40	62	D	26529
124.8255	124.8303	-11.7634	-11.7512	13	33	14	D	26530
124.1581	124.1746	-11.5643	-11.5484	22	37	14	D	26531
130.9825	131.1197	-11.9437	-11.8655	-4	8	88	D	26533
150.7931	150.7982	-23.1567	-23.1520	3	7	1,325	D	27313
150.7852	150.7877	-23.1613	-23.1594	1	3	90	D	27314
150.7871	150.7894	-23.1637	-23.1609	0	3	298	D	27315
150.7868	150.7885	-23.1658	-23.1629	-2	3	234	D	27316
145.2184	145.2484	-15.4684	-15.4549	-1	6	446	D	27317
145.1923	145.2258	-15.4757	-15.4538	-1	7	430	D	27318
145.1924	145.2259	-15.4613	-15.4390	-1	7	358	D	27319
145.2440	145.2506	-15.4667	-15.4587	-1	6	1,384	D	27320
145.2391	145.2473	-15.4685	-15.4629	-1	3	788	D	27321
150.8846	150.8991	-34.4657	-34.4533	4	18	3,525	D	27322
150.8845	150.8858	-34.4574	-34.4546	6	15	282	D	27323
150.8999	150.9041	-34.4712	-34.4689	4	16	952	D	27325
150.8918	150.8949	-34.4653	-34.4630	7	15	353	D	27326
150.9023	150.9137	-34.4725	-34.4632	4	19	2,649	D	27327
150.9030	150.9075	-34.4661	-34.4648	6	12	492	D	27328
150.8881	150.8926	-34.4586	-34.4566	12	18	670	D	27329
150.8876	150.8908	-34.4622	-34.4597	12	19	389	D	27330

150.8925	150.8936	-34.4579	-34.4542	10	17	681	D	27331
0.7293	0.7739	0.5012	0.5806	0	19	4,533	D	27333
139.7472	139.7503	-37.1650	-37.1616	-1	5	922	D	27335
145.7166	145.7174	-16.8029	-16.8015	0	4	1,014	D	27336
116.7016	116.7275	-35.0606	-35.0418	5	42	460	D	27337
116.7274	116.7822	-35.0606	-35.0181	0	45	2,000	D	27338
116.6725	116.7274	-35.1052	-35.0605	13	65	839	D	27339
116.7273	116.7821	-35.1032	-35.0605	21	66	1,001	D	27340
144.5344	144.5381	-38.0980	-38.0969	6	11	1,715	D	27341
144.2129	144.2392	-9.7668	-9.7399	2	86	84	D	27342
144.2394	144.2593	-9.7658	-9.7399	3	90	146	D	27343
144.2184	144.2394	-9.7394	-9.7134	30	59	85	D	27344
144.2394	144.2598	-9.7400	-9.7131	3	91	232	D	27345
144.2051	144.2398	-9.7036	-9.6859	33	88	139	D	27346
144.2398	144.2626	-9.7129	-9.6859	3	120	266	D	27347
144.2151	144.2391	-9.6856	-9.6586	67	115	18	D	27348
144.2399	144.2714	-9.6857	-9.6590	5	116	146	D	27349
144.2144	144.2397	-9.6570	-9.6319	25	72	12	D	27350
144.2406	144.2739	-9.6583	-9.6318	3	119	111	D	27351
144.2247	144.2398	-9.6310	-9.6171	12	97	26	D	27352
144.2404	144.2614	-9.6315	-9.6048	2	107	68	D	27353
128.0606	128.1227	-15.3207	-15.2823	-2	411	2,388	D	27355
128.0659	128.1257	-15.3659	-15.3204	-3	23	3,206	D	27356
128.0851	128.1229	-15.4111	-15.3657	-3	14	2,210	D	27357
128.0722	128.1188	-15.4563	-15.4109	-2	22	2,206	D	27358
128.0670	128.1000	-15.4745	-15.4560	-3	13	1,054	D	27359
144.7040	144.7170	-38.2654	-38.2535	0	67	21,318	D	27360
144.7042	144.7237	-38.2881	-38.2730	0	16	7,152	D	27362
140.4201	140.7118	-17.4230	-17.1512	3	14	1,141	D	27363
139.7060	140.4347	-17.3565	-17.2209	8	12	359	D	27364
139.3562	139.7199	-17.2260	-17.1127	2	21	1,657	D	27365
143.9998	144.8413	-10.0015	-9.2599	2	1365	1,628	D	sc5505_d
143.9487	145.0167	-11.0005	-10.0015	2	1650	4,320	D	sc5509_d
144.0008	144.7443	-13.9998	-13.3260	4	844	1,489	D	sd5505_d
146.0927	146.9741	-14.0009	-13.0059	2	3004	1,288	D	sd5506_d
144.0000	145.5000	-14.9982	-14.0000	3	528	4,927	D	sd5509_d
145.5000	146.9986	-14.9999	-14.0017	3	2623	4,561	D	sd5510_d
145.3083	145.8671	-15.9958	-15.0008	2	540	6,220	D	sd5514_d
147.0001	147.7857	-15.9988	-15.0046	11	1347	494	D	sd5515_d
145.4603	146.5556	-16.9989	-16.0023	3	1104	3,160	D	se5502_d
147.1580	148.4989	-17.0006	-16.0027	0	2144	3,821	D	se5503_d
148.4992	150.0001	-16.9998	-16.0010	1	1041	2,339	D	se5504_d
145.9896	146.9996	-17.9999	-17.0000	3	1022	6,975	D	se5506_d
147.0001	148.5001	-17.9995	-17.0018	2	1400	4,007	D	se5507_d
148.5012	149.9998	-17.9982	-17.0002	0	1099	2,050	D	se5508_d
146.2009	146.9990	-18.9991	-17.9999	2	194	6,427	D	se5510_d

147.0000	148.4998	-19.0096	-17.9999	3	1030	12,452	D	se5511_d
148.5001	149.6437	-18.9999	-18.0662	11	1193	1,764	D	se5512_d
146.6369	146.9998	-19.1920	-19.0009	11	27	242	D	se5514_d
147.0021	148.4997	-19.9993	-18.9999	3	80	8,741	D	se5515_d
148.5000	150.0000	-20.0001	-19.0000	2	325	15,725	D	se5516_d
150.0004	150.8871	-16.9993	-16.1022	2	820	1,418	D	se5601_d
149.9308	151.4996	-17.9854	-16.9878	2	1220	10,054	D	se5605_d
151.5004	152.3342	-17.8019	-17.0020	4	1442	3,117	D	se5606_d
150.0000	150.3614	-19.9734	-19.4063	6	314	1,389	D	se5613_d
148.6365	150.0000	-20.9993	-20.0000	4	95	17,330	D	sf5504_d
149.2552	149.9997	-22.0003	-21.0038	4	57	3,798	D	sf5508_d
150.0000	150.5625	-21.0000	-20.0016	4	79	3,491	D	sf5601_d
150.0004	150.5192	-22.0000	-21.0000	5	96	6,896	D	sf5605_d
150.0846	150.4503	-22.4341	-22.1140	4	46	3,412	D	sf5609_46_d
150.0010	151.4990	-22.9976	-22.0000	3	74	2,282	D	sf5609_7_d
151.5043	152.0012	-22.9967	-22.5730	52	98	138	D	sf5610_d
151.5008	152.7944	-23.9992	-23.0009	1	316	5,216	D	sf5614_d
112.1759	112.5001	-24.9770	-24.1009	116	380	310	D	sg4903_d
112.4999	113.4258	-25.0001	-24.0199	9	359	1,329	D	sg4904_d
112.1390	112.5001	-25.9991	-25.0020	115	417	1,441	D	sg4907_d
112.4999	113.2021	-26.0000	-24.9999	10	150	3,174	D	sg4908_d
112.2720	113.6214	-26.7641	-26.0004	7	456	3,400	D	sg4912_d
151.8869	152.9997	-24.9937	-24.0005	14	345	2,158	D	sg5602_d
153.0001	153.7066	-24.9922	-24.1828	6	740	1,260	D	sg5603_d
128.4119	128.9832	-32.0354	-31.7339	7	45	634	D	sh5214_d
128.9793	130.5177	-32.0216	-31.5793	6	58	3,474	D	sh5215_d
130.4884	132.0219	-32.0666	-31.4876	6	65	3,944	D	sh5216_d
158.9825	159.1775	-30.0221	-29.3369	2	2140	688	D	sh5707_d
114.9508	116.4379	-35.0141	-33.9918	3	67	904	D	si5010_d
116.2270	117.6032	-35.1289	-34.9939	2	67	806	D	si5015_d
124.2944	126.0132	-33.0396	-32.2943	3	63	3,904	D	si5104_d
123.3268	124.5307	-34.0627	-32.9578	5	79	3,307	D	si5107_d
124.4850	125.9974	-33.9999	-33.0003	37	380	8,026	D	si5108_d
123.3268	124.5040	-34.5920	-33.9760	3	346	1,301	D	si5111_d
124.4756	125.1669	-34.2387	-33.9786	71	338	646	D	si5112_d
125.9946	127.5141	-33.0349	-32.2778	10	85	6,566	D	si5201_d
127.4911	129.0182	-33.3844	-31.9163	13	328	8,342	D	si5202_d
128.9741	130.5759	-33.0461	-31.9708	41	98	9,115	D	si5203_d
130.5134	132.0040	-33.0042	-31.9899	25	100	8,890	D	si5204_d
126.0018	127.4980	-33.4252	-33.0004	53	392	2,937	D	si5205_d
127.4941	128.9932	-33.3966	-32.9671	71	360	3,367	D	si5206_d
129.0085	130.5351	-33.4239	-32.9663	76	404	4,045	D	si5207_d
131.9891	133.4961	-33.0536	-31.8996	6	95	8,863	D	si5301_d
133.4960	134.1966	-33.0389	-32.3325	2	70	1,483	D	si5302_d
131.9878	133.5072	-34.0519	-32.9143	65	472	8,492	D	si5305_d
133.5039	135.3545	-34.4317	-32.9553	2	96	7,281	D	si5306_d

132.4091	133.5154	-34.8951	-33.9391	91	620	3,543	D	si5309_d
133.4868	135.0735	-35.0685	-33.9193	4	492	9,638	D	si5310_d
134.9043	135.9420	-35.0159	-33.9194	4	106	3,616	D	si5311_d
133.9176	134.9932	-35.5210	-34.9317	104	432	1,652	D	si5314_d
134.9683	136.5134	-36.0265	-34.9181	38	520	2,381	D	si5315_d
136.4866	138.0067	-36.0479	-35.0005	5	112	1,457	D	si5316_d
137.9903	139.4371	-36.0212	-35.5283	2	59	2,653	D	si5413_d
135.6874	136.5226	-36.5851	-35.9593	81	1116	2,171	D	sj5303_d
136.5096	138.0164	-36.9996	-35.9784	8	692	7,840	D	sj5304_d
137.9553	139.5284	-37.0452	-35.9859	7	108	3,708	D	sj5401_d
139.4171	139.7396	-37.0044	-36.0774	6	46	1,147	D	sj5402_d
137.7503	139.5282	-37.5922	-36.3224	40	960	1,741	D	sj5405_d
139.4621	140.4514	-38.0249	-37.0024	4	371	3,323	D	sj5406_d
140.0926	141.0019	-38.5064	-37.9688	6	378	1,883	D	sj5410_d
141.0003	142.5076	-38.9998	-38.0916	2	392	2,504	D	sj5411_d
142.5001	143.9998	-39.0072	-38.4278	2	112	2,924	D	sj5412_d
142.3819	144.0000	-39.9879	-38.9975	30	568	5,391	D	sj5416_d
147.7408	148.4990	-38.0000	-37.8098	9	53	686	D	sj5507_d
148.5001	150.0000	-38.0132	-37.0571	2	141	1,750	D	sj5508_d
144.0003	145.4994	-39.0289	-38.2833	4	83	3,109	D	sj5509_d
145.5004	146.9998	-38.9999	-38.5825	4	77	2,131	D	sj5510_d
147.0000	148.4995	-39.0000	-38.0000	9	820	8,246	D	sj5511_d
148.5007	149.8570	-38.9932	-37.9806	49	426	2,189	D	sj5512_d
143.5113	146.2140	-39.9995	-38.9438	25	87	7,194	D	sj5513_d
146.9801	148.4996	-39.9993	-38.9861	2	127	7,100	D	sj5515_d
148.4979	148.8689	-39.9999	-39.0043	32	560	2,164	D	sj5516_d
143.2200	144.1080	-41.0005	-39.9950	31	623	3,185	D	sk5404_d
147.0009	148.4994	-40.8587	-40.0012	4	75	2,283	D	sk5503_d
148.5001	148.9014	-40.9574	-40.0038	24	394	1,420	D	sk5504_d
143.9018	145.1955	-42.0027	-40.9785	5	607	3,703	D	sk5505_d
144.6596	145.7130	-43.2590	-41.8700	2	578	2,914	D	sk5509_d
147.9569	148.4485	-43.0577	-42.0172	4	580	994	D	sk5511_d
147.0151	148.2789	-44.1490	-42.9613	2	1016	2,749	D	sk5515_d

Appendix B. Laser Airborne Depth Sounder (LADS) and other digital data sets received from Australian Hydrographic Service

Long. E (dec. deg.)	Long. W (dec. deg.)	Lat. S (dec. deg.)	Lat. N (dec. deg.)	Min depth (m)	Max depth (m)	No. of Points	Survey Name
143.6394	148.4504	-19.4713	-12.4539	-51	4	2,683,677	HI185.XYZ
143.6395	152.2568	-23.7062	-11.3520	-51	4	334,553	HI193.XYZ
151.5459	152.3472	-23.8901	-22.9552	-52	4	1,601,060	HI199.XYZ
141.5830	145.3210	-14.6089	-10.0000	-48	4	306,778	HI206.XYZ
143.4557	145.9213	-16.4939	-11.2330	-50	5	2,354,048	HI220.XYZ
143.5495	145.7391	-15.0296	-10.3631	-51	5	1,461,784	HI221.XYZ
145.5451	145.8202	-15.7528	-15.1332	-50	4	606,984	HI241.XYZ
152.1346	152.4132	-19.3056	-18.9251	-51	4	321,408	HI245.XYZ
142.5693	144.2526	-9.8787	-9.6073	-77	0	67,410	HI255.XYZ
141.1668	142.1382	-11.6830	-10.4822	-46	4	111,763	HI257.XYZ
143.0323	144.7105	-10.3987	-10.0000	-50	6	372,152	HI258.XYZ
145.3292	145.3914	-14.9270	-14.9243	-30	-3	78,599	HI258B.XYZ
153.4508	153.6179	-25.1532	-24.8615	-61	-21	2,724	HI259B.XYZ
150.4930	150.5809	-22.3885	-22.2938	-38	0	8,438	HI261_A.XYZ
150.1724	150.4107	-22.2598	-22.0918	-46	-4	6,909	HI261_B2.XYZ
150.3187	150.3754	-22.3169	-22.2717	-23	-2	3,566	HI261_E.XYZ
145.3893	145.7426	-15.1743	-14.4421	-51	5	1,452,619	HI263.XYZ
149.6820	149.8473	-10.7350	-10.4559	-1380	-3	25,757	HI268.XYZ
148.8968	149.2290	-20.6933	-20.2161	-49	0	14,160	HI270.XYZ
149.9731	149.9909	-20.3156	-20.2868	-52	1	1,842	HI270A.XYZ
146.0197	146.0735	-16.9683	-16.9176	-40	-26	303,225	HI273.XYZ
143.6202	143.9501	-13.5038	-13.2048	-51	0	403,869	HI274.XYZ
142.6803	142.7147	-10.7636	-10.7430	-24	-10	2,348	HI274A.XYZ
144.4122	145.4265	-14.6089	-13.9052	-50	5	2,027,565	HI275.XYZ
147.9722	147.9852	-19.0194	-18.9953	-58	-53	11,708	HI276A.XYZ
142.9797	143.1533	-11.7422	-11.2012	-34	-3	1,267	HI279A.XYZ
151.2791	151.5100	-23.7280	-23.4947	-31	-8	33,285	HI282.XYZ
149.4724	149.5330	-20.1484	-20.1262	-67	-8	19,460	HI282.XYZ
143.4557	145.3135	-14.8425	-10.0609	-50	6	1,675,160	HI285.XYZ
142.3298	143.9791	-11.5909	-10.5533	-88	0	175,770	HI286.XYZ
142.3298	142.7357	-10.7873	-10.5533	-29	0	34,875	HI286A.XYZ
142.3305	142.7356	-10.7875	-10.5533	-30	0	52,688	HI286B.XYZ
143.7248	143.9791	-11.5909	-11.0267	-88	0	10,198	HI286C.XYZ
143.7250	143.9733	-11.5909	-11.0267	-87	-5	76,864	HI286.XYZ
142.8723	142.8758	-11.2249	-11.2226	-20	-12	1,145	HI286F.XYZ
146.3754	149.1312	-20.5976	-17.2324	-58	-12	30,653	HI288.XYZ
146.3754	146.3967	-17.2436	-17.2324	-49	-16	2,578	HI288area1.XYZ
148.8025	148.8993	-20.1527	-20.0262	-47	-13	17,927	HI288area2.XYZ

149.0640	149.0853	-20.5976	-20.5874	-26	-12	6,935	HI288area3.XYZ
149.0962	149.1312	-19.6926	-19.6454	-58	-52	3,213	HI288area4.XYZ
148.3885	149.8259	-10.7531	-10.2339	-1508	0	308,075	HI289.XYZ
142.3716	143.0551	-10.0231	-9.6222	-29	0	457,477	HI293.XYZ
142.4236	142.5188	-10.5080	-10.4410	-19	-7	10,737	HI293A.XYZ
142.2542	142.2653	-10.5122	-10.5022	-16	-11	910	HI293pullar_rock.XYZ
145.6676	145.9832	-16.8931	-16.7101	-45	-2	282,936	HI294.XYZ
145.2498	145.3634	-15.5114	-15.3446	-22	-2	99,309	HI294B.XYZ
145.4562	145.4827	-16.4889	-16.4627	-10	-2	14,209	HI294C.XYZ
148.8610	148.8977	-20.1656	-20.0211	-49	-9	33,836	HI294.XYZ
144.4239	144.9193	-14.4674	-14.0805	-20	-14	701	HI296C.XYZ
148.6666	148.7554	-20.2516	-20.1719	-35	-3	5,555	HI298.XYZ
148.8593	148.8768	-20.1086	-20.0638	-38	-14	702	HI298B.XYZ
145.7699	145.8510	-16.9663	-16.8470	-11	2	114,490	HI299.XYZ
145.7921	145.7982	-16.9663	-16.9569	-11	1	3,996	HI299A.XYZ
145.7797	145.7803	-16.9305	-16.9295	-10	-1	615	HI299B.XYZ
145.7781	145.7794	-16.9375	-16.9356	-5	2	19,419	HI299.XYZ
145.7699	145.7999	-16.9216	-16.8839	-10	1	9,924	HI299E.XYZ
150.2566	150.7100	-10.9403	-10.6851	-239	0	36,256	HI301A.XYZ
148.9993	149.8251	-10.6579	-10.3296	-1682	211	151,868	HI301BC.XYZ
147.8655	151.6480	-23.8913	-19.4236	-65	1	26,745	HI302.XYZ
149.0685	149.1184	-20.2000	-20.1217	-65	1	11,999	HI302EFG.XYZ
147.8655	147.8970	-19.4519	-19.4236	-40	-16	2,543	HI302M.XYZ
150.9198	151.0021	-22.8661	-22.8010	-36	-19	2,629	HI302R.XYZ
148.8759	148.8819	-20.0490	-20.0407	-33	1	5,824	HI302V.XYZ
149.0353	149.0717	-20.5288	-20.5186	-30	0	664	HI302W.XYZ
149.0353	149.0717	-20.5288	-20.5186	-30	0	862	HI302XL.XYZ
151.6349	151.6480	-23.8913	-23.8844	-27	-21	2,224	HI302Z.XYZ
141.2272	141.4773	-10.5297	-10.4983	-21	-1	194,117	HI305A.XYZ
141.3197	141.6106	-10.4649	-10.2331	-19	-2	97,538	HI305C.XYZ
145.4382	145.4963	-14.6215	-14.5410	-35	-4	35,220	HI306.XYZ
146.1198	146.1559	-17.9557	-17.9195	-16	0	8,415	HI316A.XYZ
146.1245	146.1395	-17.6125	-17.5841	-13	-3	743	HI316AT.XYZ
143.5894	143.7635	-13.0190	-12.8165	-44	-6	14,220	HI317.XYZ
145.7781	145.7796	-16.9375	-16.9356	-8	0	565	HI318E.XYZ
150.9198	151.0020	-22.8431	-22.8324	-38	-19	2,616	hi302r_shoal.xyz
141.2539	141.8589	-10.5645	-10.3421	-22	-2	38,823	hi311.xyz
144.5443	144.5580	-14.1144	-14.0904	-33	-22	5,850	hi311a.xyz
144.5376	144.5503	-14.1150	-14.0999	-29	-15	5,766	hi311b.xyz
141.5781	141.8046	-10.5376	-10.4583	-15	-9	5,472	hi311supp.xyz
Total						**18,720,814**	