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Geomorphology of the Lord Howe Island shelf and submarine volcano

SS06-2008 Post-Survey Report

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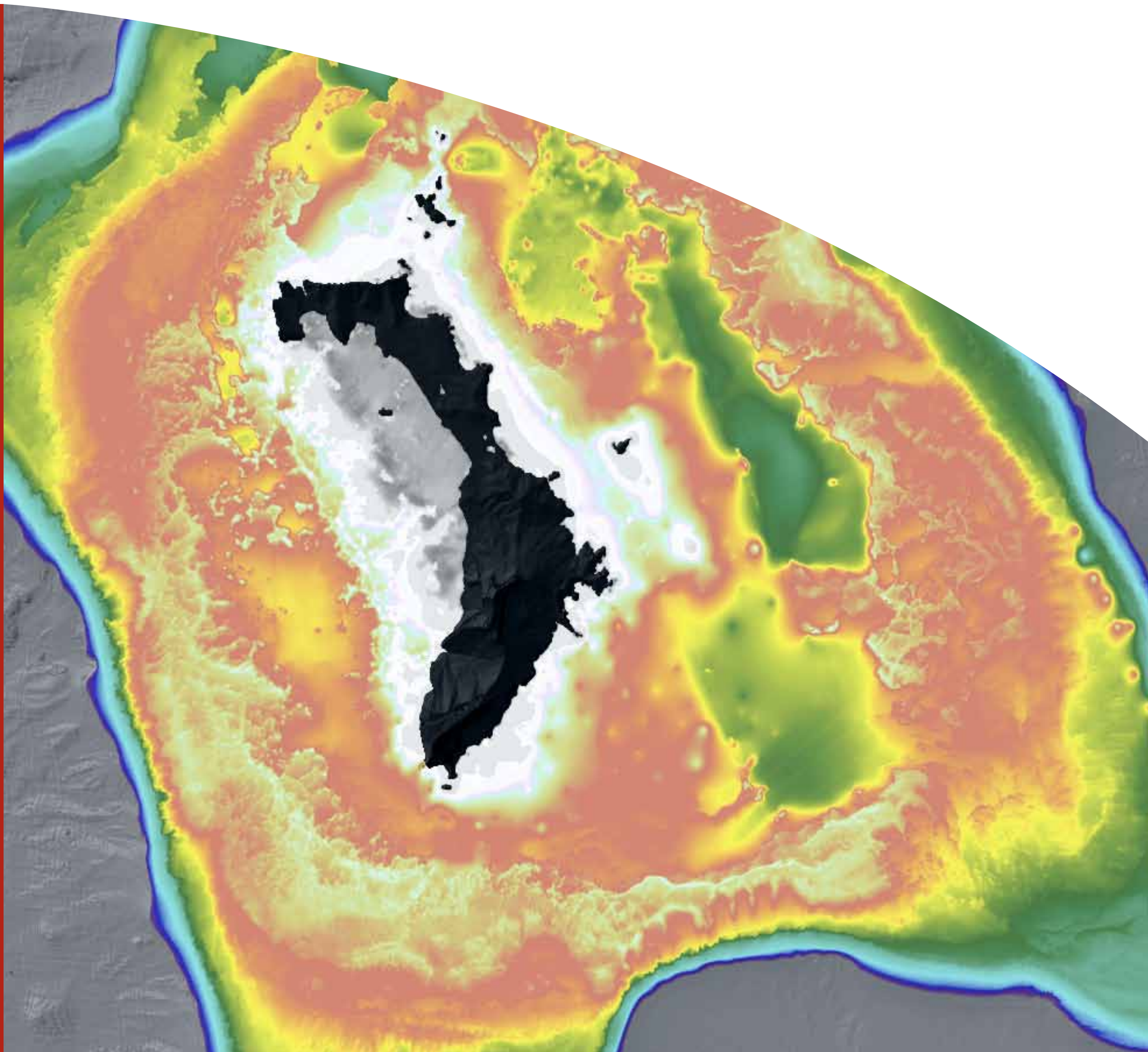

APPLYING GEOSCIENCE TO AUSTRALIA'S MOST IMPORTANT CHALLENGES

GEOSCIENCE AUSTRALIA SURVEY SS06-2008

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By

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EXECUTIVE SUMMARY

The Lord Howe Island survey SS06-2008 in April 2008 aboard the *RV Southern Surveyor* was a collaboration between the University of Wollongong and Geoscience Australia. The survey was also an activity of the Commonwealth Environment Research Facilities' (CERF) Marine Biodiversity Hub, of which Geoscience Australia is a partner, and will contribute to the revised Plan of Management for the Lord Howe Marine Parks. The objectives of the survey were to map the morphology and benthic environments of the shallow shelf that surrounds Lord Howe Island as well as the deeper flanks of this largely submarine volcano. Of particular interest was the apparent drowned reef structure on the shelf and the spatial distribution of seabed habitats and infauna. The data collected are required to better understand the history of reef growth at Lord Howe Island, which sits at the southernmost limit of reef formation, and links between the physical environment and ecological processes that control the spatial distribution of biodiversity on the shelf. The morphology of the flanks of the submarine volcano was also examined to reveal whether they provide evidence of major erosional and depositional processes acting on the volcano. This report provides a description of the survey activities and the results of the processing and initial analysis of the data and samples collected.

During the survey multibeam sonar bathymetry, acoustic sub-bottom profiles, sediment grab samples and shallow cores of the seabed were collected. Seabed sediment samples were also collected for analysis of infauna. Benthic sled samples and towed video footage were collected to provide information on epifauna. A current meter (ADCP) previously deployed on the outer shelf was retrieved and the data successfully downloaded.

High resolution (4 and 8m) relief models of the shelf were generated from the multibeam sonar bathymetry data. The models reveal an extensive relict reef structure (~145 km^2) in approximately 45 – 20 m water depth on the middle of the shelf that surrounds the island. This reef is approximately 25 times larger than the modern fringing reef on the island's west coast. Inboard of the relict reef is an extensive sandy basin that appears to represent a lagoon that formed with the relict reef. Cores recovered from the relict reef confirm that it was a coral reef, and radiocarbon and uranium-thorium ages of core samples reveal that this structure largely formed during the early to middle Holocene (9 – 7 ka). However, some reef growth also occurred in the late Holocene.

Acoustic sub-bottom profiles show the relict reef has a hard, acoustically opaque surface that in some areas has a thin cover of sediment. In contrast, a number of acoustic reflectors are well defined in profiles through the basin areas and show that up to 20 m of sediment has accumulated in these areas. The multibeam bathymetry data enabled shelf geomorphic features to be mapped (e.g. inner shelf, basin, relict reef, outer shelf) and when related to underwater towed video footage the features appear to support distinctive habitat types (e.g. relict reef: patches of macro algae, encrusting algae and sand). Infauna samples collected on 3 of the major geomorphic features (sandy basin, relict reef, outer shelf) show distinct differences in the number of individuals and species richness, which are higher on the outer shelf and relict reef. Preliminary work on the amphipod taxa suggests that they exhibit high levels of endemism.

The data collected on the survey are enabling new research into the evolution of submarine volcanoes and coral reefs, and the spatial patterns of biodiversity on the Lord Howe Island shelf. Importantly, the data are also being used by managers of the Lord Howe Marine Parks to better inform the sustainable management of these unique marine environments.

1. INTRODUCTION

The primary purpose of this report is to provide a description of the survey activities and the results of the processing and initial analyses of the data and samples collected. The report provides the context to the survey work and a preliminary assessment of the relationship between seabed geomorphology and biodiversity as represented by benthic infauna. An initial analysis of the geomorphology of the relict reef on the Lord Howe Island shelf and the submarine flanks of the Lord Howe volcano are also presented. More detailed analyses of the data will be provided in upcoming papers in scientific journals.

1.1 AIMS AND OBJECTIVES OF THE SURVEY

This report provides a description of the work completed during the survey of the seabed around Lord Howe Island, NSW, aboard *RV Southern Surveyor*. The survey was a collaboration between the University of Wollongong's GeoQuest Research Centre and Geoscience Australia, as part of Geoscience Australia's contribution to the Surrogates Program under the Commonwealth Environment Research Facilities' Marine Biodiversity Hub. The survey was undertaken from the 16th April to 1st May, 2008. The main objectives were to better understand the history of coral reef development at Lord Howe Island, identify the spatial distribution of benthic habitats on the shallow shelf that surrounds the island, and identify links between physical environmental parameters and ecological processes that influence the pattern of benthic biodiversity. As well, a better knowledge was sought of the erosional and depositional processes acting on the Lord Howe submarine volcano. To achieve these objectives a range of acoustic and video data and seabed samples were collected. The shelf and deeper flanks of the volcano were mapped using the ship's multibeam sonar bathymetry system and acoustic sub-bottom profiler to determine in high resolution the morphology of the seabed and the thickness of sediment deposits. Shallow drill cores were collected on the shelf to determine the composition and age of the relict reef features. Seabed sediment, epifauna and infauna samples and towed underwater video were collected on the shelf to characterise benthic habitats and patterns of biodiversity.

Australia's marine estate is one of the largest and most diverse in the world, and we are just beginning to map its physical environmental characteristics let alone patterns of biological diversity. Where environmental variables are shown to act as surrogates of benthic biological habitats, communities or species, they may be used to predict patterns of marine biodiversity and thereby better enable its sustainable management (McArthur et al., 2010). Therefore, a realistic method of obtaining an initial indication of patterns of biodiversity over these very large areas of seabed is to first map useful physical parameters. The purpose of field surveys in the Marine Biodiversity Hub is to collect high-quality, accurately co-located data to enable the robust testing of a range of physical parameters as surrogates of patterns of benthic biodiversity. The aim is to test these relationships in strategically selected, spatially discrete areas that are representative of much broader benthic environments, and where the bio-physical data collected complement existing data for these areas. As such, Lord Howe Island represents a remote carbonate shelf environment for which there is a range of sediment and benthic video footage available that is likely comparable to similar shallow carbonate shelves in other regions of the Australian marine estate such as Norfolk Island, the Queensland Plateau and the Northwest Shelf. Physical surrogates of biodiversity identified at Lord Howe Island may be useful for predicting biodiversity patterns at these sites.

Key tasks of Survey SS06-2008 were to:

- map the bathymetry and substrate of the shelf around Lord Howe Island and Balls Pyramid using the ship's multibeam sonar system;
- map the deeper flanks and foot of the Lord Howe volcano;
- accurately determine the extent, morphology and composition of drowned reef structures known to occur at sites outboard of the island, including the recovery of shallow drill cores;
- sample shelf sediments, infauna and epifauna using a grab sampler, towed benthic sled and towed underwater video;
- explore the shallow stratigraphy of the shelf using the ship's acoustic sub-bottom profiler, and;
- recover an Acoustic Doppler Current Profiler (ADCP) instrument that recorded waves and currents. The instrument was previously deployed on the Lord Howe shelf in November 2007 on Geoscience Australia Survey TAN0713.

Survey Personnel

Scientific crew and ships crew during the survey are listed below (Tables 1.1 and 1.2).

Table 1.1: *Scientific crew aboard Southern Surveyor SS0608.*

Name	Institution	Role
Prof Colin Woodroffe	SEES, UOW	Chief Scientist
Assoc-Prof Brian Jones	SEES, UOW	Senior Scientist
Dr David Kennedy	VU, Wellington NZ	Geologist
Javier Leon	SEES, UOW	PhD student, geospatial
Dr Brendan Brooke	GA	Deputy Chief Scientist
Dr Matt McArthur	GA	Benthic Ecologist
Cameron Buchanan	GA	Swath Technician
Andrew Hislop	GA	Mechanical Technician
Gareth Crooke	GA	Mechanical Technician
Jack Pittar	GA	Electronics Technician
Ian Atkinson	GA	Science/Swath Technician
Michele Spinoccia	GA	Swath Technician
Ron Plaschke	CMAR, MNF	Voyage Manager
Karl Forcey	CMAR, MNF	Electronics Support
Lindsay Pender	CMAR, MNF	Computing Support

Table 1.2: *Ships Crew aboard Southern Surveyor SS0608.*

Name	Role
Les Morrow	Master
John Barr	First Mate
Rob Ferries	Second Mate
Rob Cave	First Engineer
Roger Thomas	Chief Engineer
Seamus Elder	Second Engineer
Darcy Chalker	Chief Steward
Adam O'Connor	Chief Cook
Julie Milne	Second Cook

Tony Hearne	Boatswain
Rob Artaud	Integrated Rating
John Howard	Integrated Rating
Gareth Gunn	Integrated Rating
Josh Liley	Integrated Rating

1.2 LORD HOWE ISLAND & SHELF

Lord Howe Island (31° 33'S, 159° 04'E) sits approximately 580 km east of the eastern coast of Australia and is officially part of New South Wales (Figure 1.1). The island, along with Balls Pyramid 20 km farther south, form the only subaerial volcanic exposures in the Lord Howe Seamount Chain, a north–south trending line of seamounts related to Tertiary hot-spot volcanism (Quilty, 1993). The subaerial geology of Lord Howe Island (Figure 1.2) is dominated by alkaline basalt, hawaiites, and tuffs (Standard, 1963; McDougall et al., 1981), while at lower (< 100 m) elevations a veneer of Quaternary aeolianites has been deposited during sea-level highstands, dating back to at least oxygen isotope stage 7 (Brooke et al., 2003a; b). The oldest lithologies on the island are the Roach Island Tuff, which is overlain by a series of tholeiitic lava flows of the North Ridge basalt, the latter dating around 6.6 - 7.2 Ma (McDougall et al., 1981). Caldera collapse is inferred to form the next youngest unit, the Boat Harbour Breccia, with the final stage of volcanism being represented by the Mount Lidgbird basalt (c. 6.4 Ma; McDougall et al., 1981). Balls Pyramid is also composed of a similar mid-ocean basaltic sequence.

Erosion of these basalts has dominated island evolution since the cessation of volcanism (McDougall et al. 1981). This has led the to development of a rhomboidal shaped shelf around Lord Howe Island, 24 km wide and 36 km from north to south, and an oval shelf around Balls Pyramid, 15 km wide and 22 km from north to south. Both of these shelves have an average water depth of 50 m across their surface and are relatively flat (<1°). The two distinct volcanic edifices are separated by a trough on average 600 m deep (Kennedy et al., 2002). At present subtropical coralline algae dominate the shelf sediments, with coral reefs restricted to the shallow margin of Lord Howe Island (Kennedy and Woodroffe, 2000; Kennedy et al., 2002). It appears, however, that a much more extensive reef feature occurs in the middle of the shelf rising to a water depth of 30 m and covered with a veneer of coralline algae (Woodroffe et al., 2005).

The mean annual sea surface temperature (SST) around the island varies between 18 and 23°C (Veron and Done, 1979) at this oceanographic boundary marking the southern limit of the poleward flowing, warm-water East Australian Current (EAC). This boundary shifts on a annual basis from 30°S in winter to 34°S in summer (Hamon, 1962; 1968; Stanton, 1981), alternately bathing Lord Howe Island in warm waters. In the western Tasman Sea the EAC extends to at least 500 m depth with the upper 1000 m consisting of various central, equatorial and subtropical water masses. Below 1000 m, Antarctic Intermediate Water dominates, characterised by a salinity minimum of 34.4‰ and temperature of 5.5°C (Marchesiello and Middleton, 2000). The tidal range at Lord Howe Island is 1.5 m at springs and 0.8 m at neaps, with a mean significant wave height of 2.5 m (Dickson, 2006).

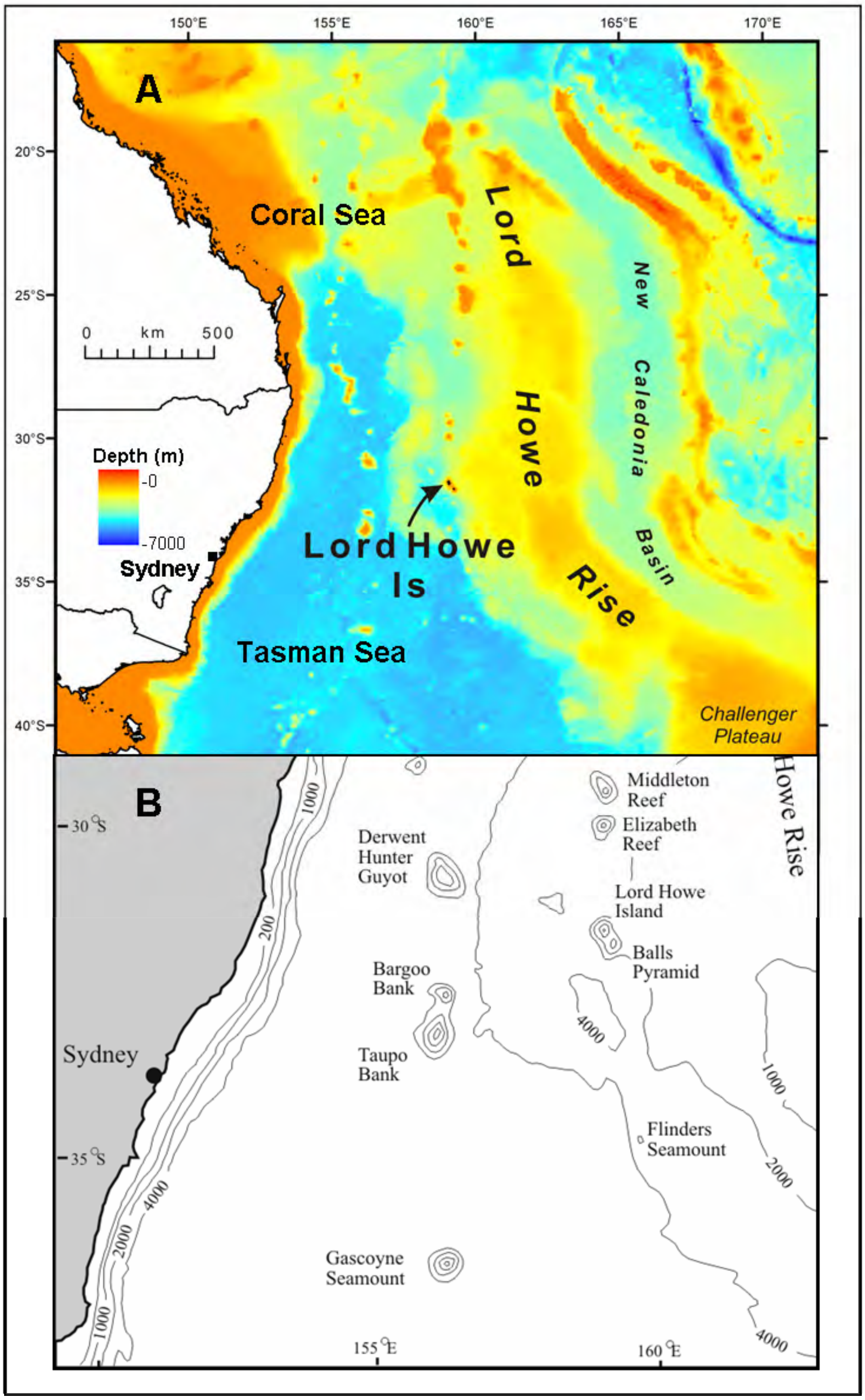


Figure 1.1: *Lord Howe Island is located in the Tasman Sea on the western margin of the Lord Howe Rise (A).The island is part of the Lord Howe Seamount Chain that includes Elizabeth and Middleton Reefs (B).*

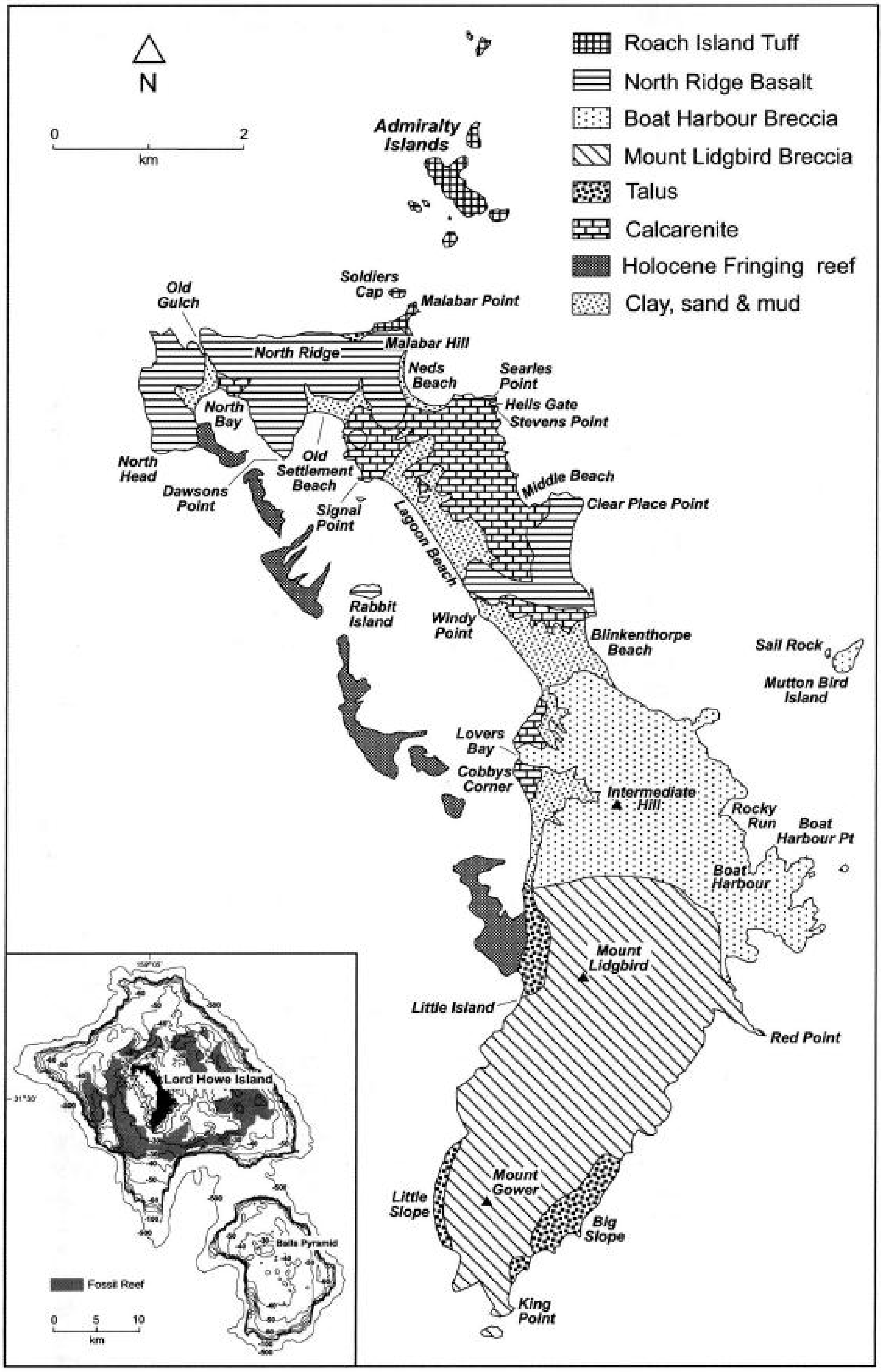


Figure 1.2: *The geology of Lord Howe Island. The island and the surrounding shallow shelf (inset) sit at the summit of a Late Miocene volcano (Woodroffe et al. 2006).*

Lord Howe Island and its fringing reef has been the subject of many biological and geological surveys that date back to the 19th century. Much less is known of the shelf that surrounds the island. Recent studies include preliminary investigations of its sediment composition (Kennedy et al. 2002) and benthic habitats (Speare et al., 2004), as well as its geological evolution (Woodroffe et al., 2006).

Lord Howe Island was recognised as a World Heritage area in 1982. The surrounding waters have been declared a State Marine Park since 1999 and a Commonwealth Marine Park since 2000 (MPA 2004). The State Marine Park extends 3 nautical miles from the mean high water mark of Lord Howe Island and Ball's Pyramid, while the Commonwealth Marine Park reaches between 3 to 12 nautical miles offshore (Figure 1.3). Within the Commonwealth zoning, the marine park is further divided into Habitat Protection Zones and Sanctuary Zones (LHIMP Management Plan, 2002). The State Marine Park is divided into three Special Purpose Zones (Fish Feeding): North Bay, Ned's Beach and Erscotts Hole; and seven Sanctuary Zones: North Bay, Admiralty Islands and Ned's Beach, East Coast and Shelf, Sylph's Hole, Lord Howe Island Lagoon, Observatory Rock, and Ball's Pyramid Sanctuary Zones (MPA, 2004).

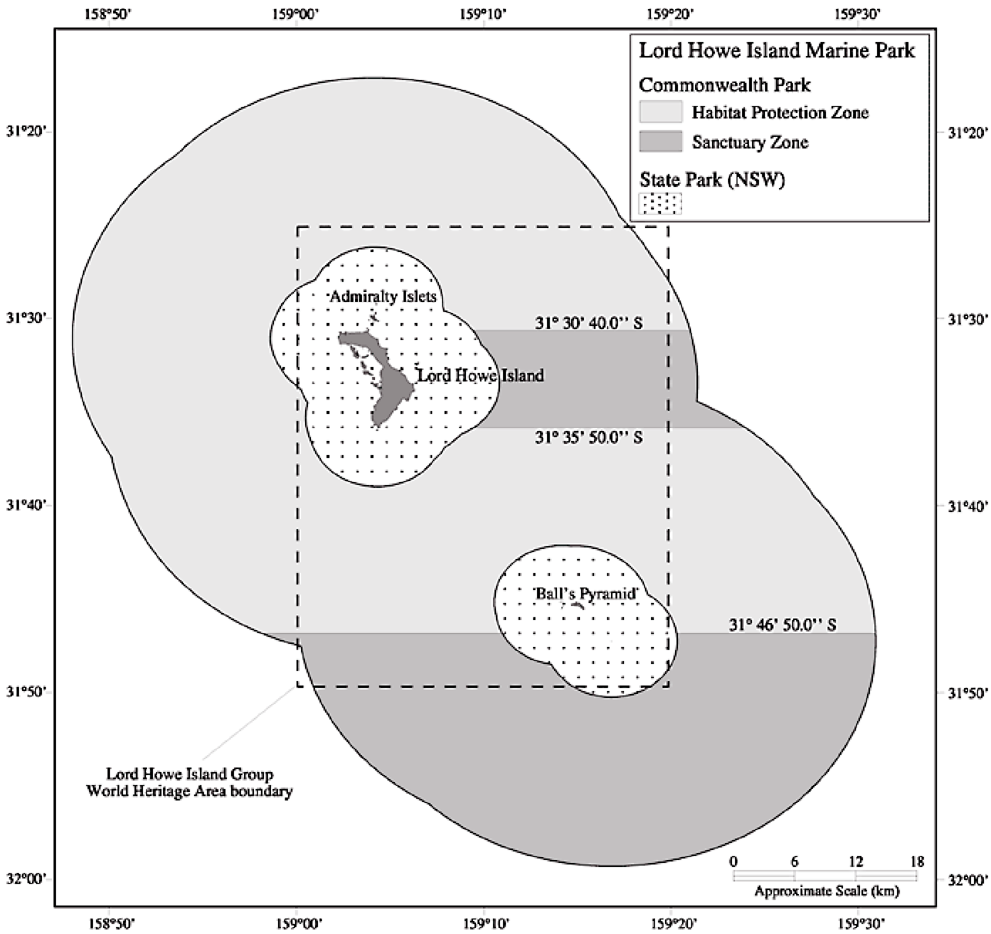


Figure 1.3: *Zoning in the Lord Howe Island Marine Park (LHIMP Management Plan 2002).*

2. METHODS

2.1. SURVEY AREA

The main focus of the survey was the shallow shelf surrounding Lord Howe Island, which ranges in depth from 25 to 150 m (see voyage summary, Appendix 6.1). Multibeam acoustic data were collected for the majority of the shelf, with the exception of the inshore areas where the vessel could not be operated. The acoustic data collected included multibeam bathymetry and backscatter data and acoustic sub-bottom profiles. Physical samples were also attained of the shelf surface through grab sampling, and the upper relict reef with drill cores. Additionally, limited towed video footage was collected, supplemented with the Australian Institute of Marine Science (AIMS) seabed video descriptions (Speare et al., 2004) and the New South Wales Government (Department of Environment, Climate Change & Water, DECCW) Baited Remote Underwater Video (BRUV) footage.

2.2. BATHYMETRY DATA

Multibeam sonar bathymetry

A large majority of the shelf on which Lord Howe Island sits was swath mapped using the Southern Surveyor's 30 kHz Simrad EM300 multibeam echo sounder. The EM300 system is a mid-water system and was adjusted to perform optimally in the shallower depth ranges encountered on the shelf. Coverage extended across the shelf as shown by the vessel's track lines (Figure 2.1). A Reson 8101 multibeam sonar system was also installed on the vessel to collect higher-resolution data, but unfortunately the system's data acquisition unit was unable to continuously record input from the ship's motion sensing system and no usable bathymetry data were collected.

Supplementary bathymetry data

Supplementary data were used to provide coverage of the areas unable to be mapped with the ship's multibeam system. This area comprised approximately 80 km^2 of the 500 km^2 shelf. Sources of the legacy multibeam data, single beam data and additional data are listed in Table 2.1. These data included high-resolution (2.4 m grid) very shallow (<15 m) bathymetry around Lord Howe Island derived from a Quickbird (satellite) scene by Stephen Sagar (GA; described in detail in Mleczko et al., in prep.). The distribution and extent of these datasets are shown in Figures 2.2 and 2.3. Significant coverage of the eastern lagoon is provided by the Navy's Laser Airborne Depth Sounder (LADS, Fig. 2.3) data grid, which has a 35 m cell size (Appendix 6.3). Supplementary data were merged with Southern Surveyor SS0608 multibeam data and gridded using Intrepid software. More information on the supplementary data is provided in Appendix 6.4 and Mleczko et al. (in prep).

Table 2.1: *Bathymetric data sources for the Lord Howe area (AHS – Australian Hydrographic Service; CSIRO – Commonwealth Scientific & Industrial Research Organisation; BGR – Federal Institute for Geosciences and Natural Resources, Germany; GA – Geoscience Australia; NGDC – National Geophysical Data Centre, USA).*

Survey Name	Vessel Name	Data Type	Source Institution
"AHS Chart"	unknown	chart	AHS
"AHS LADS"	unknown	LADS	AHS
Sonne 7	R/V Sonne	echo sounder	BGR
Sonne 36A	R/V Sonne	echo sounder	BGR
FR01/97	R/V Franklin	echo sounder	CSIRO
FR12/98	R/V Franklin	echo sounder	CSIRO
TAN0308 - NORFANZ	R/V Tangaroa	multibeam	CSIRO
SS0906	R/V Southern Surveyor	multibeam	CSIRO
SS0608	R/V Southern Surveyor	multibeam	CSIRO
SS2009 T02	R/V Southern Surveyor	multibeam	CSIRO
GA 12	M/V Hamme	echo sounder	GA
GA 14	M/V Lady Christine	echo sounder	GA
GA 15	M/V Lady Christine	echo sounder	GA
GA 77	R/V rig Seismic	echo sounder	GA
GA 222 – AUSTREA 1	N/O L'Atalante	multibeam	GA
TAN0713	R/V Tangaroa	multibeam	GA
"Satellite data"	Quickbird satellite scene - 9/Feb/2009	derived bathymetry	GA
ETOPO1		grid	NGDC
VI49	M/V Vityaz	echo sounder	NGDC
DME06	M/V Dmitrij Mendeleev	echo sounder	NGDC
19920013	HMY Britannia	echo sounder	NGDC
EW9202	R/V Maurice Ewing	multibeam	NGDC
"CEEDUCER"	unknown	echo sounder	University of Wollongong

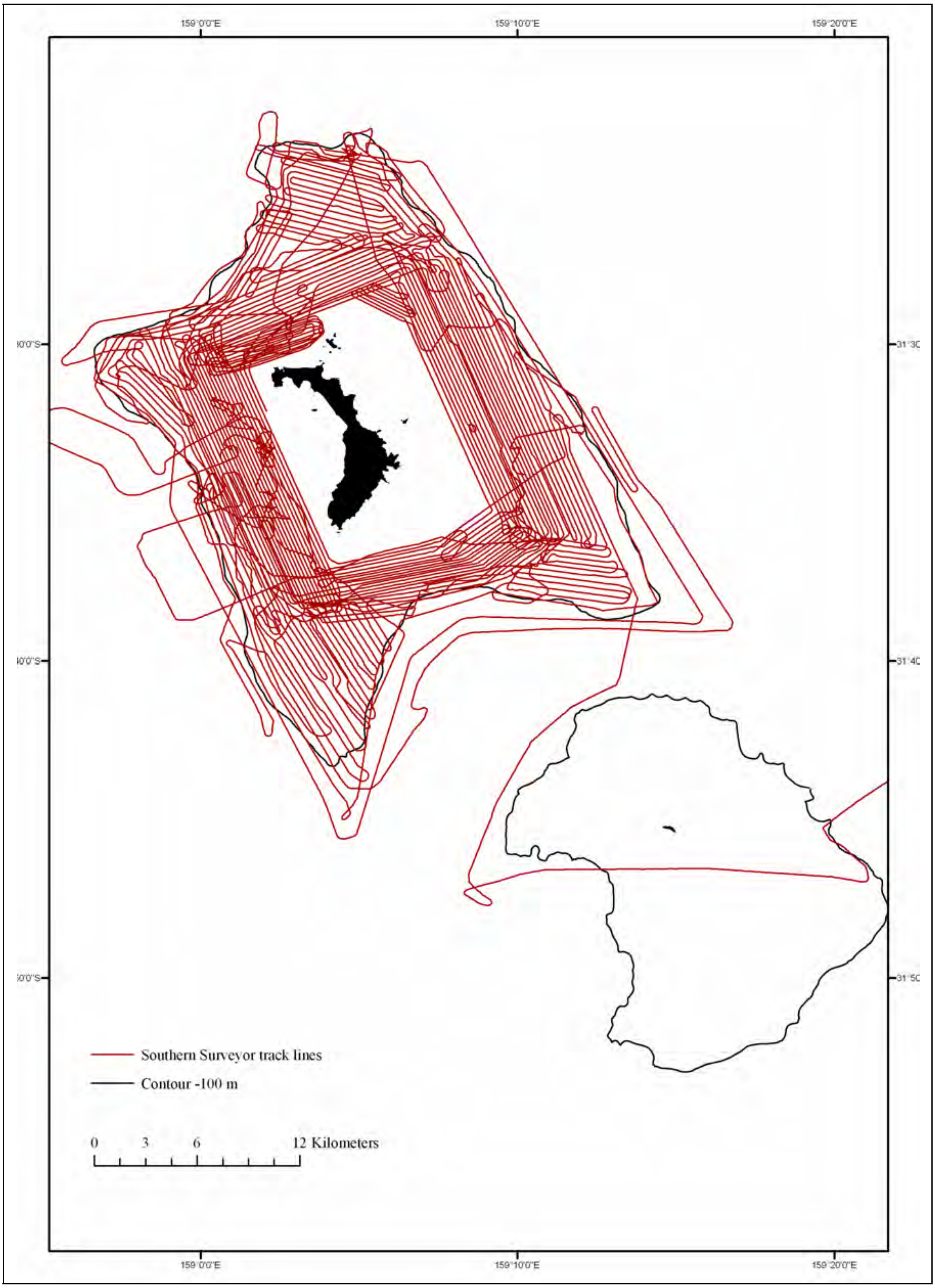


Figure 2.1: *Southern Surveyor SS0608 track lines completed during data collection with the EM300 multibeam sonar and TOPAS sub-bottom profiler.*

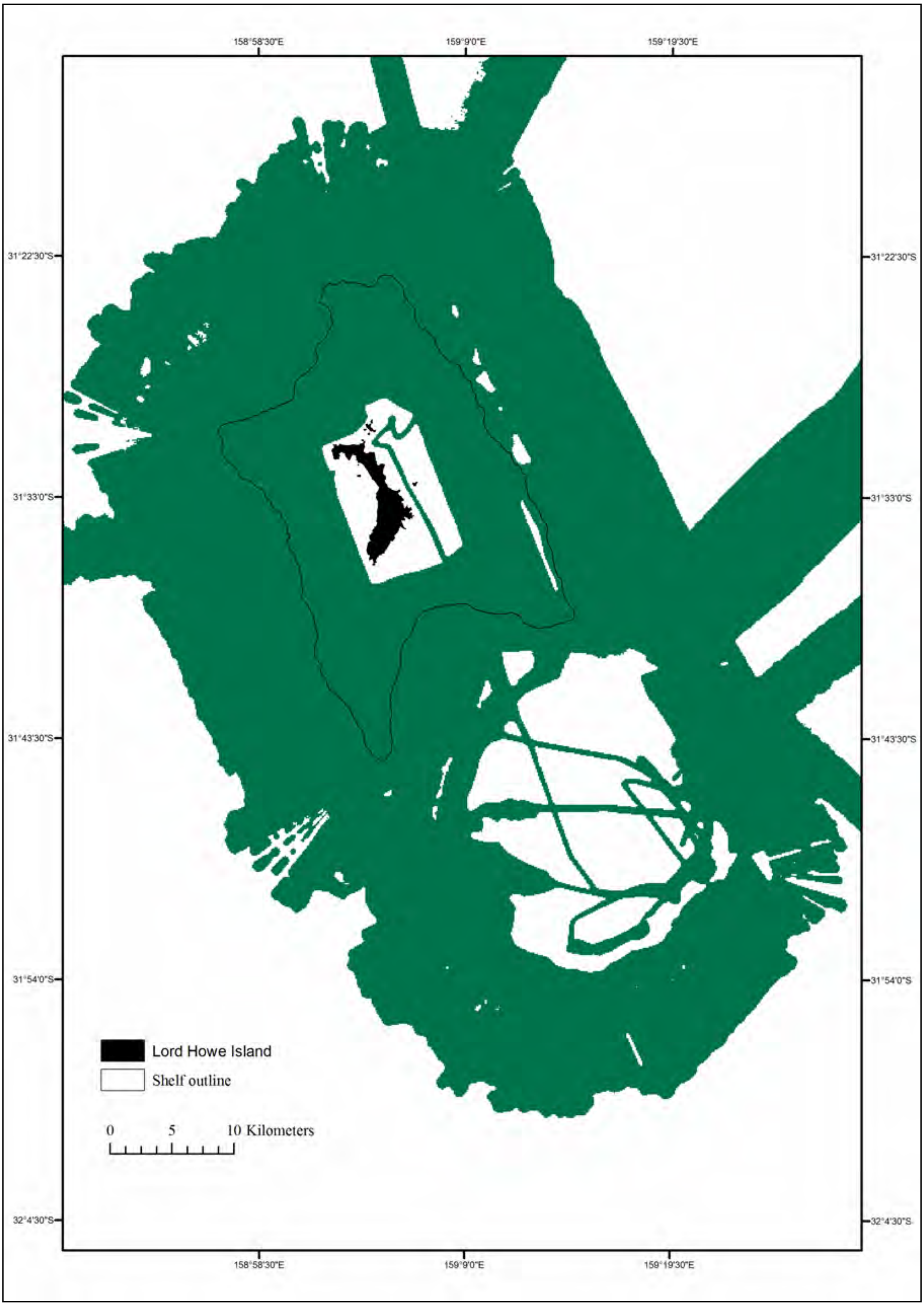


Figure 2.2: *Coverage of multibeam data from sources outlined in Table 2.1.*

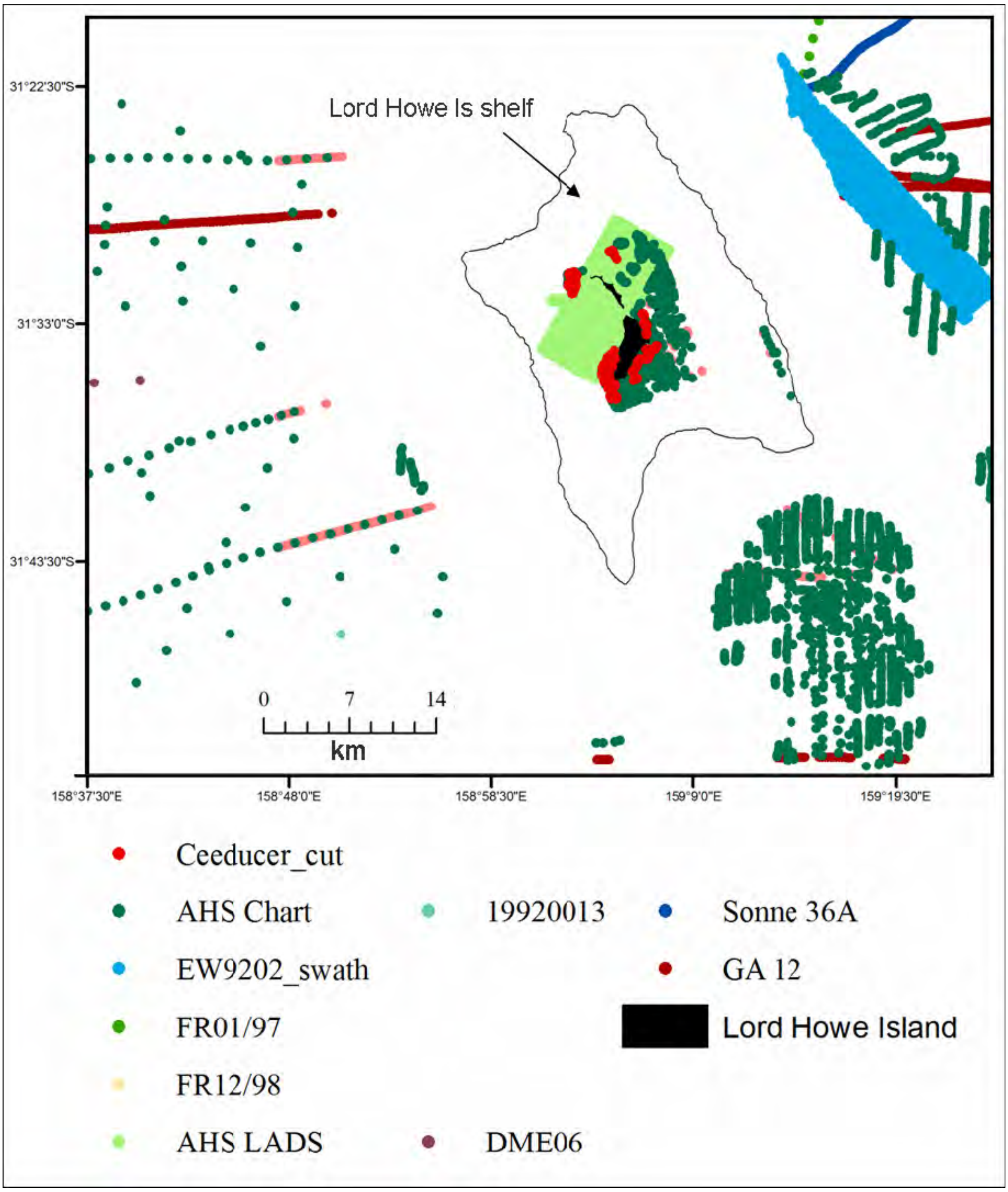


Figure 2.3: *Single-beam and LADS bathymetry data included in the DEM of the Lord Howe Is volcano and shelf. These data were only used outside the coverage of multibeam sonar bathymetry data, as shown on this map (single-beam data have been cropped). See Table 2.1 for details of data sources as listed in the legend.*

2.3 MULTIBEAM ACOUSTIC BACKSCATTER DATA

The EM300 backscatter data for the shelf is affected by the system's near-field effect due to the shallow water depth relative to the systems optimum depth range (~100 – 3000m). However, the backscatter data appear to still usefully differentiate unconsolidated material from hard surfaces. The backscatter data were processed using software co-developed by Geoscience Australia and Centre for Marine Science and Technology, Curtin University of Technology (CMST-GA MB Toolbox). To validate this process, the data were compared to the output from commercially available ENVI software and were found to produce a highly accurate representation. To create a near-continuous layer, a backscatter grid with 8 m cells was produced.

2.4 MORPHOLOGICAL CLASSIFICATION OF SHELF ENVIRONMENTS

Five primary criteria were used to map the shelf's geomorphologic features: 1) bathymetry; 2) slope; 3) rugosity; 4) backscatter and 5) visual morphological attributes. A high resolution (5 m cell size) slope map was generated using Fledermaus V7 software. To calculate rugosity (3D surface area divided by planar area) a script developed by Zhi Huang (GA) using equations derived from Jenness (2004) was employed. Data grids of 8 m cells were generated for surface area, as well as topographic relief and Local Moran's I.

Digitisation of features was performed at spatial scales set by the resolution of available datasets and the size of features (Table 2.2). Digitisation and calculation of zonal statistics was completed using an interpolated bathymetry grid (100 m cell size) created by Linklater (2009).

Table 2.2: *Spatial resolution and scale at which shelf geomorphic features were mapped (Linklater 2009).*

Geomorphic features	Cell Size of DEM	Cell Size of Slope Map	Map Scale
Shelf	4 m	5 m	1 : 20,000
Outer Shelf	4 m	5 m	1 : 20,000
Northern Shelf	4 m	5 m	1 : 50,000
Relict Reef	4 m	5 m	1 : 15,000
Upper Relict Reef	4 m	5 m	1 : 15,000
Basins	100 m	100 m	1 : 40,000
Passages	4 m	5 m	1 : 18,000
Fringing reef	35 m	35 m	1 : 20,000
Lagoon	35 m	35 m	1 : 20,000
Rugose nearshore	35 m; 100 m	35 m; 100 m	1 : 30,000
Spur and Grooves	4 m	5 m	South = 1 : 18,000 East/West = 1 : 7,000

2.5 ACOUSTIC SUB-BOTTOM PROFILES

The acoustic signal of sub-bottom profilers is both reflected from the seafloor and penetrates the seafloor to varying degrees depending on the type of substrate. The sub-bottom signal is reflected when it encounters boundaries between sediment layers that have different acoustic impedance. This reflected signal provides information on the stratigraphy and type of sediment that has accumulated. The Southern Surveyor's TOPAS PS 18 Parametric Sub-bottom Profiler was operated in conjunction with the multibeam system (Figure 2.1). A Sparker sub-bottom profiler was deployed on two occasions during the survey but failed to produce a useful signal at least in part due to the high ambient noise created by waves and strong wind. The extensive coverage of the shelf by the TOPAS profiler provided substantial sub-surface data. Excellent penetration across areas of unconsolidated sediment provided high-resolution data that showed a range of discernable stratigraphic features.

2.6 SEABED SAMPLING

2.6.1 Grab samples

For each sample station (Figure 2.4), a Smith-McIntyre bottom sediment sampler (10 litre, 0.1 m^2 gape) was operated from the starboard deck of Southern Surveyor. The grab was used to collect sediment and infauna samples. It uses a spring-loaded scoop triggered by contact with the seabed and can collect an intact sample of sediment. Upon triggering, the grab immediately covers the sample, which prevents disturbance during retrieval to the surface. In some locations, three replicate samples were taken.

Visual descriptions of the grab samples were categorised based on sediment class (such as sand and gravel) and other constituents (such as basalt and rhodoliths). Sediment grain size, sorting and calcium carbonate content were measured in the sedimentology laboratory at Geoscience Australia. Percentages of mud, sand and gravel were measured with sieves, and the grain size distribution of the sand and mud component was measured with a Malvern Mastersizer laser analyser. Sample metadata is provided in Appendix 6.5.

2.6.2 Biological samples

Samples were collected using the Smith-McIntyre grab sampler. After a sub-sample was removed from the grab for sediment analysis, the remaining sample was then washed into a Nally bin, excess water was decanted into a 0.5 mm sieve and the sample was weighed. The sample was then washed through a 0.5 mm sieve and the retained material preserved in 90 % ethanol. Any macrofauna seen during this process were carefully removed, photographed, and preserved. Larger polychaetes and cnidarians were preserved in 4% buffered formalin while other taxa, such as crustaceans and echinoderms, were preserved in 90% ethanol for later identification in the laboratory.

2.6.3 Underwater coring and sample dating

The underwater rock corer was deployed at 6 sites (Figure 2.4) during the two days when sea conditions were calm enough to work safely on the aft deck and for the vessel to be held stable with the dynamic positioning system. The cores penetrated the upper few metres of the relict reef. Core recovery was considerably less than penetration and the recovered depths were extrapolated to penetrated depths using drill time and penetration rate data collected at each deployment of the corer (Appendix 6.5). The cores were analysed in terms of their composition, appearance (detailed descriptive lithological and facies logs) and age (Appendix 6.6).

Material that visually appeared most suitable for age analyses was extracted from the cores, assessed for aragonite and calcite content by XRD to determine whether the samples were suitable for dating (Appendix 6.7). If suitable the material was dated using two techniques. Radiocarbon Accelerator Mass Spectrometry (AMS) was performed at the ANTARES facility at ANSTO. Samples were cleaned in an ultrasonic bath (deionised water), dried in an oven for two days (60˚C), hydrolysed to carbon dioxide (using 85% phosphoric acid) and converted to graphite using the methods of Zn/Fe outlined by Hua et al. (2001). Thermal Ionisation Mass Spectrometry was performed by the University of Queensland. For mass fractionation of the samples, a known $^{236}U/^{233}U$ ratio in a ^{229}Th-^{233}U-^{236}U mixed spike was used, with the remaining methodology following procedures of Zhao et al. (2001). Calibration of radiocarbon ages were carried out using the CALIB 5.01

program and the ΔR value of -11 ± 39 calculated from the paired TIMS and AMS ages of samples within 13RDC01-016 and 15RDC01-040.

2.6.4 Towed Underwater Video

The video system was employed at only one station, due to technical problems and adverse weather conditions. The position of the track line is shown in Figure 2.4. To gain further understanding of the seafloor habitats and composition, BRUV images captured by the NSW Department of Environment, Climate Change and Water in November 2009 (Appendix 6.8) and pre-existing towed video footage and benthic habitat descriptions undertaken by the Australian Institute of Marine Science (Speare et al. 2004; see Appendix 6.9) were utilised.

2.7 NEAR BED CURRENT MEASUREMENTS

As part of Geoscience Australia survey TAN0713 to the Lord Howe Rise, an oceanographic mooring was deployed on the northern edge of Lord Howe Island shelf to collect current data (velocity and direction) for the period 28/10/2007 to 26/4/2008 (Heap et al. 2009). The mooring was deployed at station 23 (-31^{o} 24.000’ S, 159^{o} 04.870’) in a water depth of 59 m and housed an Acoustic Doppler Current Profiler (RD Instruments Workhorse Sentinel 600 kHz ADCP). The ADCP collected velocity measurements through a vertical profile that extended from 3 to 25 m above the seabed, in addition to near-bed water temperature and water depth. The instrument was not programmed to collect wave data. The ADCP mooring was retrieved toward the end survey SS06-2008 by means of a grappling hook to the 100 m ground line following failure of the acoustic release mechanism.

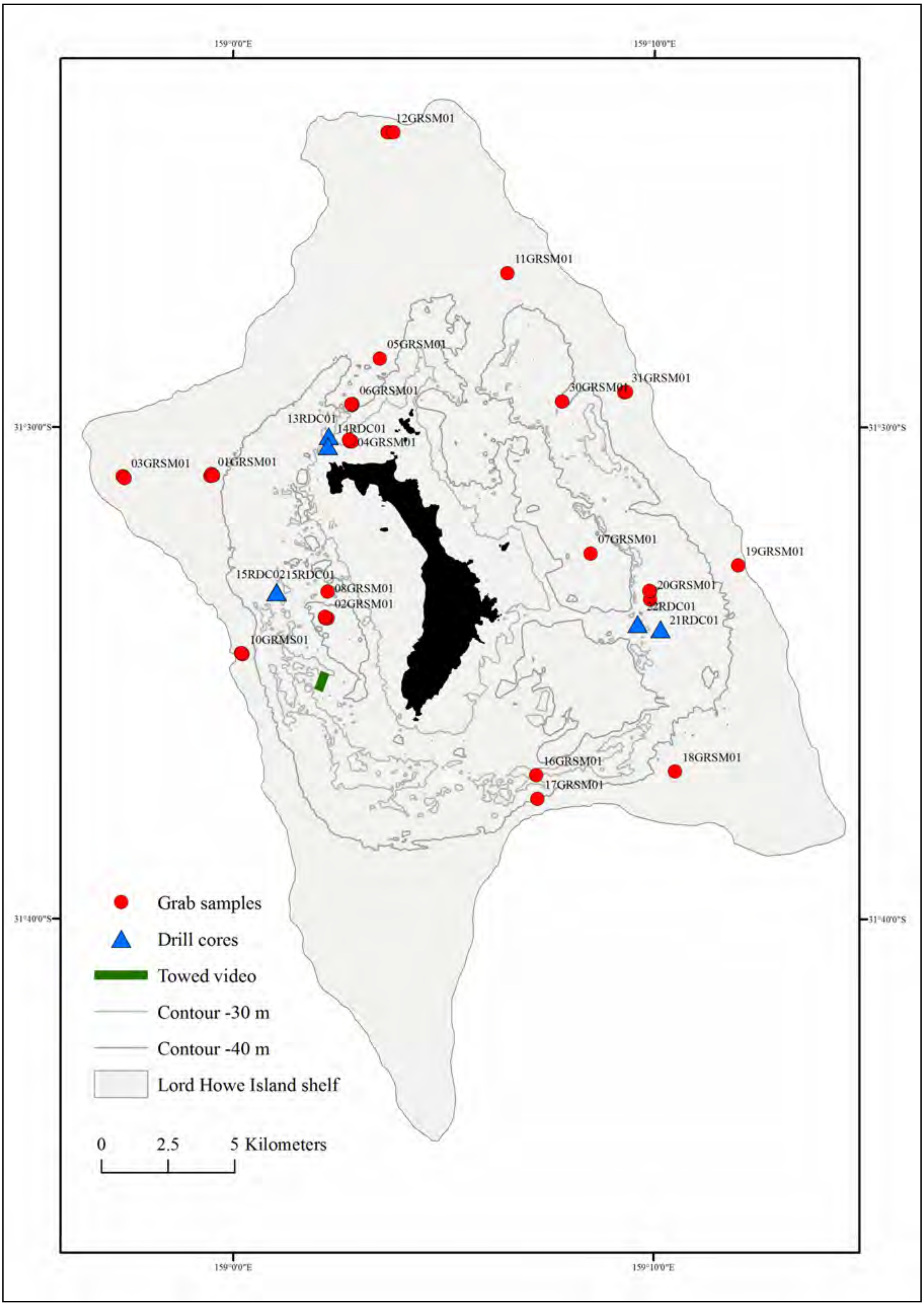


Figure 2.4: *Location of grab samples, drill cores and towed video data R.V. Southern Surveyor 2008 voyage. Multiple grab samples were collected at some stations, see Appendix Table 6.2.1. For details of the towed video station see Appendix Table 6.2.3*

3. Results

3.1 MULTIBEAM SONAR MAPPING

Bathymetry data grids of the shelf were created at 4 m and 8 m cell size, with grids of the entire volcano produced at 40 m and 100 m cell size (Figures 3.1, 3.2 and 3.3). Given the vertical and horizontal errors inherent within the equipment, multibeam data have vertical uncertainties of approximately ± 0.02 m and horizontal uncertainties no more than ± 5 m. The swath mapping clearly defines the extent of the relict reef structure on the shelf surrounding Lord Howe Island.

Balls Pyramid

One transect only of swath was acquired across the shelf surrounding Balls Pyramid because of time constraints and bad weather. Initial interpretation suggests that there may be features similar to those on the Lord Howe shelf, and further mapping could better define the morphology of this area.

3.1.1 Surface Analysis

Slope:

The multibeam sonar data (Figure 3.2) were used to generate a slope map (Figure 3.3). The steepest areas occur at the shelf break, the inner margin of the relict reef and on the northern shelf. Gentle slopes are found across most of the outer and inner shelf areas.

Morphology:

Areas of greater topographic heterogeneity (Figure 3.4), relief (Figure 3.5) and roughness (Figure 3.6) occur along the shelf break, the inner rim of the relict reef, the upper surface of the relict reef and on sections of the northern shelf.

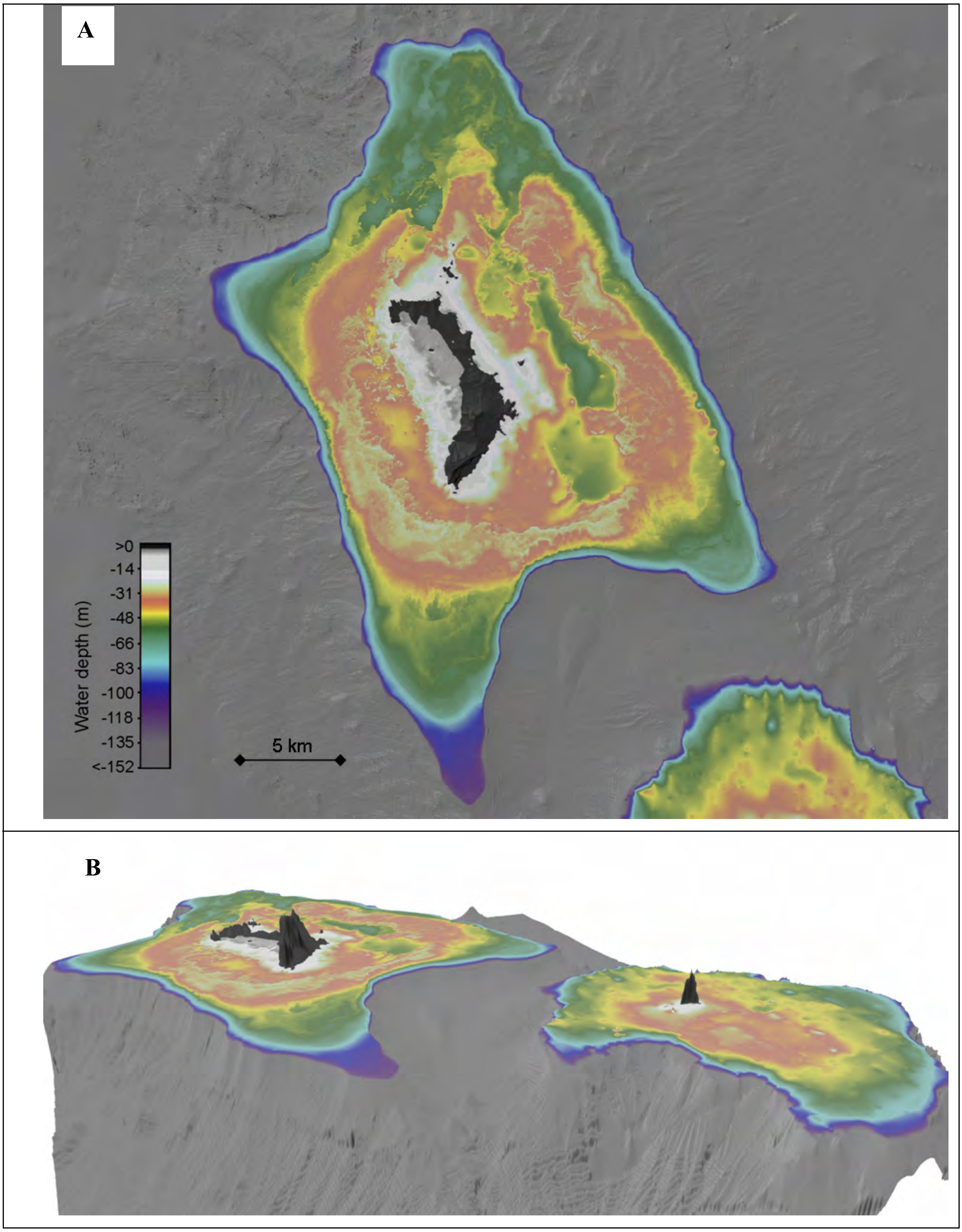


Figure 3.1: *Bathymetric models of the Lord Howe Island shelf based on the collated multibeam sonar, LADS, Quickbird and single-beam sonar bathymetric data (Table 2.1). A: The shelf around Lord Howe Island showing the extensive relict reef feature (red - grey). B: Three dimensional image of the Lord Howe Island and Balls Pyramid shelves.*

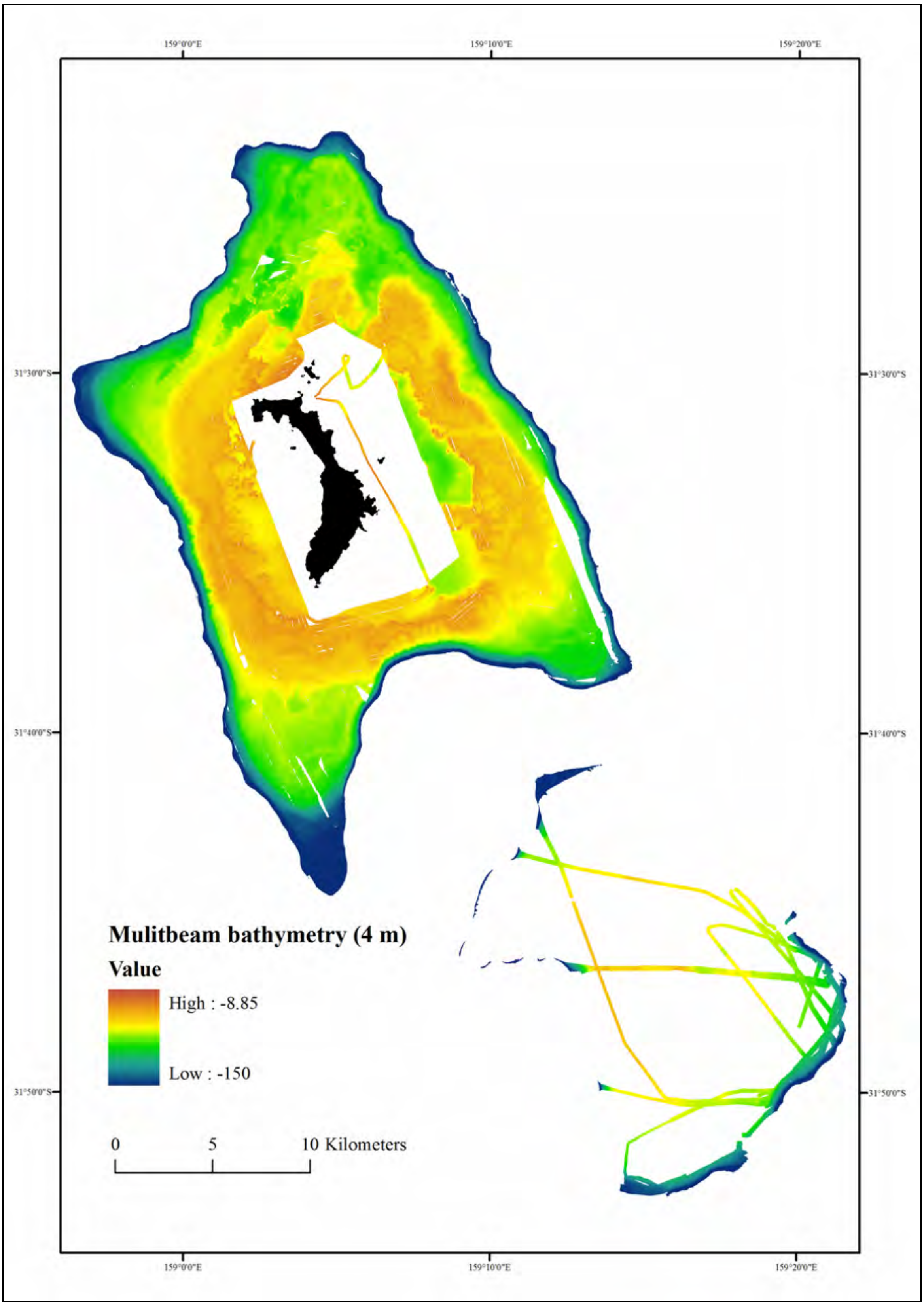


Figure 3.2: *Bathymetry of shelf generated from a bathymetry grid with 4 m cells.*

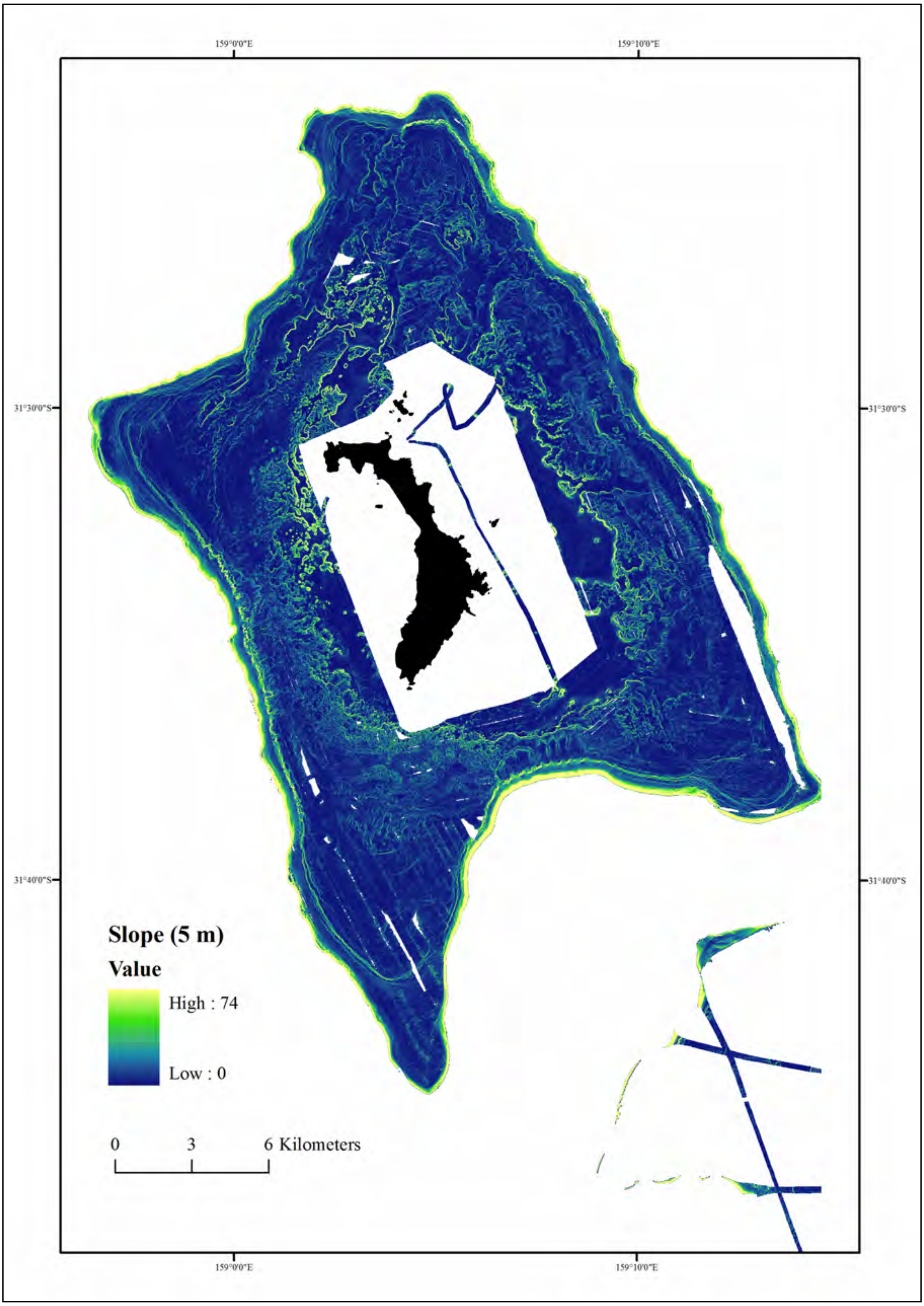


Figure 3.3: *Slope map produced using bathymetry with 4 m cells. Steep areas are green-yellow, lower gradient areas are dark blue.*

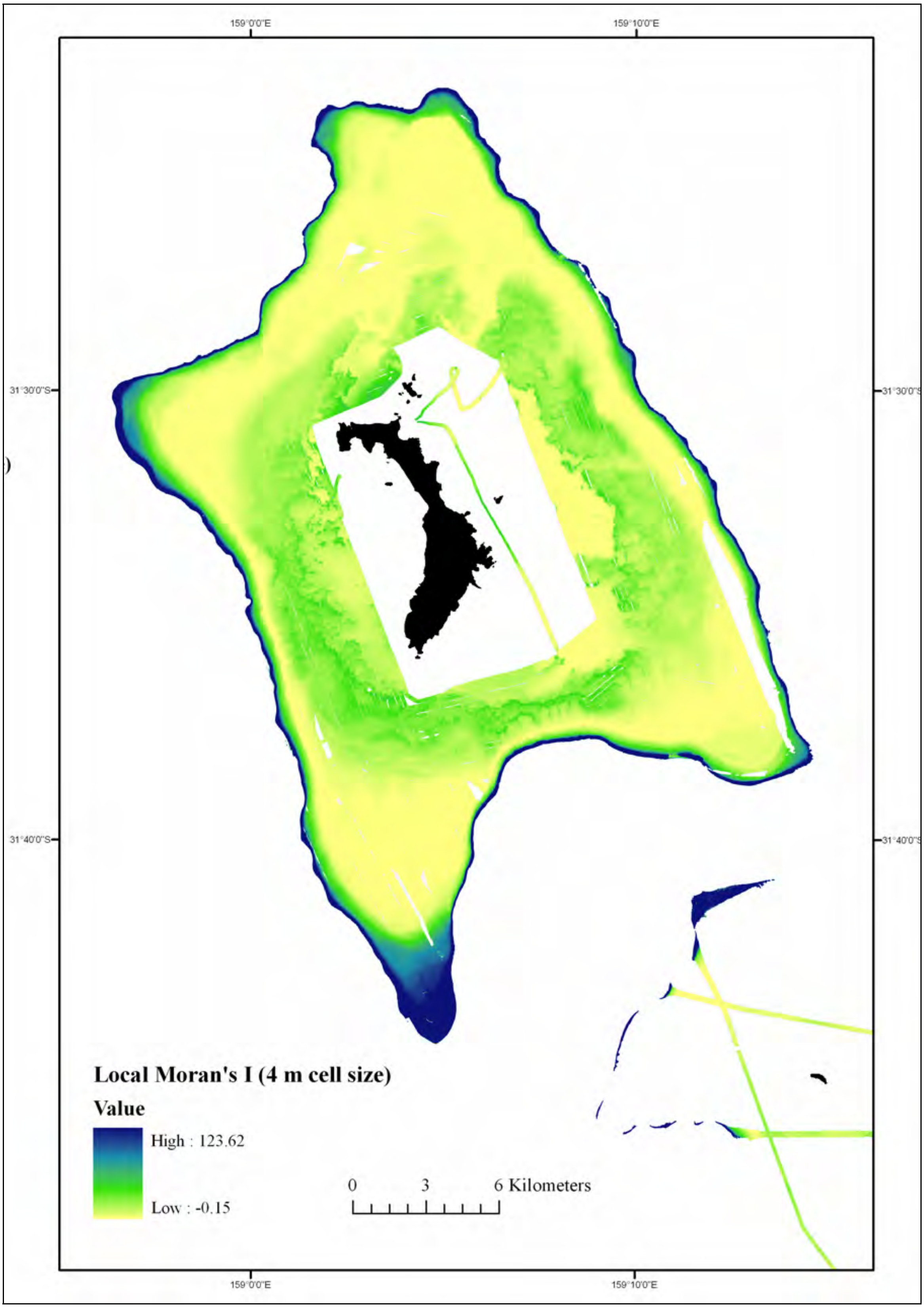


Figure 3.4: *Seabed topographic heterogeneity as represented by the Local Moran's I parameter. High values indicate a greater degree of local uniformity of seabed topography.*

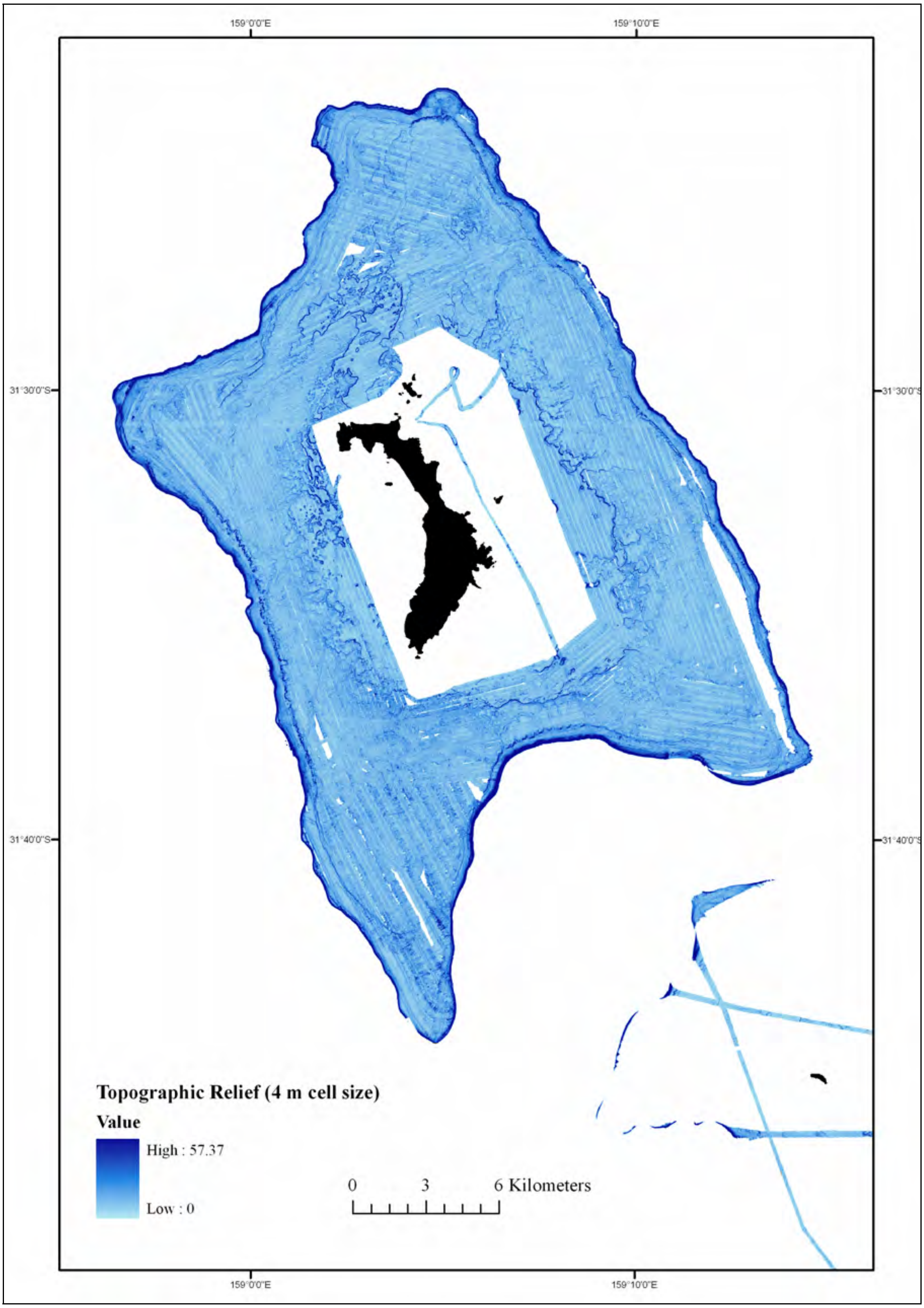


Figure 3.5: *Topographic relief of the shelf.*

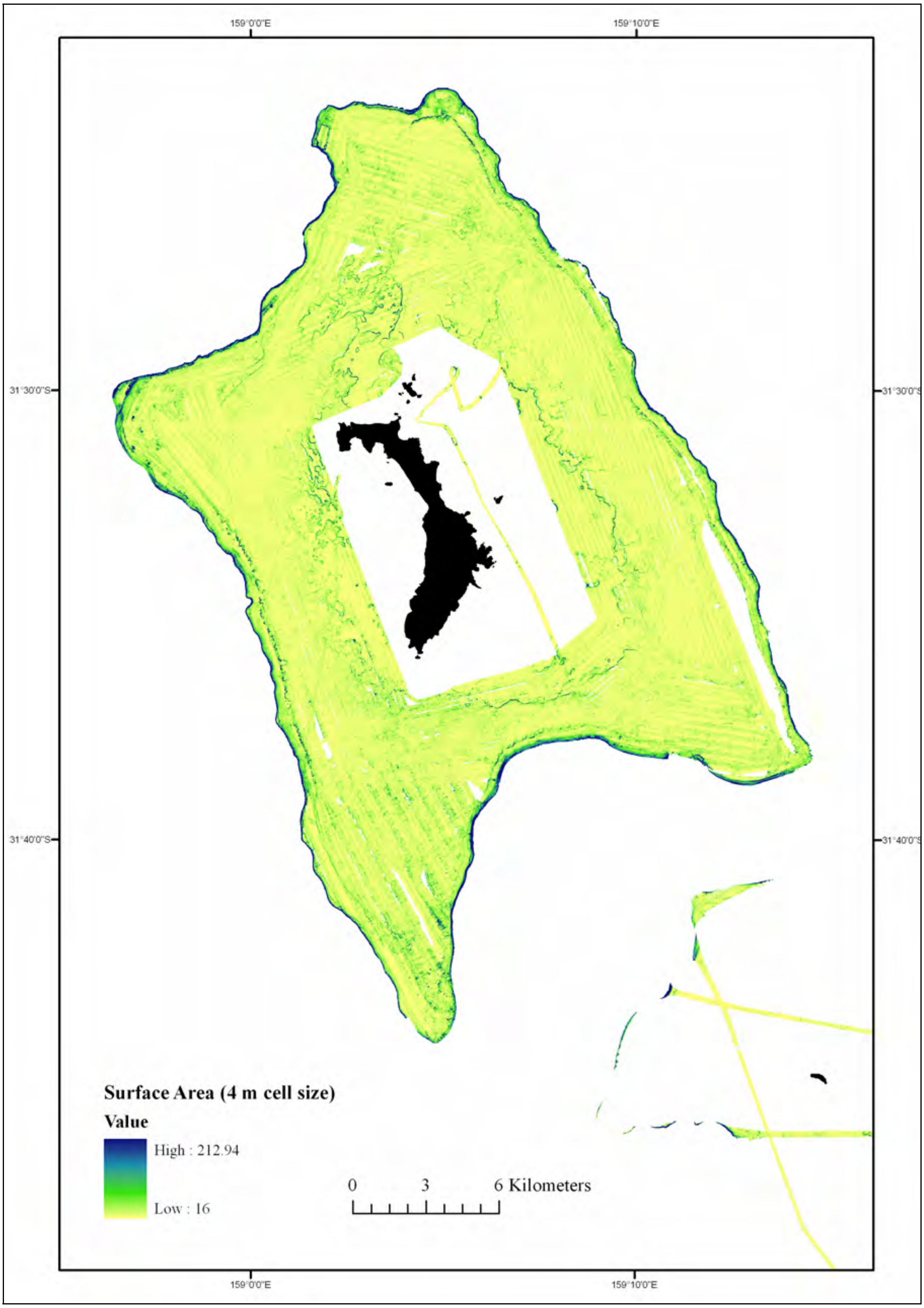


Figure 3.6: *Shelf roughness as indicated by the Surface Area parameter.*

3.2 MORPHOLOGICAL CLASSIFICATION OF FEATURES:

Large areas of the shelf lie in depths of around 25 – 45 m and 50 – 60 m (Figure 3.7). These areas represent the submerged or relict reef and adjacent sandy basins, respectively. The modern fringing reef on the island's western coast largely lies in depths of 0 – 10 m, in contrast to the relict reef. Classification of the shelf divided the environment into ten key morphological features (Figure 3.8). Zonal statistics were calculated for each feature class and are shown in Tables 3.1 and 3.2. A detailed description of the mapping method is provided in Linklater (2009). A generalised morphological classification of the shelf comprising six broad-scale features (outer shelf, relict reef, basin, inner shelf, fringing reef, lagoon) was also produced by combining similar classes (Figure 6.11.1).

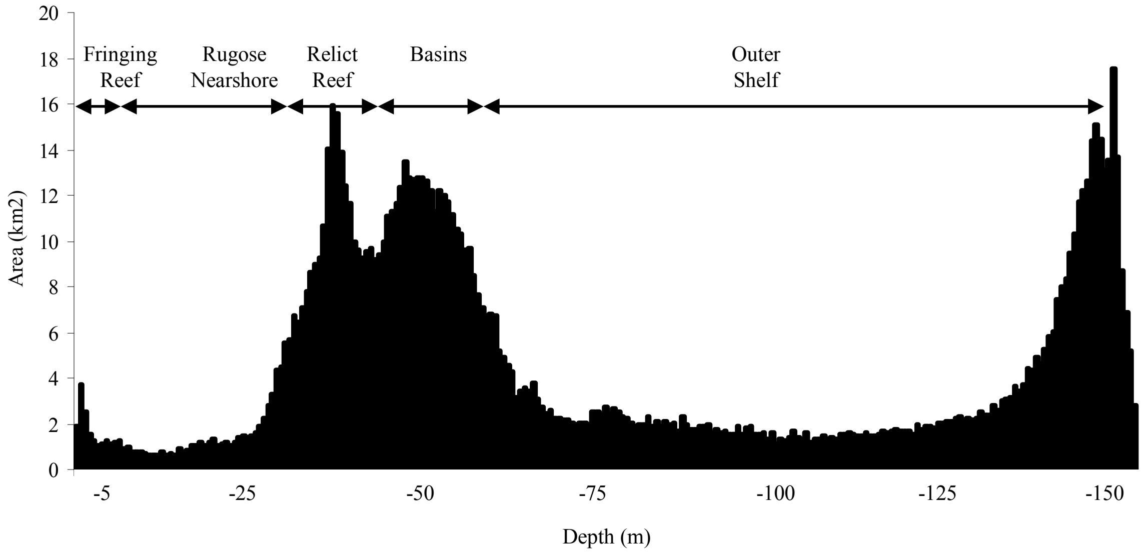


Figure 3.7: *Hypsometric curve of depth data across Lord Howe shelf. Depths greater than 120 m were removed in the morphological classification.*

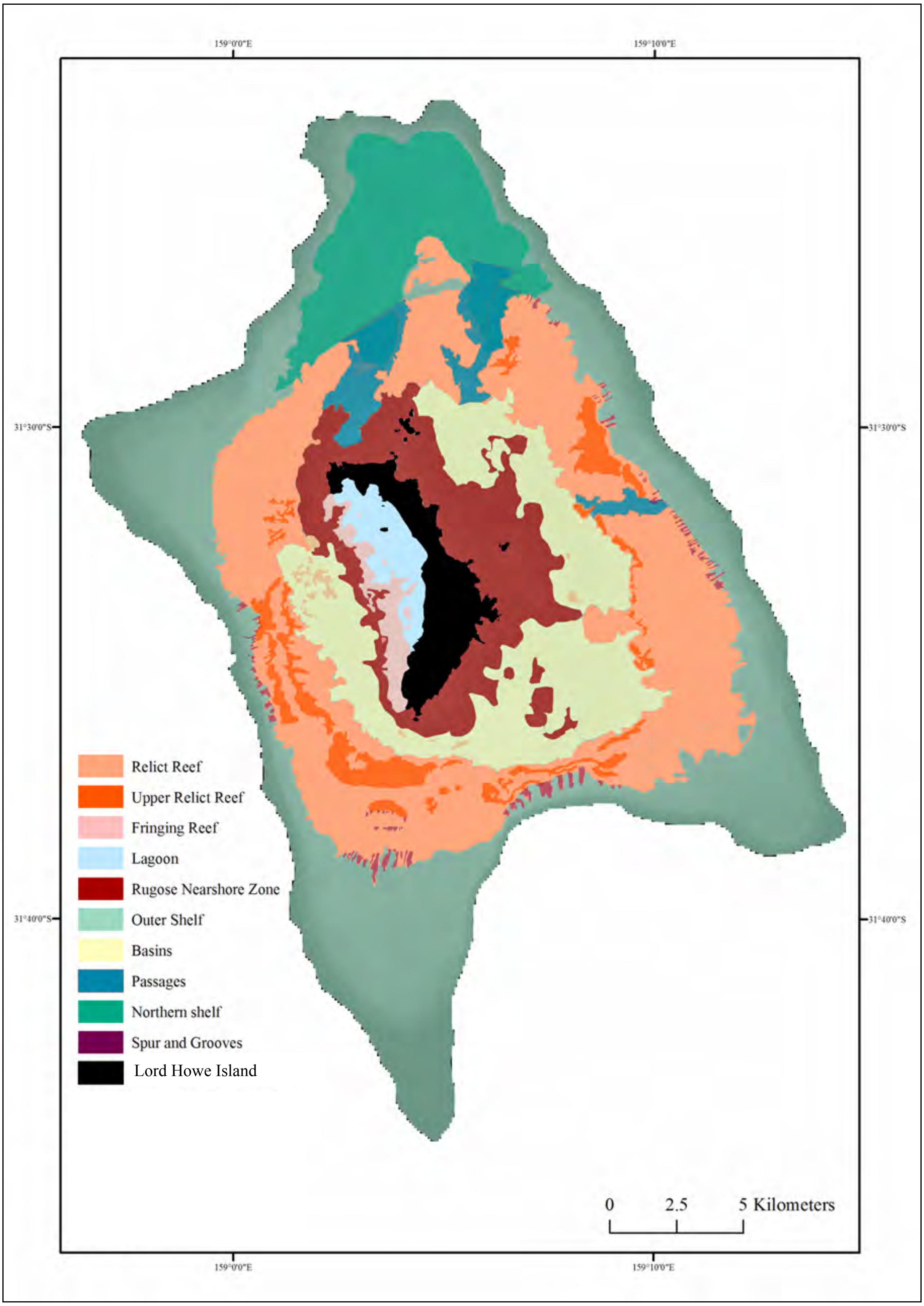


Figure 3.8: *Fine-scale morphological classification of the shelf around Lord Howe Island (Linklater,2009).*

Table 3.1: *Dimensions and zonal statistics of the morphological habitats on the shelf using bathymetry grid (100 m cell size) from Linklater (2009).*

Geomorphological Feature	Length (km)	Width (km)	Area (km2)	Deepest (m)	Shallowest (m)	Mean Depth (m)	± STD (m)
Shelf	31.7	21.4	511.9	-143.3	4.3	-46.3	21.1
Outer Shelf	31.7	21.4	166.5	-143.3	-30.1	-65.7	17.4
Northern Shelf	10.3	11.2	45.3	-67.2	-40.7	-56.3	3.4
Relict Reef	22.3	5.8	144.9	-53.4	-23.5	-38.6	3.5
Upper Relict Reef	-	1.6	17.3	-40.1	-23.5	-30.0	1.7
Rugose nearshore	13.4	4.1	48.8	-55.3	2.4	-34.5	4.7
Fringing reef	8.6	1.7	8.9	-32.1	-0.1	-11.1	2.9
Lagoon	7.0	2.4	5.9	-18.4	2.1	-2.3	3.2
Basins - Eastern	11.3	3.4	20.7	-60.8	-26.8	-49.5	5.3
Basins - Western	10.5	2.9	16.2	-48.4	-23.1	-38.1	3.4
Basin - Southern	7.2	3.6	24.3	-54.0	-29.9	-46.1	4.7
Passage 1	2.5	5.0	7.4	-59.2	-21.4	-42.2	6.7
Channel 1	1.9	1.9	2.5	-67.1	-34.3	-58.1	4.1
Passage 2	1.9	4.5	5.7	-62.1	-35.8	-50.9	3.9
Channel 2	1.1	2.8	2.3	-64.1	-49.3	-58.4	2.3
Passage 3	1.1	3.1	1.8	-47.6	-28.0	-39.6	2.2
Spur and Grooves (all)	-	-	3.2	-49.4	-28.5	-39.8	1.2

Table 3.2: *Dimensions and sinuosity of passages on the Lord Howe Island shelf using bathymetry grid (100 m cell size) from Linklater (2009).*

PASSAGES	Oceanward entrance width (km)	Landward entrance width (km)	Passage width (km)	Straight length (km)	Sinuous length (km)	Sinuosity value
Passage 1	2.93	0.88	2.45	4.95	5.12	1.03
Channel 1	2.25	-	1.80	1.88	1.86	0.99
Passage 2	1.95	0.89	1.91	4.49	4.69	1.04
Channel 2	1.67	-	1.12	2.84	2.91	1.02
Passage 3	0.37	1.11	1.14	3.07	3.20	1.04

Relict Reef:
The seabed relief models reveal an extensive reef structure on the middle shelf that surrounds Lord Howe Island. The depth and morphology of this structure suggests it is a relict barrier reef system, typical of many modern coral reefs. Coral reef morphology is best developed on the southern, eastern and western margins (Figures 3.2, 3.8, 3.9), and what appear to be inter-reef channels or passages dissect the relict reef in the northeast.

The area of the relict reef is 144.9 km^2, which represents 28% of the shelf. The average depth of the reef is 39 m (± 3.5 m). The reef averages 2.5 to 3.5 km in width. It is widest in the southeast, where it reaches 5.8 km, and narrowest in the south at 0.5 km. The reef extends more than 7.5 km outboard of the island.

The surface of the reef exhibits two main morphologies (Figure 3.9). In the inner area it is rough and highly rugose, while the outer reef is relatively smooth with gently sloping surfaces. Rugosity is greatest on the margin of the inner reef, where in places it merges with the nearshore zone. Delineation of the relict reef and rugose nearshore features is largely based on their location, and further investigation into the surface structure and composition of these features is required to better determine whether they represent distinctive benthic habitats. The eastern section of relict reef has relatively steep inner and outer margins, with a sharp change in slope between the reef and the inshore sandy basin that increases northwards (Figure 3.9).

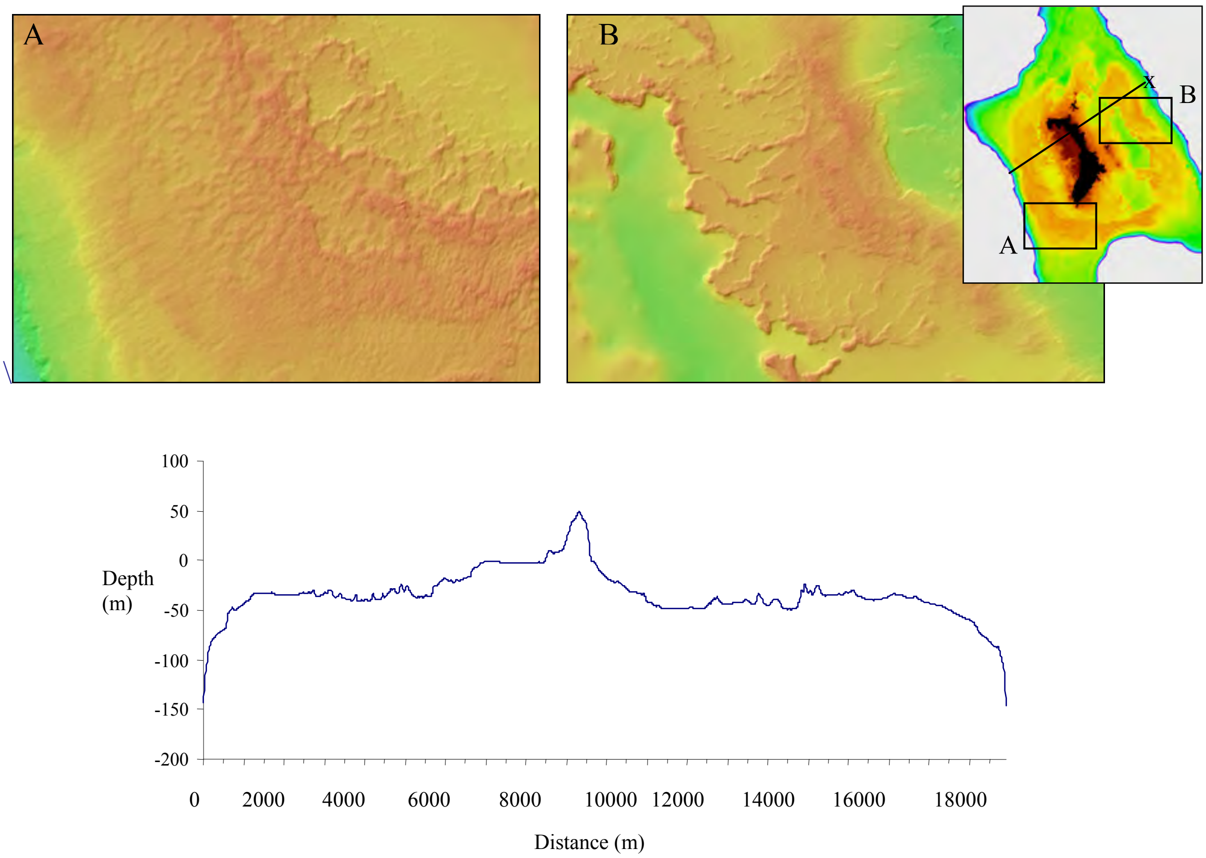


Figure 3.9: *Images of representative areas of the relict reef: (A) the extensive western reef; (B) eastern reef and sandy basin (green). The profile depicts relief across the shelf. Inset map shows location of profile, with X marking the end of the profile.*

Shelf and Outer Shelf:

The total shelf area is 511.9 km^2 with an E-W width of 21.4 km and N-S length of 31.7 km. The depth of the shelf break lies between 143 to 30 m, though it predominantly occurs at 85 to 100 m. Several distinct terraces occur around the outer margin of the shelf in depths of 57 to 80 m (Figure 3.10).

The outer shelf is relatively smooth with occasional shallow depressions between the shelf edge and the relict reef. This feature is best developed in the southwest where it extends 10.4 km out from the relict reef.

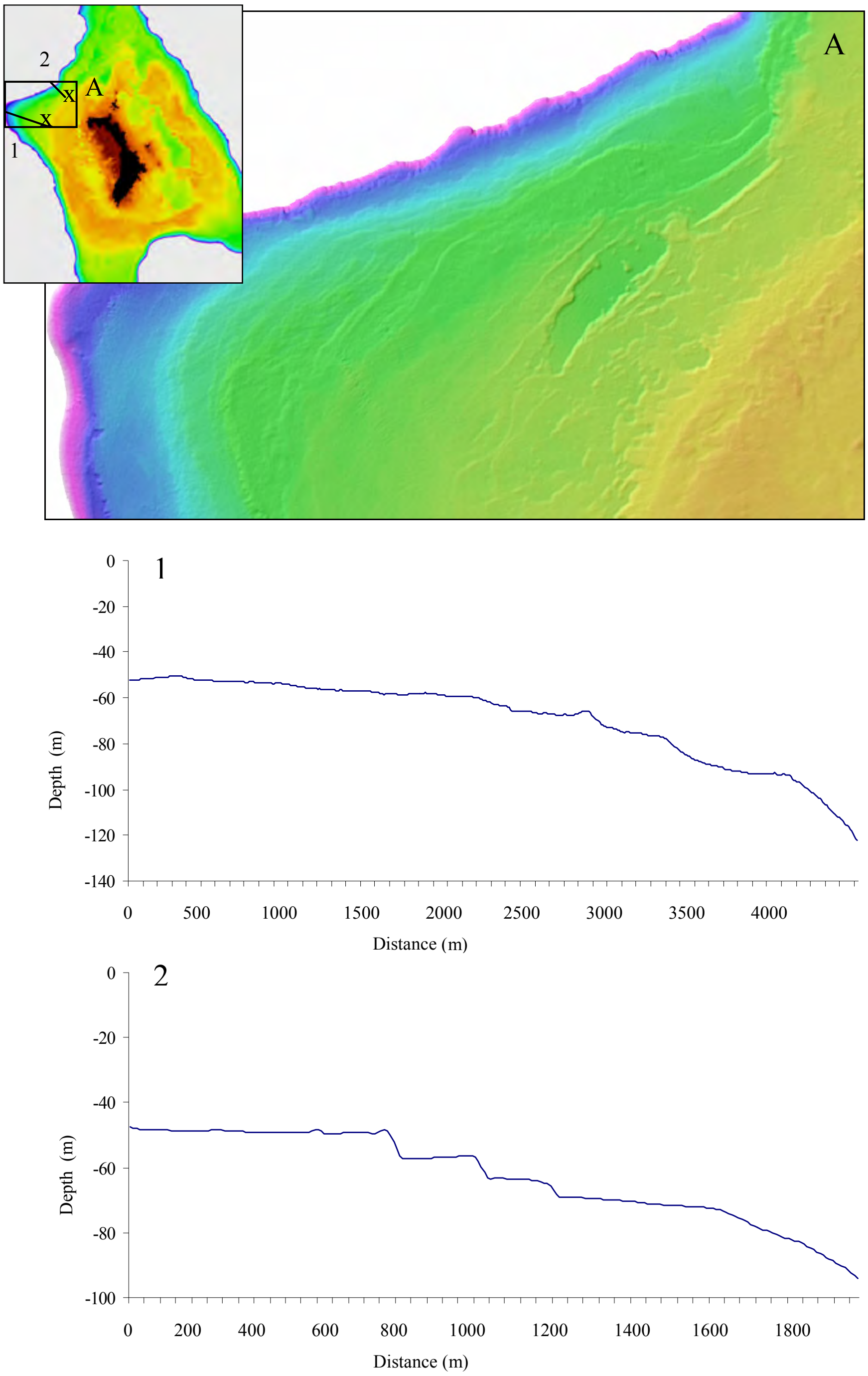


Figure 3.10: *The outer shelf in the northwest. Profile 1 shows the relatively smooth sloping surface; the well-developed terraces are shown in profile 2. Inset map shows location of profiles 1 and 2, with X marking the start of the profiles.*

Modern Fringing reef and Lagoon:
The fringing reef and lagoon occur on the western margin of the island (Figures 3.1 and 3.8). The reef is 8.9 km long and predominantly lies in water less than 20 m deep (depths range from 0.1 to 32 m); the lagoon is 5.9 km long and mostly less than 2 m deep, with holes up to 18 m deep. The relict reef is 25 times larger than the modern fringing reef.

Rugose Nearshore:
A relatively rough seabed forms a zone in the nearshore around most of the island, in depths of predominately 20 to 30 m, covering an area of 48.8 km^2 (Figures 3.1 and 3.8). It includes patches of coral and pinnacle structures, especially on the western side of the island. A number of isolated coral communities are know to occur in the northern and eastern sections of this feature. Extensions of several small basaltic islands and reefs form much of the northeast area of this feature. The nearshore zone is distinctly rougher than the relict reef surface and occurs within a shallower depth range (Figures 3.9 and 3.12c).

Northern Shelf:
The northern shelf is characterised by numerous depressions, channels and mounded structures (Figure 3.11). The average water depth is 56 m (± 3.4 m) and the total area is 45.3 km^2. Channels and mounds are more prevalent on the western half of this feature.

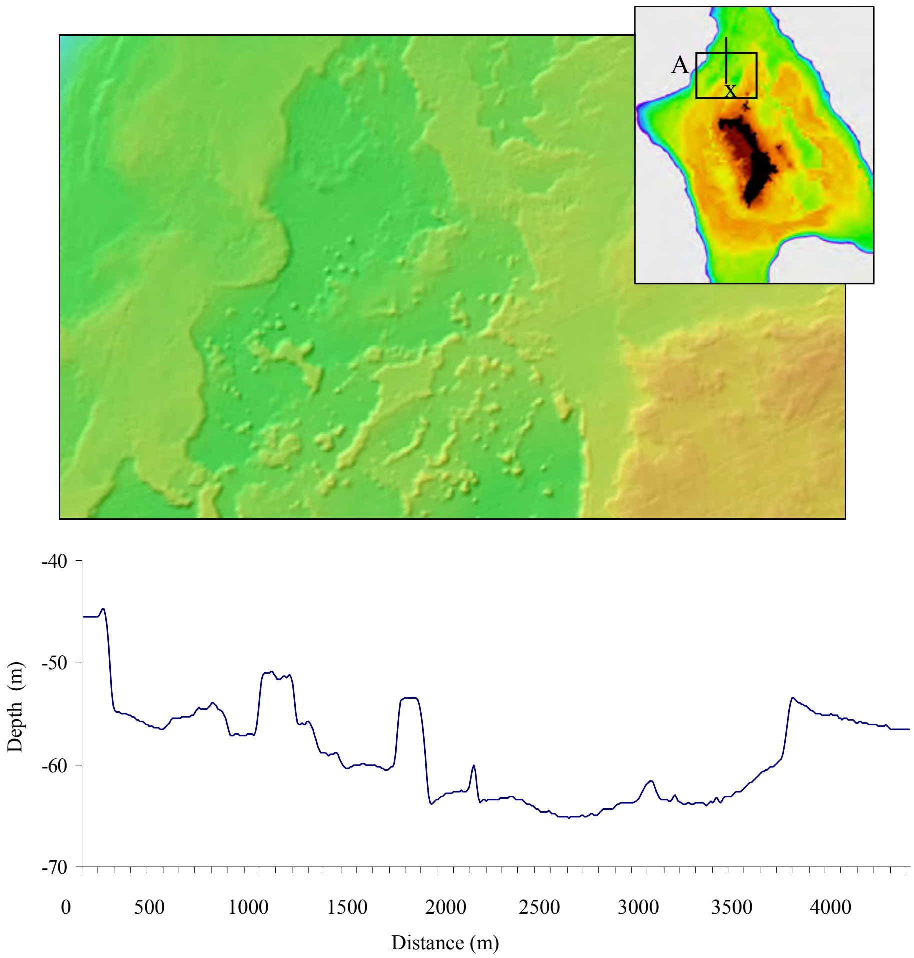


Figure 3.11: *The northern shelf. Inset map shows location of profile, with X marking the start of the profile.*

Basin Environments:

Three large, trough shaped depressions characterise the inner shelf. These basin features are bounded outboard by the relict reef and inboard by the fringing reef and rough nearshore zone (Figures 3.8 and 3.12). The largest and deepest basin occurs in the east, with a maximum depth of 61 m. A unique attribute of this basin is the sharp change in slope at its margin with the relict reef (Figure 3.12a). The southern basin is smaller and up to 54 m deep (Figure 3.12b). The western basin is the shallowest with a maximum of depth 48 m, and contains reef patches (Figure 3.12c).

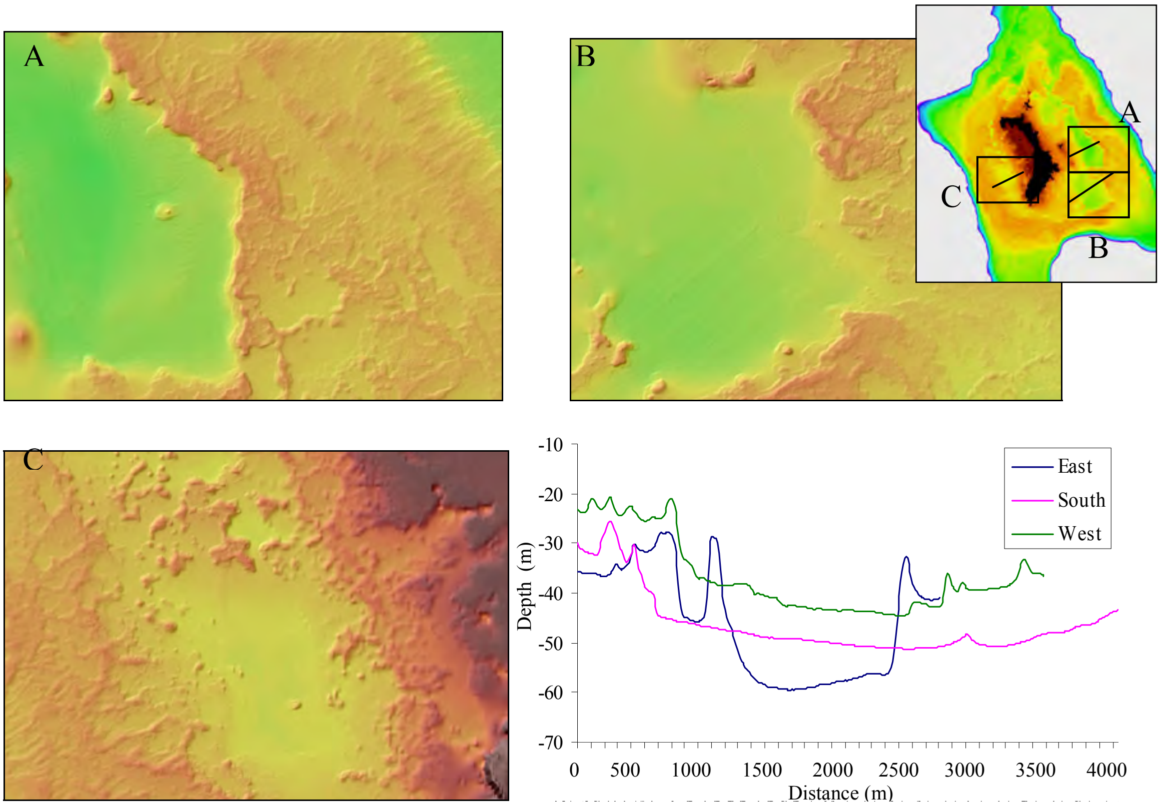


Figure 3.12: *Detailed maps and surface profiles of the sandy basins. A: eastern basin; B: southern basin; C: western basin and representative profiles. Inset map shows location of profiles.*

Passages:

Inter-reef passages dissect the relict reef in the north (Passage 1), north east (Passage 2) and east (Passage 3; Figure 3.13). The best developed passages occur in the north. Here Passage 1 and 2 exhibit similarities in their depth, asymmetry and inset channels. The internal channels appear to represent a second phase of incision of the seabed. For example, channel 1 (67 m deep) in Passage 1 is 16 m deeper than the surrounding floor of the passage (Table 3.2).

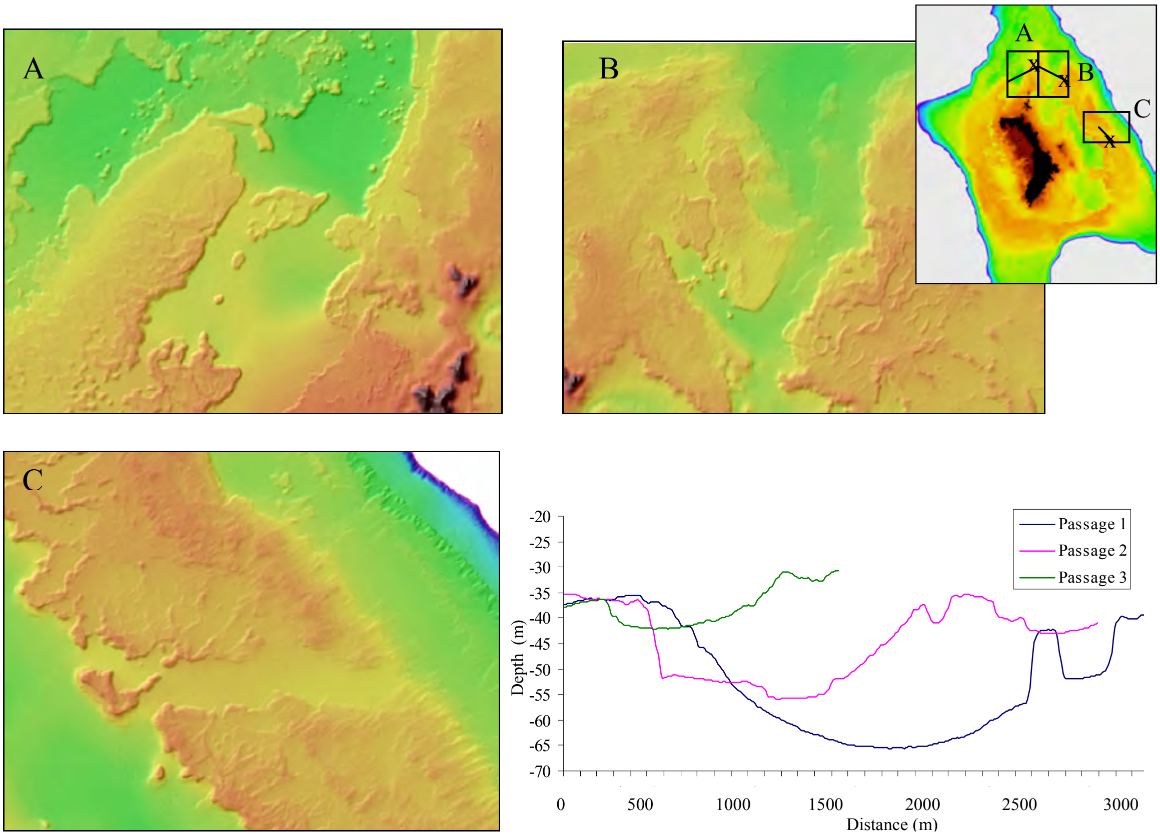


Figure 3.13: *Detailed maps and surface profiles of (A) Passage 1, (B) Passage 2, and (C) Passage 3. Inset map shows location of profiles, with X marking the start of the profiles.*

Spur and grooves:

Structures typical of spur and groove morphology, often found on the outer margin of high-energy coral reefs, occur on the eastern and western margins of the relict reef (Figure 3.14). The best developed features are in the south where the spurs are several metres high, in a water depth of around 35 m. Spur and grooves along the eastern and western margins of the relict reef are significantly smaller (Figure 3.14a) and more numerous (Figure 3.14b).

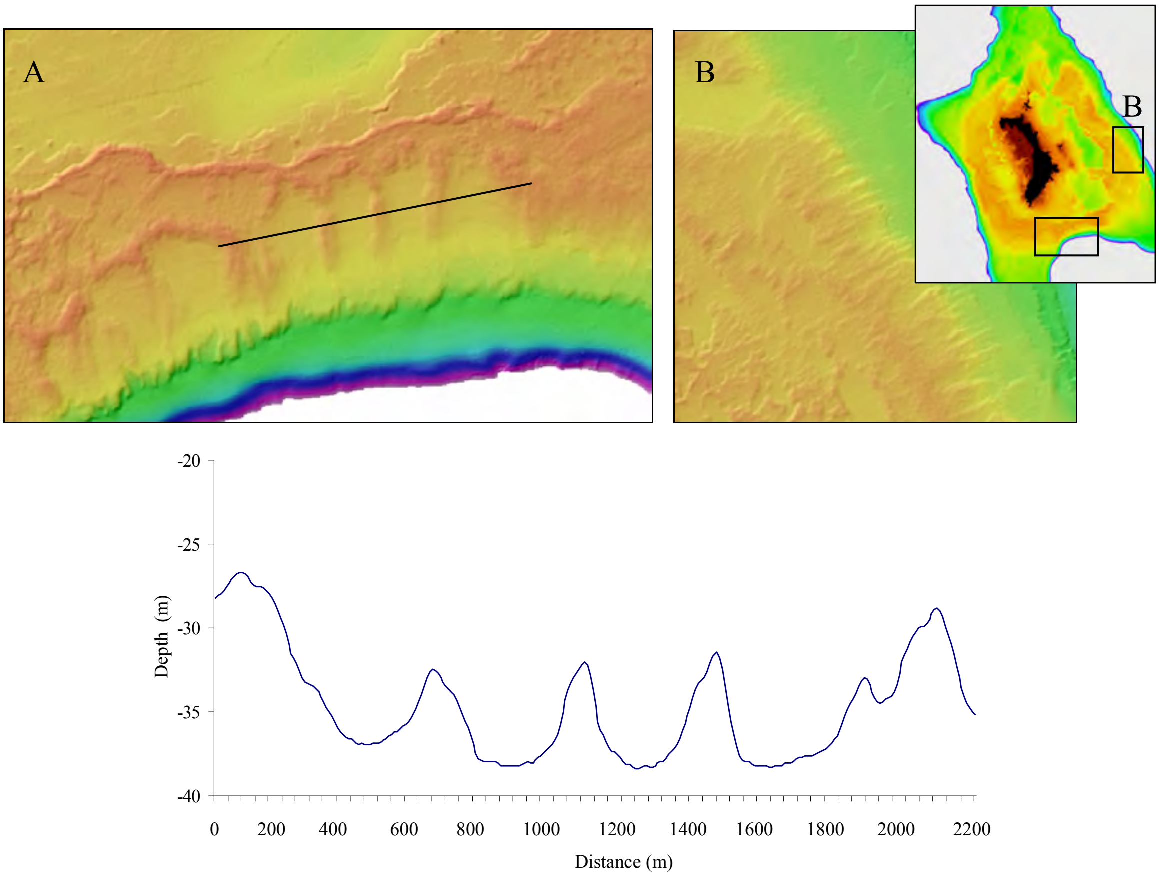


Figure 3.14: *Spur and groove features on the southern (A) and eastern (B) margins of the relict reef. Inset map shows locations. The surface profile is for the features shown in A (line in A indicates profile position).*

3.3 BACKSCATTER DATA:

Strong multibeam acoustic backscatter signals (harder substrates) on the outer shelf and relict reef contrast with low values in the basins and passages (soft substrates, Figure 3.15). The northern shelf appears to have a surface that generates intermediate values.

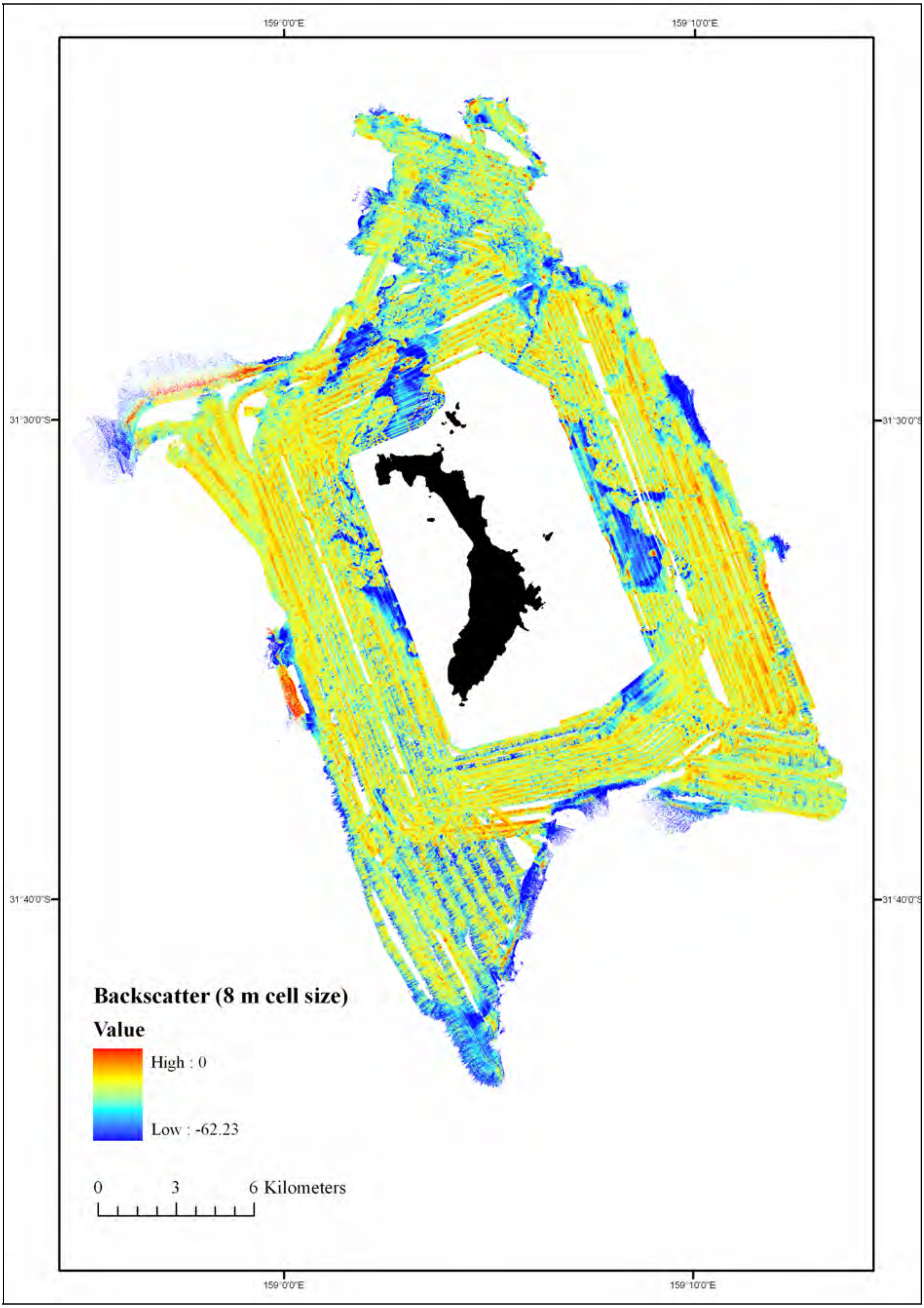


Figure 3.15: *Multibeam acoustic backscatter map of the shelf. Strong backscatter returns (red) most likely represent hard substrates and low returns (dark blue) softer substrates.*

3.4 ACOUSTIC SUB-BOTTOM PROFILES

The Topas sub-bottom profiler achieved good penetration over some of the sandy areas, with several sub-bottom reflectors apparent. The Topas signal did not provide differentiation of reef limestone thickness or the topography of the underlying basalt. Representative profiles of different surface and subsurface deposits identified in the initial analysis of the data are provided below, with profile locations shown in Figure 3.16. A more detailed classification of the data may enable differentiation of a greater range of seabed and deposit types, for example following the Damuth (1980) type approach (Table 3.3).

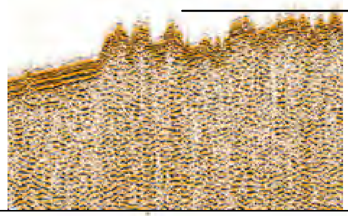
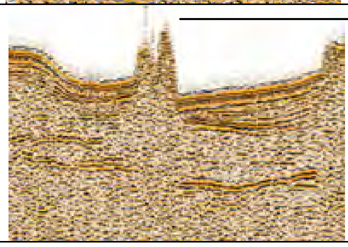
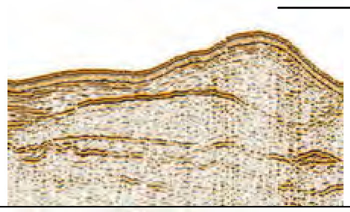
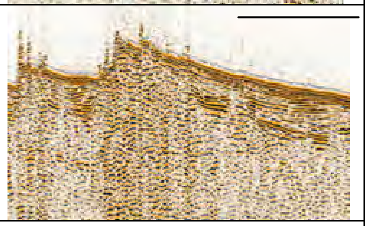
Different classes of reflectors appear to match up with different geomorphological features. Across the shelf, distinct sub-bottom profiles of Type 1A and Type 1C are most common (Table 3.3). Typically, Type 1A reflectors are evident in areas of relict reef where hard surface material generates strong returns and the seabed cannot be penetrated. Sub-bottom reflectors are more prevalent in areas of unconsolidated material where the acoustic signal penetrates the seabed, such as in the basins and passages. These reflectors are often well resolved (Type 1C) and indicate the presence of unconformable layers that likely reflect dynamic depositional processes. The deepest reflectors evident in these areas are discontinuous and lie approximately 15 to 25 m below the seabed. Above these reflectors are multiple continuous horizontal reflectors, several metres apart, often with a strong reflector near the surface. Further descriptions of the sub-bottom profiles are given below for the different geomorphic zones on the shelf. Additional descriptions of the profiles are provided in Linklater (2009).

Sub-surface depositional patterns:

Relict Reef:
Topas profiles of the relict reef show intermittent deposits of sediment within large areas of hard seabed (Figure 3.17). An example of the hard surface, which comprises the majority of the relict reef, can be seen in profile RR4 (Figure 3.17). Infill typically ranges from 1 to 4 m thick and may be in the form of angular bedding (profiles RR1, RR3) or deposits that onlap older hard substrate (RR2). Topographically, the reef surface is generally rough and undulating, with pinnacles in localised areas. The position of drill cores on sub-bottom profiles are shown in Figure 3.18.

Infill patterns evident in areas of relict reef include parallel reflectors at shallow depths below the seafloor which are typically continuous (e.g. RR1, RR2, Type IB; Figure 3.18), and occasionally discontinuous (e.g. RR3, Type IIA). Across the majority of the reef there is no penetration and the seabed forms the only reflector (e.g. RR4, Type IA).

Table 3.3: *Classification of depositional patterns based on Damuth (1980) with examples from the Lord Howe Island Shelf.*

Type	**Classification**	**Description**	**Example** Scale = 500 m
IA	Distinct	Sharp, continous echo with no sub-bottom reflectors - single seafloor reflector	
IB	Distinct	Sharp, continous parallel sub-bottom reflectors	
IC	Distinct	Sharp, continuous with non-conformable sub-bottom reflectors	
IIA	Indistinct - prolonged	Semi-prolonged with intermittent sub-bottom reflectors	
IIB	Indistinct - prolonged	No sub-bottom reflectors	Nil known

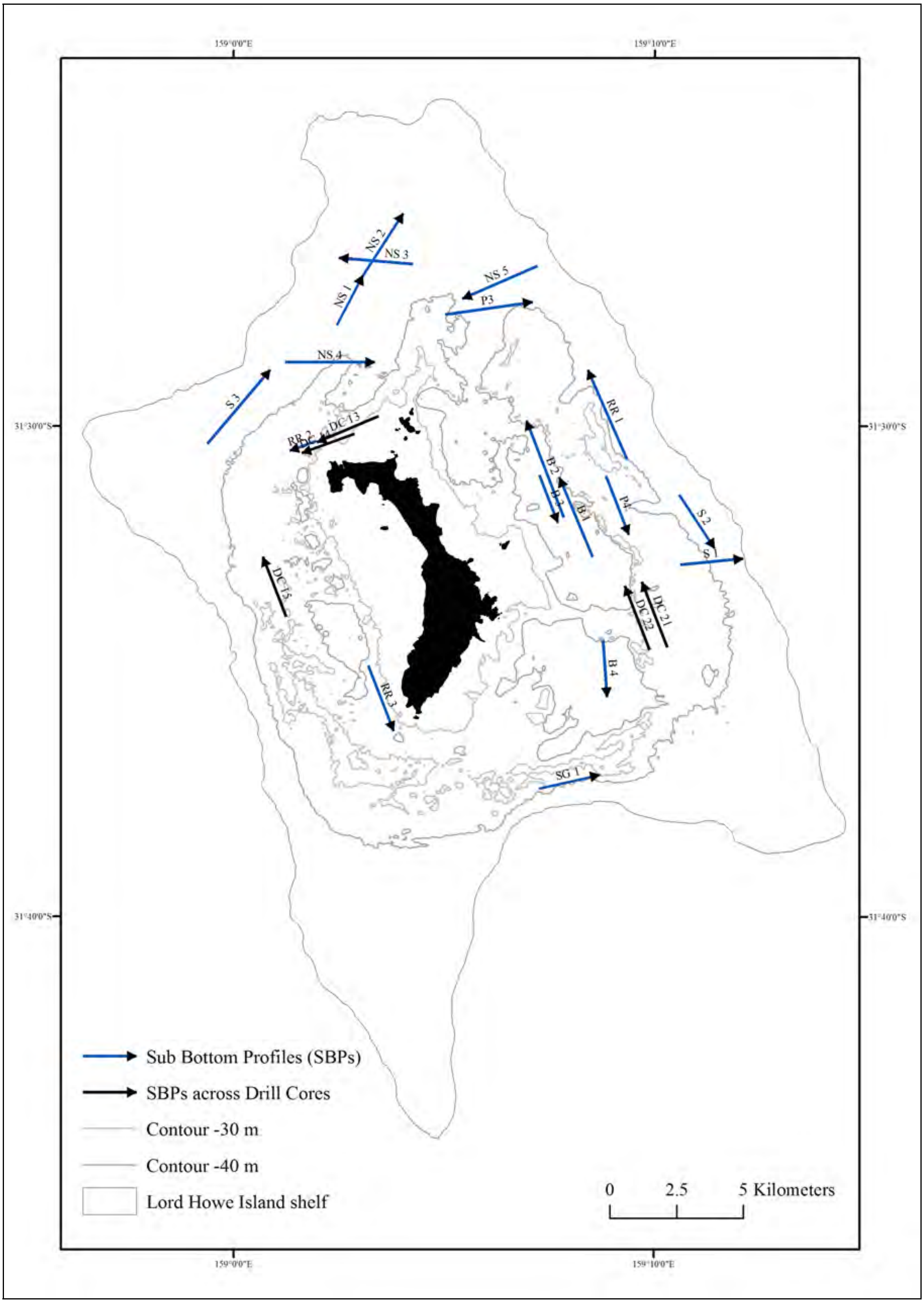


Figure 3.16: *Location of sub-bottom profiles referred to in the text. Sub-bottom profiles which pass through drill core sites are indicated (back lines). Arrows indicate the vessel heading during data acquisition.*

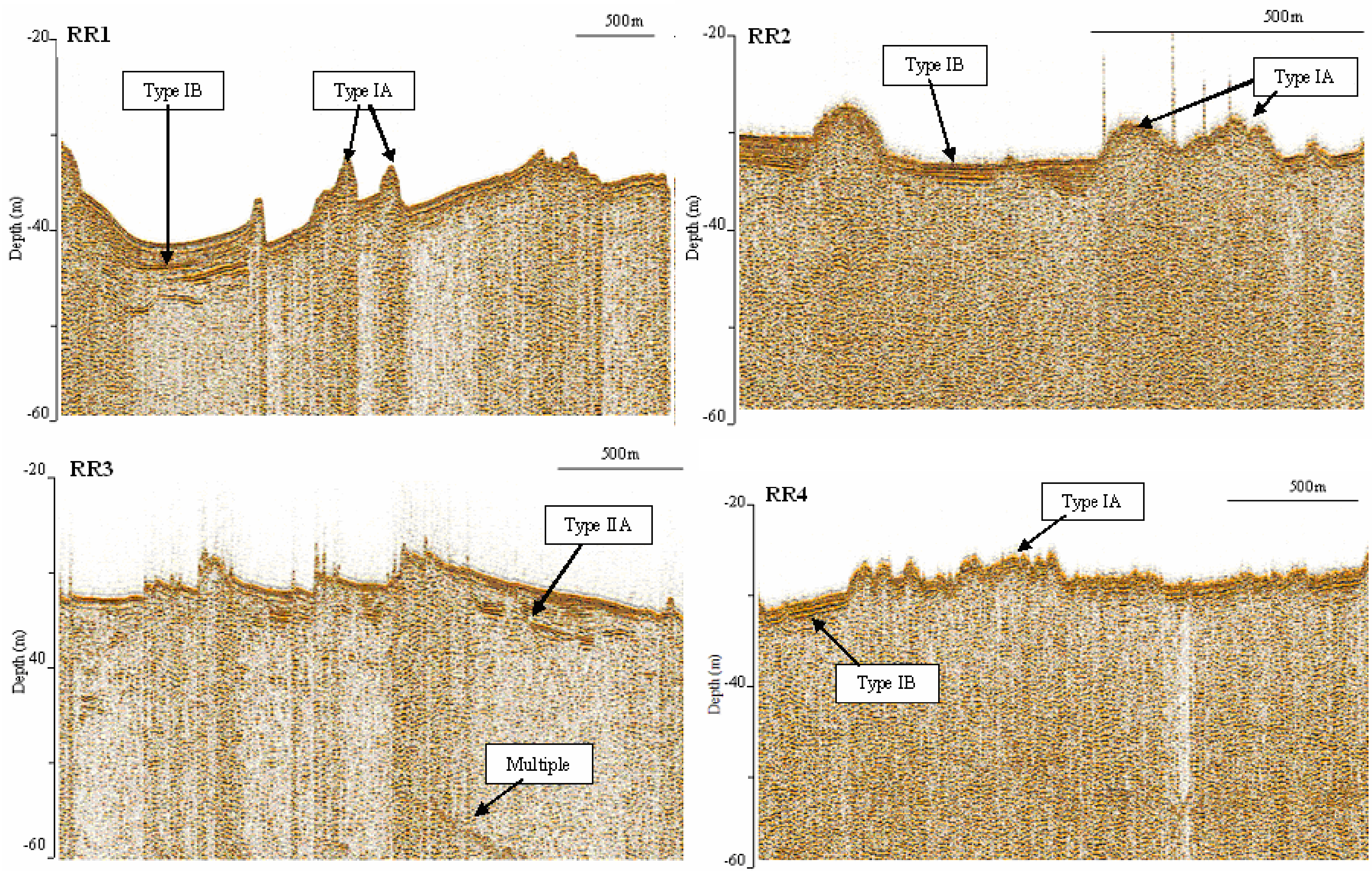


Figure 3.17: *Sub-bottom profiles of the relict reef structure.*

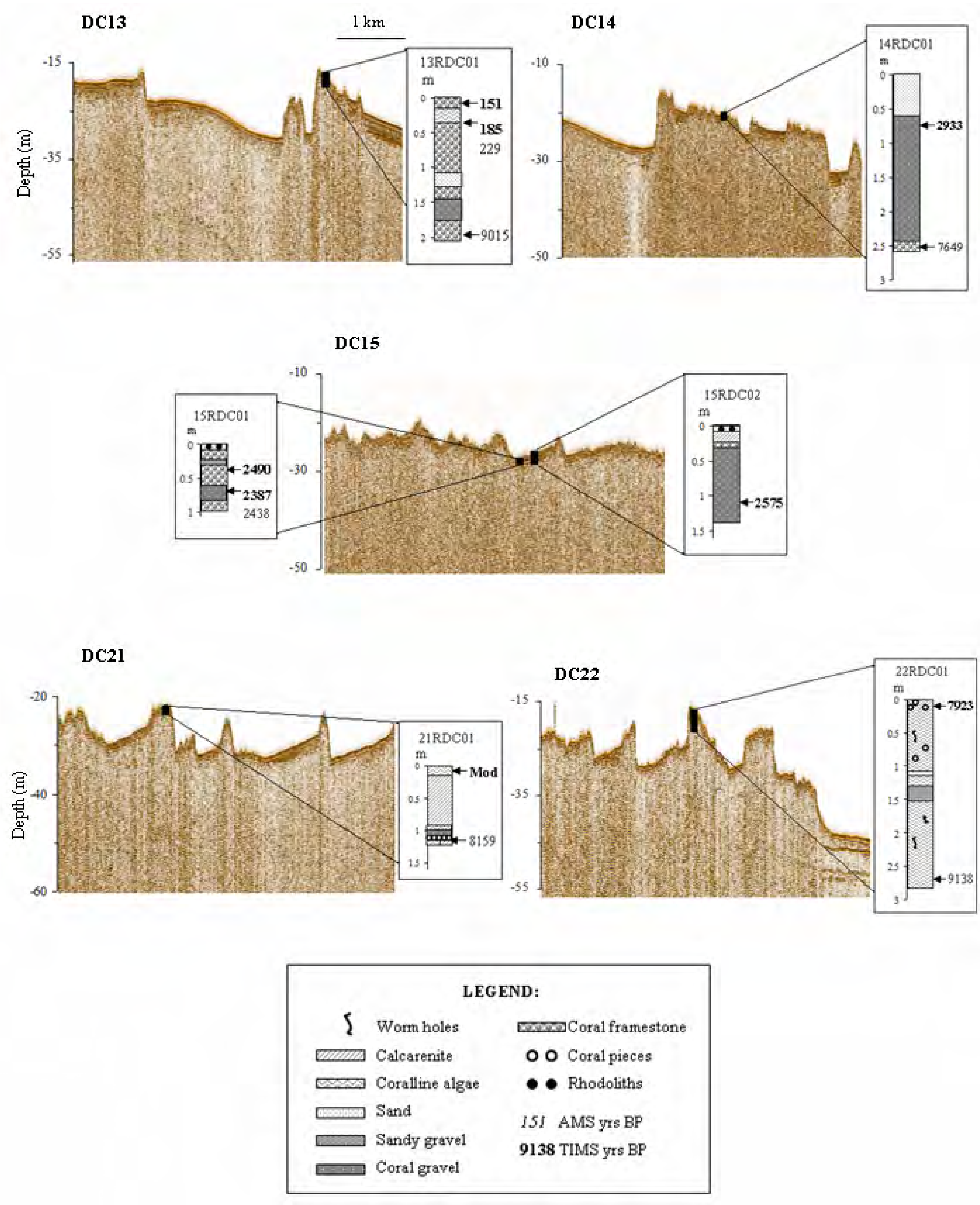


Figure 3.18: *Sub-bottom profiles of the coring sites. Locations of profiles are shown in Figure 3.16. Drill core 15RDC01 and 15RDC02 are positioned along the closest profile, line DC15.*

Outer Shelf and Shelf Margin:

Few sub-bottom reflectors were recorded on the outer shelf indicating a hard seabed (e.g., S1, Figure 3.19). Occasional reflectors are evident near the margin of the shelf where unconsolidated material appears to have accumulated. These reflectors occur 5 to 6 m below the seafloor and appear to slope oceanwards in an intermittent pattern (Type IIA, S2 and S3, Figure 3.19). Terraces are well resolved in the seabed reflector on the shelf margin in water depths of 45 to 60 m (e.g. S1, Figure 3.19).

Northern Shelf:

The northern shelf is characterised by patch reefs and inter-reef deposits of apparently unconsolidated sediment (Figure 3.20). The small patch reefs appear similar to coral 'bommies' with a rounded or pinnacle-like morphology. Between these high-relief structures there are several metres of sediment, with reflectors visible up to 25 m below the seabed. Infill patterns include prograding (profiles NS1, NS4; Figure 3.20), onlap (NS2) and divergent depositional sequences (NS5). Semi-prolonged reflectors interrupted by the usually acoustically opaque patch reefs are common (Type IB, NS1, NS4; Figure 3.20).

Basins:

The acoustic signal achieved deep penetration of the seabed in these areas. The sub-bottom profiles include laterally extensive reflectors with strong returns, particularly in the eastern and southern basins (B1-4; Figure 3.21). Most reflectors occur within 10 to 15 m below the seafloor with some more subtle and discontinuous reflectors evident down to 20 m.

Intersecting sub-bottom profiles (Figure 3.22) provide a three-dimensional view of reflectors in the southern basin. Deposits are thickest at the outer margin of the basin and thin towards the centre. Adjacent to the relict reef there is a hummocky pattern of thick sediment accumulation which suggests a substantial volume of sediment has moved into the basin from the reef (B2; Figure 3.21).

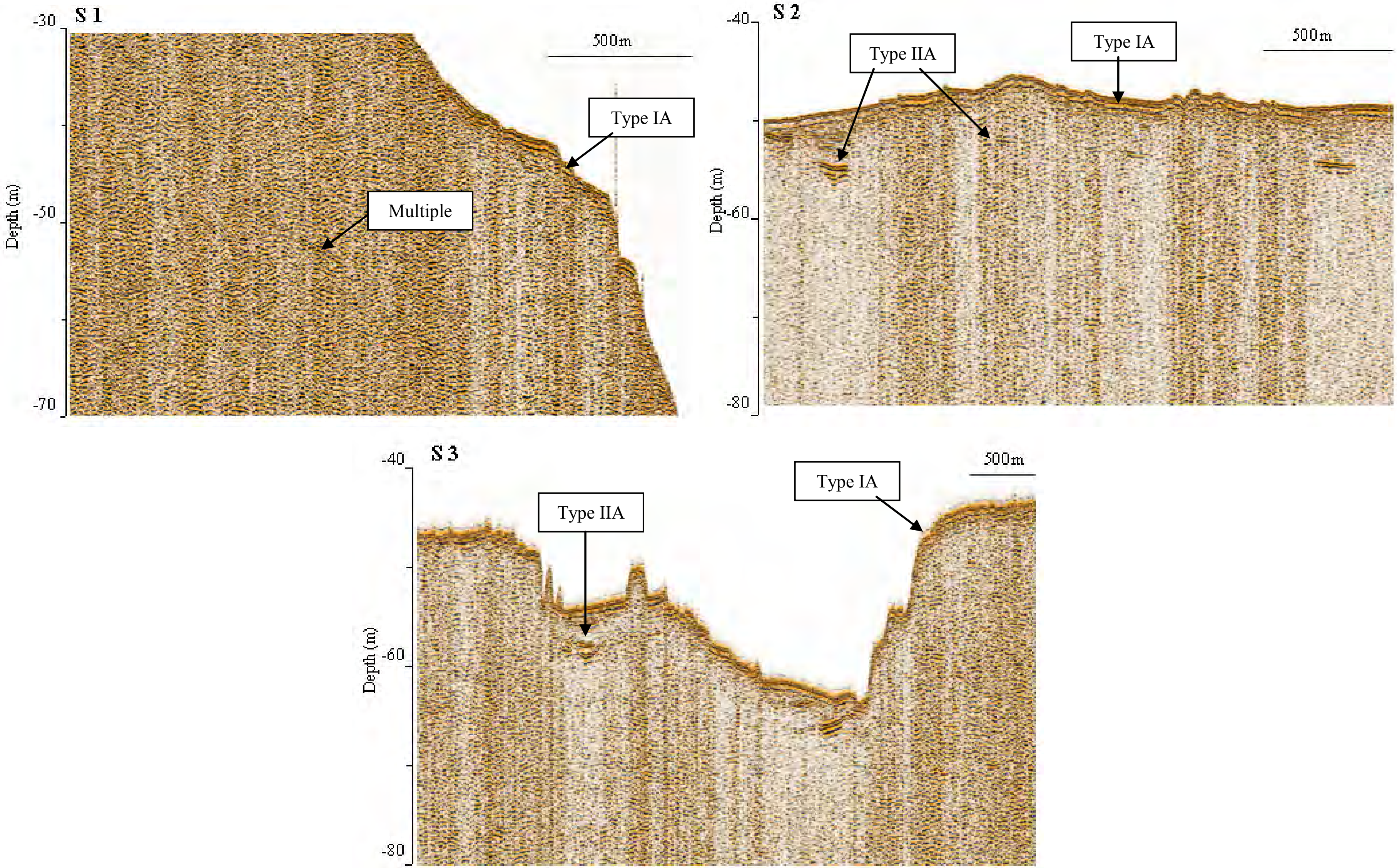
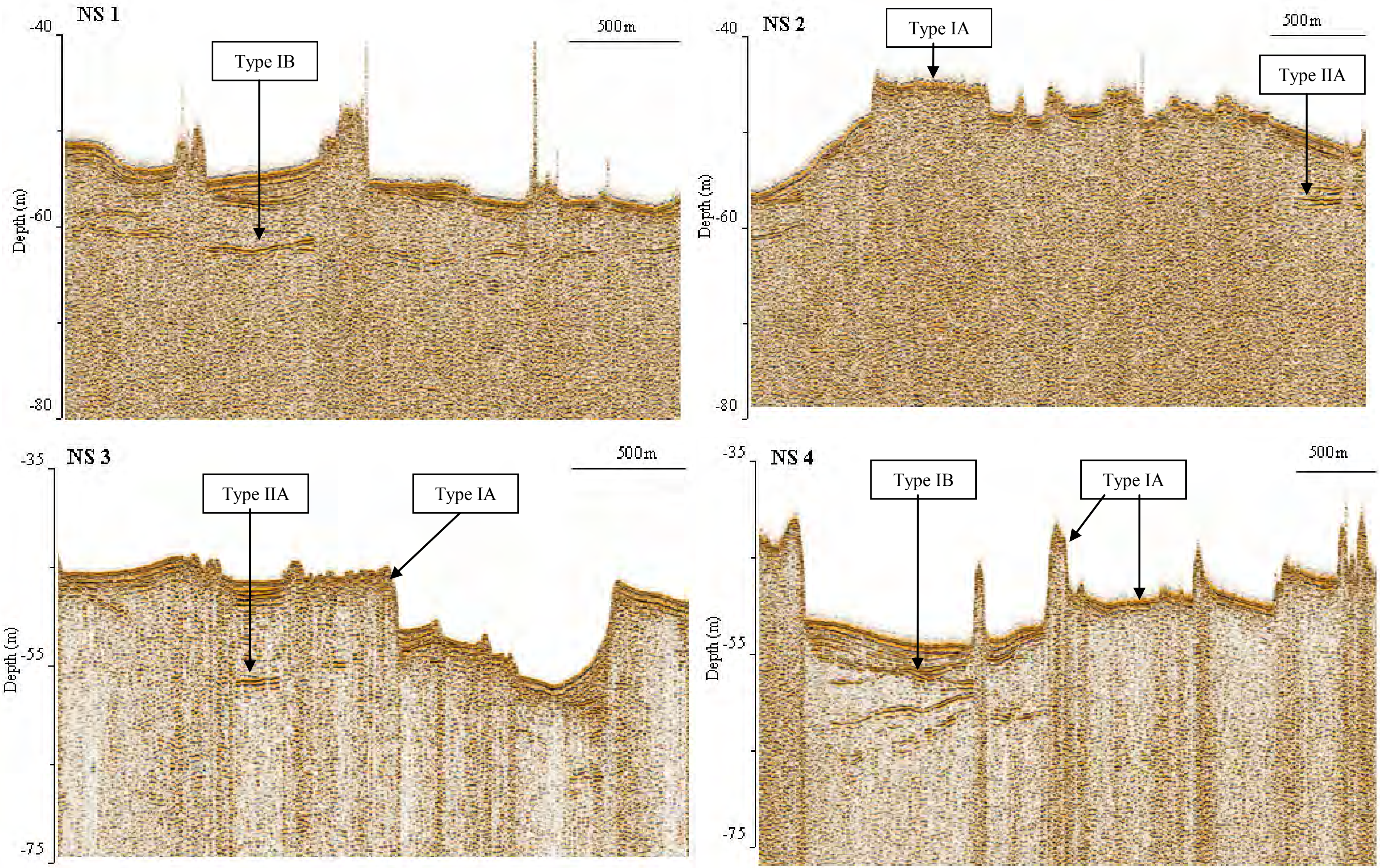


Figure 3.19: *Sub-bottom profiles of the outer shelf and shelf margin.*


NS 1
500m
Type IB
-40
Depth (m) -60
-80
NS 2
Type IA
500m
Type IIA
-40
Depth (m) -60
-80
NS 3
500m
Type IIA
Type IA
-35
Depth (m) -55
-75
NS 4
Type IB
Type IA
500m
-35
Depth (m) -55
-75

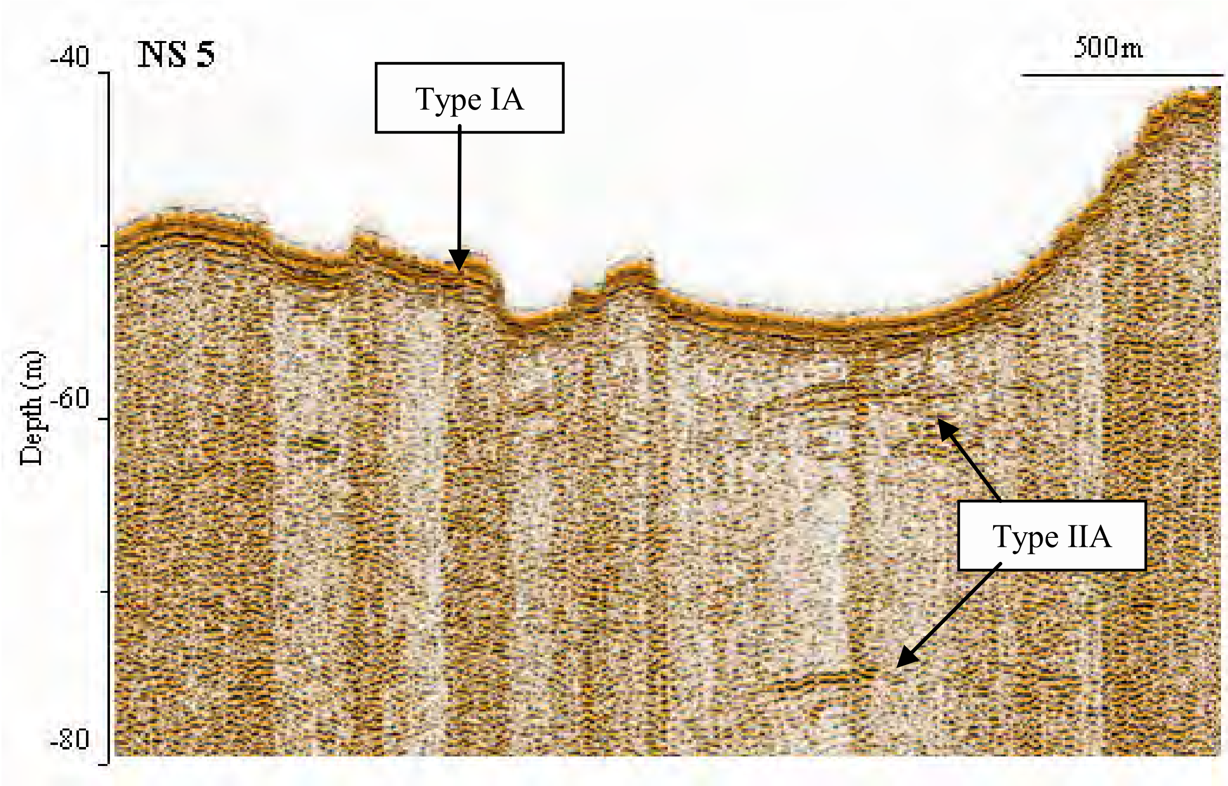


Figure 3.20*: Sub-bottom profiles of the northern shelf, lines NS1 - NS5.*

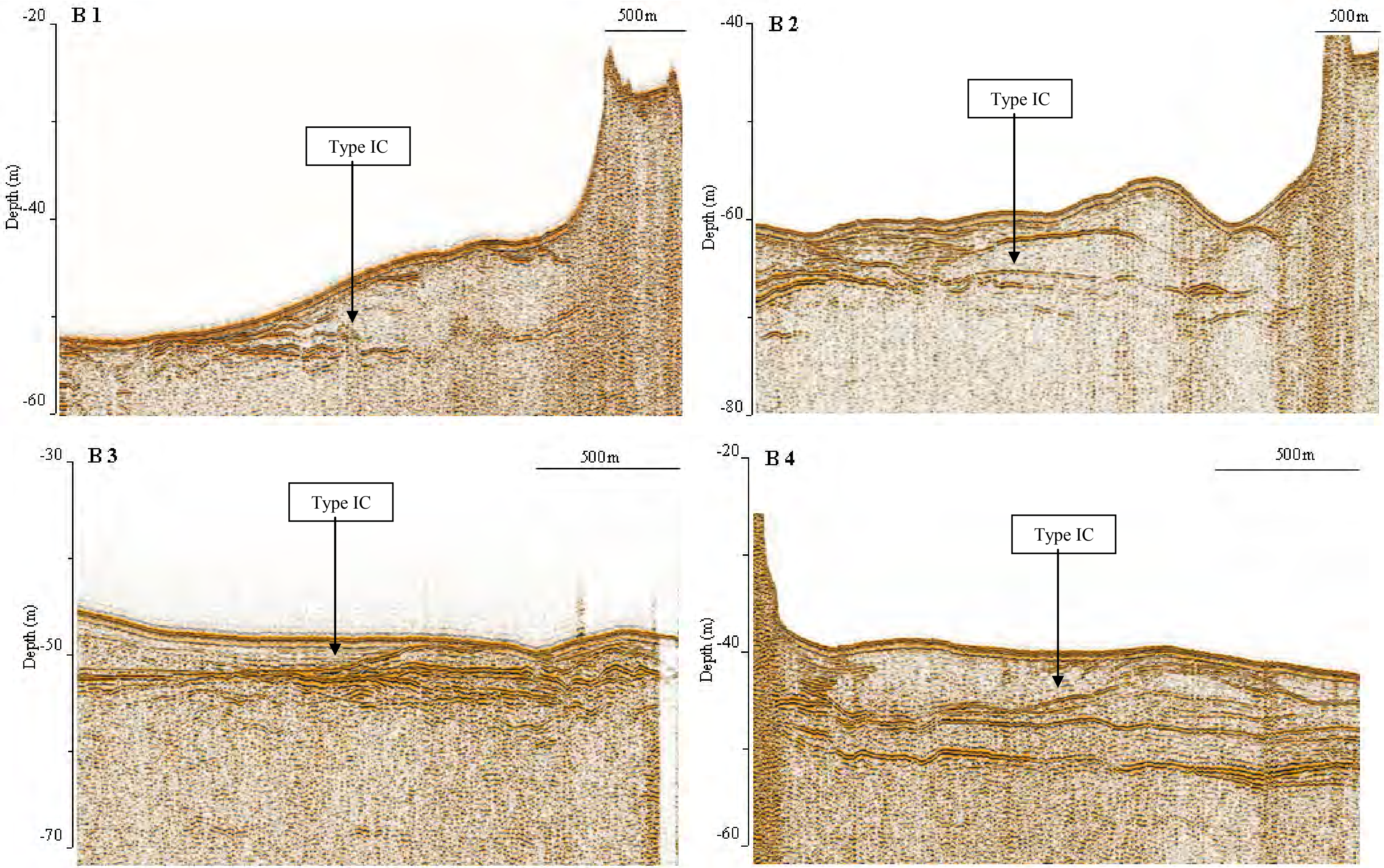


Figure 3.21*: Sub-bottom profiles of the eastern basin (B1-3) and southern (B4) basins.*

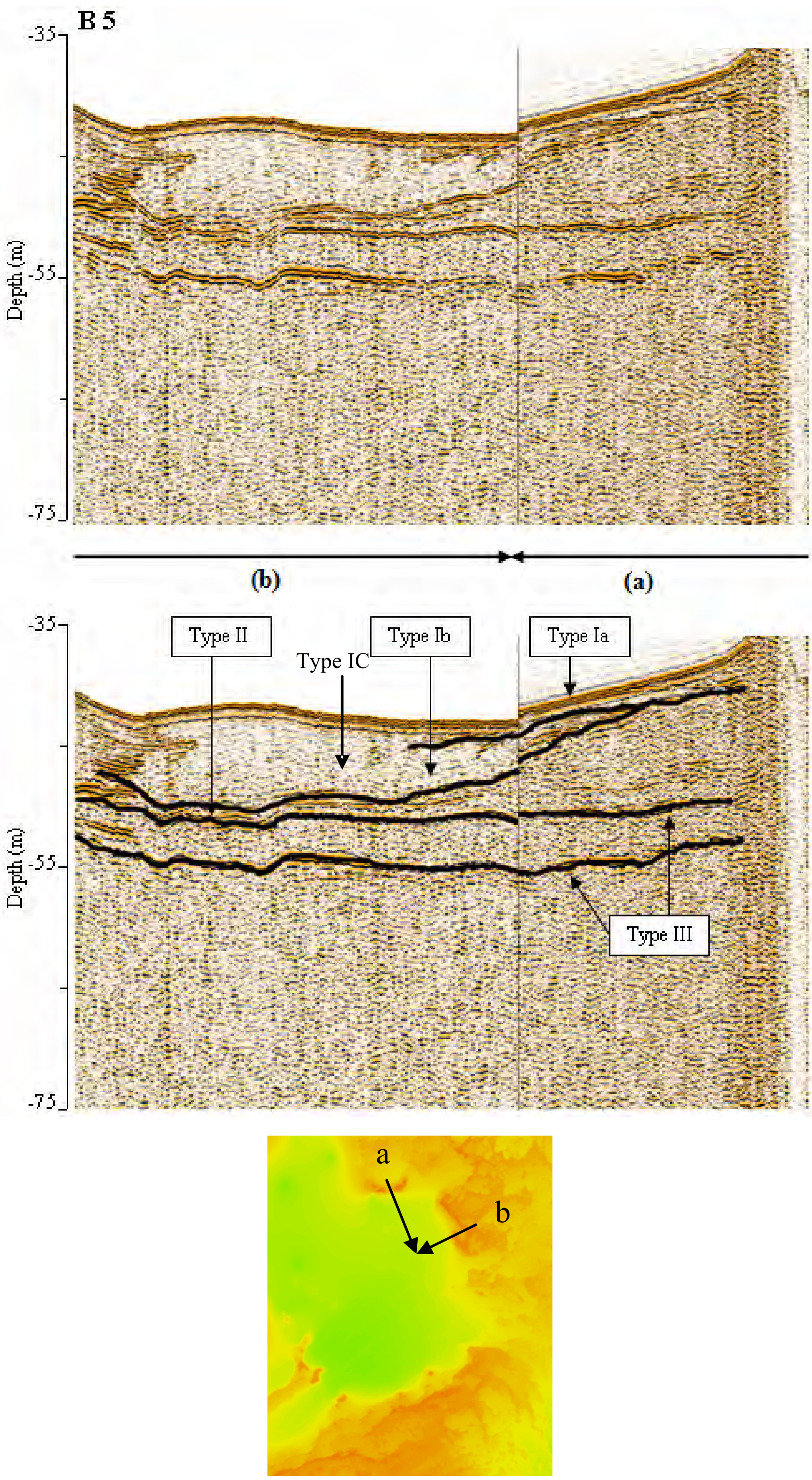


Figure 3.22: *Intersection of sub-bottom profiles through the southern basin. Location of profiles shown with arrows indicating the ship's heading.*

Passages

Multiple reflectors are evident in these areas, especially in narrow passages or channels between hard reef walls where there is up to 15 m of sediment fill. Typically, progradational deposits occur adjacent to the thalweg of channels that sit within passages (Figure 3.23). Closely spaced reflectors are visible near the surface, while deeper (up to 30 m beneath the seafloor), widely spaced (up to 8 m) reflectors are also evident. Sequences of sub-bottom profiles in Passages 1 and 2 are shown in Figures 3.23 and 3.24 respectively. Here, strong reflectors appear to diverge vertically to the south which suggests sediment was transported towards the island. Reflectors within Passages 3 and 4 are significantly less pronounced (Figures 3.25 and 3.26).

Spur and grooves:

As shown by Topas line SG1 (Figure 3.27), very little sediment has accumulated in the groves between the well defined spurs. The lack of penetration of the spurs and grooves indicates a hard substrate.

Ball's Pyramid:

A very preliminary examination of the sub-bottom profiles recorded on the shelf around Ball’s Pyramid suggests there are sediment deposits with similar depositional patterns to those seen in the basins on the Lord Howe Island shelf.

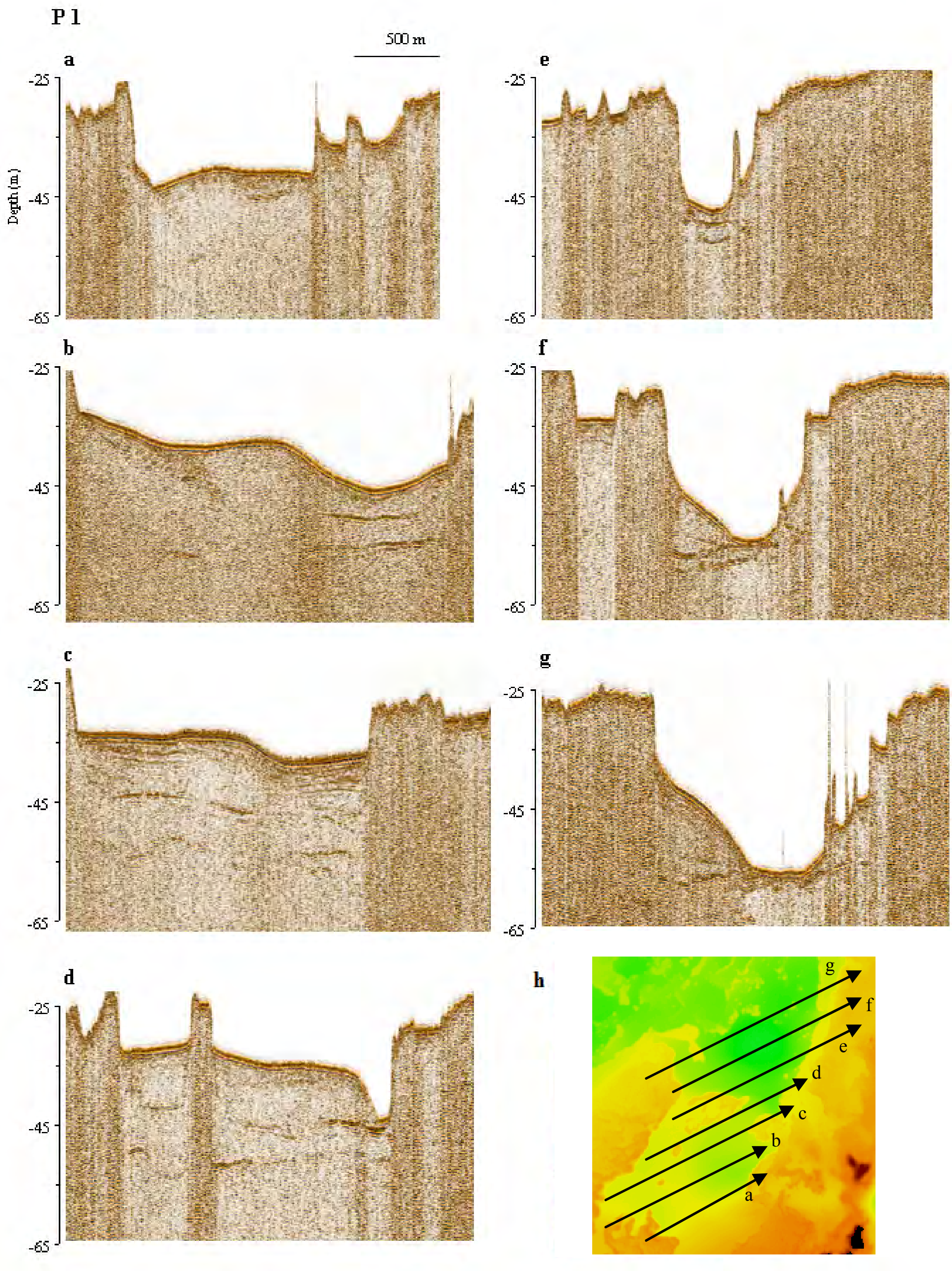


Figure 3.23: *A sequence of sub-bottom profiles through Passage 1, (a) - (g). Locations are shown in (h).*

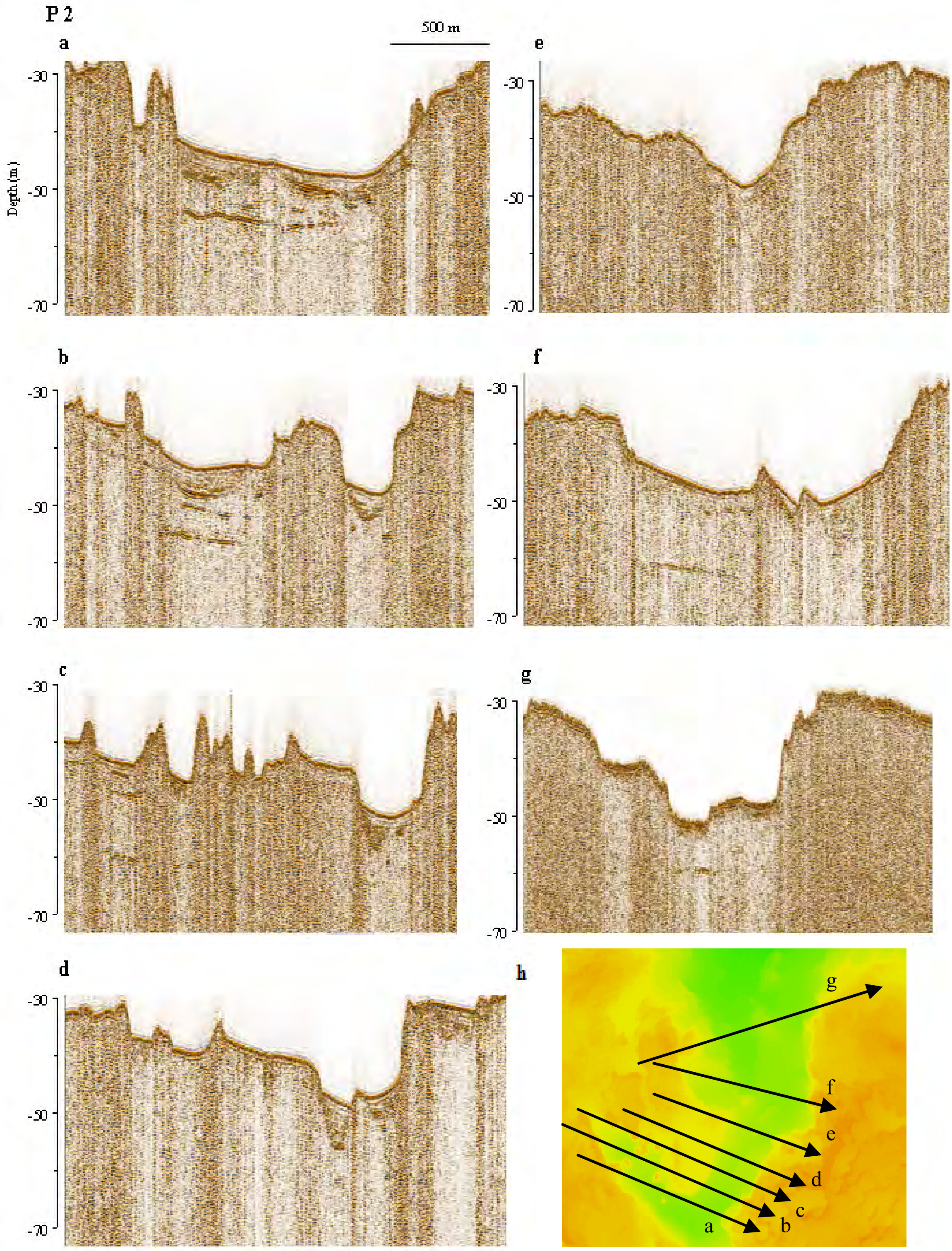


Figure 3.24: *Sub-bottom profiles through Passage 2, (a) - (g). Locations of profiles are shown in (h).*

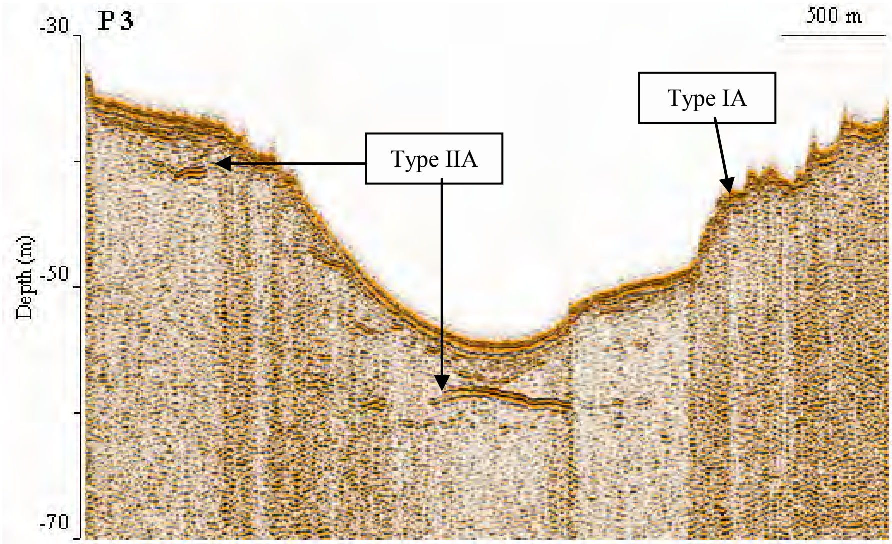


Figure 3.25: *Sub-bottom profiles of Passage 3.*

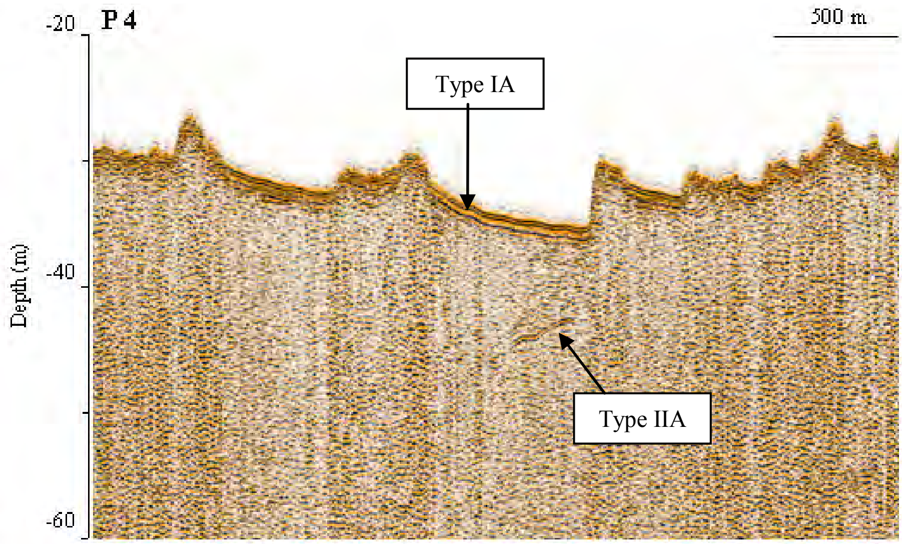


Figure 3.26: *Sub-bottom profiles of Passage 4.*

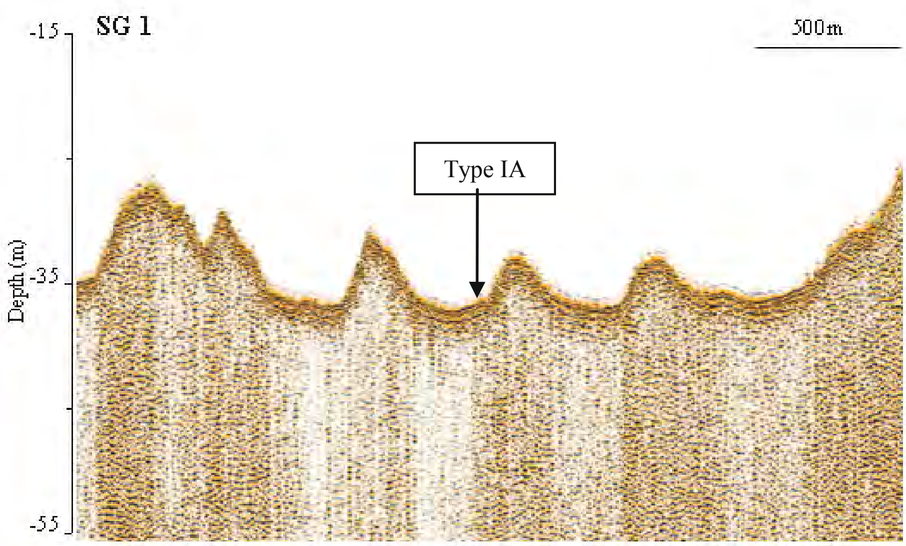


Figure 3.25: *Topas line across the southern spur and groove features.*

3.5 SHELF SEDIMENTS

Grain-size analysis of the grab samples shows that the shelf is dominated by sandy and gravely sediment, with very little mud in any of the samples (Figure 3.28; Table 3.4). This is consistent with the relatively high-energy depositional environment on the shelf where most fine sediment would be winnowed off the shelf into deep water. Samples from the basin areas are predominantly medium to coarse sand (Figure 3.29). Samples from the relict reef and outer shelf, in contrast, are a mix of sand and gravel, including gravel dominated sediment in samples from the southern and northwest margins of the relict reef. Note that for the display of sediment results a generalised geomorphic features map is used, shown also in Appendix 6.11.

At six sites, three grab samples were recovered. Grain-size data for these samples indicate the degree of sediment heterogeneity within an area of a few metres to a few hundreds of metres. The differences in samples within these sample sites likely relate to typical variations in grain size that occur between the crests and troughs of subaqueous dune bedforms. Overall, the three samples from these sites display very similar grain-size characteristics. Sediment sorting tends to be greater in the basin areas, reflecting the lack of gravel in these samples (Figure 3.30).

Table 3.4: *Summary sediment data for Lord Howe shelf grab samples.*

Sample ID	Latitude	Longitude	Depth (m)	%Gravel	%Sand	%Mud	Sorting (phi)	Mean (microns)	%Carbonate (bulk)	%Carbonate (sand)
SS062008_01GR02a	-31.5163	158.9910	48.35	87.69	12.22	0.09	n/d	n/d	95.90	96.90
SS062008_01GR03	-31.5162	158.9920	48.18	58.55	40.81	0.64	2.80	528.58	96.79	94.0
SS062008_01GR04	-31.5000	158.9920	60.45	62.11	37.82	0.07	2.05	792.99	96.18	97.6
SS062008_02GR01	-31.5648	159.0373	43.79	4.27	95.71	0.02	1.67	767.28	97.05	95.9
SS062008_02GR02	-31.5648	159.0365	43.43	20.18	79.78	0.05	1.81	718.98	96.96	98.4
SS062008_02GR03	-31.5643	159.0363	43.17	12.34	87.62	0.04	1.65	811.25	97.05	97.1
SS062008/03GR01	-31.5172	158.9568	77.00	33.52	66.23	0.25	2.42	500.20	96.60	95.1
SS062008/03GR02	-31.5167	158.9565	77.00	4.23	95.66	0.12	1.71	676.54	96.90	95.7
SS062008/03GR04	-31.5173	158.9570	77.00	9.60	90.28	0.12	2.01	601.78	97.20	98.0
SS062008_04GR01	-31.5050	159.0462	27.54	0.00	99.91	0.09	1.40	290.38	88.72	90.5
SS062008_04GR02	-31.5050	159.0468	26.48	0.00	99.94	0.06	1.40	285.55	86.81	90.6
SS062008_04GR03	-31.5043	159.0458	28.89	0.00	99.94	0.06	1.40	307.55	89.41	90.5
SS062008/05GR01	-31.4768	159.0580	60.00	20.60	79.36	0.04	3.31	482.78	95.20	98.5
SS062008_06GR01	-31.4925	159.0470	42.60	0.00	99.87	0.13	1.46	308.99	91.15	93.8
SS062008_06GR02	-31.4923	159.0472	42.70	0.00	99.88	0.12	1.44	305.59	91.32	93.6
SS062008_06GR03	-31.4923	159.0467	43.07	0.00	99.88	0.12	1.48	334.76	91.49	94.0
SS062008_07GR01	-31.5428	159.1415	60.89	2.77	96.89	0.34	1.80	488.27	96.70	96.6
SS062008_10GR01	-31.5770	159.0037	71.31	44.14	55.68	0.18	2.55	729.77	95.31	95.4
SS062008_10GR02	-31.5767	159.0032	72.49	27.49	72.30	0.21	2.42	673.74	94.79	97.7
SS062008_10GR03	-31.5767	159.0033	71.49	46.09	53.62	0.29	2.61	686.31	96.53	98.2
SS062008_11GR01	-31.4467	159.1067	61.69	30.80	69.12	0.07	1.69	622.82	96.96	96.1
SS062008_12GR01	-31.3980	159.0593	79.25	27.34	72.64	0.02	2.09	727.40	96.61	98.8
SS062008_12GR02	-31.3980	159.0595	79.41	39.30	60.69	0.02	1.97	751.35	96.35	98.1
SS062008_12GR03	-31.3983	159.0595	77.30	38.41	61.50	0.09	2.43	571.63	94.79	97.8

Sample ID	Latitude	Longitude	Depth (m)	%Gravel	%Sand	%Mud	Sorting (phi)	Mean (microns)	%Carbonate (bulk)	%Carbonate (sand)
SS062008_16GR01	-31.6180	159.1200	30.68	66.48	33.26	0.25	4.69	488.76	95.83	97.7
SS062008_18GR01	-31.6167	159.175	46.50	77.57	22.42	0.01	1.75	892.67	96.53	92.4
SS062008_19GR01	-31.5468	159.1998	76.33	8.01	91.93	0.05	3.10	642.51	96.01	94.4
SS062008_19GR02	-31.5468	159.2002	77.50	10.07	89.73	0.20	2.03	584.21	95.66	96.2
SS062008_19GR03	-31.5468	159.2003	78.69	31.25	68.59	0.16	2.87	485.47	94.88	95.5
SS062008_20GR01a	-31.5555	159.165	40.48	5.86	94.14	0.00	1.43	992.75	81.10	92.80
SS062008_20GR02a	-31.5557	159.165	40.47	52.82	47.18	0.01	1.55	858.59	93.20	98.20
SS062008_20GR03	-31.5555	159.1647	40.17	60.73	39.27	0.00	2.19	707.10	96.53	95.3
SS062008_30GR01a	-31.4905	159.1305	40.62	29.60	70.40	0.00	1.43	551.54	93.90	95.30
SS062008_30GR02a	-31.4907	159.1302	40.50	21.55	78.45	0.00	1.45	952.11	88.50	97.10
SS062008_30GR03a	-31.4908	159.1298	40.62	23.60	76.40	0.00	1.59	833.10	91.20	93.60
SS062008_31GR01	-31.4883	159.1553	69.29	28.81	71.16	0.02	n/d	n/d	79.50	93.50

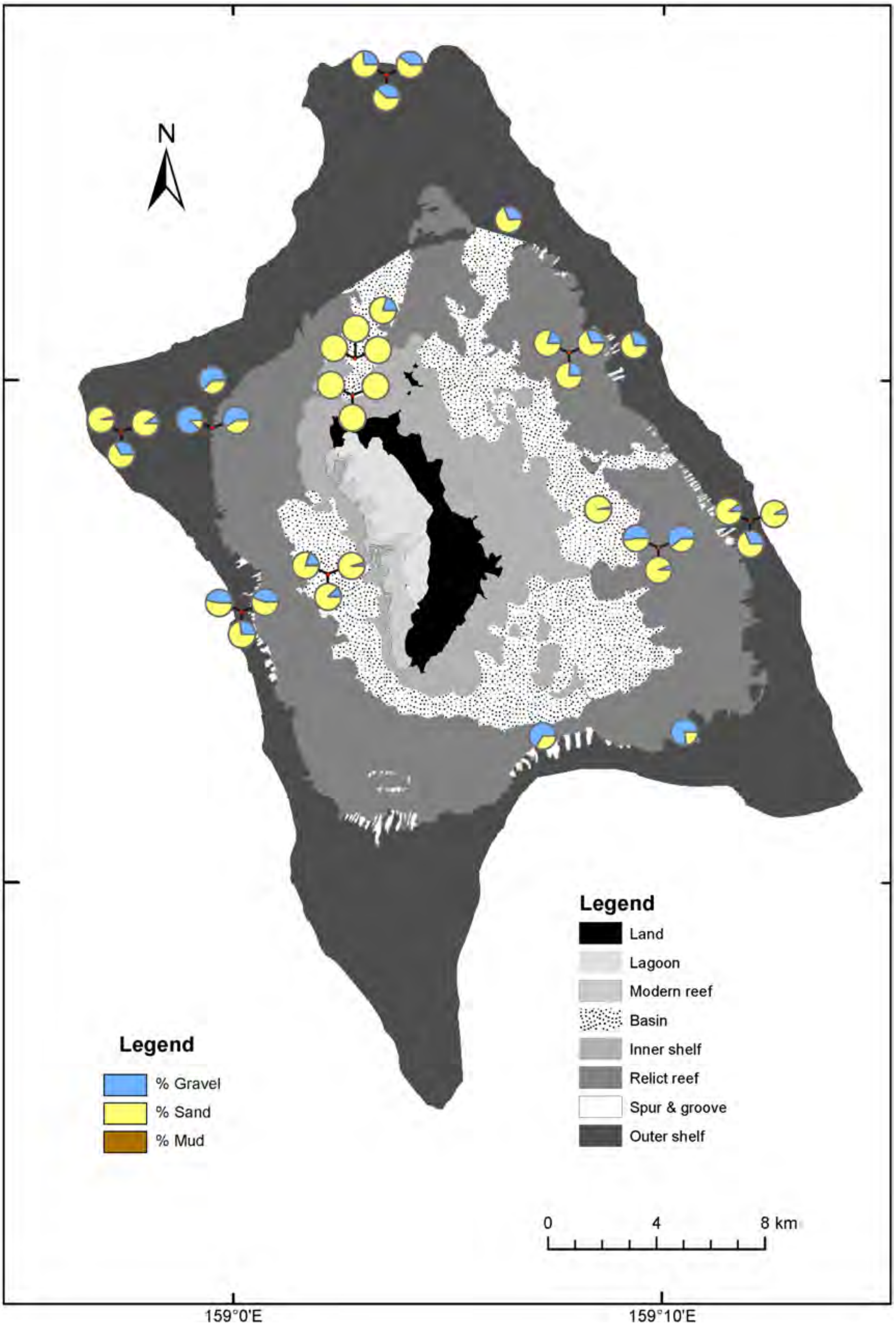


Figure 3.28: *Sediment texture of samples collected on the Lord Howe Island shelf, shown as gravel, sand and mud content.*

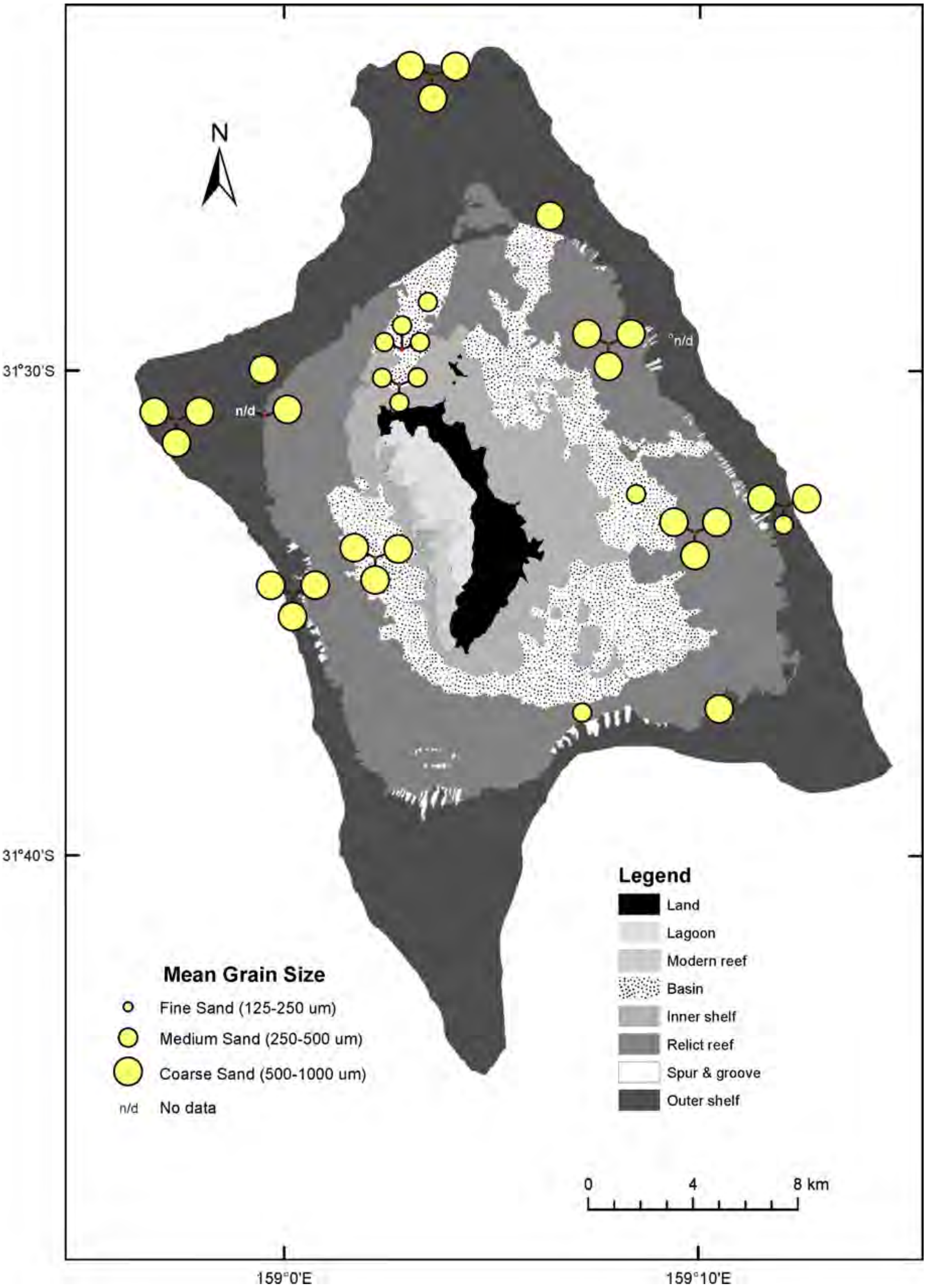


Figure 3.29: *Mean grain size (microns) of samples collected on the Lord Howe Island shelf.*

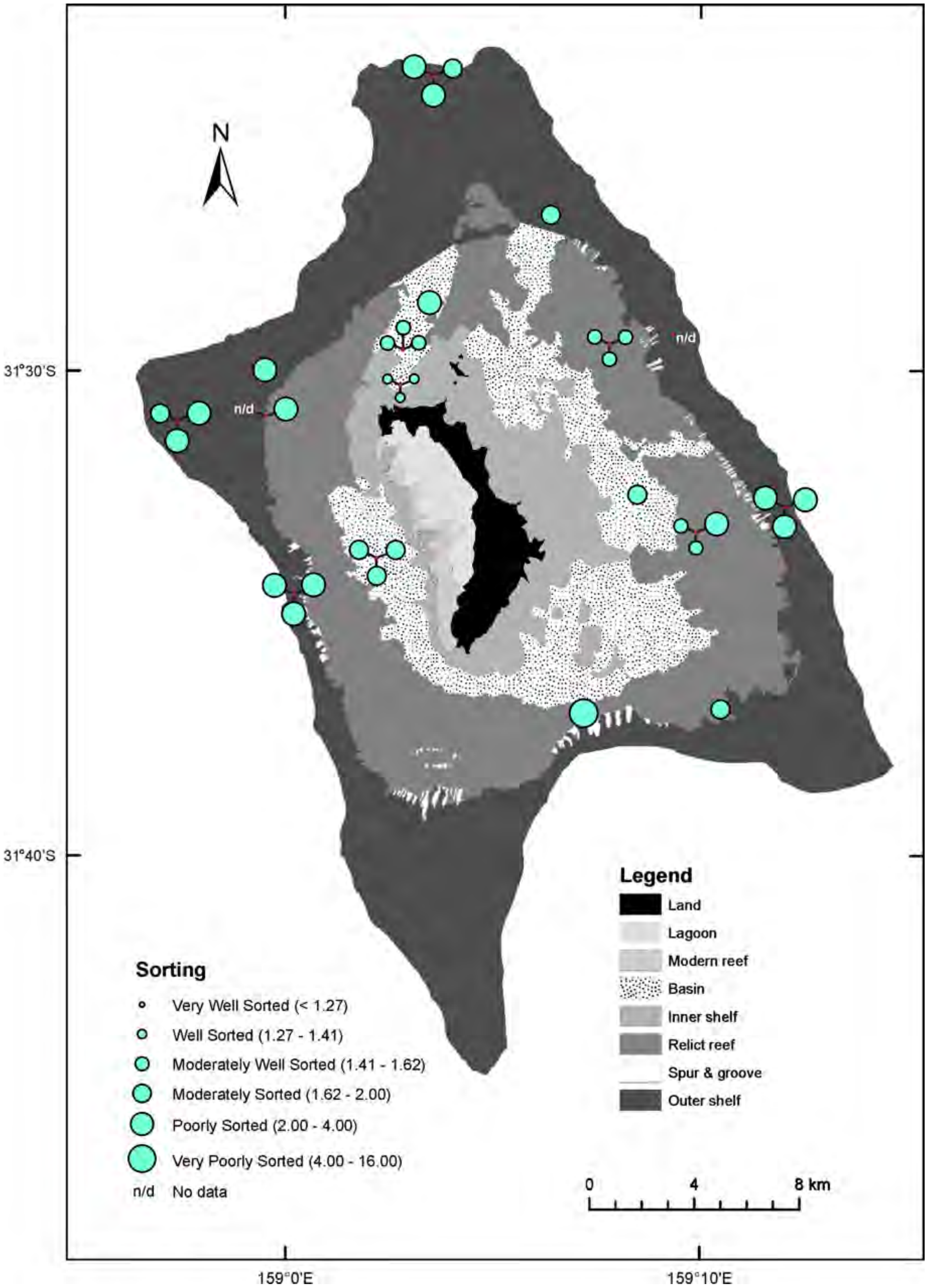


Figure 3.30: *Sorting (phi-scale) of sediments across the Lord Howe Island shelf.*

3.6 INFAUNA AND TOWED VIDEO DATA

Infauna

The shallow waters surrounding Lord Howe Island are home to the southernmost reef-forming coral colonies in the world and have attracted considerable attention as a result (Veron and Done, 1979; Harriott et al., 1995). The geographic isolation of seamounts and the benthic habitat oases they offer in otherwise pelagic areas tend to promote high levels of endemism (Richer de Forges et al., 2000). The fauna of Lord Howe Island conforms to this pattern and Ponder et al. (2000) identified 10% of the local mollusc fauna as endemic.

Towed video has been used to classify benthic substrate, epifauna and fish assemblages of the middle to outer shelf of Lord Howe Island and Balls Pyramid by the Australian Institute of Marine Science (Speare et al., 2004). Coralline algae and hard corals were found on the middle shelf. Abundant fish assemblages were observed over the rock rubble dominated outer shelf, which was also home to gorgonian corals. Finer sediments, gorgonians and brown algae were associated with the drop-off on the margin of the shelf. In the north, the shelf areas surveyed were sandy and the dominant biota observed was urchins.

Within the region mapped during the SS06/2008 cruise, 33 sediment and infauna samples were collected from 15 stations using a Smith-McIntyre grab sampler (Figure 2.4). Stations were selected prior to the survey to represent three depth zones (30, 50, 70 m) around the island. Due to dangerously rough weather, particularly on the south-western side of the island and inner shelf, the complete number of planned stations (n=30) were unable to be sampled. However, samples collected represented a range of depths and locations around the island. In addition, multiple samples were taken at ten stations to characterise fine-scale variation in sediment and infauna.

A total of 2,139 individual infaunal organisms were identified, from which 163 operational taxanomic units (OTUs) were defined. Among the OUT's, 57 were observed only once and a further 20 were observed in two samples. The main taxa included amphipods, crustaceans and polychaetes. Representative photographs of these and other taxa are shown in the Appendices (Figure 6.10).

Infaunal assemblages identified in the grab samples fell into three categories, consistent with the geomorphological categorisation of the stations from which they came: high numbers of individuals (N) and high species richness (S) on the outer shelf; moderate N and high S on the relict reef; and low N and S in the basin systems landward of the relict reef (Figure 3.31 and 3.32). Both S and N exhibit an apparent decrease from otherwise equivalent stations from east to west across the shelf. The low number of samples, particularly in the south west quadrant of the shelf, precludes this trend from consideration as more than a sampling artefact.

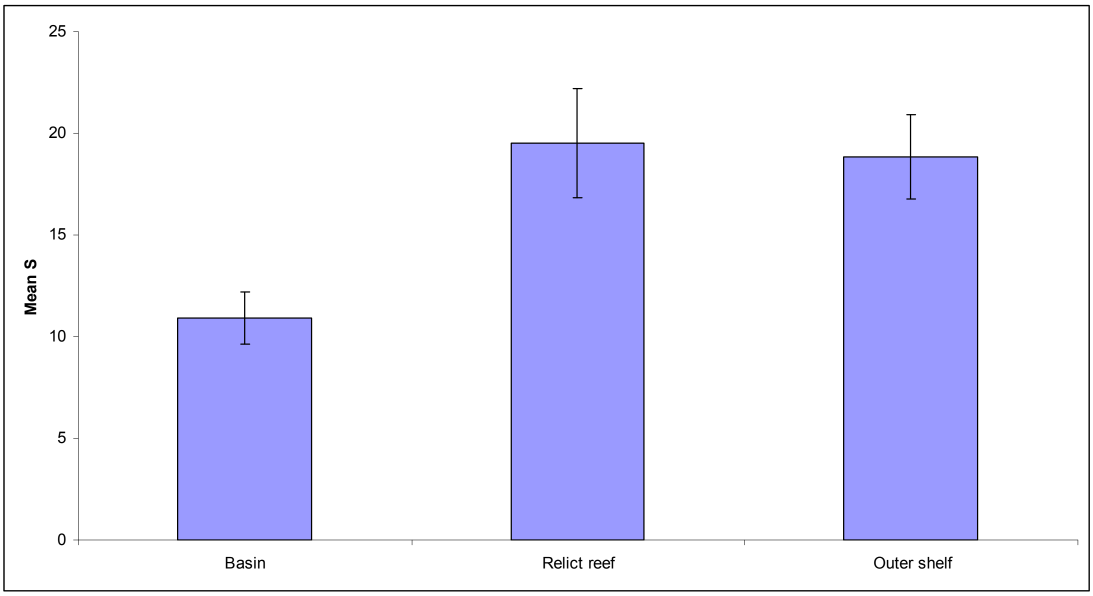


Figure 3.31: *Mean infauna species richness (± SE) for samples collected on three major seabed geomorphic features.*

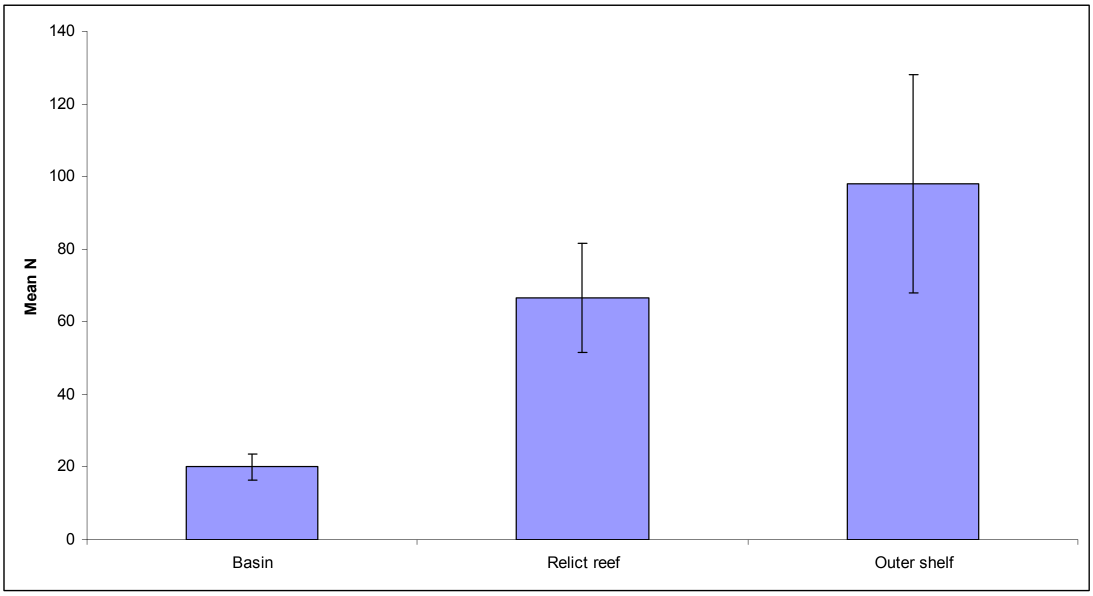


Figure 3.32: *Mean number of infauna individuals per sample (± SE) for samples collected on three major geomorphic features.*

Piellou's evenness (j), a measure of the proportionality of species counts within a sample where a value of one indicates count parity between all taxa present, decreased from the basins to the outer shelf (Figure 3.33). Basin samples featured a small number of taxa in near equal numbers whereas outer shelf samples were dominated by a small number of taxa and included many singletons of rare taxa.

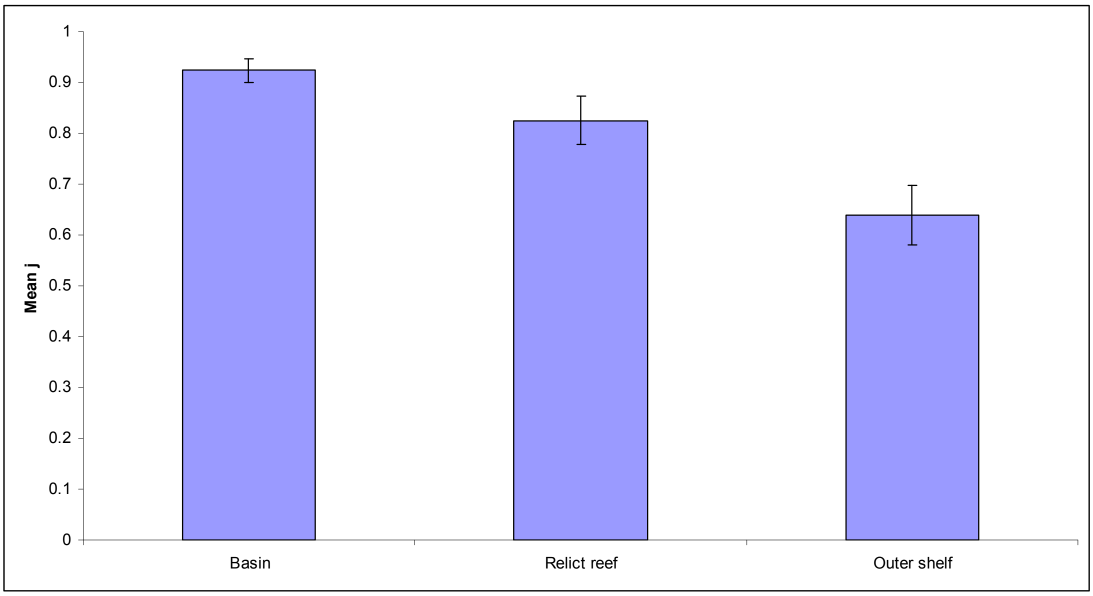


Figure 3.33: *Mean Piellou's evenness (± SE) for samples collected on three major geomorphic features..*

High numbers of suspension feeding taxa (Kalliapseudes sp2 and Spiochaetopterus sp1) were observed at four stations beyond the relict reef to the east and west of the island, with counts for Kalliapseudes sp2 constituting two of the highest records of all samples in the survey (n = 114 and n = 301) and accounting for much of the sample dominance of outer shelf samples (Figure 3.33). The presence of high numbers of suspension feeding taxa at these stations is consistent with the epifaunal characterisation of the shelf by Speare et al., (2004) wherein the shelf margins were dominated by suspension feeding taxa.

While Kalliapseudes sp2 occurred in high numbers, its distribution was limited to samples from four stations, giving the taxon little scope to contribute to meaningful analysis of surrogates on the Lord Howe Island shelf. It was therefore excluded from other analyses other than those concerned exclusively with suspension feeding organisms. Mean counts for the other numerically dominant taxa show the Operational Taxonomic Unit (OTU) known as Maeridae sp1 (Figure 3.34) was the most abundant infaunal organism. This taxon exhibited a similar distribution to the suspension feeding organisms but, as it is of an undescribed genus and may even be an undescribed family (Lauren Hughes, pers. comm.), determining its feeding mechanism was not possible and it was excluded from feeding guild categories. The depth gradient usually associated with a straight-forward relationship with species richness and abundance was confounded at Lord Howe Island by the nature of depth change with distance from the island. The basins represent entirely different oceanographic, depositional and sediment mobilisation systems to those at an equivalent depth on the outer shelf.

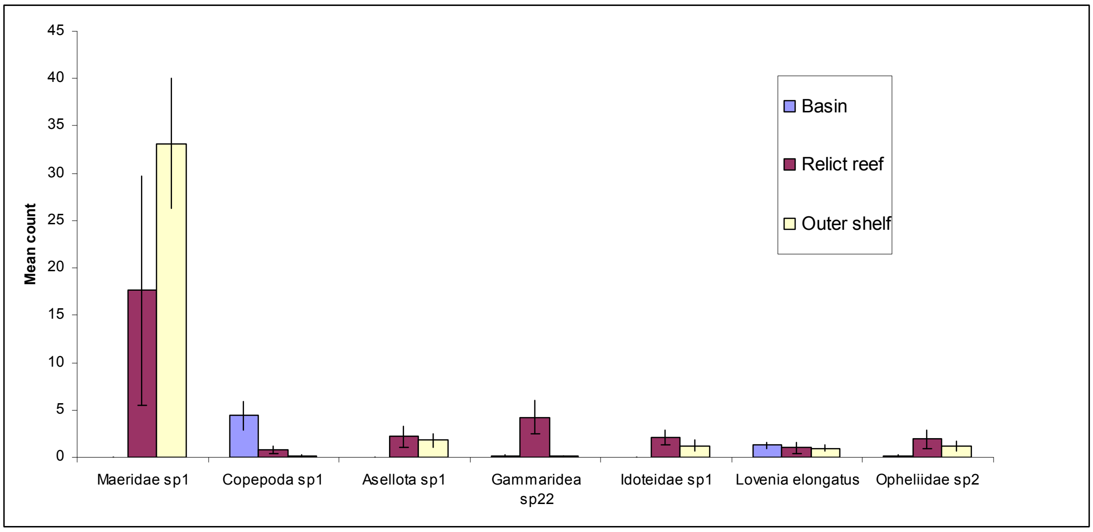


Figure 3.34: *Mean count (+ SE) of numerically dominant, wide-spread taxa against geomorphic category.*

Levels of endemism in the Lord Howe Island shelf infauna are yet to be determined through examination of the material by taxonomic experts. Preliminary work on the amphipod taxa suggests the ten percent endemism found in the mollusc fauna of the Lord Howe Island slope sediments (Ponder et al., 2000) is likely to be matched, if not exceeded.

Towed underwater video

Frames extracted from the video footage demonstrate the relict reef appears to be a largely low profile surface with little structural macro biota (Figure 3.35) that is dominated by encrusting algae (Figure 3.36). The basins are sandy environments and there are large patches of sand with ripples on the relict reef (Figures 3.37 and 3.38).

In studies by the NSW Government's Department of Environment, Climate Change and Water (Marine Conservation Science Unit) and Speare et al. (2004) Baited Remote Underwater Video (BRUV) and towed video data were collected at a number of sites across the Lord Howe Island and Balls Pyramid shelves (see Appendix 6.8 and 6.9, respectively). This footage was used to characterise the substrate and dominant biota on the middle to outer shelves. Coralline algae and hard coral growths were recorded on the middle of the Lord Howe Island shelf. On the outer shelf, rock rubble was common, with gorgonians and abundant fish communities. In the shelf drop off zone, finer sediment is noted as well as gorgonians and brown algae. Sites on the northern shelf were shown to be dominated by sand with urchin populations common.

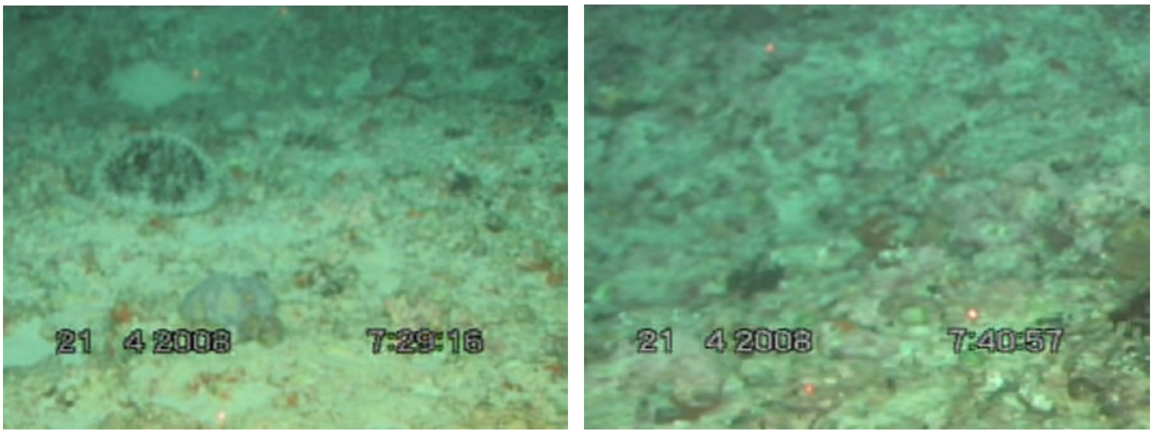


Figure 3.35: *Relict reef: low-relief algal coverage and isolated communities of urchins.*

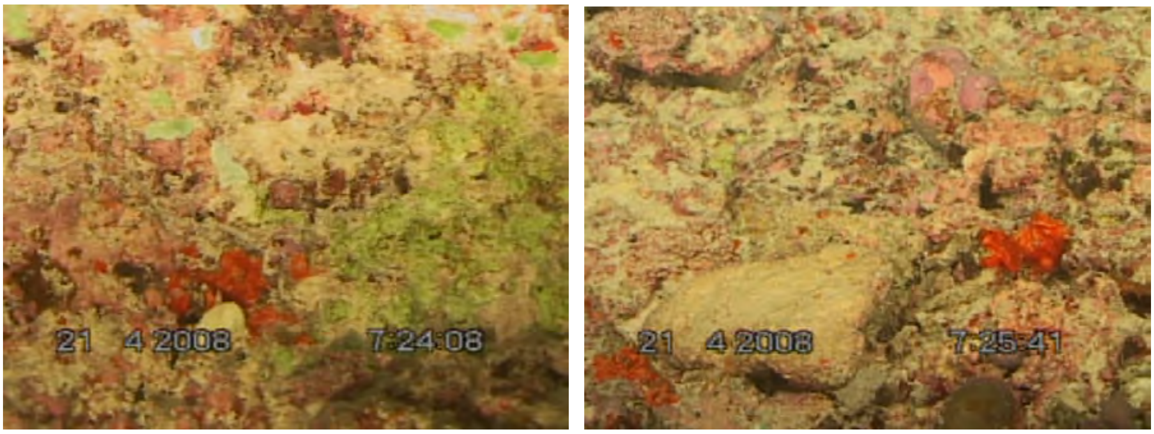


Figure 3.36: *Close up of the relict reef surface: Evidence of more substantial biota, with coral and algal growths.*

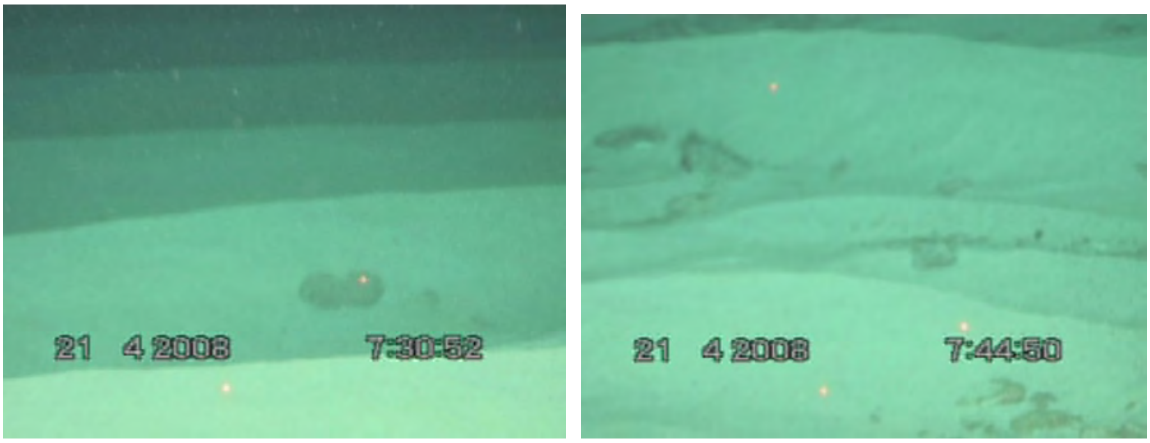


Figure 3.37: *Sand ripples: Large ripples between relict reef structures demonstrate a high energy environment.*

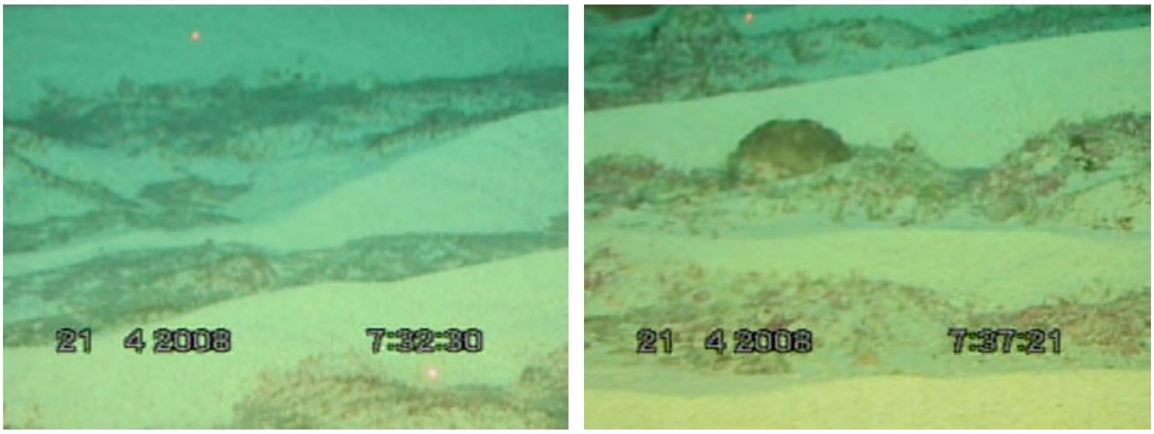


Figure 3.38: *Large sand ripples between patches of relict reef, with material accumulating within the troughs.*

3.7 REEF CORES

The reef limestone samples recovered in drill cores are particularly significant because they confirm the hypothesis that the prominent feature on the shelf is a relict reef. The cores included relict coral material, as well as a range of other relict reef organisms. Coralline algae and coral gravel comprise a large component of the recovered material, with cemented sand also a substantial component. Weathering features in the form of bore holes, pores, cavities and discolouration are common.

Ages and depths of samples are shown below (Table 3.5 and 3.6), with lithological and facies core logs included in Appendix 6.6. All depths reported are penetration depth as shown in the core logs (not recovery depth as shown in the core photos), unless otherwise stated (drill depth/penetration rate data are provided in Appendix 6.5). Photographic mosaics of the cores are shown in Figure 3.39. The cores are depicted in a seabed geomorphological context in Figure 3.40.

Results of the XRD analysis of core samples, which indicate the degree of aragonite re-crystallisation or contamination of the coral samples, are provided in Appendix 6.7. The results of AMS (radiocarbon) and TIMS (uranium/thorium) dating of the best preserved samples indicate that reliable radiometric ages were obtained which reveal a Holocene age for most of the core material (Tables 3.6 and 3.7).

Table 3.5: *Position, depth and length of reef cores.*

Core ID	Water Depth (m)	Core Length (m) P= Penetration; R= Recovery	Location
13RDC01	27	P: 2.03	31˚30.18' S; 159˚02.26' E
		R:0.85	
14RDC01	27	P: 2.58	31˚33.39' S; 159˚02.55' E
		R: 0.75	
15RDC01	34	P: 0.97	31˚33.35' S; 159˚01.03' E
		R: 0.50	
15RDC02	34	P: 1.43	31˚33.35' S; 159˚01.03' E
		R: 0.40	
21RDC01	30	P: 1.22	31˚34.10' S; 159˚10.17' E
		R: 0.87	
22RDC01	24	P: 2.72	31˚33.10' S; 159˚09.62' E
		R: 1.20	

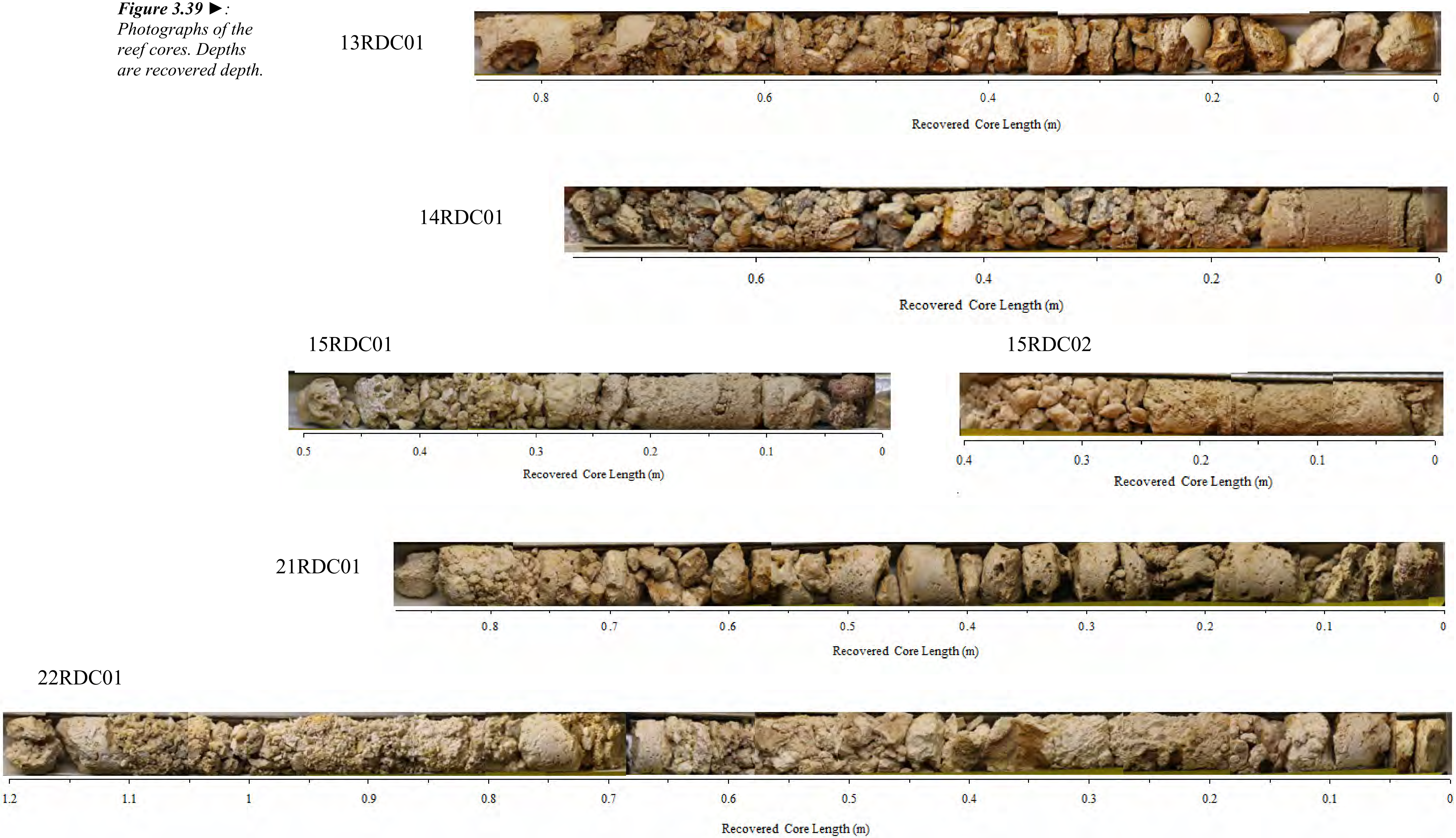
***Table 3.6:** AMS dating results for samples from the reef cores.*

Sample ID	Sample depth (cm) R= Recovered I= Interpreted	Material	d ^{13}C (‰) 1σ error	Modern Carbon % pMC 1σ error	C^{14} Age yrs BP 1σ error	Th age (cal BP) 2σ	Calibrated C^{14} age (cal BP)				
							1σ		2σ		Median cal. age (2σ)
							lower	upper	lower	upper	
13RDC01 a-6	R = 6; I = 22	Coral	0.3 ± 0.4	93.82 ± 0.43	510 ± 40	n/a	87	244	0	260	151 (0-260)
13RDC01 b-16	R = 16; I = 40	Coral	-0.2 ± 0.1	93.42 ± 0.36	545 ± 35	170 +/- 2	132	262	0	291	185 (0-291)
14RDC01 a-17	R = 17; I = 62	Mollusc Operculu m	3.4 ± 0.2	67.71 ± 0.39	3135 ± 50	n/a	2842	3017	2768	3111	2933 (2768-3111)
15RDC01 a-27	R = 27; I = 27	Coral	-0.3 ± 0.1	71.02 ± 0.36	2750 ± 45	n/a	2363	2572	2336	2669	2490 (2336-2669)
15RDC01 c-40	R = 40; I = 60	Coral	-1.3 ± 0.2	71.73 ± 0.38	2670 ± 45	2379 +/- 13	2305	2457	2225	2605	2387 (2225-2605)
15RDC02 -32	R = 32; I = 120	Coral	0.5 ± 0.1	70.44 ± 0.33	2815 ± 40	n/a	2499	2678	2390	2717	2575 (2390-2717)
21RDC01 a-2	R = 2; I = 8	Clam shell Genus *Tridacna*	1.9 ± 0.4	94.76 ± 0.44	430 ± 40	n/a	Out of the range of Marine 04 - Modern				Modern
22RDC01 b-9	R = 9; I = 10	Coral	-0.5 ± 0.1	43.16 ± 0.25	6750 ± 50	n/a	7235	7364	7169	7407	7293 (7169-7407)

***Table 3.7:** TIMS dating results for coral samples from the reef cores.*

Sample ID	Sample depth (cm) (as above)	Material	Aragonite %	U (ppm) ± 2σ	^{232}Th (ppb)	(^{230}Th/ ^{232}Th)	(^{230}Th/^{238}U) ±2σ	(^{234}U/ ^{238}U) ±2σ	uncorr. ^{230}Th Age (ka) ±2σ	corr. ^{230}Th Age (ka) ±2σ
13RDC01-016	R = 16; I = 40	Coral	>99	4.3918 ± 0.0068	0.3466	93.8	0.002441 ±0.00002	1.1488 ±0.0014	231±2	229±2
13RDC01c-085	R = 85; I = 190	Coral	98.5	2.7683 ± 0.0038	2.3752	323.7	0.091547 ±0.00027	1.1501 ±0.0020	9037±32	9015±34
14RDC01b-055	R = 55; I = 200	Coral	96.8	2.6819 ± 0.0025	2.6086	244.7	0.078430 ±0.00028	1.1528 ±0.0011	7674±30	7649±32
15RDC01-040	R = 40; I = 60	Coral	98.6	4.0243 ± 0.0064	0.5404	574.8	0.025438 ±0.00013	1.1455± 0.0014	2438±13	2438±14
21RDC01c-079	R = 79; I = 115	Coral	93.9	2.8866 ± 0.0049	0.9895	735.5	0.083091 ±0.00045	1.1502 ±0.0019	8168±48	8159±48
22RDC01d-117	R = 117; I = 270	Coral	92.6	4.1408 ± 0.0066	0.6595	1768.3	0.092813± 0.00049	1.1531 ±0.0017	9142±52	9138±52

***Figure 3.39* ► :** *Photographs of the reef cores. Depths are recovered depth.*



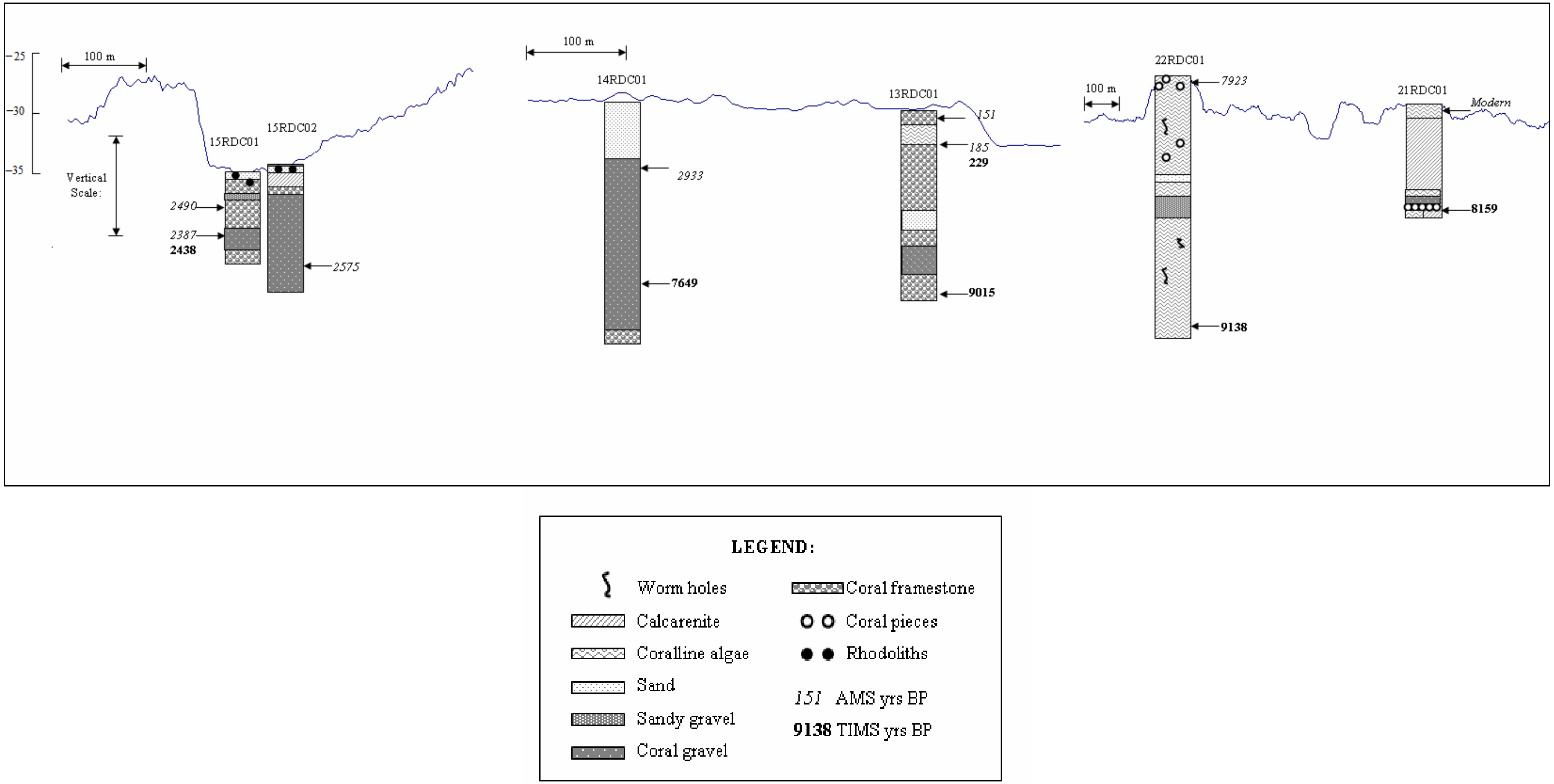


Figure 3.40: *Drill cores shown on topographic profiles of the seabed. The locations of the cores are shown in Figure 2.4.*

Initial Core Descriptions
13RDCO1:
Modern coral (0 – 22 cm): There is a clear distinction between the upper and lower sections of this core (Figure 3.39). The upper unit comprises white coral fragments and has a modern age, 151 (0 - 260) to 229 (0 - 291) yrs BP.

Early Holocene rudstone and framestone (22 – 203 cm): Coral rudstone is the main facies in the lower unit, with a section of coral framestone at the base. The unit has strong orange-brown colouration and dissolution weathering features (cavities and mottles). Coral from a depth of 190 cm has an age of 9015 ± 34 yrs BP.

Weathering features, in particular, discolouration are unusual in Holocene reef cores. The orange-brown colouration and alteration features also occur in the other cores, though not as intensely developed as in this core.

14RDCO1:
Modern shelf (0 – 7 cm): Unconsolidated medium to coarse sand, comprising fresh (modern?) carbonate fragments.

Late Holocene reef (7 - 62 cm): Medium to coarse grained moderately cemented calcarenite. Coral rudstone underlies the calcarenite, with a thin coral framestone with gastropod fragments between the two deposits. A mollusc at a depth of 62 cm has an age of 2933 (2768-3111) yrs BP.

Early Holocene reef (62 - 258 cm): The lower section of this core comprises predominantly rudstone, as well as a thin band of bindstone, with framestone at the base of the core. A coral sample from 200 cm has an age of 7649 ± 32 yrs BP. This core had the lowest recovery, with 0.75 m of material recovered from a penetration depth of 2.58 m.

15RDCO1:
Modern shelf (0-27 cm): Unconsolidated medium-coarse bioclastic sand and reddish brown rhodolith gravel, likely of modern age.

Late Holocene reef (27 – 97 cm): Encrusting coral caps well-cemented sand, which extends to 53 cm. The coral has an age of 2490 (2336 - 2669) yrs BP. Below the calcarenite is rudstone that comprises fragments of coral and calcaerous red algae, bivalve and gastropod shells, and coarse sand. Coral within this unit at 60 cm has a ^{14}C age of 2387 (2225 - 2605) and U/Th age of 2438 ± 14 yrs BP. A heavily bored and algal encrusted framestone forms the base of the core.

15RDC02:
Modern shelf (0 – 8 cm): Similar to 15RDC01, sand and rhodoliths.

Late Holocene reef (8 – 143 cm): Sandy floatstone appears to extend from 8 – 97 cm. At the base of this unit is heavily bored coral and encrusting algae that caps a rudstone facies which forms the remainder of the core. A coral from 120 cm has an age of 2575 (2390 - 2717) yrs BP.

21RDCO1:
Modern reef (0 – 8 cm): A Tridacna shell and encrusting coralline algae form the top 8 cm of this core and appear to be modern.

Early Holocene reef (8 – 122 cm): The lower section of core comprises predominantly coarse calcarenite, with a few thin layers of bindstone and framestone. Borings and cavities are common in the cemented sand, from 10 – 88 cm. Framestone and bindstone occurs in the base of the core, 88 – 122 cm. A coral sample from 115 cm has an age of 8159 ± 48 yrs BP.

22RDCO1:
Modern reef (0 – 10 cm): Well preserved white coral in the top of the core appears to be modern.

Early Holocene reef (10 – 272 cm): Bindstone down to around 40 cm comprises bored and encrusted coral and coralline algae. A coral sample from 10 cm has an age of 7293 (7169-7407) yrs BP. The rest of the core comprises rudstone and bindstone facies. A coral samples from near the base of the core (270 cm) has an age of 9138 ± 52 yrs BP.

An accumulation rate for this core below 10 cm was calculated based on the age-depth data. Reef accumulation during the early Holocene was calculated to be 140.9 ± 13 cm/ka. The standard deviation was derived from the maximum (i.e. 9190 - 7169 yrs BP = 128.6 cm/ka) and minimum (i.e. 9086 - 7407 yrs BP = 154.9 cm/ka) ages.

Core data summary

The cores comprise sediments typical of a coral reef environment, especially reef rudstone, framestone and bindstone facies. These types of deposits are typical of a reef flat or back-reef depositional setting. The age data indicate that the cores record significant coral reef growth during the early to middle Holocene, then much reduced rates of reef growth, or no accretion, since that time.

3.8 NEAR BED CURRENT DATA

The time series of sea level, current direction and velocity, as measured 3 m above the bed by the ADCP provide a unique insight into the near-bed current regimes on the Lord Howe Island shelf (Figure 3.41). There is a break in the current record between mid-December 2007 and mid-January 2008 when the mooring temporarily shifted the ADCP mounting from its upward-looking position (Heap et al. 2009). During the remainder of the deployment, maximum current speeds in the range of ~0.85 - 0.93 m/s were recorded on two occasions (early Nov-07 and early Mar-08), with a third event in late Nov-07 peaking at ~0.75 m/s. These were relatively brief events, as current speeds exceeded 0.65 m/s for only 1% of the measurement time and the overall mean current speed was 0.19 m/s. Directional data show that the current is broadly directed west during the flood stage of the tide and east for ebb tide. During the deployment, mean spring tidal range was 1.55 m and mean neap tidal range was 0.81 m. The sea level record also shows a gradual rise in mean sea surface height that Heap et al. (2009) show corresponds with increased water temperature and likely relates to the passage of a warm core eddy. Further details regarding the oceanographic mooring data are presented in Heap et al. (2009).

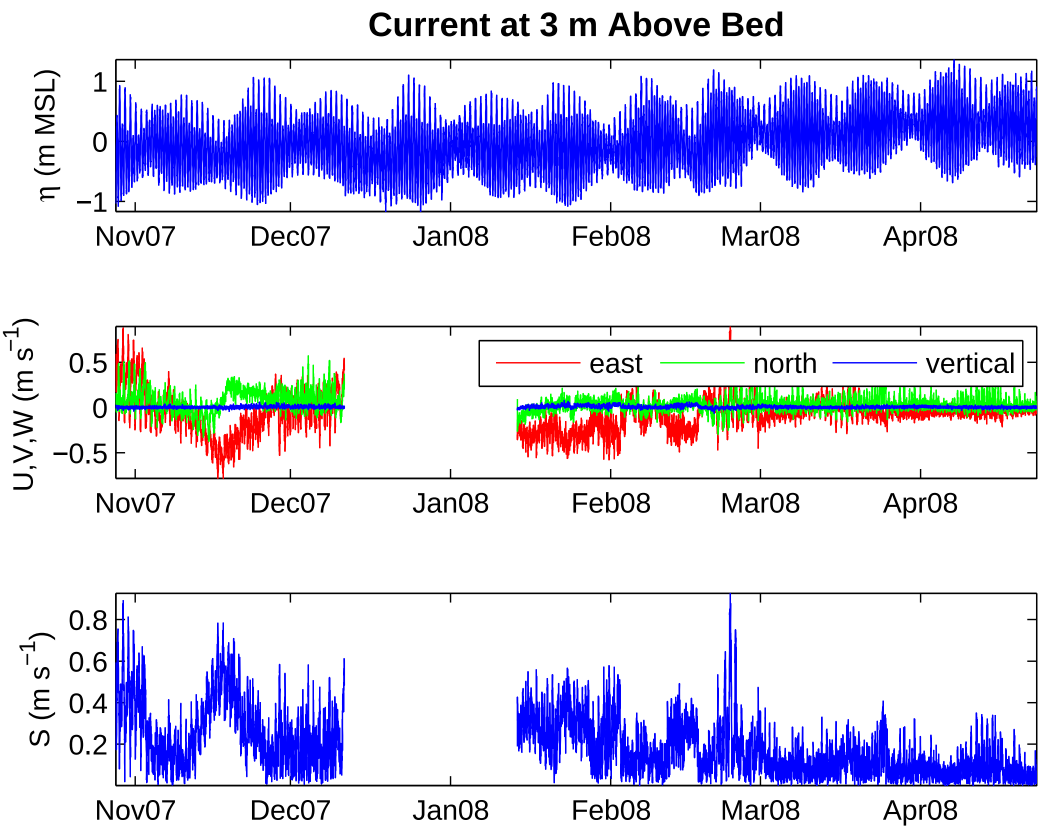


Figure 3.41: *Time series of sea level (top panel); east, north and vertical components of the current vector (middle); and, current velocity measured 3 m above the seabed by the ADCP (bottom panel). Figures reproduced from Heap et al. (2009).*

3.9 VOLCANO MORPHOLOGY

Multibeam sonar bathymetry data show the island flanks grade into the surrounding planar sea floor (Figure 3.42). Several slump features are evident, the largest being over 130 km^2 in area (Figure 3.42b). These features are inferred to be old (late Tertiary) based on an extensive cover of marine sediment as indicated by low multibeam backscatter intensity (Figure 3.3), subdued topography and sediment samples collected in the trough between the Lord Howe Island and Balls Pyramid shelves (Kennedy et al., *in press*). Most likely the slumps formed during the immediate post-eruptive stage of volcano evolution, before the bulk of the subaerial portion of the volcano was removed by marine erosion. Flank processes are now dominated by the deposition of carbonate sediment (Kennedy et al., *in press*). The erosional morphology, sediment cover and tectonic stability of the region suggest that the flanks of the volcano are at present relatively stable.

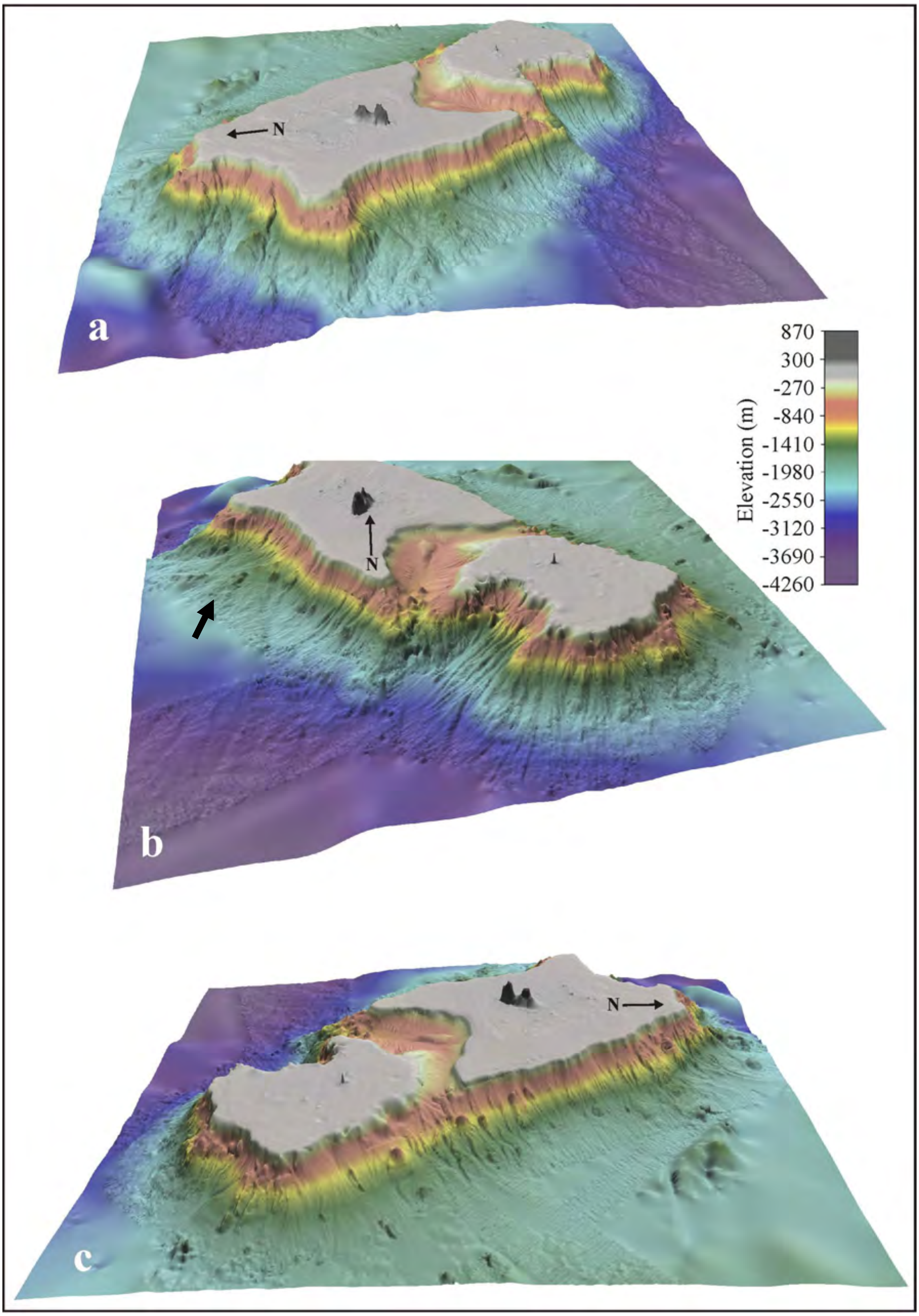


Figure 3.42: *A series of 3D views of the volcano flanks, from (a) the north looking south, (b) the southwest facing northeast (arrow marks large slump) and (c) the southeast facing northwest (from Kennedy et al., in press).*

4. Summary

The major objectives of Survey SS06-2008 aboard RV *Southern Surveyor* were successfully achieved. Multibeam sonar bathymetry and sub-bottom profiler data coverage were obtained for most of the shelf surrounding Lord Howe Island. Initial analysis of these data shows that they reveal in detail the morphology of a relict reef on the middle shelf that surrounds the island. These data also enable distinct morphological features to be mapped, providing a first order delineation of seabed habitats on the shelf. The acoustic sub-bottom data also provide insights into a much longer history of carbonate sediment accumulation on the shelf. Importantly, the composition of cores recovered from the reef structure confirms that it formed as a coral reef. Preliminary dating of the cores reveals that the top 3 metres of the reef was predominantly deposited during the early Holocene, between 9 to 7 ka. The age data also show that some parts of the relict reef continued to grow vertically during the last few thousand years, but at a slower rate than in the early Holocene. These data are especially important as they provide unique insights into periods when reef growth appears to have been much more prolific than the present day and will enhance our understanding of the controls on reef growth at the southern latitudinal limits of reef formation.

Multibeam sonar coverage of the flanks of the volcano have enabled high-resolution relief models and calibrated backscatter grids to be generated that reveal morphological evidence of the major erosional processes that have been acting on the volcano since it became inactive. Important insights obtained are that most large mass failures have occurred on the western margin of the volcano, and most of the flanks appear to be mantled by soft marine sediment.

Seabed sediment samples were collected from stations across the shelf and show the distribution of different sediment types in terms of size, carbonate content and sorting. Sediment samples have also been processed to extract infauna samples. An initial assessment of these biological data reveals the character and unique spatial pattern of biodiversity on this remote shelf, in particular an increase in number of species and individuals from the basins to the outer shelf. These data will be compared with the co-located sediment and morphological data to identify physical parameters that may act as useful surrogates for patterns of shelf biodiversity, a key aim of the Marine Biodiversity Hub. The results of this analysis will be the subject of upcoming science journal papers.

The ADCP (current) meter retrieved from the outer shelf has provided a unique time-series of current data that span nearly six months. This record of near-surface currents is important as it documents the influence on the shelf of fluctuations in the East Australian Current in terms of current speed and direction and changes in sea level.

In conclusion, the data collected on the survey are enabling a much better understanding of the pattern of seabed biodiversity on the Lord Howe Island shelf. Importantly, the data have been provided to managers of the Lord Howe Marine Parks to help better inform the sustainable management of these unique marine resources.

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6. Appendices

6.1. VOYAGE NARRATIVE

Transit

The RV Southern Surveyor left Sydney on the morning of 16 April and sailed to the shelf around Lord Howe Island, reaching the shelf on the night of the 17th April. Research at the island commenced on the morning of Friday 18 April after a relatively rough transit.

Mapping the shelf

The EM300 swath mapper was used to map the topography of the seafloor throughout the eight days that we were working on the Lord Howe Island shelf. The Reson 8101 shallow-water swath system, installed on the vessel and deployed through the moonpool, was also operated although issues of software incompatability and low-performance of the supplied computer mean that it has not been possible to assess the quality of data from that swath mapper while in the field.

The Topas sub-bottom profiler was also operated over the entire survey area and provided an indication of phases of sediment accumulation and bottom roughness, enabling differentiation of rocky substrate from those areas which had a sandy bottom. Grab samples were collected using the Smith-Macintyre grab sampler; three replicate samples were taken for benthic ecological analysis at ten sites.

Several instruments failed to function when first deployed. This included the first attempts to use the underwater camera, the Sparker sub-bottom profiler system, the acoustic release on the moored ADCP and the submersible rock corer. After adjustments, the underwater camera was used to acquire a video of the seafloor at a site off the west of the island.

Sea conditions limited the deployment of several pieces of equipment for the first few days of fieldwork, with swells of 4 to 6 metres, and gale force winds, with the weather complicated by the influence of Lord Howe Island itself. On Tuesday 22 April and Wednesday 23 April the seas were somewhat less unfavourable, and we were able to deploy the submersible rock corer off the rear of the vessel to recover short cores of reef limestone and to confirm that the prominent features that we had been mapping were indeed relict reefs. The weather subsequently deteriorated and no further deployment of the submersible corer was possible.

The benthic sled was deployed at six sites to the west of Lord Howe Island and several further grab samples were obtained. Throughout the voyage the EM300 multibeam sonar system continued to be used to map bathymetry across the shelf, and overnight the shelf margin at each of the major corners of the shelf were mapped. On conclusion of this mapping, a brief swath profile was undertaken across the shelf surrounding Balls Pyramid. A strong swell and gale-force winds then necessitated departure from Lord Howe Island on the transit to Noumea.

6.2 LOCATIONS OF ALL SURVEY STATION OPERATIONS

Table 6.2.1.

Smith-Macintyre Sediment Grab Sample Sites		
Sample No.	**Latitude**	**Longitude**
01GRSM01	31:31.00S	158:59.46E
01GRSM02	31:30.96S	158:59.48E
01GRSM03	31:30.99S	158:59.52E
01GRSM04	31:30.99S	158:59.51E
02GRSM01	31:33.89S	159:02.24E
02GRSM02	31:33.89S	159:02.19E
02GRSM03	31:33.86S	159:02.18E
03GRSM01	31:31.03S	158:57.41E
03GRSM02	31:31.00S	158:57.39E
03GRSM03	31:31.00S	158:57.38E
03GRSM04	31:31.04S	158:57.42E
04GRSM01	31:30.30S	159:02.77E
04GRSM02	31:30.30S	159:02.81E
04GRSM03	31:30.26S	159.02.75E
05GRSM01	31:28.61S	159:03.48E
06GRSM01	31:29.55S	159:02.82E
06GRSM02	31:29.54S	159:02.83E
06GRSM03	31:29.54S	159:02.80E
07GRSM01	31:32.57S	159:08.49E
08GRSM01	31:33.35S	159:02.24E
10GRMS01	31:34.62S	159:00.22E
10GRMS02	31:34.60S	159:00.19E
10GRMS03	31:34.60S	159:00.20E
11GRSM01	31:26.87S	159:06.50E
12GRSM01	31:24.01S	159:03.68E
12GRSM02	31:24.01S	159:03.66E
12GRSM03	31:24.01S	159:03.68E
16GRSM01	31:37.08S	159:07.20E
17GRSM01	31:37.56S	159:07.23E
18GRSM01	31:37.00S	159:10.50E
19GRSM01	31:32.81S	159:11.99E
20GRSM01	31:33.29S	159:09.90E
20GRSM02	31:33.33S	159:09.90E
20GRSM03	31:33.33S	159:09.88E
30GRSM01	31:29.48S	159:07.81E

30GRSM02	31:29.48S	159:07.81E
30GRSM03	31:29.48S	159:07.81E
31GRSM01	31:29.29S	159:09.28E
31GRSM02	31:29.28S	159:09.32E

Table 6.2.2

Reef Core Sites					
Core No.	**Latitude**	**Latitude**	**Water Depth (m)**	**Penetration (m)**	**Recovery (m)**
13RDC01	31:30.18S	159:02.26E	27	P: 2.03	R:0.85
14RDC01	31:33.39S	159:02.55E	27	P: 2.58	R: 0.75
15RDC01	31:33.35S	159:01.03E	34	P: 0.97	R: 0.50
15RDC02	31:33.35S	159:01.03E	34	P: 1.43	R: 0.40
21RDC01	31:34.10S	159:10.17E	30	P: 1.22	R: 0.87
22RDC01	31:33.10S	159:09.62E	24	P: 2.72	R: 1.20

Table 6.2.3

Camera Tow				
Tow No.	**Latitude**	**Longitude**	**Depth (m)**	**Ends**
09CAM01	31:34.99S	159:02.18E	35	in
	31:35.36S	159:02.02E		out

Table 6.2.4

Benthic Sled Site				
Sled No.	**Latitude**	**Longitude**	**Depth (m)**	**Ends**
24BS01	31:31.88S	159:00.82E	35	in
	31:31.91S	159:00.98E		out
25BS01	31:32.68S	159:01.41E	40	in
	31:32.67S	159:01.62E	38	out
26BS01	31:33.26S	159:02.11E	36	in
	31:33.29S	159:02.24E		out
27BS01	31:34.73S	159:02.13E	36	in
	31:34.81S	159:02.27E		out
28BS01	31:35.43S	159:02.61E	38	in
	31:35.50S	159:02.76E		out
29BS01	31:35.17S	159:02.07E	32	in
	31:35.18S	159:02.25E	34	out

6.3 COVERAGE OF LADS DATA (GRID CELL SIZE: 35m)

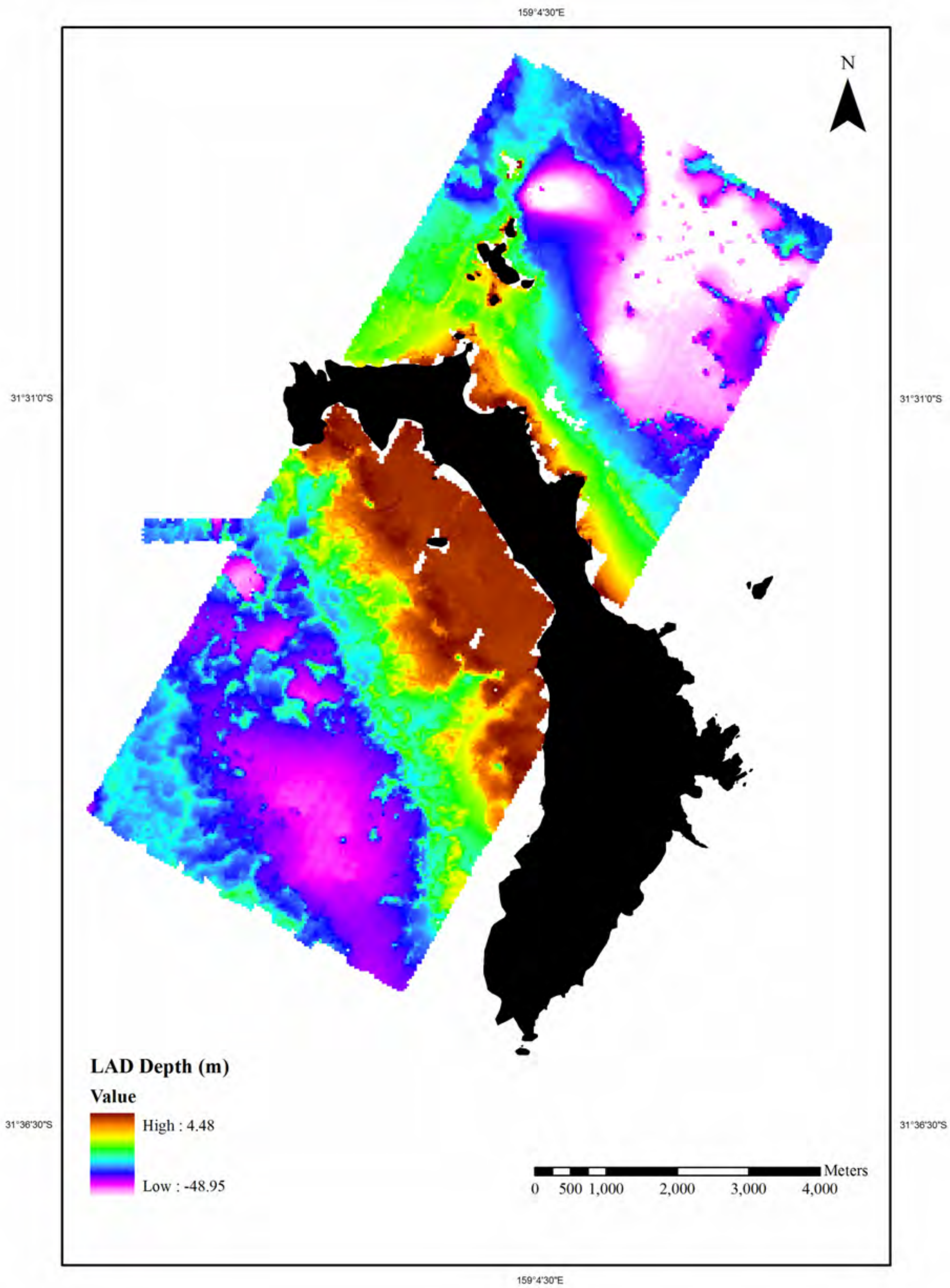


Figure 6.1: *LADS bathymetry data coverage.*

6.4 DENSITY OF MULTIBEAM AND SINGLEBEAM DATA

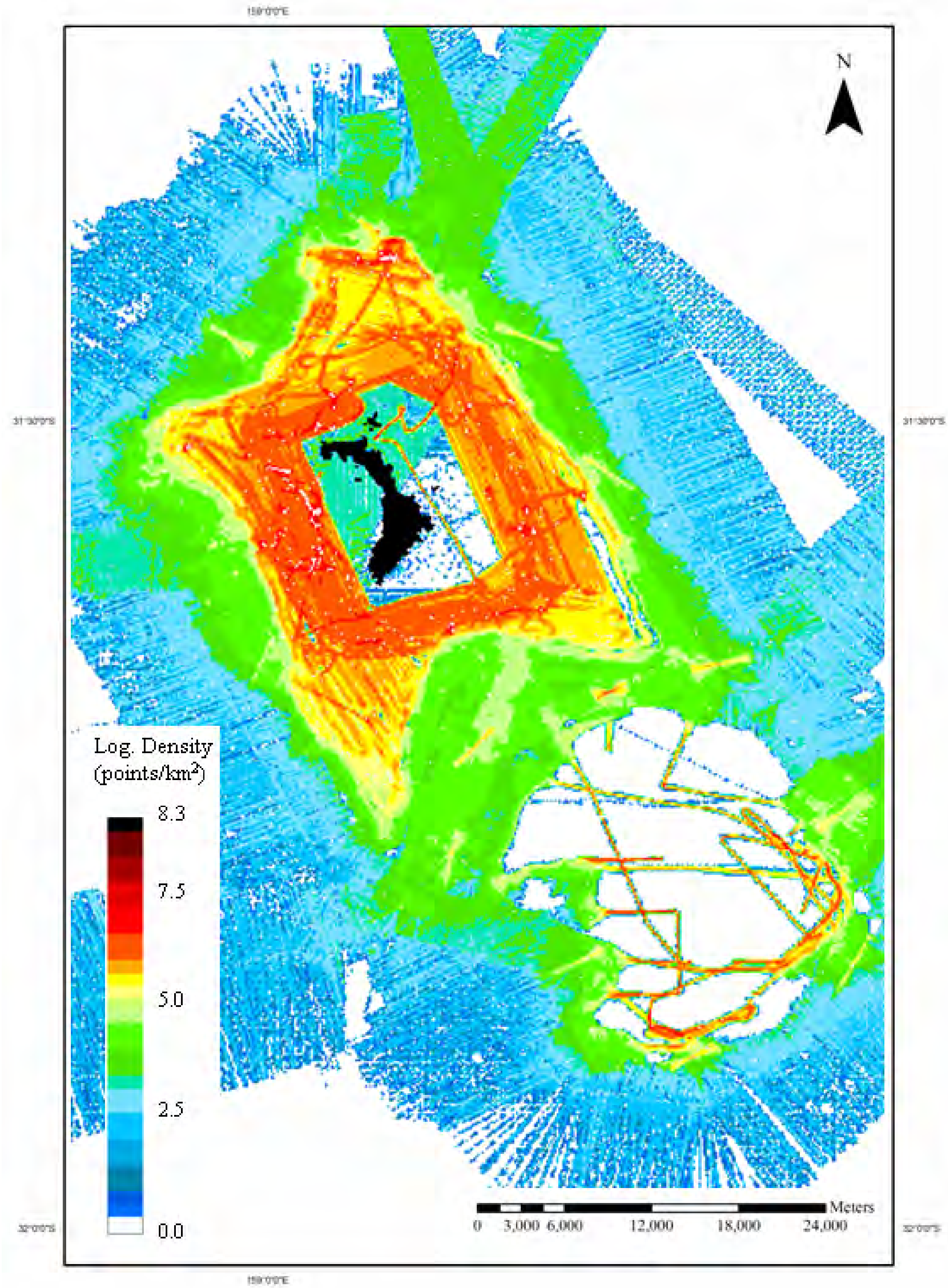
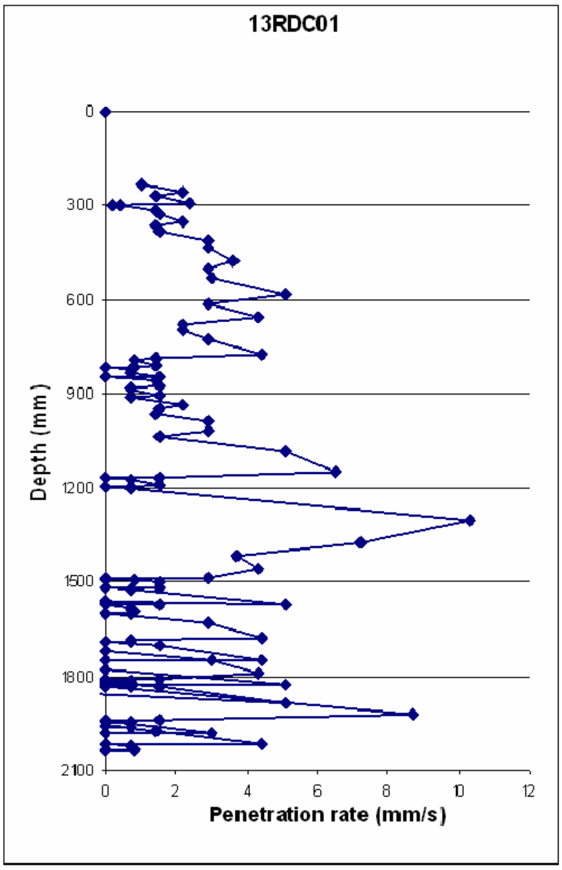
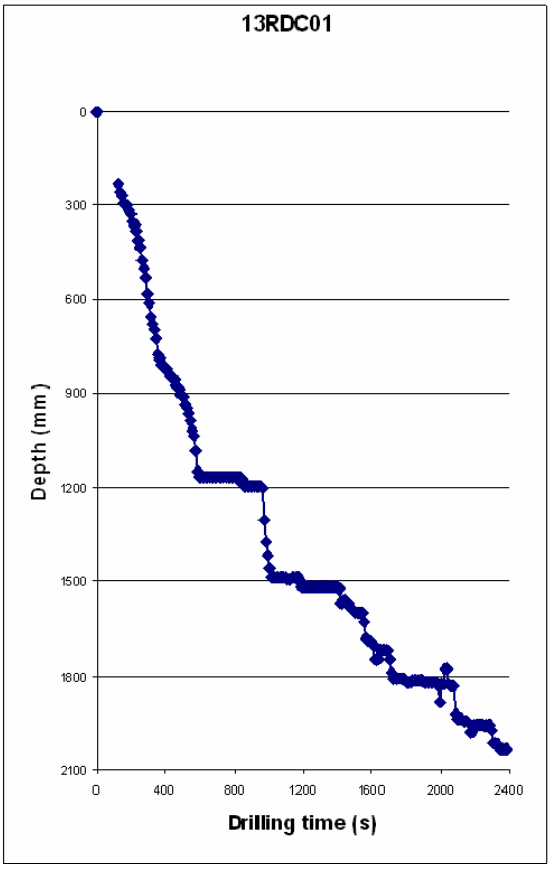


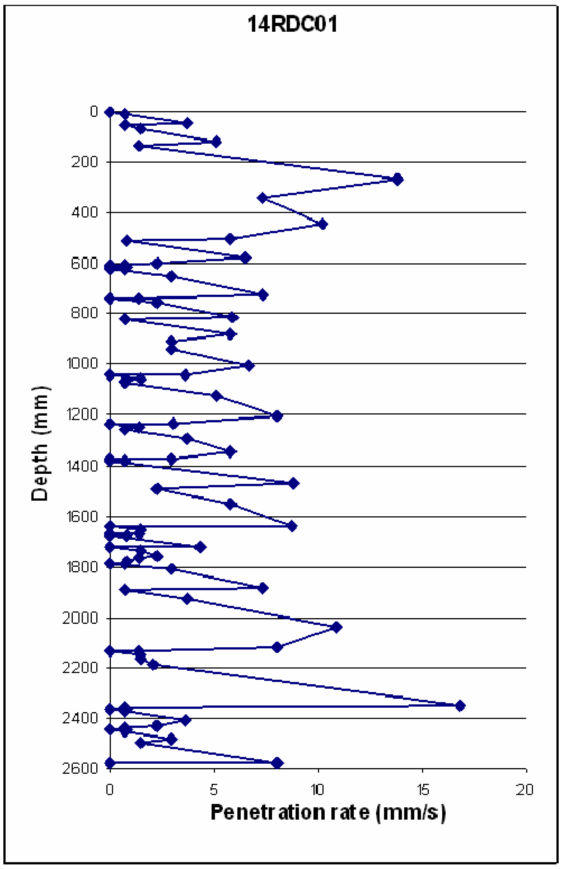
Figure 6.2: *Density of acoustic bathymetry data points (logarithmic scale). The map highlights the high density of soundings in areas of multibeam coverage compared to areas with single beam data only.*

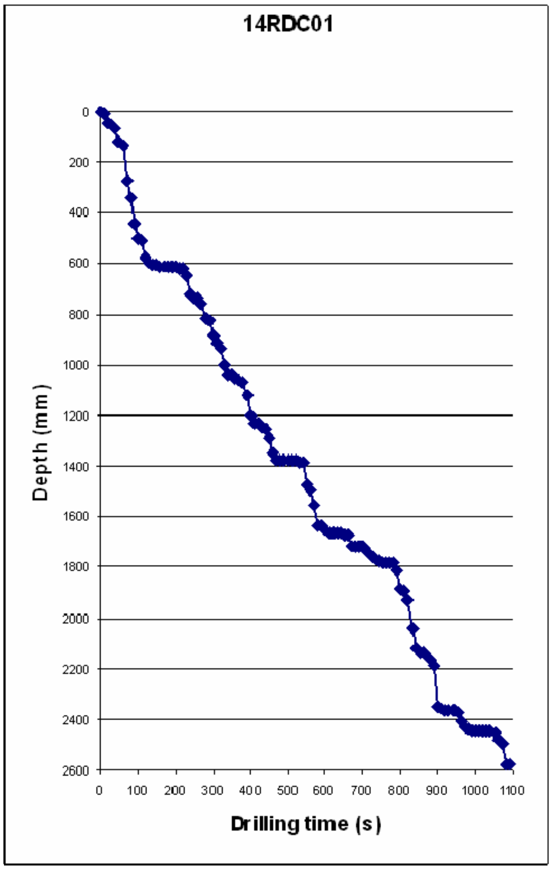
6.5 DRILL TIME/RATE DATA

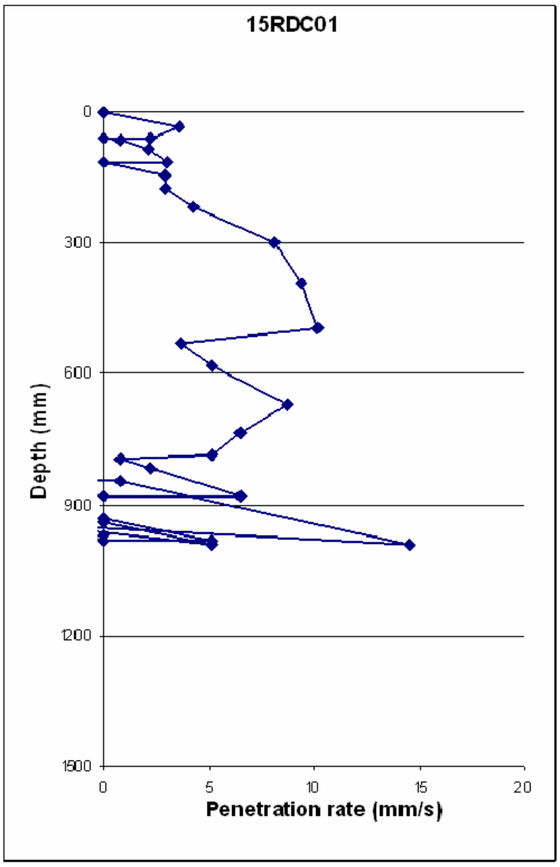
The graphs below display the drilling time and rate of penetration of the drill for each core.

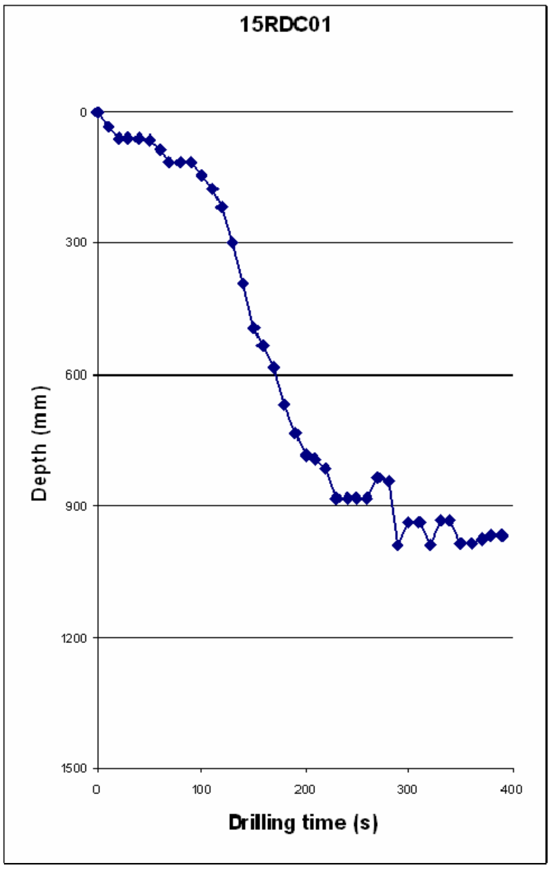


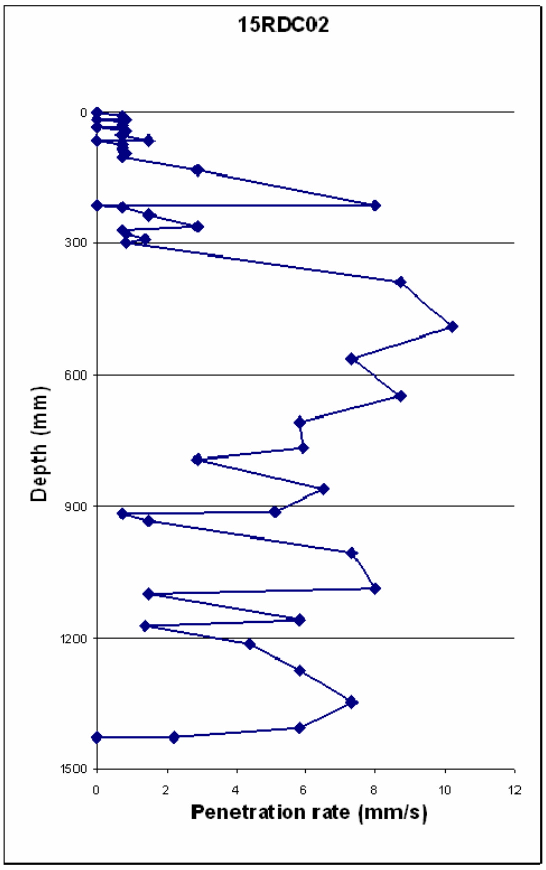


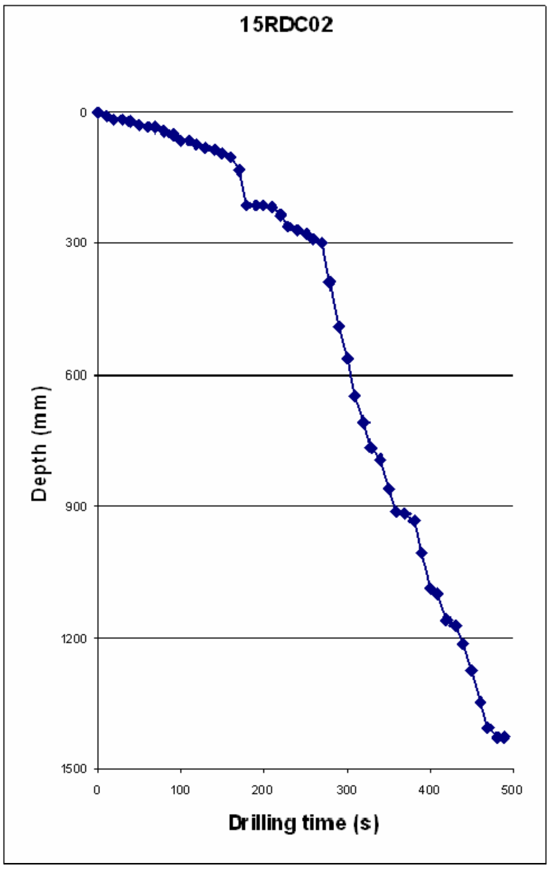

14RDC01
Depth (mm)
Penetration rate (mm/s)
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
0
5
10
15
20

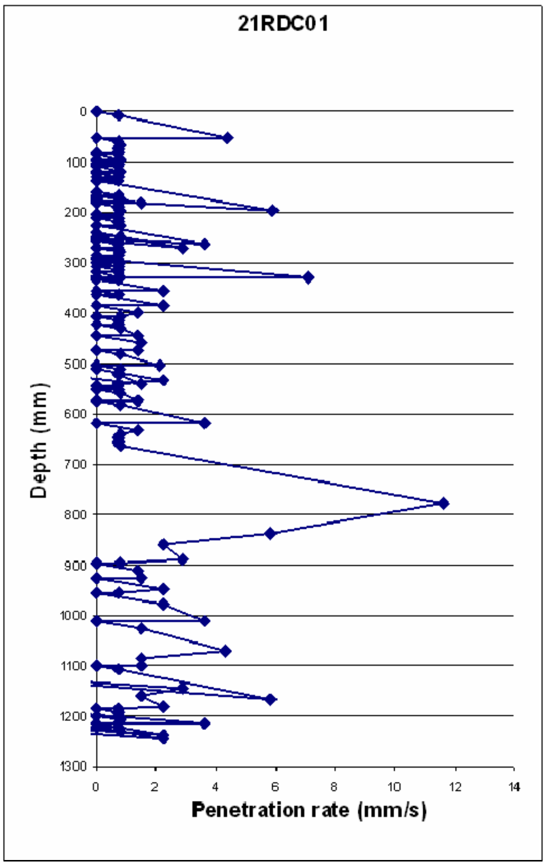

14RDC01
Depth (mm)
Drilling time (s)
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
0
100
200
300
400
500
600
700
800
900
1000
1100

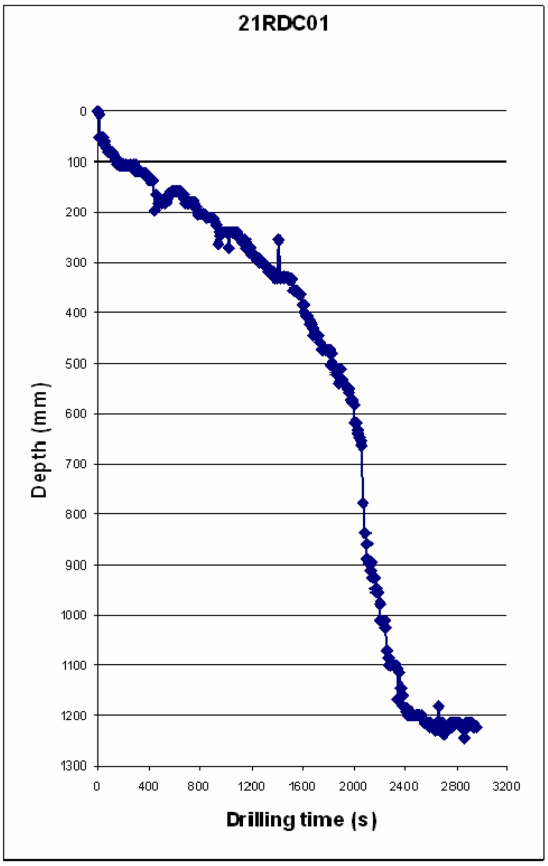

15RDC01
Depth (mm)
0
300
600
900
1200
1500
0
5
10
15
20
Penetration rate (mm/s)


15RDC01
Depth (mm)
0
300
600
900
1200
1500
0
100
200
300
400
Drilling time (s)


15RDC02
Depth (mm)
Penetration rate (mm/s)
0
300
600
900
1200
1500
0
2
4
6
8
10
12


15RDC02
Depth (mm)
Drilling time (s)
0
300
600
900
1200
1500
0
100
200
300
400
500


21RDC01
Depth (mm)
Penetration rate (mm/s)
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
0
2
4
6
8
10
12
14


21RDC01
Depth (mm)
Drilling time (s)
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
0
400
800
1200
1600
2000
2400
2800
3200

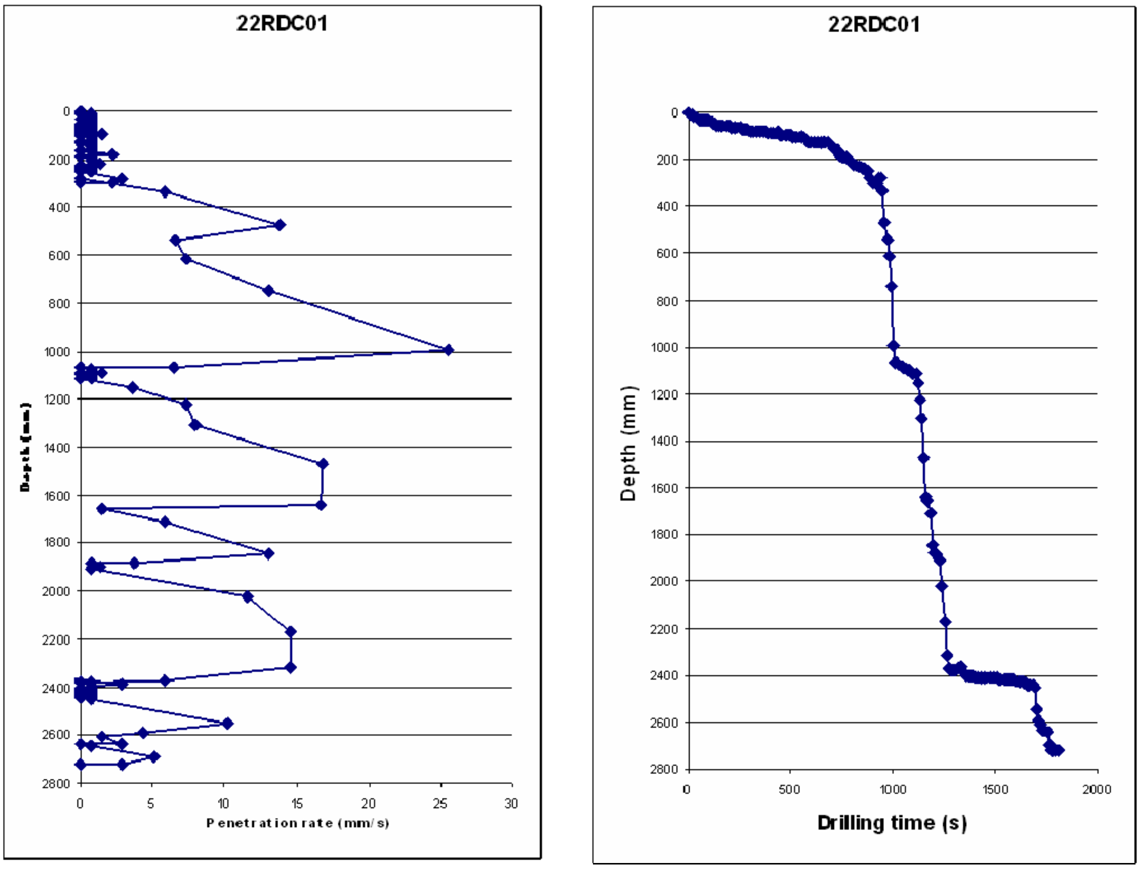
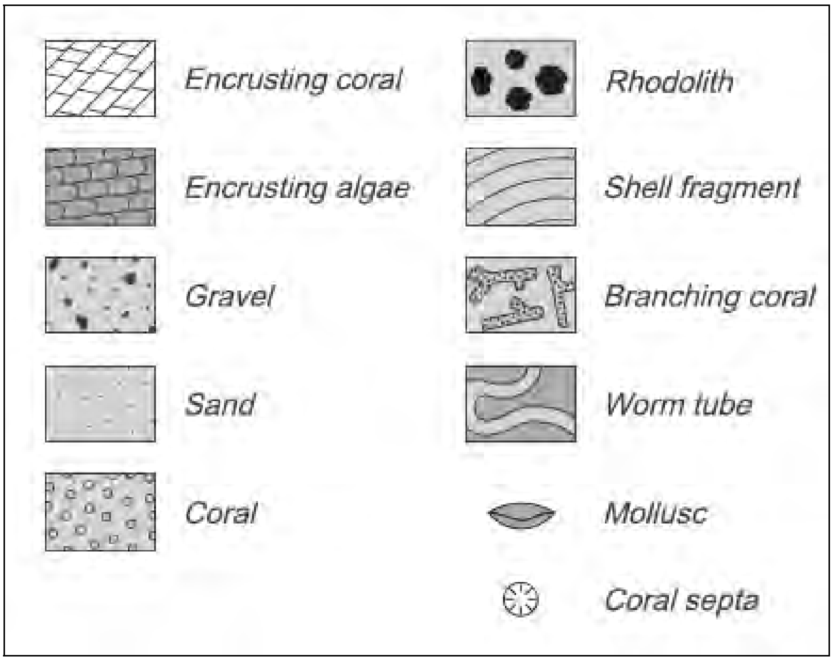


__Figure 6.3:__ Drill core penetration rate and drilling time data for each core site.

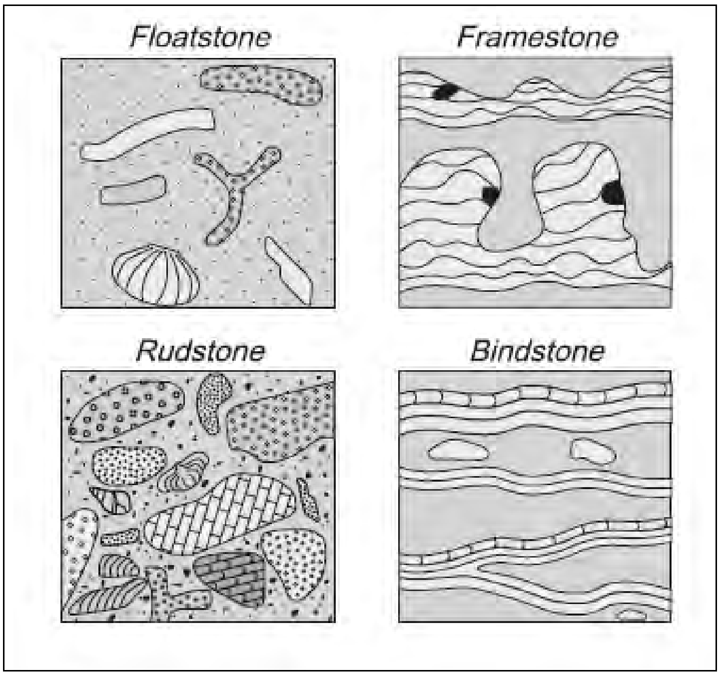
6.6 CORE LITHOLOGICAL AND REEF-FACIES LOGS

Legends

Lithology – sediment types

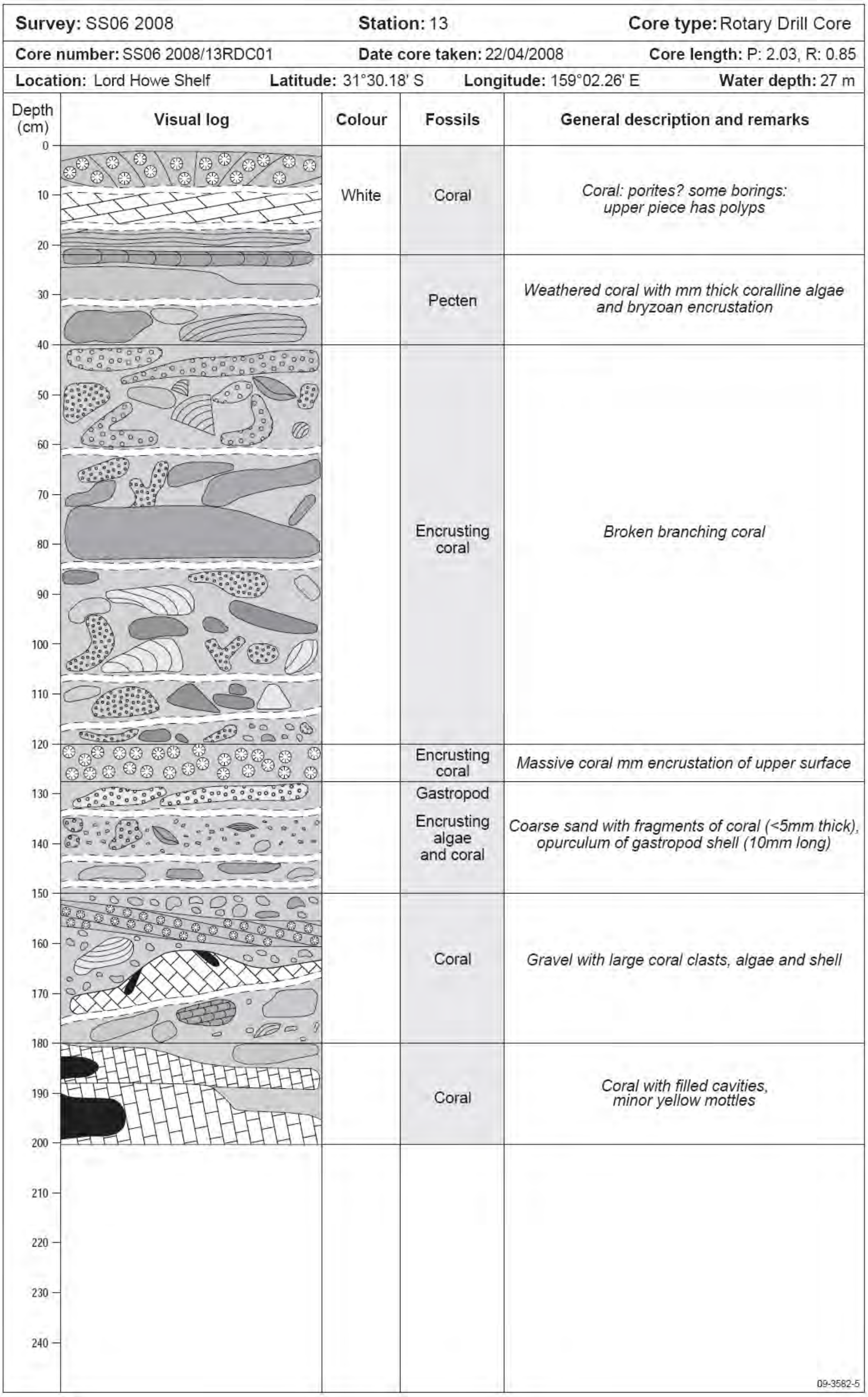


Reef Facies

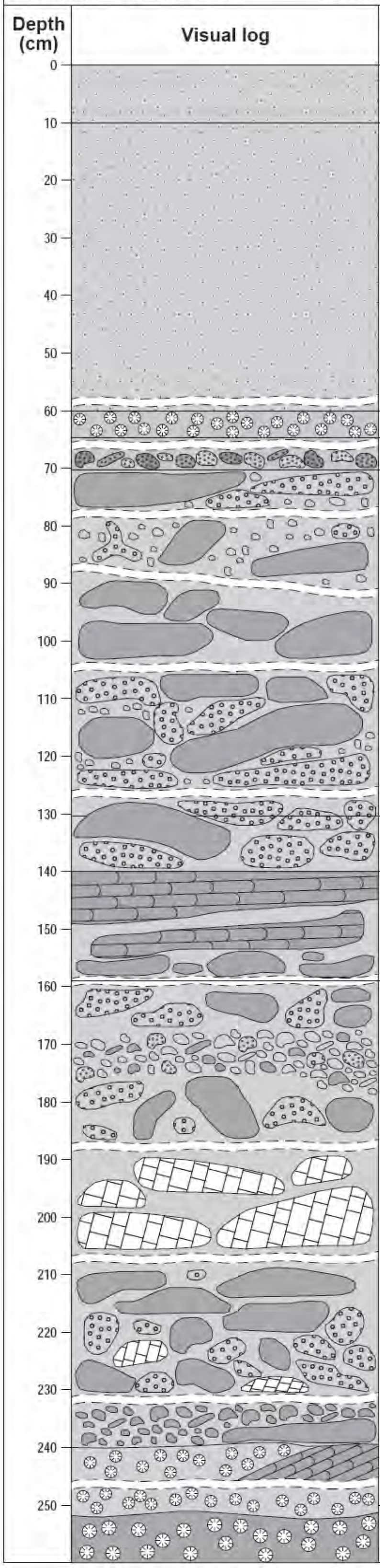


Lithological Logs:

*(Below - **Figure 6.4:** Lithological logs of the cores collected on the shelf around Lord Howe Island.)*



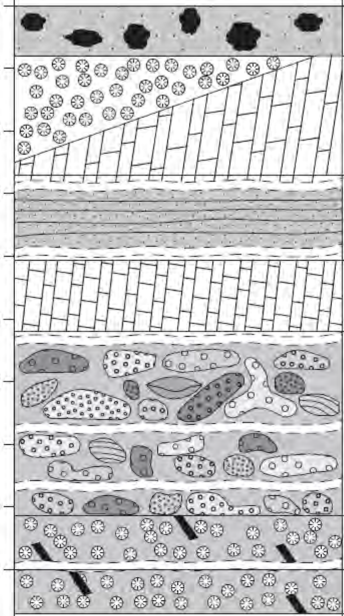
Survey: SS06 2008	**Station:** 14	**Core type:** Rotary Drill Core
Core number: SS06 2008/14RDC01	**Date core taken:** 22/04/2008	**Core length:** P: 2.58, R: 0.75
Location: Lord Howe Shelf **Latitude:** 31°33.39' S	**Longitude:** 159°02.55' E	**Water depth:** 27 m



Colour	Fossils	General description and remarks
V. pale brown		*Medium sand (uncemented)*
		Sand
	Coral gastropod	*Coral*
	Mollusc operculatum	*Coral gravel*
	Coral Mollusc operculatum	*Coral gravel*
		Coral gravel
		Coral gravel
		Coral gravel
		Coral framestone

09-3582-4

Survey: SS06 2008	**Station:** 15	**Core type:** Rotary Drill Core
Core number: SS06 2008/15RDC01	**Date core taken:** 22/04/2008	**Core length:** P: 0.97, R: 0.50
Location: Lord Howe Shelf **Latitude:** 31°33.35' S	**Longitude:** 159°01.03' E	**Water depth:** 34 m

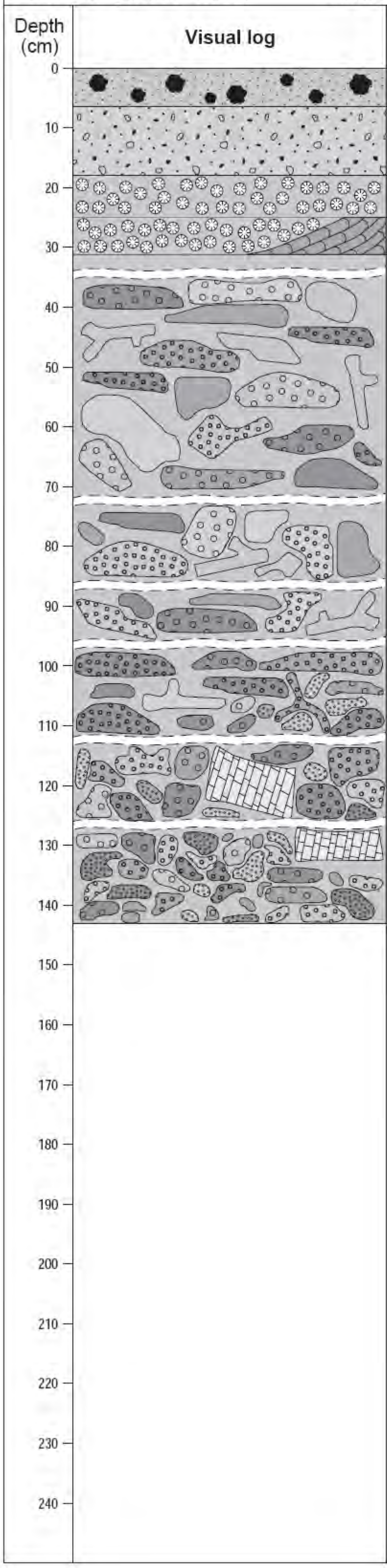


Depth (cm)	Colour	Fossils	General description and remarks
0–8	Reddish-brown		*Rhodoliths and sand*
8–27		Encrusting coral	*Encrusting coral*
27–41			*Bedded cemented coarse gravelly sand*
41–52		Coral	*Coral*
52–81		Mollusc/ bivalve small gastropod	*Gravel clasts of coral, bivalves, algae*
81–90			*Heavily bored and encrusted coral*
90–97			*Well preserved and cemented coral*

Depth scale: 0, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120, 130, 140, 150, 160, 170, 180, 190, 200, 210, 220, 230, 240

09-3582-3

Survey: SS06 2008	**Station:** 15	**Core type:** Rotary Drill Core
Core number: SS06 2008/15RDC02	**Date core taken:** 22/04/2008	**Core length:** P: 1.43, R: 0.40
Location: Lord Howe Shelf	**Latitude:** 31°33.35' S	**Longitude:** 159°01.03' E
Water depth: 34 m		



Visual log	Colour	Fossils	General description and remarks
		Coral	*Sand and rhodolith*
	V. pale brown		*Calcarenite: cemented massive and gravelly very coarse sand and gravel*
		Coral	*Coral clast*
		Coral algae	*Heavily bored coral / algae*
	Sand white	Coral	*Coral gravel*

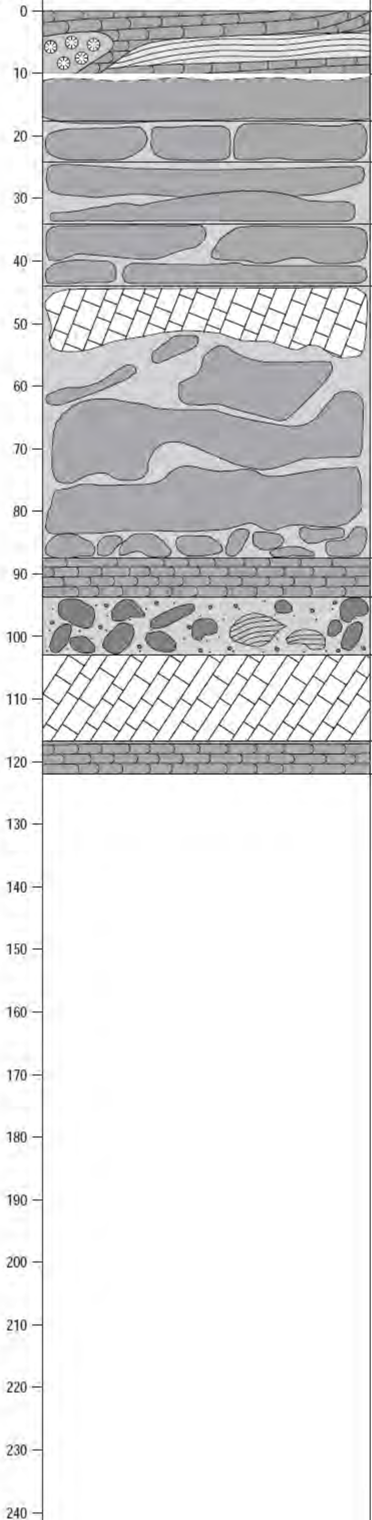
09-3582-2

Survey: SS06 2008 **Station:** 21 **Core type:** Rotary Drill Core

Core number: SS06 2008/21RDC01 **Date core taken:** 23/04/2008 **Core length:** P: 1.22, R: 0.87

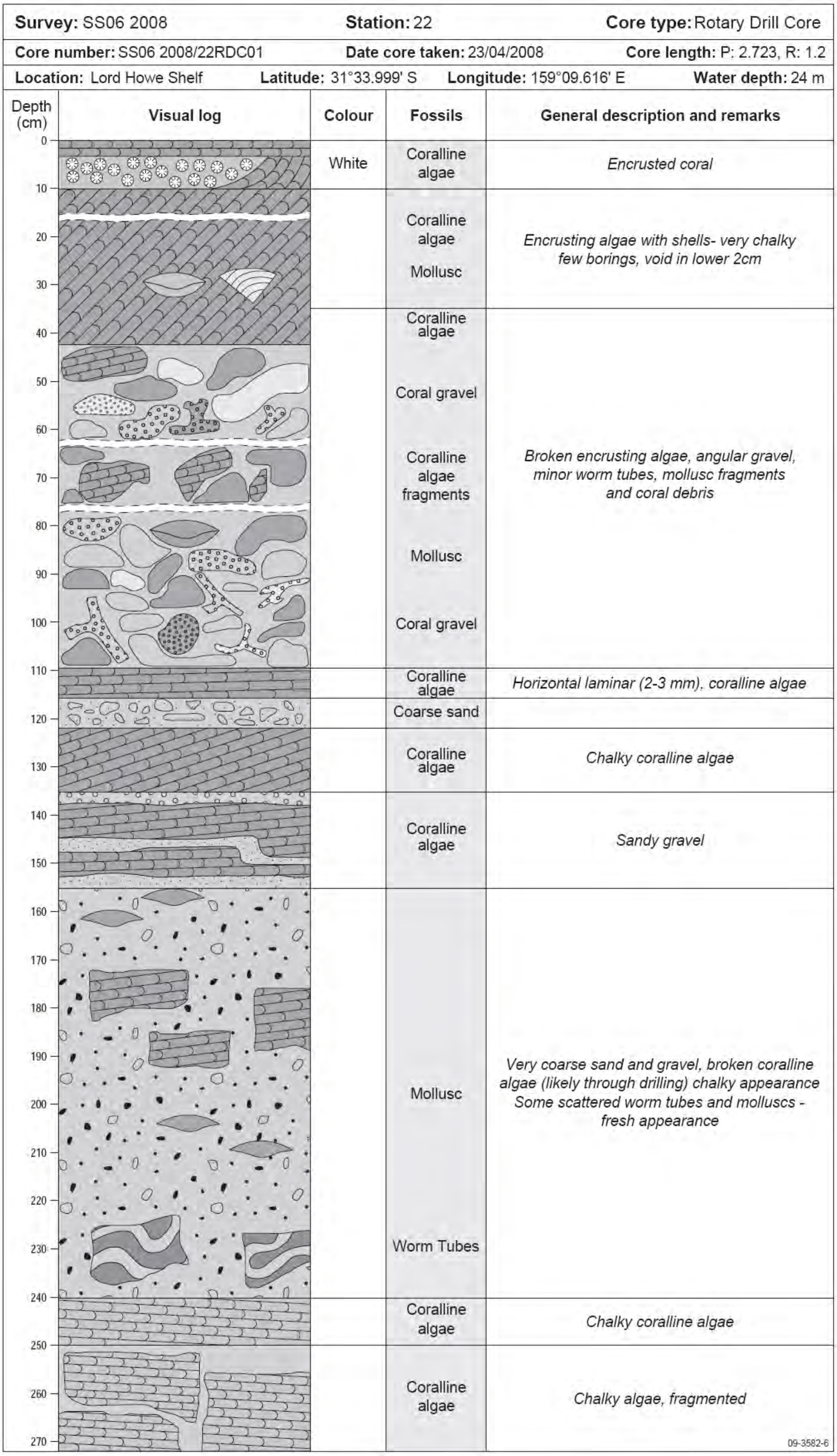
Location: Lord Howe Shelf **Latitude:** 31°34.10' S **Longitude:** 159°10.17' E **Water depth:** 30 m

Depth (cm) / Visual log



Colour	Fossils	General description and remarks
	Algae mollusc	*Encrusting algae/coral on Tridacna shell*
		Calcarenite: heavily weathered/dissolved porous
		More massive, well indurated calcarenite
		Very porous/cavities calcarenite
		Massive calcarenite/calcrete
Reddish-yellow	Mollusc shell	*Calcarenite: cavities/highly porous broken with reddish-yellow calcrete/cement - dissolution features*
		Layer of encrusting algae
	Mollusc	*Coral rubble and mollusc shell (Placostylus?)*
	Coral	*Coral (Favid?)*
	Encrusted by algae	*Calcarenite and encrusting algae*

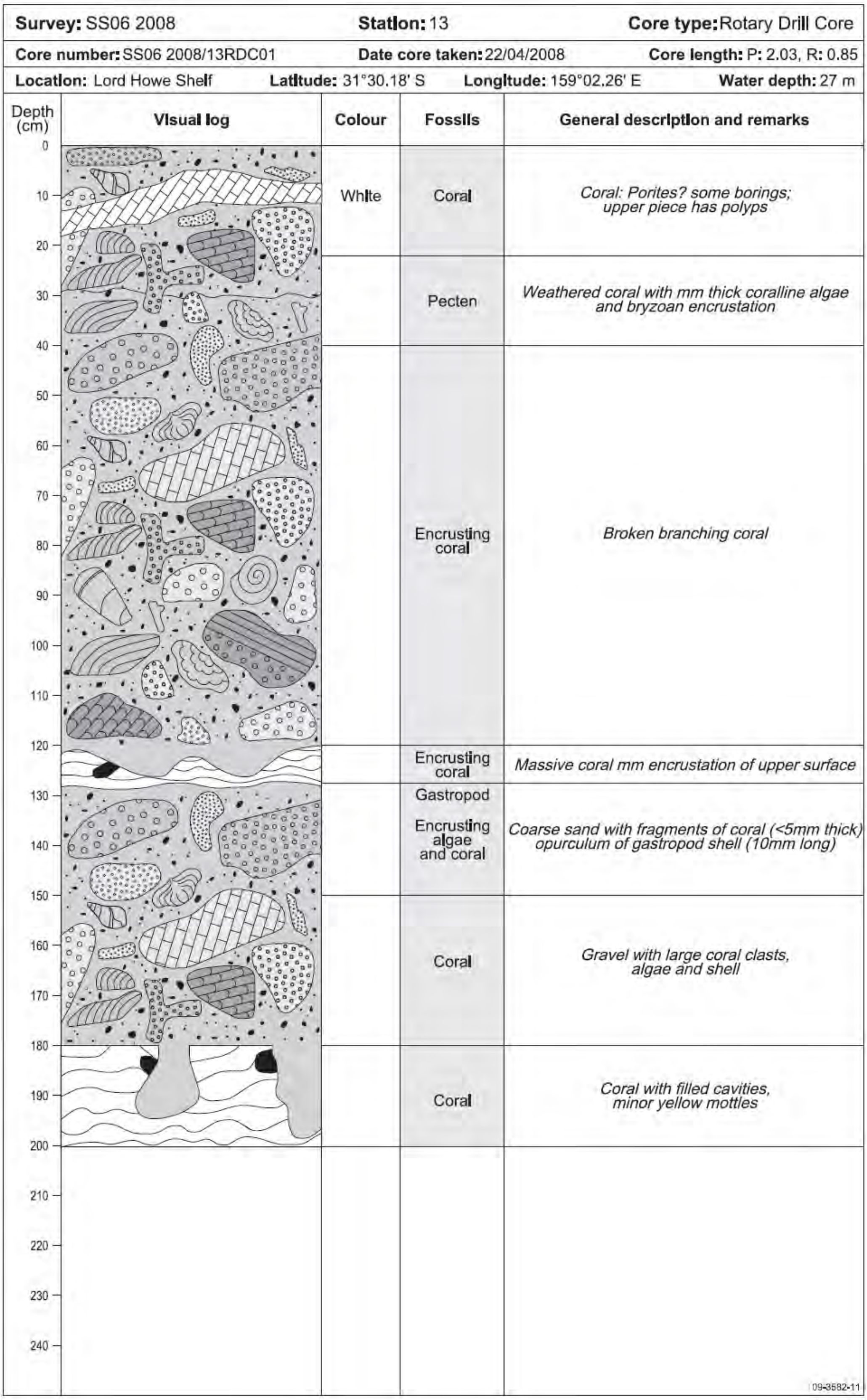
09-3582-1



Survey: SS06 2008
Station: 22
Core type: Rotary Drill Core
Core number: SS06 2008/22RDC01
Date core taken: 23/04/2008
Core length: P: 2.723, R: 1.2
Location: Lord Howe Shelf
Latitude: 31°33.999' S
Longitude: 159°09.616' E
Water depth: 24 m
Depth (cm)
Visual log
Colour
Fossils
General description and remarks
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
210
220
230
240
250
260
270
White
Coralline algae
Encrusted coral
Coralline algae
Mollusc
Encrusting algae with shells- very chalky few borings, void in lower 2cm
Coralline algae
Coral gravel
Coralline algae fragments
Mollusc
Coral gravel
Broken encrusting algae, angular gravel, minor worm tubes, mollusc fragments and coral debris
Coralline algae
Horizontal laminar (2-3 mm), coralline algae
Coarse sand
Coralline algae
Chalky coralline algae
Coralline algae
Sandy gravel
Mollusc
Worm Tubes
Very coarse sand and gravel, broken coralline algae (likely through drilling) chalky appearance Some scattered worm tubes and molluscs - fresh appearance
Coralline algae
Chalky coralline algae
Coralline algae
Chalky algae, fragmented
09-3582-6

Reef Facies Logs:

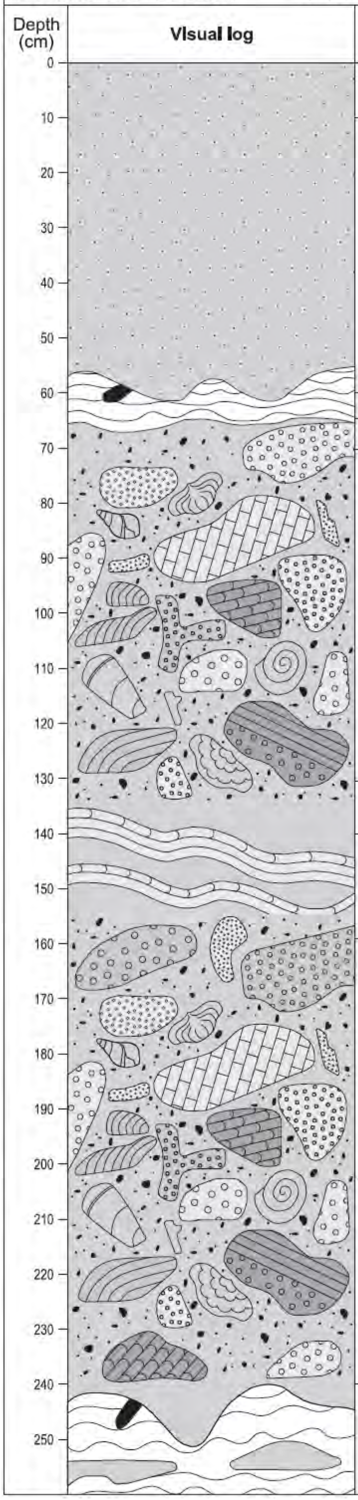
*(Below - **Figure 6.5**: Reef-facies logs of the cores collected on the shelf around Lord Howe Island.)*



Survey: SS06 2008 **Station:** 14 **Core type:** Rotary Drill Core

Core number: SS06 2008/14RDC01 **Date core taken:** 22/04/2008 **Core length:** P: 2.58, R: 0.75

Location: Lord Howe Shelf **Latitude:** 31°33.39' S **Longitude:** 159°02.55' E **Water depth:** 27 m



Colour	Fossils	General description and remarks
V. pale brown		*Medium sand (uncemented)*
		Sand
	Coral gastropod	*Coral*
	Mollusc operculatum	*Coral gravel*
	Coral Mollusc operculatum	*Coral gravel*
		Coral gravel
		Coral gravel
		Coral gravel
		Coral framestone

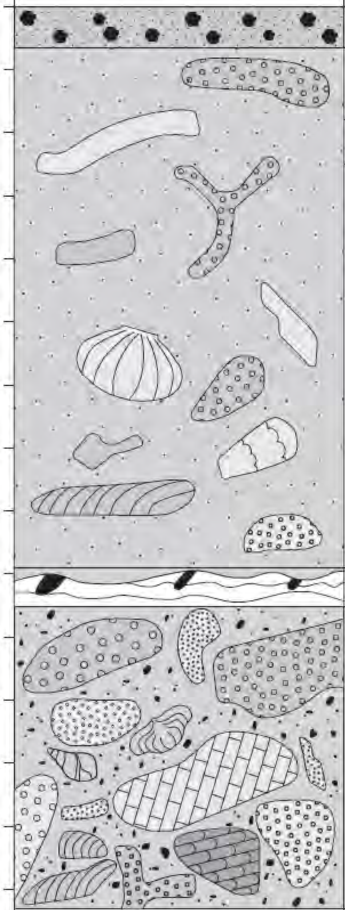
09-3582-10

Survey: SS06 2008 | **Station:** 15 | **Core type:** Rotary Drill Core

Core number: SS06 2008/15RDC02 | **Date core taken:** 22/04/2008 | **Core length:** P: 1.43, R: 0.40

Location: Lord Howe Shelf | **Latitude:** 31°33.35' S | **Longitude:** 159°01.03' E | **Water depth:** 34 m

Visual log (Depth (cm): 0–240)



Depth (cm)	Colour	Fossils	General description and remarks
0–6		Coral	*Sand and rhodolith*
6–18	V. pale brown		*Calcarenite: cemented massive and gravelly very coarse sand and gravel*
18–25		Coral	*Coral clast*
25–89			*Cemented sandy gravel*
89–95		Coral algae	*Heavily bored coral / algae*
95–143		Coral	*Coral gravel*

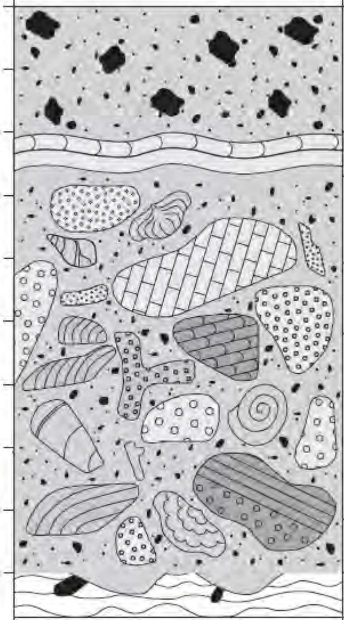
09-3582-8

Survey: SS06 2008 | **Station:** 15 | **Core type:** Rotary Drill Core

Core number: SS06 2008/15RDC01 | **Date core taken:** 22/04/2008 | **Core length:** P: 0.97, R: 0.50

Location: Lord Howe Shelf | **Latitude:** 31°33.35' S | **Longitude:** 159°01.03' E | **Water depth:** 34 m

Depth (cm): 0, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120, 130, 140, 150, 160, 170, 180, 190, 200, 210, 220, 230, 240



Visual log	Colour	Fossils	General description and remarks
	Reddish-brown		*Rhodoliths and sand*
		Encrusting coral	*Encrusting coral*
			Bedded cemented coarse gravelly sand
		Coral	*Coral*
		Mollusc/ bivalve small gastropod	*Gravel clasts of coral, bivalves, algae*
			Heavily bored and encrusted coral
			Well preserved and cemented coral

09-3582-9

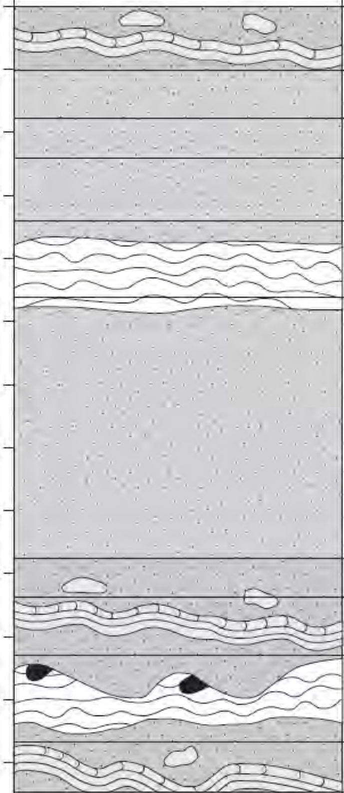
Survey: SS06 2008 **Station:** 21 **Core type:** Rotary Drill Core

Core number: SS06 2008/21RDC01 **Date core taken:** 23/04/2008 **Core length:** P: 1.22, R: 0.87

Location: Lord Howe Shelf **Latitude:** 31°34.10' S **Longitude:** 159°10.17' E **Water depth:** 30 m

Depth (cm): 0, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120, 130, 140, 150, 160, 170, 180, 190, 200, 210, 220, 230, 240

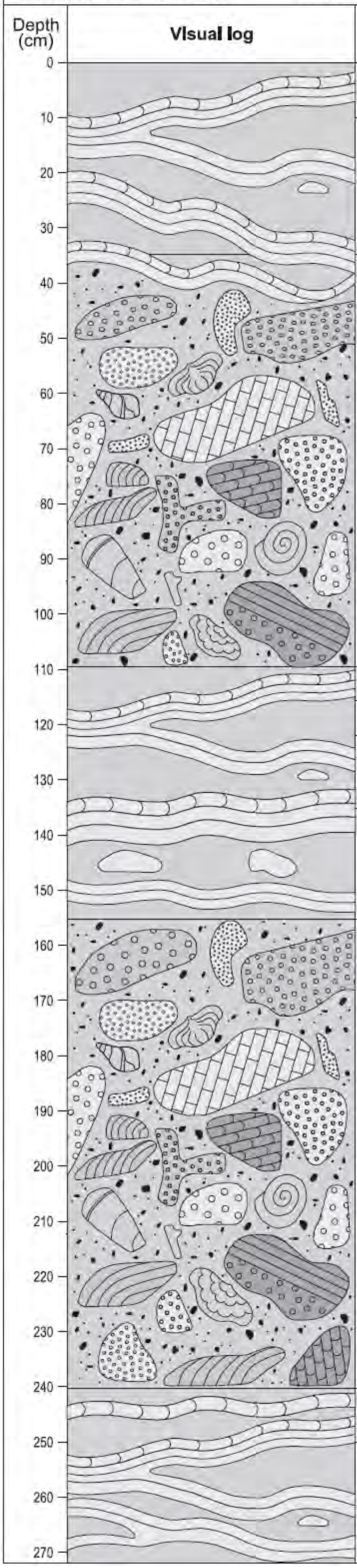
Visual log



Colour	Fossils	General description and remarks
	Algae mollusc	*Encrusting algae/coral on Tridacna shell*
		Calcarenite: Heavily weathered/dissolved porous
		More massive, well indurated calcarenite
		Very porous/cavities calcarenite
		Massive calcarenite/calcrete
Reddish-yellow	Mollusc shell	*Calcarenite: cavities/highly porous broken with reddish-yellow calcrete/cement - dissolution features*
		Layer of encrusting algae
	Mollusc	*Coral rubble and mollusc shell (Placostylus?)*
	Coral	*Coral (Favid?)*
	Encrusted algae	*Calcarenite and encrusting algae*

09-3582-7

Survey: SS06 2008	**Station:** 22	**Core type:** Rotary Drill Core
Core number: SS06 2008/22RDC01	**Date core taken:** 23/04/2008	**Core length:** P: 2.723, R: 1.2
Location: Lord Howe Shelf **Latitude:** 31°33.999' S	**Longitude:** 159°09.616' E	**Water depth:** 24 m



Colour	Fossils	General description and remarks
White	Coralline algae	*Encrusted coral*
	Coralline algae Mollusc	*Encrusting algae with shells - very chalky few borings, void in lower 2cm*
	Coralline algae Coral gravel Coralline algae fragments Mollusc Coral gravel	*Broken encrusting algae, angular gravel, minor worm tubes, mollusc fragments and coral debris*
	Coralline algae	*Horizontal laminar (2-3 mm), coralline algae*
	Coarse sand	
	Coralline algae	*Chalky coralline algae*
	Coralline algae	*Sandy gravel*
	Mollusc Worm tubes	*Very coarse sand and gravel, broken algae (likely through drilling) chalky appearance Some scattered worm tubes and molluscs - fresh appearance*
	Coralline algae	*Chalky coralline algae*
	Coralline algae	*Chalky algae, fragmented*

09-3582-12

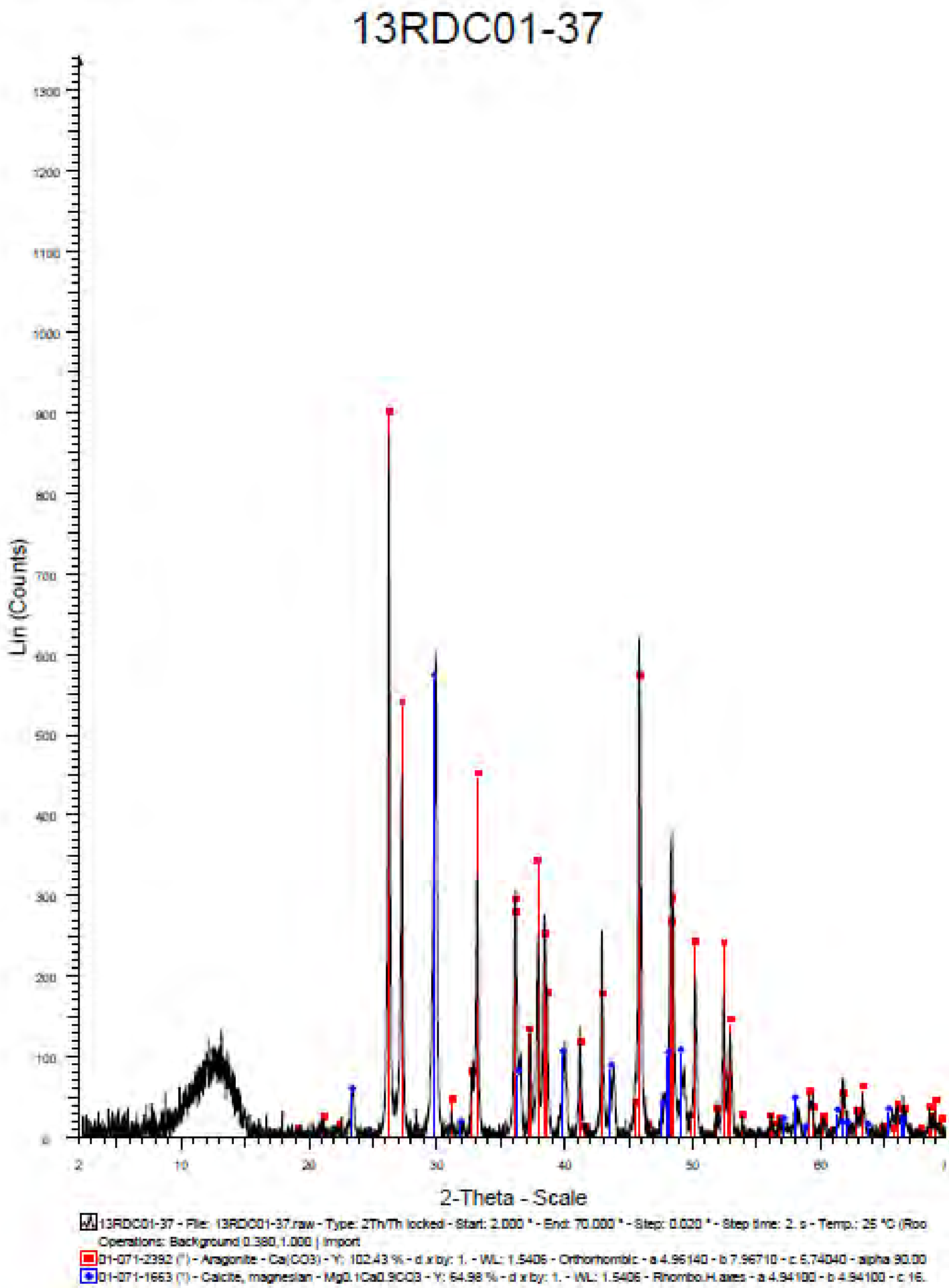
6.7 XRD ANALYSIS OF THE ARAGONITE CONTENT OF SAMPLES

Twelve samples were submitted for XRD analysis and quantification, specifically to identify the ratio of Aragonite to Calcite. Samples were scanned on a Siemens D500 Diffractometer, from 2° to 70° 2θ, in 1° increments, using a Cu- anode X-ray tube. Minerals were identified using Bruker Diffrac^{plus} Eva and Siroquant V3 was used to quantify minerals.

All samples contained Aragonite. Calcite was identified in most samples, but varied from negligible to 22%. All samples exhibited a broad peak from 8.5° to 15.5° 2θ. This indicates the presence of a poorly diffracting or amorphous material, possibly clay. No attempt was made to identify this and it was not taken into consideration in the quantification of Aragonite/Calcite. The XRD traces and carbonate mineral composition results for all samples analysed are provided below.

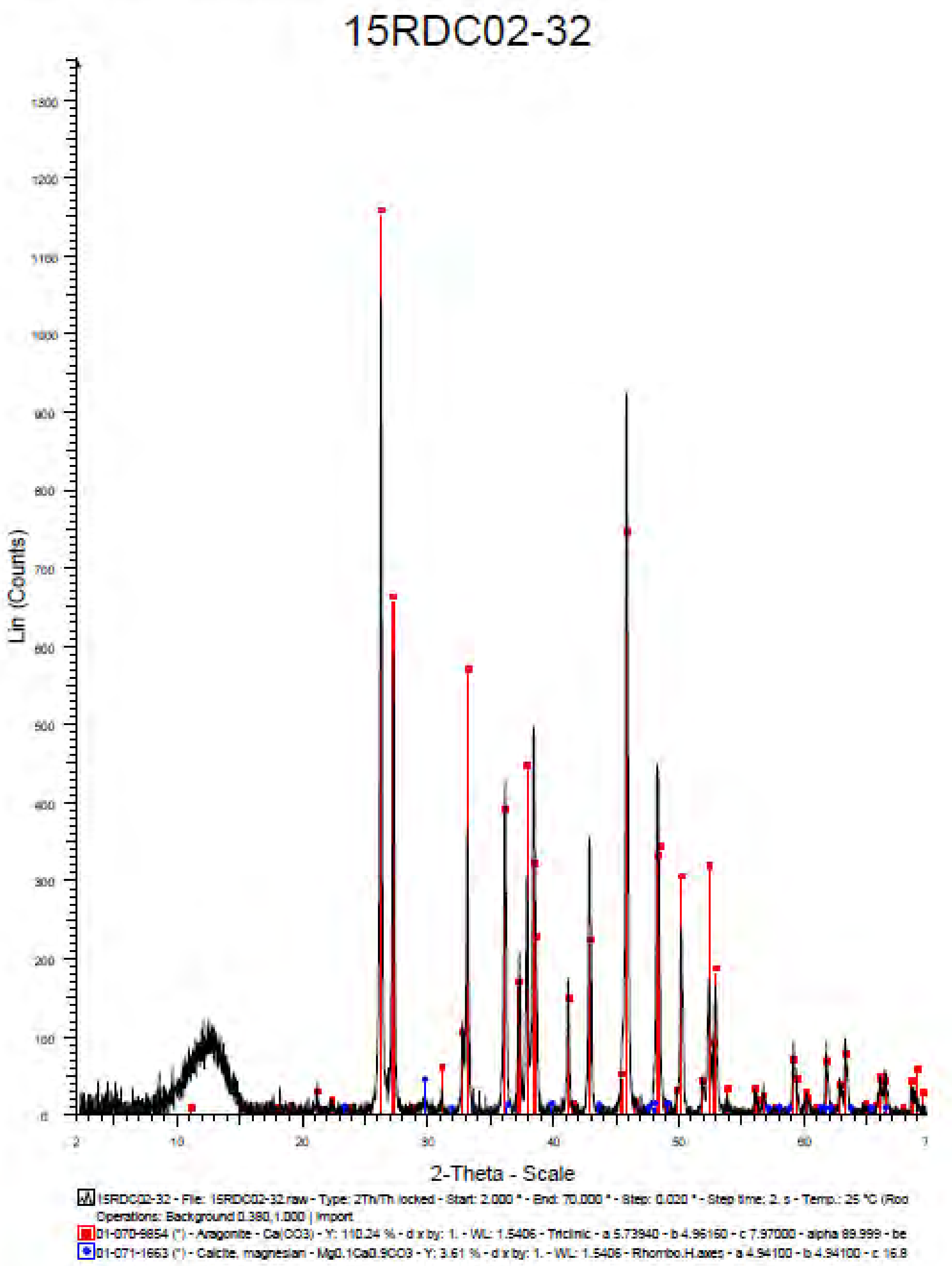
(Below - ***Figure 6.6:*** *XRD traces of core samples*.)

Sample #: 1959461
Sample ID: SS062008/13RDC01_37 (37 cm)



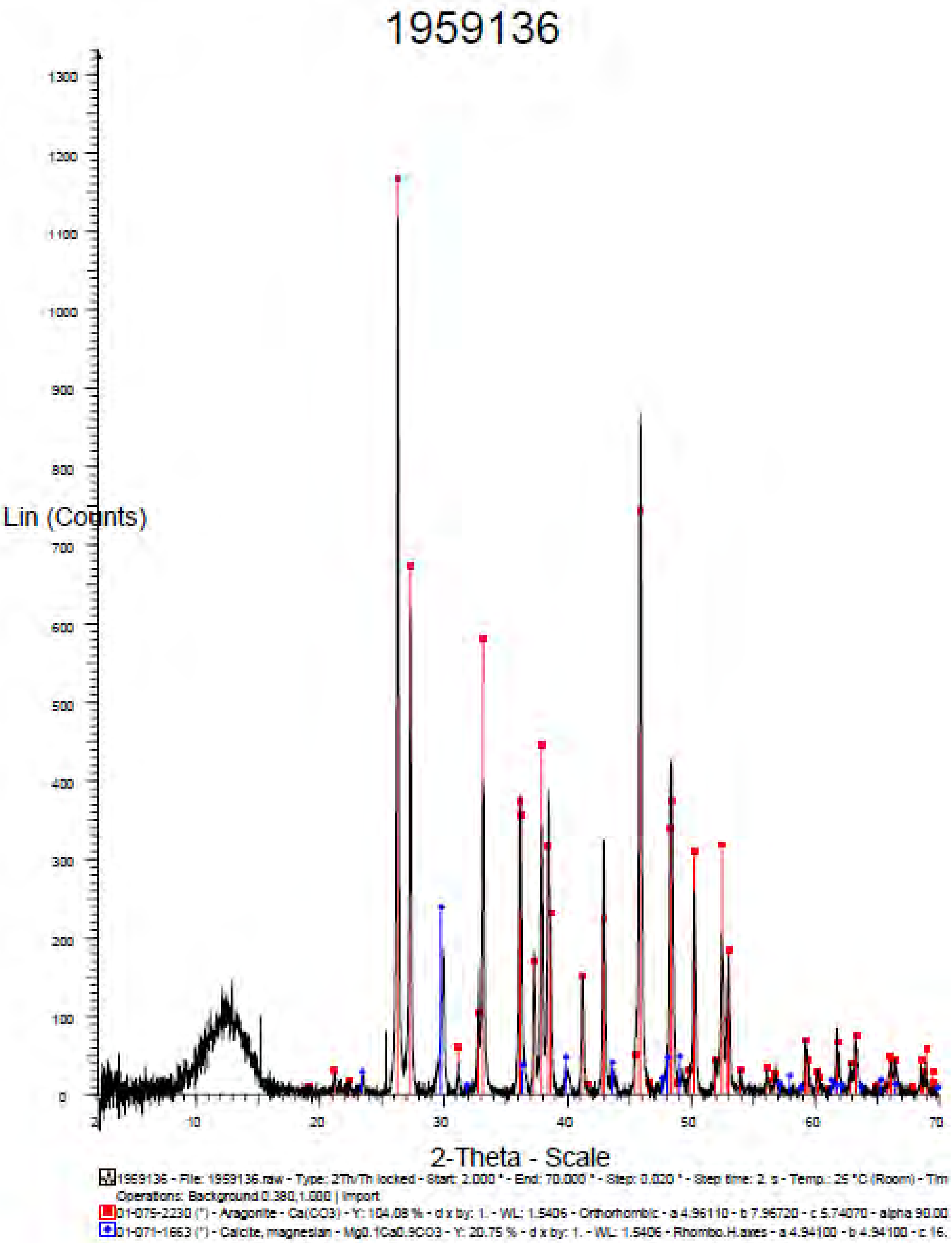
Aragonite- 78%; Calcite – 22% **Amorphous material not identified or quantified**

Sample #: 1959462
Sample ID: SS062008/15RDC02_32 (32 cm)



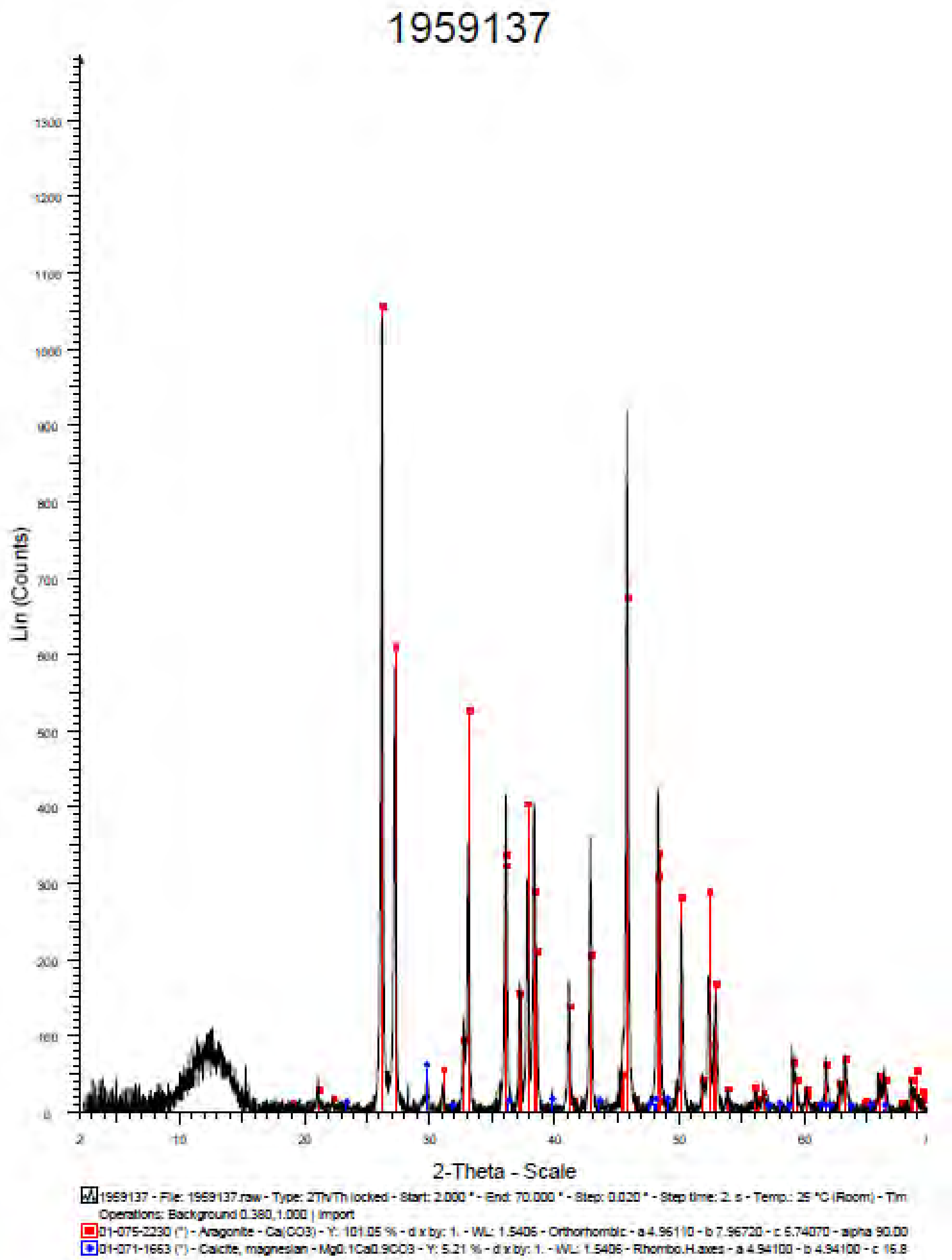
Aragonite – 99.2%; Calcite – 0.8% **Amorphous material not identified or quantified**

Sample #: 1959136
Sample ID: SS062008/21RDC01c (79 cm)



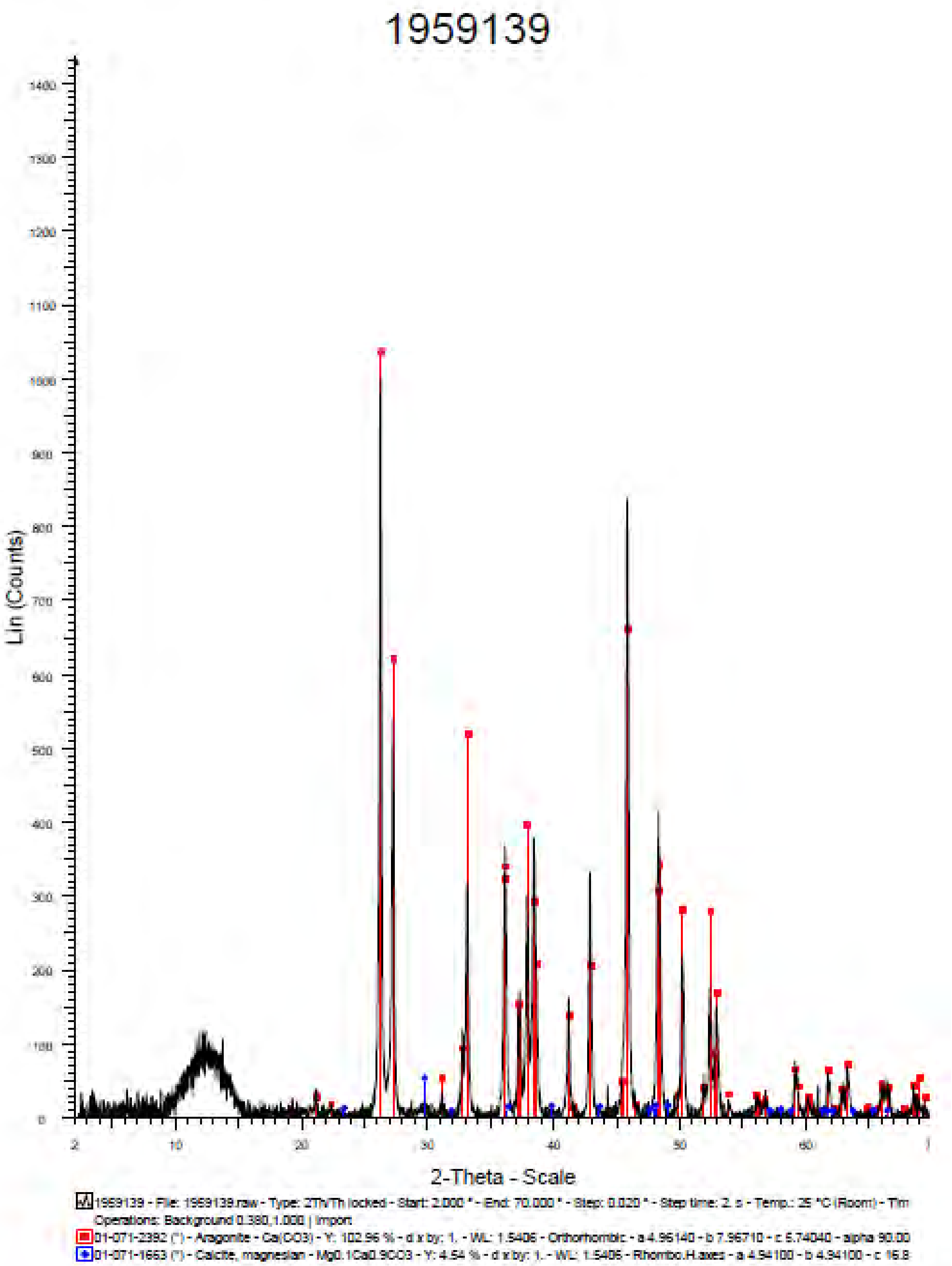
Aragonite – 93.9%; Calcite – 6.1% **Amorphous material not identified or quantified**

Sample #: 1959137
Sample ID: SS062008/15RDC01a (27 cm)



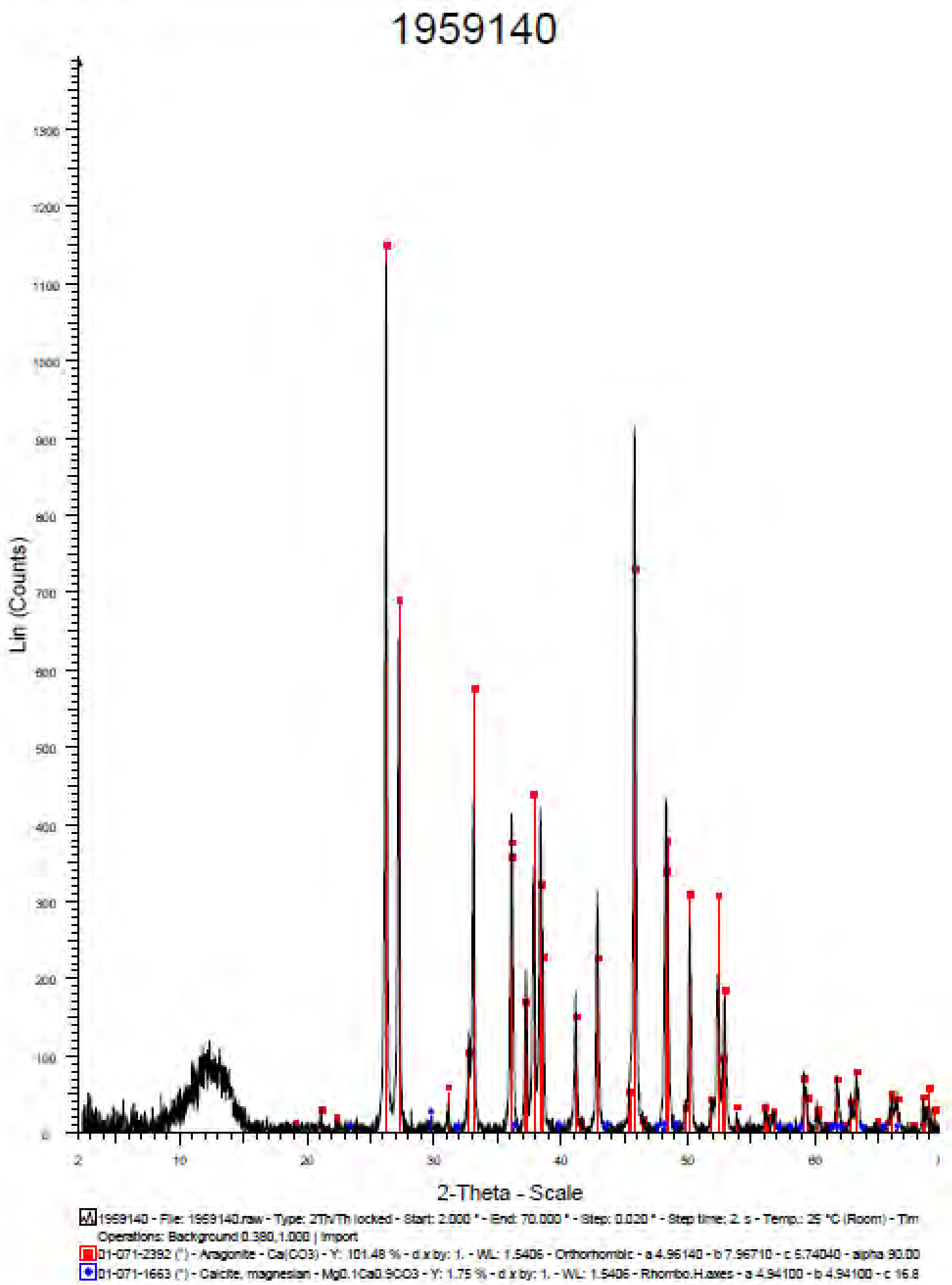
Aragonite – 98.4%; Calcite – 1.6% **Amorphous material not identified or quantified**

Sample #: 1959139
Sample ID: SS062008/15RDC01c (40 cm)



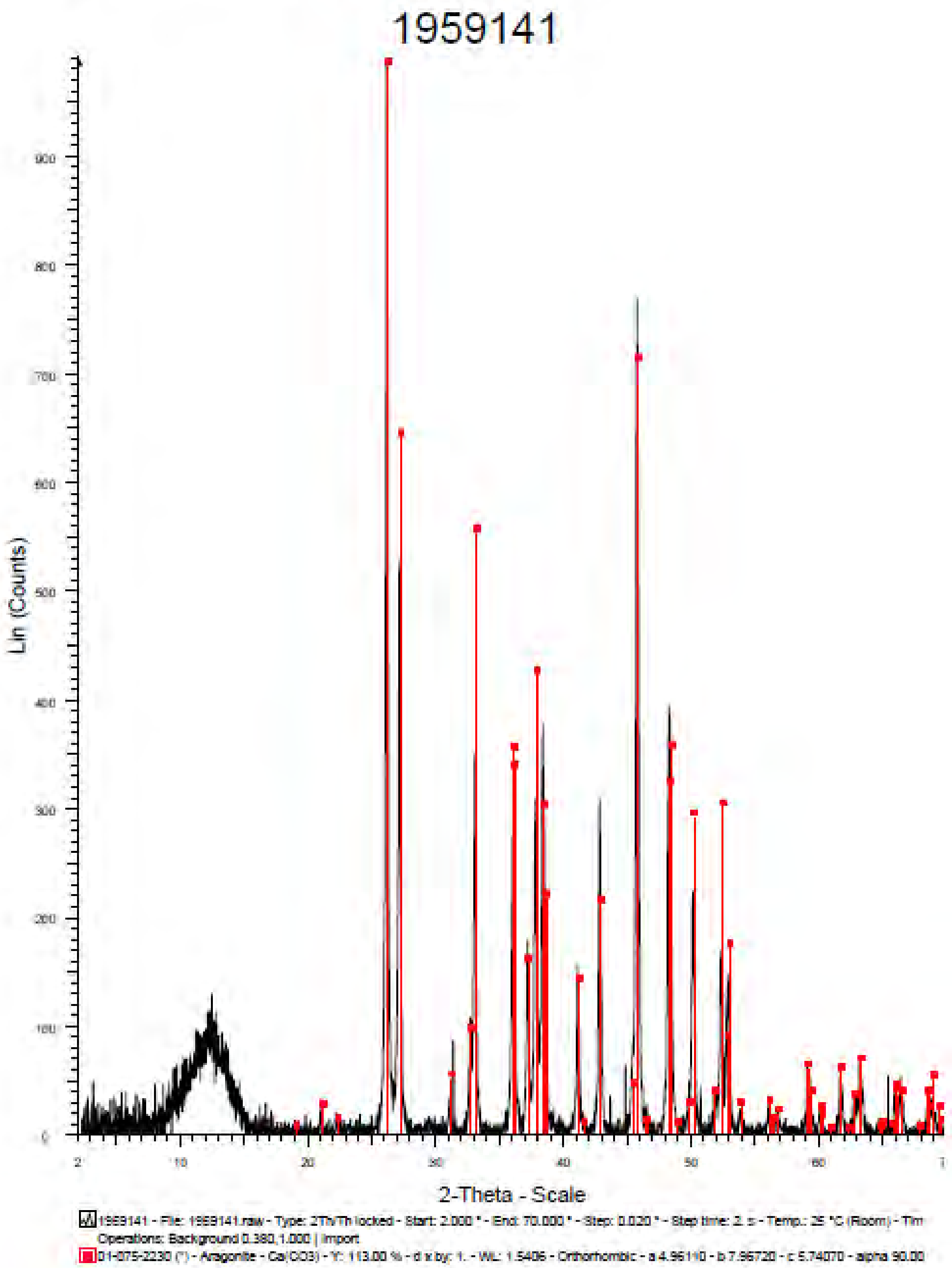
Aragonite – 98.6%; Calcite – 1.4% **Amorphous material not identified or quantified**

Sample #: 1959140
Sample ID: SS062008/13RDC01a (6 cm)



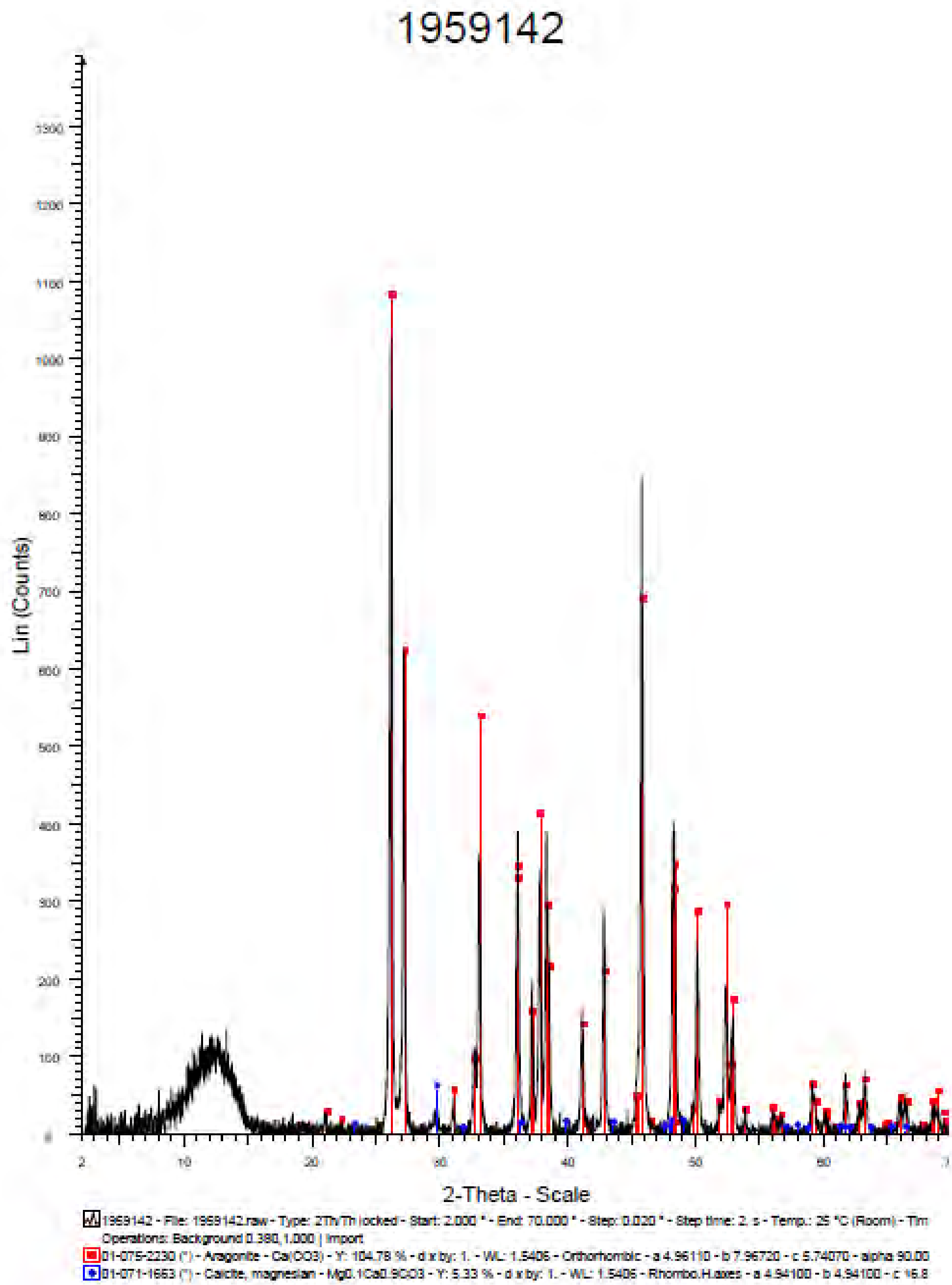
Aragonite – 99.4%; Calcite – 0.6% **Amorphous material not identified or quantified**

Sample #: 1959141
Sample ID: SS062008/13RDC01b (16 cm)



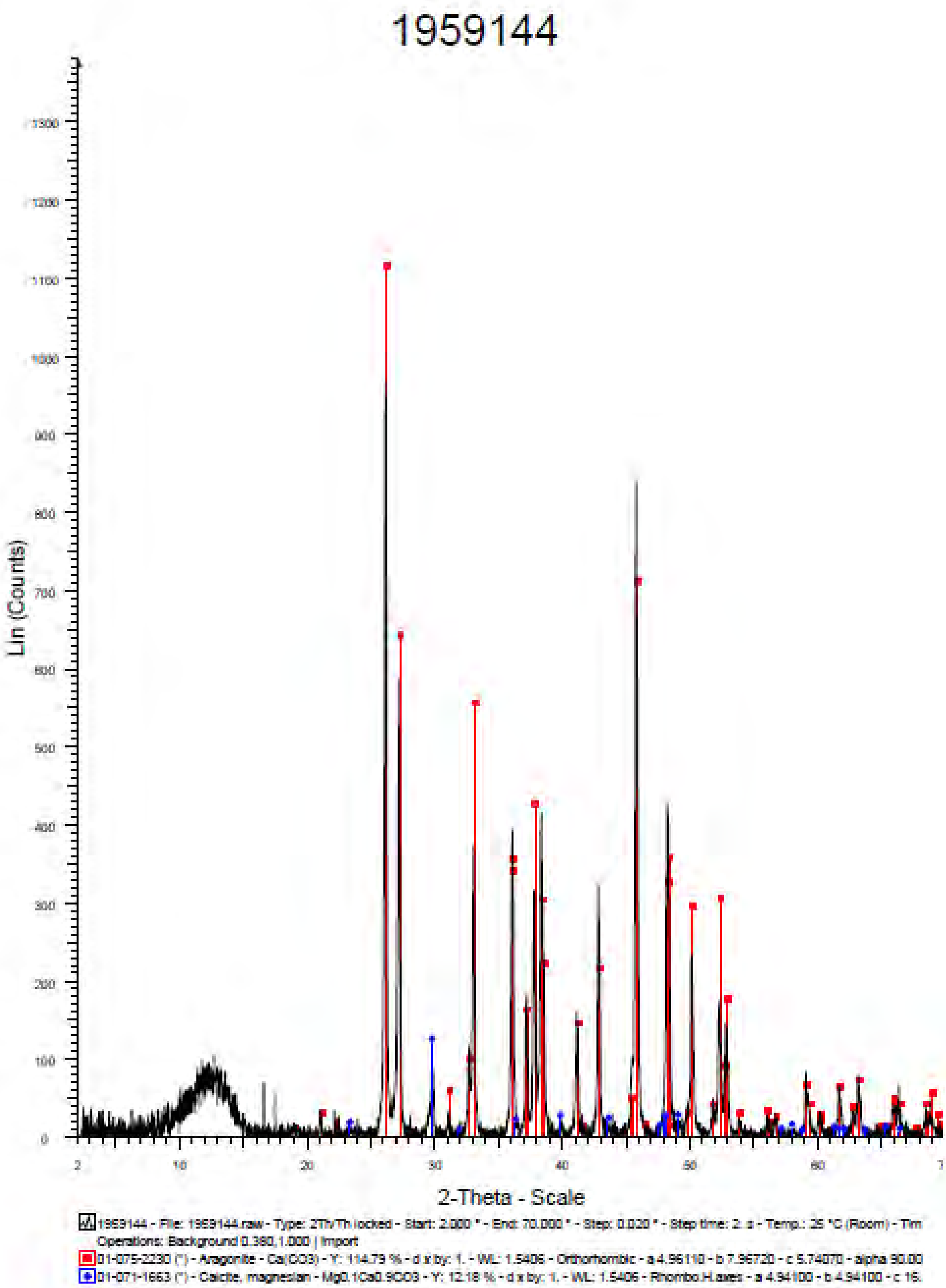
Aragonite – 99.2%; Calcite – 0.8% **Amorphous material not identified or quantified**

Sample #: 1959142
Sample ID: SS062008/13RDC01c (85 cm)



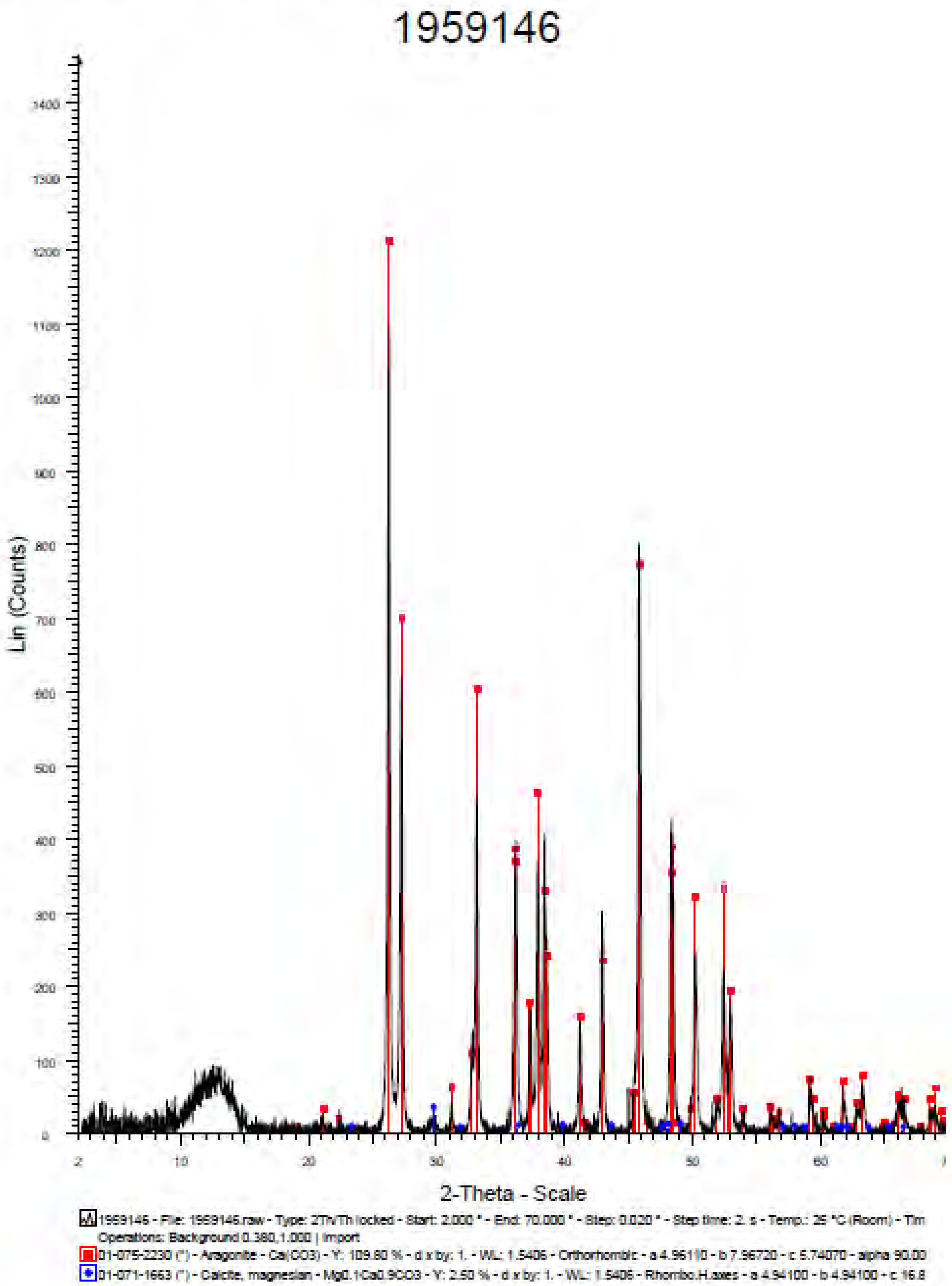
Aragonite – 98.5%; Calcite – 1.5% **Amorphous material not identified or quantified**

Sample #: 1959144
Sample ID: SS062008/14RDC01b (55 cm)



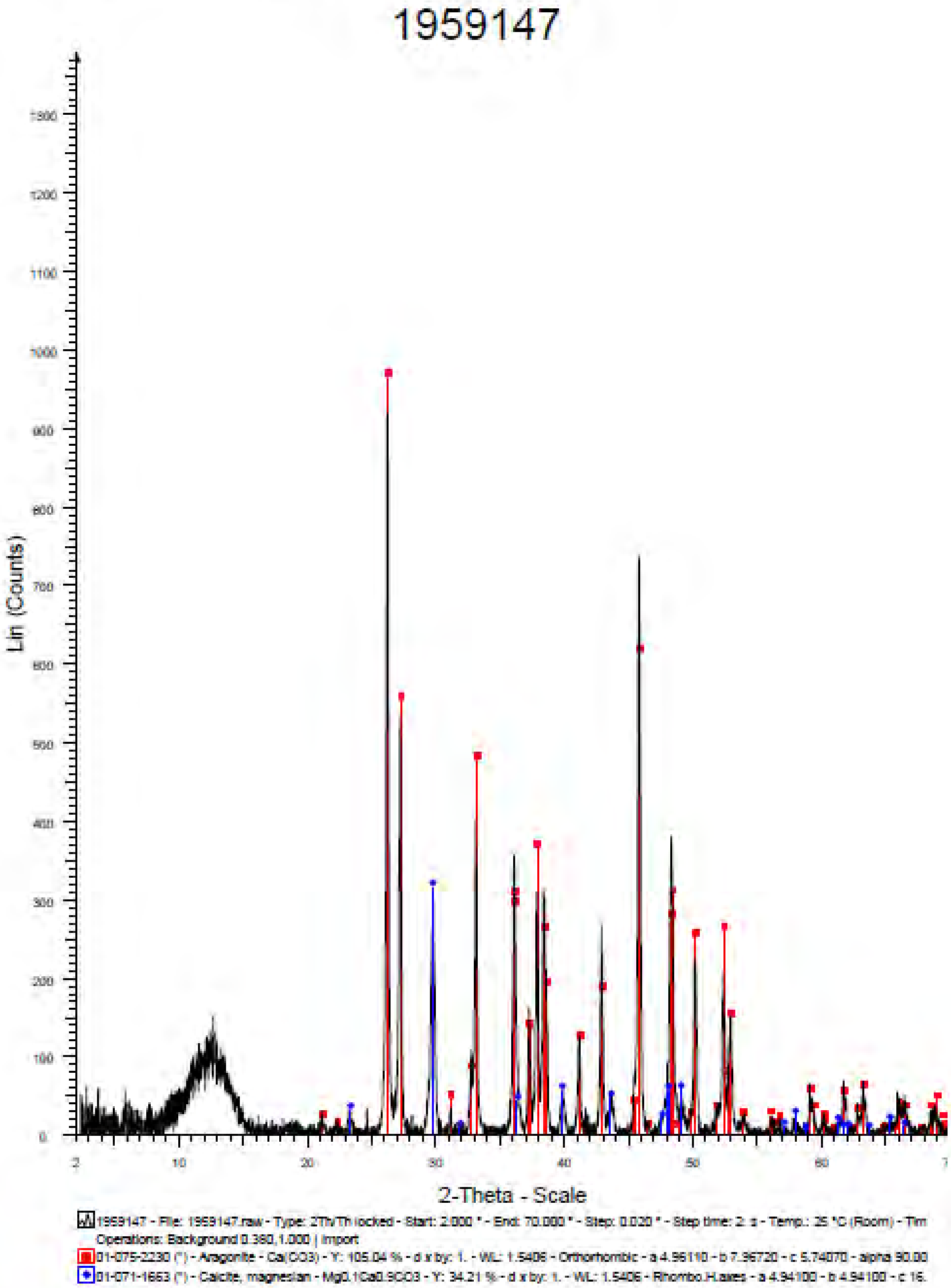
Aragonite – 96.8%; Calcite – 3.2% **Amorphous material not identified or quantified**

Sample #: 1959146
Sample ID: SS062008/22RDC01b (9 cm)



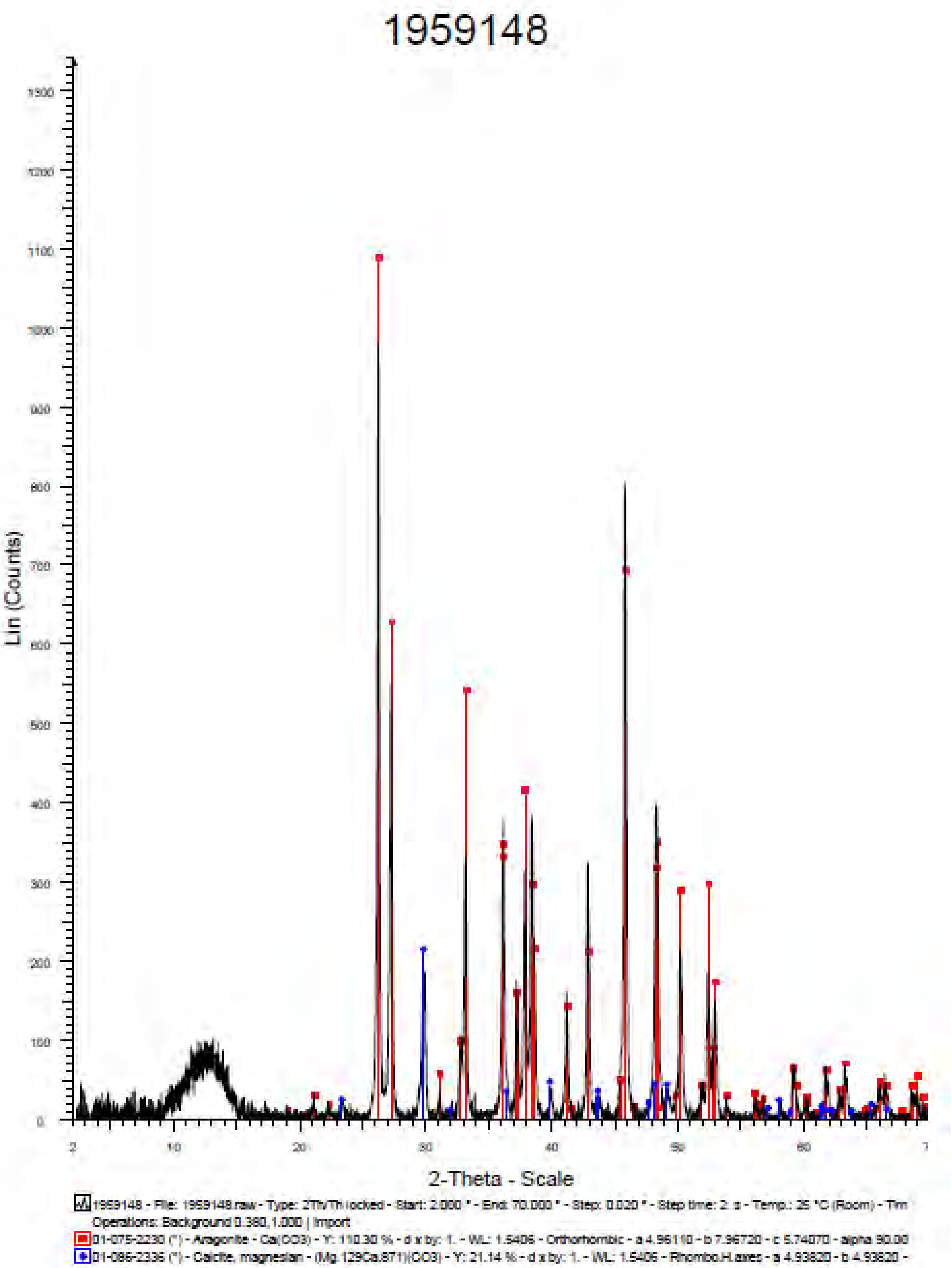
Aragonite – 98.8%; Calcite – 1.2% **Amorphous material not identified or quantified**

Sample #: 1959147
Sample ID: SS062008/22RDC01c (63 cm)



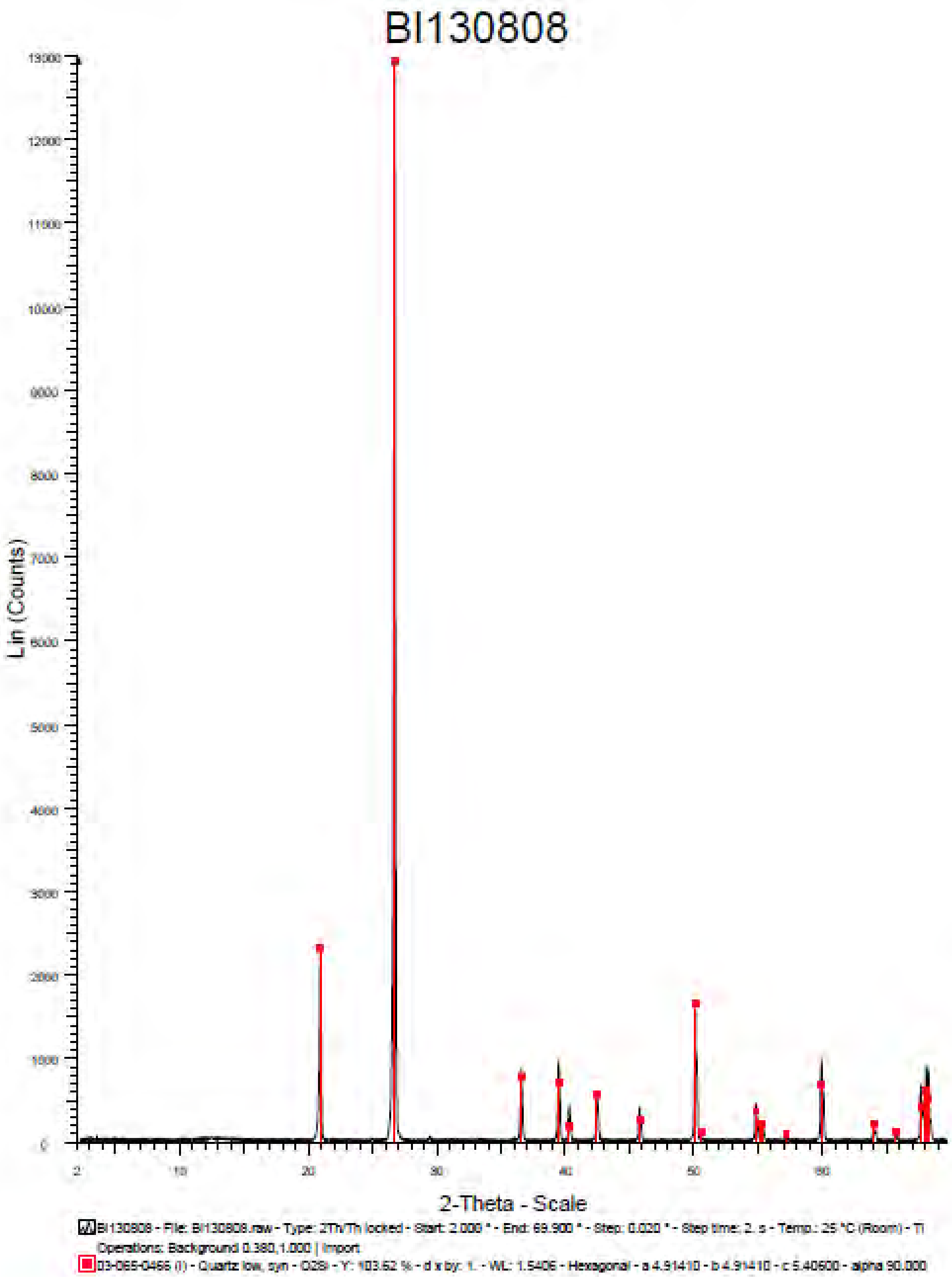
Aragonite – 89.3%; Calcite – 10.7%. **Amorphous material not identified or quantified.**

Sample #: 1959148
Sample ID: SS062008/22RDC01d (117 cm)



Aragonite – 92.6% Calcite – 7.4% **Amorphous material not identified or quantified**

Quartz Blank (Instrumental check)



6.8 VIDEO SCREEN SHOTS FROM NSW DECCW 2009 SURVEY STATIONS

The images below were recorded by the NSW Government's Department of Environment, Climate Change and Water (Marine Conservation Science Unit) at Baited Remote Underwater Video (BRUV) stations on the shelf around Lord Howe Island in November 2009. Figures 6.8.1 and 6.8.2 show the seabed on the nearshore reef. Figure 6.8.3 provides an example of the extensive relict reef surface with encrusting algae and macro algae. An example of the sediment-covered areas of the relict reef is shown in Figure 6.8.4.

Figure 6.8.1: Nearshore reef.

Figure 6.8.2: Nearshore reef with abundant Galapagos sharks.

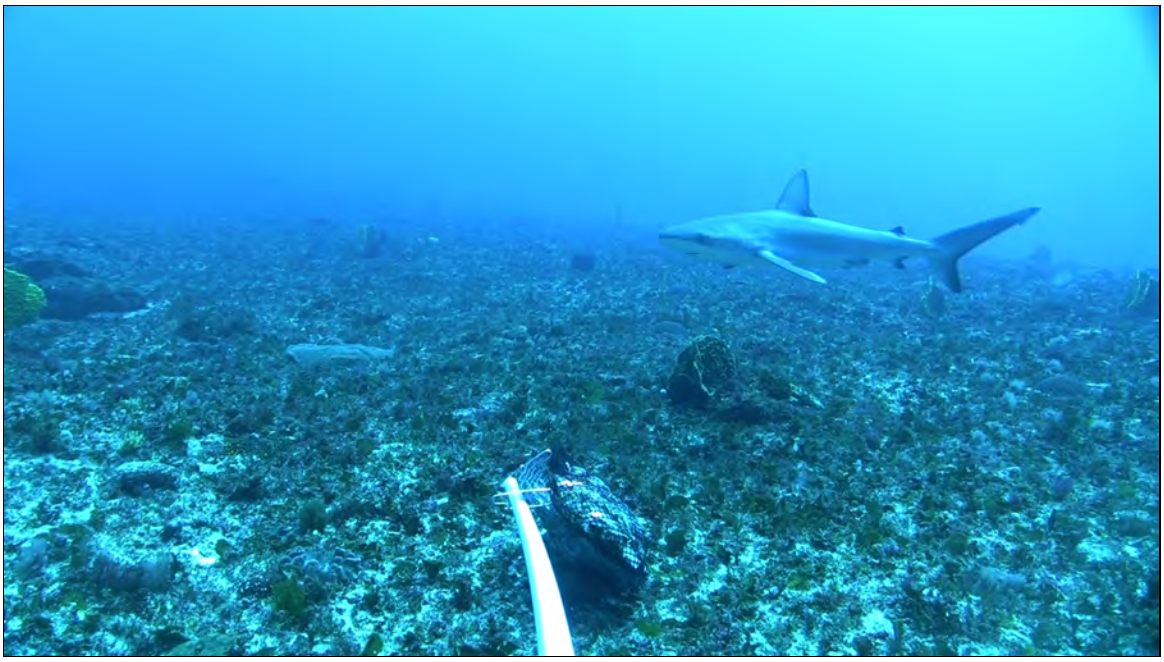


Figure 6.8.3: Relict reef with algal hardground and green macro algae.

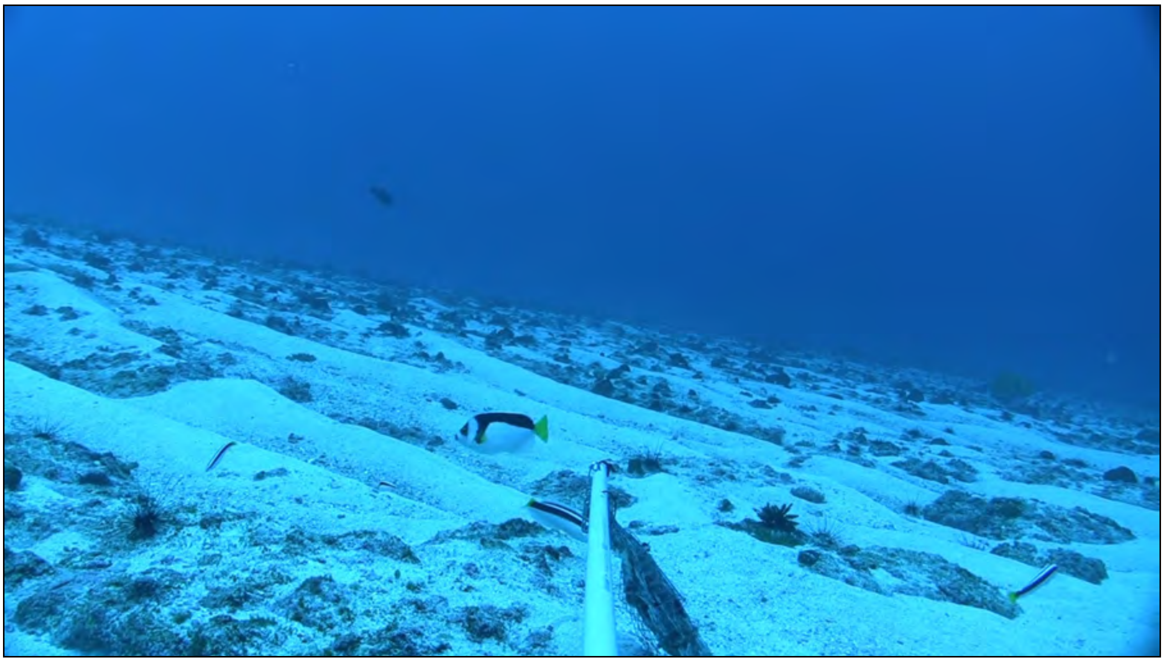


Figure 6.8.4: Rippled sand bed on the relict reef.

6.9 AIMS UNDERWATER IMAGES OF THE SHELF

The images below were collected by the Australian Institute of Marine Science (AIMS) at towed underwater video stations on the shelves around Lord Howe Island and Balls Pyramid in February 2004 (for more information see Speare et al., 2004; http://www.aims.au/pages/research/marine-surveys/lord-howe-island/).

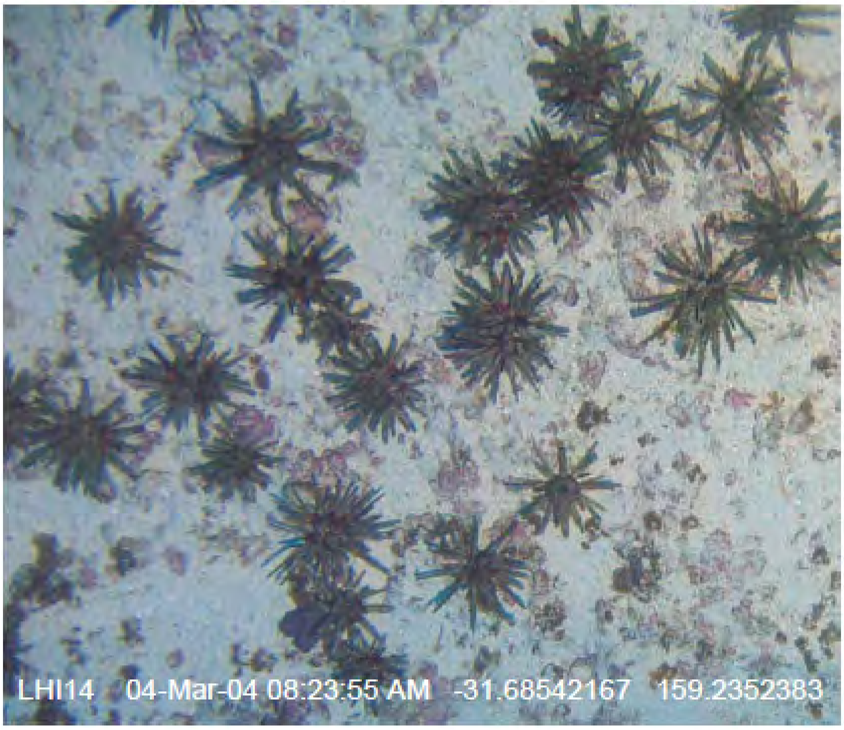


Figure 6.9.1: High densities of pencil urchins on the shelf north of Balls Pyramid.

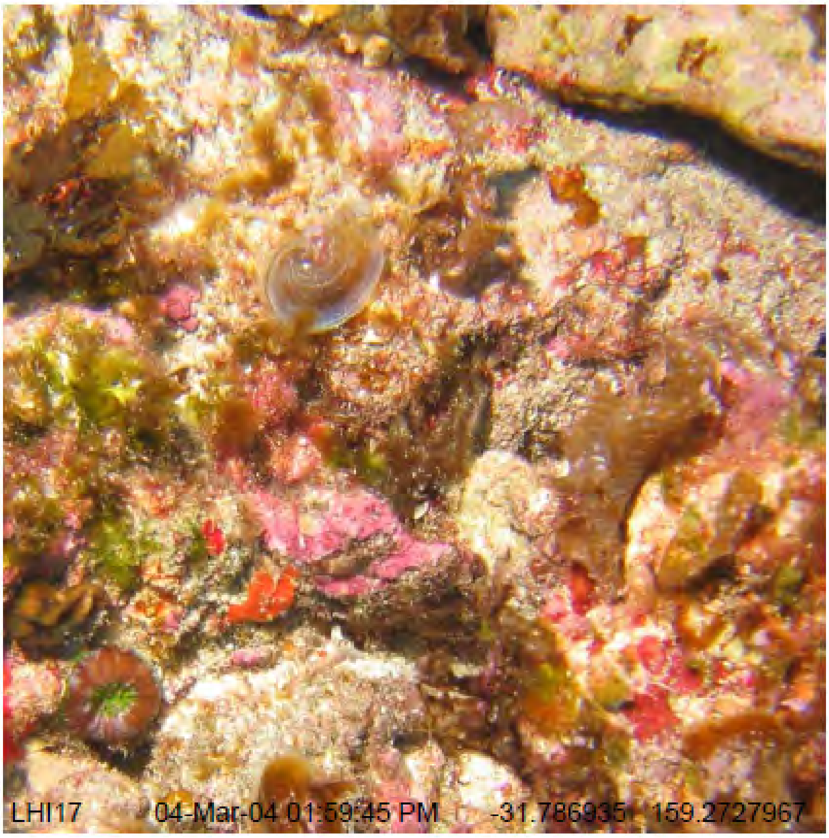


Figure 6.9.2: Reef community near Shouth East Rock showing hard coral, *Parascolymia vitiensis*, encrusting coralline algae, *Padina* sp., brown and filamentous green algae.

Figure 6.9.3: Large flat brown sponge, small purple sponge, *Padina* sp., green and brown algae on a hard bottom covered in sand.

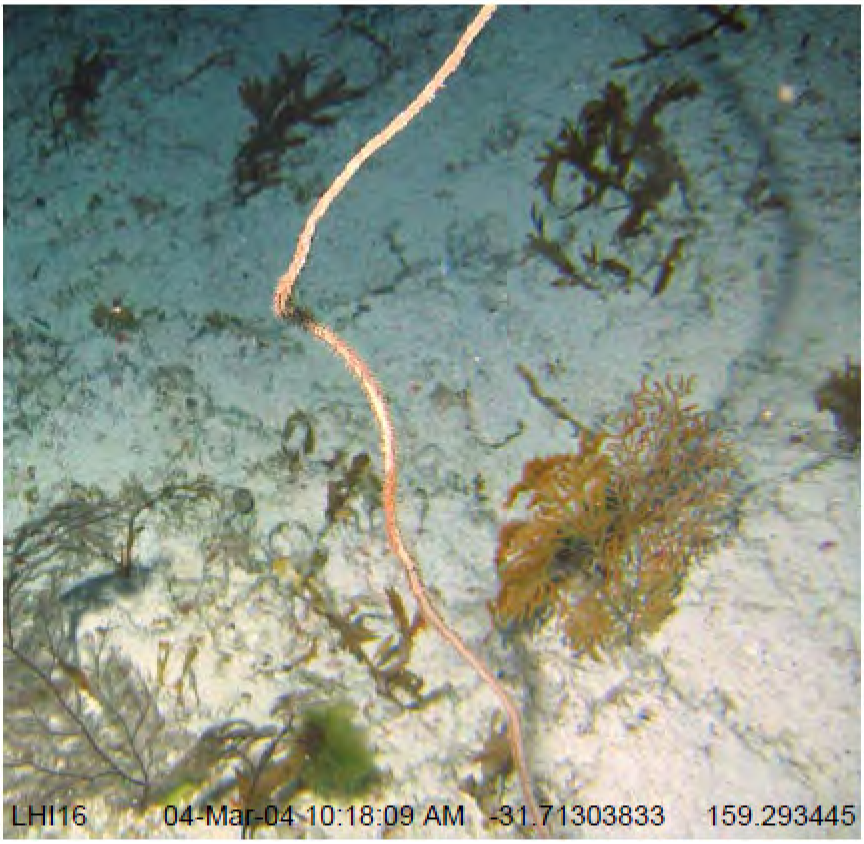


Figure 6.9.4: Shelf break community of whip and fan gorgonian, black coral, brown filamentous green algae.

Figure 6.9.5: Sandy bottom beyond the shelf break with whip gorgonian, bryozoans and brown algae.

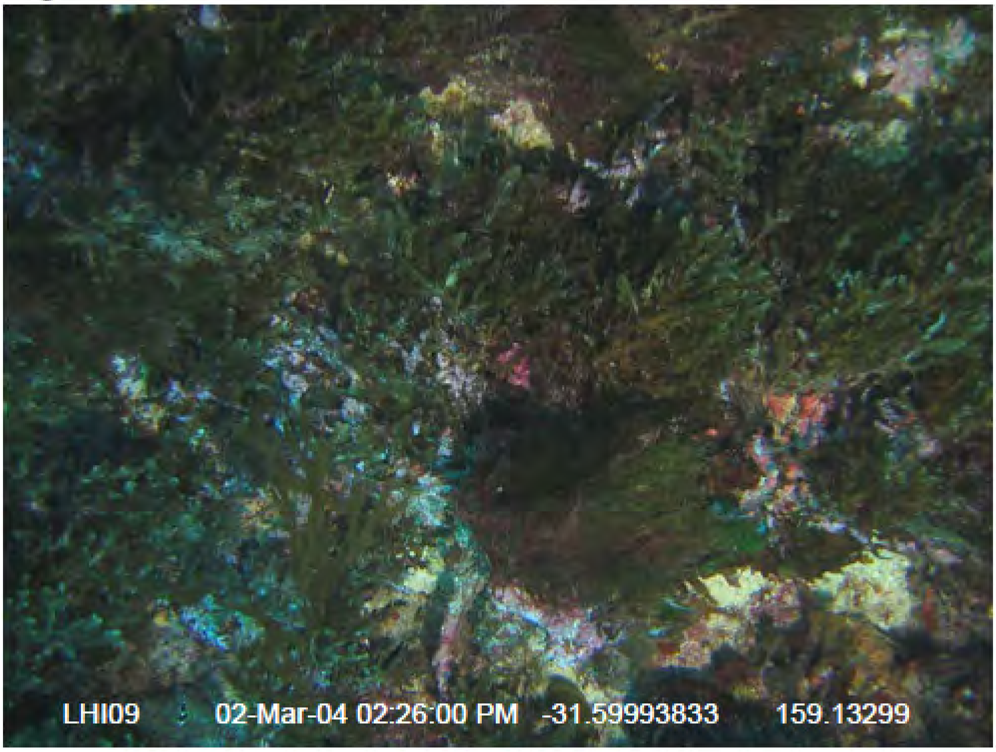


Figure 6.9.6: Dense green macro algae on bedrock.

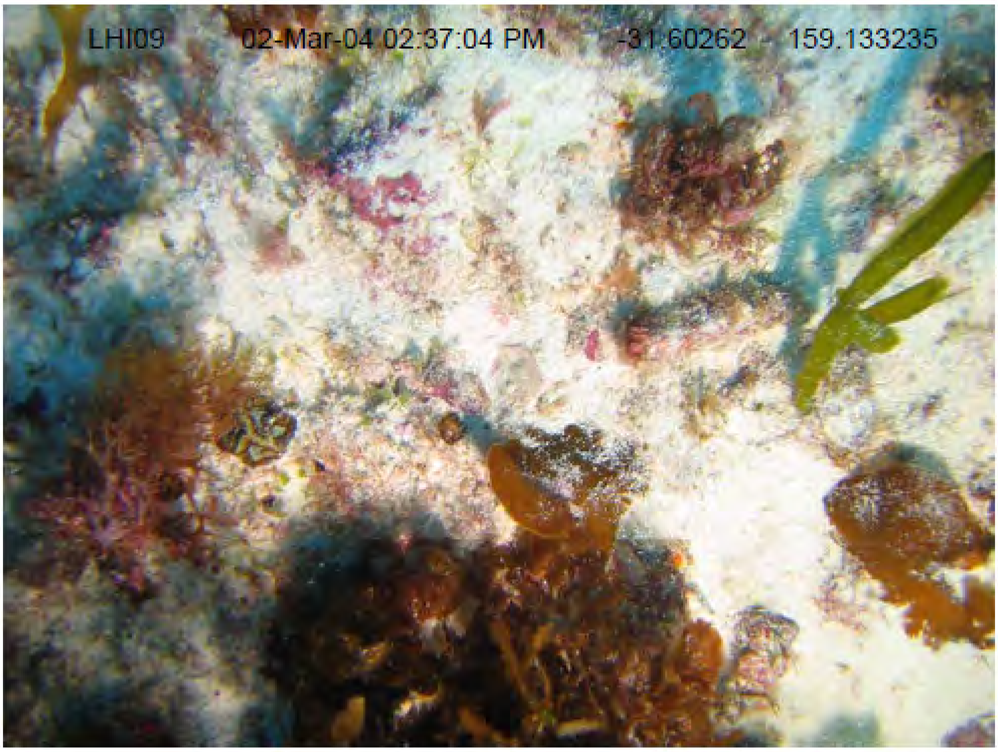


Figure 6.9.7: Coarse sand overlying the bedrock with brown, green and coralline algae and a small coral colony of *Acanthastrea lordhowensis*.

6.10 INFAUNA DATA

Table 6.10.1 *Infauna data, samples by operational taxonomic units.*

Operational taxonomic unit	Acoetidae sp1	Alpheidae sp1	Ampelisca toora	Amphinomidae sp2	Amphioctopus kagoshimensis	Anemone Z1 LH	Anthuridae sp2	Anthuridae sp3	Anthuridea sp1	Anthuridea sp2	Anthuridea sp3	Aplacophora sp1	Apseudomorpha sp1	Arabella sp1	Asellota sp1	Biscuit sp1	Bivalve sp12	Bivalvia sp10	Bivalvia sp11	Bivalvia sp13	Bivalvia sp14	Bivalvia sp15	Bivalvia sp6	Bivalvia sp7	Bivalvia sp8	Bivalvia sp9	Burrowing bivalve	Calappa sp1	Capitellidae sp1	Capitellidae sp3	Capitellidae sp4	Capitellidae sp5	Caridea sp4	CarideA sp5	Caridea sp6	Caridea sp7	Chaetopterus sp1
01GR02	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
01GR03	0	15	0	0	0	0	3	1	7	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	1	0	0	0
01GR04	1	0	0	1	0	0	4	0	5	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
02GR01	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
02GR02	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
02GR03	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
04GR01	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
04GR02	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
04GR03	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
06GR01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0
06GR02	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
06GR03	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
07GR01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
10GR01	0	1	0	0	0	0	0	0	0	0	0	0	0	0	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10GR02	1	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10GR03	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11GR01	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12GR01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0
12GR02	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
12GR03	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
16GR01	0	0	0	0	0	0	0	0	0	0	1	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0
18GR01	2	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0
19GR01	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
19GR02	0	0	0	3	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
19GR03	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	0	0	0	0	1	0
20GR01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20GR02	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
20GR03	1	1	0	0	0	0	0	2	0	0	0	0	0	0	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30GR01	3	0	0	0	1	1	2	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11	0	0	0	0	0
30GR02	2	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11	0	0	0	0	0
30GR03	2	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	0	0	0	0	0	0	0	0
31GR01	0	1	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0
31GR03	1	0	39	1	0	0	0	0	0	1	0	0	0	0	3	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0

Operational taxonomic unit	Chrysopatelidae sp2	Cirratulidae sp2	Clypeaster australasiae	Copepoda sp1	Cylindroberididae sp3	Cypridinidae sp5	Cypridinidae sp6	Cypridinidae sp7	Diastylidae sp1	Ericthonius pugnax	Euchone variabilis	Eunicidae sp2	Eunicidae sp3	Euphausiacea sp1	Flabelligeridae sp1	Gammaridea sp16	Gammaridea sp22	Gammaridea sp24	Gammaridea sp27	Gammaridea sp25	Gastopoda sp13	Gastopoda sp14	Gastropoda sp11	Gastropoda sp12	Gastropoda sp15	Gastropoda sp16	Gastropoda sp17	Gastropoda sp18	Gastropoda sp20	Globoso lembos	Glycera sp1	Glycerid P56	Goniadidae sp1	Haliotidae sp1	Heart urchin sp1	Hesionidae sp3	Holothuroidea sp2
01GR02	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	1	0	0	1
01GR03	1	0	0	0	1	0	0	0	0	0	1	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	2	1
01GR04	1	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1
02GR01	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0
02GR02	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
02GR03	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
04GR01	0	0	0	14	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	2	0	0	0	0	0	0	0	0	0	0
04GR02	0	0	0	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	0	0	0	0	0	0	0	0	0
04GR03	0	0	0	5	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
06GR01	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
06GR02	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1
06GR03	0	0	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
07GR01	0	1	0	0	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0
10GR01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
10GR02	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0
10GR03	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
11GR01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12GR01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0
12GR02	0	0	1	0	0	1	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
12GR03	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
16GR01	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2
18GR01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
19GR01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1
19GR02	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0
19GR03	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1
20GR01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20GR02	3	0	0	2	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
20GR03	4	0	0	4	0	0	0	19	0	0	0	0	0	0	0	0	14	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
30GR01	12	0	0	1	0	3	0	5	0	0	0	0	0	0	0	1	8	0	5	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30GR02	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30GR03	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
31GR01	1	0	2	1	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
31GR03	0	0	2	0	1	0	1	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	2	0	0	0	0

Operational taxonomic unit	Holothuroidea sp3	Holothuroidea sp4	Hyperiidea sp2	Idoteidae sp1	Ischyroceridae sp1	Kalliapseudidae sp1	Kalliapseudidae sp2	Latigammaropsis sp1	Leptocheliidae sp1	Leucosia sp1	Leucothoidae sp3	Lovenia elongatus	Lysianassidae sp3	Maeridae sp1	Magelona sp1	Marphysa sp1	Melita sp1	Melitidae sp2	Mysidacea sp2	Mysidacea sp3	Mysidacea sp4	Mysidacea sp5	Nephtyidae sp2	Nereididae sp3	Oedicerotidae sp6	Onuphidae sp2	Opheliidae sp1	Opheliidae sp2	Opheliidae sp3	Opheliidae sp4	Ophiuroidea sp5	Ophiuroidea sp7	Ophiuroidea sp8	Ophiuroidea sp9	Orbiniidae sp1	Orbiniidae sp2	Paguridae sp1
01GR02	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0
01GR03	0	0	0	0	0	1	3	5	7	0	0	0	0	13	0	0	0	0	0	0	0	0	1	1	1	0	1	3	8	0	0	0	0	0	0	0	0
01GR04	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0
02GR01	0	1	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
02GR02	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
02GR03	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
04GR01	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
04GR02	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	3	1	0	0	0	0	0	0
04GR03	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
06GR01	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
06GR02	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	0	0	0	0	0	0
06GR03	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	1	0	0	0	0	0	1	0	0	0	4	0	0	0	0	0	0	0
07GR01	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0
10GR01	0	0	0	0	0	0	0	0	0	0	0	0	0	17	0	0	0	0	0	0	1	0	0	0	0	0	0	0	2	0	0	1	0	0	0	0	1
10GR02	0	0	0	1	0	0	3	0	0	0	1	1	0	43	0	1	1	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0
10GR03	0	0	0	0	0	0	0	0	3	0	2	0	0	61	0	0	0	0	0	0	3	0	1	0	0	0	0	3	0	2	0	0	0	0	0	0	0
11GR01	0	0	0	0	0	0	0	0	0	0	0	4	0	72	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0
12GR01	0	0	0	3	0	0	0	0	0	0	0	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	1	0	0	0	0	0	0
12GR02	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0
12GR03	0	0	0	0	0	0	0	0	0	0	0	0	0	34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16GR01	0	0	0	4	0	0	0	0	1	0	0	0	0	123	0	0	0	0	0	0	1	0	0	0	0	0	0	0	8	2	0	0	0	0	0	0	0
18GR01	0	0	1	0	0	0	0	0	3	0	0	0	0	28	0	0	0	1	0	0	0	0	0	0	0	0	0	9	0	0	0	0	0	0	0	0	0
19GR01	0	0	0	6	2	0	3	0	0	0	2	2	0	74	0	0	0	0	0	0	0	0	0	0	0	1	0	0	2	1	0	0	0	0	0	0	0
19GR02	0	0	0	5	0	0	1	0	0	0	2	0	0	34	0	0	0	0	0	0	0	6	0	0	0	0	0	2	0	0	0	0	2	0	0	0	0
19GR03	1	0	0	0	3	0	0	0	0	0	1	2	1	33	0	0	0	0	0	0	0	1	0	1	0	0	0	5	0	0	0	0	1	0	0	0	0
20GR01	0	0	1	7	0	0	0	0	0	0	0	6	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
20GR02	0	0	0	2	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	1	0	0	0	0	0	0
20GR03	0	0	0	2	0	0	0	0	0	0	0	2	0	6	0	0	0	0	0	0	4	0	0	0	0	0	0	4	0	0	1	0	1	1	0	0	0
30GR01	0	0	0	4	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
30GR02	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	1	0	0	0	0
30GR03	0	0	0	2	3	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	3	0	0	0	0	1	0	0	0	0
31GR01	0	0	0	1	0	0	114	1	1	0	1	1	0	16	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	1	0	0	0	0
31GR03	0	0	0	0	0	0	301	0	1	0	3	1	0	39	0	0	0	0	0	2	1	0	1	0	0	0	0	1	0	0	0	0	2	0	0	0	0

Operational taxonomic unit	Paratanaidae sp1	Pardaliscidae spX	Pereondus thomsoni	Petrocheles australiensis	Philinidae sp1	Phoxocephalidae sp12	Phylladiorhynchus pusillus	Phyllodocidae sp2	Pisionidae sp1	Plumiliophotis sp1	Portunus rugosus	Prionicidaris callista	Pycnogonid sp2	Ranellidae M20	Sabellariidae sp1	Scaphopoda sp3	Seapen sp1	Serpulidae sp1	Sigalionidae sp2	Sigalionidae sp3	Solemyidae sp2	Spiochaetopterus sp1	Spionidae sp10	Spionidae sp11	Spionidae sp12	Spionidae sp13	Spionidae sp5	Cirolanid2 5	Spionidae4 6	Spionidae sp7	Spionidae sp8	Spionidae sp9	Syllidae sp10	Syllidae sp11	Syllidae sp12	Syllidae sp13	Syllidae sp14
01GR02	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	4	0	0	0	1	0	0	0	0
01GR03	0	0	0	0	0	0	3	0	0	0	0	0	1	0	0	0	0	1	4	1	0	1	0	0	0	0	0	0	0	3	0	0	0	1	0	2	1
01GR04	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	1	0	0
02GR01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
02GR02	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
02GR03	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
04GR01	0	0	0	0	0	9	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0
04GR02	0	0	0	0	0	8	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	2	0	0	0	0	0	0
04GR03	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0
06GR01	0	0	0	0	1	2	0	0	0	0	0	0	1	0	0	4	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0
06GR02	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
06GR03	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0
07GR01	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	3	0	0	0	0	1	0	0	0	3
10GR01	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	2	1	2	0	0	0	2	1	0	0	1	0	0	0	0	0
10GR02	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	8	0	0	2	0	0	0	0	0
10GR03	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	5	0	0	5	0	1	0	0	0
11GR01	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0
12GR01	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	1	0	0	3	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0
12GR02	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	2	0	0	0	0	0
12GR03	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	1
16GR01	0	0	0	0	0	0	0	1	3	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	2	0	0	1	0	0	0	2	0	0	0	1	0
18GR01	0	0	0	0	0	0	0	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	4	0	0	0	0	0	0	0	2
19GR01	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19GR02	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	0	2	0	0	0	0	0	1	0	0	0	0	0	1
19GR03	1	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	1	2	0	0	0	1	0	0	2	0	0	0	0	0
20GR01	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0
20GR02	0	0	0	0	0	0	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20GR03	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	2
30GR01	0	0	0	1	0	0	0	1	6	4	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0
30GR02	0	0	0	0	0	0	0	1	4	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	2
30GR03	0	0	0	0	0	0	0	1	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	2	0	0	0	0	0	0	0	1
31GR01	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	1	0	0	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31GR03	0	0	1	0	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	2	0	0	0	1	0	1	11	0	0	0	0	0	0	0	0

Operational taxonomic unit	Syllidae sp15	Syllidae sp16	Syllidae sp17	Syllidae sp9	Tanaidacea sp2	Tanaidacea sp3	Tanzapsuedes sp1	Terebellidae sp1	Terebellidae sp2	Thalamita sp1	Tomopteridae sp1	Umalia trirufomaculata	Urothoidae sp1	Valvifera sp1	Xanthidae sp1
01GR02	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
01GR03	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1
01GR04	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
02GR01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
02GR02	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
02GR03	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
04GR01	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
04GR02	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
04GR03	1	0	0	0	0	0	0	0	0	0	0	0	2	0	0
06GR01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
06GR02	2	0	0	0	0	0	0	0	0	0	0	0	1	0	0
06GR03	1	0	0	0	0	0	0	0	0	0	0	0	2	0	0
07GR01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10GR01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10GR02	0	0	0	1	0	0	0	0	2	0	0	0	1	0	0
10GR03	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
11GR01	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
12GR01	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
12GR02	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12GR03	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0
16GR01	0	0	0	1	0	0	1	0	1	0	0	0	0	1	0
18GR01	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
19GR01	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0
19GR02	0	0	0	0	0	0	0	2	1	0	0	1	0	0	0
19GR03	3	0	0	0	0	0	0	0	2	0	0	0	0	0	0
20GR01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20GR02	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
20GR03	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30GR01	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
30GR02	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30GR03	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31GR01	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0
31GR03	0	1	1	0	0	0	0	0	1	0	0	0	0	0	0

Figure 6.10.1: Representative amphipods: A) Phoxocephalidae sp12, B) Maeridae sp1, C) Gammaridea sp22, D) Lysianassidae sp3.

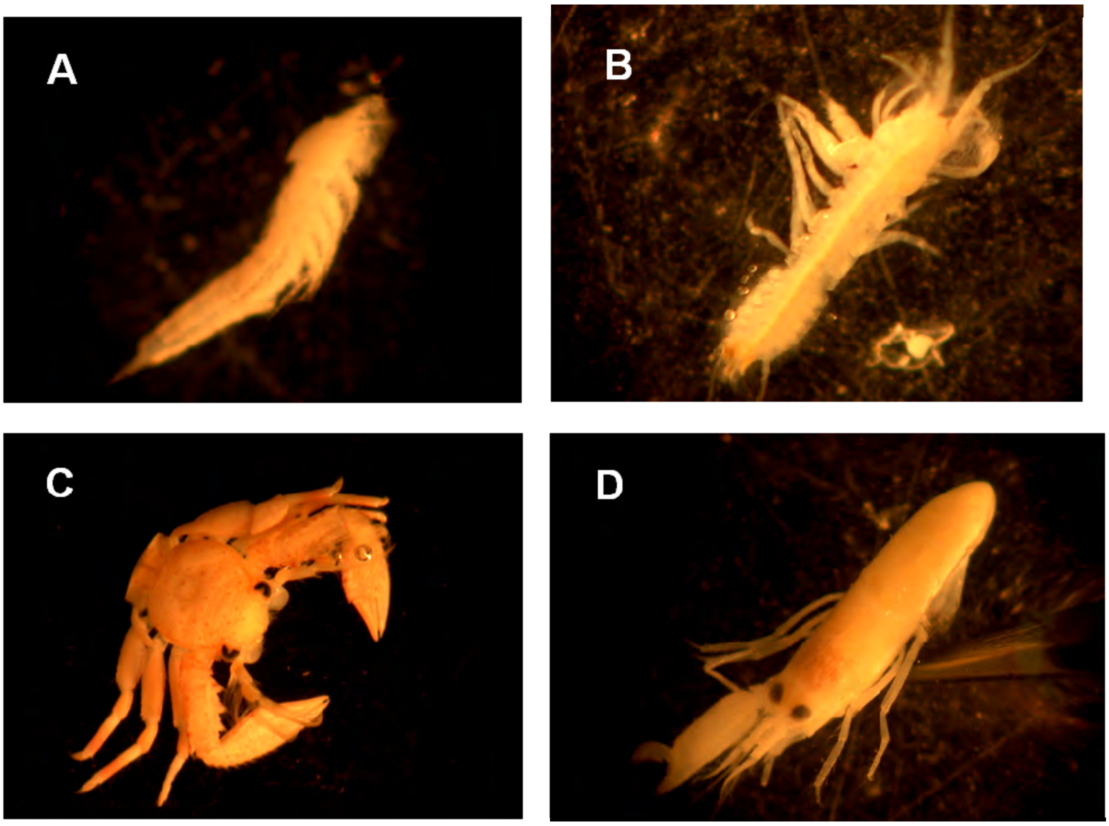


Figure 6.10.2: Other crustaceans: A) Copepoda sp1, B) Kalliapseudidae sp2, C) *Petrocheles* sp1, D) Alpheidae sp1.

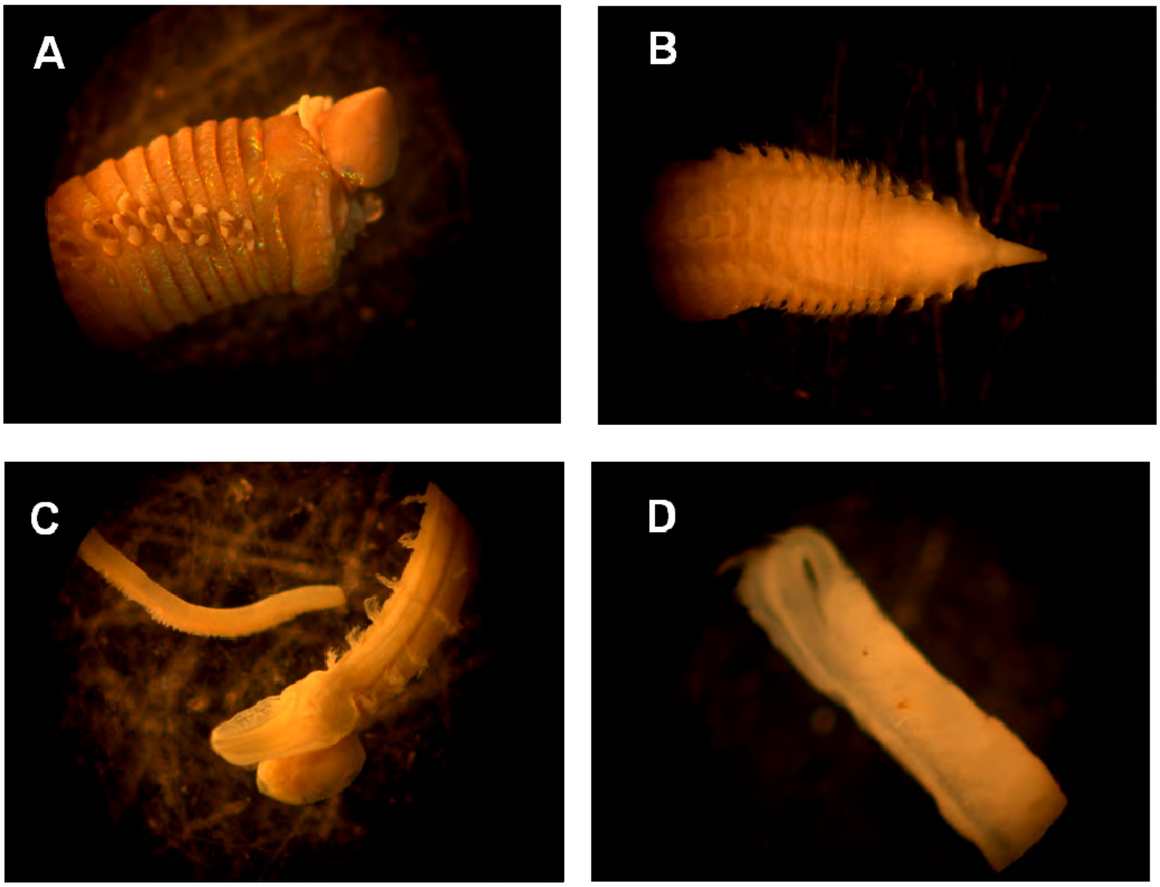


Figure 6.10.3: Representative polychaetes: A) *Marphysa* sp1, B) Orbiniidae sp2, C) *Magelona* sp1, D) *Spiochaetopterus* sp1.

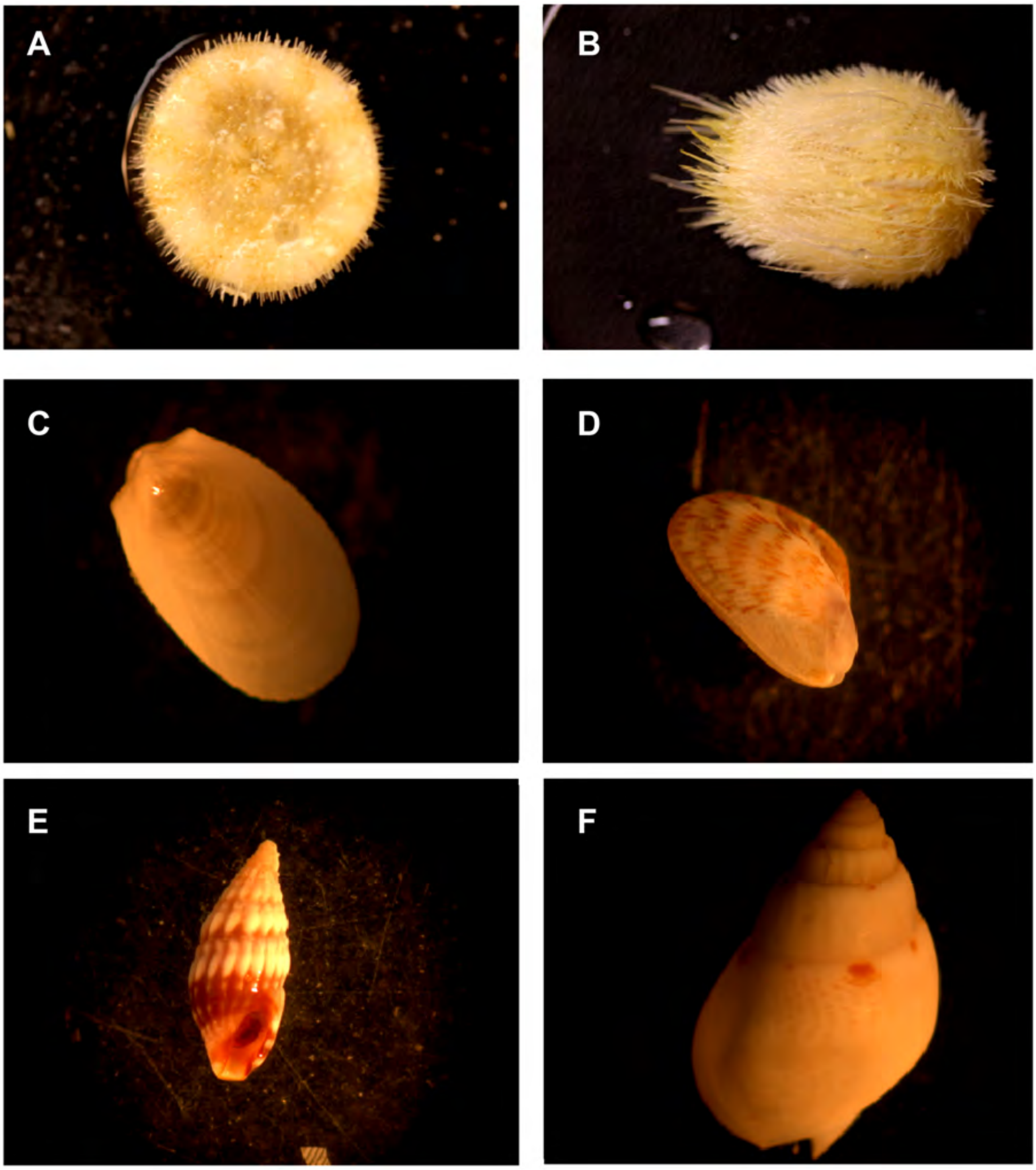


Figure 6.10.4: Other taxa: A) *Clypeaster australasiae*, B) *Lovenia elongatus*, C) Bivalvia sp9, D) Bivalvia sp14, E) Gastropoda sp11, F) Gastropoda sp13.

6.11 GEOMORPHIC FEATURES

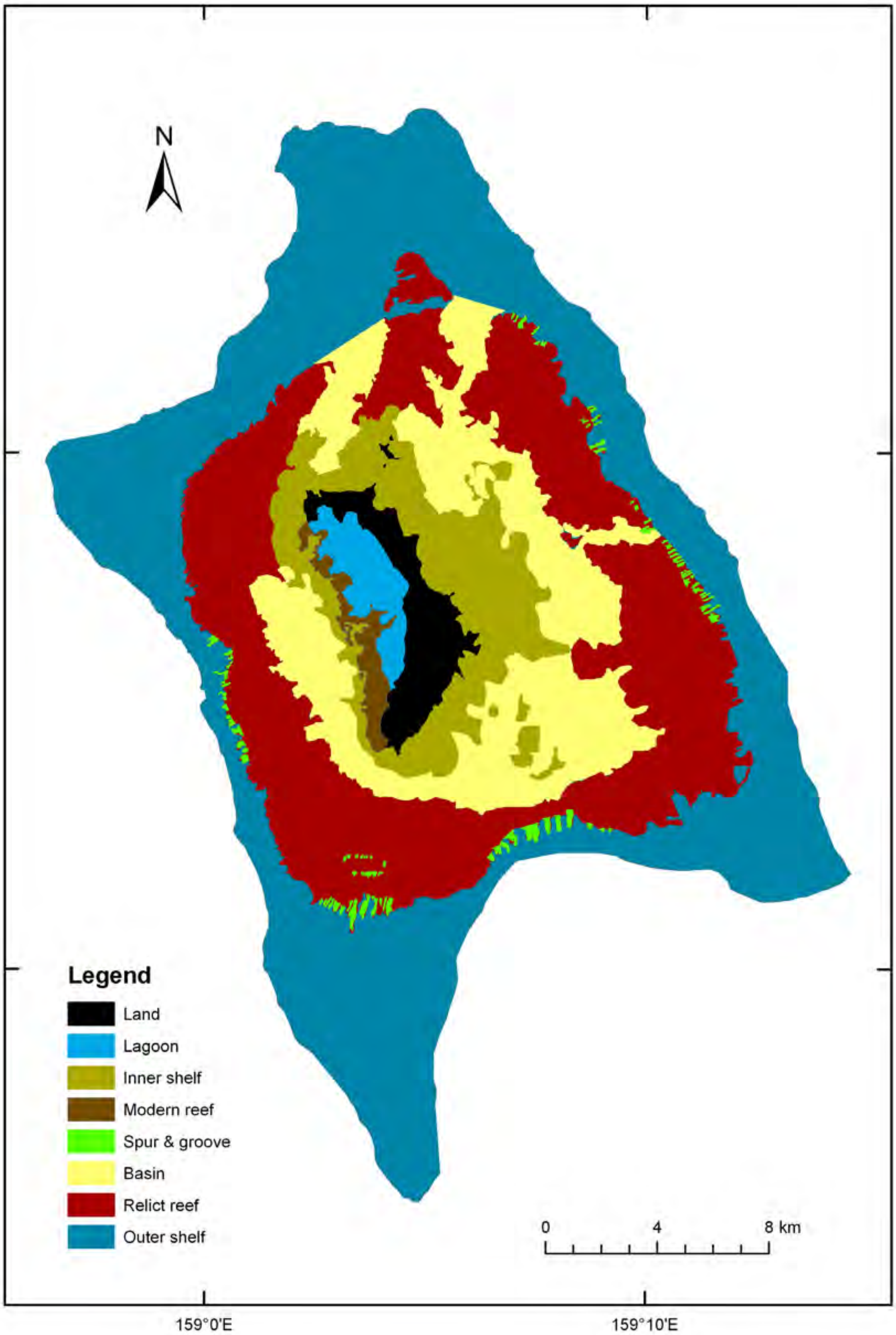


Figure 6.11.1: Generalised geomorphic features map for the Lord Howe Island shelf.