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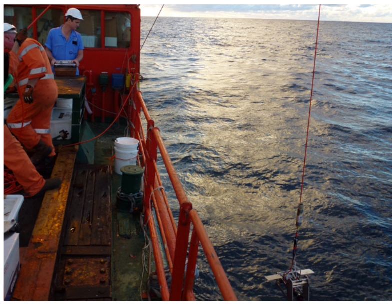

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Seabed Environments and Shallow Geology of the Vlaming Sub-Basin, Western Australia:

Marine Data for the Investigation of the Geological Storage of CO_2

GA0334 Post-Survey Report

Nicholas, W. A., Borissova, I., Radke, L., Tran, M., Bernardel, G., Jorgensen, D., Siwabessy, J., Carroll, A., Whiteway, T.

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Executive Summary

Geoscience Australia undertook a marine survey of the Vlaming Sub-basin in March and April 2012 to provide seabed and shallow geological information to support an assessment of the CO_2 storage potential of this sedimentary basin. The survey was undertaken under the Australian Government's National CO_2 Infrastructure Plan (NCIP) to help identify sites suitable for the long term storage of CO_2 within reasonable distances of major sources of CO_2 emissions. The Vlaming Sub-basin is located offshore from Perth, Western Australia, and was previously identified by the Carbon Storage Taskforce (2009) as potentially highly suitable for CO_2 storage.

The principal aim of the Vlaming Sub-basin marine survey (GA survey number GA334) was to look for evidence of any past or current gas or fluid seepage at the seabed, and to determine whether these features are related to structures (e.g. faults) in the Vlaming Sub-basin that may extend up to the seabed. The survey also mapped seabed habitats and biota in the areas of interest to provide information on communities and biophysical features that may be associated with seepage. This research addresses key questions on the potential for containment of CO_2 in the Early Cretaceous Gage Sandstone (the basin's proposed CO_2 storage unit) and the regional integrity of the South Perth Shale (the seal unit that overlies the Gage Sandstone).

The Vlaming Sub-basin contains sediments ranging from 5 to 14 km thick and comprises terrestrial and marine sediments deposited over the past 300 million years. Data were acquired in two separate areas of the Rottnest Shelf which forms the upper surface of the Vlaming Sub-basin, lying above the regional CO_2 seal, the South Perth Shale, and the underlying CO_2 -suitable reservoir, the Gage Sandstone. Area 1, located within the former Greenhouse Gas acreage release area VLAM-01 (now closed), was chosen because of wide-spread seismic anomalies that indicate sites of possible seepage. Area 2, located within the former Greenhouse Gas acreage release area VLAM-02 (now closed), was chosen because of potential containment risk associated with fault reactivation.

During the survey a total of 2,370 line km (418 km^2) of multibeam sonar bathymetry, backscatter and co-located acoustic shallow sub-bottom profile data were acquired. In smaller areas of special interest, 6.65 km^2 of side-scan sonar imagery, 4.25 km of towed video footage and 89 seabed grab samples were taken at 43 sample stations.

The collection of high-resolution multibeam sonar data on the Rottnest Shelf has been particularly valuable, revealing in great detail numerous seafloor features, and enabling significant new insights into seabed processes and environments in this shallow marine setting.

Area 1, located to the north of Rottnest Island, lies in water depths of 37-53 m. The seabed here is characterised by shallow valleys, terraces and sediment mega-ripples. Structural lineaments identified on the seabed may be the surface expression of faults. Area 2, situated to the southwest of Rottnest Island, is in slightly deeper water (34-125 m). The seabed here has gravelly beds of coralline red algae and some sediment mega-ripples. Large-scale structures include prominent parabolic ridges and numerous low mounds, with ridges and mounds also forming sites of rhodolith accumulation. A thin veneer of carbonate sand is present over large areas of seabed between rhodolith beds in both survey areas.

Structural discontinuities within bedrock that crops out on the seabed form linear scarps in Area 1. In Area 2, north-south trending ridges formed by structural discontinuities have in places formed sites of significant rhodolith accumulation, which in places rise 4-5 m above the seafloor in water depths of 80-85 m. The relationships between these mounds, possible seepage and faults are the focus of ongoing data analysis.

Preliminary analyses indicate an apparent spatial correlation between the location of ridges, mounds, large-scale structural lineaments on the seabed and faults imaged in seismic data. Identifying the links between these structures, fluid seepage from the sub-basin and fault reactivation is the focus of continuing work. Samples and data will be compared with deep basin structures evident in 2D seismic data collected in the area. The results of this analysis are anticipated to significantly improve the knowledge base on which to assess the suitability of these areas for CO_2 storage.

Acknowledgements

The Vlaming Sub-basin marine survey was run in a tight timeframe and would not have been possible without the hard working teams in the Basin Resources Group and the Coastal Marine and Climate Change Group who provided advice, support and feedback. We would like to thank the Master and crew of the *MV Southern Supporter* and land-based support provided by Fugro Pty Ltd who ensured that this survey ran smoothly. We are grateful to both GA crews who made sure our time spent on the Southern Supporter was effectively used, and returned with many samples and high quality data. Also, we acknowledge the Field and Engineering Support, the Energy Project Support and the Innovation and Specialist Services Groups, who individually and collectively gave their expertise in tight timeframes. In particular, we would like to thank John Pugh for managing contractor negotiation interactions. We would also like to thank reviewers, John Clarke and Anna Potter, for comments on the draft. This report is published with the permission of the Chief Executive Officer of Geoscience Australia.

1. Introduction

1.1. Introduction and Background

In 2009 the Carbon Storage Taskforce report identified the Vlaming Sub-basin, Western Australia (Figure 1.1) as a site potentially suitable for CO_2 sequestration because of its close proximity to high CO_2 emitters located in Perth, and because of its geological storage potential (Carbon Storage Taskforce, 2009). In 2011, the Vlaming Sub-basin was identified for further investigation under the Commonwealth-funded National CO_2 Infrastructure Plan (NCIP) designed to “facilitate identification and development of sites suitable for the long-term storage of CO_2” and to facilitate potential uptake by industry of the former offshore Greenhouse Gas (GHG) acreage release areas (now closed).

As part of the NCIP program Geoscience Australia started pre-competitive data acquisition and geological storage assessments in several offshore basins, including the Vlaming Sub-basin. The aim of this work is to provide information that will enable more accurate and up-to-date assessments of this area for the long-term geological storage of CO_2.

In March and April of 2012, Geoscience Australia (GA) undertook a marine survey, the Vlaming Sub-basin marine survey (survey number GA334), to acquire seabed information to complement existing seismic data in two representative areas of the Rottnest Shelf (Figure 1.1). These datasets will contribute to the assessment of the Vlaming Sub-basin (Figure 1.1) as a potential site for CO_2 sequestration. In addition to the deep geological (2D and 3D seismic) perspective, seabed information was required to understand the connection between the deep geology of the basin and the seabed. The collection and analysis of seabed and sub-surface physical, chemical and biological information enables the evaluation of potential seepage from the seafloor, which can be used to help assess the integrity of the seal within the Vlaming Sub-basin.

This report describes the rationale for the design of the marine survey, scientific methods for data collection, and the geophysical, sedimentological, geochemical and biological data collected. It also outlines some preliminary observations on the seabed geomorphology in relation to potential seepage from the basin and the geological history of this part of the Rottnest Shelf that has influenced the present shelf geomorphology and distribution of seabed habitats.

1.2. Scientific Rationale

The Vlaming Sub-basin, located approximately 30 km west of Perth, is a major Jurassic-Early Cretaceous depocentre in the offshore Perth Basin. The Jurassic to Early Cretaceous crustal extension in Gondwana culminated in the breakup between Australia and India during the Valanginian (Early Cretaceous). Uplift prior to breakup led to wide-spread erosion creating a prominent, often angular, unconformity showing several hundred metres of relief (Nicholson *et al.,* 2008). The earliest sedimentation after the breakup event is represented by the Gage Sandstone (Figures 1.1, 1.2, 1.3), which comprises fine-grained to granular feldspathic sandstones with less common fine-grained interbeds (Crostella and Backhouse, 2000). This unit represents high quality reservoir rocks with porosities of 23-30% and permeabilities of 200–1,800 mD (Marshall *et al*., 1993). The Gage

Sandstone has been identified as the main reservoir suitable for CO_2 storage in the Vlaming Sub-basin (Causebrook et al., 2006).

Located at depths suitable for injection of supercritical CO_2 (>800 m depth), the Gage Sandstone (Figure 1.1, 1.2, 1.3) has a spatial extent of approximately 1,890 km^2 (Figure 1.1), a maximum thickness of 450 m to the south of Rottnest Island, and is overlain by the South Perth Shale (Figure 1.2). This latter unit is the regionally extensive seal, and consists of interbedded marine shales, siltstones and minor sandstones. The thickness of the South Perth Shale varies from less than 100 m to about 800 m.

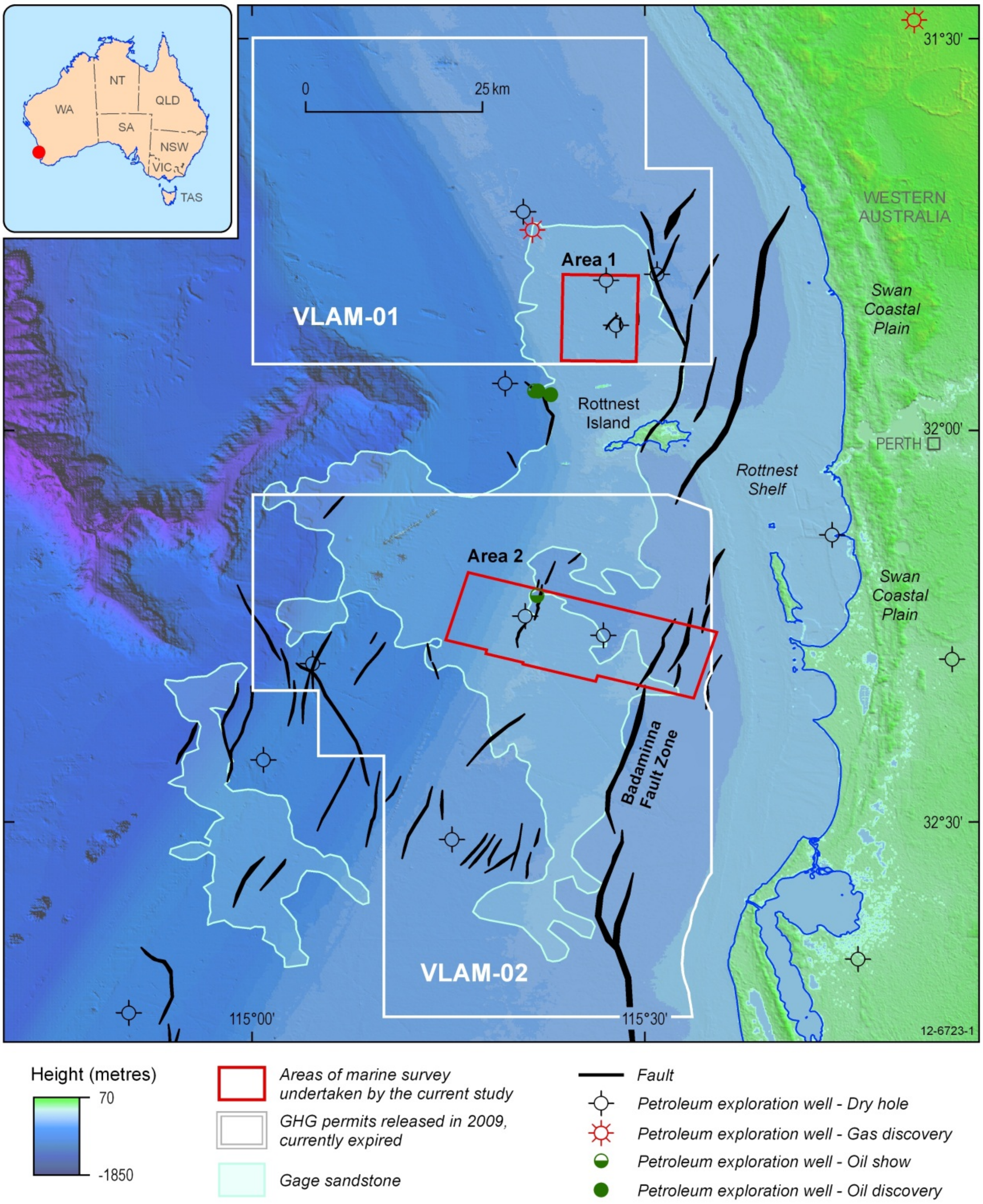

Figure 1.1. *Location map of areas surveyed during Marine Survey GA334, showing the extent of the main reservoir unit (Gage Sandstone) considered for the geological storage of CO_2 in the Vlaming Sub-Basin, and the location of Greenhouse Gas Acreage release areas VLAM 01 and VLAM 02, offered in 2009 (now closed).*

A previous assessment of the suitability of the Vlaming Sub-basin for storage of CO_2 focused on estimating the potential storage capacity of the Gage Sandstone reservoir (Causebrook *et al*., 2006). Although concerns about the effectiveness of the seal in some areas, as well as the presence of potential seepage features and re-activated faults were mentioned in the report, these aspects were not investigated in detail. The study of the Vlaming Sub-basin under the NCIP program aims at assessing these geological features in more detail by collecting and analysing seismic and seabed datasets.

Physical, chemical and biological samples and data collected from the seabed, water column, and shallow subsurface environments provide the primary datasets to assess whether fluid flow from the subsurface is, or has been, occurring at the seabed (Judd and Hovland, 2007). Bathymetric data informs on the presence or absence of structures that may be associated with seepage; whereas sub-bottom profile imaging enables an understanding of the link between the seabed and the sub-surface geology. The presence of authigenic carbonates which may be the result of seepage, or ground-water flow, may be determined by visual examination and laboratory analysis of seabed surface sediments. Chemical analyses can inform whether hydrocarbons or other fluids are present in surface environments.

Geoscience Australia contracted Fugro Survey Pty. Ltd. to undertake a marine survey using the vessel the *MV Southern Supporter*. Geoscience Australia staff were onboard to oversee the acquisition of geophysical data and to obtain seabed sediment and biological samples. The two areas that were surveyed lie within the former GHG release areas VLAM-01 and VLAM-02 (now closed) (Figure 1.1). Data collected during the survey and the results of the subsequent sample analysis will contribute to the assessment of seal integrity in the Vlaming Sub-basin as well as provide environmental information for the Department of Resources, Energy and Tourism (RET) and Department of Sustainability, Environment, Water, Population, and Communities (SEWPaC) to support their future work programs.

1.3. Survey Aims and Objectives

The principal aim of the Vlaming Sub-basin marine survey was to provide geophysical and biophysical data and information on the seabed and underlying shallow geology in two areas of the Rottnest Shelf to contribute to the assessment of seal integrity and the potential to store CO_2 in the Vlaming Sub-basin.

Indications of possible seepage were recognised in previously collected seismic data from the northern and southern lobes of the Gage Sandstone. Features in the seismic data that indicate potential seepage include areas with loss of seismic reflectivity, which are observed to be located above large synrift faults (Figure 1.4). In some areas, fault reactivation is indicated on seismic sections, whilst in other areas faults are obscured by artifacts in the seismic signal due to the apparent seepage. Several mature source rock intervals are present in the Vlaming Sub-basin (Nicholson *et al*., 2008). Hydrocarbons generated by these source rocks may leak to the surface through recently reactivated faults resulting in part from the geomechanical properties of the seal. When hydrocarbon-carrying fluids reach the seafloor they may result in the development of specific seabed geomorphic features, including pockmarks, bioherms, carbonate mounds and chimneys. Seabed seepage and the related seabed features may give rise to differences in the geochemical composition of sediments and may result in the development of particular biota, habitats and ecologies.

The survey objectives, therefore, were to collect data that contribute to our understanding on:

- seabed geomorphic features, such as scarps and ridges, which may indicate recent fault reactivation;
- geomorphic expressions of seepage on the seabed (e.g. bioherms, pockmarks);
- seabed sediment types and composition;
- benthic species, particularly any anomalies in their type, distribution or abundance, especially those known to be related to seepage, and;

- geomorphic features that may be hazardous for potential future CO_2 storage and infrastructure (e.g. pipelines, drilling rigs).

A range of seabed data were collected to fulfill the objectives of the project:

- spatially extensive multibeam bathymetry;
- sub-bottom profiles;
- side-scan sonar data; and
- surface sediment, biological and geochemical samples.

These seabed data will be used to investigate potential indicators of seepage, including for example geochemical indicators such as authigenic carbonate or other mineral precipitates, specific trace elements, isotopic and/or biochemical signatures that may indicate hydrocarbon seepage on the seabed of the Rottnest Shelf.

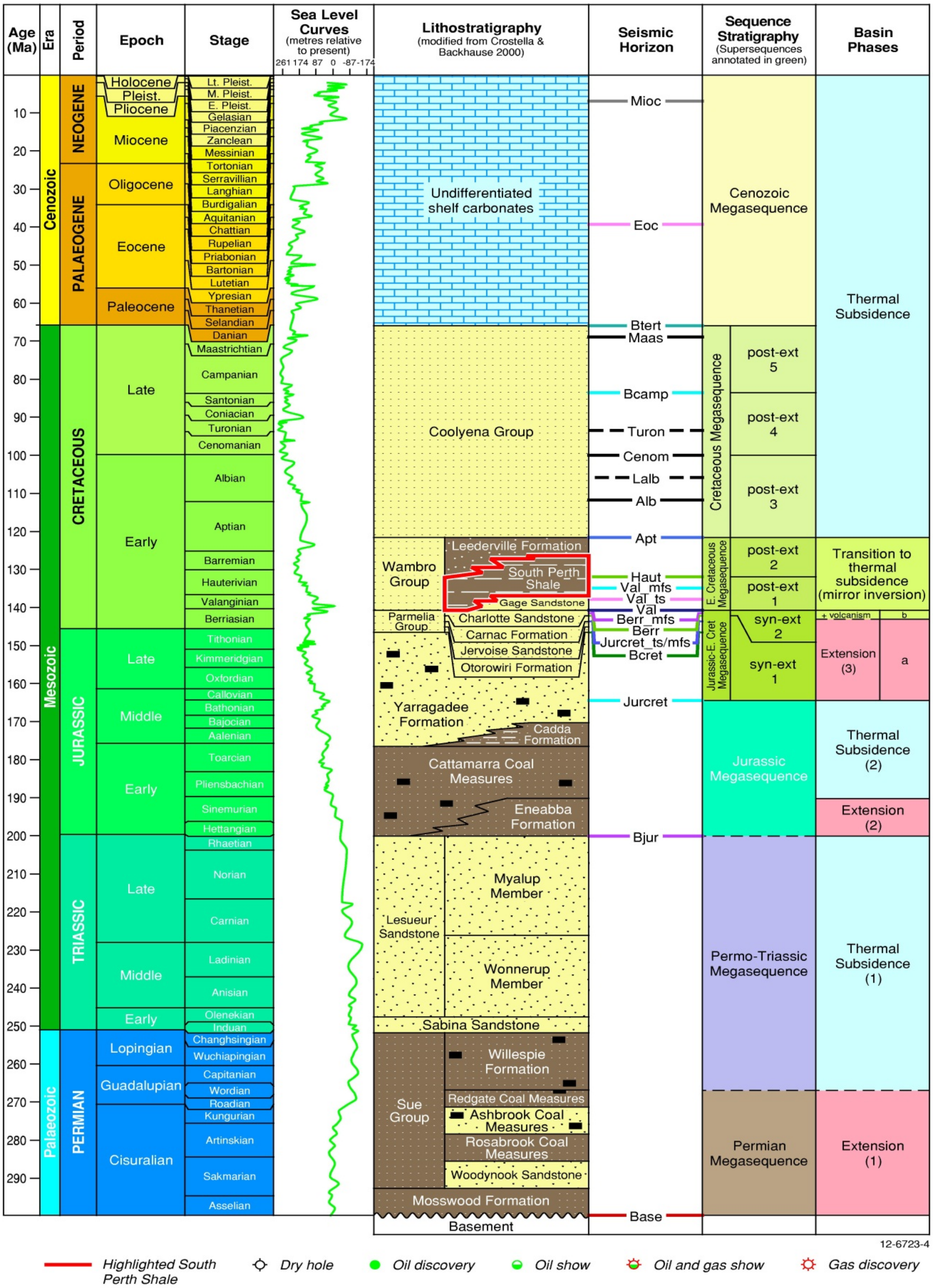

***Figure 1.2:** Stratigraphy of the Vlaming Sub-basin (modified after Nicholson et al., 2008). The geological units of interest (reservoir and seal) within the Vlaming Sub-basin are the Early Cretaceous Gage Sandstone, and the overlying South Perth Shale.*

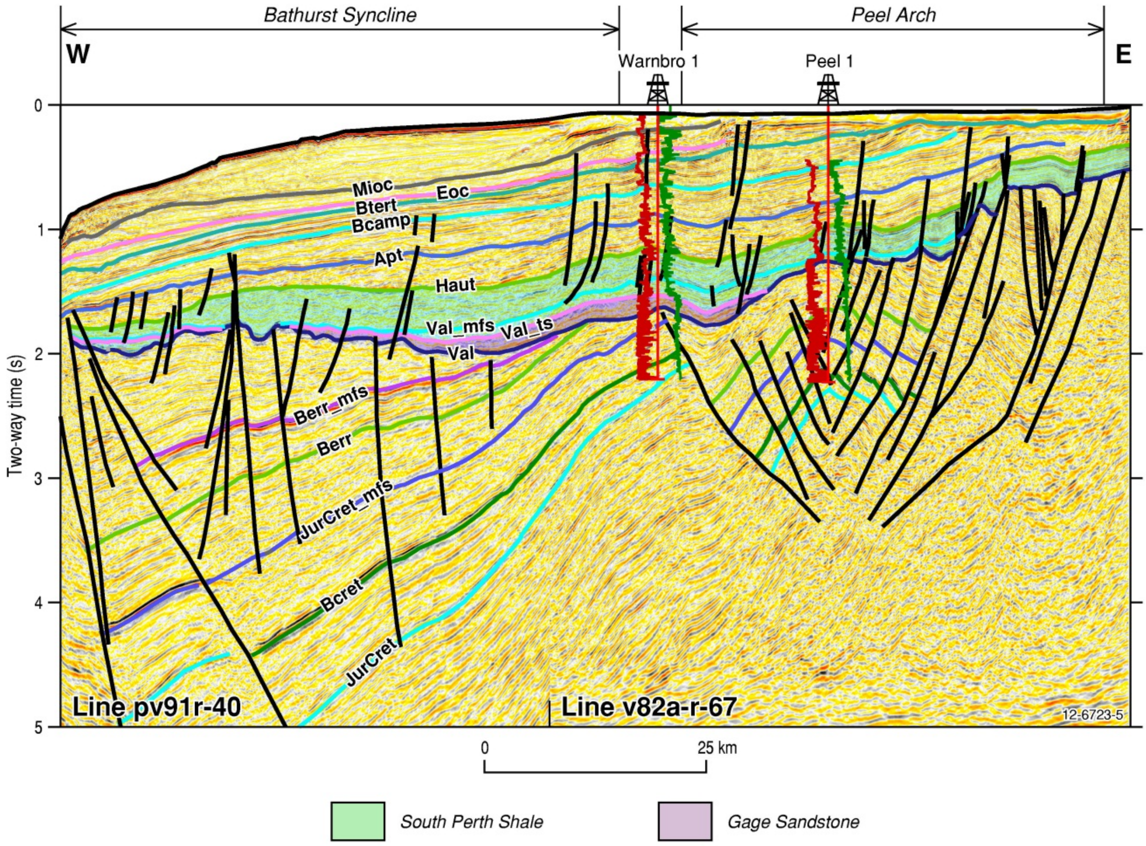

Figure 1.3: *Seismic cross-section of the Vlaming Sub-basin, showing location and thickness of the Gage Sandstone and South Perth Shale in relation to other stratigraphic units. The Gage Sandstone consists of channelised turbidites and mass flow deposits that were transported during a sea level lowstand across the post breakup shallow marine shelf.*

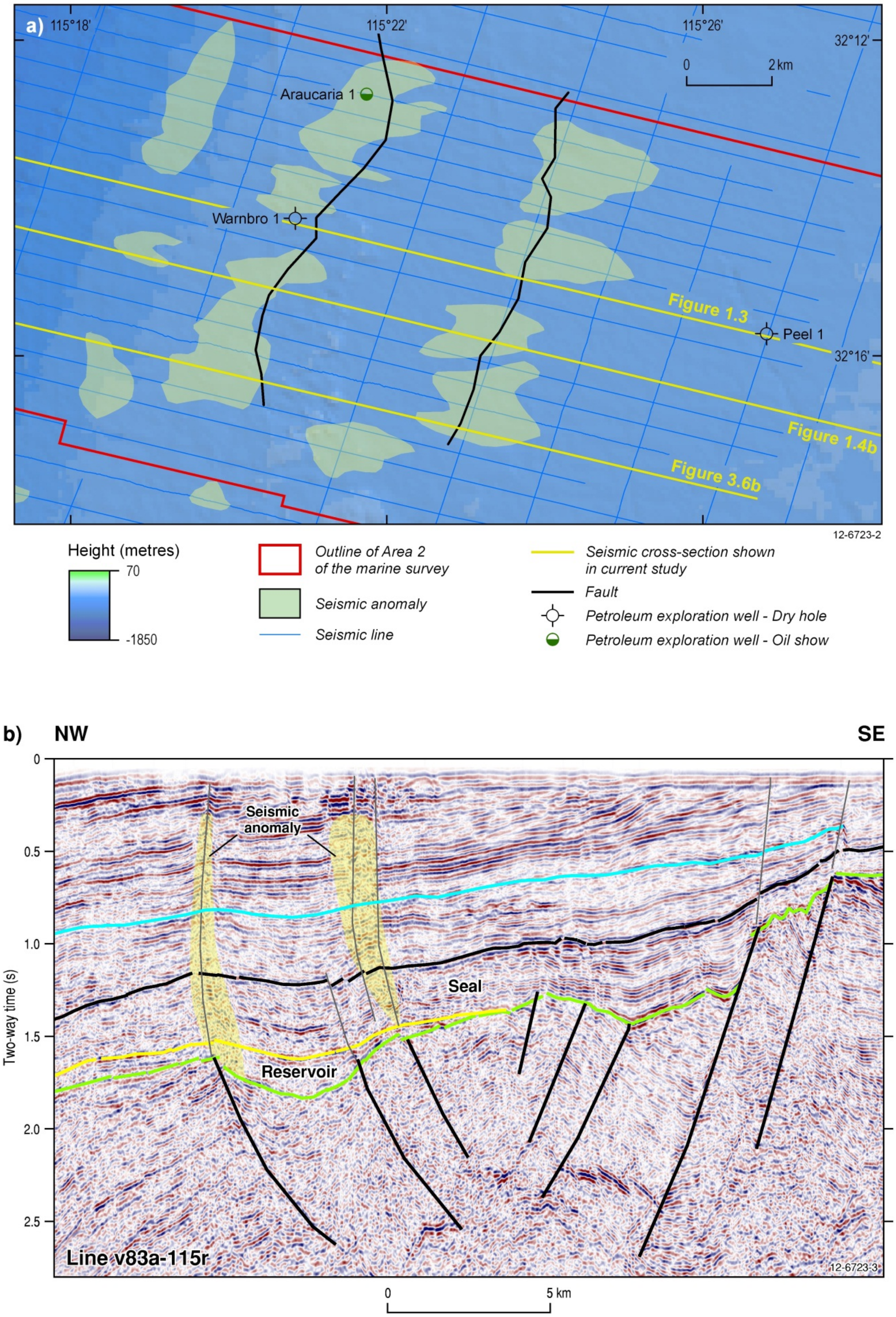

Figure 1.4: *Location of a) seismic anomalies at the seabed, interpreted from b) seismic profile data in Area 2 (see Figure 1.1).*

1.4. Physical Setting and Study Areas

The two areas surveyed lie in shallow water (30-135 m) on the Rottnest Shelf, Western Australia (Figure 1.1; Table 1.1). The Rottnest Shelf, centred on Rottnest Island and forming the modern surface of the Vlaming Sub-basin, is a narrow, wave-dominated, open shelf characterised by carbonate sediments (Collins, 1988). This shelf extends from latitude 29° 30' S to 33° 30' S. The adjacent coastal hinterland, including the Swan Coastal Plain, consists of north-south trending Quaternary aged coastal deposits dominated by coastal dune systems backed by the undulating Darling Plateau which developed on the Archaean shield. Regionally, the coastal Quaternary strata includes the:

- Quindalup Dune System (Holocene marine and aeolian sands);
- Spearwood Dune System (Pleistocene Tamala Aeolianite/Tamala Limestone);
- Bassendean Dune System (Bassendean Sand), Pinjara Plain (Guilford Formation);
- Ridge Hill Shelf (Ridge Hill Sandstone); and
- Darling Plateau (Archean granite and gneiss) (Searle, 1984).

Detailed studies of the geology of the Rottnest shelf are less in number than of the Swan Coastal Plain. The Quaternary geology of the shelf, including Rottnest Island, has been described primarily in terms of cemented aeolianite and shallow-marine carbonate sequences, commonly described as the Tamala Limestone (Brooke, 2001; Collins, 1988; James *et al*., 1999; Playford, 1997; Price *et al*., 2001).

These geologically recent sedimentary sequences are partially the result of the Mediterranean climate of Southwest Australia. The dominant onshore winds are from the south and west, with average velocities of 20-28 km h^{-1}. Swell occurs continuously throughout the year with wave periods ranging from 10 to 20 s, from the southwest (Collins, 1988). The southward flowing Leeuwin Current delivers cool (17-19° C) tropical-derived waters (McGowran *et al*., 1997; Spooner *et al*., 2011) with comparatively low nutrient levels (Reason *et al*., 1999) compared to similar subtropical eastern boundary currents. The influence of the Leeuwin Current on the Rottnest Shelf is expressed primarily by the generation of a large-scale downwelling as it travels along the continental shelf break, and results in low nutrient levels on the shelf (Collins, 1988; Reason *et al*., 1999; Spooner *et al*., 2011). This current was likely to have been active during glacial periods as well as previous interglacials (McCulloch and Esat, 2000; Spooner *et al*., 2011), though probably stronger during the latter periods.

The Rottnest Shelf is generally flat-topped, with a moderately steep shelf margin, although a number of ridges have previously been noted on its surface (James *et al*., 1999). These are postulated to have formed as coastal dune barriers during previous lower levels of the sea when a greater extent of shelf was exposed (Brooke *et al*., 2010; Collins, 1988; Richardson *et al*., 2005). The timing and processes involved in the induration and cementation of these and similar features are important for understanding the role that seepage has played in the formation of these shelves, and in the inheritance of shelf geomorphic features through time.

1.4.1. Northern Area (Area 1)

Area 1, the northern acquisition area, approximately 9 x 12 km in extent, is located in the former Greenhouse Gas (GHG) release area VLAM-01 (now closed) (Figure 1.1; Table 1.1). Prior to this survey this area had very limited multibeam bathymetry coverage, of varying resolution. There are no previously collected seabed samples in this area. Seismic data shows the presence of a seismic anomaly which may be related to recent seepage. It is known, however, that carbonate hardgrounds may cause a distortion of the seismic signal by preventing the imaging of the basin underneath the hardground.

Data acquisition in Area 1 was designed to:

- establish whether carbonate hardgrounds could be responsible for the large-scale seismic anomaly;
- identify seabed features that potentially indicate the presence of seepage and/or recent fault reactivation; and
- collect representative seabed and biological samples, in the vicinity of specific geomorphic features, which may provide indicators of seepage in this area.

1.4.2. Southern Area (Area 2)

Area 2, the southern acquisition area, located in the former southern GHG release area VLAM-02 (now closed), is approximately 10 km wide by 31 km long (Figure 1.1; Table 1.1). This area was identified in the initial analysis of pre-existing data as potentially more suitable for CO_2 storage than the northern area, and was therefore the priority area for data acquisition. Previously acquired seismic data was used to map re-activated faults on the eastern border and in the centre of VLAM-02 where the Gage Sandstone is expected to be thickest. In these areas, seismic anomalies were also identified that may relate to seepage. Seismic anomalies in Area 2 are less extensive than in Area 1, but occur just above large synrift faults (Figure 1.4b). This suggests that these faults were reactivated, and the seepage may be masking fault planes.

Data acquisition in Area 2 was designed to:

- identify seabed features that potentially indicate the presence of seepage and/or recent fault reactivation;
- establish whether there is a spatial correlation between seabed features, sub-bottom structures and features observed on previously collected seismic lines, and
- collect representative seabed and biological samples, especially in the vicinity of specific geomorphic features, which may indicate past or present fluid seepage.

Table 1.1: *Bounding coordinates for Vlaming Sub-basin Marine Survey, GA 334, Areas 1 and 2. Datum: WGS84. Map Projection: UTM Zone 50*

Area	Latitude	Longitude	Easting (m)	Northing (m)
Area 1 NW corner	32° 10’ 57.205” S	115° 16’ 32.144” E	337 433.634	6 438 025.746
Area 1 SE corner	32° 20’ 33.318” S	115° 33’ 38.885” E	364 561.750	6 420 679.816
Area 1 SW corner	32° 16’ 02.048” S	115° 14’ 52.418” E	334 974.875	6 428 595.301
Area 1 NE corner	32° 15’ 27.627” S	115° 35’ 22.757” E	367 153.434	6 430 129.724
Area 2 NW corner	31° 48’ 05.760” S	115° 23’ 13.199” E	348 433.434	6 480 439.073
Area 2 SE corner	31° 52’ 06.964” S	115° 29’ 13.199” E	356 878.197	6 473 130.892
Area 2 SW corner	31° 52’ 04.799” S	115° 23’ 52.799” E	348 457.333	6 473 076.663
Area 2 NE corner	31° 48’ 09.720” S	115° 29’ 16.799” E	356 871.084	6 480 437.787

2. Survey and Sampling Methods

2.1. Geophysical Data Acquisition and Processing

Geophysical data acquired on the survey included multibeam sonar (MBS) for bathymetry and backscatter data, sub-bottom profiler (SBP) and side-scan sonar (sidescan) imagery. The multibeam sonar and SBP units are hull-mounted systems and data were acquired continuously on all mapping tracks for Areas 1 and 2 (Figure 2.1), as well as on transits. The sidescan unit is a deployable towed system and used over three distinct areas, one in Area 1, and two in Area 2. Multibeam sonar bathymetry was the primary and highest priority geophysical data acquired in the two survey areas. Continuous SBP data was collected with the MBS data, whilst the sidescan data was acquired only in relatively calm sea states across targeted areas.

All the acquired data required some post-acquisition shipboard processing for calibration, format adjustments and noise elimination. Data collected during periods of rough seas required a greater effort for noise removal and, where practicable within the survey constraints, some re-acquisition in calmer sea conditions took place. Due to the high concentration of crayfish pots in some areas, especially in Area 1, some survey lines were adjusted to avoid the pots, while ensuring full mapping coverage. A more complete description of the acquisition systems and processing streams used by the contractor can be found at www.fugro.com.

2.1.1. Multibeam Sonar

A Reson Seabat 7101-ER multibeam sonar system was used to simultaneously collect bathymetry and backscatter data in swaths perpendicular to the ship track. The system is hull-mounted, operates at 240 kHz and provides swath coverage of up to 150o across a maximum of 511 equidistant beams. It is ideally suited to shallow water depths of 10-300 m. In addition, an Odom Echotrac DF3200 dual frequency (15 and 210 kHz) echosounder operated in tandem to provide quality assurance when processing the MBS data.

Beam time-depth calibration, via sound-velocity profiling, was provided by deployment of a Valeport Midas Conductivity, Temperature and Depth cast (CTD) and an eXpendable Sippican Bathy Thermograph (XBT). The CTD was deployed at fixed stations, when it was necessary to calibrate major changes in water depths and sea conditions within the two mapped areas. Sippicans were used regularly, whilst mapping between the CTD stations.

For onboard processing, sensor-derived vessel position, heading, motion and water sound velocity profiles were applied to the raw multibeam data to produce geo-referenced bathymetry and backscatter points. Additional filtering with tide and draft corrections were also applied. Adjacent processed swath lines were then compared, between themselves and to cross-lines where run, to confirm consistent corrections. Evident bad/noisy data was then flagged and either reacquired in more suitable sea conditions or deemed acceptable by GA. The onboard interpolated XYZ soundings were provided at nominal 3-5 m spacing. The backscatter data supplied by Fugro Pty. Ltd. is being reprocessed using GA methods.

2.1.2. Sub-Bottom Profiler

An EdgeTech 3300 HM chirper system was used to acquire SBP data (Figure 2.1). The chirper system was used concurrently with the multibeam, and operates in the 2-24 kHz range over a 4 x 4 transceiver array. Pre-survey testing of the system in the area resulted in the following parameters being adopted: 2-8 kHz range, pulse sweep of 40 ms and a record length of 200 ms. For onboard processing, the chirper data was corrected for vessel heave and position, with final depths calibrated to the tide-corrected swath data. Some time-variable gain filtering was then applied prior to conversion to SEGY format. Sub-bottom penetration and, therefore resolution, is dependent both on the sediment composition of the substrate and the acquisition system. Additionally, rougher sea states result in weaker penetration and less uniform resolution.

2.1.3. Side-scan Sonar

An EdgeTech 4200FS dual (simultaneous) pulse frequency (100 and 400 kHz) system was deployed as a towfish with positioning provided by an Ultra Short BaseLine (USBL) positioning beacon on the tow cable. The slant range for the unit was set to 100 m. For onboard processing, sonar mosaics of the area mapped were compiled, filtered and rectified for ground positioning. These were then combined into one complete geotiff image for each location (Figure 2.1).

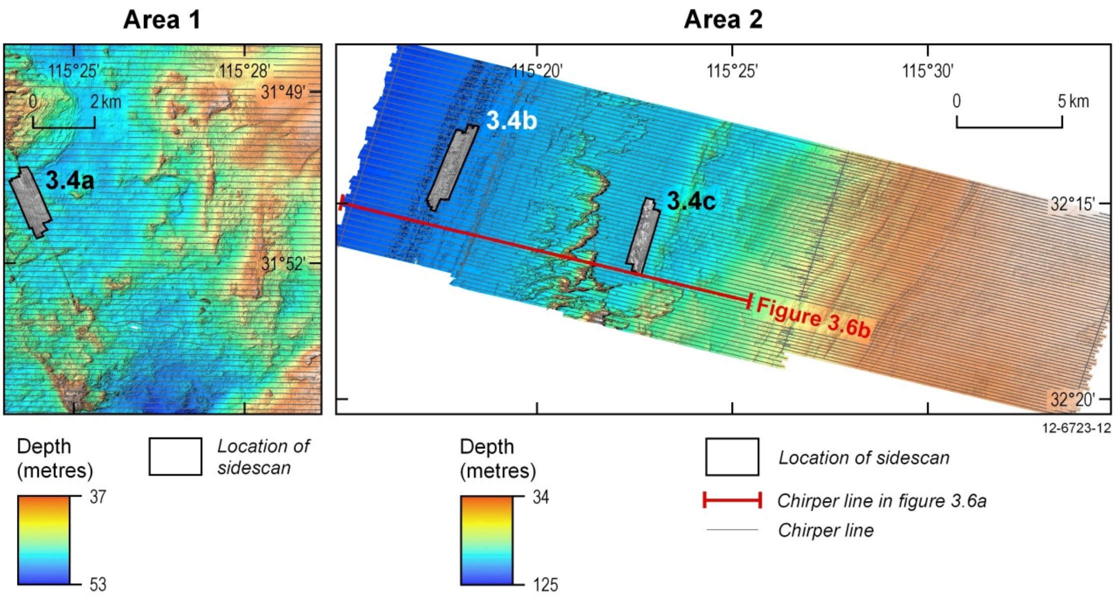

Figure 2.1: *Extent of acoustic sub-bottom profile lines and of side-scan sonar coverage collected during Marine Survey GA334. The selection of sample stations was dependant on observations made on these data, and on seismic profiles.*

2.2. Sample Site Selection

The selection of sampling stations to acquire sediment and biological samples and to obtain towed video data were based primarily on shipboard analysis of acquired bathymetry, sub-bottom profiles, side-scan sonar and backscatter data (Figures 2.1, 2.2, 2.3, 2.4; Appendix A). Site selection was undertaken in two stages:

1. general areas of interest with features and environments that may be related to active or ancient seepage were identified, and
2. site specific sampling and towed video stations were chosen based on observations of surface morphology and the correlation with shallow subsurface features in sub-bottom profiles.

The objective was to identify sampling stations where there was a possible connection between surface features and structures identified in sub-bottom profiles. Regular discussions between onboard Geoscience Australia staff (Appendix A) and Canberra-based Geoscience Australia staff facilitated final decisions on site selection.

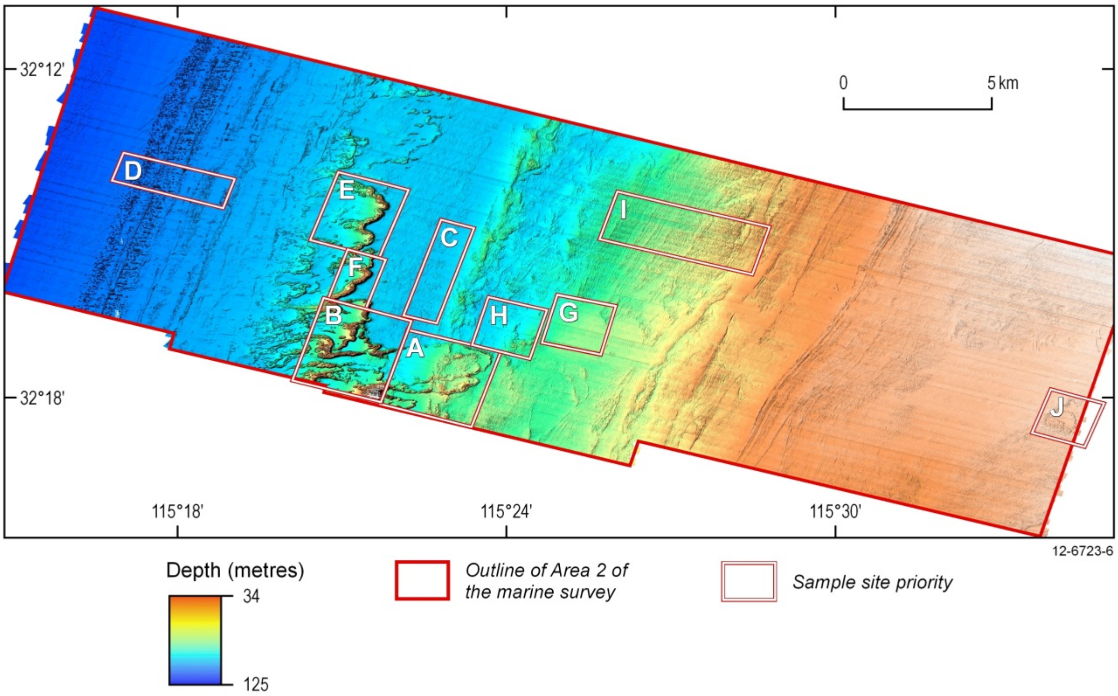

Figure 2.2: *Example of sampling station selection in Area 2. Locations of interest were prioritised from A (highest priority) to J (lowest priority) based on the presence or absence of possible geomorphic expressions of subsurface structural discontinuities visibile in bathymetry, and on the recognition of structures and strata visible in sub-bottom profiles and backscatter data. (Bathymetry provided by Fugro, and used in planning).*

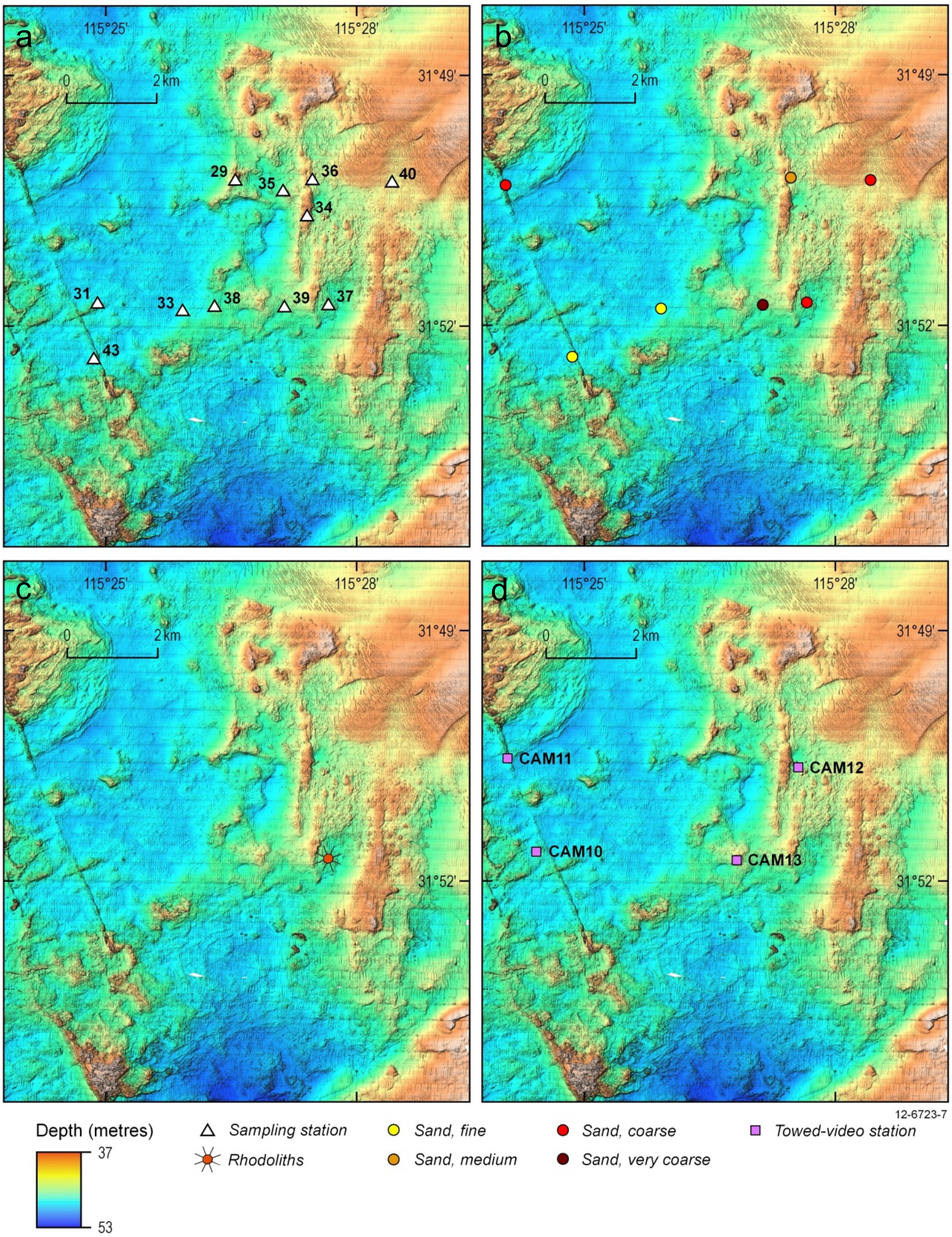

Figure 2.3: *Sampling locations in Area 1 on Rottnest Shelf, with a) sample stations, b) sediment sample textures, c) locations at which rhodoliths were collected, and d) locations of towed video transects. The northern 1/3 of Area 1 was not accessible for sampling because of an exclusion order in place due to the presence of a submarine cable. The southern 1/3 of Area 1 was mapped overnight in the final stages of the survey after bad weather stopped sampling.*

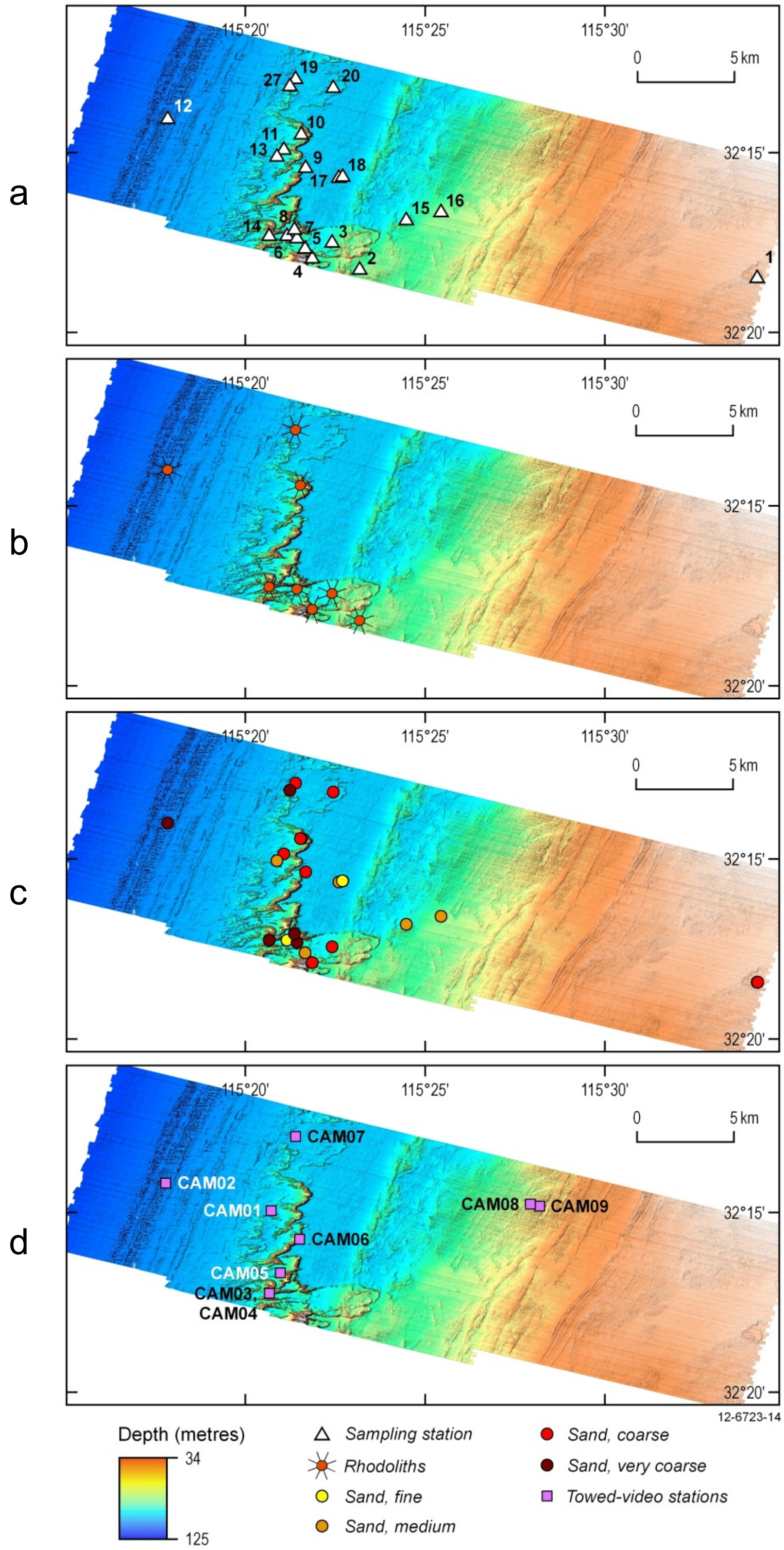

Figure 2.4: *Sampling stations in Area 2, Rottnest Shelf, illustrating a) grab sample locations, b) locations from which rhodoliths were recovered, c) observations on sediment texture from grab samples, and d) locations where towed video transects were undertaken. Observations made at each successive sampling station contributed to the sampling process.*

2.3. Gravity Coring

Gravity coring was attempted at 21 stations during Leg 2, using a 3 m corer with clear polycarbonate inner tubing, and deployed from the A-frame of the *MV Southern Supporter*. The gravity corer was lowered to a height of approximately 10 m above the seabed, where the tension was released from the winch and the gravity corer fell to the seabed. Initially, and for most sample stations in Area 2, two attempts at coring were undertaken at each station. The scope of coring was subsequently reduced from the original plan as most of the surveyed areas are characterised by hard carbonate surfaces and there was not enough penetration to retain sample within the core liner/barrel.

2.4. Sedimentology Samples

The principal aim of obtaining sediment samples was to characterise the texture and composition of the seabed sediments, and identify if authigenic carbonate or other minerals, commonly associated with seep-related environments, are present at the seabed. Unconsolidated surface sediment samples were collected from Van Veen or Shipek grabs at 43 sampling stations. Up to 500 g or more of bulk sediment was sampled from individual Van Veen grabs. However, many grab attempts recovered no sediment because the seabed in many places is composed only of rhodolith accumulations or bedrock. Ten surface sediment samples were also collected from material retained in the core catcher of the gravity corer. Sediment samples have been submitted to the GA laboratories for measurements of gravel, sand and mud content, carbonate content (%), and grain size distributions (including mean, median, standard deviation, skewness and kurtosis indices) by laser diffraction using a Malvern Mastersizer 2000 particle size analyser.

2.5. Geochemistry Samples

Seabed sediment geochemistry can indicate current or past seepage. The Shipek grab was used to obtain undisturbed surface sediment samples, at 12 stations (Figure 2.5; Table 2.1). At two stations (grabs 73 and 84) where the Shipek grab failed to obtain sufficient sediment, or the sediment consisted only of rhodoliths, surface sediment samples were collected using the Van Veen grab (Table 2.1).

The samples designated for geochemistry analysis were sub-sampled into six separate containers for analysis (Table 2.1). An account of the shipboard processing, and the laboratory pre-processing and analytic techniques to be undertaken at GA laboratories is provided in Table 2.2.

Figure 2.5: *Grab sampling methods. Example of (a) carbonate sand in Shipek grab from Area 1, and (b) deployment of the Van Veen grab sampler from the aft deck of the MV Southern Supporter.*

Table 2.1: *List of samples, and corresponding geochemistry sub-samples from Shipek and Van Veen grabs (continued overleaf). Grab numbers are shown in columns. SOD = sediment oxygen demand; DIC = dissolved inorganic carbon; P-fractions = carbonate samples for isotopic analyses.*

Station Number	Sedimentology Including Carbonate P-fractions (A)	Biology (B)	Chlorins Porosity (0-2cm) Mineralogy (C_B1)	Chlorophyll ABC (C_B2)	Porosity (0-0.5 cm) (C_B3)	SOD (C_C1)	DIC Flux (C_C2)^	Elements Carbonate Surface Area (C_D1)
01	02*	01*,03*						
02	04*							
03	05*, 06*							
04	07*		08	08	08	08	08	08
05	09*							
06	11*	10*,11*	12	12	12	12	12	12
07	13*							
08	14*	15*	16	16	16	16	16	16
09	19*	18*	17	17	17	17	17	17
10	20*							
11		21,22,23,24*						
12	25,27*	27*,28*	26	26	26	26	26	26
13	31*	30*,32*	29	29	29	29	29	29
14	33*	34*						
15	35*							
16	36*							
17	37*	48*,49*	47	47	47	47	47	47
18	38*							

Station Number	Sedimentology Including Carbonate P-fractions (A)	Biology (B)	Chlorins Porosity (0-2cm) Mineralogy (C_B1)	Chlorophyll ABC (C_B2)	Porosity (0-0.5 cm) (C_B3)	SOD (C_C1)	DIC Flux (C_C2)^	Elements Carbonate Surface Area (C_D1)
19	39*,40*							
20	42*	41*,43*						
21		44*,45*,46*						
24		53*,54*						
27	51*	52*	50	50	50	50	50	50
28	*56	55,56						
29	58, 59	*57						
30		*60, 61						
31	*62	*62						
33	*64	*64	63	63	63	63	63	63
34	*65	*65						
35	*66	*66						
36	*67, *69	*68, *70, 82	83	83	83		83+	83
37	*72,*73	*71, *73	*73				*73+	*73
38	*77	74, *75, *76						
39	*80	*78, *79	81	81	81		81+	81
40	*84	*84,*85	*84				*84+	*84
43	*87	*88, *89	86	86	86		86	86

* denotes Van Veen grab samples.

+ (Initial sample only (T=0) due to limitations with ship time)

Table 2.2: *Details of shipboard/laboratory processing and proposed analytical techniques used to prepare and analyse the geochemistry sub-samples (continued overleaf). The sub-sample codes (C_B1 etc) correspond to the file extension assigned to the sub-sample types in Geoscience Australia's MARS database (e.g. GA334/07GR07C_B1; see also header row in Table 2.2).*

Sub-Sample	Shipboard Processing	Parameters Measured	Laboratory Pre-Processing	Analytic Procedures And Sample Post Processing
C_B1	7.5 ml samples of surface sediment (0-2 cm) were syringed into plastic container wrapped in Al foil. The samples were frozen.	Porosity and wet/dry bulk densities (0.0-2.0cm)	Freeze-dry	Weight difference after drying and after correction for seawater salts (porosity) and normalisation to wet/dry volumes (bulk density).
		Total chlorins and chlorin indices	Triple extraction in 100% acetone after freeze-drying and grinding (in dark).	Fluorometry
		Mineralogy	10% Zinc oxide added to dried samples	X-Ray diffraction
C_B2	4 ml samples of surface sediment (0-0.5 cm) were syringed into plastic bags. The samples were wrapped in Al foil and frozen.	Chlorophyll a,b,c and phaeophytin	Thaw in refrigerator and then extracted in 90% acetone	Extracts analysed by spectrophotometry (630, 647, 664 and 750 nm). Individual pigments quantified by trichometric equations and expressed on a per g dry wt basis utilising data from C_B3.
C_B3	4 ml samples of surface sediment (0-0.5 cm) were syringed into plastic bags. Samples were frozen.	Porosity and wet/dry bulk densities 0-0.5cm)	Freeze-dry	Weight difference after drying and after correction for seawater salts (porosity) and normalisation to wet/dry volumes (bulk density).
C_C1	Bulk sub-sample (6.5 ml) of surface sediment (0-2 cm) incubated in BOD bottles for ~24 hrs in the dark at SST. Dissolved oxygen concentrations (and saturation values) were measured at the start and finish of each incubation.	Sediment oxygen demand	N/A	Results expressed on a per g dwt basis utilising C_B1 results.
C_C2	Salinity, temperature and pH were measured on pore waters extracted from sub-samples C_D1. These pore waters were then filtered (0.45 µm) into 3 ml gas-tight vials (pre-charged with 0.025 $HgCl_2$) within 1 hr of collection (T=0). The procedure was repeated on pore waters from an additional bulk sample collected as per C_D1 and incubated for ~24 hrs at SST (T=1). All samples were refrigerated prior to laboratory analysis.	CO_2 production rates	Samples brought to room temperature in dark.	1. Dissolved inorganic carbon (DIC) determined using a DIC analyser and infrared-based CO_2 detector. (Geoscience Australia) 2. CO_2 production rates calculated by concentration differences (T=1 – T=0) over the incubation period, after correction for $CaCO_3$ fluxes. Results expressed on a per g dwt basis utilising C_B1 data.

Sub-Sample	Shipboard Processing	Parameters Measured	Laboratory Pre-Processing	Analytic Procedures And Sample Post Processing
C_D1	Surface sediment (0-2 cm) was syringed into acid-washed falcon vials. Pore waters were removed within 1 hr of collection. Residual sediment was frozen for transport to the laboratory.	Major, minor, trace and rare earth elements	1. Freeze-dry 2. Grind in agate mill	X-Ray Fluorescence and ICP AES (Geoscience Australia)
		Bulk carbonate	1. Freeze-dry 2. Grind	Carbonate Bomb (Geoscience Australia)
		Particle surface area	1. Freeze dry. 2. Slow heating to 350°C (12 hours).	5-point BET (Geoscience Australia)
		TOC, TN and C & N isotopes	1. Freeze-dry 2. Grind 3. Acid treatment	Mass spectrometry

2.6. Seabed habitats and biota

Towed-video transects were undertaken to examine the seabed sediments in situ, to document geomorphic features and environments on the seabed, and to characterise seabed habitats and biological communities. Samples were collected to inform patterns observed in video and provide a higher resolution for species identification. This would allow the investigation of possible relationships between potential seep and non-seep communities.

2.6.1. Towed Video

Seabed habitats and associated benthic macro-organisms were surveyed using a Raytech towed-camera system supplied by Fugro (Figure 2.6). This system was fitted with a single forward-facing camera and two 150 W lights placed on either side of the camera, resulting in an on-screen resolution of 625 lines. At each camera station (Appendix D), the camera was towed for an average of 450 m (approximately 30 min duration) with distances ranging from 250 to 605 m, and tow times from 18 to 46 min, respectively. The camera system was deployed from a winch on the starboard side of *MV Southern Supporter*, with a ship speed of approximately 0.5-1 knots and at an altitude of 0.5 - 2 m above the seabed. The geo-location of each video transect was recorded using an Ultra-Short Baseline (USBL) acoustic tracking system. The USBL data was linked to the video transects by correlating the time-stamp on the video to the navigation files. Video footage was transferred in real-time by a coaxial cable to enable winch operators to effectively control the altitude of the towed-video system above the seabed. All video footage was recorded to digital format (.avi) with a visual date/time stamp to ensure accurate co-location of USBL navigation data.

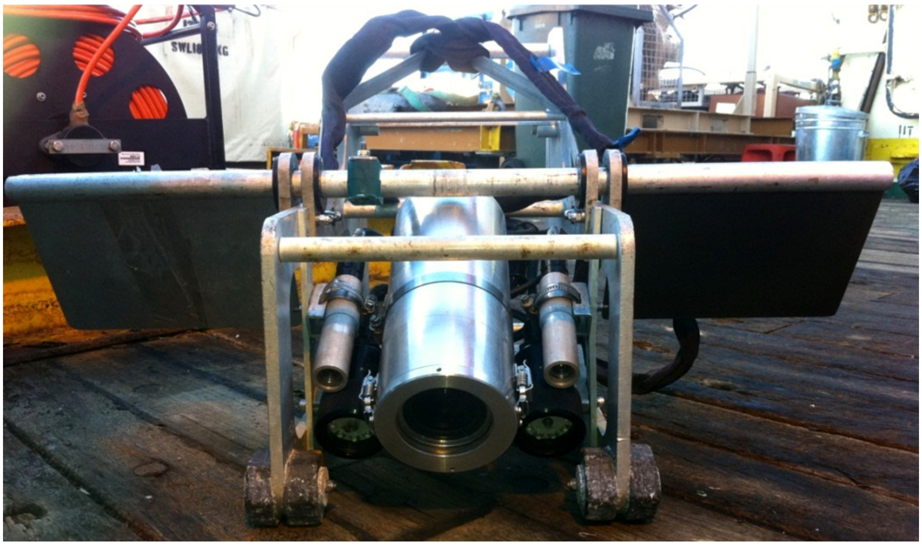

Figure 2.6: *Towed Video System. Raytech towed-camera showing the forward facing camera, light mountings and two lasers.*

2.6.2. Samples of seabed biota

Infaunal samples were collected using a 27 L capacity Van Veen grab (volume estimated as 1/2 the volume of a cylinder with dimensions radius of 0.19 m, and length 0.49 m). At each station the Van Veen grab was deployed twice (Figure 2.7) to collect benthic infauna. All sediment was released into a 52 L Nally bin, with excess water decanted into a 500 µm sieve, and the sample was weighed. Sediments were sub-sampled by elutriating for 5 minutes, and passing the elutriated water through the same 500 µm sieve. The remaining sediments were then coarsely sorted by hand for heavier organisms (e.g. gastropods, ophiuroids, holothurians, heart urchins and hermit crabs). Finally, all elutriated sediments and heavier organisms were preserved in ethanol for laboratory processing of microscopic animals. Additionally, due to the nature of the collected samples, epifaunal samples including rhodoliths, were kept and preserved for analysis.

In the laboratory, elutriated samples were examined under a microscope with intact animals sorted into broad classes. Fauna are currently being identified to operational taxonomic units (OTUs) with voucher specimens photographed for reference. Once this is complete, polychaetes and echinoderms will be lodged at the Museum of Victoria for identification of the specimen to species level. All other groups will be sent to appropriate institutions pending agreements.

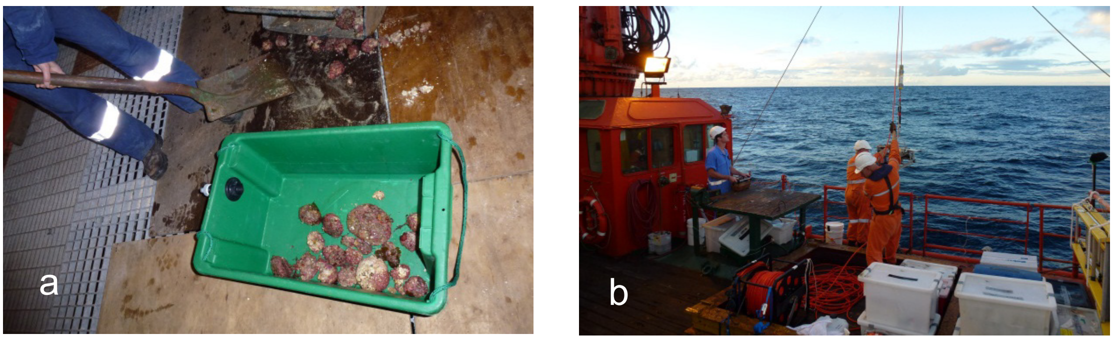

Figure 2.7: *Example of deck operations. a) Collecting a typical sample of rhodoliths from the Van Veen grab sampler at night; b) deployment of the towed video camera from the aft starboard deck of the MV Southern Supporter.*

3. Preliminary Results

Multibeam bathymetry and backscatter data were collected from a total of 418 km^2 of the Rottnest Shelf: 108 km2 in Area 1 and 341 km^2 in Area 2. This represents 2,370 line km of mapped seabed (1,709 km in leg 1 and 661 km in leg 2). Chirper sub-bottom profiling was conducted in tandem with bathymetric mapping, but penetration was poor due to the hard carbonate bedrock and carbonate banks at the seabed surface. A total of 57.25 line km of side-scan sonar was also collected, covering 1.26 km^2 in Area 1 and 5.39 km^2 in Area 2. Unconsolidated sediment samples (n = 127) were collected from 89 grabs at 43 stations. These include samples for sedimentology (n = 61) (Appendix B), environmental geochemistry (n = 14) and biology (n = 52). In addition, ten surface sediment samples (Appendix B), were collected at nine sampling stations in the core catcher. Two large rocks that may represent the in situ geology were recovered at two sampling stations in Area 1. From the recovered biology samples 33 suitable infaunal samples were retained. Towed video was collected at 12 stations, in water depths from 39 to 88 m (Figures 2.2, 2.3, 2.4; Appendix C).

3.1. Seabed Characteristics Area 1

Area 1, located to the north of Rottnest Island lies in water depths of between 37 and 53 m (Figures 1.1, 2.3, 3.1). Sediments here are dominated by carbonate sand (~ 70% $CaCO_3$). Area 1 is characterised by four main geomorphic features: valleys, terraces, large-scale sandwaves, and low linear ridges (Figure 3.2).

A shallow valley trending NNW-SSE is located in the southern portion of Area 1 that dips gently (~ 0.1°) in a southerly direction. It is separated by a low-lying ridge at right-angles to the trend of the valley from an area of flat-lying seabed to the north (Figure 3.2c). This flat seabed lies approximately 48 m water depth, while the floor of the valley exists between 47 and 53 m (Figure 3.2c). Separating these is a low and discontinuous ridge (Figure 3.2c) that rises from 45.5 m water depth at its south-western end (located adjacent to the easternmost lineament noted above), to approximately 43 m water depth at its north-eastern end, where it meets a terrace in the northeastern quadrant of Area 1. The terrace east of the ridge is flat-lying and lies in water depths of 42-45 m.

Linear and sinuous sandwaves (mega-ripples), identified in bathymetry, backscatter, and sidescan imagery, are located in the northeastern sector of Area 1 (Figure 3.2d). These bedforms are located on and between terraces, and have variably low to moderate backscatter strength. These have a height of ~ 30 cm, an average wavelength of 250 m and average crest width of 19 m (based on 10 representative measurements each). These mega-ripples are aligned orthogonal to the dominant southwesterly swell direction, as noted by Collins (1988). A sample taken from the margin of the sandwave field in the northeast of Area 1 consists of coarse-grained, mixed carbonate and quartz sand (48:52 carbonate to quartz ratio) with a moderate component of relict and discoloured grains. This seafloor sample suggests that sands on the mega-ripple features are of mixed origin, with the mega-ripples being formed by tide and wave-induced currents reworking recently formed (grown) skeletal carbonate and older grains.

Two low-lying linear ridges, each indicative of a structural discontinuity, and interpreted as fault scarps, are located in the southwest section of Area 1 (Figure 3.2b, c). The fault scarp along the longest (easternmost) linear structure in Area 1 (arrowed in Figure 3.2b) has a vertical throw of approximately 1 m and an apparent dip to the northeast. Sediment with very low backscatter signal strength is located directly adjacent to the western side of this feature (Figure 3.3b)

Two boulder-sized rock samples were recovered in separate Van Veen grabs from Area 1. One of these comprised coarse-grained limestone and the other calcrete. These samples indicate that limestone is either cropping out on the seafloor and/or being reworked in this shelf environment. It is inferred that these rock samples are representative of hard seabed, including rock outcrops in this area.

A sediment sample, representative of seabed sediment in Area 1 with very low acoustic backscatter strength, was recovered at sample station 33 adjacent to a low-lying linear ridge (Grab 64; Figure 3.2a, Appendix B). This sample was composed of fine-grained, well-sorted, sub-angular carbonate sand with minor red calcareous algal grains. This contrasts with other sediment samples from this area which are dominantly of coarse sand (0.5-2.0 mm), with individual grains being variably rounded to sub-angular, with moderate amounts (15-65%) of generally rounded quartz grains. By comparison with the quartz in these samples, the fresh unaltered carbonate grains are angular in morphology, while relict grains are commonly rounded and discoloured. Overall, carbonate seabed sediments have been moderately reworked in Area 1, and are of mixed origin. In contrast the evidence from sample station 33 indicates that fine grained and well sorted carbonate-rich sediments appear to be concentrated in the lee of structural features in Area 1.

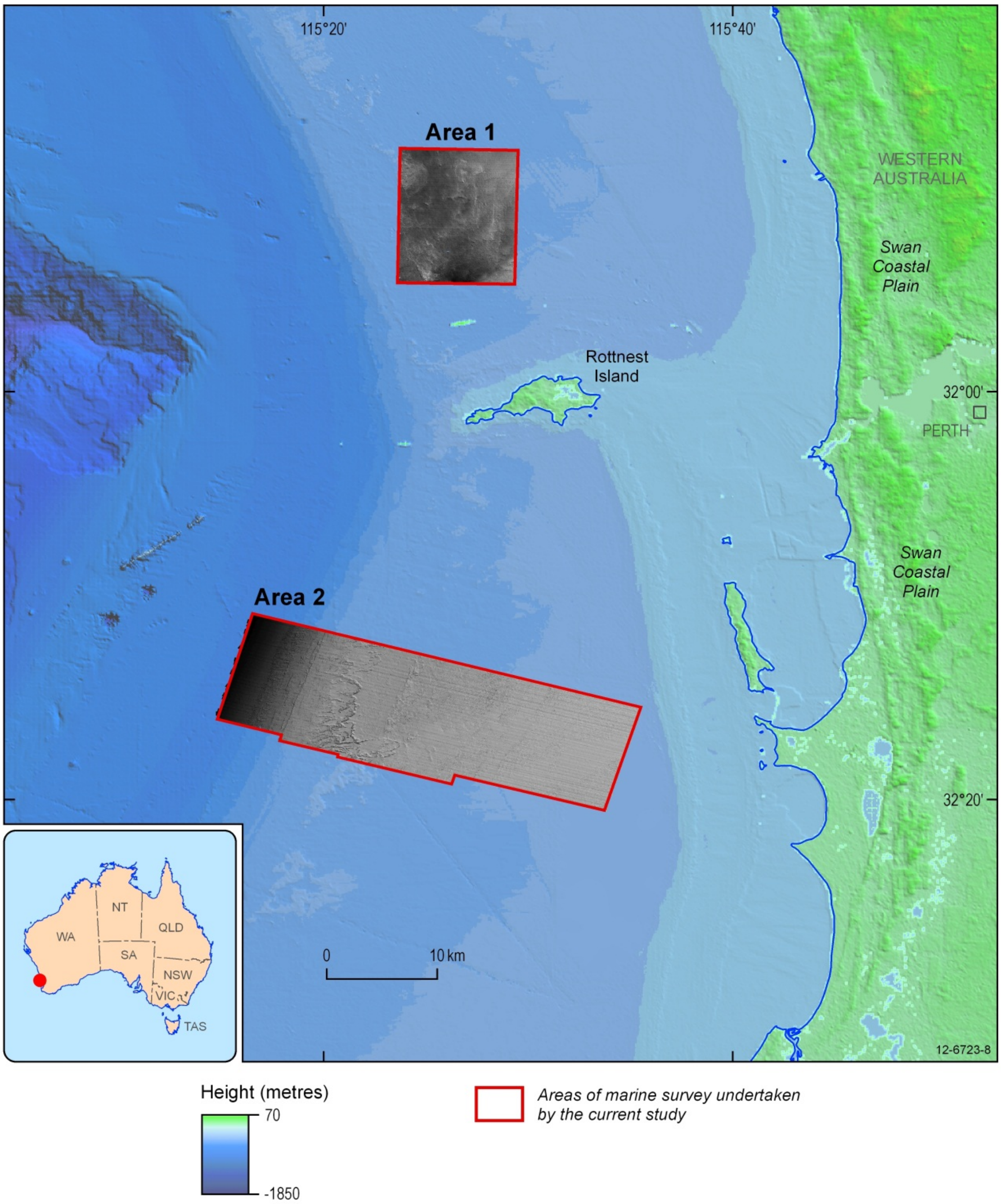

Figure 3.1: *Greyscale images of the new bathymetry in the surveyed areas and regional setting.*

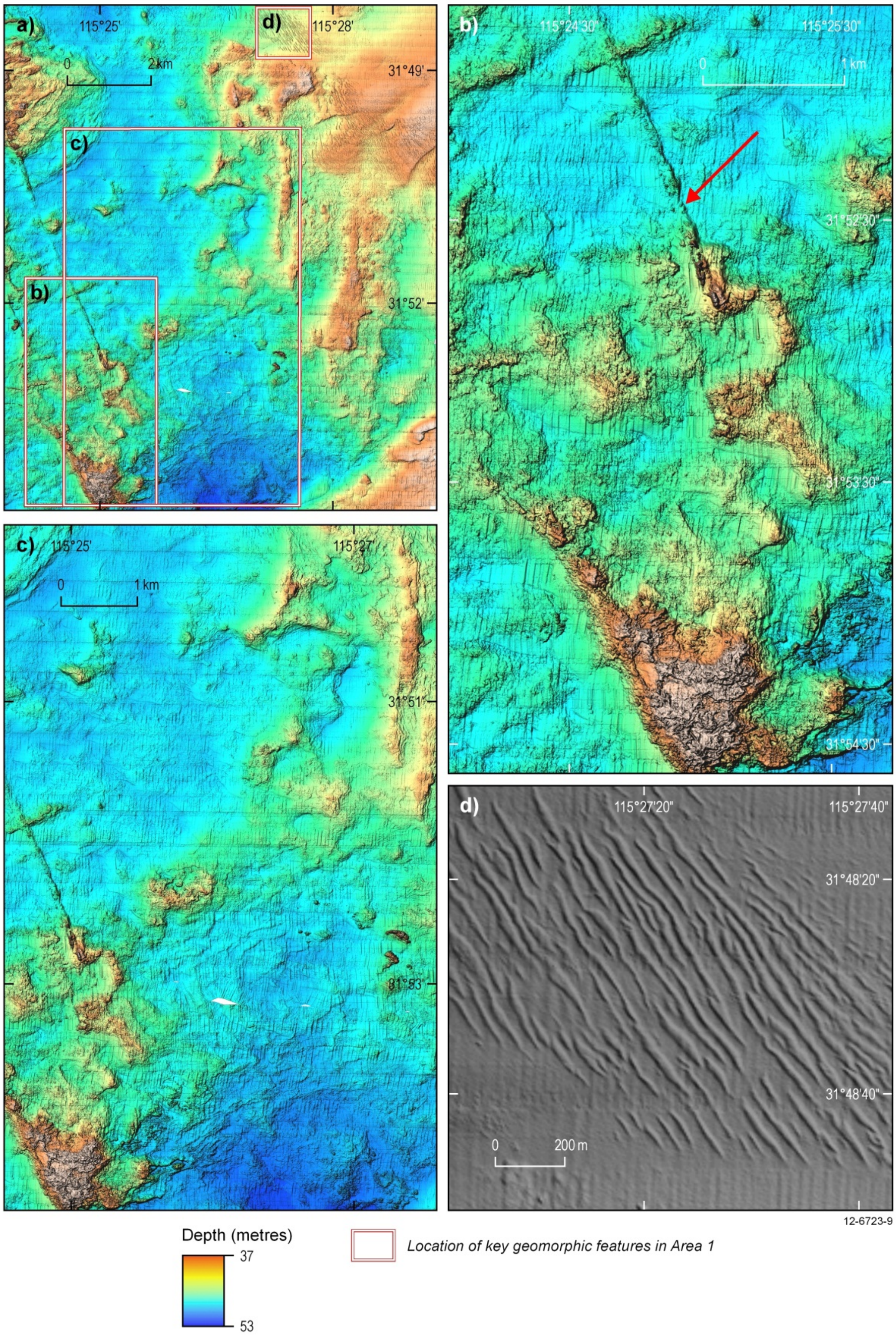

Figure 3.2: *Bathymetric images of Area 1. a) overview; b) two lineaments in southwest corner of Area 1; c) two valleys (blue colours) separated by a low-lying ridge (green to brown colours), bordered by a major lineament on the western margin of the northern valley; d) grey-scale view of linear and sinuous mega-ripples, northeastern Area 1.*

3.2. Seabed Characteristics Area 2

Area 2 is located to the southwest of Rottnest Island in water depths between 34 and 125 m (Figures 1.1, 2.4, 3.1, 3.3). Area 2 can be subdivided into four spatially-related geomorphic sub-areas (Figure 3.3):

- The outer shelf, with mounds and rhodolith beds. (Figure 3.3a);
- Outer mid shelf, with parabolic ridges, mounds and rhodolith beds (3.3b);
- Sediment starved exposed bedrock plains of the inner mid shelf (Figure 3.3c), and
- The inner shelf with partially exposed bedrock and thin sediment cover (Figure 3.3d).

3.2.1. Outer shelf

The mapped area of the outer shelf has water depths of 50-125 m. Individual and interconnected mounds occur on the outer sloping section of the shelf, in water depths of approximately 70 to 85 m (Figures 3.3a, 3.4c, 3.4d). These mounds are capped with aggradations of rhodoliths, and have high backscatter reflectivity (Figure 3.4c). The mounds are in places aligned either parallel to the generally north-south orientation (strike) of bedrock structures, or occasionally at right angles to the strike of structural lineaments. The most prominent mounds on the outer shelf are 3-4 m high, trend roughly east-west and commonly consist of several aligned mounds adjacent to each other, forming in places an apparent ridge-like structure. The mounds generally stand 3-4 m above the adjacent seafloor. Sediments from sample station 12, located adjacent to a mound were recovered from 82.8 m water depth (Figure 2.4a, 3.3a). Here, sediments are very poorly sorted and consist of very coarse sand to granule-sized grains (1-4 mm) including corraline algae, bryozoan and other skeletal carbonate fragments, and also relict, brown-coloured carbonate grains. Backscatter imagery suggests the presence of soft/smooth seafloor on the deeper western margin of Area 2, in depths of ~ 120 m. It is likely these deeper sediments have a significantly higher proportion of mud as they occur at or below storm wave-base. Other features on this area of continental slope include notches, possibly related to a past lower sea-level, and/or bedrock outcrops at the surface.

3.2.2. Outer mid shelf

Ridges dominate the outer section of the mid shelf in Area 1, generally in water depths of 40 to 45 m, but occasionally up to 50 m (Figure 3.3b). These ridges form extensive nested parabolic to crescent-shaped features, are aligned sub-orthogonal to the prevailing southwesterly swell direction (Collins, 1988), and commonly sit up to 10 m or more above the adjacent seafloor. Their eastern margin rises steeply from the seafloor, while their windward (seaward) slope appears (from chirper sonar, backscatter, towed video and sediment samples) to be overlain by rhodoliths and carbonate sand-rich sediment that the gravity corer could not penetrate. In some rare cases, rhodolith beds have a preferred orientation, suggestive of a current-related depositional fabric. These parabolic features in places cross-cut the underlying bedrock, and are therefore younger than the bedrock.

These rhodolith-dominated parabolic ridges are similar in shape (plan view) to the subaerial parabolic dunes noted at Point Cloates, Western Australia (Nichol and Brooke, 2011) and to coastal dunes at many other locations in western Australia. Sub-bottom profiles across the ridges in Area 2 indicate that in some places the ridges are composite features (Figure 3.6, see also Appendix B), where earlier and perhaps successive phases of sedimentation, cementation and colonisation form the current ridge structure. Between the larger ridges are flat or low-lying rhodolith beds, and intervening areas of carbonate sands. A number of small annular ridges, which are also covered by rhodoliths and other organisms, are located windward (to the west) of the main ridges. Sediment samples from adjacent to the ridges (Figure 2.4) are dominated by coarse-grained carbonate sands that commonly consist of rounded grains, indicating sediment transport and reworking. Located to the eastern side of the ridges are plains with rhodolith beds and carbonate sand.

Towed video imagery and sediment and biological samples indicate that ridges provide rhodolith and other encrusting algae habitat, and also sparse bryozoans and sponges (Figures 3.3b, 3.5a, c, d, e, f). Infaunal assemblages collected from these locations, and those of Area 1, are dominated by crustaceans and polycheates, and to a lesser extent echinoderms (Figure 3.7). These results indicate a similarity to infaunal assemblages in the Gulf of Carpentaria (Long and Poiner, 1994), Carnarvon Shelf (Brooke et al., 2009), Great Australian Bight (Currie et al., 2009), and offshore the northern Perth Basin (Jones et al., in press). No species indicative of seepage have been found at this stage.

3.2.3. Inner mid shelf

The mapped area of the inner mid shelf features a single prominent structural ridge that bisects the grid from north to south, in water depths of 48 m (Figure 3.3c). This ridge marks the western margin of the central portion of Area 2. This central section rises 8 m over a horizontal distance of 9-10 km. Another series of low-lying, north-south trending ridges occur in water depths of ~ 38 to 40 m on the eastern margin of this area. Notably, this section of Area 2 is characterised by exposed bedrock, with an apparent thin sediment veneer (i.e. sediment starved). Tentative correlations between these and other ridges in Area 2 and structural discontinuities in seismic sections are being explored (Figures 3.3, 3.6).

3.2.4. Inner shelf

The eastern-most section of Area 2 has a flat to gently seaward dipping slope of less than 1˚, and water depths of between 38 and 33 m. Here, there are no prominent high-relief ridges, and the seafloor is flat with rhodolith beds, some carbonate sand and hardgrounds, most probably bedrock (Figure 3.3d). The bedrock in the eastern extent of Area 2 comprises numerous low relief ridges that trend north-south and NNE-SSW. A single, though spatially extensive sediment lobe overlies bedrock, upon which some mega-ripples are located, though not as extensive as in Area 1. Seabed surface sediments, represented by a single sample from (sample station 01) from 36.2 m water depth, is composed of coarse-grained carbonate sand that includes many relict, subrounded and stained (brown) carbonate and quartz grains (Figure 2.4a). This brown staining is similar to that observed on several clasts from Area 1 from similar water depths, and may be related to groundwater and/or subaerial exposure.

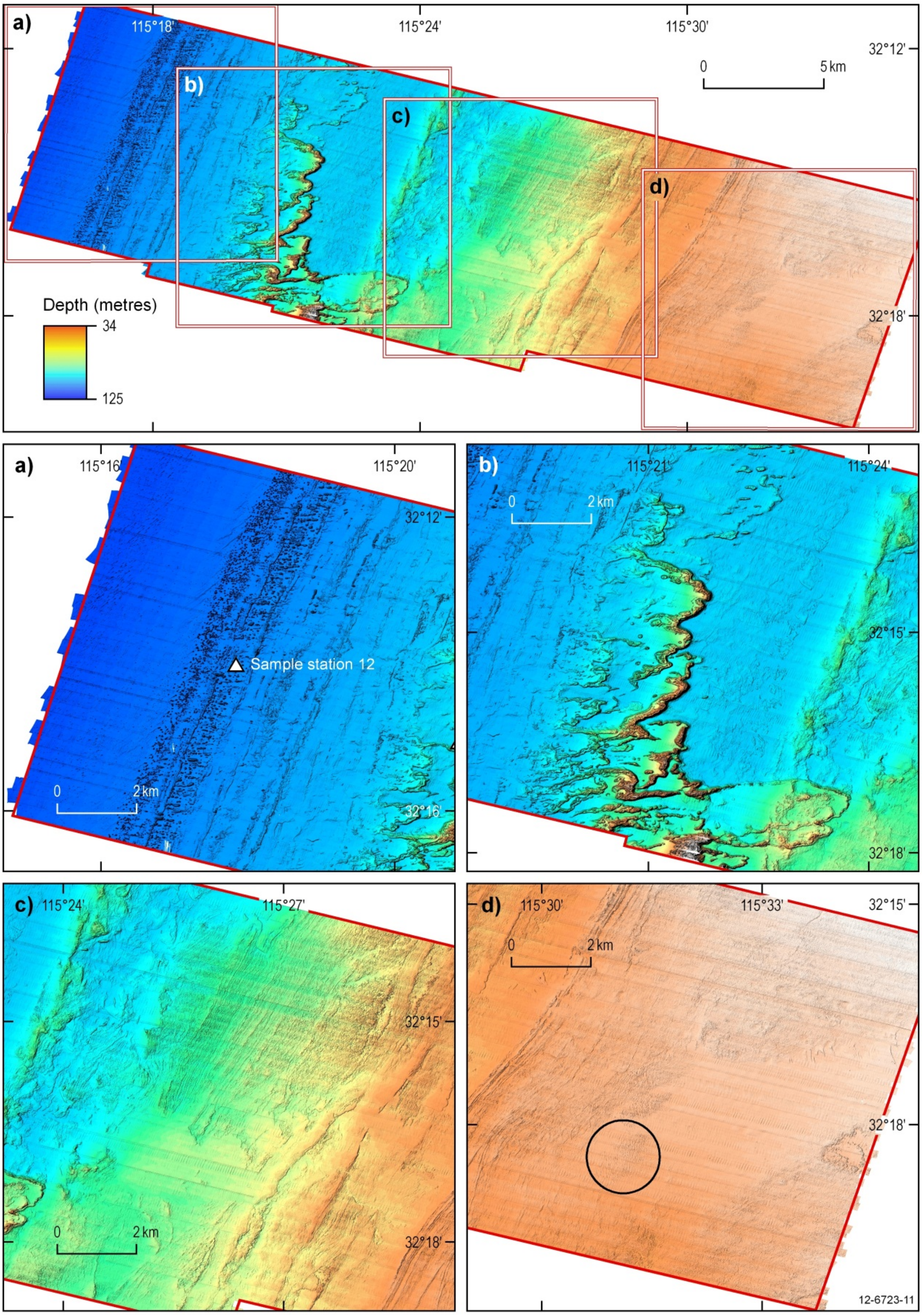

Figure 3.3: *Principal geomorphic features of Area 2, Rottnest Shelf. a) a linear concentration of mounds and structural (bedrock) features on the outer shelf section of the surveyed area; b) nested parabolic ridges in water depths of 40-50 m ; c) exposed bedrock with patches of rhodolith rich sediment; d) northeast-southwest trending thin lobe of sediment (smooth surface), with localised sandwaves (encircled).*

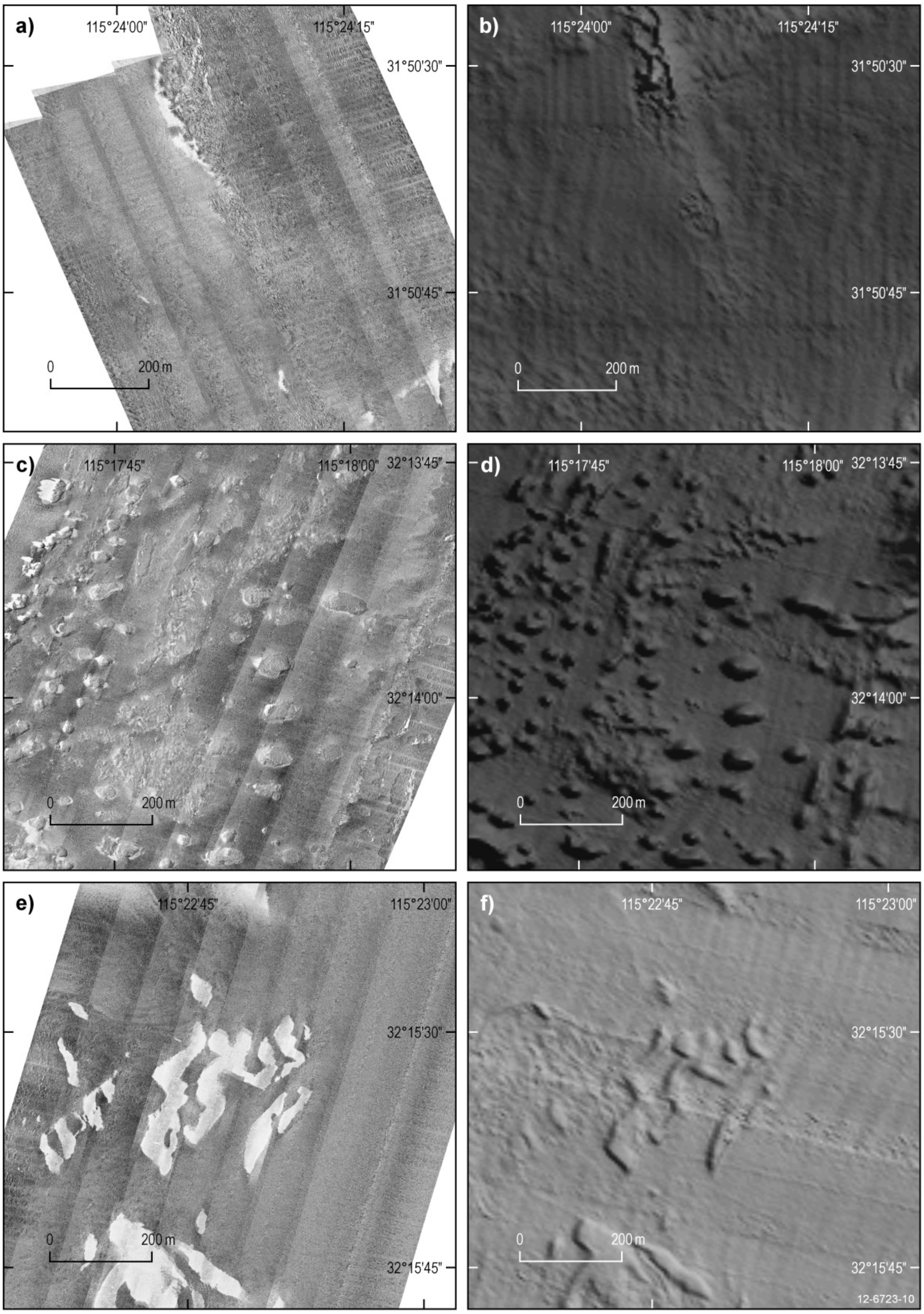

Figure 3.4: *Contrasting images based on detailed sidescan (a, c, f) and lower resolution swath bathymetric mapping (b, d, f) from this survey. The generally flat topography of Area 1 (a, b) contrasts strongly with the outer and deeper section of Area 2 (c, d), but is similar to that of the central and eastern portions of Area 2 (e, f) where sandwaves are evident. Thus the low reflectivity of the sidescan imagery in places suggests the presence of accumulations of unconsolidated sediment. Particularly evident are unconsolidated material on the downslope side of many rhodolith mounds (80-100 m water depths; c, d above).*

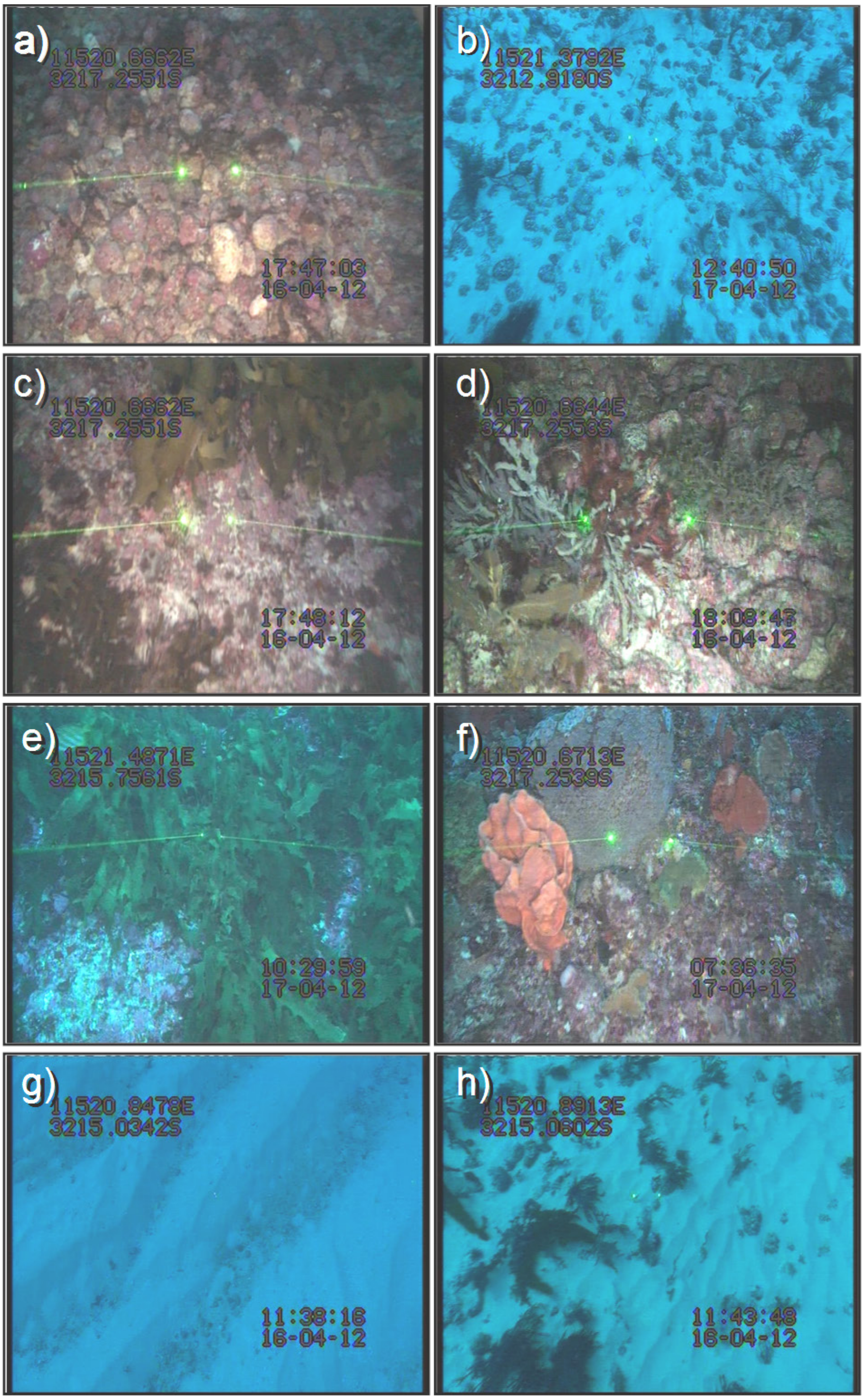

Figure 3.5: *Benthic habitats present in Area 2. Towed-video imagery from this survey has been particularly important in identifying geomorphic features on the seabed. a-b) common rhodolith beds with, and set in, a matrix of sand; c-d) coralline-algal encrusted seabed with high macroalgal growth; e) kelp growth on bedrock (Ecklonia radiata) and f) diverse sponge gardens; g-h) sand waves and ripples with macroalgal growth in sediment covered substratum adjacent to annular ridge feature. a, c, d, e, f located on ridges, b on plain to the north of the most prominent ridges. In places, rhodoliths appear to be preferentially orientated; suggesting that water flow influences their position on the seabed.*

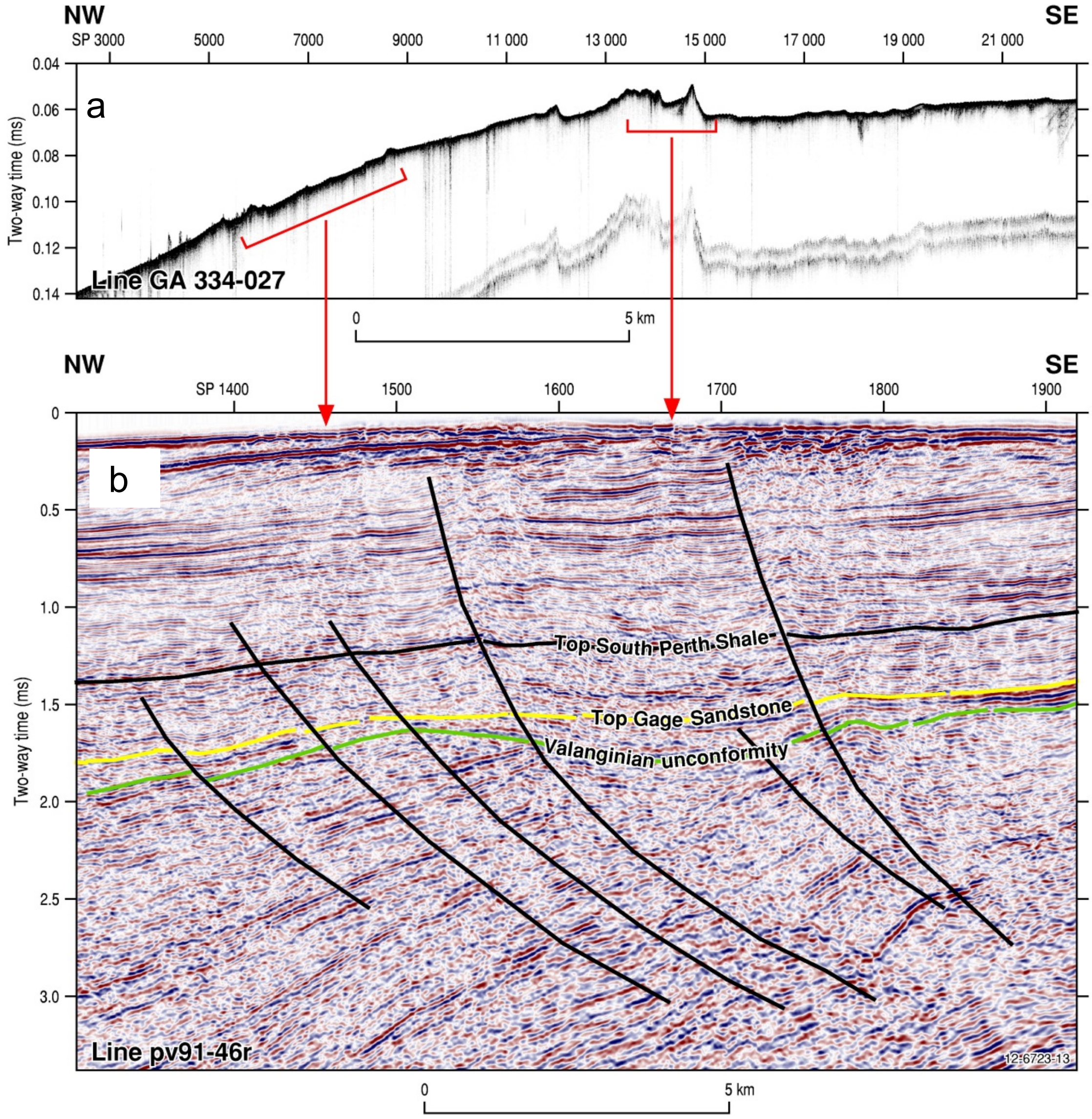

Figure 3.6: *Tentative correlation between a) surface geomorphology (linear ridges and mounds, and parabolic ridges), and b) sub-surface structures in Area 2. A number of ridges at the seabed in Area 2 appear to correlate with faults indicated in seismic imagery*

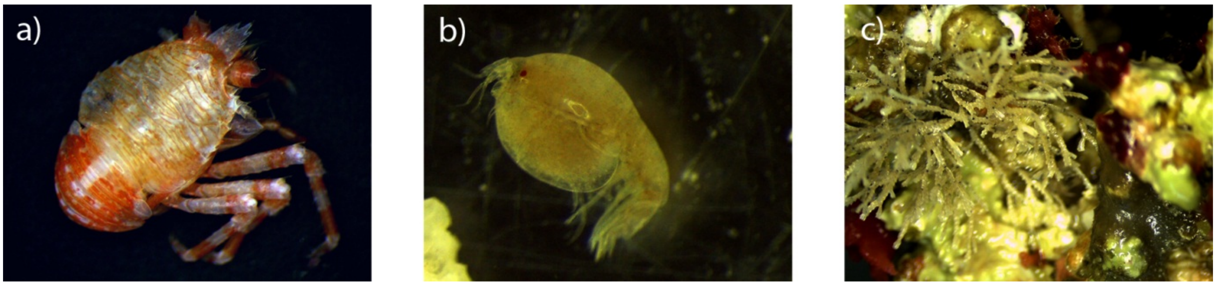

Figure 3.7: *Infaunal communities from grab sample 11GR21 (a) decapod, (b) amphipod, and (c) hydroids and bryozoans on the surface of a rhodolith.*

4. Summary and Concluding Remarks

The Vlaming Sub-basin marine survey was designed to support assessment of the Vlaming Sub-basin as a site for potential long-term geological storage of CO_2. The survey successfully acquired extensive datasets to characterise the seabed and investigate possible evidence of connectivity between the geology of the basin, the shallow sub-surface, and the seafloor. For two areas of the Rottnest Shelf, 418 km^2 of multi-beam bathymetry, backscatter and sub-bottom profiler data and 6.7 km^2 of side scan sonar imagery was acquired. Samples were collected at 43 sampling stations, including 89 grab samples, 10 core catcher samples (from gravity cores) and 12 towed video lines.

The high quality bathymetry data obtained during this survey has enabled new insights into the seabed environment and evolution of the Rottnest Shelf. Initial observations indicate the two surveyed areas are set within a shallow and sediment-starved shelf setting. The sediments in both areas are commonly composed of variably fine to coarse carbonate-rich sand. The sediments in Area 1 are of more recent (Holocene) origin, while those in Area 2 have a greater proportion of relict grains, and are thus derived from perhaps a mixed sediment source.

Due to the sediment-starved environment, geomorphological indicators of active seepage such as pockmarks or bioherms were not observed on the Rottnest Shelf. Neither were infaunal species indicative of fluid seepage recorded. However, many such species are microscopic (e.g. siboglinid worms), and may yet be discovered as species identification progresses.

Area 1, located to the north of Rottnest Island, is characterised by a carbonate-dominated environment with shallow valleys, terraces and sediment mega-ripples in water depths of 37-53 m. Two distinct structural lineaments are present in the southwest corner; the scarp on the eastern lineament indicates that these are probably faults. The extent to which these faults contribute to any fluid or gas seepage on Rottnest Shelf is at present uncertain, and is currently being studied. The sediment mega-ripples, located in the northeast of Area 1, are comprised of fine-grained carbonate sand and indicate that moderately high energy conditions exist on this shelf.

Area 2, the principal focus of this study, is situated to the southwest of Rottnest Island. It is dominated by spatially extensive beds of free-living coralline red algae (rhodoliths), and accumulations of free-living rhodoliths overlying ridges and mounds, and some areas of bedrock. The predominant geomorphic features in Area 2 are nested parabolic ridges, in water depths of about 40-50 m, whose surface is dominated by free-living, nodular calcareous red algae (rhodoliths), with fewer sessile organisms present. The relationship between the rhodolith-covered ridges and the subsurface geological structures is not clear, though there is an apparent spatial correlation between seabed geomorphology and large reactivated faults evident in the basinal succession. The similarity of these ridges to those onshore (e.g. at Point Cloates; Nichol and Brooke, 2011) suggests they are paleo-sub-aerial dunes located close to a palaeo shoreline. However, for them to remain on the shelf they must have been cemented after deposition. To establish whether this occurred due to seep-related mineralisation requires more seabed sample data and more detailed investigation. Thus the historical relationship between parabolic ridges and mounds in water depths of 40-50 m in Area 2 and fluid seepage at the seabed is an area of further study.

North-south trending structural lineaments on the outer (western) section of Area 2 in water depths of 80-85 m have in places mounds that rise 4-5 m above the seafloor and are covered by rhodoliths and some sessile organisms. The relationship between these mounds, possible cementation, seepage and the underlying geological structures is also the subject of further study. A number of datasets and physical samples acquired on the survey are still undergoing processing and analyses. Whether the development of the ridges and mounds are partly linked to fluid seepage from the subsurface in the recent and/or geological past is still being explored. The results of analyses of all the geological, geochemical and biological samples and geophysical data provided by the Vlaming Sub-basin marine survey will be provided in a subsequent report.

The data obtained from the Vlaming Sub-basin marine survey complements other marine surveys undertaken by Geoscience Australia. Data from the survey will be made publically available for use as pre-competitive offshore GHG storage information and to support marine zone management in Western Australia.

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Appendix A. Scientific Party GA0334

Table A.1: *Geoscience Australia staff members onboard Marine Survey, GA 334.*

Survey Leg	Dates	GA Staff Member
1	17-26 March 2012	George Bernardel
1	17-26 March 2012	Diane Jorgensen
2	12-20 April 2012	George Bernardel
2	12-20 April 2012	Tony Nicholas
2	12-20 April 2012	Diane Jorgensen
2	12-20 April 2012	Lynda Radke
2	12-20 April 2012	Maggie Tran

Appendix B. Sampling Station Selection

Sampling stations were selected based on the location of geomorphic features on the seabed and their proximity to apparent sub-surface structural features, visible in seismic profiles. Sampling stations were chosen using the multibeam and sub-bottom data. The reasoning and images used for the selection of sampling stations are presented below.

GA 334, Area 1, locations identified from which to choose sampling stations

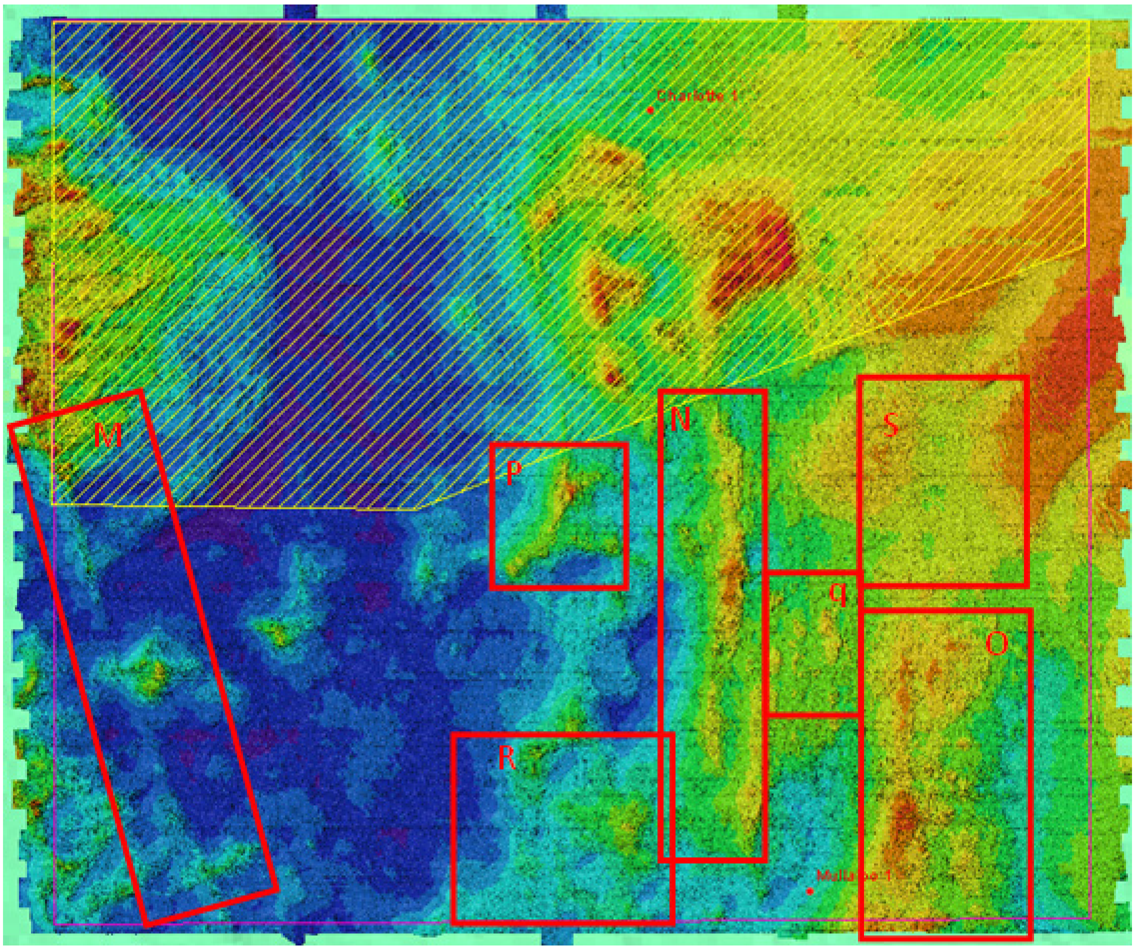

Figure A1: *Sampling areas of interest in Area 1 identified onboard the MV Southern Supporter, from which individual sampling sites were chosen. Hatched zone = cable exclusion zone (no sampling). Grid 1M designated highest priority, with for example, area 1O being a lesser priority than M. See also Fig. 2.1, showing designated locations of interest for Area 2, and priority A (highest) to J. Colour scale for this and all subsequent figures as per Fig 2.1.*

GA334, Area 1, sampling grid M, sample station selection

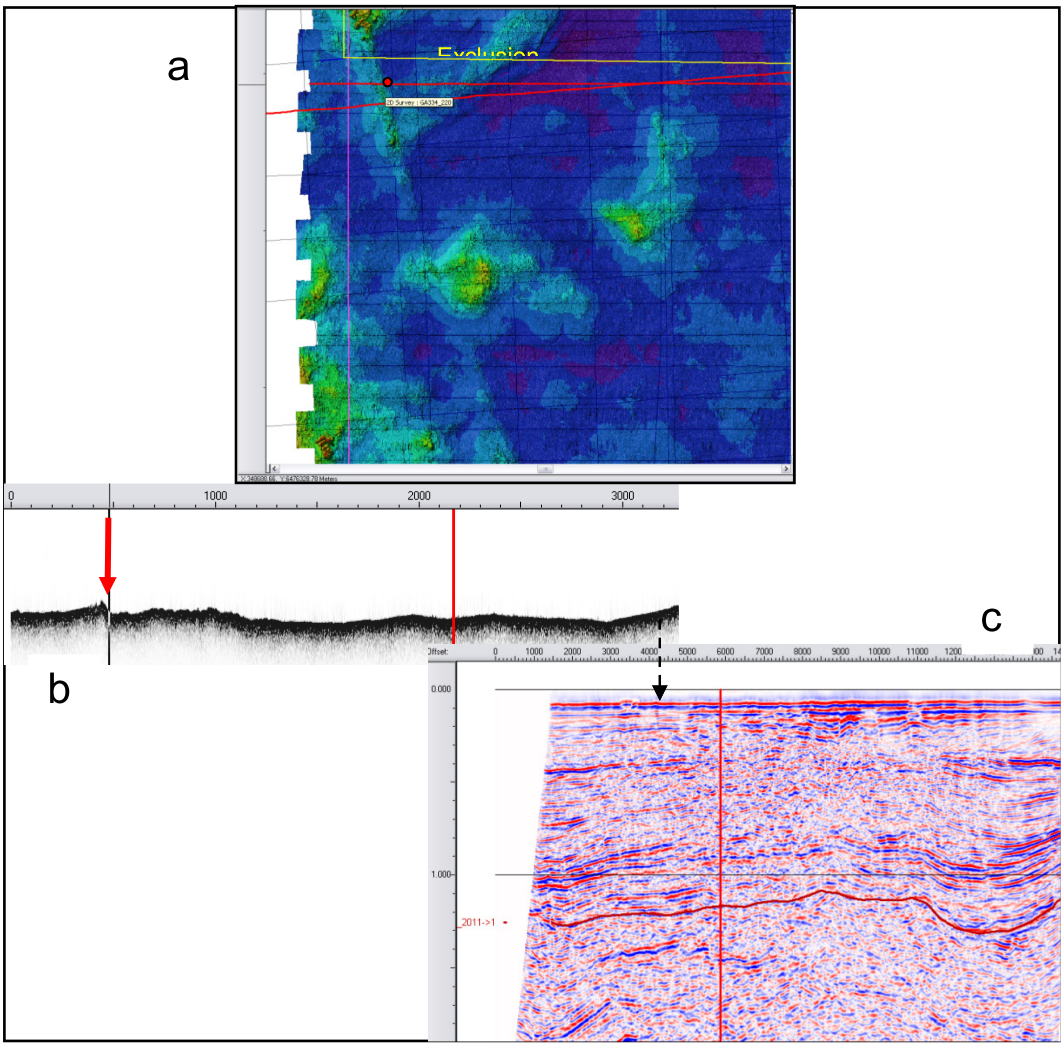

Figure A2: *Composite figure using a) multibeam sonar,b) sub-bottom profile and c) seismic profile along SBP line GA334_220. This combined imagery was used to choose sampling stations. The location of the chosen sampling station (red dot) on the bathymetry image of Area 1, was positioned using the locator red arrow on the sub-bottom profile line (Kingdom software), at the position of a distinct break in slope along a linear feature. The corresponding black arrow on the associated seismic line points to this same position, using Kingdom software.*

Location: seafloor ridge over deep seismic fault

Easting: 348688

Northing: 6476328

Depth: 46 m

Map projection for this and subsequent figures: Transverse Mercator UTM Zone 50South

Datum: World Geodetic System 1984 (WGS84)

Units: Metres

GA334, Area 1, sampling grid M, sample station selection

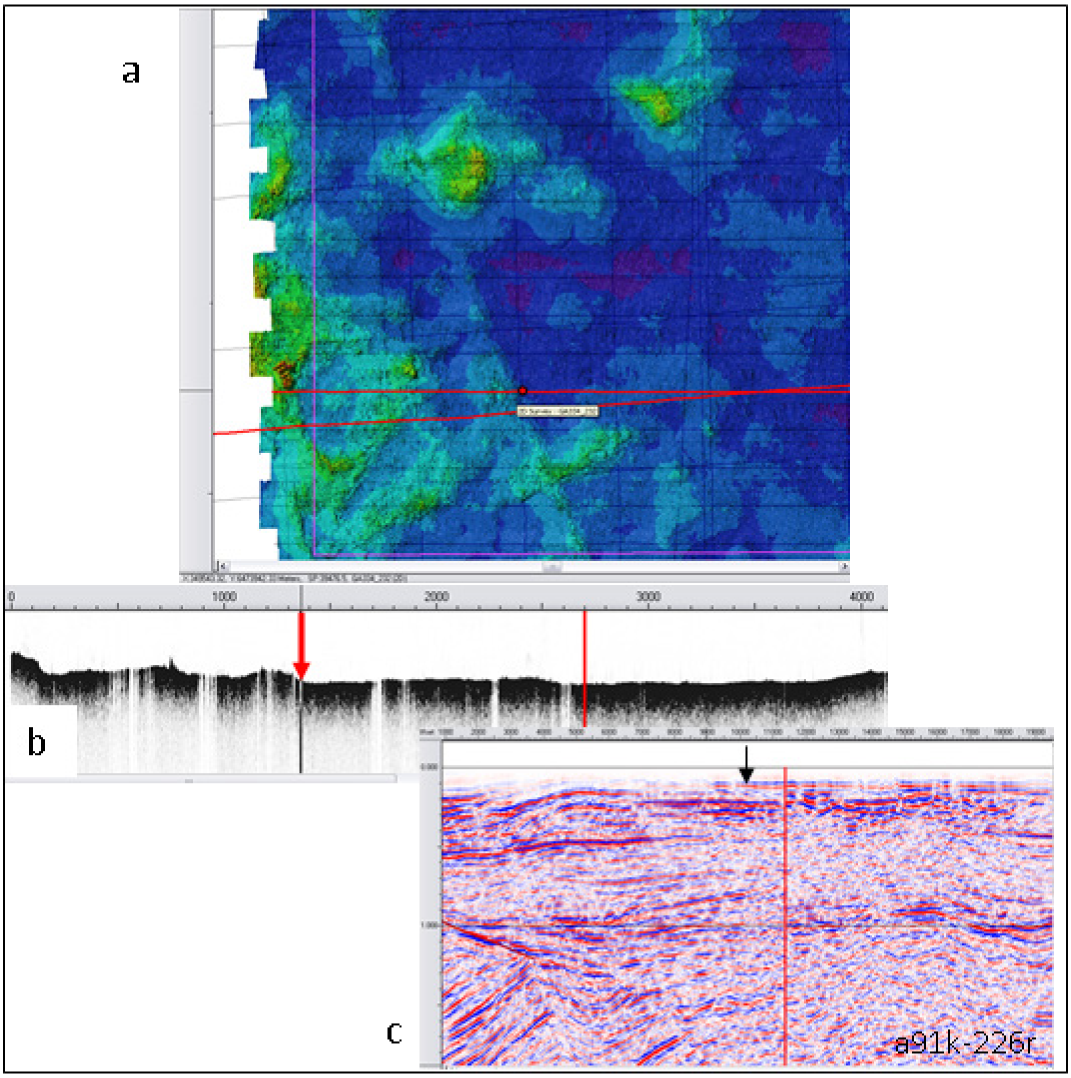

Figure A3: *Composite figure along SBP line GA334_232 using a) multibeam sonar,b) sub-bottom profile and c) seismic profile. Red dot in a) and arrows in b) and c) pointing to same location on the east side of a small ridge/scarp. The purpose of choosing a sampling station here was to investigate the seabed over a possible fault.*

Location: seafloor ridge over deep seismic fault

Easting: 349543

Northing: 6473942

Depth: 47 m

GA334, Area 1, sampling grid M, sample station selection

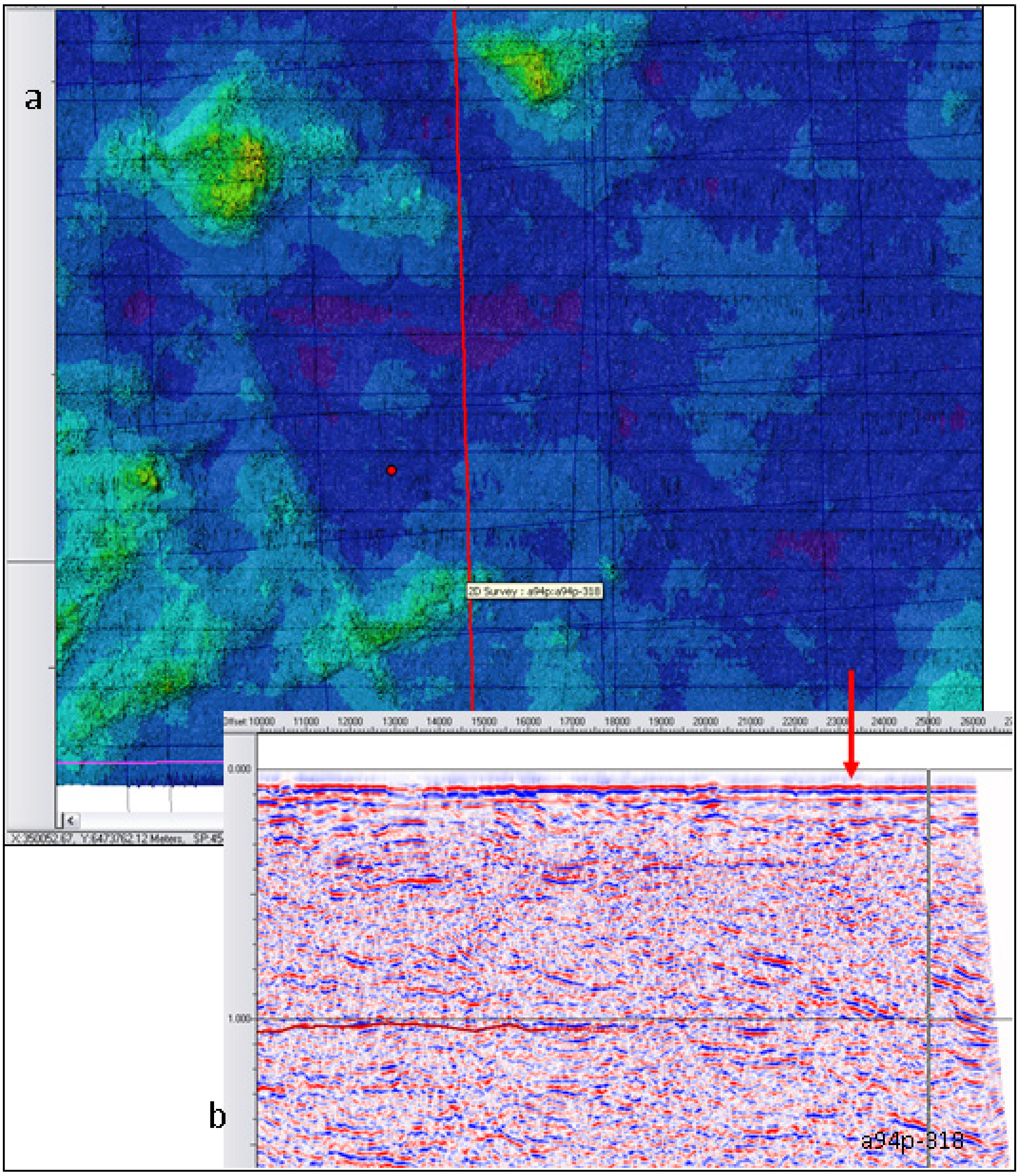

Figure A4: *Composite figure using a) bathymetry and b) seismic profile used to identify a seabed sampling station. Red arrow on b) pointing to possible fault in subsurface, while the dot on a) represents the approximate location on the seabed. Choosing a sampling station at this location was aimed at investigating the seabed above evidence for faulting seen in the seismic line.*

Location: seafloor ridge over deep seismic fault

Easting: 350052

Northing: 6473762

Depth: 46 m

Sub-bottom profile line: GA334_232

GA334, Area 1, sampling grid N, sample station selection

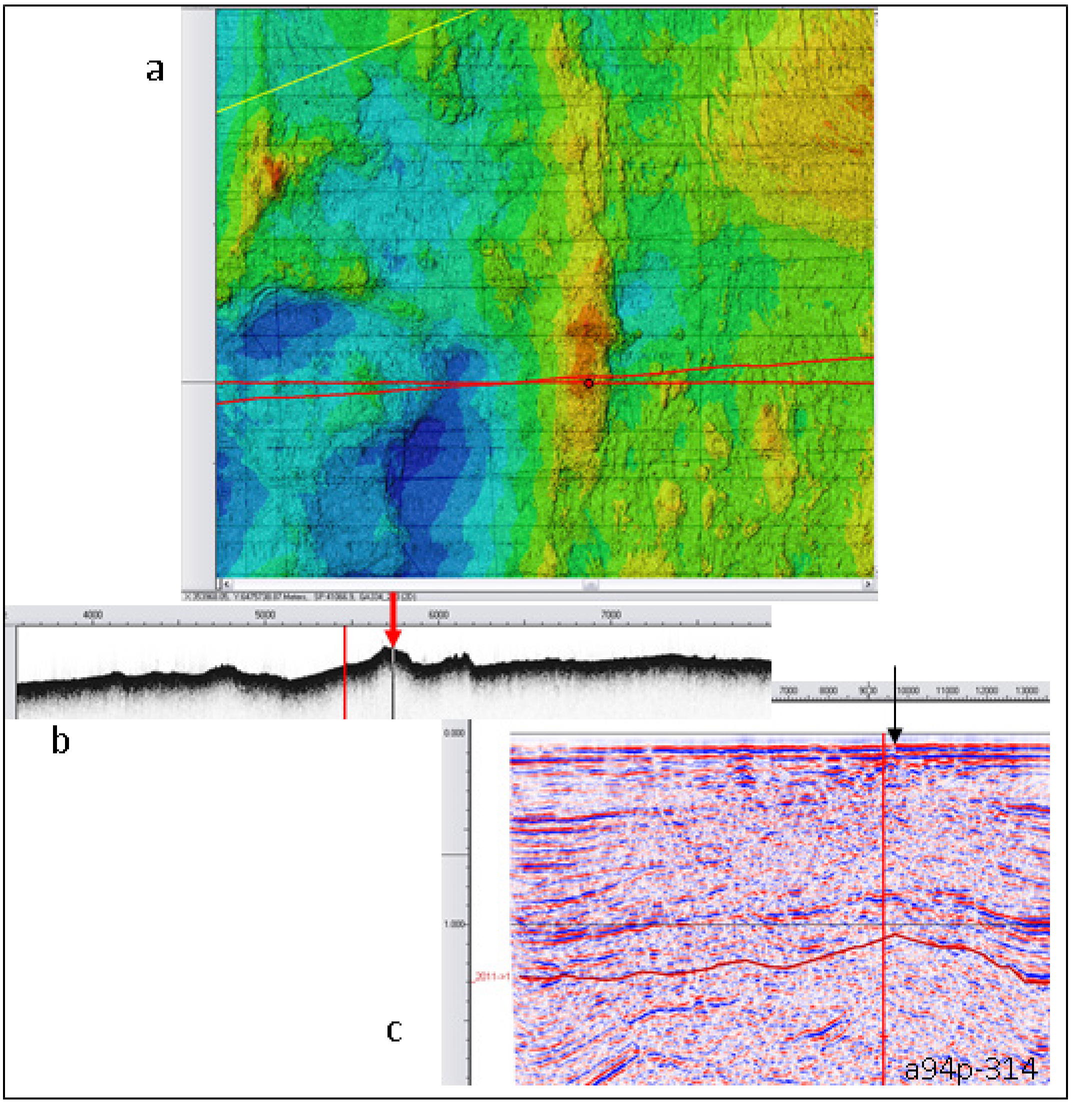

***Figure A5**: Composite figure of a) bathymetry, b) sub-bottom profile line GA334_223, and c) seismic line adjacent to the sub-bottom line. The sampling location targeted was a shallow ridge adjacent to a possible fault (arrowed in c), indicated in a) by the red dot.*

Location: seafloor ridge over deep seismic fault

Easting: 353968

Northing: 6475738

Depth: 42 m

GA334, Area 1, sampling grid N, sample station selection

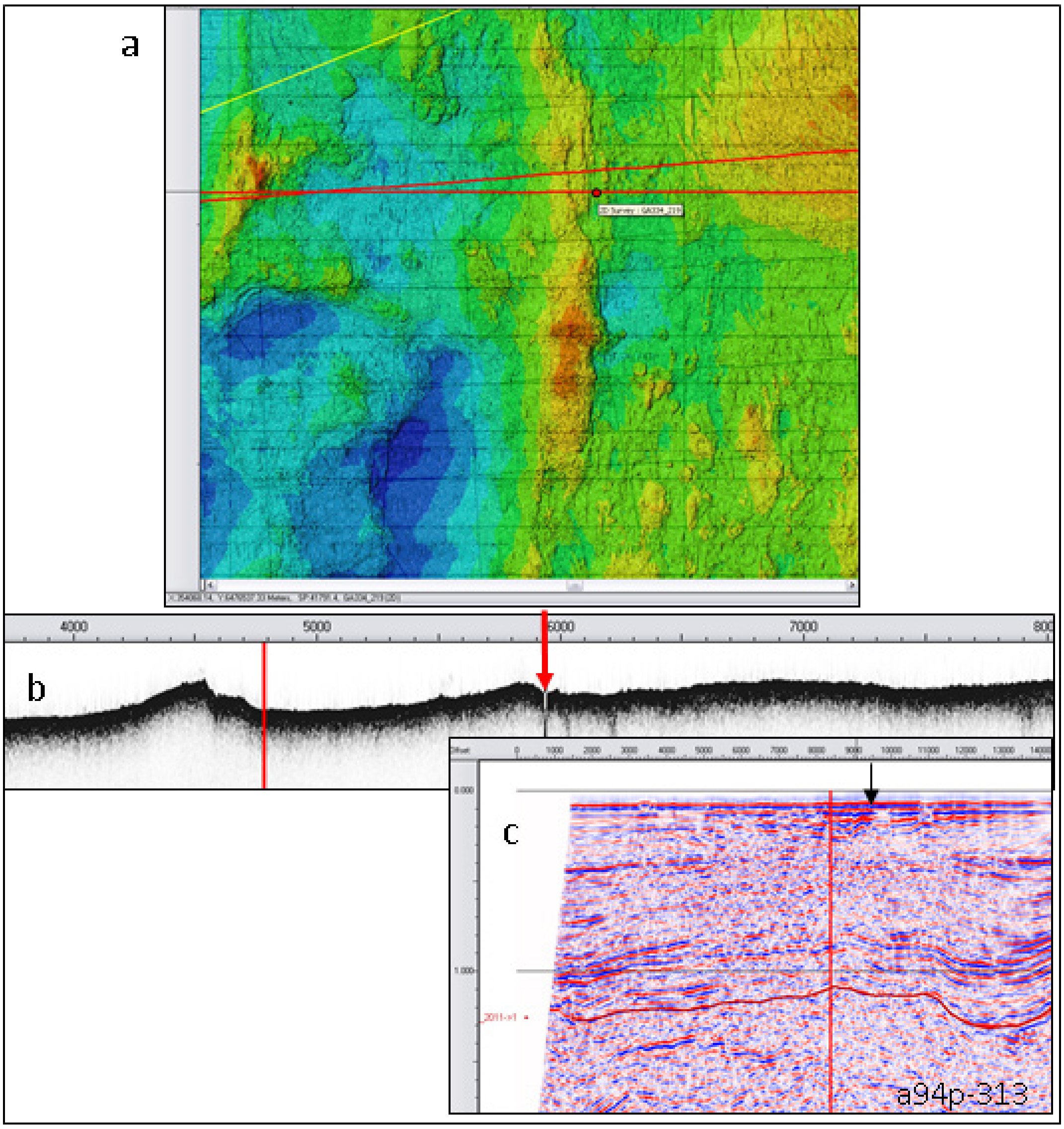

Figure A6: *Composite figure of a) bathymetry, b) sub-bottom profile line GA334_219, and c) seismic line adjacent to the sub-bottom line. The targeted area was a shallow depression to the east of the ridge targeted in Fig. A5, possibly related to faulting.*

Location: seafloor ridge over deep seismic fault

Easting: 354068

Northing: 6476537

Depth: 43 m

GA334, Area 1, sampling grid N, sample station selection

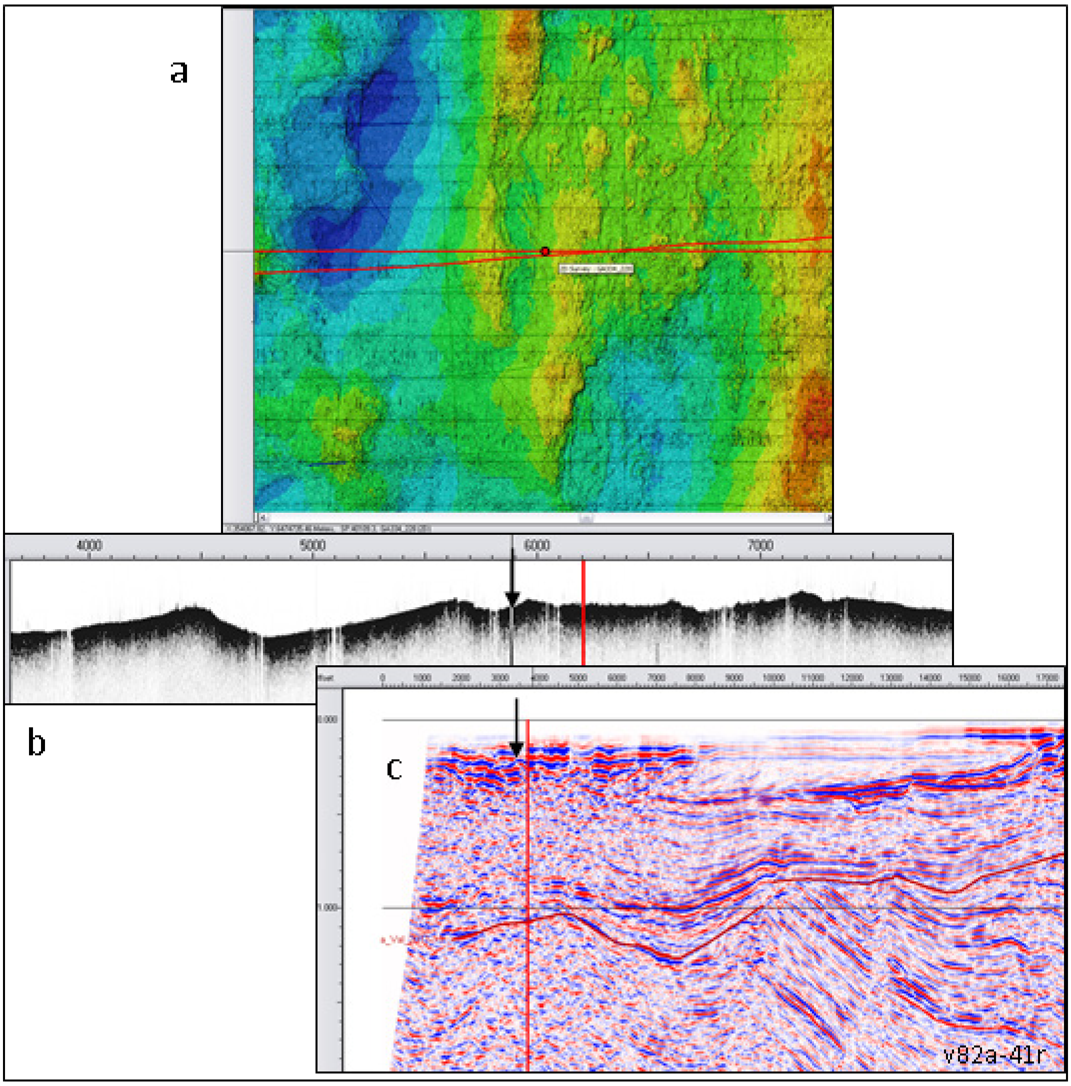

Figure A7: *Composite figure of a) bathymetry, b) sub-bottom profile line GA334_228, and c) seismic line adjacent to the sub-bottom line. The identified target for sampling was a shallow north-south trending depression, arrowed in b) and c), possibly above faulting in the accompanying seismic line.*

Location: seafloor ridge over deep seismic fault

Easting: 354067

Northing: 6474735

Depth: 43 m

GA334, Area 1, sampling grid N, sample station selection

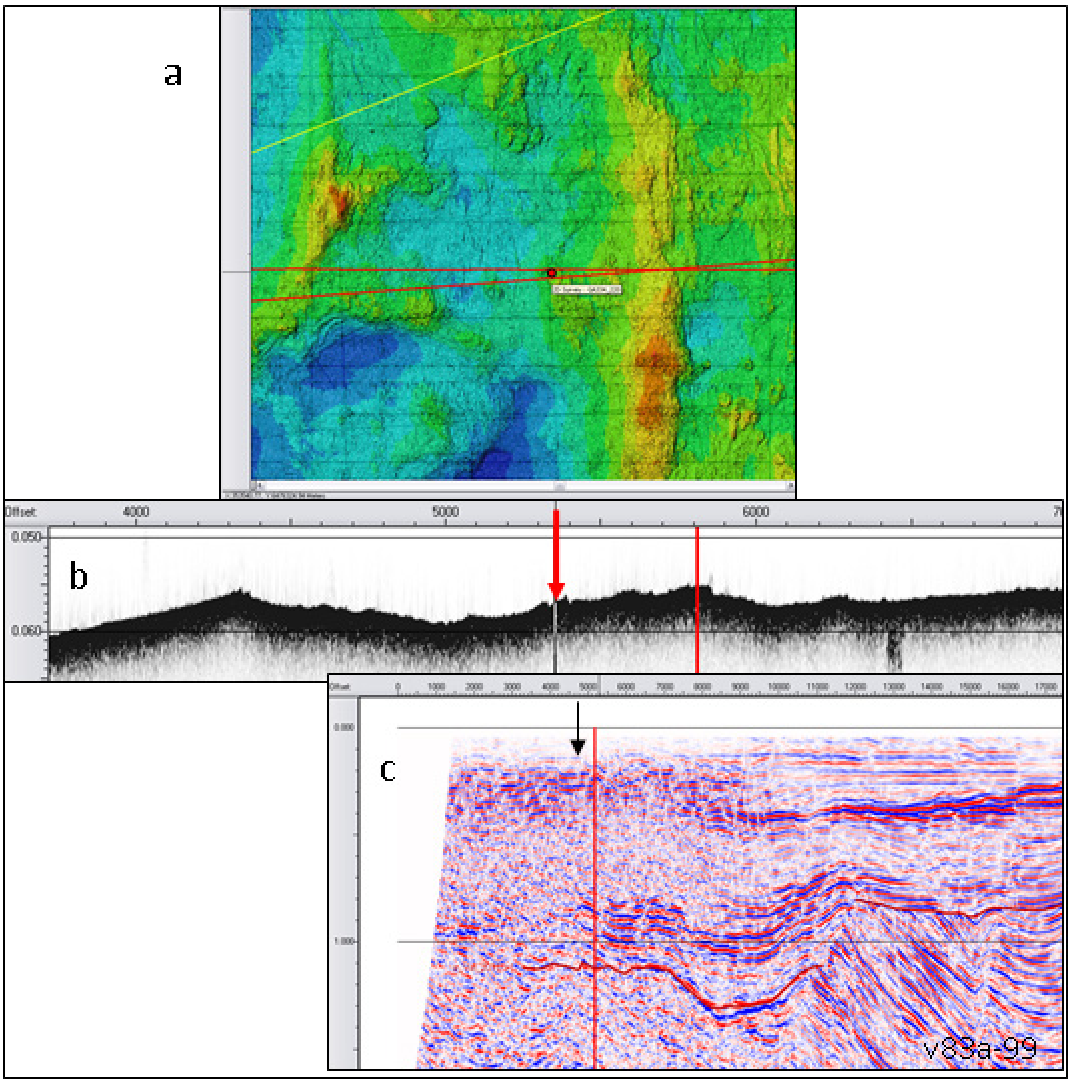

Figure A8: *Composite figure of a) bathymetry, b) sub-bottom profile line GA334_220, and c) seismic line adjacent to the sub-bottom line. The identified target was a circular feature clearly visible in bathymetry (obscured here because the dot in a) covers the location) and located 20 m south of the sub-bottom profile line.*

Location: circular feature in seabed over deep seismic fault zone

Easting: 353540

Northing: 6476324

Depth: 43 m

GA334, Area 1, sampling grid N, sample station selection

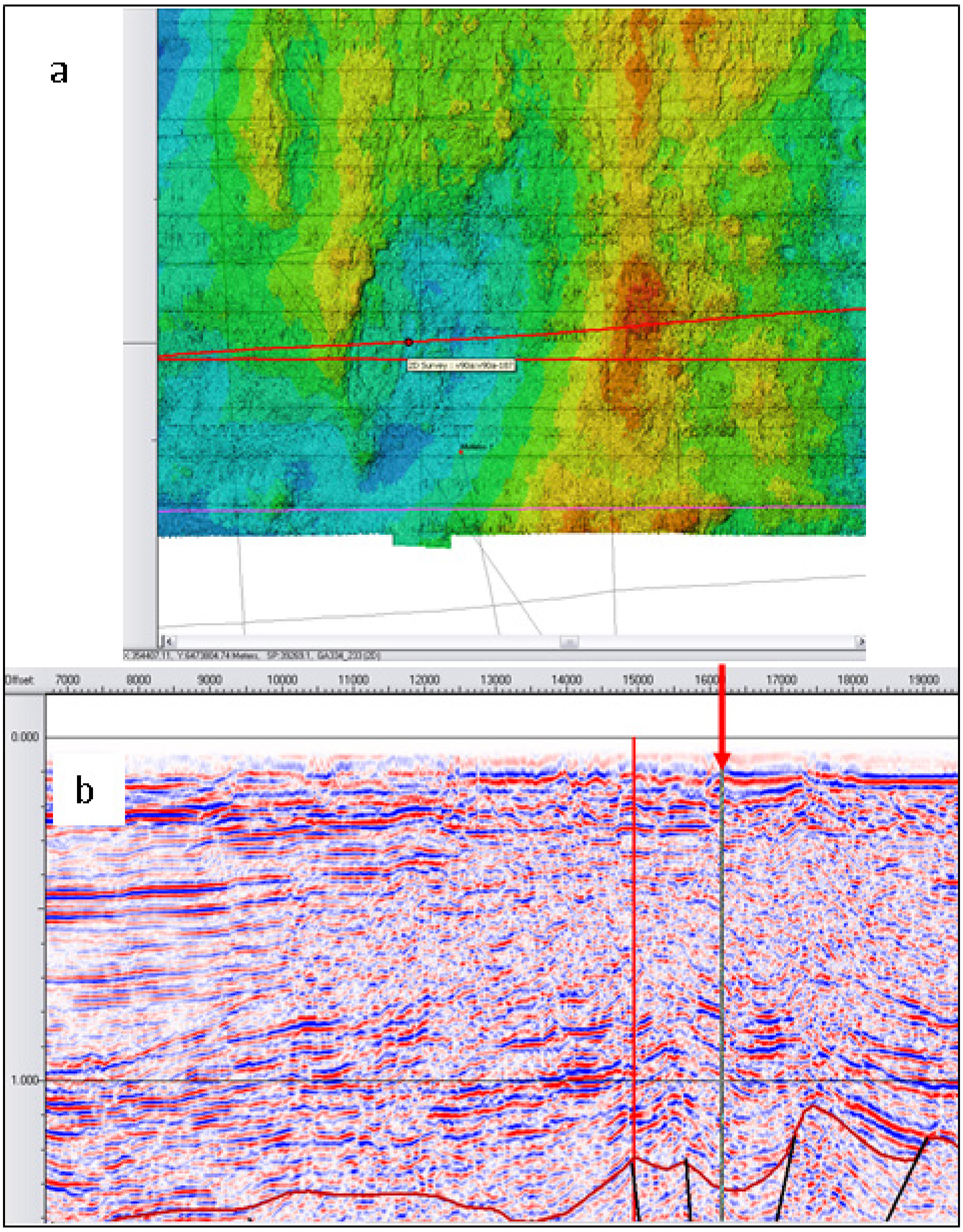

Figure A9: *Composite figure of a) bathymetry and b) seismic profile indicating location of sampling station chosen in sampling grid N aimed at providing information on the seabed above faulting at depth.*

Location: east of seafloor ridge, in a shallow trough, over deep seismic fault zone

Easting: 354407

Northing: 6473804

Seismic line: v90a-187

GA334, Area 1, sampling grid O, sample station selection

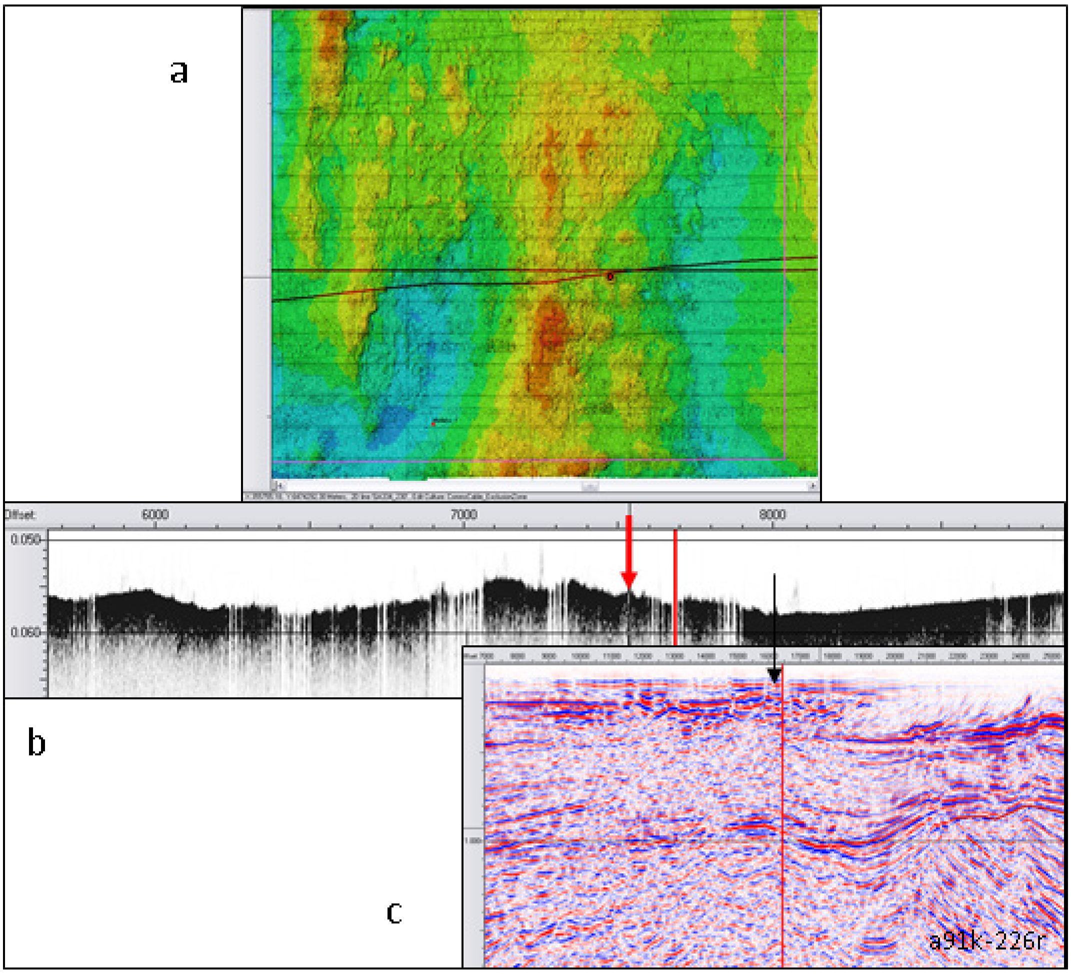

Figure A10: *Composite figure of a) bathymetry, b) sub-bottom profile line GA334_230, and c) seismic profile, indicating location of sampling station targeted (red dot) in sampling grid O on a small ridge 40 m south of the sub-bottom profile line, and located above a possible gas source and faulting.*

Location: raised circular feature over deep seismic fault zone

Easting: 355755

Northing: 6474292

Depth: 42 m

GA334, Area 1, sampling grid O, sample station selection

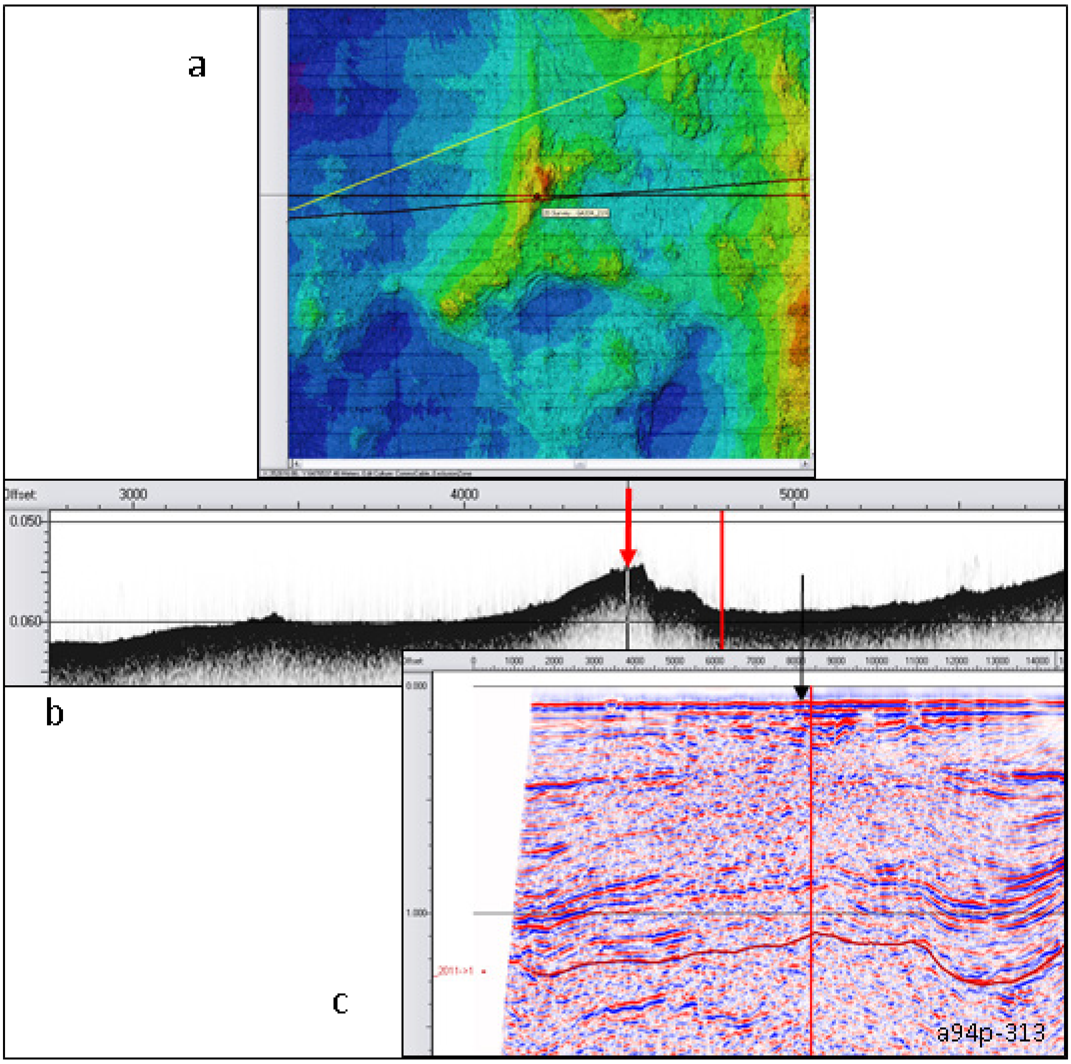

Figure A11: *Composite figure of a) bathymetry, b) sub-bottom profile line GA334_219, and c) seismic profile, indicating location of sampling station targeted (red dot) and located on a ridge with scarp on its eastern side (possible fault) in sampling grid O.*

Location: seafloor ridge over deep seismic fault zone

Easting: 352616

Northing: 6476537

Depth: 44 m

GA334, Area 1, sampling grid Q, sample station selection

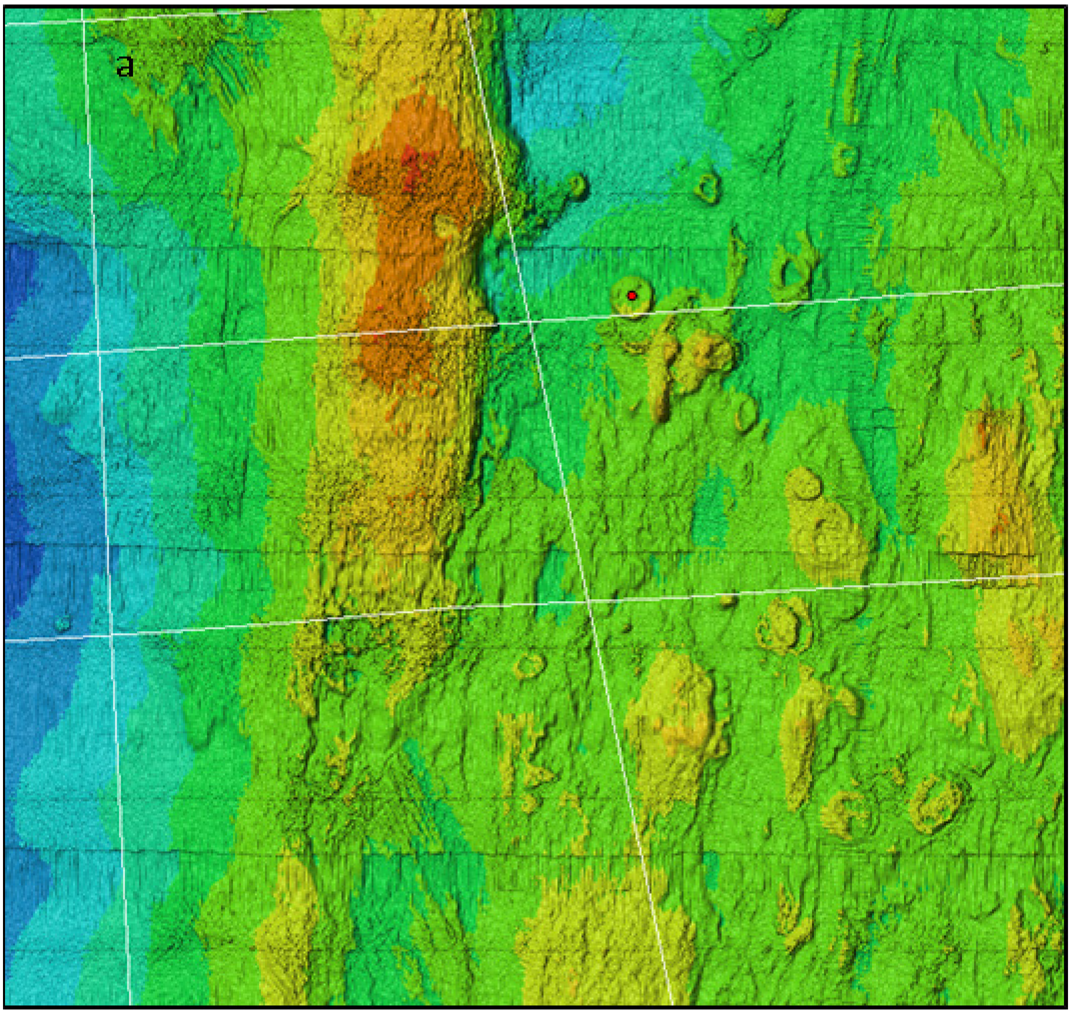

__Figure A12:__ Selected bathymetry in Area 1, sampling grid Q, with many circular features visible, one chosen for sampling based on this imagery.

Location: raised seafloor circular feature in a field of circular features

Easting: 354257

Northing: 6475799

Depth: 43 m

GA334, Area 1, sampling grid R, sample station selection

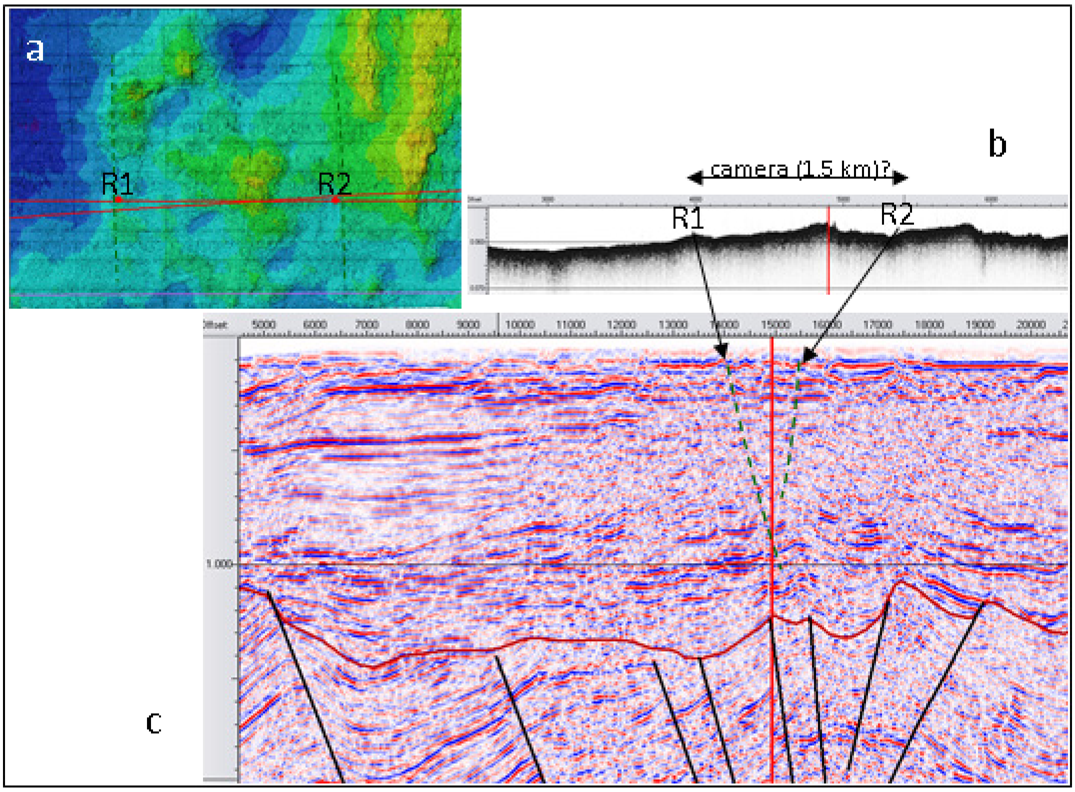

Figure A13: *Composite figure of a) bathymetry, b) sub-bottom profile line GA334_233, and c) seismic profile, indicating location of towed-video station targeted (line R1-R2) across a ridge to investigate surface geomorphology visually. These features possibly related to faulting.*

Location: rugose section of seafloor

Start point: R1

Easting: 352268

Northing: 6473738

End point: R2

Easting: 353582

Northing: 6473738

Variable depth: (~30-40 m)

GA334, Area 1, sampling grid R, sample station selection

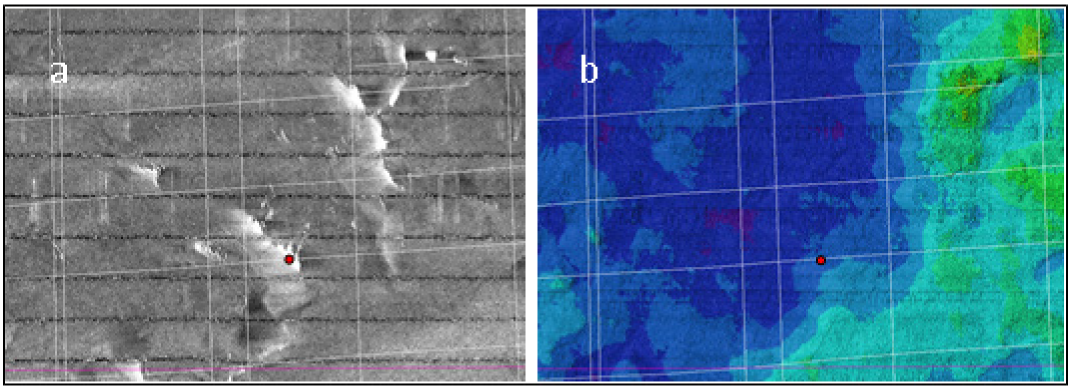

Figure A14: *a) Backscatter and b) bathymetry on side of shallow valley. Backscatter indicates sediment accumulation.*

Location: sediment lobe over deep faults

Point: R1

Easting: 351665

Northing: 6473632

GA334, Area 1, sampling grid S, sample station selection

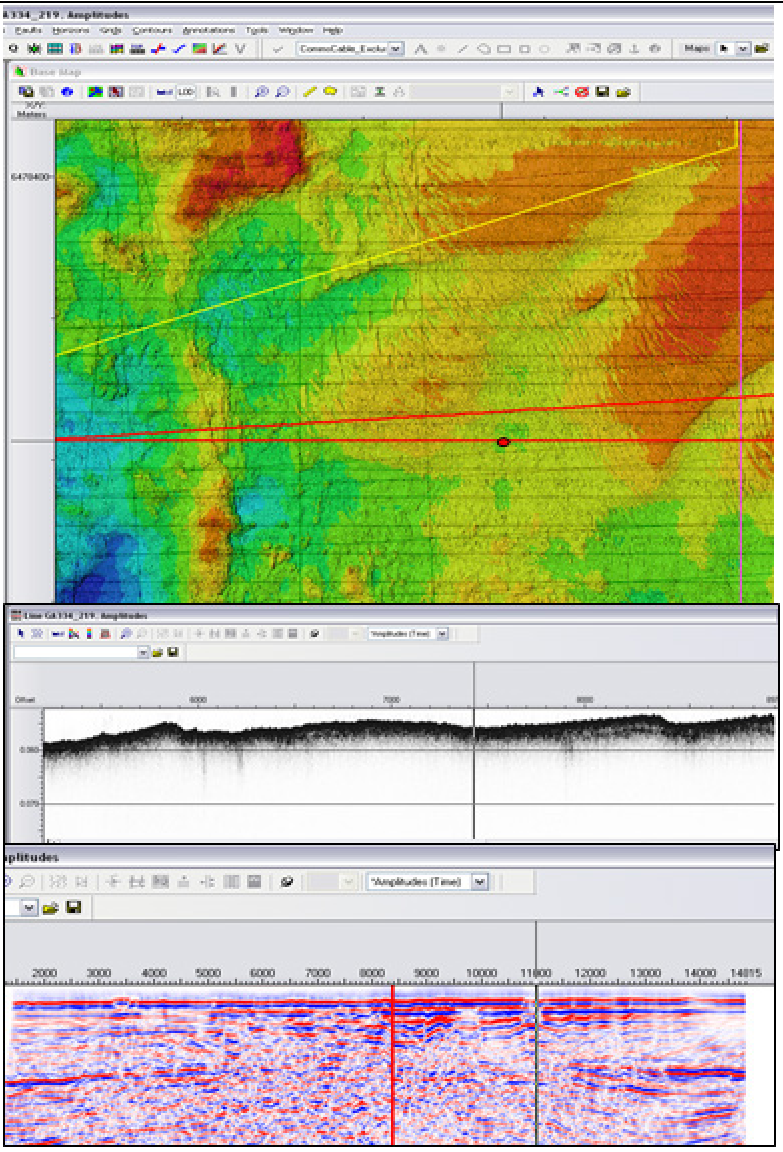

Figure A15: *Composite figure of a) bathymetry, b) sub-bottom profile line GA334_219, and c) seismic profile, indicating location of sampling station targeted (red dot) in a shallow valley which may be related to shallow sub-surface faulting/displacement.*

Location: slight depression in seabed, directly over seismic feature of interest on seismic line a94p-313

Easting: 355562

Northing: 6476532

GA334, Area 1, sampling grid T, sample station selection

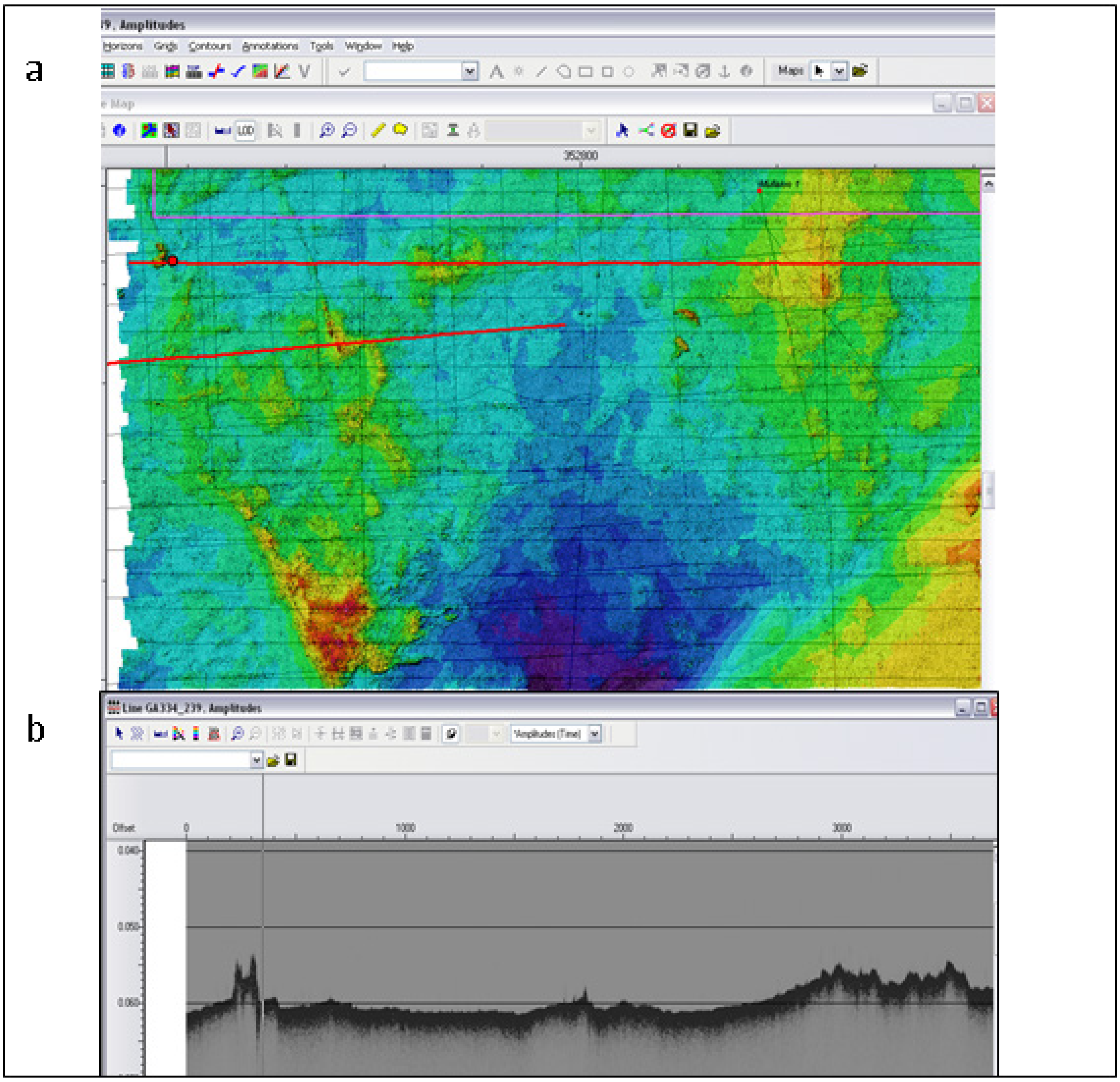

Figure A16: *Composite figure of a) bathymetry, b) sub-bottom profile line GA334_239 with position of sampling station located in the lee of the main swell direction, and adjacent to a ridge that may be fault related.*

Location: east of seafloor ridge

Easting: 348575

Northing: 6472634

GA334, Area 1, sampling grid T, sample station selection

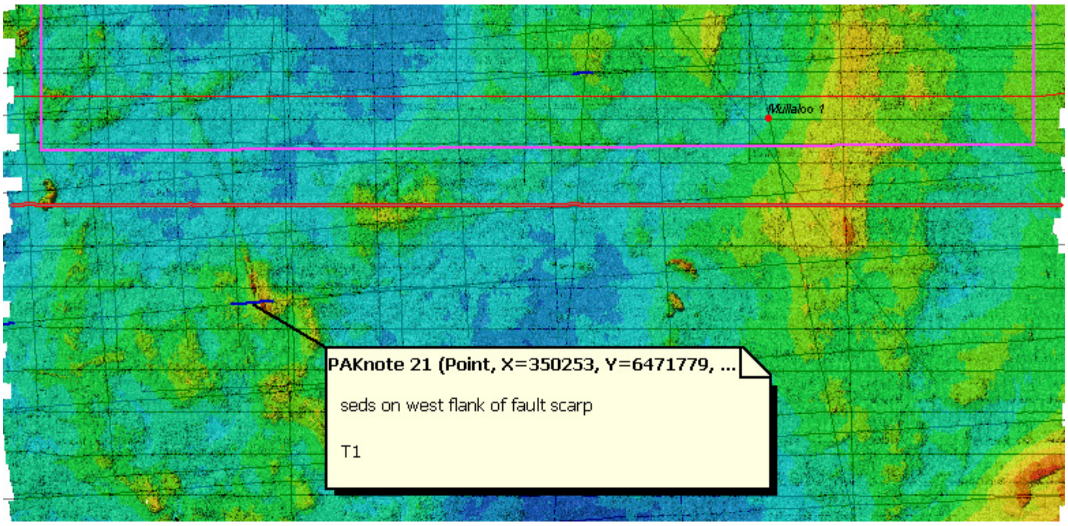

Figure A17: *showing bathymetry obtained in the final stages of marine survey GA334 (below red line) and the location of a sampling station chosen to collect surface sediment adjacent to the western side of a possible fault scarp.*

Location: slight depression on west flank of fault scarp

Easting: 350253

Northing: 6471779

GA334, Area 1, sampling grid T, sample station selection

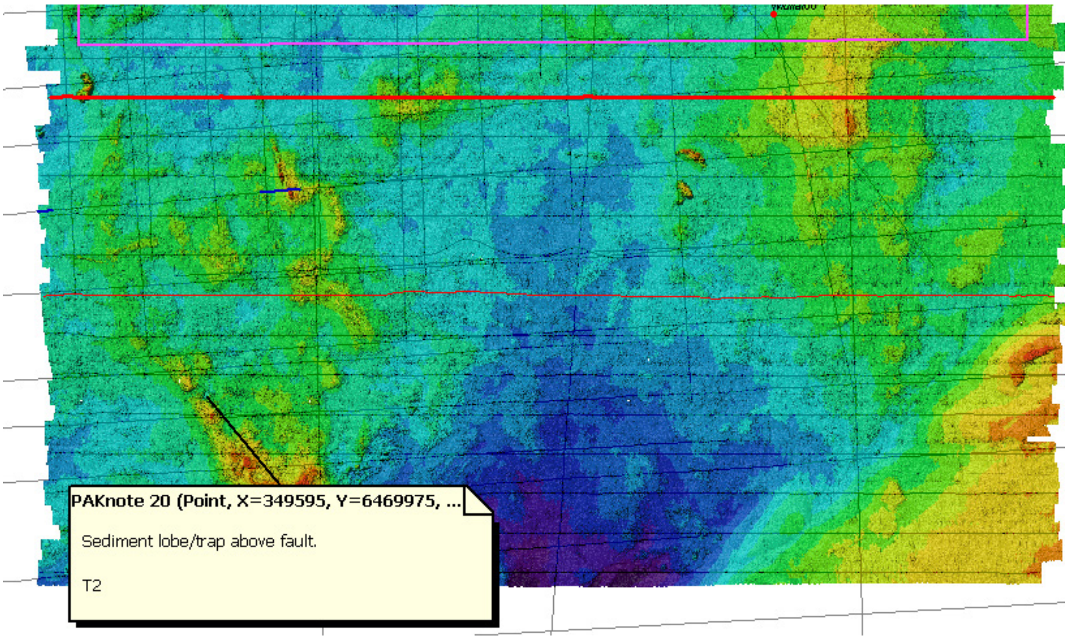

Figure A18: *Bathymetry of the southern portion of Area 1, obtained in the final stages of marine survey GA334 (below red line) and the location of a possible sediment sampling location. The aim in this was to collect sediment adjacent to a possible fault, to if possible, collect samples that may have been derived from the fault.*

Location: east of seafloor ridge

Easting: 349595

Northing: 6469975

Seismic line: hv85a_5

GA334, Area 2, sampling grid A, sample station selection

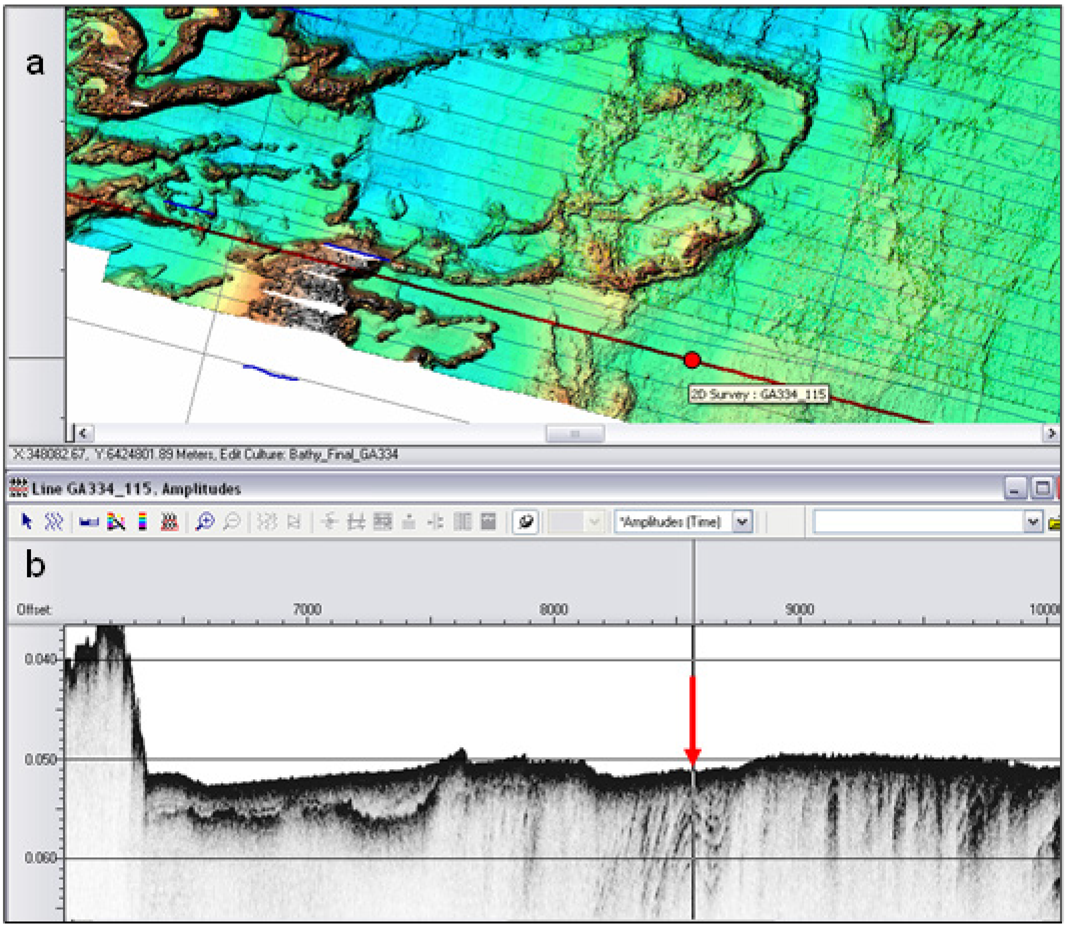

Figure A19: *Composite figure of a) bathymetry and b) sub-bottom profile line GA334_115. Sampling location chosen to the east (i.e. slightly inshore) of large ridges, in a shallow depression. This area with large parabolic ridges was given a high priority because of observations made on seismic data suggesting gas in the sub-surface in the vicinity of these ridges.*

Location: over slight depression in seafloor

Easting: 348082

Northing: 6424801

Depth: 46 m

GA334, Area 2, sampling grid A, sample station selection

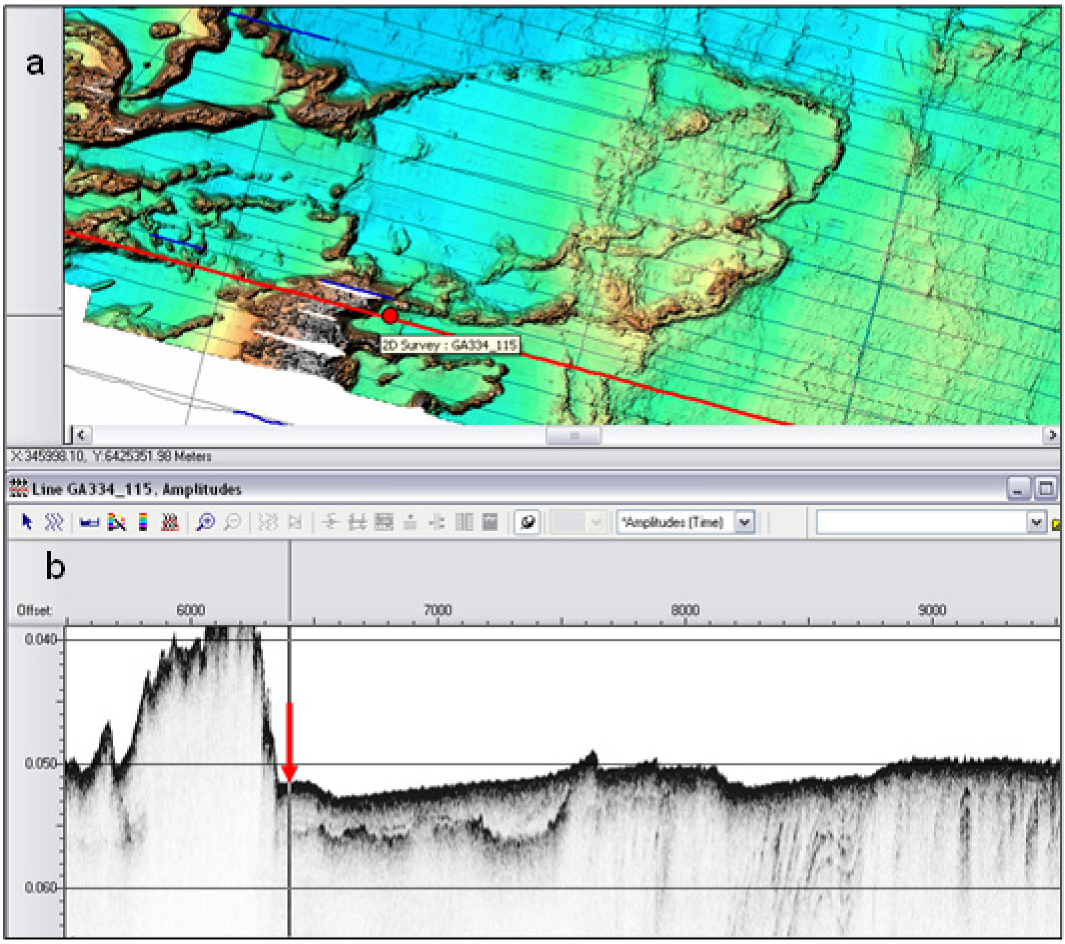

Figure A20: *Composite figure of a) bathymetry and b) sub-bottom profile line GA334_115. Sampling station chosen is located on the inshore side of a large ridge, with the aim of acquiring carbonate rubble derived from the ridge.*

Location: within slightly elevated terrace of sediment deposited alongside carbonate embankment

Easting: 345998

Northing: 6425351

Depth: 45 m

GA334, Area 2, sampling grid A, sample station selection

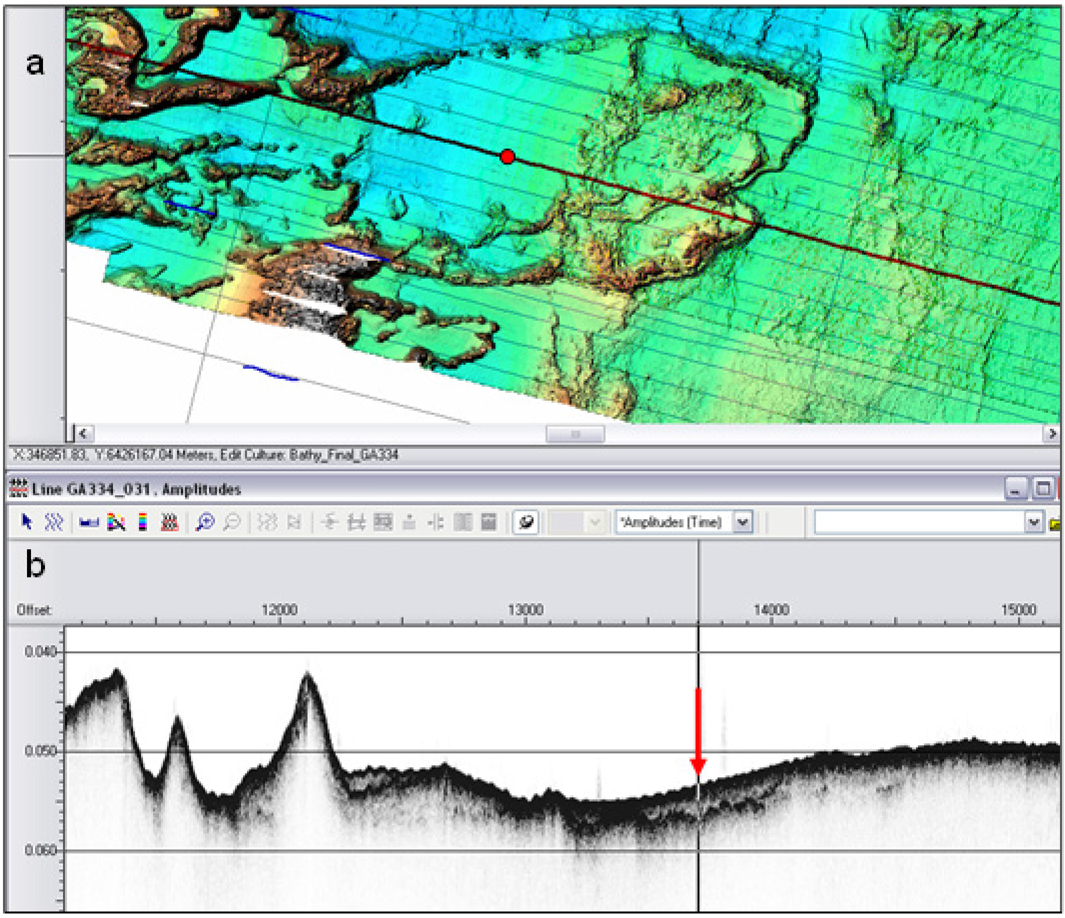

Figure A21: *Composite figure of a) bathymetry and b) sub-bottom profile line GA334_115. The targeted location (arrowed in b) was suggestive of some sediment above bedrock, and located within an area of seabed circumscribed by large ridges.*

Location: within slightly elevated terrace of sediment deposited alongside carbonate embankment

Easting: 345998

Northing: 6425351

Depth: 45 m

GA334, Area 2, sampling grid B, sample station selection

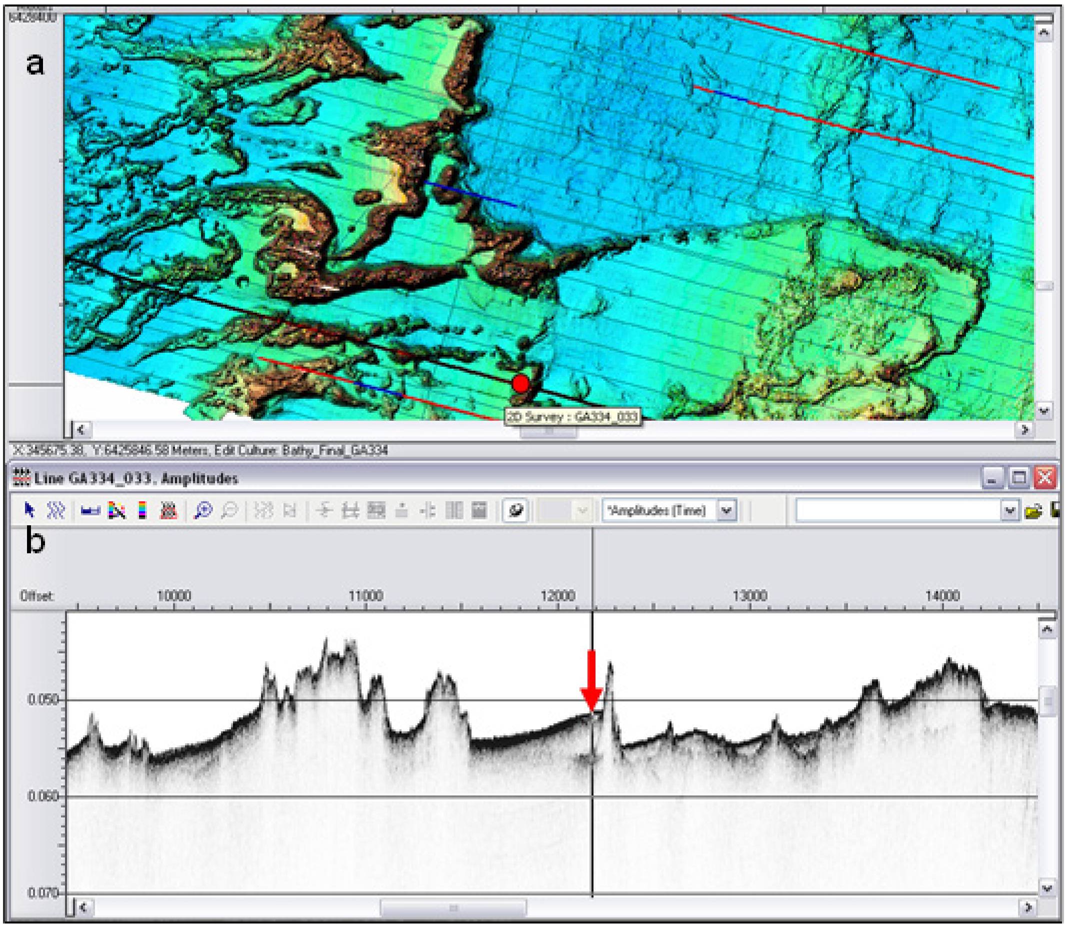

Figure A22: *Composite figure composed of a) bathymetry and b) sub-bottom profile line image from line GA334_053. The feature identified as a possible sampling location was a high adjacent to a narrow high ridge, with the possibility of sediment build-up at this location.*

Location: within carbonate bank

Easting: 345675

Northing: 6425846

Depth: 45 m

GA334, Area 2, sampling grid B, sample station selection

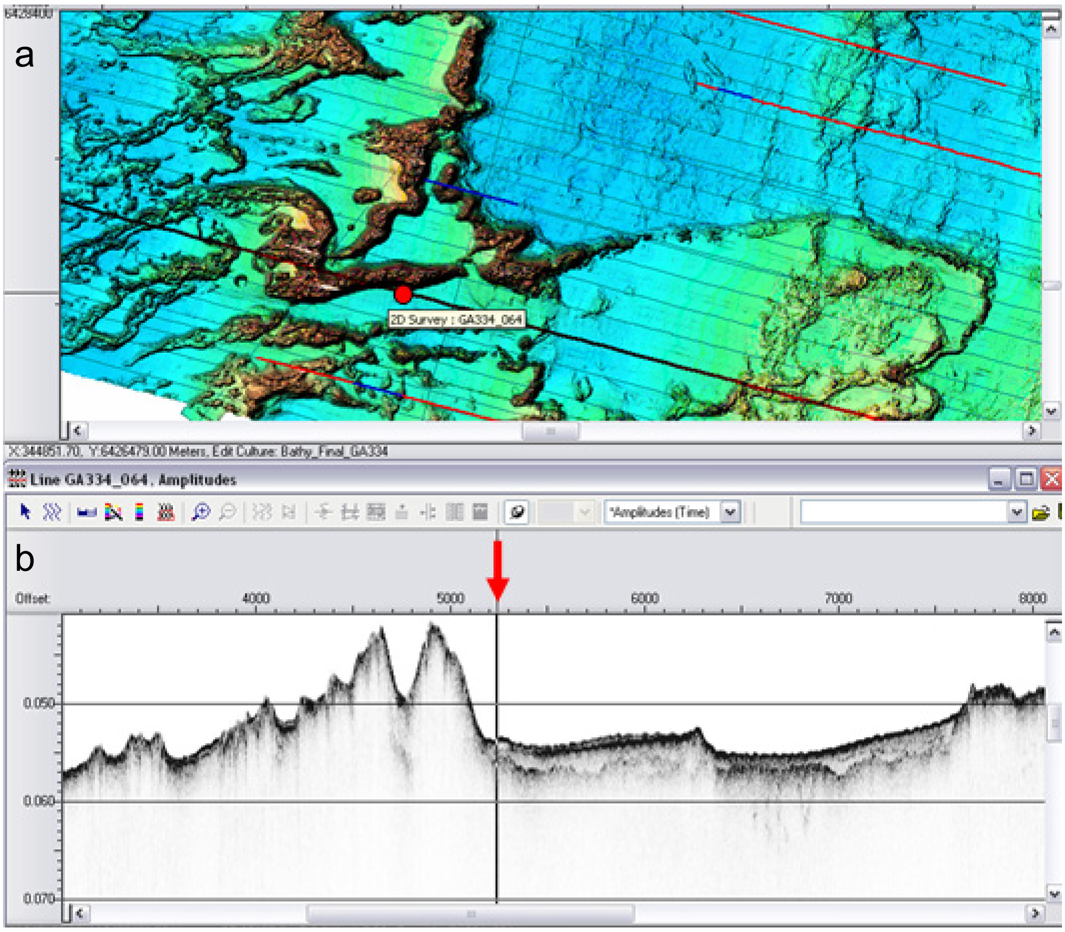

Figure A23: *Composite figure of a) bathymetry and b) sub-bottom profile line GA334_064 used to identify a single sampling location on the landward (inshore) side of large ridges. Sampling of the identified target was expected to yield carbonate rubble from the ridges.*

Location: within carbonate bank

Easting: 344851

Northing: 6426479

Depth: 45 m

GA334, Area 2, sampling grid B, sample station selection

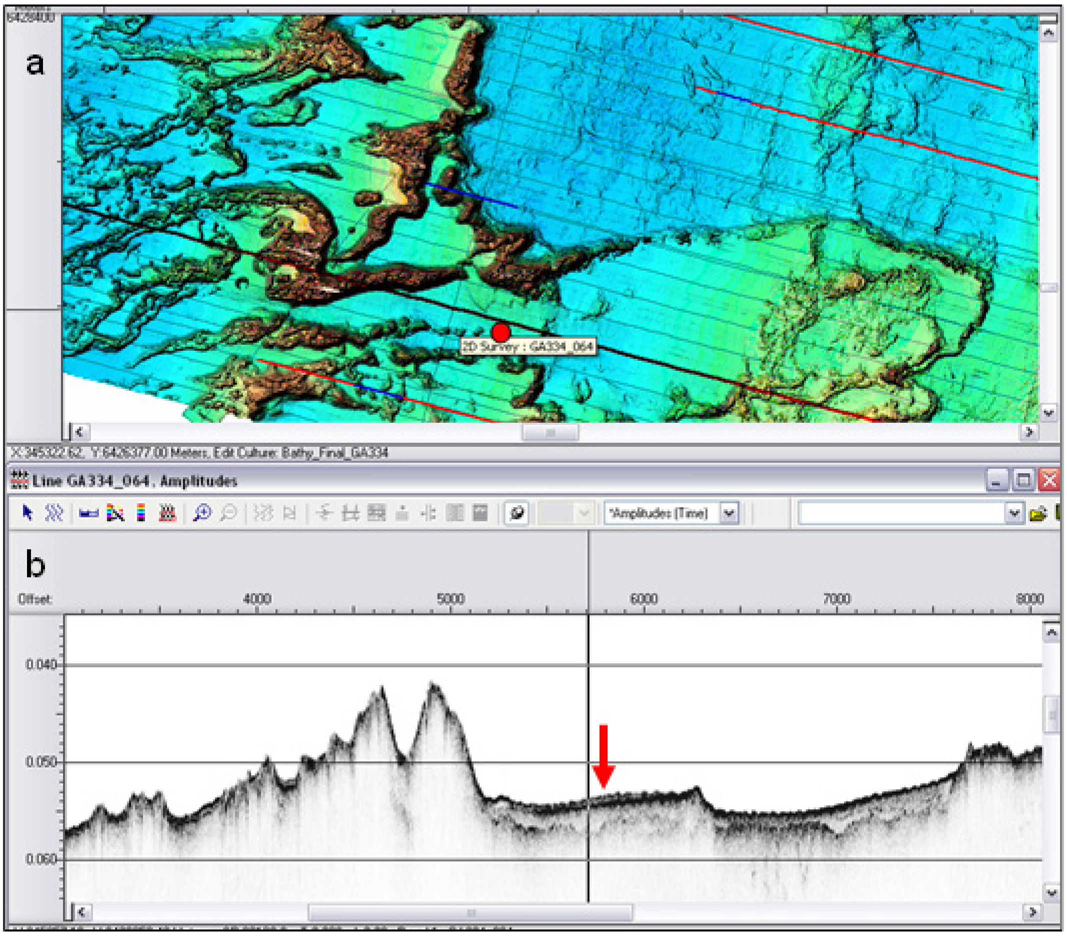

Figure A24: *Composite image using a) bathymetry and b) sub-bottom profile line GA334_064. The sampling location identified sits between large ridges, and the sub-bottom profile indicates the possibility of some sediment at this location.*

Location: within carbonate bank

Easting: 345322

Northing: 6426377

Depth: 46 m

GA334, Area 2, sampling grid B, sample station selection

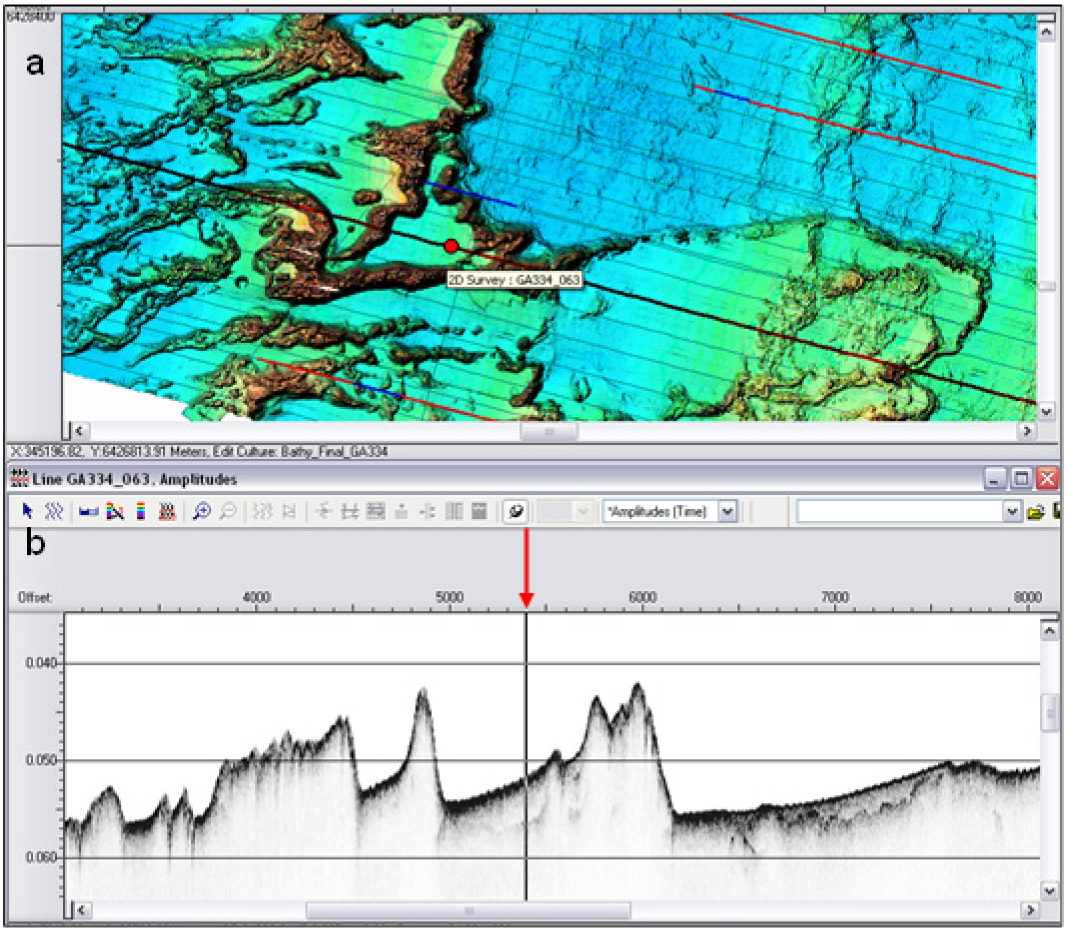

Figure A25: *Composite figure of a) bathymetry and b) sub-bottom profile line GA334_063 indicating the location of a single sampling station chosen because of the possiblity of recovering sediment from this location representative of an inter-ridge environment.*

Location: within carbonate bank

Easting: 345197

Northing: 6426814

Depth: 44 m

GA334, Area 2, sampling grid C, sample station selection

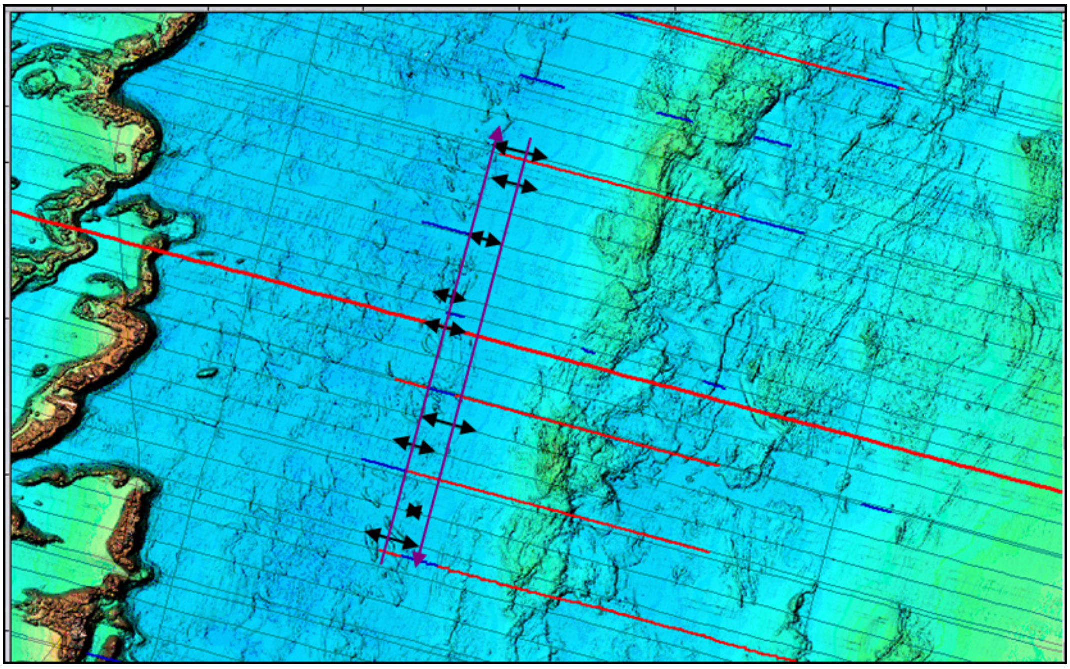

Figure A26: *Bathymetry with possible location of towed-video and side-scan sonar to ascertain the composition of the seabed at this location.*

Location of possible towed-video runs on broad seafloor shallow depression

X1 Easting: 347421 **X2 Easting:** 347200

Y1 Northing: 6428682 **Y2 Northing:** 6428756

Depth 1: 48 m **Depth 2:** 48 m

SBP chirper lines (North to South): GA334_49, GA334_17, GA334_51, GA334_52, GA334_53, GA334_55, GA334_23, GA334_57, GA334_25

GA334, Area 2, sampling grid C, sample station selection

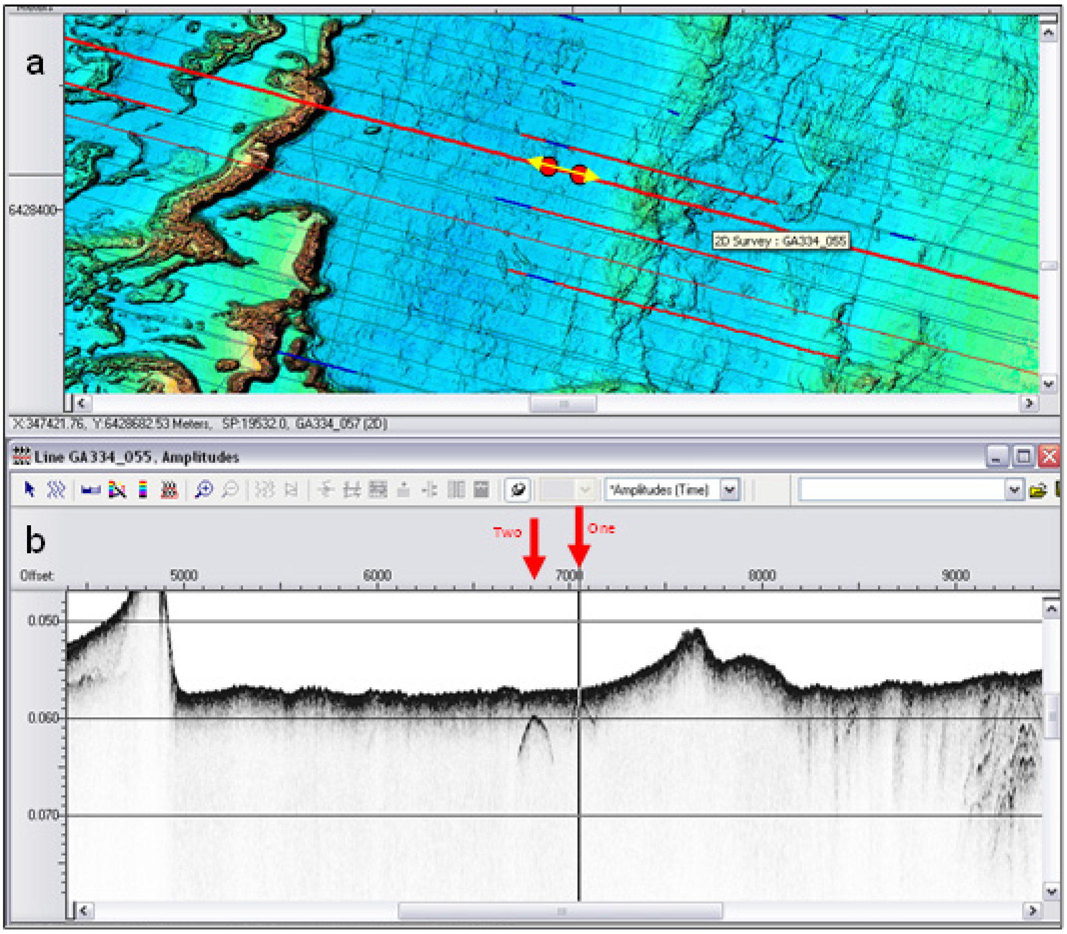

Figure A27: *Composite figure consisting of a) bathymetry and b) sub-bottom profile line GA334_055 with location of possible towed-video transect and sediment sampling station(s), arrowed, over reflectors identified in the sub-bottom profile.*

Location: eastern flank of carbonate bank

X1 Easting: 347421	**X2 Northing:** 347200
Y1 Easting: 6428682	**Y2 Northing:** 6428756
Depth 1: 48 m	**Depth 2:** 48 m

GA334, Area 2, sampling grid C, sample station selection

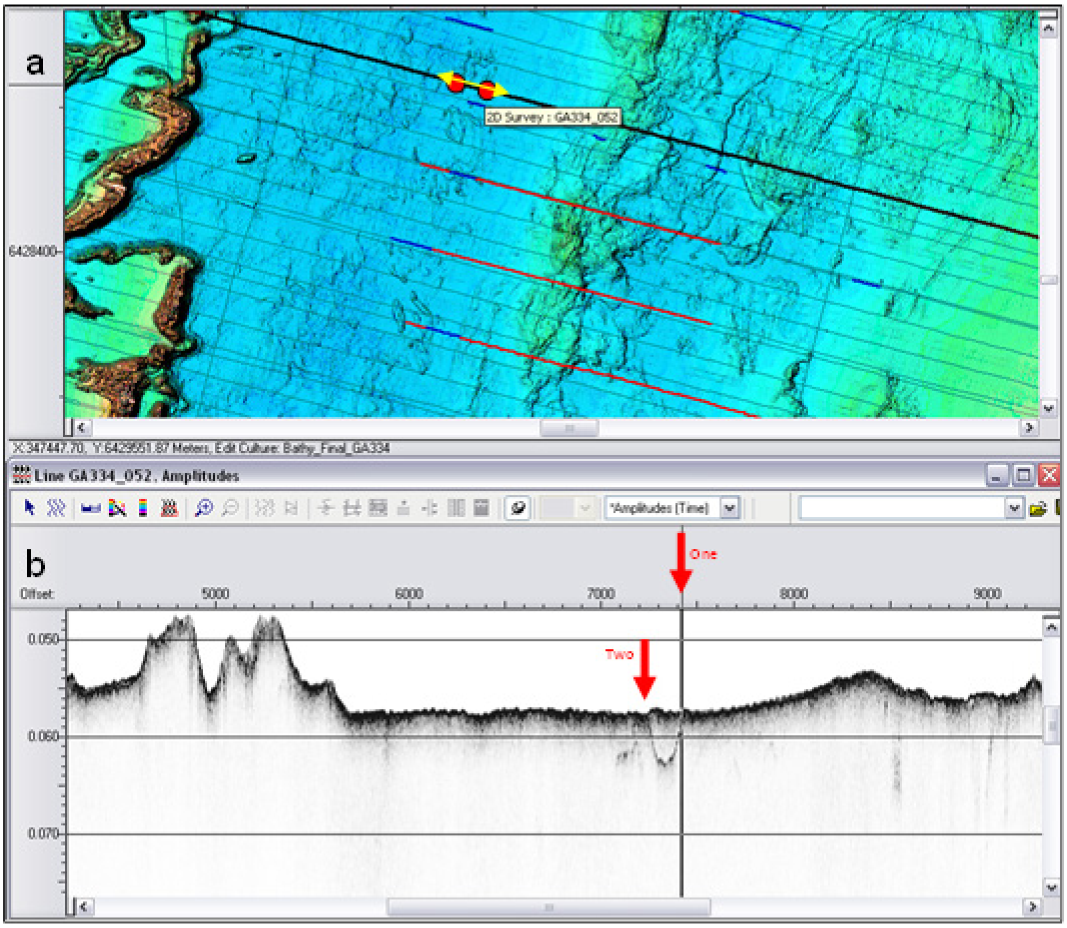

Figure A28: *Figure consisting of a) bathymetry with sub-bottom profile lines, and b) sub-bottom line GA334_052 used to choose sampling station and possible towed-video transect above anomaly visible in the SBP line.*

Location: eastern flank of carbonate bank

X1 Easting: 347447 **X2 Easting:** 347251

Y1 Northing: 6429551 **Y2 Northing:** 6429571

Depth 1: 48 m **Depth 2:** 49 m

GA334, Area 2, sampling grid D, sample station selection

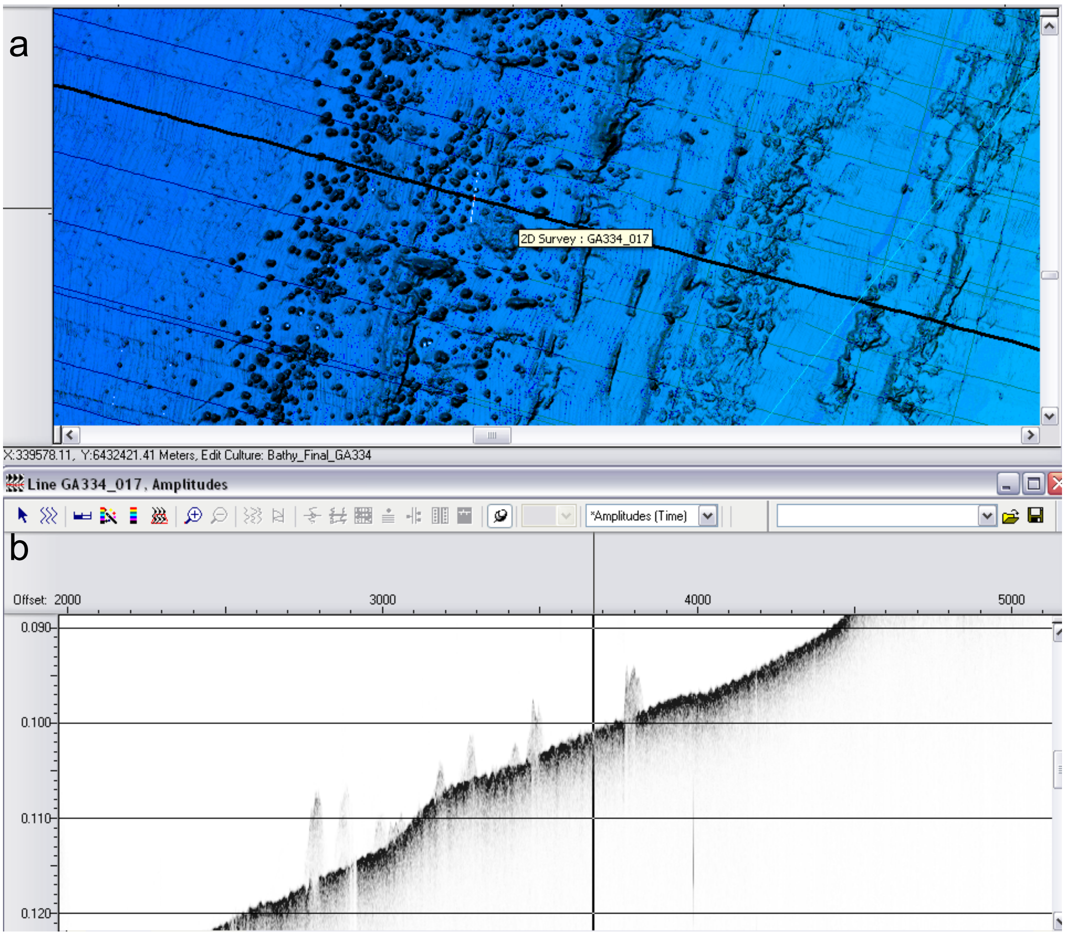

Figure A29: *Image consisting of a) bathymetry and b) sub-bottom profile line GA334_017 showing mounds on upper continental shelf which may be associated with hydrocarbon seepage and/or faulting.*

Location: upper part of slope within mound field

Easting: 339578

Northing: 6432421

Depth: 82 m

GA334, Area 2, sampling grid E, sample station selection

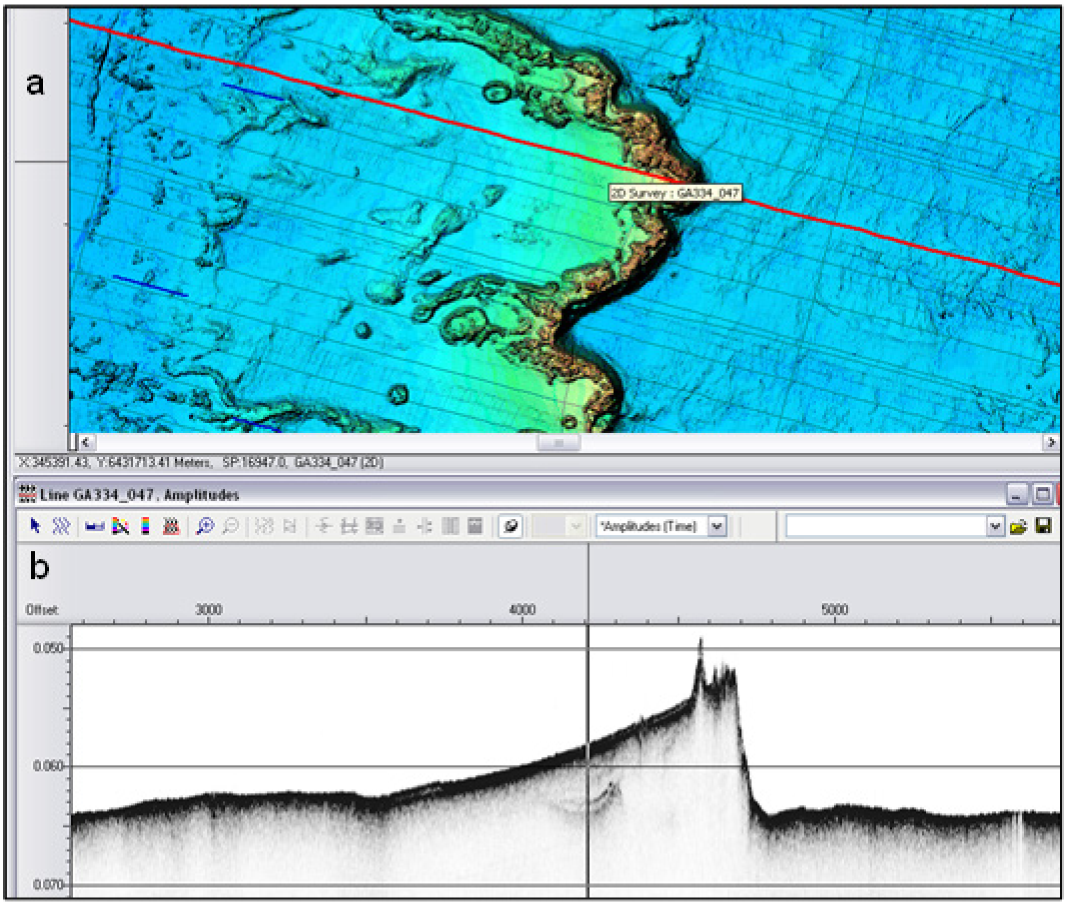

Figure A30: *Figure consisting of a) bathymetry and b) sub-bottom profile line GA334_047 at the seaward side of a major parabolic ridge. This location was chosen as a possible source for carbonate sediment over an unidentified structure in the sub-bottom imagery.*

Location: western flank of major carbonate bank

Easting: 345391

Northing: 6431713

Depth: 44 m

GA334, Area 2, sampling grid E, sample station selection

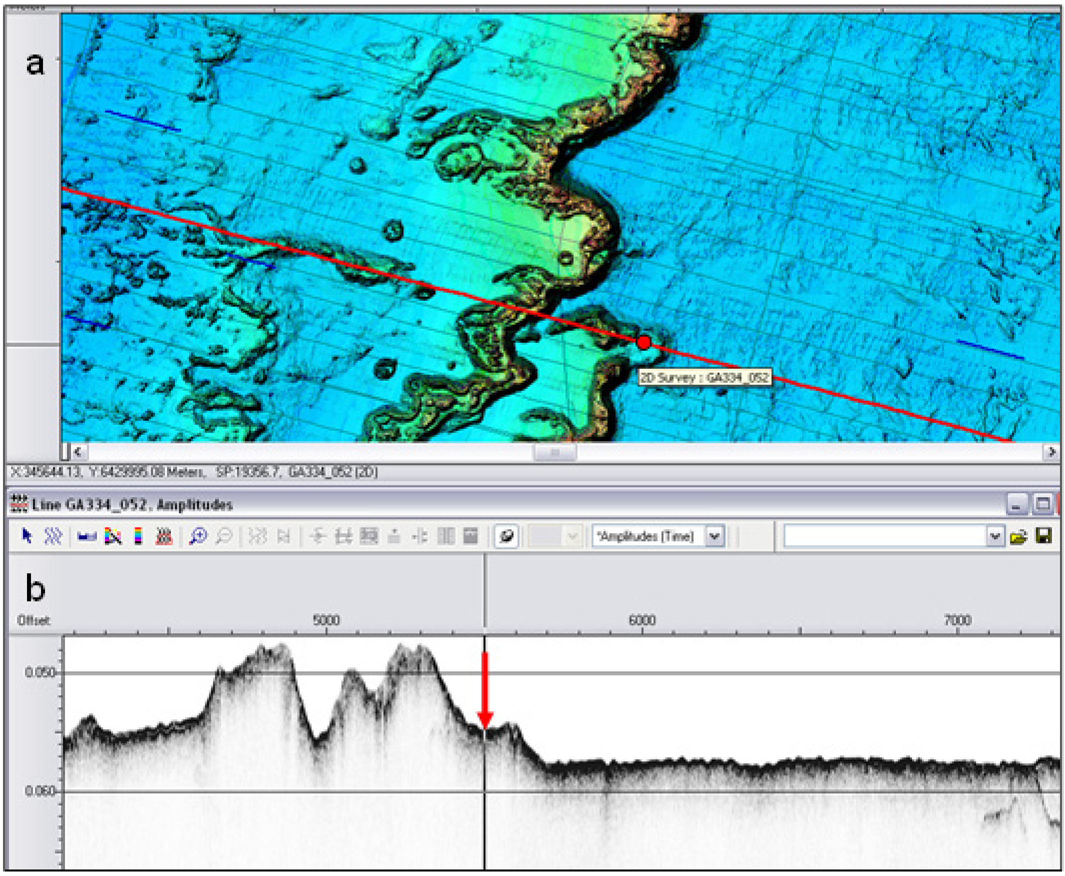

Figure A31: *Composite figure consisting of a) bathymetry and b) sub-bottom profile line GA334_052, with the chosen target being the landward side of a carbonate bank, possibly having loose sediment at the base of the ridge.*

Location: eastern flank of major carbonate bank

Easting: 345644

Northing: 6429995

Depth: 47 m

GA334, Area 2, sampling grid E, sample station selection

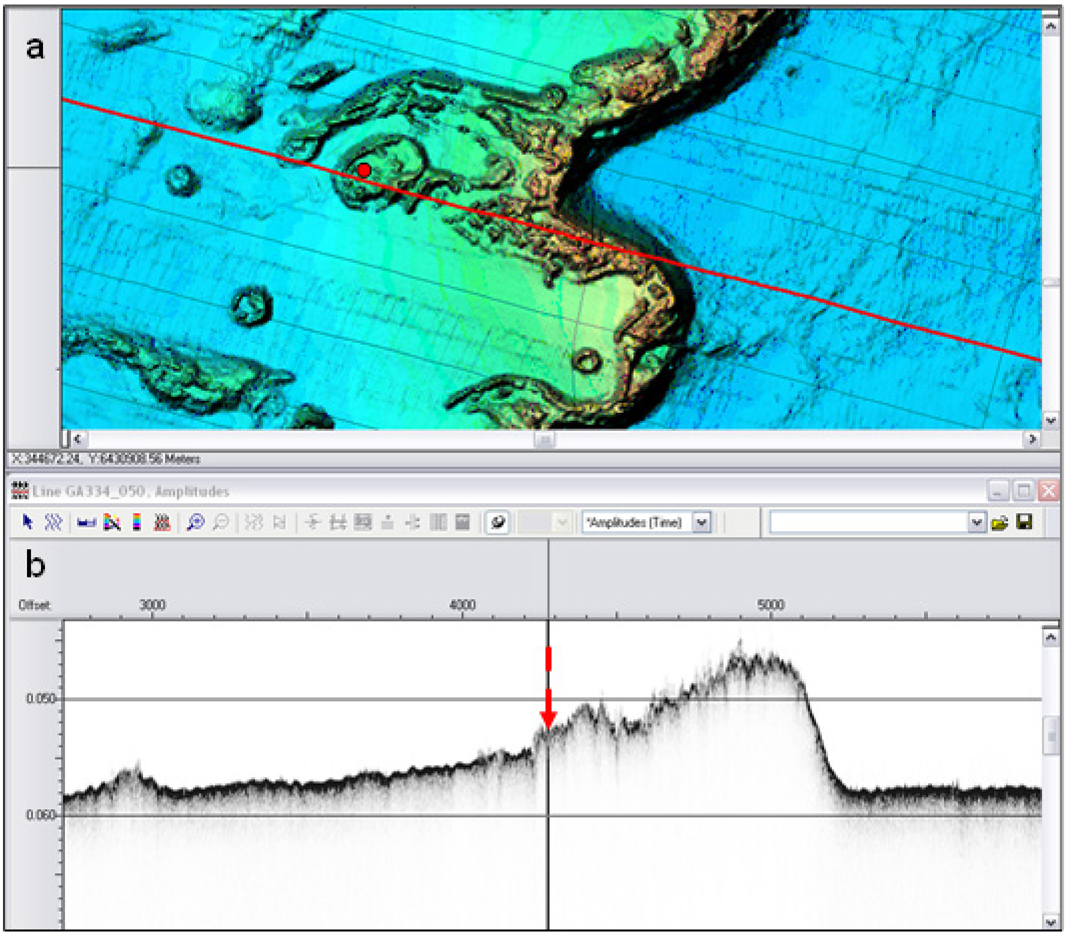

Figure A32: *Location of a single sampling station chosen (red dot) based on the annular structure in the bathymetry (a) and noted as a small bank (arrowed) in the sub-bottom profile (line GA334_050) with poor acoustic penetration.*

Location: western side of carbonate bank, within semi-circular reefal build-up.

Easting: 344672

Northing: 6430908

Depth: 45 m

SBP chirper line: GA334_050. Sampling station is 30 m north of SBP line.

GA334, Area 2, sampling grid F, sample station selection

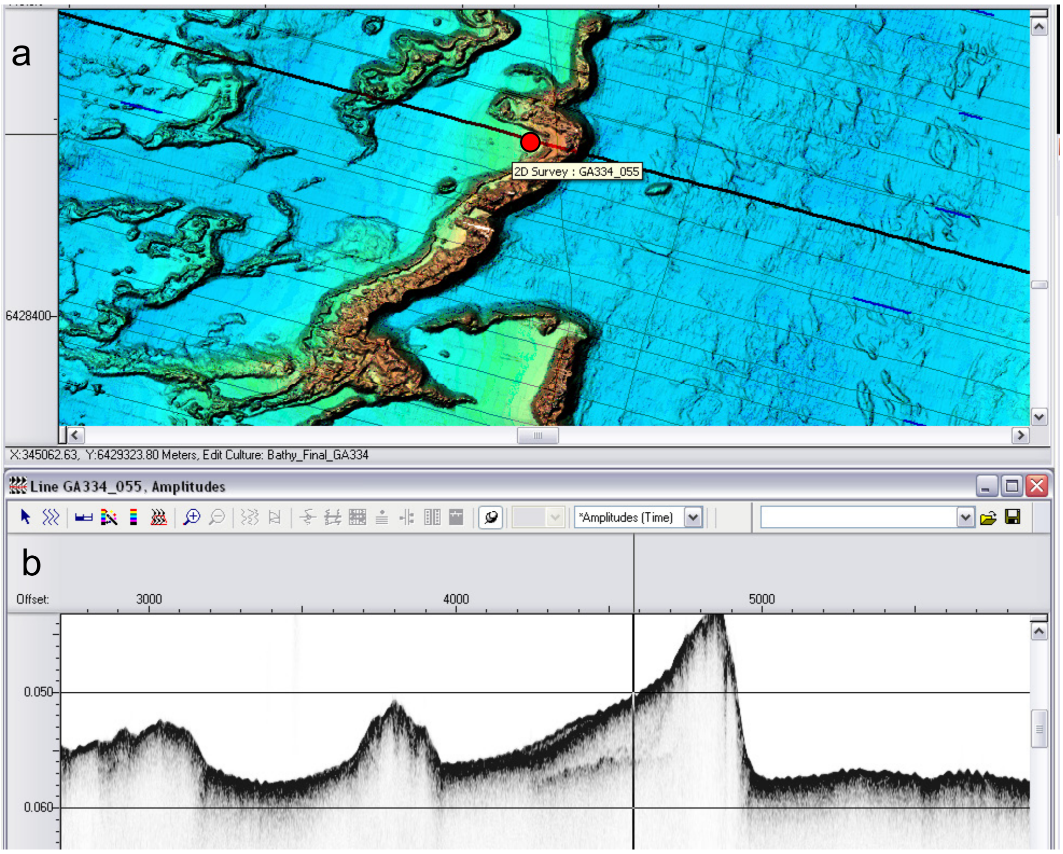

Figure A33: *Location of a single sampling station chosen because it is adjacent to a significant ridge, visible in bathymetry (a) as a parabolic ridge, and in b) as a structural high lacking major internal reflectors in the sub-bottom profile line (GA334_055).*

Location: western flank of carbonate bank

Easting: 345062

Northing: 6429323

Depth: 43 m

GA334, Area 2, sampling grid G, sample station selection

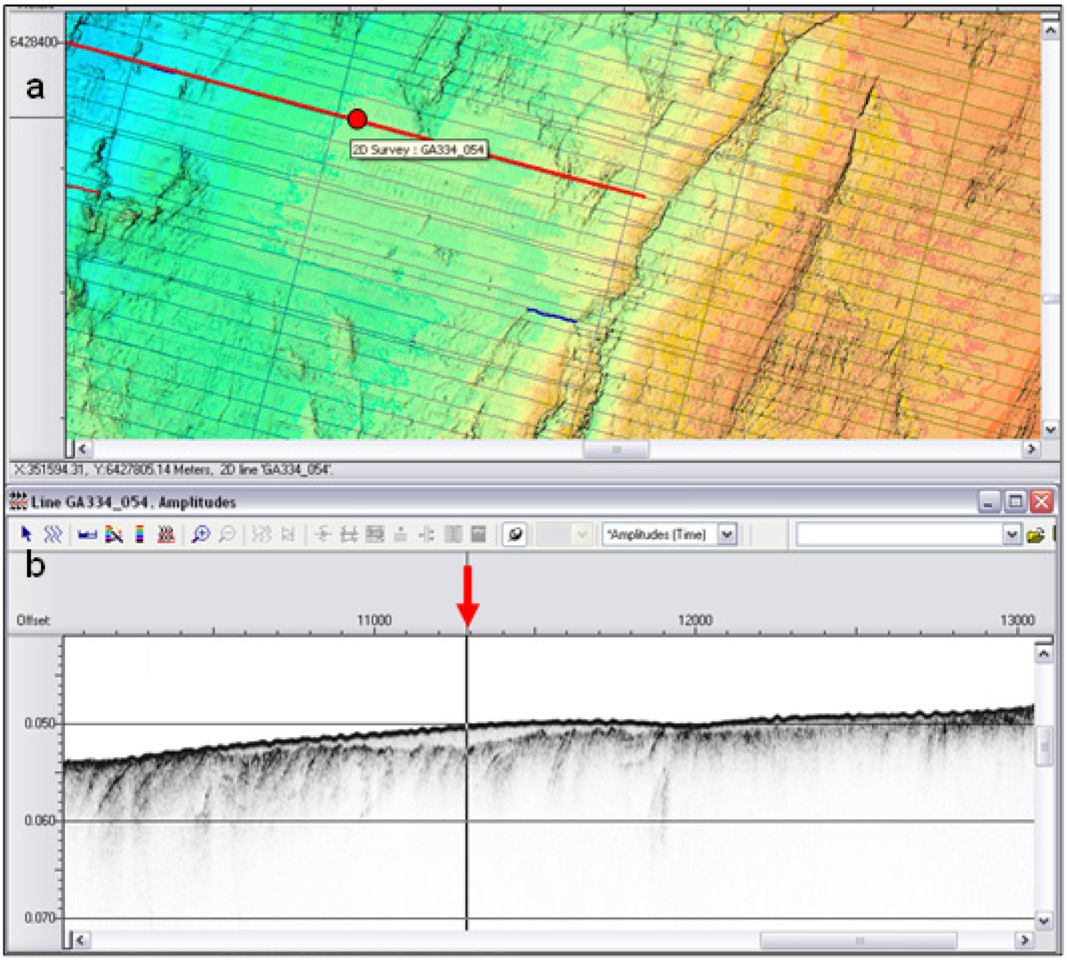

Figure A34: *Composite figure of a) bathymetry and b) sub-bottom profile line GA334-054 indicating a smooth seabed, possibly indicating some sediment cover. The red dot on bathymetry and arrow on the sub-bottom profile indicating the chosen location of sampling at this low priority site.*

Location: sediment lobe in middle section of Area 2 over palaeo-surface.

Easting: 351594

Northing: 6427805

Depth: 43 m

GA334, Area 2, sampling grid H, sample station selection

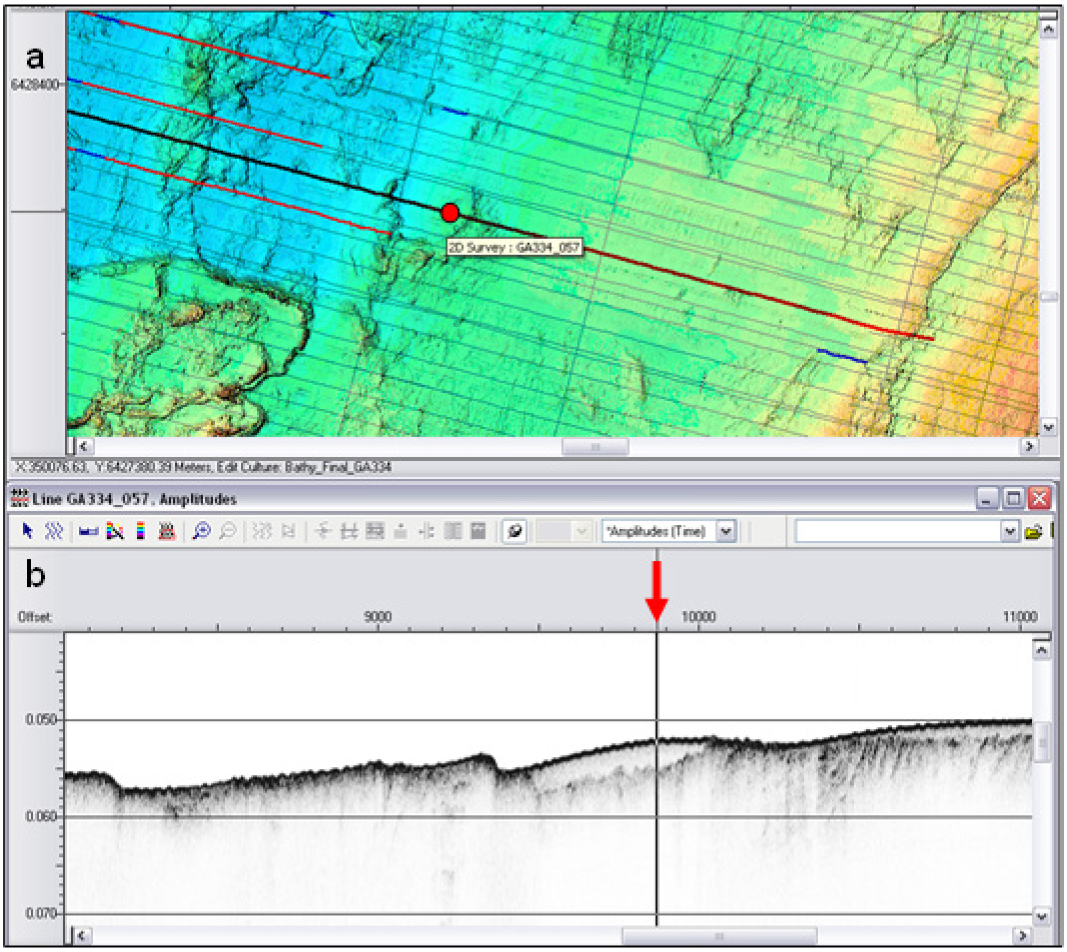

Figure A35: *Composite figure of a) bathymetry and b) sub-bottom profile line GA334-057 over what may be a sediment wedge (arrowed) that in turn overlies bedrock. This location was identified as a possible sampling station to collect surface sediment.*

Location: sediment lobe in middle section over palaeo-surface

Easting: 350076

Northing: 6427380

Depth: 45 m

GA334, Area 2, sampling grid I, sample station selection

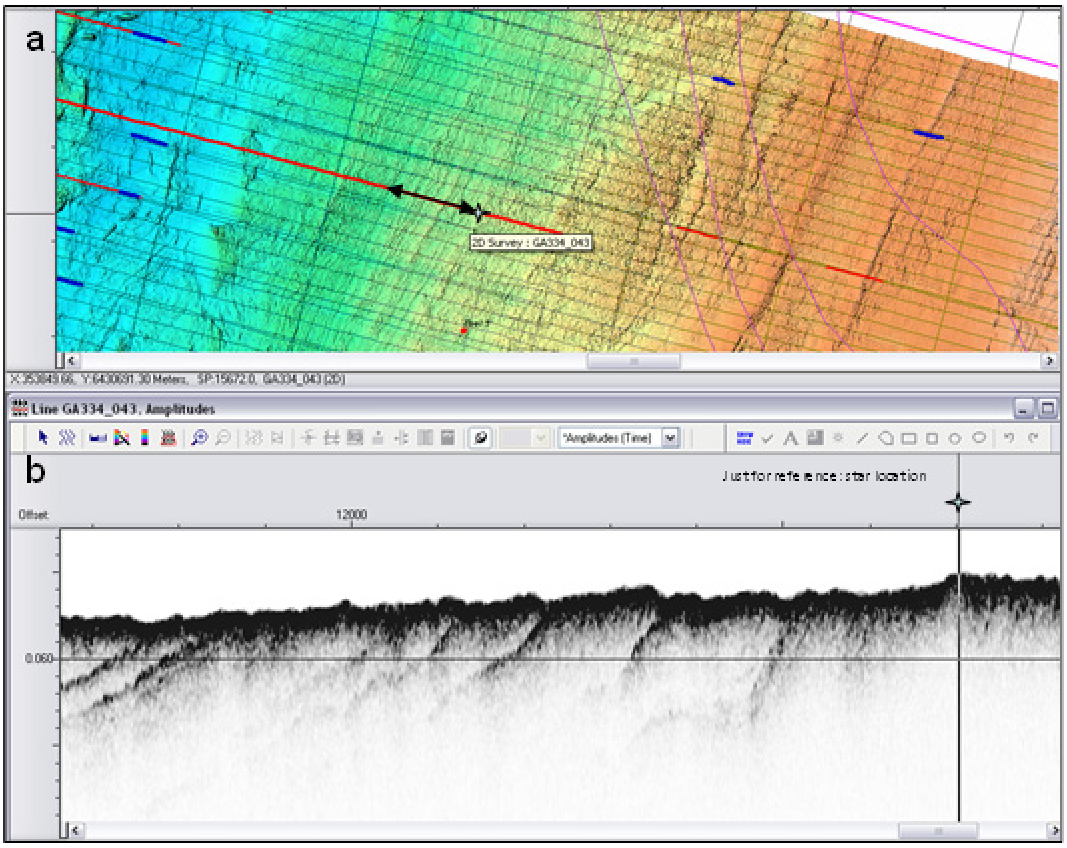

Figure A36: Location of possible towed-video station based on a) bathymetry and b) sub-bottom profile line GA334_094 indicating dipping reflectors and bedrock at the surface. Location of star indicating easternmost extent of the selected transect.

Location: middle section of Area 2 with exposed bedrock surface.

Start Easting: 353849 **Start Northing:** 6430691

End Easting: 352903 **End Northing:** 6430960

Length: ~ 900 m

Depth: ~ 43 m

GA334, Area 2, sampling grid J, sample station selection

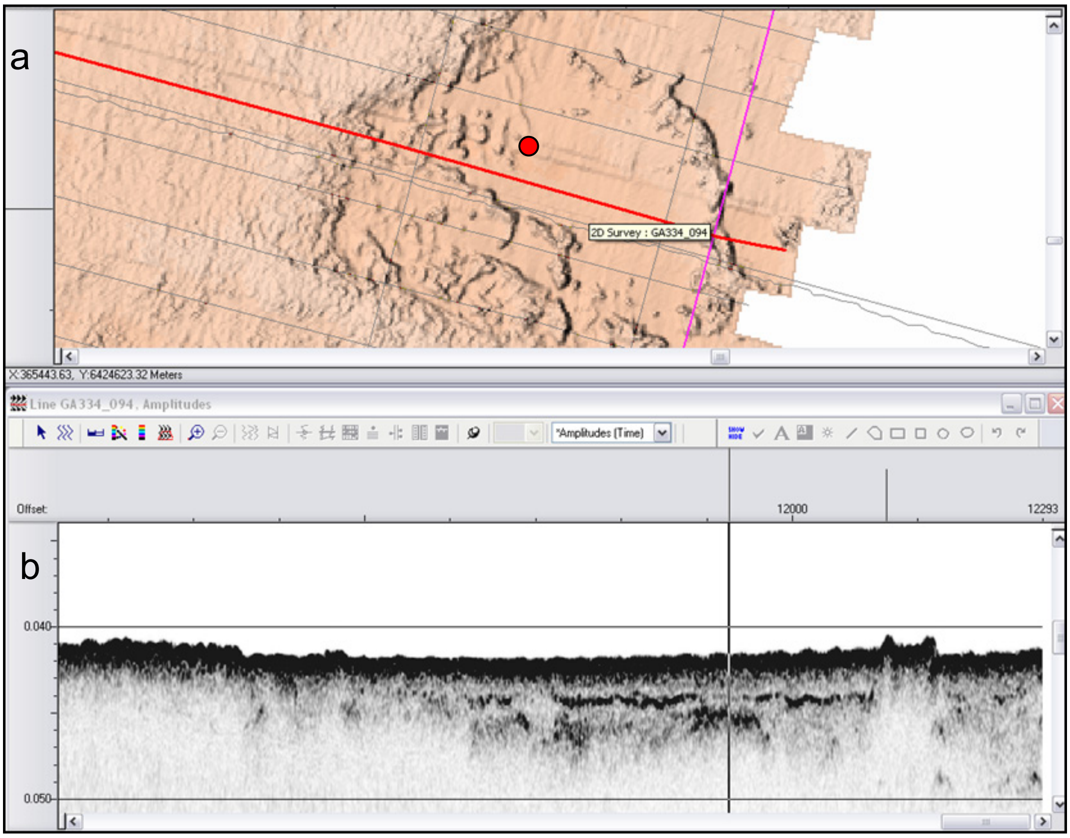

Figure A37: *Shallow depression visible in a) bathymetry, and b) sub-bottom profile line (GA334_094), and chosen as the only sampling station to acquire sediment samples from, on the innermost section of Area 2 because the main focus was on the large ridges on the mid and outer sections of Area 2. The targeted location (red dot in a; arrowed in b) chosen because of the possiblity of collecting a reasonable amount of sediment.*

Location: eastern end of Area 2, over a shallow seafloor depression.

Easting: 365443

Northing: 6424623

Depth: 36 m

Appendix C. Initial Observations on Sediment Samples

Table A.2: *Initial sediment sample descriptions from core catcher and grab samples GA 334 Vlaming Sub-basin marine survey (continued overleaf).*

Sample	Station	Method	Longitude	Latitude	Depth	Brief Description
01GC01 cc	1	GRAVITY CORER (core catcher)	115.57071167	-32.30710833	36.2	Generally dark brown coarse-grained sand, many apparent relict grains, dominantly subrounded, dominantly brown colours for both carbonate and non-carbonate grains.
01GC02 cc	1	GRAVITY CORER (core catcher)	115.57071333	-32.30711333	36.2	Dark brown, coarse-grained sand, many apparent relict grains, dominantly subrounded, dominantly brown colours for carbonate and non-carbonate grains.
05GC05 cc	5	GRAVITY CORER (core catcher)	115.36103000	-32.29355000	44	Pale yellow fine sand, mixture of angular recently broken shells and other fragments and forams, and older grains, minor rounded quartz present
09GC06 cc	9	GRAVITY CORER (core catcher)	115.36136111	-32.25613333	46	Pale yellow, coarse sand, generally subrounded grains, shell fragments, forams, sponge spicules. Particularly noticable that shell fragments display some dissolution features consistent with subaerial exposure
10GC07 cc	10	GRAVITY CORER (core catcher)	115.35936111	-32.24062778	46	Very coarse-grained sand, consisting of mixed shell fragments, forams, rhodolith pieces, almost 100% carbonate. Same as 09 GC 06 cc.
11GC08 cc	11	GRAVITY CORER (core catcher)	115.35117222	-32.24776389	46	Coarse-grained angular sand including forams and rhodolith pieces.
12GC09 cc	12	GRAVITY CORER (core catcher)	115.29738611	-32.23340556	82.8	Very coarse to granular, poorly sorted carbonate sand rich in byrozoan and other sekeletal carbonate fragments. Rare modern red coralline algal grains, brown relict carbonate grains dominant.
17GC10 cc	17	GRAVITY CORER (core catcher)	115.37662217	-32.26082500	48.9	Mixed rhodolith and carbonate rubble with few shell fragments. At least two rhodolith pieces, freshly broken, have their core visible and consists of an open framework grey limestone.
18GC11 cc	18	GRAVITY CORER (core catcher)	115.37854167	-32.26031388	49.1	Very coarse-grained sand, dominantly subrounded carbonate grains, poorly sorted, many carbonate grains with brown/yellow colouration (oxidation/exposure?), minor component of recent fine grained, white, angular carbonate grains, very little if any silicate sand.
20GC12 cc	20	GRAVITY CORER (core catcher)	115.37405000	-32.21904722	48.7	Small amount of mixed coarse-grained carbonate sand and subrounded carbonate clasts, many of which are rhodolith fragments.
01GR02	1	VAN VEEN	115.57088000	-32.30713333	36.3	Dark brown, coarse-grained sand, many apparent relict grains, dominantly subrounded, dominantly brown colours for carbonate and non-carbonate grains.

Sample	Station	Method	Longitude	Latitude	Depth	Brief Description
02GR04	2	VAN VEEN	115.38639167	-32.30330833	43	Rhodoliths, mostly partially bleached, various colours.
03GR05	3	VAN VEEN	115.37353667	-32.29081333	45	Single rhodolith.
03GR06	3	VAN VEEN	115.37353833	-32.29081167	45.4	Coarse-grained yellow sand, shell pieces, forams, many grains exhibit evidence of dissolution, rare heavy minerals, rhodolith pieces.
03GR06	3	VAN VEEN	115.37353833	-32.29081167	45.4	2nd bag, rhodoliths, few shells, 2 clasts_one sandstone, the other black fine grained, as yet unknown composition.
04GR07	4	VAN VEEN	115.36436333	-32.29806167	44.1	Single rhodolith.
04GR07	4	VAN VEEN	115.36436333	-32.29806167	44.1	Coarse-grained sand, mixture of fresh and older grains, many older grains distinct by dissolution and rounding of shell margins, forams ostracods rhodolith pieces, sponge spicules, minor rounded quartz grains
05GR09	5	VAN VEEN	115.36103611	-32.29353611	44	Medium sand, includes elphiid forams, sponge spicules, and various other rounded and angular grains of carbonate including rhodolith pieces
06GR11	6	VAN VEEN	115.35264500	-32.28773000	46.2	Fine-grained, carbonate sand, well sorted, light yellow colour
07GR13	7	VAN VEEN	115.35736167	-32.28871333	45.6	Very coarse sand, small Batillaria_like gastropods, forams, rhodolith pieces and shell fragments, angular and subangular dominant
08GR14	8	VAN VEEN	115.35609667	-32.28476333	44.8	Very coarse-grained, moderately well sorted, carbonate dominant sand, with most grains being relict, some recent coralline algal grains, distinct by red colour
09GR19	9	VAN VEEN	115.36135556	-32.25614722	46.2	Sub angular to sub rounded grains including forams, rhodolith pieces, shell fragments and micromolluscs.
10GR20	10	VAN VEEN	115.35894444	-32.24061111	43.9	Single bleached rhodolith.
10GR20	10	VAN VEEN	115.35894444	-32.24061111	43.9	Pale coarse-grained carbonate sand, mixed angular and subrounded carbonate grains (i.e. mix of recent and relict grains), minor quartz, red coralline algal grains, well sorted. Yellowed relict carbonate ~ 10%
12GR25	12	VAN VEEN	115.29738056	-32.23340833	82.7	Very coarse-grained, angular carbonate sands, many individual grains are brown coloured.
13GR29	13	VAN VEEN	115.34795278	-32.25093050	47.8	Rhodoliths, mostly partially bleached, various colours.
13GR29	13	VAN VEEN	115.34795278	-32.25093050	47.8	Pale yellow medium carbonate sand, with coraline algal grains, well sorted.
14GR33	14	VAN VEEN	115.34436388	-32.28767222	38.1	Rhodoliths.
14GR33	14	VAN VEEN	115.34436388	-32.28767222	38.1	Very poorly sorted, coralline algal rubble, very small amount of very coarse and angular carbonate sand, rhodoliths to 5 cm long

Sample	Station	Method	Longitude	Latitude	Depth	Brief Description
15GR35	15	VAN VEEN	115.40796388	-32.28033333	44.6	Well sorted, medium-grained, subangular carbonate rich (60%) sand, subrounded quartz sand, fresh appearance (i.e. little discolouration of the carbonate to yellow/brown as visible in some other samples from this survey).
16GR36	16	VAN VEEN	115.42413888	-32.27667222	43.2	Well sorted medium-grained carbonate sand, angular and subangular carbonate grains, some of which are yellow colour (subaerial exposure/oxidation?)
17GR37	17	VAN VEEN	115.37680555	-32.26073333	49	Well sorted medium-grained carbonate sand, minor component of relict grains, evident by brown/yellow colouration.
18GR38	18	VAN VEEN	115.37836112	-32.26030278	48.9	Well sorted fine-grained carbonate sand, approximately 90% angular to sub-angular carbonate grains, the remainder principally rounded quartz grains
19GR39	19	VAN VEEN	115.35664722	-32.21489445	49.7	Rhodoliths
19GR40	19	VAN VEEN	115.35664167	-32.21490000	49.7	Rhodoliths and other fragments, one rhodolith recent_(pink), the rest partially discoloured (pink to green tobleached colours).
19GR40	19	VAN VEEN	115.35664167	-32.21490000	49.7	Coarse-grained angular carbonate sand, well sorted, coralline algal grains present
19GR41	19	VAN VEEN	115.35664167	-32.21490000	49.7	Single bleached rhodolith
20GR42	20	VAN VEEN	115.37404445	-32.21904722	48.7	Corraline red algal, and coralline algal encrusted clasts, few white precipitate coated (algal probably) and rounded, one particularly dense (limestone/sst core?). Occasional serpulid worm casts on some outer surfaces.
21GR46	21	VAN VEEN	115.35322500	-32.21925555	47.9	Single rhodolith
27GR51	27	VAN VEEN	115.35398055	-32.21831667	50.1	Rhodoliths, or rhodolith-like clasts
27GR51	27	VAN VEEN	115.35398055	-32.21831667	50.1	Poorly sorted very coarse carbonate sand consisting overwhelmingly of subrounded, relict, carbonate grains, also angular rhodolith rubble (gravel) of up to 4 cm length.
29GR56	29	VAN VEEN	115.44246333	-31.83736333	42.4	2 small boundstone clasts, brown staining on surface of one, and aragonite needles present.
29GR57	29	VAN VEEN	115.44246333	-31.83736333	42.4	Rhodoliths, mostly partially bleached, various colours
29GR57	29	VAN VEEN	115.44246333	-31.83736333	42.4	Small 1.5 cm long angular clast, iron/red-brown staining on bottom half, similar colour to other larger clasts recovered from this survey, staining only on outside.
29GR58	29	VAN VEEN	115.44246333	-31.83736333	42.4	Rhodoliths, mostly bleached, cobble-sized.
30GR59	30	SHIPEK	115.40102833	-31.83877500	44.7	Pale to white coarse-grained carbonate sand, moderately sorted, minor quartz (5%). The carbonate grains are generally angular to subangular, and some few red coralline algal grains present also (5%)
31GR62	31	VAN VEEN	115.41505500	-31.86193333	25.7	Cobble-sized rhodoliths, bleached, partly bleached to red/pink.

Sample	Station	Method	Longitude	Latitude	Depth	Brief Description
31GR62	31	VAN VEEN	115.41505500	-31.86193333	25.7	Two small tube-like pieces, probably organic carbonate originally, now replaced?
33GR64	33	VAN VEEN	115.43196167	-31.86341333	46.6	Fine-grained, pale yellow carbonate sand, dominantly angular carbonate grains, approximately 100% carbonate, few red coralline algal pieces/grains
34GR65	34	VAN VEEN	115.45679167	-31.84448667	41.3	Cobble-sized, open-framework porous carbonate clast with possible qtz grains.
35GR66	35	VAN VEEN	115.45198333	-31.83952167	44	Cobble-sized rhodoliths, porous open framework algal bound clasts, commonly consisting of fine to medium grained sand interlayered with discontinuous algal encrustations
36GR67	36	VAN VEEN	115.45783000	-31.83726333	43.3	Medium-grained, well sorted carbonate sand with rare red coralline algal grains. Bimodal angularity: rounded relict and subangular and angular modern carbonate grains
36GR67	36	VAN VEEN	115.45783000	-31.83726333	43.3	Single pebble-sized (carbonate-rich?) sandstone with rounded brown crystalline grains (coloured qtz?), encrusted by bryozoa, coralline algae and serpulid worm casts.
36GR69	36	VAN VEEN	115.45781167	-31.83726333	43.3	Cobble sized, red coralline algal encrusted open framework clasts, one rhodolith
36GR69	36	VAN VEEN	115.45781167	-31.83726333	43.3	Rock sample; limestone clast, algal encrusted on upper surface, mostly bleached, and red-brown rust like staining on lower half. Some few encrusting bryozoans, medium-grained, crystalline, bedding present. No encrustation on iron?-stained, lower half. Effervesces on fresh surface with dilute HCl.
37GR72	37	VAN VEEN	115.46100278	-31.86221112	45.3	Rock sample: large carbonate clast, calcretised, algal carbonate coatings on undersurface, encrusting algae on upper corner
37GR73	37	VAN VEEN	115.46100555	-31.86220833	45.5	Coarse-grained, quartz rich sand, moderately well sorted, rounded to angular carbonate grains and rounded quartz and other crystalline minerals.
38GR77	38	VAN VEEN	115.43838888	-31.86252217	45.1	Rhodoliths, mostly coloured (unbleached).
39GR80	39	VAN VEEN	115.45226388	-31.86268612	45.7	Very coarse-grained sand, moderately well sorted angular carbonate grains, including coralline algal pieces, approximately 100% carbonate.
40GR84	40	VAN VEEN	115.47370278	-31.83775000	43.1	Coarse-grained, quartz rich sand, rounded to angular carbonate grains and rounded quartz and other crystalline minerals.
43GR87	43	VAN VEEN	115.41426667	-31.87303055	45.9	Fine carbonate sand, angular carbonate grains dominant.

Appendix D. Locations of Towed Video Transects

Table A.3: *Towed video survey location and video transect details. Transect duration is in minutes:seconds.*

Station Number	Camera	Start Latitude	Start Longitude	End Latitude	End Longitude	Start Depth (M)	End Depth (M)	Transect Duration	Transect Length (M)	Seabed Description
12	CAM02	-32.236428	115.29635	-32.234975	115.290161	82.287	88.069	34:04	606	Rhodolith pavement (?) with sand waves between, few organisms
13	CAM01	-32.249227	115.345254	-32.251159	115.348484	48.195	46.025	31:37	373	Rhodolith pavement, kelp/algae, sand waves/ripples, sparse organisms
14	CAM03	-32.287599	115.344401	-32.287547	115.344702	39.479	38.388	10:08	81	Rhodolith beds (non-consolidated and consolidated)
22	CAM06	-32.262401	115.358506	-32.264892	115.353665	37.709	39.233	45:51	534	Rhodolith beds/pavement, dense organisms, kelp/algae
23	CAM04	-32.287584	115.344439	-32.286936	115.348989	39.039	37.111	30:29	438	Rhodolith pavement (consolidated), kelp/algae, few organisms, some unconsolidated rhodolith beds with sand, plating (sponges?) with nodules
24	CAM05	-32.278018	115.349545	-32.279093	115.354857	43.154	43.472	27:25	515	Rhodolith pavement kelp/algae, interspersed rhodolith rubble and sand, dense organisms on pavement
25	CAM07	-32.214877	115.356656	-32.219247	115.353262	49.418	49.632	40:55	580	Sand ripples, rhodolith rubble/bed, kelp on pavement
26	CAM08	-32.247136	115.469792	-32.246638	115.467188	40.675	41.081	18:19	256	Rocky outcrops, algae/kelp, sand waves, few organisms

Station Number	Camera	Start Latitude	Start Longitude	End Latitude	End Longitude	Start Depth (M)	End Depth (M)	Transect Duration	Transect Length (M)	Seabed Description
26	CAM09	-32.246174	115.465615	-32.245149	115.46101	41.213	41.93	30:43	448	Rocky outcrops, algae/kelp, sand waves, few organisms
30	CAM11	-31.842147	115.401388	-31.837621	115.40007	45.623	45.725	35:34	517	Rhodolith pavement interspersed with rhodolith beds and sand. Kelp.
32	CAM10	-31.8608	115.407092	-31.859689	115.410277	45.898	47.204	22:42	326	Rhodolith beds/unconsolidated with sand, kelp on rhodolith pavement
41	CAM12	-31.843966	115.45933	-31.846779	115.462399	43.965	42.35	33:26	426	Sand-waves, bedrock/pavement, kelp beds, .
42	CAM13	-31.862509	115.447048	-31.862408	115.442483	42.901	44.787	30:09	432	bedrock, kelp/algae, sand waves