GEOSCIENCE AUSTRALIA

Australian Government

Geoscience Australia

GEOSCIENCE AUSTRALIA SURVEY 267, POST SURVEY REPORT:

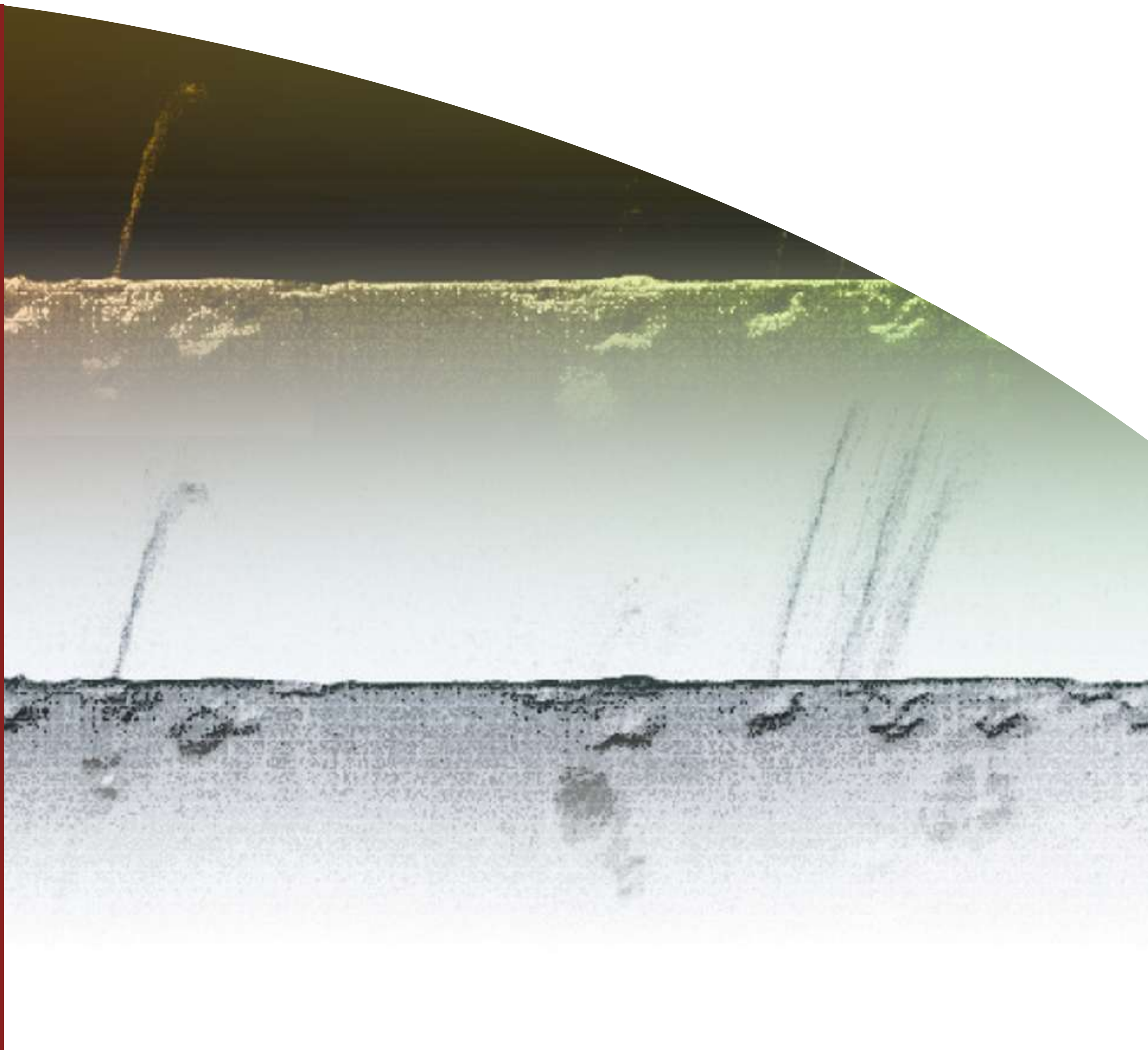
Testing natural hydrocarbon seepage detection tools on the Yampi Shelf, northwestern Australia

March 2004

Andrew T. Jones, Graham A. Logan, John M. Kennard, Phil E. O'Brien, Nadege Rollet, Mike Sexton and Kriton C. Glenn.

Record

2005/15



SPATIAL INFORMATION FOR THE NATION

Australian Government
Geoscience Australia

GEOSCIENCE AUSTRALIA SURVEY 267, POST SURVEY REPORT:

Testing natural hydrocarbon seepage detection tools on the Yampi Shelf, northwestern Australia

March 2004

GEOSCIENCE AUSTRALIA
RECORD 2005/15

by

Andrew T. Jones, Graham A. Logan, John M. Kennard, Phil E. O’Brien, Nadege Rollet, Mike Sexton and Kriton C. Glenn.

Department of Industry, Tourism & Resources

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

Geoscience Australia

Chief Executive Officer: Dr Neil Williams

ISSN: 1448-2177
ISBN: 1 920871 52 7

GeoCat No. 61717

Bibliographic reference: Jones, A.T., Logan, G.A., Kennard, J.M., O'Brien, P.E., Rollet, N., Sexton, M. and Glenn, K.C. Geoscience Australia Survey 267, Post Survey Report: Testing natural hydrocarbon seepage detection tools on the Yampi Shelf, northwestern Australia. *Geoscience Australia Record* 2005/15.

CONTENTS

FIGURES

TABLES

Executive Summary

The aim of the survey was to apply a range of electronic data gathering techniques over a known area of seepage to identify the signature of active natural hydrocarbon seepage in these various data sets.

It was found that plumes of gas bubbles are released from the sea floor and can be identified using side-scan sonar (100 and 500 kHz) and echo sounder (200 kHz). These plumes are most active during low tides and decrease in intensity as the tide height increases. Based on side-scan data, seepage is most commonly found within fields of pockmarks and/or reflective blocks a few meters across. These zones usually correlated with the edges of high velocity sea floor amplitude identified on 3D seismic.

Multi-beam sonar data was found to be very useful for mapping bathymetric features but did not have the resolution for feature mapping that the side-scan sonar provides. The mapped bathymetry provides new evidence for channel features not marked on hydrographic charts. The channels correlate with Synthetic Aperture Radar slicks, previously interpreted as hydrocarbon related. Acoustic Doppler Current Profile data collected around the channels shows that current velocities and tidal effects are most probably responsible for slick formation.

The combination of geological data gathered, within an onboard Geographic Information System, correlated with side-scan, and multi-beam sonar plus echo sounder data is a very powerful survey mode for the identification of active natural hydrocarbon seepage. This allows the identification of features within the water column and on the sea floor, which can then be targeted for sampling. These techniques should be used in combination on future seepage surveys, along with the collection of sub-surface data provided by sub-bottom profiles.

Chapter 1. Introduction

This report outlines the methods that were used to collect and analyse the data and details the operational results of the survey. This report does not document the scientific outcomes of the survey, which are to be published in peer reviewed journals. These papers will be referred to if they have been published/submitted prior to the compilation of this report.

The Yampi Shelf is a proven hydrocarbon province on the North West Shelf (NWS), which forms the eastern flank of the northern Browse Basin and adjoins the Caswell Sub-basin to the west (Fig. 1.1). Total sediment thickness in this area is less than 1 km, and it lies in 40-100 m water depths. It is the inboard part of a Palaeozoic to Mesozoic structural ramp which dips to the northwest (Symonds et al., 1994; Struckmeyer et al., 1998). Oil and gas discoveries at the Gwydion and Cornea fields, although considered uneconomic, have validated the existence of an Early Cretaceous petroleum system and suggest that the Yampi Shelf is favourably situated to receive charge from the mature source rocks within the adjacent Caswell Sub-basin (Spry and Ward, 1997; Blevin et al., 1998; Ingram et al., 2000).

Over the last decade, investigations have revealed the Yampi Shelf to be an area of widespread and intense palaeo- and present day hydrocarbon seepage (O'Brien et al., 1998, 1999, 2000, 2001, 2002, 2003). Seepage has been identified via seismic, water column geochemical sniffer, airborne laser fluorosensor (ALF), LANDSAT and synthetic aperture radar (SAR) data.

The seepage model for the region includes mature, Early Cretaceous, oil-prone source rocks and older, over-mature, gas-prone source rocks generating hydrocarbons 50 to 80 km outboard of the Yampi Shelf (O'Brien et al., 2000). This oil and gas migrates, through a number of stages, into structures on the edge of the basin (Fig. 1.2). Gas migrates through the regional seal where the seal thins over topographically prominent tilt blocks and basement highs. Further inboard these topographic highs are largely bald of sealing facies and massive gas seepage results. At the basin edge, significant volumes of oil seep at, or close to, the effective regional zero edge of seal. Therefore the model suggests progressive seal capillary failure towards the basin margin having naturally fractionated the migrating hydrocarbons (O'Brien et al., 2000).

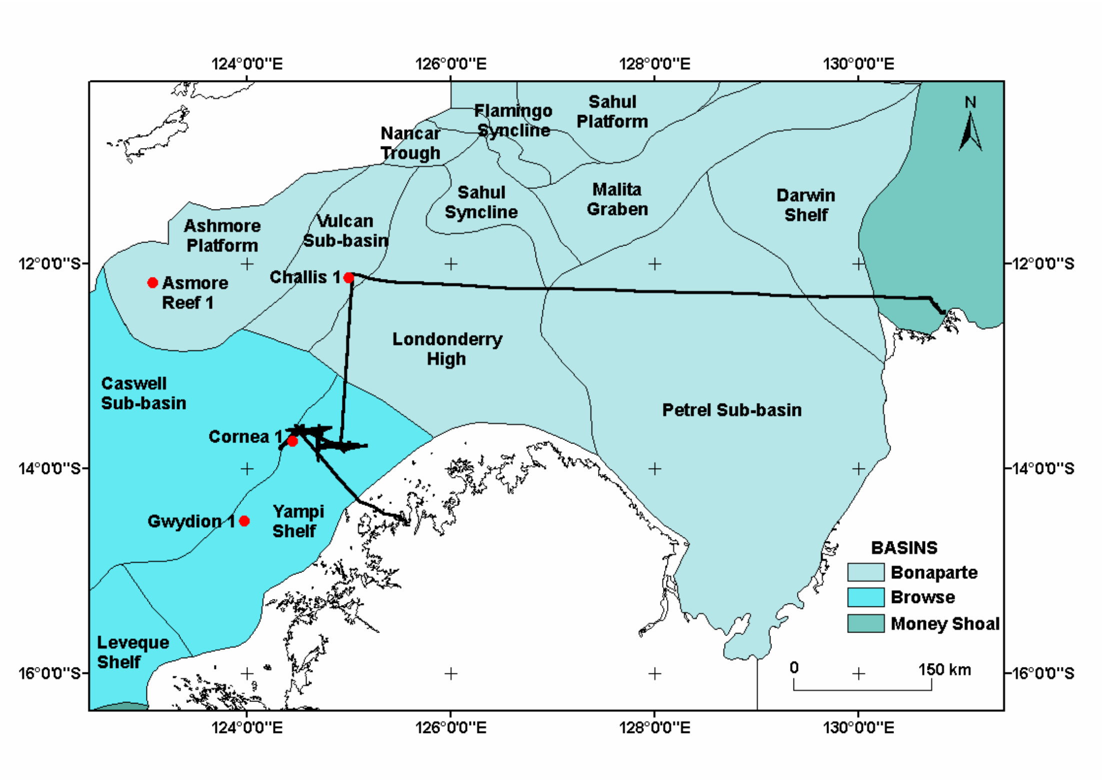


Figure 1.1. Basin elements of the northern North West Shelf, some of the key wells in the region, and the ship track taken by S267 (not including the final transit to Broome)

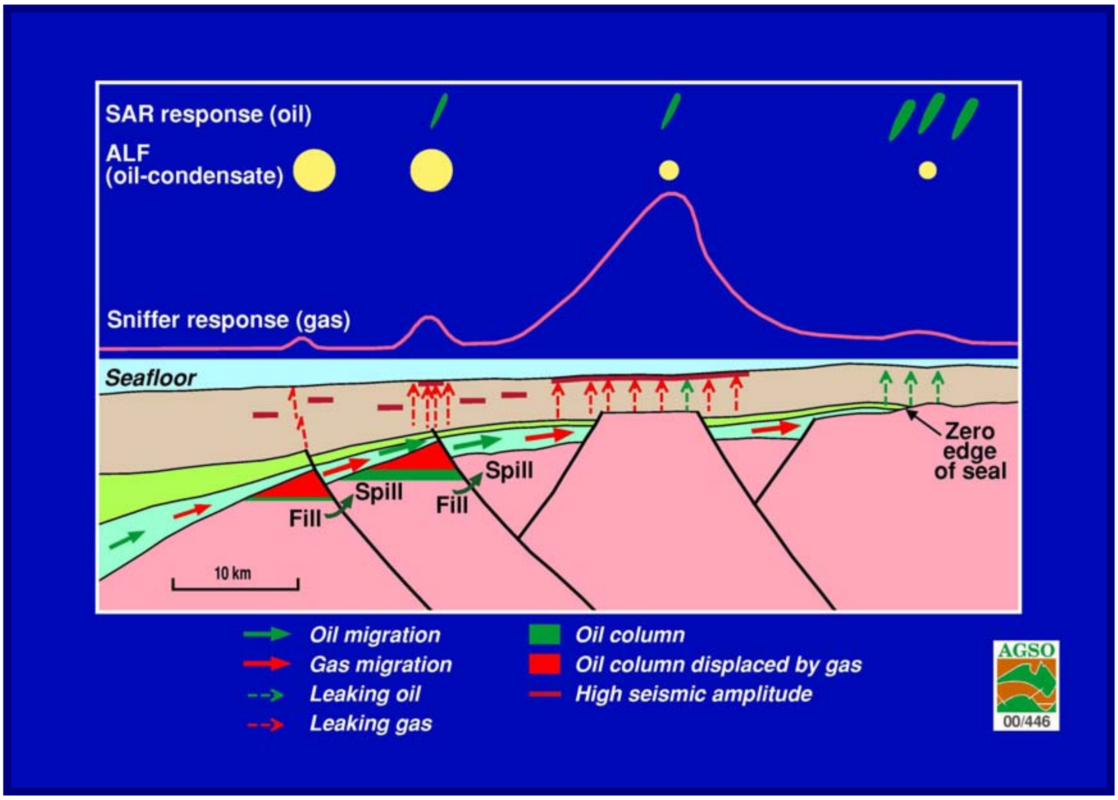


Figure 1.2. Hydrocarbon seepage model for the Yampi Shelf (O'Brien et al., 2000)

The aims of Survey 267 were to test and validate a range of techniques used in the detection/identification of natural hydrocarbon seepage. The Yampi Shelf was selected as a test location due to the well documented occurrences of seeps in the region. The purpose of ground-truthing the various survey and remote sensing techniques was so that the knowledge and experience gained could be used in detecting active petroleum systems in frontier basins.

The survey was undertaken on the vessel *Parmelia K* (Fig. 1.3), a 28 m pearling boat that forms part of the *Broome Pearls* fleet, based out of Broome, Western Australia. Survey staff are listed in Appendix A. The vessel had not been used for survey work before and required an extensive re-fit process to accommodate the digital processing and sediment sampling equipment. Initial transit from Darwin on the 2^{nd} of March lasted only 3 hours, making 4 knots headway into 25 to 36 knot winds. Sea conditions were very rough, and the Bureau of Meteorology reported Cyclone *Evan* reforming in Bonaparte Gulf, therefore the vessel's Master and the survey leader agreed to turn back for Darwin.

The survey re-departed Darwin for the Challis production facility at 20:50 on the 3^{rd} of March (UTC).

Figure 1.3. The 'Parmelia K'

The preliminary phase of the survey involved a circumnavigation of the Challis production facility (Fig. 1.1). The purpose of this step was to ground-truth the towed fluorometer with the produced formation water (PFW) pumped from the Challis facility. PFW slicks from this facility have been imaged in multiple SAR scenes covering the area (NPA et al., 1999).

The second, primary phase of the survey involved electronic data acquisition and sampling in four areas on the Yampi Shelf (Fig. 1.4). In selecting the four areas the following features were analysed in a Geographic Information System (GIS): the spatial distribution of oil and gas fields (Ingram et al., 2000), hydrocarbon related diagenetic zones (HRDZs; O'Brien and Woods, 1995; Shell, 2000), pockmarks (O'Brien et al., 2002), SAR slicks (NPA et al., 1999), LANDSAT and sniffer anomalies (O'Brien et al., 1996, 2000, 2001; Wilson, 2000) and fluorescent sea surface samples (Edwards and Crawford, 1999). The potential seepage indicators being assessed in each of the areas was as follows:

Area 1 – HRDZs, Cornea oil and gas field;

Area 2 – HRDZs, LANDSAT anomalies, fluorescent sea surface sample, close to significant (>100x background) sniffer anomaly;

Area 3 – SAR slicks, LANDSAT anomaly;

Area 4 – SAR slicks, close to pockmarks.

The survey was abandoned at 22:30 on the 14th of March (UTC), slightly earlier than planned, due to bad weather associated with the approaching Cyclone *Faye* (Fig. 1.5).

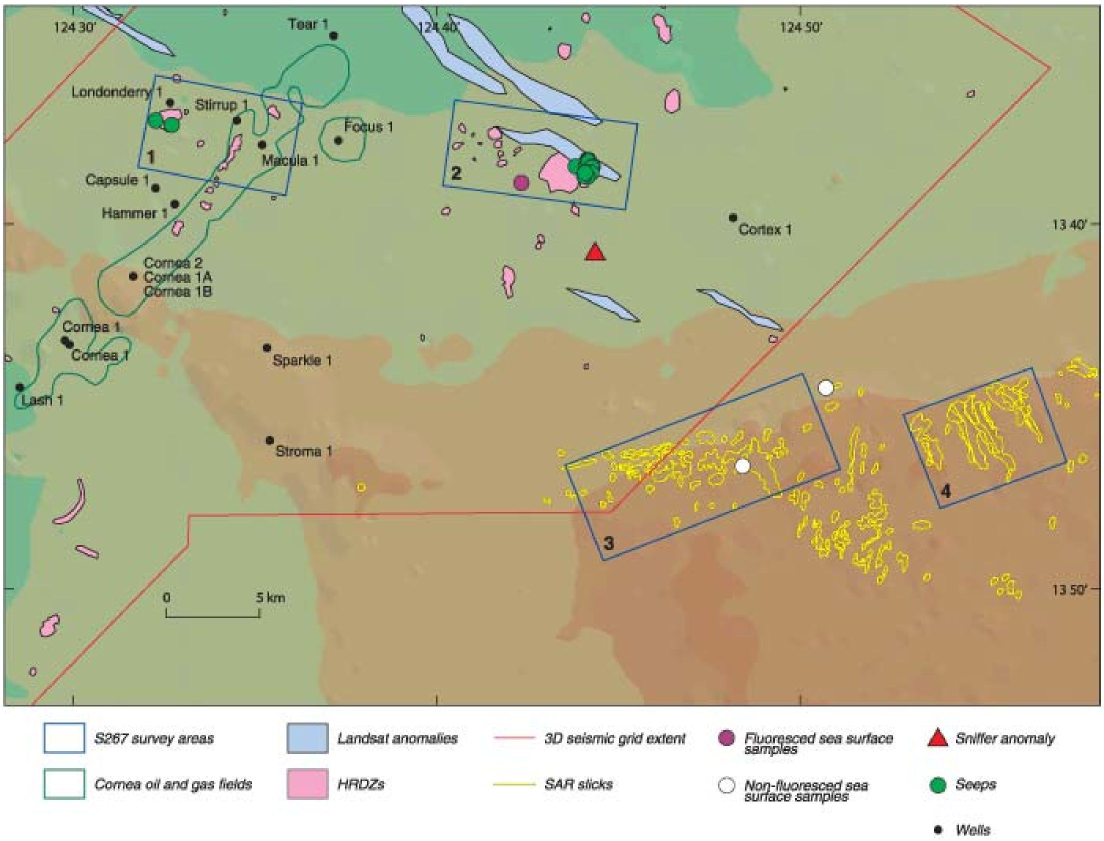


Figure 1.4. SAR, LANDSAT and HRDZ datasets utilised in planning S267. Location of the Cornea oil and gas field, active seeps imaged and observed during S267, the 100 times background sniffer anomaly and surface seawater samples from GA survey 207

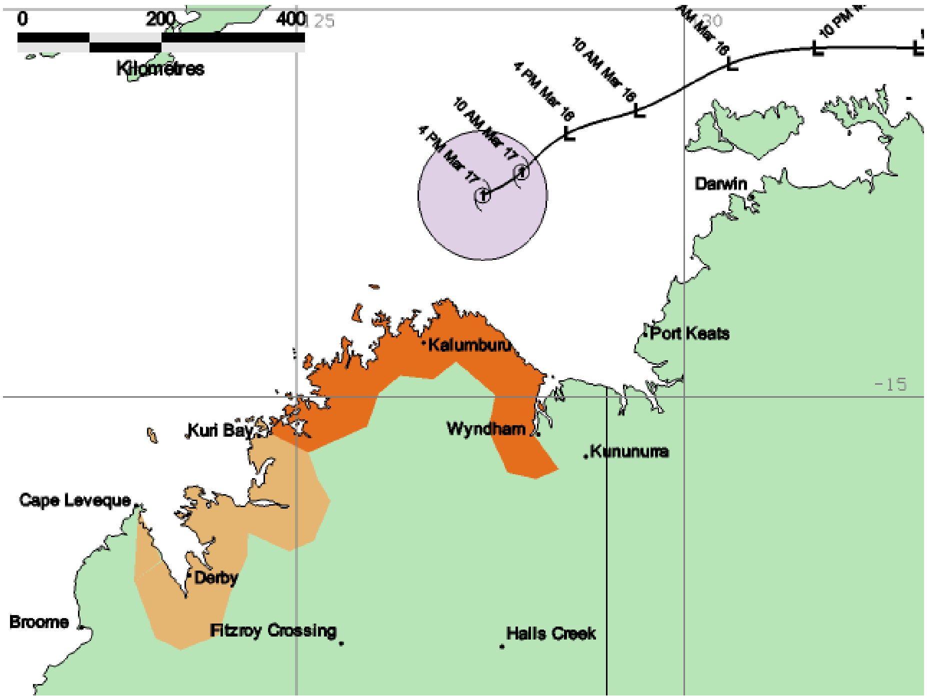


Figure 1.5. Track of tropical cyclone *Fay*. Colours indicate degree of predicted impact on coastal communities

Chapter 2. Methods

2.1. Echosounder

200 kHz echosounders were located near the bow and stern of the survey vessel, approximately 10 m apart. The echosounders came with the vessel as part of its navigation system, and digital recording was impossible. The echosounders provided a one-dimensional image of the entire water column directly below the vessel, a magnified view of the basal few metres of the water column, and gave an indication of the substrate type at that point. Attempts were made to capture images of the echosounder screens with the survey digital camera, but the resultant images were generally blurry or masked by the flash of the camera.

The objectives in monitoring the echosounders were to identify water column features that may represent natural seepage plumes and to accurately locate sampling tools relative to seeps when attempting to sample seafloor sediments.

2.2. Multibeam Swath Bathymetry

Multibeam swath bathymetry was collected using a SEABEAM shallow water multibeam echo sounder leased from Seismic Asia Pacific (SAP). The multibeam bathymetric system comprised two LSE-296 transducer arrays configured on a single V-shaped head, mounted at the end of a long pole which was firmly fixed to the port side of the vessel (Fig. 2.1). The transducers were approximately 4 m below the water line and were connected to a SEE-30 Transmit/Receive Unit operating at 180 kHz (Fig. 2.2). This unit was in turn interfaced with a Triton Elic workstation capable of running the applications Hydrostar, ISIS Sonar, BathyPro and DelphMap. A Geoscience Australia PC system running the Caris HIPS/SIPS processing software was networked to the Triton Elics system and had a HP650C plotter attached. The final components of the multibeam system were an IXSEA –"Octans" inertial motion sensor (leased from S.A.P.) which measured the attitude of the vessel and a DGPS system for supplying accurate navigation (Geoscience Australia owned). The Geoscience Australia PC had a DVD Burner and was networked to the Triton Elic workstations (Multibeam and Sidescan) by their engineer.

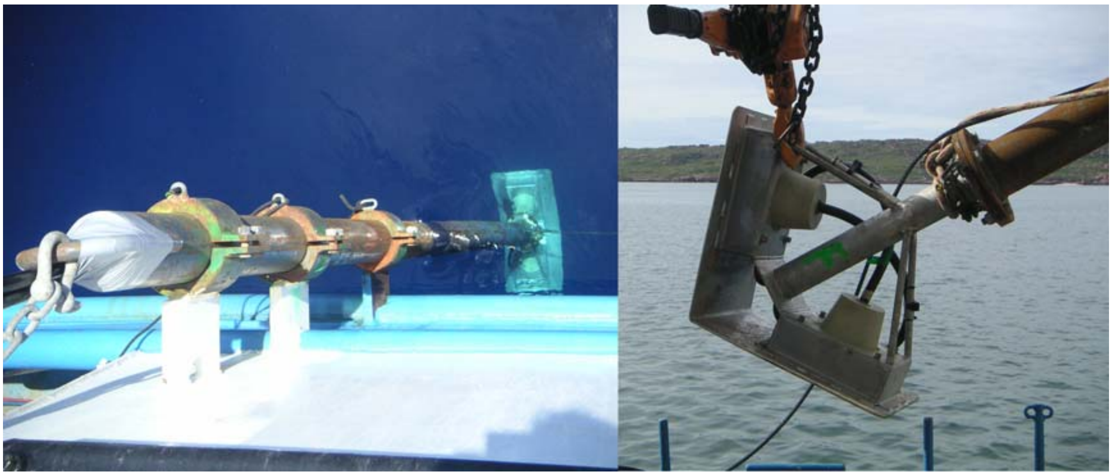


Figure 2.1. The V-shaped swath head mounted on the side of the vessel

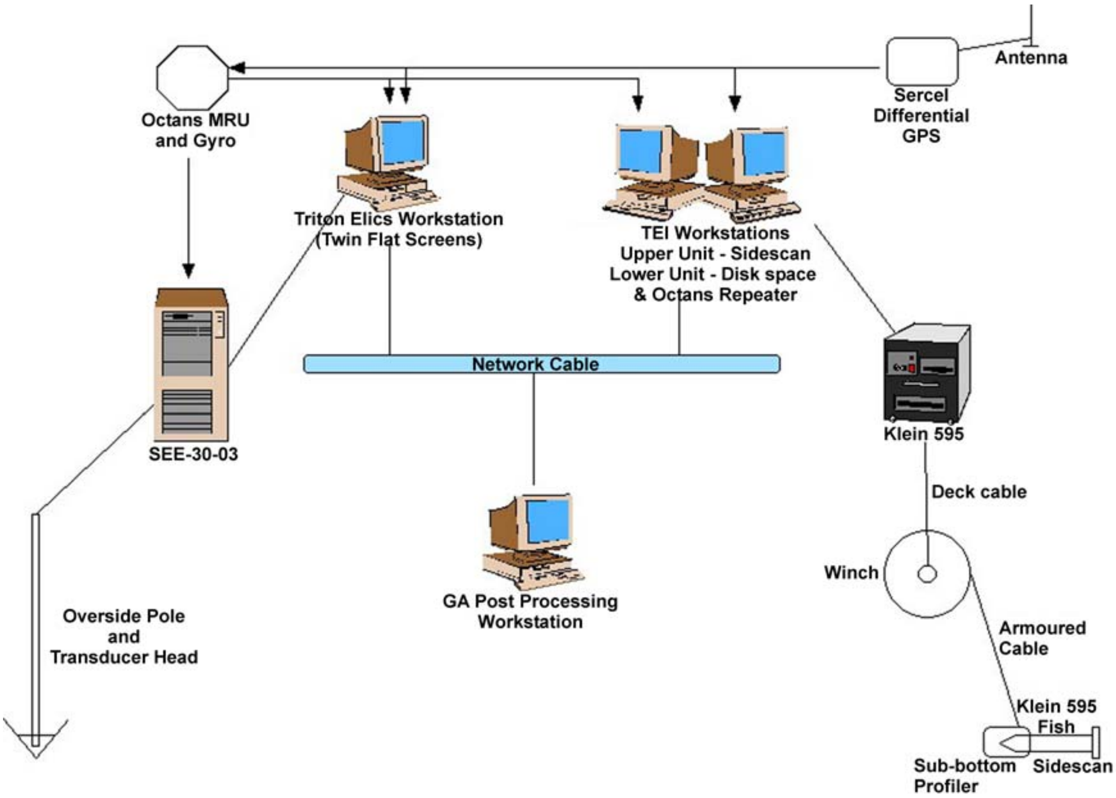


Figure 2.2. Setup of the multibeam/sidescan system used on the survey

Swath mapping was undertaken with the aim of detecting evidence of sea bed features associated with seepage, such as seabed mounds or pockmarks (Hovland and Judd, 1988) and to map the bathymetry of the study area at high resolution.

2.3. Sidescan Sonar (& Sub-bottom Profiler)

The sidescan used on the survey was a Klein 540 dual frequency unit with transducers of 100 kHz and 500 kHz (Fig. 2.3). Location information was provided by the main

GPS unit. It was stored uncorrected in the digital file (xtf format) using TRITON ISIS software. The 100 and 500 kHz records were recorded digitally in the xtf files along with the sub-bottom profiler system.

Figure 2.3. The sidescan/sub-bottom profiler used on the survey. Inset shows the sidescan fish (metal cylinder) mounted inside the profiler head

The objectives in acquiring sidescan data were two fold: 1) to image any water column features that may be associated with seepage, particularly gas bubble plumes; and 2) to image the character of the seafloor, with particular attention on hardgrounds and pockmarks that may have formed through seepage related processes (Hovland and Judd, 1988).

The sub-bottom profiler, which was combined with the sidescan fish, failed after 12 hours of operation so was not used thereafter. Therefore the sub-bottom profiler is not discussed any further in this document.

2.4. Towed Fluorometer

A catamaran-mounted skimmer device deployed in undisturbed seawater beyond the bow wake off the side of the vessel (Fig. 2.4), supplied the marine fluorometer

SAFIRE (manufactured by WETLabs) with a continuous flow of surface water, sampled within a depth interval of about 0 - 30 cm (depending on weather conditions), to investigate for hydrocarbon slicks floating in the sea surface.

Figure 2.4. Skimmer device constructed by GA technical staff to sample the sea surface and supply sampled water to the fluorometer.

The instrument acquires fluorescence data excited by a Xe lamp at 6 wavelengths (228, 265, 310, 340, 375 and 435 nm) into 16 wavelength channels (typical bandpass 25 nm) covering the spectral range 228 - 900 nm, plus 6 absorption channels and one reference channel (lamp intensity monitor), at a rate of 5 records per second. Records were averaged (binned) over a preselected time period, typically 2 seconds, and recorded into the output file. The data were recorded using Windows-based software providing both the computer time and a direct GPS reference for every data point (binned every 2 seconds), backed up by a DOS-based, computer-time-referenced system. Detailed description of the principle of operation of the marine fluorometer SAFIRE can be found in Holdway et al. (2000).

2.5. Acoustic Doppler Current Profiler (ADCP)

A RD Instruments 300kHz Workhorse ADCP was hired from Underwater Video Systems in Melbourne (Fig. 2.5). The mounting frame was constructed from scrap metal by a contract boilermaker, under the guidance of GA technical staff, while in Darwin port. The ADCP was deployed during the course of the survey to measure the velocity and direction of current flow within the region, specifically to test the potential contribution of tidal flow to the formation of SAR slicks identified over the Yampi Shelf (NPA et al., 1999).

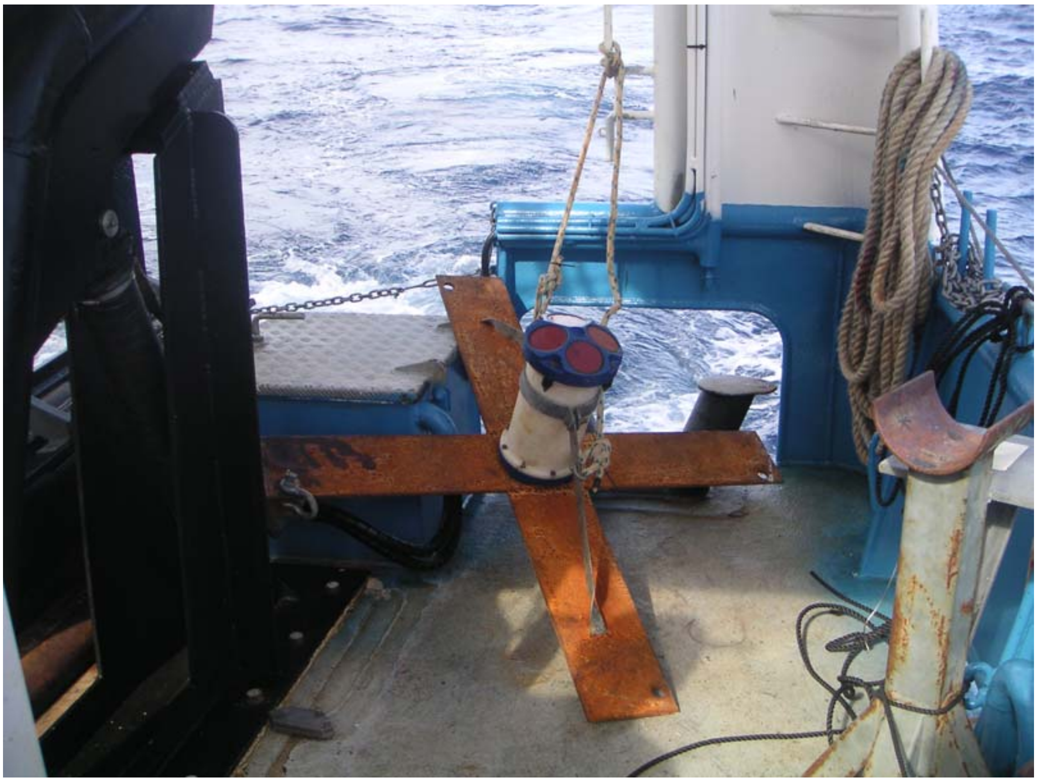


Figure 2.5. The ADCP deployed on S267

2.6. Underwater Camera

An attempt was made to record video footage of the sea floor within the survey area. The camera used was a Sony Digital Camcorder DSR-PDX10, mounted in a Geoscience Australia designed and manufactured housing (Fig. 2.6). The objective of underwater filming was to visually examine the nature of hydrocarbons seeping from the sea floor.

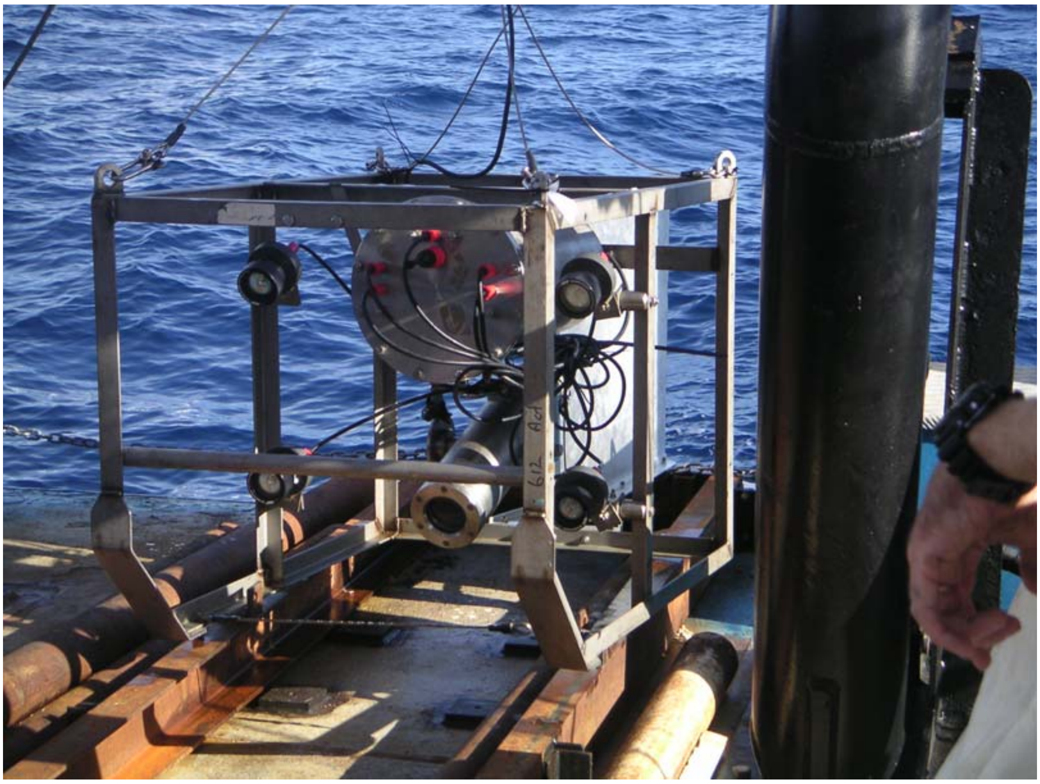


Figure 2.6. The underwater camera used on S267

2.7. Submersible Data Logger (SDL)

A SDL was taken on the survey for numerous deployments through the region, both to understand the vertical stratification of the water column, and also to provide velocities to correct the swath system.

2.8. Water Samples

Water samples were collected in three ways during the survey:

1. Sea surface waters were sub-sampled from the fluorometer sample stream.
2. Niskin bottle samples were taken from approximately the middle of the water column.
3. One sample was collected over the side of the vessel during transit using a bucket and rope.

Sample types 1 and 2 were stored in glass bottles and refrigerated in the dark (Samples were not poisoned). Sample type three was stored in an empty drinking water bottle, in a bucket of seawater (Note – this sample was not intended for lab analysis, but was only collected to potentially test the fluorescence signal of algae using the onboard SAFIRE system).

The objective in sampling sea water was to allow for laboratory analysis upon return to Geoscience Australia, to test for the presence of hydrocarbons that may have seeped naturally from the sea bed. In particular, testing fluorescence levels would allow for direct comparison with the fluorescence signal detected with the towed fluorometer.

2.9. Sediment Samples (Grabs, Dredges & Cores)

Seabed sediment samples were collected using a Smith Macintyre grab (Fig. 2.7), a box dredge (Fig. 2.8) and the Geoscience Australia 1 tonne gravity corer (Fig. 2.9).

Where sufficient sample was retrieved the grab sampling process was as follows:

- 10 cm mini-cores were sub-sampled directly from the centre of the grab and frozen at -20°C;
- Two bulk samples were taken from the grab, one was frozen at -20°C and the other was placed in cold storage at 4°C;
- The remaining sample was sieved. Items in the coarse fraction of particular interest (eg. worm tubes) were frozen and the remaining coarse fraction was placed in cold storage.

Freezing and mini-coring of the grab samples was undertaken with the aim of testing for hydrocarbons in the laboratory upon returning to Geoscience Australia. Retaining a sample of the coarse fraction was primarily done to allow for identification of benthic fauna associated with seep sites.

The sampling process from the dredge return was similar to the process followed for the grabs, without the mini-core sub-sampling, but the primary objective with dredging was to sample authigenic carbonate that may have formed at the sea bed in association with natural hydrocarbon seepage (Hovland and Judd, 1988).

Gravity coring was undertaken with the aim of sampling sediments from as deep as possible below the seabed, potentially allowing for laboratory analysis of sediments below the zone of maximum disturbance where there is differential loss of volatile gas, pore water flushing and aerobic/anaerobic bacterial activity (Abrams, 1992).

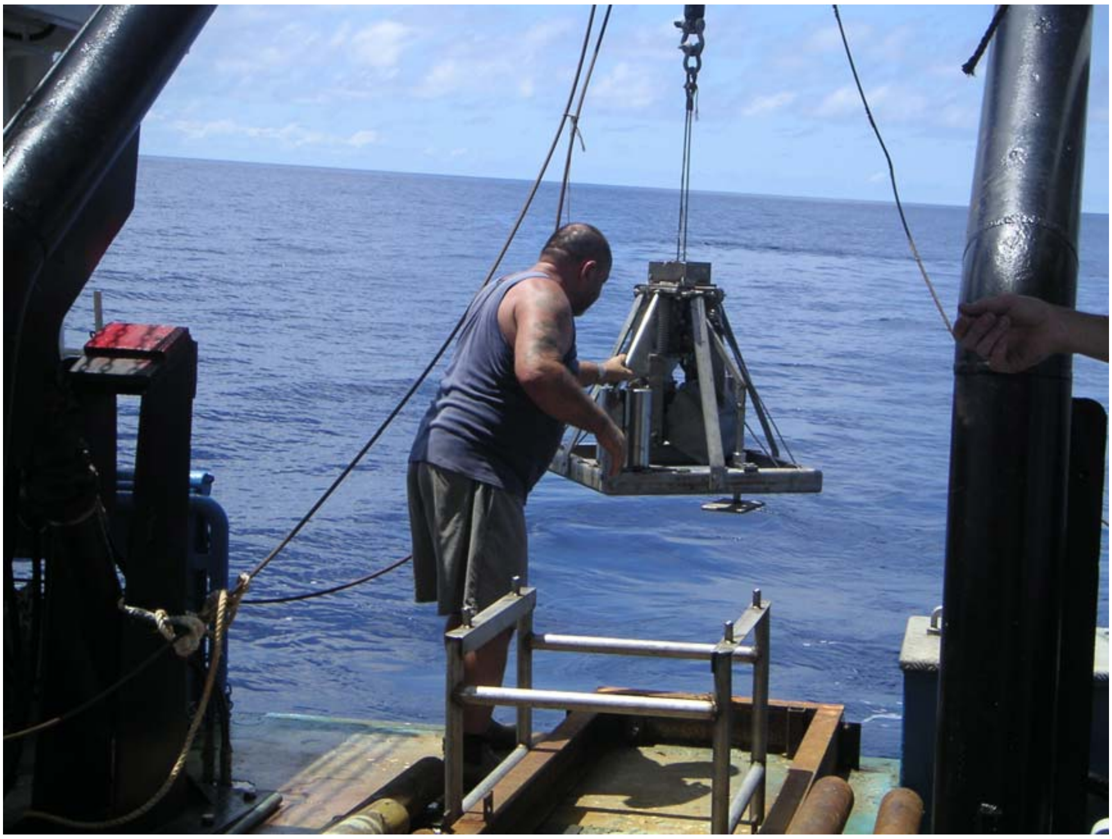


Figure 2.7. Deploying the Smith-Macintyre Grab

Figure 2.8. The dredge used on S267

Figure 2.9. Deploying the gravity corer. Note the slightly bent bomb

Chapter 3. Operational Results

3.1. Echosounder

Active seepage over Cornea sites 1 & 2 was initially imaged using the vessel's echosounders (Fig. 3.1). 76 digital images and two short digital video clips of the echosounder display were captured with a digital camera.

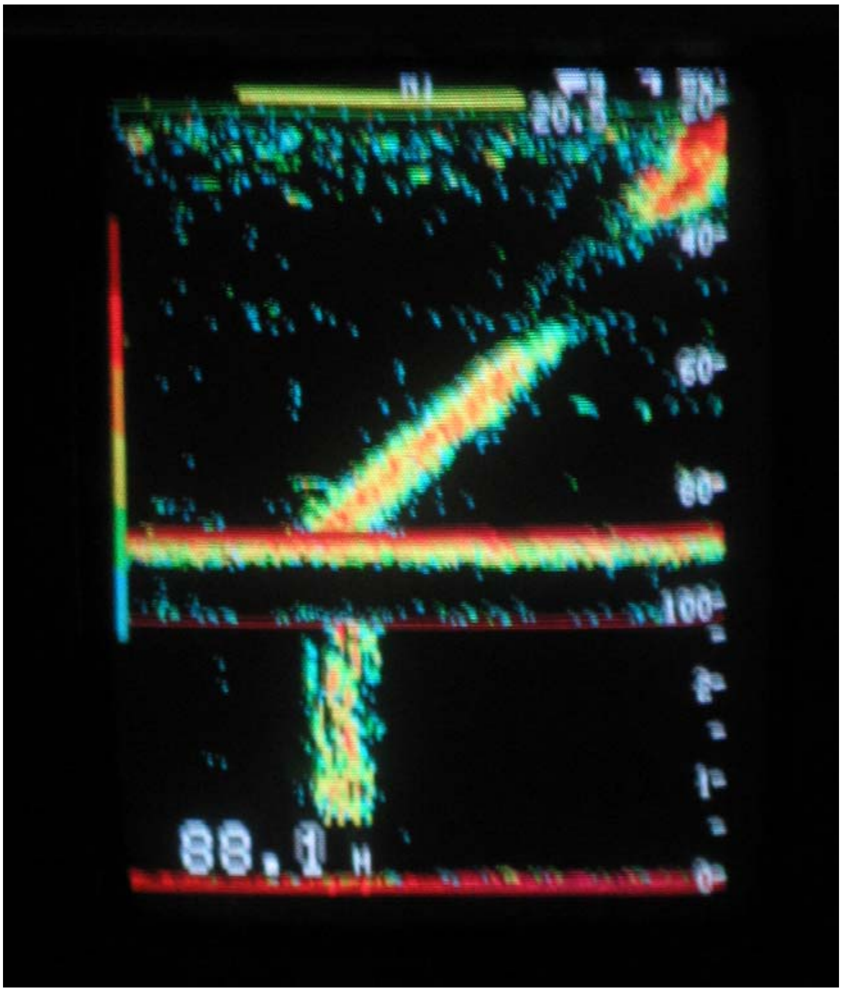


Figure 3.1. Image of the echosounder display captured with a digital camera, showing a hydrocarbon seepage plume rising from the seabed at 88.1 m water depth

Images of seepage varied considerably between continuous vertical or sub-vertical plumes, discontinuous plumes, and suppressed masses. It was not clear whether the discontinuous plumes represent episodic seepage or curvilinear plumes that passed in and out of the one-dimensional echosounder trace. Some of the seepage plumes appeared to be deflected by tidal currents as they rose from the seabed, and many flattened out at about 50 m depth, possibly following an isodensity surface in the water column.

The echosounder was also used extensively in attempting to position the survey vessel for accurate sampling of seepage sites, which was one of the primary concerns in planning the survey, particularly given the inability of the vessel to hold station. To address this issue the vessel's echosounders were used to locate the vessel over seeps and to observe sampling tools in the water column as they moved to the sea bed. Through this exercise it was possible to note whether samples were taken from directly over a seepage site, within close proximity to a seepage site, or from a location that was not associated with seepage.

3.2. Multibeam Swath Bathymetry

The initial patch test over the *Booyha* wreck site in the outer part of Darwin harbour was a limited success, with difficulties experienced in locating the wreck and then equipment malfunctioning. Ongoing trouble during the early part of the survey prevented useful data capture. The problems were remedied to the extent that 158 km^2 of multibeam data was collected over the Cornea sites (Figs. 3.2-3.5). Appendix B details the digital data acquired on the survey.

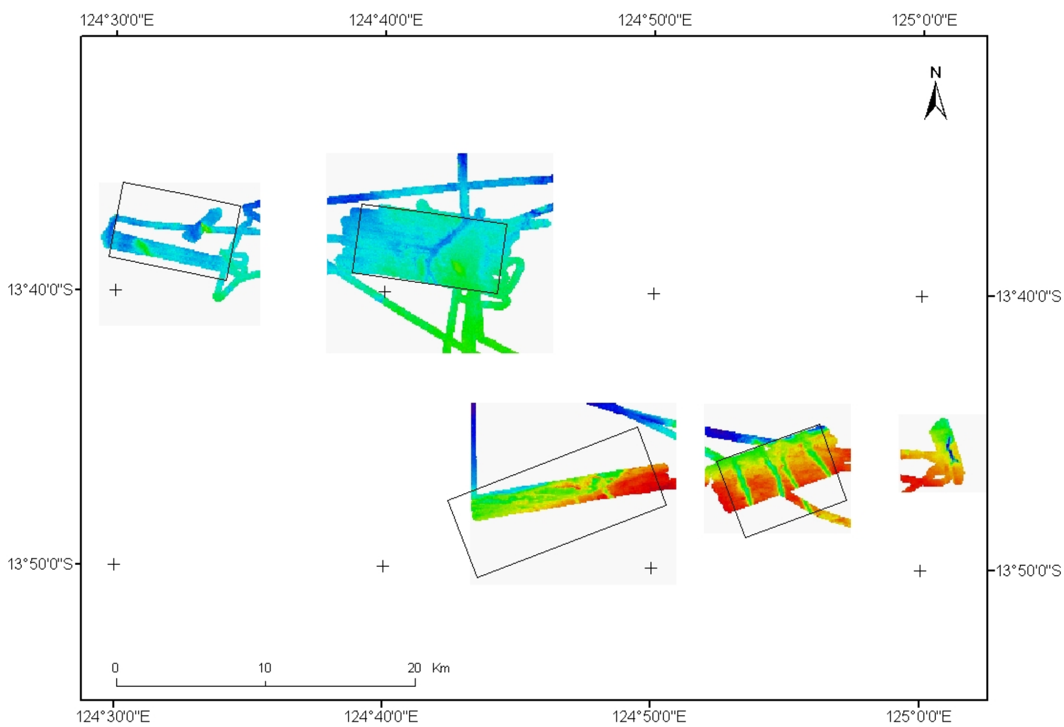


Figure 3.2. Coverage of multibeam swath bathymetry acquired during Survey 267

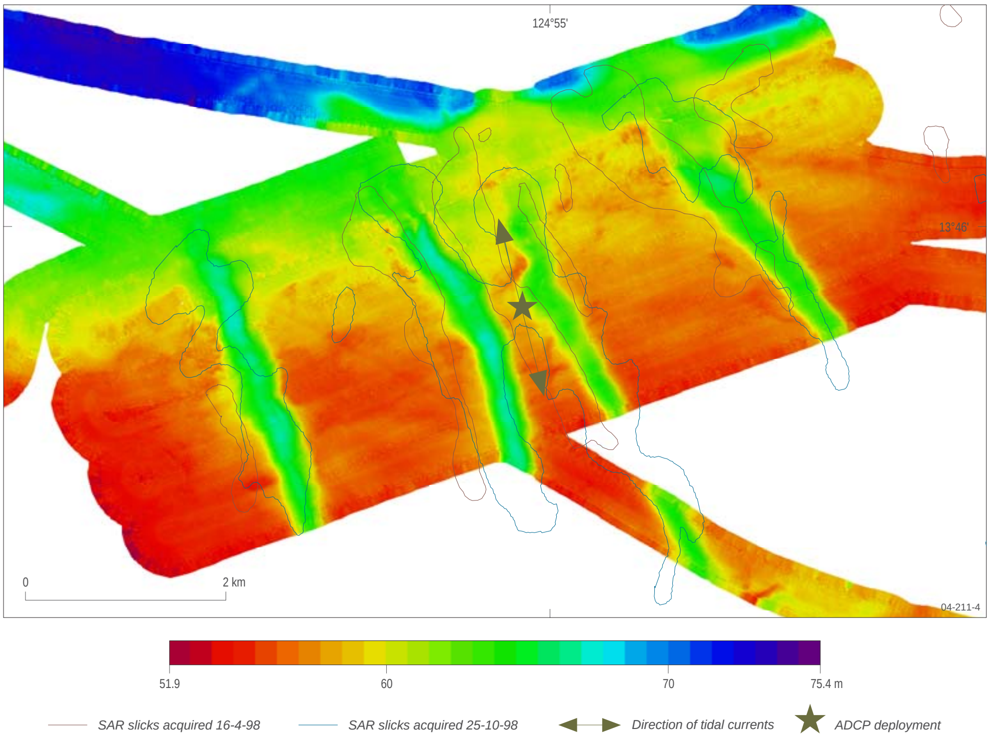


Figure 3.3. Multibeam swath bathymetry of GA Marine Survey 267 area 4, covering a section of the edge of the northern Yampi Shelf. See Jones et al. (2005) for details regarding spatial relationship between SAR slick outlines and channels

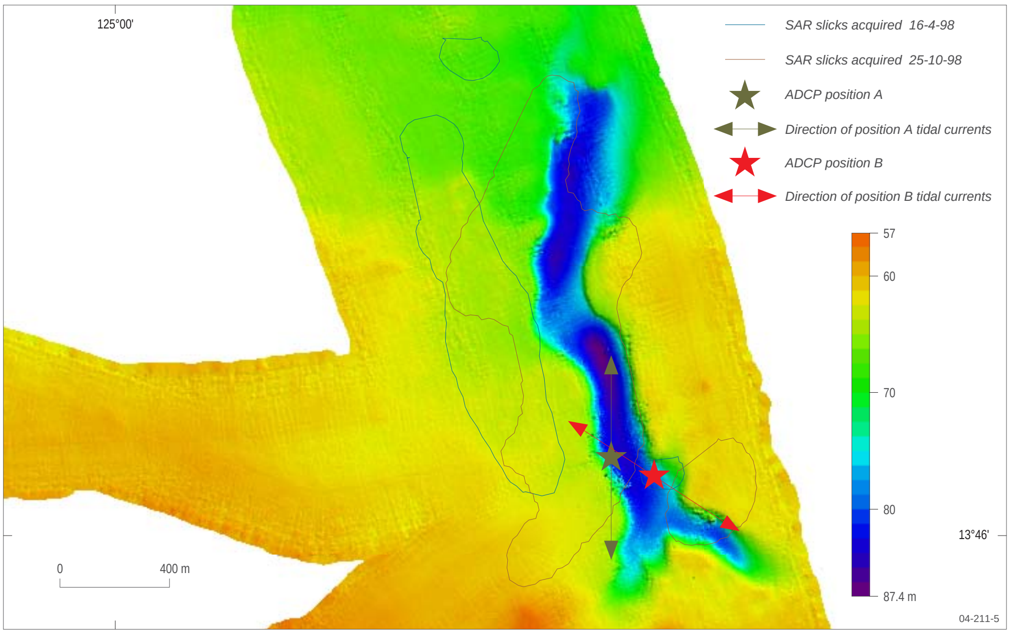


Figure 3.4. Multibeam swath bathymetry of an area 7.5 km east of Geoscience Australia Marine Survey 267 area 4, showing the deepest channel discovered on the northern Yampi Shelf. The acoustic Doppler current profiler was initially deployed in position A, and was moved to position B by tidal currents through drag on the buoy rope.

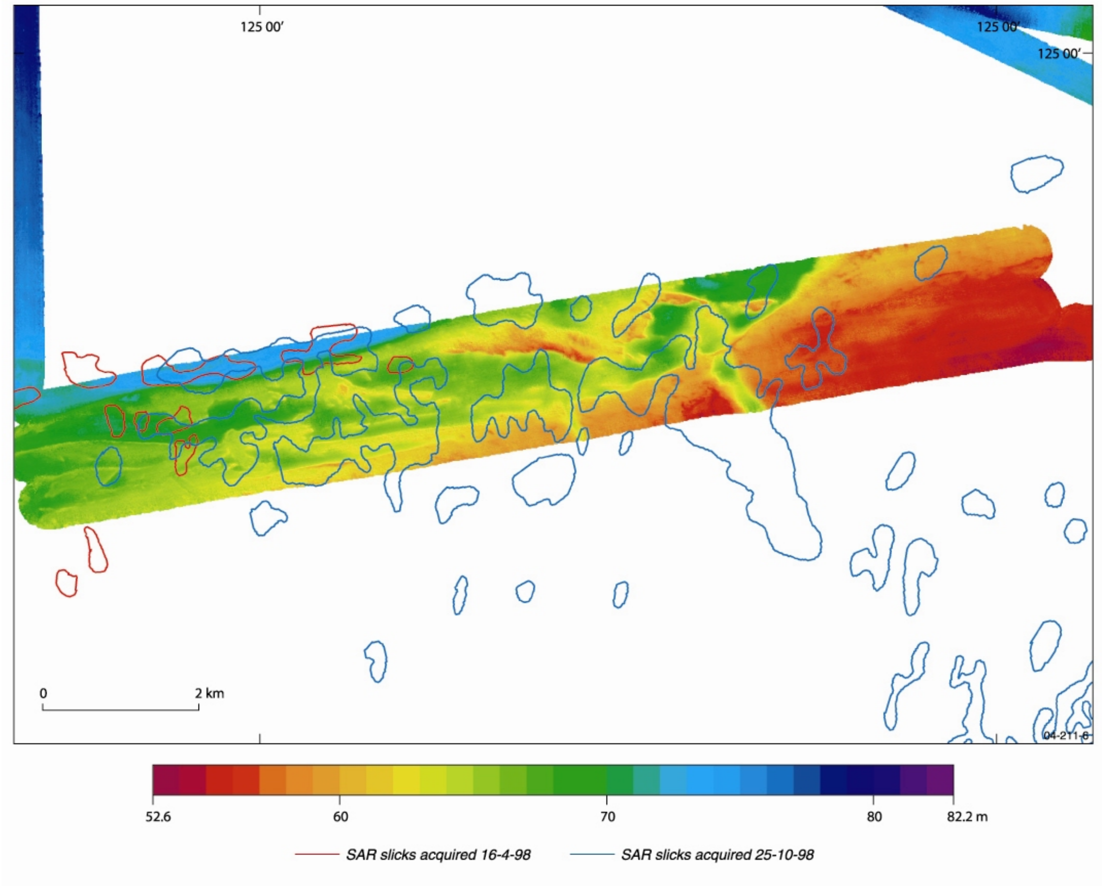


Figure 3.5. Multibeam swath bathymetry of GA Marine Survey 267 area 3, covering a section of the edge of the northern Yampi Shelf

3.3. Sidescan Sonar

About 770 km of sidescan data were collected during Survey 267 (Fig. 3.6; Appendix B). The sidescan was deployed during surveys of the Cornea areas and collected along parallel lines about 300 meters apart. The sidescan unit produced good quality data on the starboard side but the port data was of lower quality. The 500 kHz record also features pings from the multibeam transducer that operated at 490 kHz but this did not degrade the images significantly.

The thermal printer recorded the 500 kHz record but could not record the 100 kHz channels in spite of replacement printer cards being sent on a re-supply vessel. The sidescan data were presented and stored as "normal" sidescan images, that is, high backscatter appears as dark on the record.

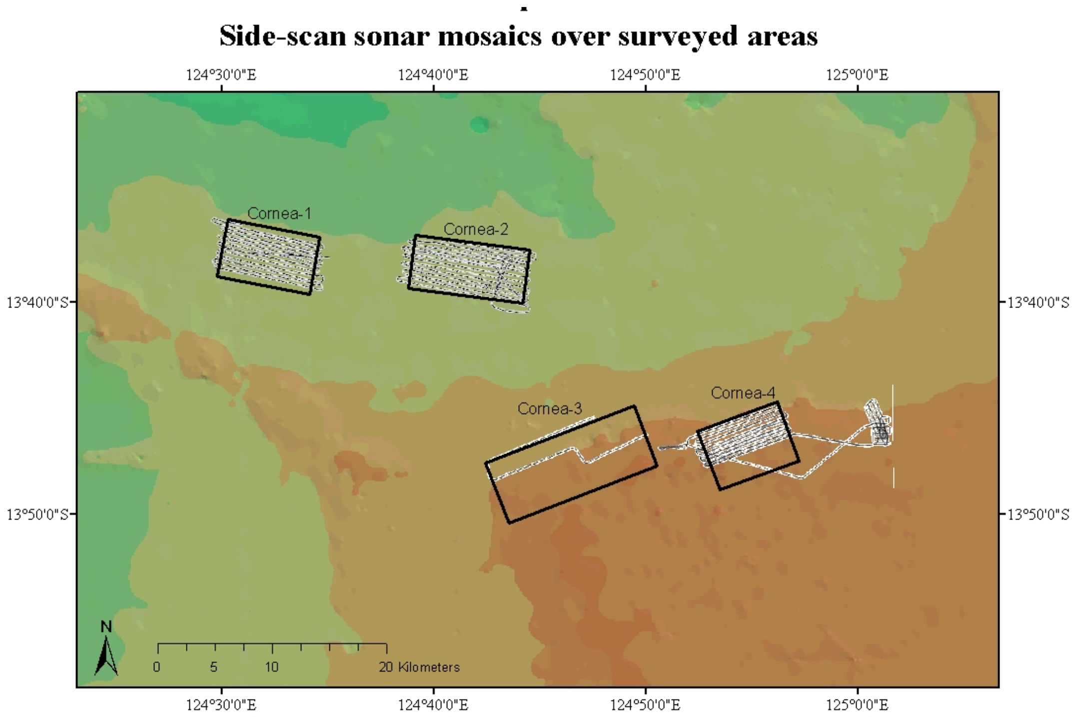


Figure 3.6. Track of sidescan data acquired during S267

The winch provided did not have a ‘wire out’ meter, so this was estimated by counting drum revolutions, each revolution representing about 10 meters of wire on the outer wraps. Lack of wire metering and depth transducer on the sidescan fish meant that distance behind the vessel could not be calculated during the recording. Accurate estimates of distance could only be achieved by comparing the location of a recognizable bottom feature on the multibeam records with the location of the same feature on sidescan record. This was possible only in a few places because of the generally featureless seafloor on most multibeam lines. Thus it was decided to record the raw GPS data and make corrections during post processing. The poorly performing port transducer meant that overlap of swaths was not feasible and therefore mosaic construction was generally not possible.

Active seeps were recognized by plumes of bubbles in the water column over Cornea Sites 1 & 2 (Fig. 3.7). They were particularly well imaged by the 100 kHz transducer. Bubble plumes are single or multiple streams of bubbles sloping upward in the direction of the tidal current or as overlapping parabolic streams.

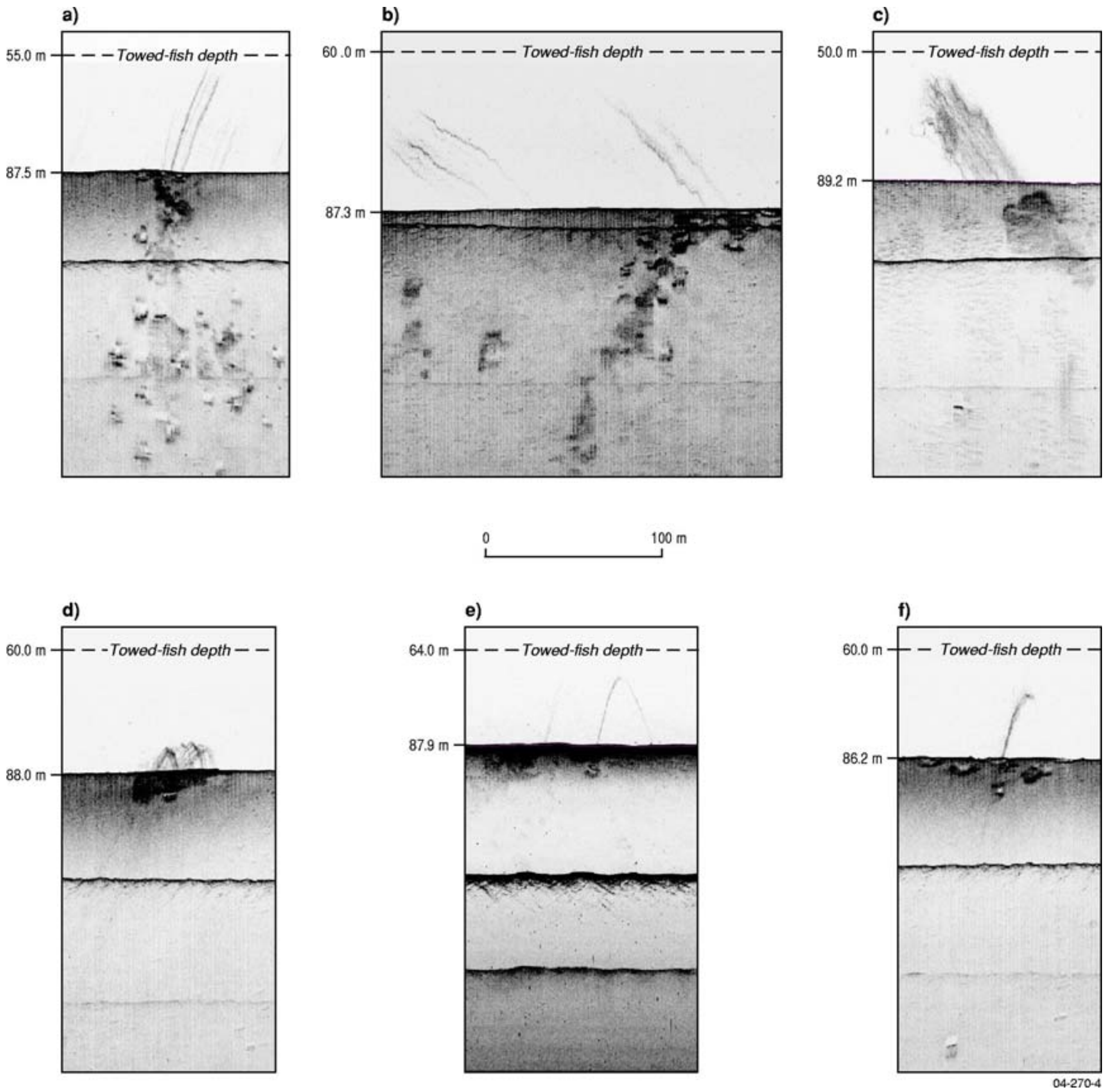


Figure 3.7. Natural hydrocarbon seepage plumes imaged with the sidescan sonar, A-C) linear plumes , D-F) hyperbolic-shaped plumes.

Sea floor features associated with gas seeps are variable and frequently difficult to interpret. Most common is cemented hardground that appears as slightly raised bright irregular patches on the 100 kHz records. Pockmarks are also present and associated with seeps, but not all pockmarks imaged were actively seeping. The pockmarks are roughly circular and vary from 1-2 m across and up to 1 m deep to larger features 10 m across and 2 m deep. They have a crater-like shape, with a slightly raised rim around a central depression.

Over survey areas 3 & 4 the sidescan data imaged an area of pockmarks that had previously been identified (Fig. 3.8; O'Brien et al., 2002), but there was no evidence of active seepage.

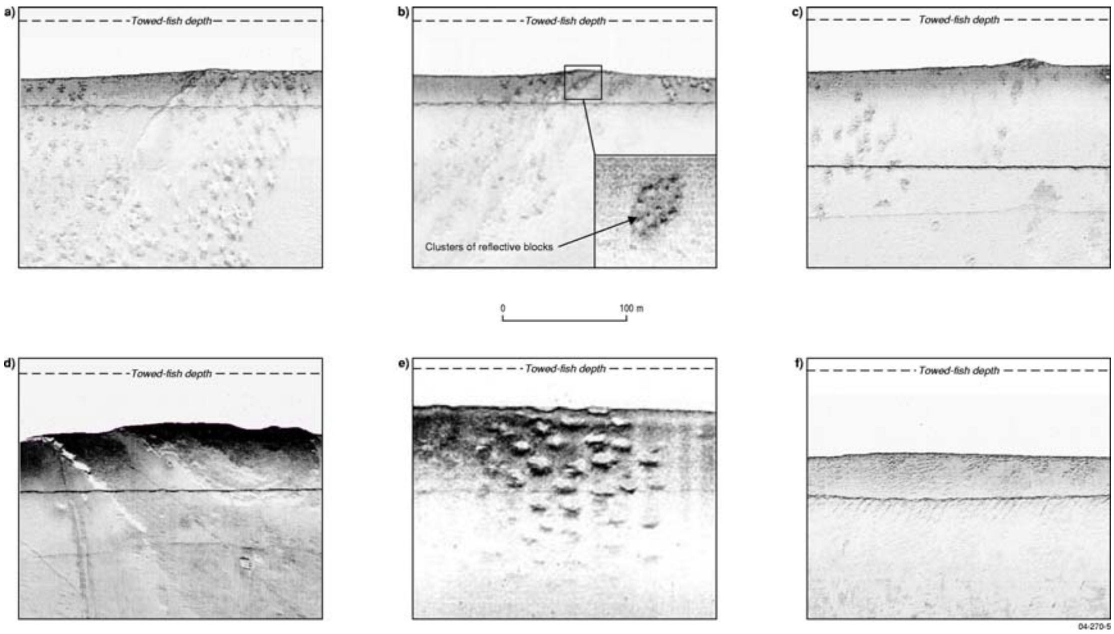


Figure 3.8. Side-scan sonar images of seabed features related to seepage. A-B) Clusters of strongly reflective blocks aligned on a linear trend; C) Clusters of strongly reflective blocks and a cemented mound; D) A reflective hardground; E) A pockmark field; F) Large ripples on the seabed suggesting recent seabed current activity

Scientific finding – Sidescan sonar images of some areas show seepage occurring during ebbing tides, but not during flooding tides. Plumes were also observed to be more active during the low spring tidal cycles (5 m tides) compared to low neap tidal cycles (2 m tides). This is likely due to reduction in water pressures allowing expulsion of gas plumes from sediments into the water column. See Rollet and others (in press) for details.

3.4. Towed Fluorometer

The fluorometry data were collected in two survey areas (Fig. 3.9; Appendix B):

- On a 2.3 km radius circle around the Challis Venture facility while produced formation waters were discharging (3h 46min of data);
- Over the 9.7 x 4.1 km^2 Cornea Area 1, on 330 m spaced lines, followed by a 56.2 km long, East-South East trending line (total of 19h 54min of data).

SAFIRE fluorescence data for Challis Venture indicate that there are small amounts of hydrocarbons and no humic matter in surface seawater at a distance of 2.3 km in any direction from the point of produced formation waters discharge (Figs. 3.10-3.12). There is no SAFIRE evidence of elongated, discharge-related hydrocarbon slicks intersecting the ship track, as detected by pre-existing SAR data. A possible explanation could be prevention of slick formation due to rough weather. Another possible explanation is a discrepancy between the extent of the production water slick at the time of the survey and the extent of the slick as previously recorded in SAR data, which was used to plan the diameter of the Challis survey circle.

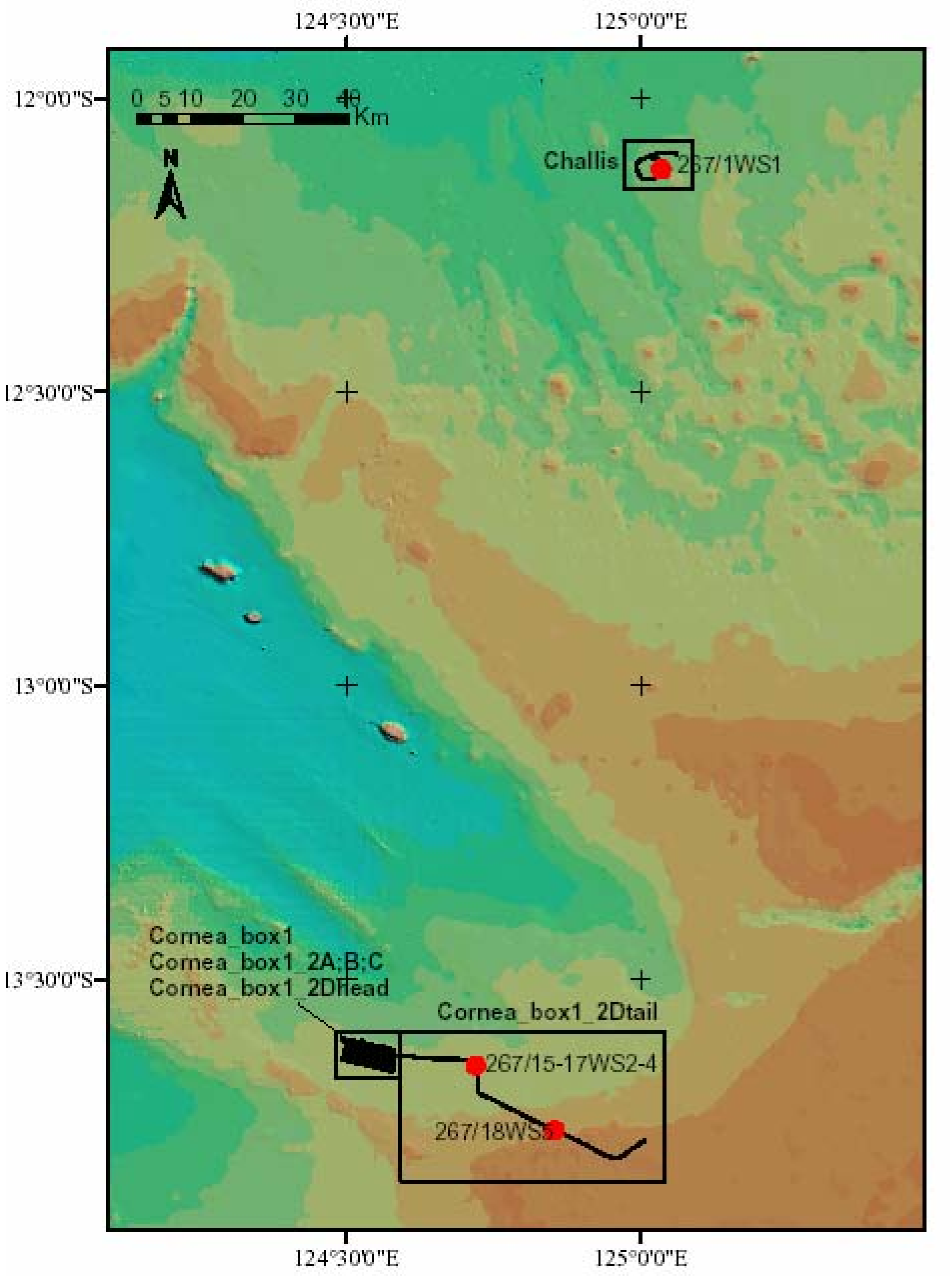


Figure 3.9. Regions in which fluorometer data was acquired, and location of water samples (red dots – Numbers correspond to Table 3.2)

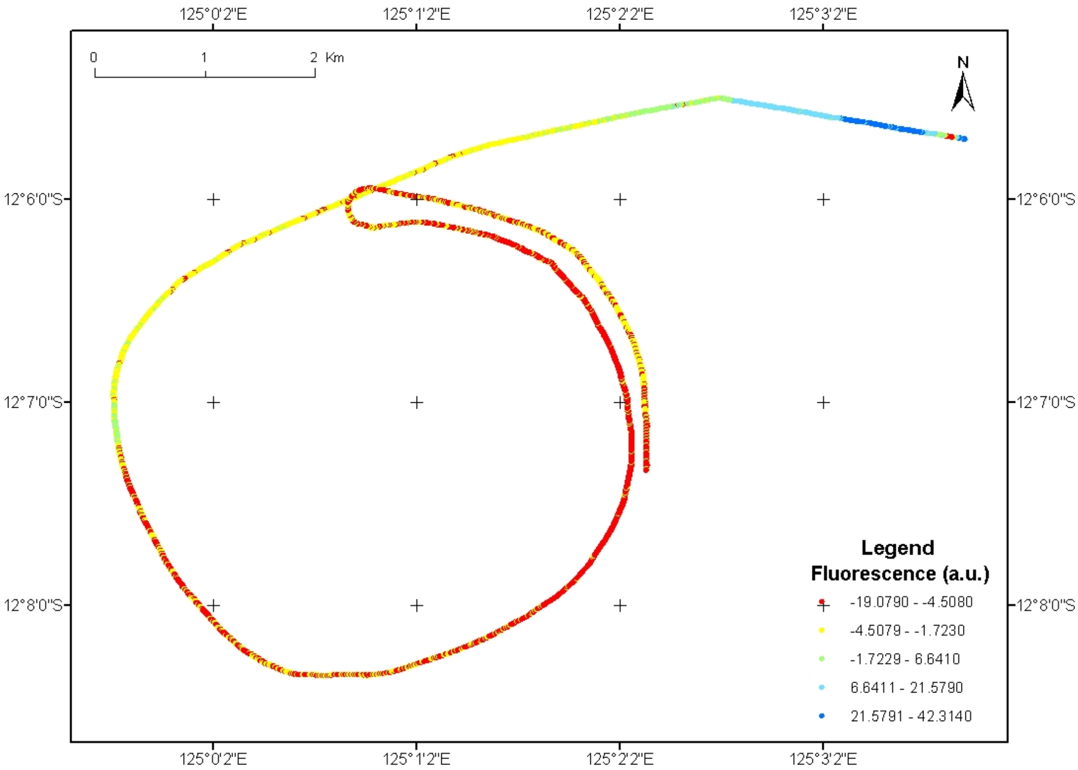


Figure 3.10. Fluorescence map for Challis area – SAFIRE data: excitation at 265 nm, emission at 340 nm (shoulder of UV hydrocarbon fluorescence band)

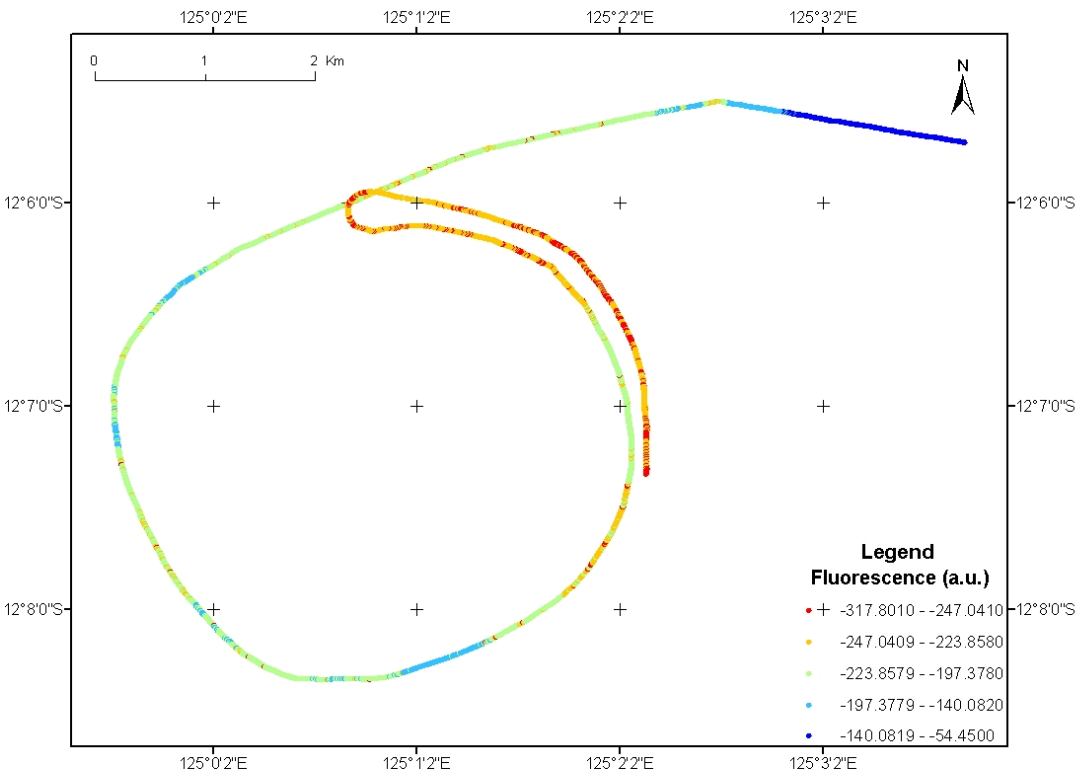


Figure 3.11. Fluorescence map for Challis area – SAFIRE data: excitation at 265 nm, emission at 365 nm (peak UV hydrocarbon fluorescence)

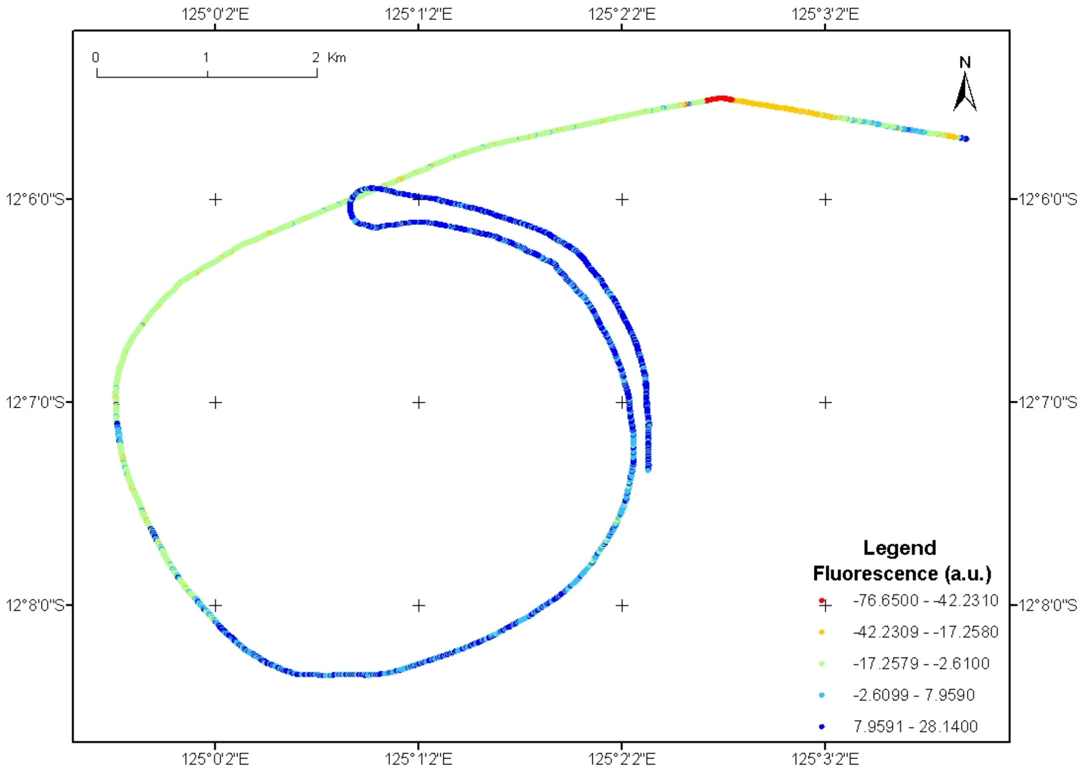


Figure 3.12. Fluorescence map for Challis area – SAFIRE data: excitation at 265 nm, emission at 475 nm (peak humic matter fluorescence)

Throughout the entire Cornea Area 1 there is no evidence of marked geographically isolated fluorescence increases (anomalies; Figs. 3.13-3.15). There is, however, an area-wide pattern of low fluorescence signal to the north and south, with a maximum at the center of the survey area, especially pronounced for the 475 nm channel (humic) data, but also clearly visible in the hydrocarbon channels.

Along the east-southeast trending line near the Cornea Area 1 the fluorescence signal is relatively high and steadily rising along the entire survey line, both in the hydrocarbon and humic spectral region (Figs. 3.16-3.17). Near a previously recorded Sniffer anomaly, however, there is a small region across which the intensity of fluorescence varies markedly both in the hydrocarbon and humic channels (124°43’28”E, 13°41’18”S). A spiky absorption and emission anomaly recorded where the line passes over the edge of the Yampi Shelf submarine headland (124°51’18”E, 13°45’27”S) is an artifact caused by sparking in the Xenon lamp emission.

For details on the scientific findings of the fluorometry survey see Radlinski and others (2004).

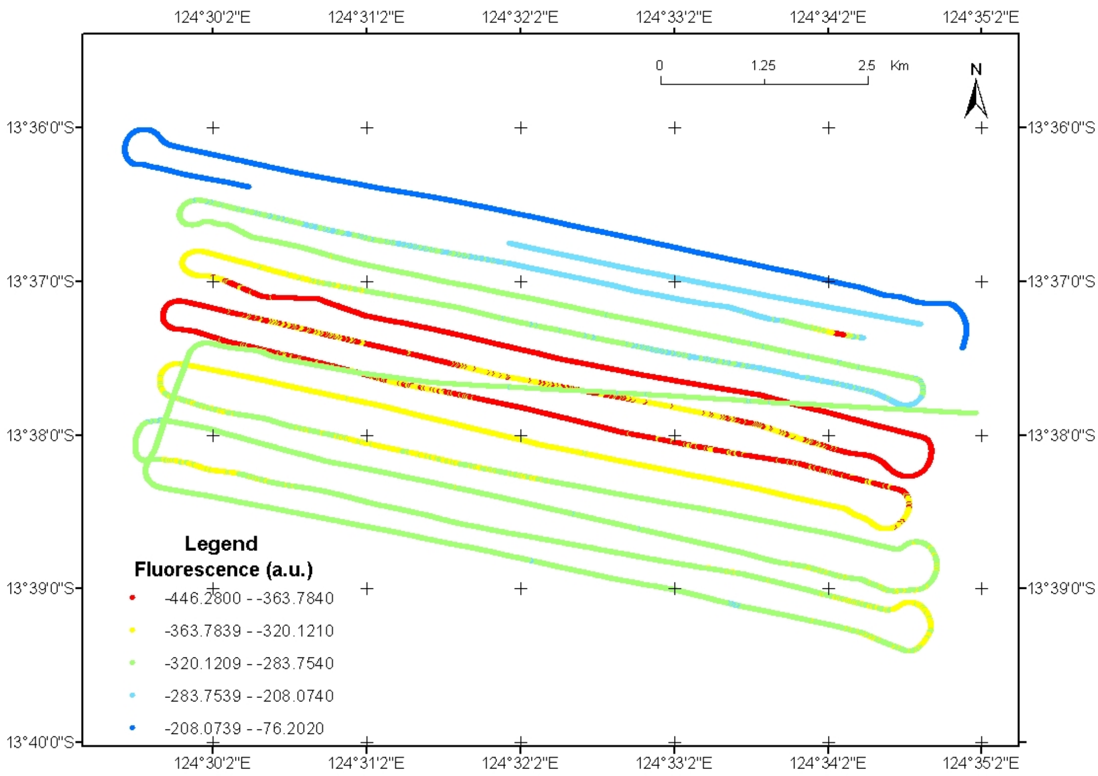


Figure 3.13. Fluorescence map for survey Area 1 – SAFIRE data: excitation at 265 nm, emission at 340 nm (shoulder of UV hydrocarbon fluorescence band)

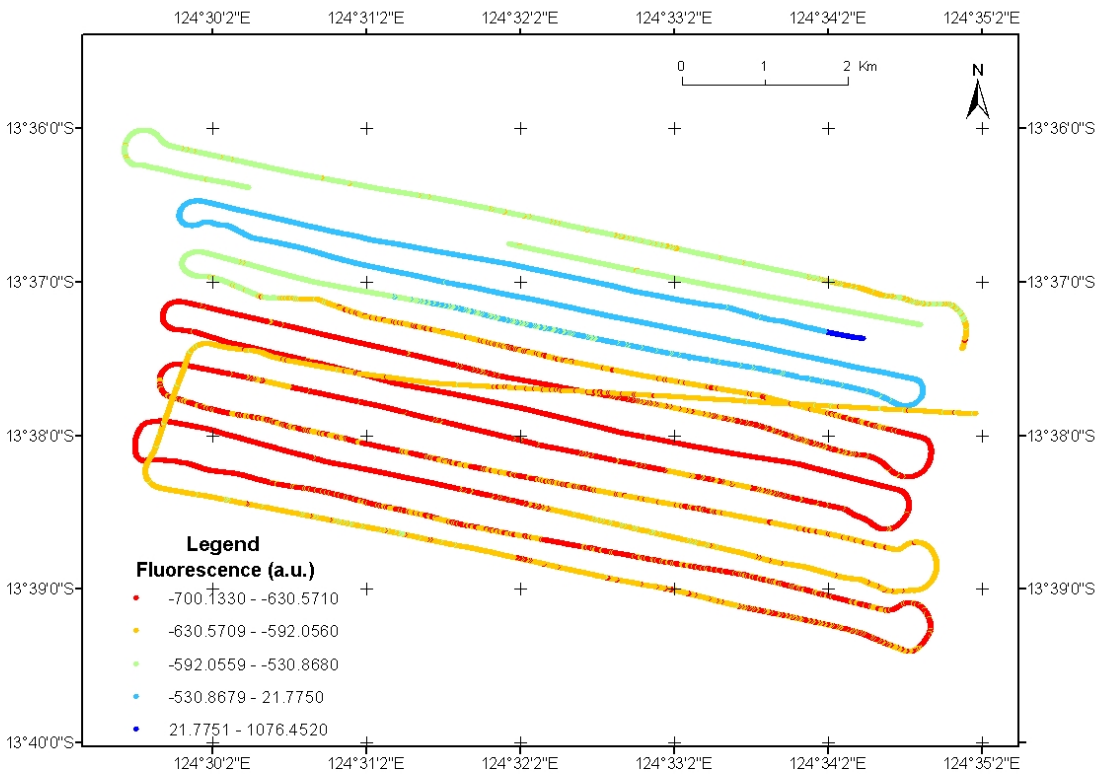


Figure 3.14. Fluorescence map for survey Area 1 – SAFIRE data: excitation at 265 nm, emission at 365 nm (peak UV hydrocarbon fluorescence)

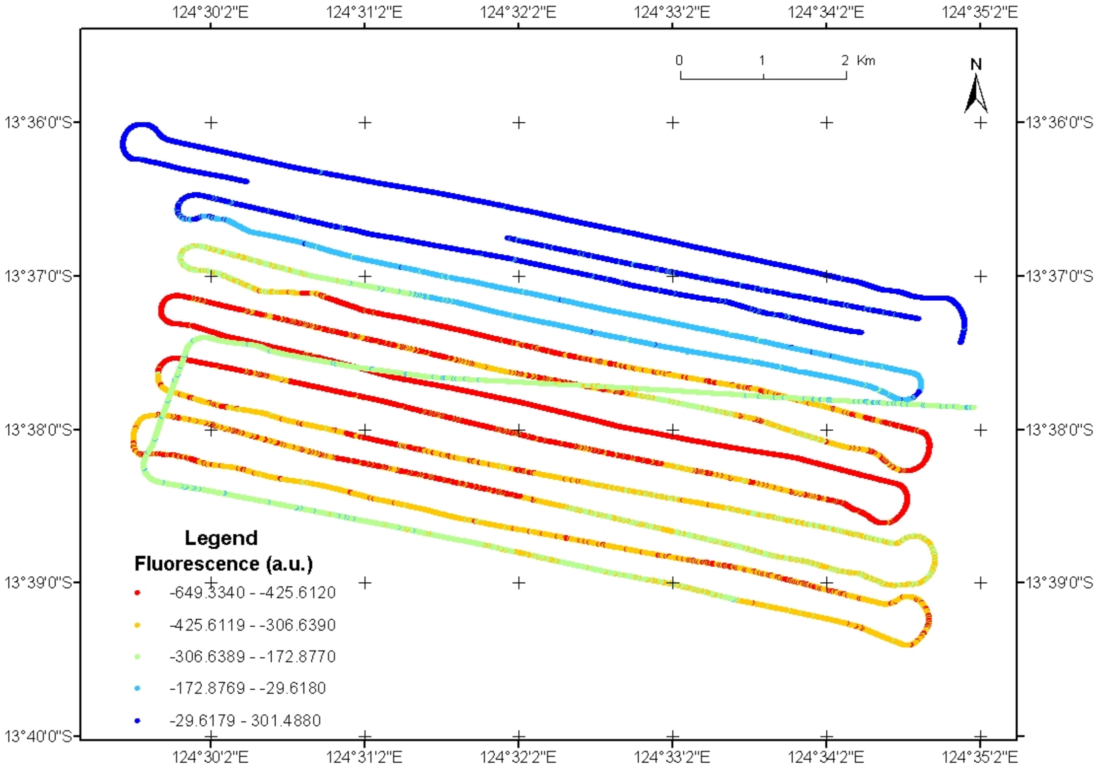


Figure 3.15. Fluorescence map for survey Area 1 – SAFIRE data: excitation at 265 nm, emission at 475 nm (peak humic matter fluorescence)

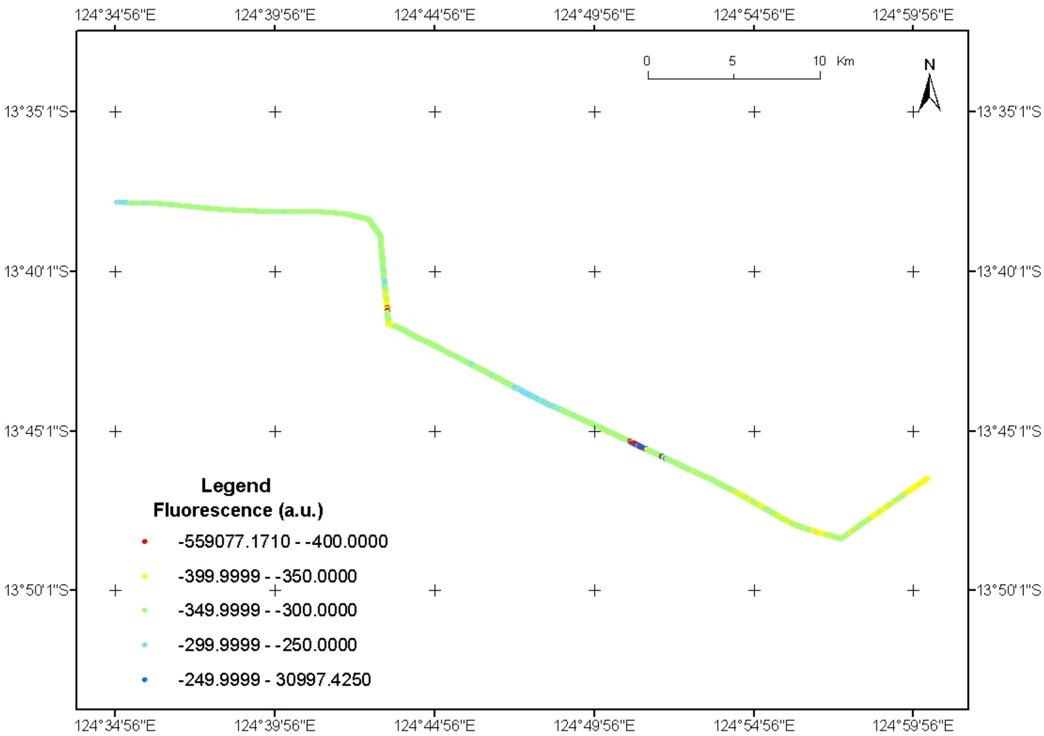


Figure 3.16. Fluorescence map for East-South East trending line near survey Area 1 – SAFIRE data: excitation at 265 nm, emission at 340 nm (shoulder of UV hydrocarbon fluorescence band)

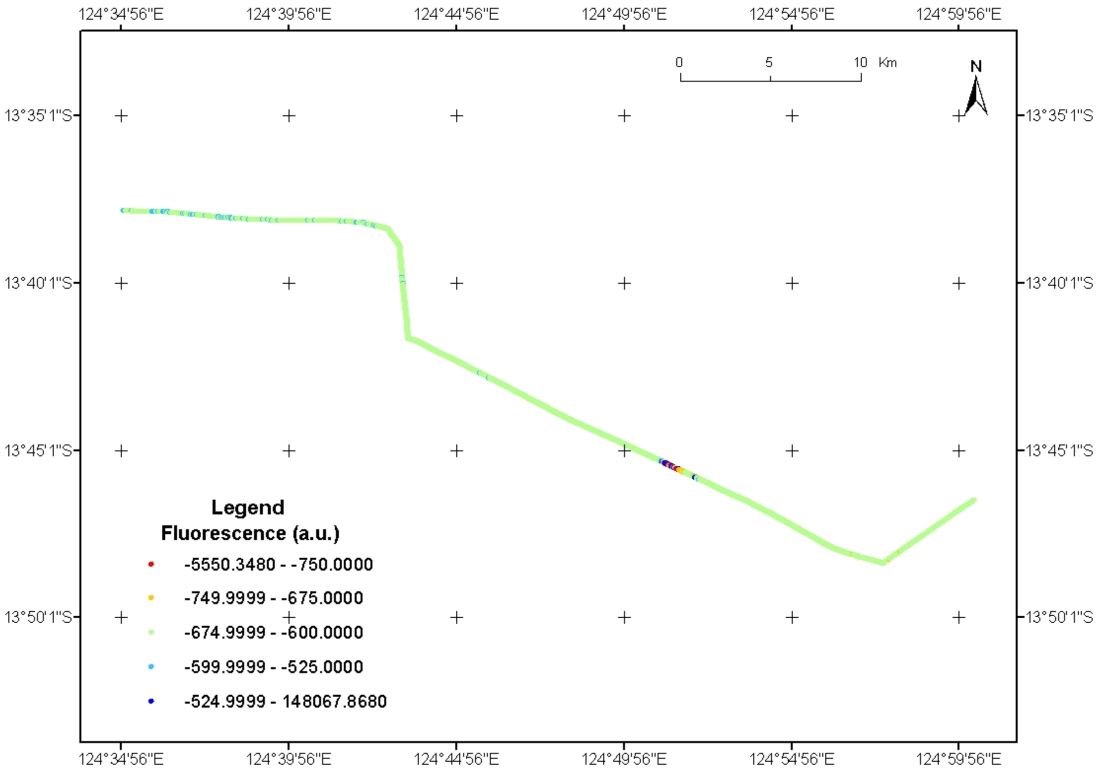


Figure 3.17. Fluorescence map for East-South East trending line near survey Area 1 – SAFIRE data: excitation at 265 nm, emission at 365 nm (peak UV hydrocarbon fluorescence)

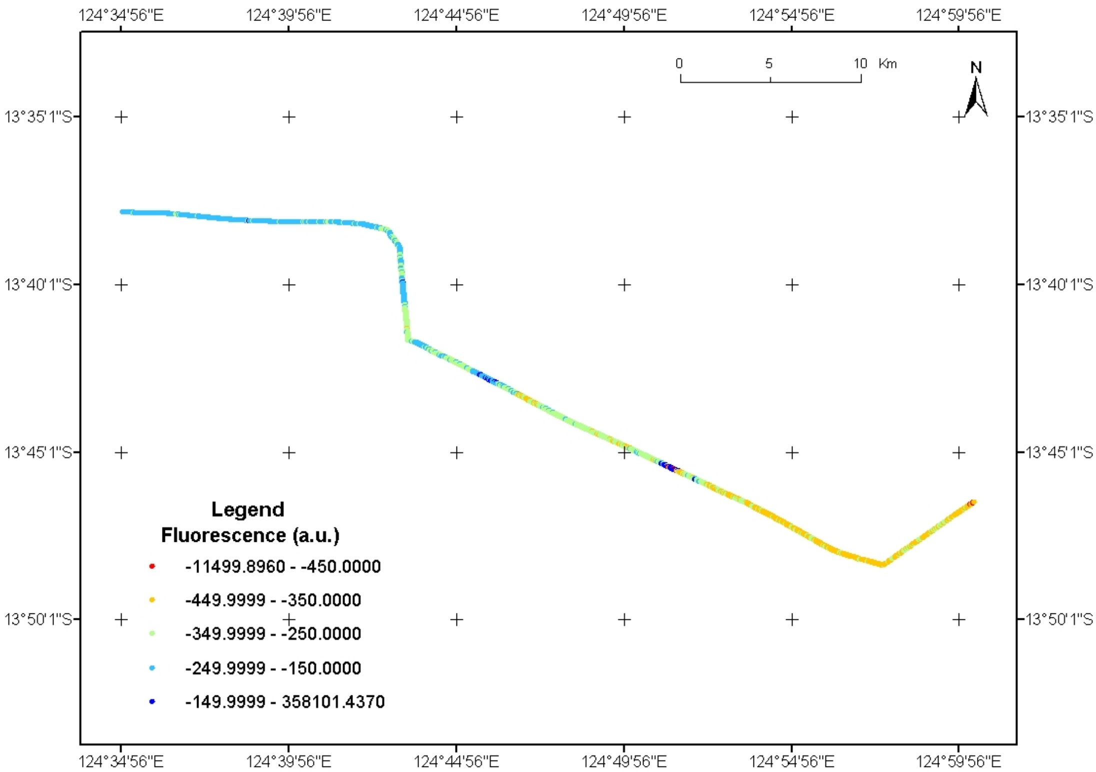


Figure 3.18. Fluorescence map for East-South East trending line near survey Area 1 – SAFIRE data: excitation at 265 nm, emission at 475 nm (peak humic matter fluorescence)

3.5. Acoustic Doppler Current Profiler (ADCP)

The ADCP was deployed in two localities on the Yampi Shelf, within and in the vicinity of Cornea Site 4 (124°54'37"E, 13°46'30"S and 125°1'7"E, 13°45'52"S; Figs. 3.3 and 3.4; Appendix B – CORN1000.DAT and HOLE1000.DAT respectively). ADCP data were recorded and visualised with Windows based software supplied with the instrument.

The western of the two deployments was directly under an area of major SAR anomalies (Fig. 3.3), in approximately 60 m of water (the instrument was retrieved after the first attempted deployment at this locality due to fouling of the deployment lines and suspected non-vertical sea-bed orientation). It recorded 2.5 tidal cycles between 1:52 UTC on the 7th of March and 8:37 UTC on the 8th of March. Tidal currents at the first deployment were orientated approximately north-northwest/south-southeast.

The most eastern of the two deployments was in the relatively deep channel to the east of area 4 (Fig. 3.4). The profiler recorded 5 tidal cycles between 11:02 on the 8th of March and 23:47 on the 10th of March (Fig. 3.19). Tidal currents during the second deployment changed orientation, from approximately north/south in the first half of the deployment to northwest/southeast in the second half of the deployment. This change in current orientation occurred because, during a flood tide, the instrument moved approximately 100 m up a bend in the channel.

The ADCP data suggest that ebb tidal currents are slightly faster than flood tidal currents. Current speed appears to be related to tidal ranges, with the maximum current velocities during spring tides.

Scientific finding – The ADCP data indicate the direction of tidal flow is aligned with the orientation of the channels and the SAR slicks (Figs. 3.3 and 3.4), and that flow direction is essentially consistent throughout the water column during peak tidal flows. Also, the greatest differences in flow velocity are seen in the upper section of the water column just before the turn of the tide. Therefore, the ADCP data provide good supporting evidence for slick formation due to current flow/bathymetric interactions over the channels on the Yampi Shelf. See Jones and others (2005) for details.

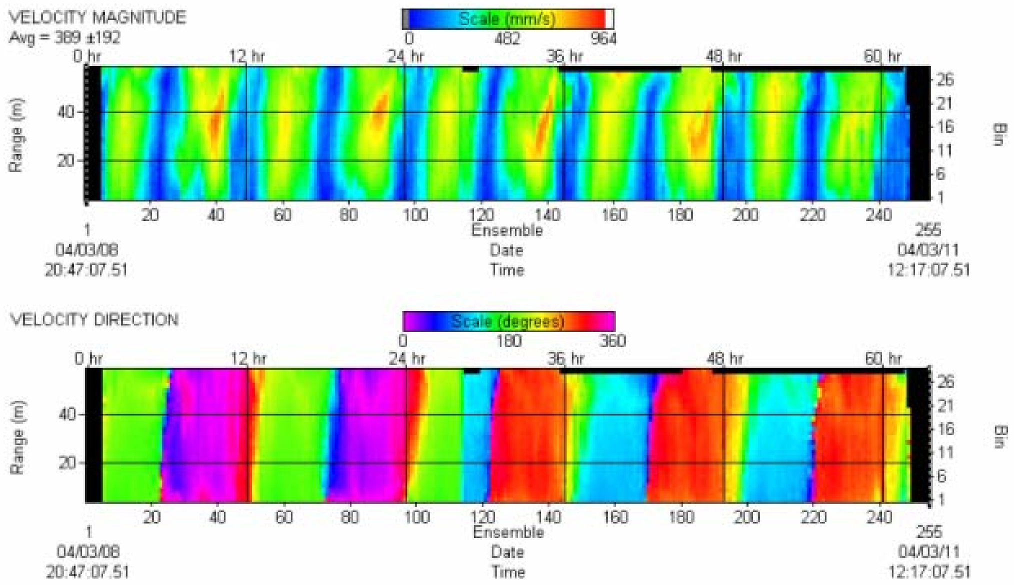


Figure 3.19. Current data (velocity and direction) measured during the eastern deployment. Note the significant change in direction midway through the deployment

3.6. Underwater Camera

Camera tows were undertaken at four localities during the survey (Fig. 3.20; Table 3.1). All attempts at recording video footage had mixed results with blurred pictures, but some footage did appear to capture the bottom, and potentially bubble streams. Footage was disappointing due to focus problems and a lack of clear video feed to the operational room. A significant length of cable was removed from the video unit in an attempt to reduce noise in the feed but this was unsuccessful. The lack of a clear feed made driving the camera a problem. An ability to hold the vessel stationary would have increased the usefulness of this tool, with the 1-2 knot tidal currents in the area sufficient to plough the camera through the sediments on the sea-floor, creating sediment clouds that obscured visibility.

3.7. Submersible Data Logger (SDL)

Problems with the Submersible Data Logger probe were experienced throughout the course of the survey. A break in the probe during the initial patch test in Darwin Harbour was repaired before deployment in the survey area. In the Cornea area, an initial cast recorded temperature and salinity data but did not record depth. This required a revision of the settings. Subsequently, a single SDL cast to 50 m obtained useful data but a second cast to 90 m ended with water leaking into the instrument.

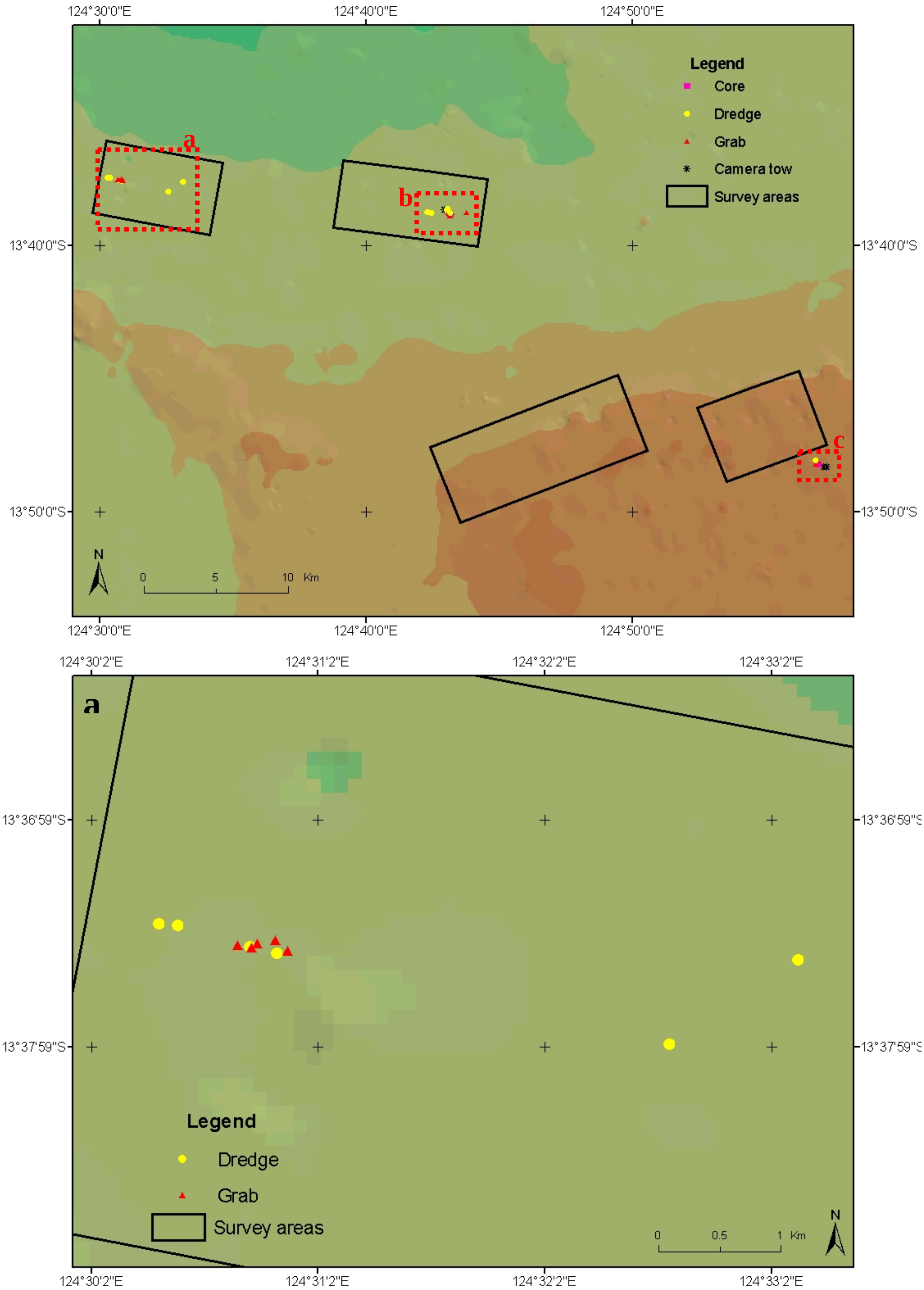


Figure 3.20. Location of camera tows and sediment samples collected during S267

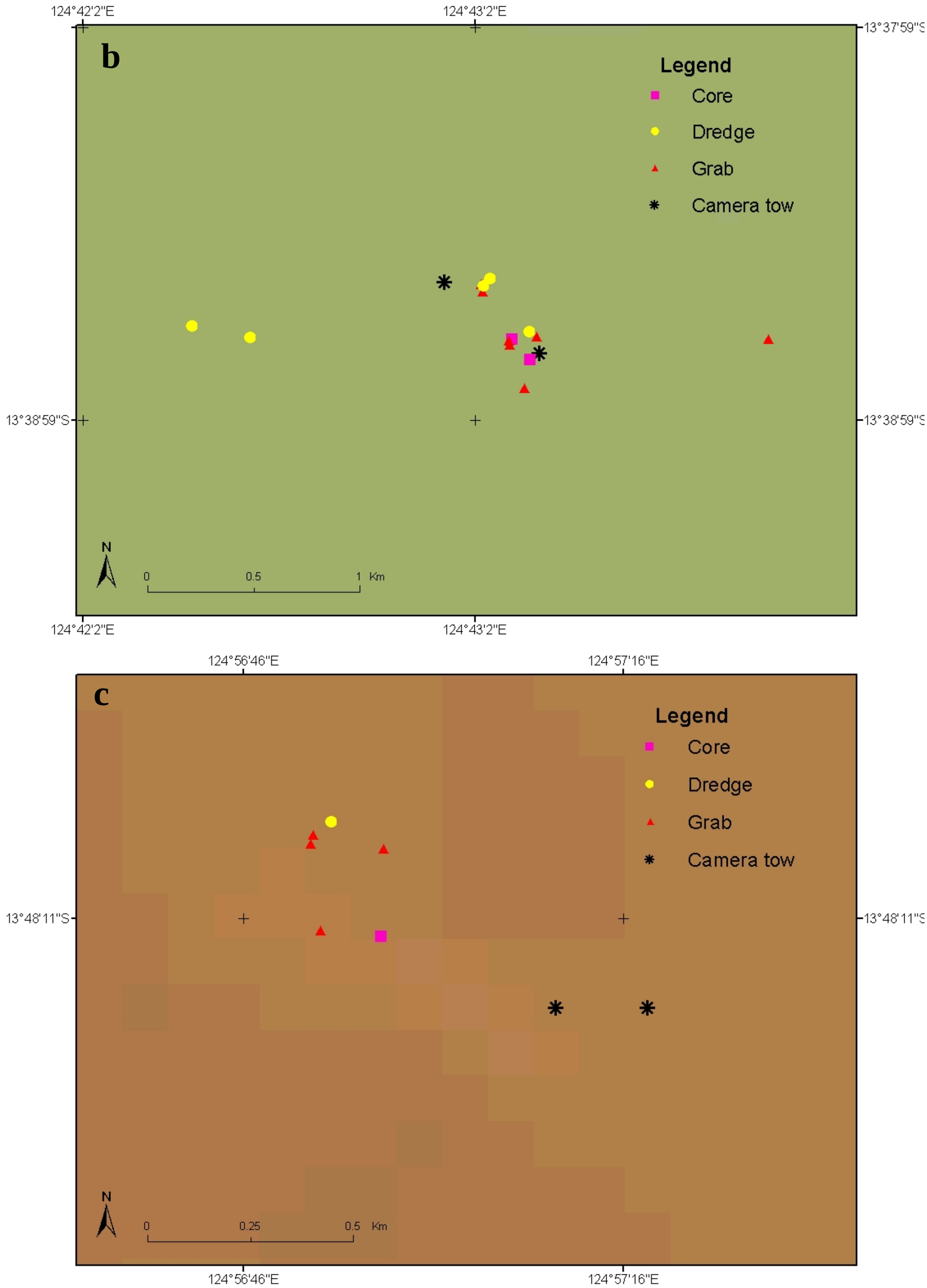


Figure 3.20. cont.

Table 3.1. List of camera tows undertaken during S267

Camera Tow	Attempting to image	Latitude	Longitude	Date
267/4/CAM1	Pockmarks	-13:48.275	124:57.307	7/03/04
267/5/CAM2	Pockmarks	-13:48.287	124:57.162	7/03/04
267/19/CAM3	Gas seepage	-13:38.862	124:43.208	11/03/04
267/29/CAM4	Gas seepage	-13:38.641	124:42.976	12/03/04

3.8. Water Samples

Six water samples were collected during the survey (Table 3.2, Fig. 3.9).

Two samples were collected from the fluorometer samples stream; the first was taken at the end of the Challis facility circuit to determine whether laboratory testing would detect the produced formation waters (267/1/WS1), and the second was taken at the site of a significant fluorometer anomaly over the Yampi Shelf (267/18/WS5; this anomaly turned out to be an artifact caused by sparking in the Xenon lamp emission – see Section 3.4. Towed Fluorometer).

Table 3.2. List of ocean water samples collected during S267

Sample name	Sample type	Latitude	Longitude	Date
267/1WS1	surface	-12:07.246	125:02.093	5/03/04
267/15/WS2	water column	-13:38.760	124:43.150	9/03/04
267/16/WS3	water column	-13:38.830	124:43.170	9/03/04
267/17/WS4	water column	-13:38.810	124:43.180	9/03/04
267/18/WS5	surface	-13:45.423	124:51.235	10/03/04
267/19/WS6	surface	-12.316025	129.620518	4/03/04

Three Niskin bottle samples (267/15-17/WS2-4) were taken at the site of the first identified active seep (Fig. 3.9). This exercise was an attempt to sample directly in the seep plume.

One sample was collected over the side of the vessel during transit, as a slick of brown algae was intersected (267/19/WS6). The sample was collected using a bucket and rope (this was collected en-route to the study area so the location is not shown in figure 3.9).

Scientific finding – Apart from the Challis Venture and algal slick surface samples, laboratory analysis of the collected waters shows very weak fluorescence signals corresponding to background levels of hydrocarbons (estimated at about 0.01 ppm) and humic matter. Fluorescence intensity in these samples is comparable with that of the IAPSO standard seawater. In contrast, the Challis sample shows a distinct hydrocarbon fluorescence signature (about 0.03 ppm) and the surface slick sample has fluorescence about 100 times stronger than water column samples (both in the hydrocarbon/protein and humic spectral regions). See Radlinski and others (2004) for details.

3.9. Sediment Samples (Grabs, Dredges & Cores)

Sixteen grabs, 12 dredges, and 2 gravity cores from S267 returned samples (Fig. 3.20). Appendix C details the types of samples, the positions from which they were taken, and their current storage locality.

Grabs generally returned light olive-grey (Munsell colour 5Y5/2), sandy, bioclastic carbonate mud. Grabs from the vicinity of active seeps returned fragments of dark encrusted material, mud pellets, worm tubes (Fig. 3.21; some of which comprised the black encrusted material; see Appendix D for description of benthic organisms from grab samples by Australian Institute of Marine Science biologist), coral fragments, shells and shell fragments, bryozoans, echinoids, and living biota. One grab sample from directly on a seep had a very strong smell of H_2S and contained the most abundant dark encrusted material. When grabs were taken away from seepage sites there was very little macro-biota or black encrusted material.

Figure 3.21. Examples of sabellariid worm tubes collected in grabs and dredges during S267

Returns from the dredge were similar to the grab samples, with a greater coarse component. A similar correlation between active seepage and macro-biota was observed in the dredge samples.

Gravity coring was largely unsuccessful. During initial test deployments it was discovered that a 6 m core barrel could not be handled on a vessel of the size of the '*Parmelia K*'. Test deployment and retrieval with a 4 m barrel proved successful. Deployment of a 4 m gravity core over/near an area of pock marks resulted in a bent barrel, with retrieval of hard coral in the core catcher and 68 cm of carbonate mud with abundant coral fragments. Further attempts at gravity coring resulted in sample retrieval from the core catcher only. One attempted core appeared to bend the core bomb. The lack of success is attributed primarily to carbonate cementation around seep sites.

Chapter 4. Discussion

This report details the operations results of survey 267, therefore this discussion involves operational aspects that need to be maintained or improved for future seepage surveys and does not comment on the scientific findings in the context of hydrocarbon seepage on the North West Shelf. As previously stated, scientific issues arising from the survey are discussed in peer reviewed journal papers (eg. Jones et al., 2005, Rollet et al., in press).

4.1. Visualising Seeps

The most significant operational result arising from the survey was the direct observation and visualisation of natural hydrocarbon seepage in the Timor Sea region of the North West Shelf, which has previously only been interpreted through remote sensing or automated water sampling techniques (sniffer; Rollet et al., in press). Seeping gas bubbles were observed at the surface by members of the survey crew (Fig. 4.1).

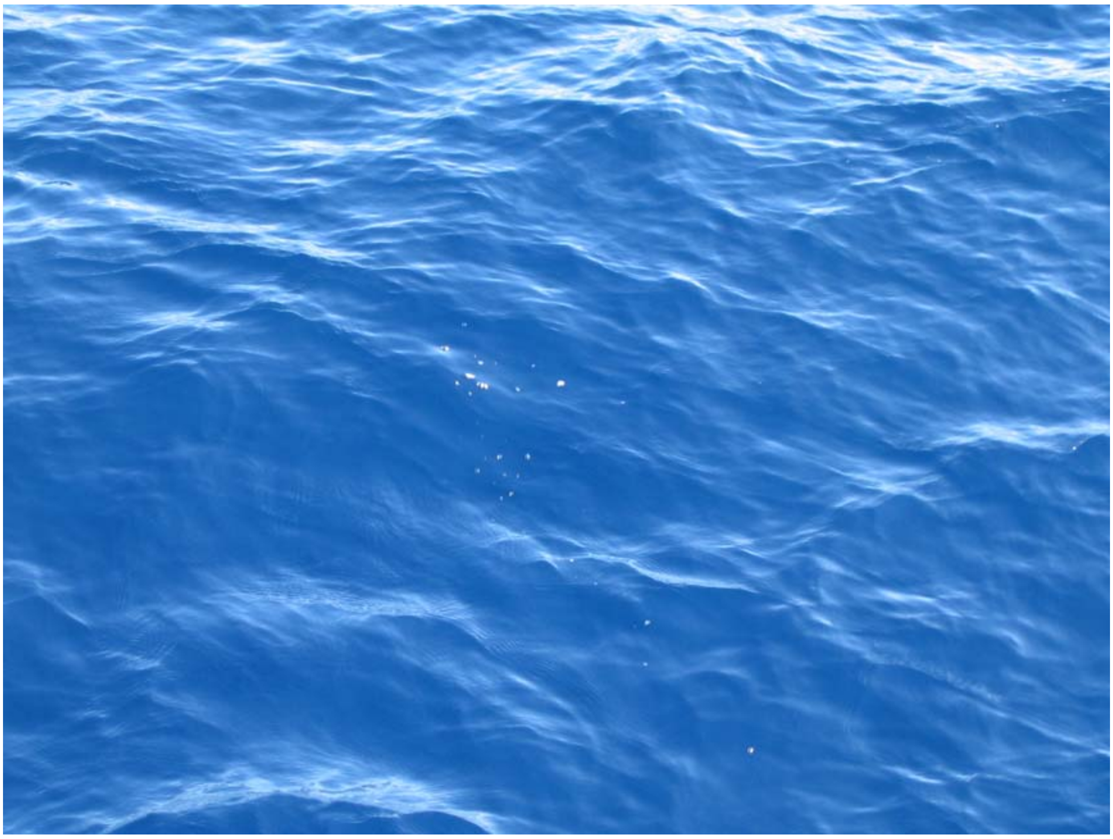


Figure 4.1. Gas bubbles that have risen to the sea surface from natural hydrocarbon seeps

The underwater video camera was deployed to observe active seepage. Footage was disappointing due to focus problems, and a lack of clear video feed to the operational room made driving the camera a problem. The video footage was given a lower priority than sampling but is considered useful. Future survey work over active vents would benefit from access to an ROV. This would show the nature and style of seepage and also any living biological communities. Clear footage is also useful from a promotional point of view to communicate our work to the general public.

In the context of seep visualisation during the survey, the vessels 200 kHz echo sounders (bow and stern) were used to great effect. This was an unexpected bonus, as they were able to clearly visualise gas plumes and could provide information throughout the water column. The echo sounders also provided additional qualitative information on the nature of the sea bed (e.g. sand versus hard surface), but much of this interpretation relied on the skipper’s experience. The echo-sounder could not be digitally recorded (screen display only) and future surveys would benefit significantly from access to a digitally recordable 200 kHz echo-sounder.

The side-scan sonar provided a picture of the sea-bed at the ideal resolution to identify pock-marks, sedimentary bed-forms and surface hard grounds, therefore it proved to be one of the most important tools during the survey. It also provided water column information that allowed the detection and visualisation of gas seepage features (plumes) up to 20-30 m above the sea-bed (depending on depth of towed fish). The 100 kHz signal was most effective for identifying water column gas.

The resolution of the multi-beam does not allow identification of fine scale sea-bed features associated with seepage, but can delineate medium scale seabed features (fault scarps, mounds, mud volcanoes). However, mapping the sea-bed with multi-beam during a seepage survey remains important, as demonstrated through linking submarine channels with SAR slicks previously thought to be oil slicks associated with natural hydrocarbon seepage (Jones et al., 2005).

The presence of active seepage on the edge of various hard grounds and seismic features emphasises the need for a shallow seismic capability for seepage work. Shallow seismic can be tied to existing deeper seismic and also allows identification of seepage features and gas within the upper parts of the sedimentary pile. Fortunately the survey was undertaken in an area of active seepage on the Yampi Shelf; future surveys will require the capability to identify gas pocks and hydrocarbon indicators even when water-column venting is not an active process.

Much of the electronic data acquisition equipment taken on the survey had not been previously tested/used by Geoscience Australia. Lack of experience and poorly functioning equipment resulted in significant down time. In future surveys equipment critical to the outcomes of the survey should either be leased from a supplier who supplies an on-board technician or should be purchased by Geoscience Australia with sufficient time for full familiarisation/training.

4.2. Site Selection

Of the numerous datasets used in assessing potential seepage sites, the most useful proxy for detecting active seepage on the survey was seismic data. Sites of active seepage were detected in direct association with HRDZ's identified in the 3D seismic data (Fig. 1.4; Rollet et al., in press). In contrast, correlations between detected seepage and previously acquired remote sensing datasets are tenuous at best. Therefore, it is highly recommended that future seepage surveys access the most up-to-date, accurate seismic data available in assessing potential sites and, if possible, seismic data should be acquired during the survey to facilitate locating and sampling seeps.

4.3. Sampling

The skimmer worked very well during the later part of the survey in calm waters. Testing for PFWs at Challis was not a success, the primary reason being the poor sea state. A combination of swell and surface chop of over 1 m probably precluded slick formation and prevented ideal skimming. During the later part of the survey the equipment appeared to work well, but there was no evidence of hydrocarbon slicks within the areas surveyed. Post survey processing has revealed value in the data so equipment should be trialled further and more training provided for staff on future surveys. The software development occurring prior to the survey reduced the training period and further work will be needed in the development.

Grab and dredge work proved effective in sampling around active seep sites. However, attempting to accurately sample seeps sites was very difficult given the inability of the vessel to hold station. To address this issue the vessel's echosounders were used to locate the vessel over seeps and to observe the sampling device in the water column as it moved to the sea bed. Geoscience Australia technical officers, along with the vessels crew, constructed an anchor during the course of the survey, which was used to slow the drift of the vessel in the relatively powerful tidal currents (sampling was most effective during the slack phase of the tide). The use of the anchor in association with the vessel's echosounders allowed for relatively accurate sampling of seep sites.

There was no capacity to retain or sample gases during the survey.

4.4. Staffing, Vessel and Crew

On a small boat it was critical that all staff work closely in a team environment. During this survey the team functioned particularly well. The science staff were all well versed in the aims of the project and this allowed a great deal of flexibility when equipment failures or problems required changes in the work program. It also allowed responses to developing situations to be made that directly benefited the project without delay. The skills mix for this survey worked well and needs to be taken into account in future surveys.

This need for flexibility also sets a range of demands on operational staff. All staff performed very well and worked closely together to provide rapid solutions to problems encountered during the survey. An example of this is the construction of an anchor from a bent core barrel and scrap metal to decrease ship movement during sampling. Welding and construction was all carried out onboard within the space of a few hours to allow deployment during the next day's sampling.

The survey component of the work was successfully handled on this relatively small vessel. The crew of the vessel proved to be particularly helpful and interested in our work. In particular, the seamanship of the skipper, Mark Winters, in manoeuvring his vessel at low speed allowed more accurate sampling than would normally be the case on a vessel of this type. He used the echo sounders on the vessel pro-actively, to help identify seeps and features of interest.

Chapter 5. Recommendations

1: There is a need for the following capacity for future data acquisition during seepage surveys

- Side-scan sonar (100 & 500 kHz)
- Recordable echo-sounder (200 kHz)
- Multi-beam/Swath capability
- Sub-bottom profiler
- CDL salinity/temperature profiler
- Shallow seismic capability

2: We recommend that GA purchase equipment vital to surveys to allow familiarization and correct maintenance. In particular, seepage survey work will need a side-scan sonar and a recordable echo-sounder.

3: The skimmer and fluorometer needs to be trialled further, as the survey did not provide a suitable test due to weather conditions.

Acknowledgements

We would like to thank to Broome Pearls, particularly the skipper, Mark Winters, and crew of the vessel *Parmelia K*, for facilitating the survey. Thanks to the Geoscience Australia operational staff who assisted in outfitting the vessel for the survey, and provided technical support while at sea. Chris Evenden of the Geospatial Applications and Visualisation Group of Geoscience Australia prepared some of the figures. This report benefited from the critical reviews of Neville Exon, Andrew Heap, Jim Colwell and Alix Post. Published with the permission of the Chief Executive Officer, Geoscience Australia.

References

Abrams, M.A. (1992) Geophysical and geochemical evidence for subsurface hydrocarbon leakage in the Bering Sea, Alaska. *Marine and Petroleum Geology Bulletin*, 9, 208-221.

Blevin, J.E., Boreham, C.J., Summons, R.E., Struckmeyer, H.I.M. & Loutit, T.S. (1998) An effective Lower Cretaceous Petroleum system on the North West Shelf: Evidence from the Browse Basin. In: Purcell, P.G. and Purcell, R.R. (eds), *The Sedimentary Basins of Western Australia 2. Proceedings of PESA Symposium*, Perth, 397-419.

Edwards, D.S. and Crawford, N. (1999) UV Fluorescence Analysis of Seawater Samples from AGSO Marine Survey 207, Northwest Australia. *AGSO Record 1999/52*, 7, unpublished.

Holdway, D. Radlinski, A.P., Exon, N., Auzende J-M. and Beuque, S. (2000) Continuous multi-spectral fluorescence and absorption spectroscopy for hydrocarbon detection in ocean waters: Fairway Basin, Lord Howe Rise. *AGSO Record 2000/35*, 57 pp.

Hovland, M. and Judd, A.G. (1988) *Seabed pockmarks and seepages: Impact on Geology, Biology and the Marine Environment*. Graham and Trotman, London, 293 pp.

Ingram, G.M., Eaton, S. & Regtien, J.M.M. (2000) Cornea case study: lessons for the future. *APPEA Journal*, 40 (1), 56-64.

Jones, A.T., Logan, G.A., Kennard, J.M. and Rollet, N. (2005) Reassessing potential origins of synthetic aperture radar (SAR) slicks from the Timor Sea region of the North West Shelf on the basis of field and ancillary data. *APPEA Journal* 45, 311-331.

NPA Ltd., Treic^{o} Ltd. & AGSO (1999) *Offshore Basin Screening*^{TM} *of Timor Sea*. 85, unpublished (Included as an appendix in O’Brien et al., 2001).

O’Brien, G.W., Blackburn, G. and Baird, J. (1996) Yampi Shelf Tie (YST) Basin Study and Interpretation Report: Yampi Shelf, Browse Basin, Northwestern Australia. *AGSO Record 1996/60*.

O’Brien, G.W., Glenn, K., Lawrence, G., Williams, A., Webster, M., Cowley, R. & Burns, S. (2002) Influence of hydrocarbon migration and seepage on benthic communities in the Timor Sea, Australia,” *APPEA Journal*, 42, 225–240.

O’Brien, G.W., Lawrence, G., Williams, A.K. (2003) Assessing controls on hydrocarbon leakage and seepage, *World Oil*, Remote sensing special focus, November 2003, 1-7.

O’Brien, G.W., Lawrence, G., Williams, A., Webster, M., Cowley, R., Wilson, D. & Burns, S. (2001) Hydrocarbon migration and seepage in the Timor Sea and Northern Browse basin North-West Shelf, Australia: An Integrated SAR, Geological and Geochemical Study. *AGSO Report and GIS. Record 2001/11*.

O’Brien, G.W., Lawrence, G., Williams, A., Webster, M., Wilson, D. & Burns, S. (2000) Using integrated remote sensing technologies to evaluate and characterise hydrocarbon migration and charge characteristics on the Yampi Shelf, north-western Australia: a methodological study. *APPEA Journal*, 40(1), 230-255.

O’Brien, G.W., Lisk, M., Duddy, I.R., Hamilton, J., Woods, P. & Cowley, R. (1999) Plate convergence, foreland development and fault reactivation: Primary controls on brine migration, thermal histories and trap breach in the Timor Sea, Australia. *Marine and Petroleum Geology*, 16 (6), 533-560.

O’Brien, G.W., Quaife, P., Cowley, R., Morse, M., Wilson, D., Fellows, M. & Lisk, M. (1998) Evaluating trap integrity in the Vulcan Sub-basin, Timor Sea, Australia, using integrated remote sensing geochemical technologies. *Petroleum Exploration Society of Australia (PESA) Western Australian Basins Symposium Volume 2* (Ed. by P.G. & R.R. Purcell), 237-254.

O’Brien, G.W. and Woods, E.P. (1995) Hydrocarbon-related diagenetic zones (HRDZs) in the Vulcan Sub-basin, Timor Sea: recognition and exploration implications. *APEA Journal*, 35 (1), 220-52.

Radlinski, A.P., Jackson, P. & Jones, A. (2004) *Spectral analysis of continuous fluorescence data for surface ocean waters and ocean water samples: Challis Venture and Cornea Area 1, Yampi Shelf, North West Shelf, Australia*. Geoscience Australia Report, 76 pp., unpublished.

Rollet, N., Logan, G, Kennard, J., O'Brien, P., Jones A. & Sexton, M. (in press) Active hydrocarbon seepage characterised and correlated within a range of geophysical datasets: an example from the tropical, carbonate Yampi Shelf, Northwest Australia. *Marine and Petroleum Geology*.

Shell (2000) *Seismic interpretation report, Cornea 3D Survey, Browse Basin*. Unpublished, 21 pp.

Spry, T.B. and Ward, I. (1997) The Gwydion discovery: a new play fairway in the Browse Basin. *APPEA Journal*, 37 (1), 87-104.

Struckmeyer, H.I.M., Blevin, J.E., Sayers, J., Totterdell, J.M., Baxter, K. & Cathro, D.L. (1998) Structural evolution of the Browse Basin, North West Shelf; new concepts from deep seismic data. In Purcell, P.G. and Purcell, R.R., (Editors). *The Sedimentary Basins of Western Australia 2: Proceedings of Petroleum Exploration Society of Australia Symposium*, Perth, Western Australia, 1998, 345-67.

Symonds, P.A., Collins, C.D.N. & Bradshaw, J. (1994) Deep structure of the Browse Basin; implications for basin development and petroleum exploration. In Purcell, P.G. and Purcell, R.R., (Editors). *The Sedimentary Basins of Western Australia: Proceedings of Petroleum Exploration Society of Australia Symposium*, Perth, Western Australia, 1994, 315-31.

Wilson, D.J. (2000) AGSO Marine Survey 176 Direct Hydrocarbon Detection North-West Australia: Yampi Shelf, Southern Vulcan Sub-Basin and Sahul Platform (July/September 1996). *AGSO Record 2000/42*, 38 pp.

Appendix A – Personnel

GEOSCIENCE AUSTRALIA STAFF

Chief Scientist	–	Graham Logan
Scientific Staff	–	John Kennard
		Phil O'Brien
		Andrew Jones
Technical Staff	–	Mike Sexton
		Jack Pittar
Operational Staff	–	Craig Wintle
		Jon Stratton

BROOME PEARLS STAFF

Captain	–	Mark Winters
1st mate	–	Michael Coppens
Engineer	–	Darryn Bailey
Deck hand	–	Michael Garrigan
Cook	–	Megan Green

Appendix B – Table of digital data captured during S267

P00 #	Data Type	Original Label	Media Type	Contents	Description/Remarks
P00487976	Sidescan	Sidescan DVD#1	DVD	XTF files	Raw Sidescan Data
P00487977	Sidescan	Sidescan DVD#2	DVD	XTF files	Raw Sidescan Data
P00487978	Sidescan	Sidescan DVD#3	DVD	XTF files	Raw Sidescan Data
P00487979	Sidescan	Sidescan DVD#4	DVD	XTF files	Raw Sidescan Data
P00487980	Multibeam	Multibeam DVD#1	DVD	XTF files	Raw Multibeam Data (except Patch Test)
P00487981	Multibeam	Multibeam DVD#1 (copy)	DVD	XTF files	Raw Multibeam Data (except Patch Test) - Copy of P00xxxxx
P00487982	Multibeam	CD#1	CD	XTF files	Raw Multibeam Data (Patch Test)
P00487983	Images	CD#2	CD	TIF files	Selected screen captures of Sidescan Images
P00487984	Miscellaneous	CD#3	CD		General Data and Petrosys Project
P00487985	Images	CD#4	CD	TIF files	Grid images of each of the survey sites and the entire survey
P00488020	Fluorometer & ADCP		CD	DAT and 0000 files	Fluorometer data captured with Windows based system ADCP data can be viewed with WinADCP – downloadable from the RD Instruments website (www.rdinstruments.com)

Appendix C – Table of Samples collected during S267

Sample No.	Sample Device	Sub-sample	Latitude	Longitude	Location
267/6GC1CC	Gravity Core	Core Catcher	-13.80345	124.94917	Cold Store
267/7GR1A	Smith-McIntyre Grab	Bulk Sample	-13.64383	124.71792	Cold Store
267/7GR1B	Smith-McIntyre Grab	Mini Core	-13.64383	124.71792	Freezer
267/8GR2A	Smith-McIntyre Grab	Bulk Sample	-13.6257	124.51145	Cold Store
267/8GR2B	Smith-McIntyre Grab	Mini Core	-13.6257	124.51145	Freezer
267/9GR3A	Smith-McIntyre Grab	Bulk Sample	-13.62615	124.5151	Cold Store
267/9GR3B	Smith-McIntyre Grab	Mini Core	-13.62615	124.5151	Freezer
267/12GR4A	Smith-McIntyre Grab	Bulk Sample	-13.62615	124.5151	Cold Store
267/12GR4B	Smith-McIntyre Grab	Mini Core	-13.62615	124.5151	Freezer
267/13DR1A	Dredge	Bulk Sample	-13.62615	124.5151	Cold Store
267/13DR1B	Dredge	Bulk Sample	-13.62615	124.5151	Cold Store
267/20GC2A	Gravity Core	Bomb Sample	-13.62615	124.5151	Freezer
267/20GC2CC	Gravity Core	Core Catcher	-13.62615	124.5151	Cold Store
267/22GR5A	Smith-McIntyre Grab	Bulk Sample	-13.62615	124.5151	Cold Store
267/22GR5B	Smith-McIntyre Grab	Coarse Fraction	-13.62615	124.5151	Cold Store
267/22GR5C	Smith-McIntyre Grab	Mini Core	-13.62615	124.5151	Freezer
267/24GR6A	Smith-McIntyre Grab	Bulk Sample	-13.80345	124.94917	Freezer
267/24GR6B	Smith-McIntyre Grab	Bulk Sample	-13.80345	124.94917	Freezer
267/24GR6C	Smith-McIntyre Grab	Bulk Sample	-13.80345	124.94917	Cold Store
267/24GR6D	Smith-McIntyre Grab	Coarse Fraction	-13.80345	124.94917	Cold Store
267/24GR6E	Smith-McIntyre Grab	Mini Core	-13.80345	124.94917	Freezer
267/27GR7A	Smith-McIntyre Grab	Bulk Sample	-13.80345	124.94917	Freezer
267/27GR7B	Smith-McIntyre Grab	Bulk Sample	-13.80345	124.94917	Freezer
267/27GR7C	Smith-McIntyre Grab	Bulk Sample	-13.80345	124.94917	Cold Store
267/27GR7D	Smith-McIntyre Grab	Coarse Fraction	-13.80345	124.94917	Cold Store
267/27GR7E	Smith-McIntyre Grab	Mini Core	-13.80345	124.94917	Freezer
267/30GR8A	Smith-McIntyre Grab	Bulk Sample	-13.80345	124.94917	Freezer
267/30GR8B	Smith-McIntyre Grab	Bulk Sample	-13.80345	124.94917	Freezer
267/30GR8C	Smith-McIntyre Grab	Bulk Sample	-13.80345	124.94917	Cold Store
267/30GR8D	Smith-McIntyre Grab	Coarse Fraction	-13.80345	124.94917	Freezer
267/31GR9A	Smith-McIntyre Grab	Bulk Sample	-13.80345	124.94917	Freezer
267/31GR9B	Smith-McIntyre Grab	Bulk Sample	-13.80345	124.94917	Freezer
267/31GR9C	Smith-McIntyre Grab	Bulk Sample	-13.80345	124.94917	Cold Store
267/31GR9D	Smith-McIntyre Grab	Coarse Fraction	-13.80345	124.94917	Freezer
267/31GR9E	Smith-McIntyre Grab	Mini Core	-13.80345	124.94917	Freezer
267/34GR10A	Smith-McIntyre Grab	Bulk Sample	-13.80345	124.94917	Freezer
267/34GR10B	Smith-McIntyre Grab	Bulk Sample	-13.80345	124.94917	Freezer
267/34GR10C	Smith-McIntyre Grab	Bulk Sample	-13.80345	124.94917	Freezer
267/34GR10D	Smith-McIntyre Grab	Bulk Sample	-13.80345	124.94917	Cold Store
267/34GR10E	Smith-McIntyre Grab	Coarse Fraction	-13.80345	124.94917	Cold Store
267/34GR10F	Smith-McIntyre Grab	Mini Core	-13.80345	124.94917	Freezer
267/37GR11A	Smith-McIntyre Grab	Bulk Sample	-13.80345	124.94917	Freezer
267/37GR11B	Smith-McIntyre Grab	Bulk Sample	-13.80345	124.94917	Freezer
267/37GR11C	Smith-McIntyre Grab	Bulk Sample	-13.80345	124.94917	Freezer
267/37GR11D	Smith-McIntyre Grab	Bulk Sample	-13.80345	124.94917	Cold Store
267/37GR11E	Smith-McIntyre Grab	Coarse Fraction	-13.80345	124.94917	Cold Store
267/37GR11F	Smith-McIntyre Grab	Mini Core	-13.80345	124.94917	Freezer

267/37GR11G	Smith-McIntyre Grab	Coarse Fraction (mud balls)	-13.80345	124.94917	Freezer
267/38DR2A1	Dredge	Bulk Sample	-13.64612	124.7196	Freezer
267/38DR2A2	Dredge	Bulk Sample	-13.64612	124.7196	Freezer
267/38DR2A3	Dredge	Bulk Sample	-13.64612	124.7196	Cold Store
267/38DR2B1	Dredge	Coarse Fraction (worm tubes)	-13.64612	124.7196	Freezer
267/38DR2B2	Dredge	Coarse Fraction (worm tubes)	-13.64612	124.7196	Cold Store
267/38DR2C1	Dredge	Coarse Fraction (carbonate)	-13.64612	124.7196	Cold Store
267/38DR2C2	Dredge	Coarse Fraction (carbonate)	-13.64612	124.7196	Cold Store
267/39DR3A	Dredge	Bulk Sample	-13.64633	124.70775	Cold Store
267/39DR3B	Dredge	Bulk Sample	-13.64633	124.70775	Freezer
267/40DR4A	Dredge	Bulk Sample	-13.64587	124.7053	Freezer
267/40DR4B	Dredge	Bulk Sample	-13.64587	124.7053	Freezer
267/41DR5A1	Dredge	Bulk Sample	-13.64383	124.71792	Cold Store
267/41DR5A2	Dredge	Bulk Sample	-13.64383	124.71792	Freezer
267/41DR5B	Dredge	Coarse Fraction	-13.64383	124.71792	Freezer
267/42DR6A1	Dredge	Bulk Sample	-13.64417	124.71763	Cold Store
267/42DR6A2	Dredge	Bulk Sample	-13.64417	124.71763	Freezer
267/42DR6B	Dredge	Coarse Fraction (worm tubes)	-13.64417	124.71763	Freezer
267/42DR6C	Dredge	Coarse Fraction	-13.64417	124.71763	Cold Store
267/43DR7A1	Dredge	Bulk Sample	-13.62583	124.51233	Cold Store
267/43DR7A2	Dredge	Bulk Sample	-13.62583	124.51233	Freezer
267/43DR7B	Dredge	Coarse Fraction (carbonate)	-13.62583	124.51233	Freezer
267/43DR7C	Dredge	Coarse Fraction (worm tubes)	-13.62583	124.51233	Freezer
267/43DR7D	Dredge	Coarse Fraction	-13.62583	124.51233	Cold Store
267/44DR8A	Dredge	Bulk Sample	-13.62633	124.51433	Cold Store
267/44DR8B	Dredge	Bulk Sample	-13.62633	124.51433	Cold Store
267/44DR8C	Dredge	Coarse Fraction	-13.62633	124.51433	Freezer
267/44DR8D	Dredge	Coarse Fraction (mud balls)	-13.62633	124.51433	Freezer
267/45DR9A1	Dredge	Bulk Sample	-13.62417	124.50567	Cold Store
267/45DR9A2	Dredge	Bulk Sample	-13.62417	124.50567	Freezer
267/45DR9B	Dredge	Coarse Fraction	-13.62417	124.50567	Cold Store
267/46DR10A1	Dredge	Bulk Sample	-13.62427	124.50702	Cold Store
267/46DR10A2	Dredge	Bulk Sample	-13.62427	124.50702	Freezer
267/46DR10B	Dredge	Coarse Fraction	-13.62427	124.50702	Cold Store
267/47DR11A1	Dredge	Bulk Sample	-13.62683	124.55263	Cold Store
267/47DR11A2	Dredge	Bulk Sample	-13.62683	124.55263	Freezer
267/47DR11B	Dredge	Coarse Fraction	-13.62683	124.55263	Cold Store
267/47DR11C	Dredge	Coarse Fraction (carbonate)	-13.62683	124.55263	Cold Store
267/48DR12A1	Dredge	Bulk Sample	-13.633	124.54317	Freezer
267/48DR12A2	Dredge	Bulk Sample	-13.633	124.54317	Cold Store
267/48DR12B	Dredge	Coarse Fraction	-13.633	124.54317	Cold Store
267/49GR12A	Smith-McIntyre Grab	Bulk Sample	-13.62537	124.51417	Freezer
267/49GR12B	Smith-McIntyre Grab	Bulk Sample	-13.62537	124.51417	Freezer
267/49GR12C	Smith-McIntyre Grab	Bulk Sample	-13.62537	124.51417	Cold Store

267/49GR12D	Smith-McIntyre Grab	Mini Core	-13.62537	124.51417	Freezer
267/50GR13A	Smith-McIntyre Grab	Bulk Sample	-13.6257	124.51145	Freezer
267/50GR13B	Smith-McIntyre Grab	Bulk Sample	-13.6257	124.51145	Freezer
267/50GR13C	Smith-McIntyre Grab	Bulk Sample	-13.6257	124.51145	Cold Store
267/50GR13D	Smith-McIntyre Grab	Mini Core	-13.6257	124.51145	Freezer
267/51GR14A	Smith-McIntyre Grab	Bulk Sample	-13.62593	124.51245	Freezer
267/51GR14B	Smith-McIntyre Grab	Bulk Sample	-13.62593	124.51245	Freezer
267/51GR14C	Smith-McIntyre Grab	Bulk Sample	-13.62593	124.51245	Cold Store
267/51GR14D	Smith-McIntyre Grab	Mini Core	-13.62593	124.51245	Freezer
267/52GR15A	Smith-McIntyre Grab	Bulk Sample	-13.62558	124.5129	Freezer
267/52GR15B	Smith-McIntyre Grab	Bulk Sample	-13.62558	124.5129	Freezer
267/52GR15C	Smith-McIntyre Grab	Bulk Sample	-13.62558	124.5129	Cold Store
267/52GR15D	Smith-McIntyre Grab	Coarse Fraction	-13.62558	124.5129	Cold Store
267/52GR15E	Smith-McIntyre Grab	Mini Core	-13.62558	124.5129	Freezer
267/53GR16A	Smith-McIntyre Grab	Bulk Sample	-13.62615	124.5151	Freezer
267/53GR16B	Smith-McIntyre Grab	Bulk Sample	-13.62615	124.5151	Freezer
267/53GR16C	Smith-McIntyre Grab	Bulk Sample	-13.62615	124.5151	Cold Store
267/53GR16D	Smith-McIntyre Grab	Mini Core	-13.62615	124.5151	Freezer

Appendix D – Description of benthic organisms from grab samples

Carstan Wolff (Australian Institute of Marine Science)

29 October 2004

267/38/DR2 B2, Coarse:

Polychaete worm tubes 8-12 mm diameter, encrusted, not recent: F. *Sabellariidae*. Plankton filter feeders.

267/47/DR 11 C, Coarse, 4˚C:

Non-recent rubble (bivalvia and corals) encrusted with recent F. Serpulidae (4+spp.) small worm tubes, bryozoa, some olive-shells(?) and two other bivalvia: A *(Noto)corbula* sp. and an oyster: possibly a *Saccostrea* sp.

267/45/DR9 B:

Multitude of recent and older shell grit. Dominant fauna class: bivalvia, with other mollusca, echinoidea (sea-urchin fragments) and bryozoa. Up to 50% of bivalve shells is F. Pectinidae (Pilgrim shells), mostly *Cryptopecten* nux. About 10% was a F. Propeamussiidae shell: *Parvamussium* sp.: possibly *P. torresi*. Other bivalves included *Zenatina* sp. (F. Mactridae) and *Barbatia?* sp. (F. Archidae). Also some interesting small, Class Scaphopoda shells: F. Dentaliidae: *Dentalium*, possibly new species. 5% of mass was another bivalvia group: possibly *Tapes* sp., (F. Veneridae (Venus shells)), *Zenatina* sp. (F. Mactridae) 30 mm; *Barbatia* sp., (F Arcidae).

Other Gastropoda were represented by: *Phos* sp. (F. Buccinidae), *Epitonium* sp., (F. Epitoniidae), *Tudivasum* (F. Turbinellidae) and spp. of the worm-like F. Siliquariidae: members of this family usually put out slime webs in which they catch detritus and plankton to feed on.

267/22 GR 5B coarse fraction:

Similar to 267/45/DR9 B, but more diverse and slightly different species composition. Coral rubble, bryozoa, echinoidea, all mostly fragmented. Notably amongst bivalves: *Placamen tiara* (F. Veneridae); 2+ *Clamys* spp. (F. Pectiniidae (Scallops)), a few *Ctenoides* cf. *ales* (F. Limidae) and an unidentified F. Cardiidae specimen (juv, ~8 mm diameter, very round specimen).

Gastropods *Murex* sp., (F. Muricidae) (fragment); *Mitra pyramis* (F. Mitridae).

Also present: another (non-dentaliid?) Scaphopod species. And a pteropod (F. Cavoliniidae) species.

Also: 10+ spp of bryozoans and some urchin fragments.

<u>267/34/ GR 10 E coarse fraction:</u>

20% non-recent sabellariid worm tubes as before. 10-20% of reaction is Gastropoda (5-10% recent):

F. Volutidae: large shell fragment, either *Amoria* or *Notovoluta* sp.

F. Muricidae: *Haustellum* cf. *dolichourus* and another *Haustellum* sp.

F. Ficidae: *Ficus eospila*

F. Turbinellidae: *Tudivasum spinosa* (non-recent)

F. Buccinidae: *Nassaria solida* (non-recent),

F. Turridae: *Crassispira harpularia* (non-recent?)

F. Strombidae: poss. *Strombus* sp.

Another scaphopod.

Bivalves make up 20-30% of the fraction:

F. Pectinidae: *Pecten* (cf. *fumatus*)- scallop

F. Placunidae: uncertain sp., non- recent fragment only

F. Veneridae: *Paphia undulata*

F. Glossidae: *Glossus* (cf. *lamarkii*)

Note: specimens in most of these fractions seem to be > 50% non-recent, and almost all spp. tend to be small/juveniles