

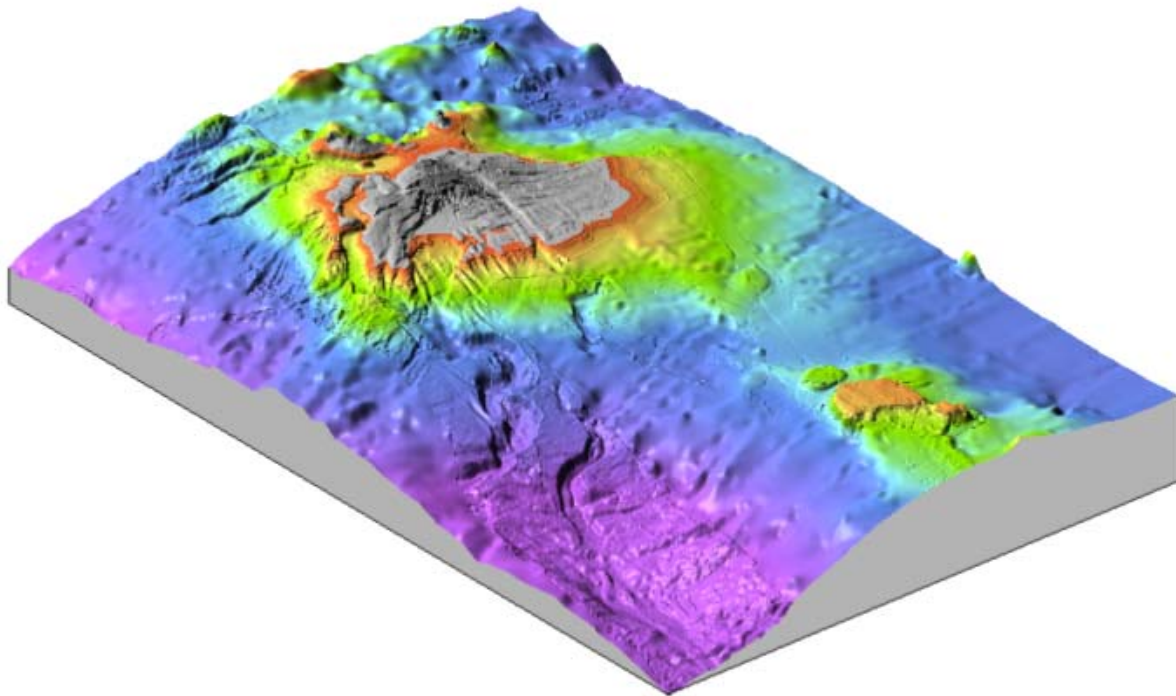


SOPAC

EU EDF 8 – SOPAC Project Report 110
Reducing Vulnerability of Pacific ACP States

VANUATU TECHNICAL REPORT
High-Resolution Bathymetric Survey of Efate
Fieldwork undertaken from 2 to 27 August 2003

October 2008



Three-dimensional perspective image of Efate topography, Vanuatu.

Prepared by:
Jens Krüger and Ashishika Sharma
SOPAC Secretariat
July 2008

PACIFIC ISLANDS APPLIED GEOSCIENCE COMMISSION

c/o SOPAC Secretariat

Private Mail Bag

GPO, Suva

FIJI ISLANDS

<http://www.sopac.org>

Phone: +679 338 1377

Fax: +679 337 0040

www.sopac.org

director@sopac.org

Important Notice

This report has been produced with the financial assistance of the European Community; however, the views expressed herein must never be taken to reflect the official opinion of the European Community.

TABLE OF CONTENTS

EXECUTIVE SUMMARY	1
1. INTRODUCTION	2
1.1 Background	2
1.2 Geographic Situation	3
1.3 Geological Setting	3
1.4 Previous Bathymetry Surveys	5
2. RESULTS.....	6
2.1 Bathymetry and Derivatives	6
2.2 Composite Bathymetry	11
2.3 Morphological Features	15
3. DATA ACQUISITION AND PROCESSING	18
3.1 Fieldwork Summary	18
3.2 Field Personnel	18
3.3 Geodetic Reference System	18
3.4 Vessel Description and Static Offsets	20
3.5 Positioning Control	21
3.6 Survey Computer	21
3.7 Multibeam Echosounder	21
3.8 Multibeam Echosounder Data Processing	22
3.9 Tidal Information	22
3.10 Sound Velocity Profiling	23
4. REFERENCES.....	26
APPENDICES.....	27
Appendix 1 – Statement of Uncertainty and Suitability for Charting	27
Appendix 2 – Multibeam Echosounder Coverage	32
Appendix 3 – CTD Profiles	36
Appendix 4 – High-resolution A0 Charts, Efate Bathymetry	41
Appendix 5 – Line Logs	42

LIST OF FIGURES

Figure 1.	Location map of Pacific Island countries and territories constituting SOPAC. . v
Figure 2.	Topography of Vanuatu islands and approximate position of the EEZ. 2
Figure 3.	Simplified tectonic elements in the Vanuatu arc and North Fiji Basin. 4
Figure 4.	Bathymetric map of SOPAC/EU 50 m-gridded multibeam echosounder data. 6
Figure 5.	Shaded relief map of Mele Bay. 7
Figure 6.	Three-dimensional bathymetry map of Mele Bay. 7
Figure 7.	Slope angle map of Mele Bay. 8
Figure 8.	Shaded relief map of Forari Bay. 8
Figure 9.	Three-dimensional bathymetry map of Forari Bay. 9
Figure 10.	Slope angle map of Forari Bay. 9
Figure 11.	Shaded relief map of Havannah Bay. 10
Figure 12.	Three-dimensional bathymetry map of Havannah Bay. 10
Figure 13.	Slope angle map of Havannah Bay. 11
Figure 14.	Data source diagram for the 50 m continuous grid around Efate. 12
Figure 15.	Composite bathymetry of Efate. 13
Figure 16.	Three-dimensional perspective image of the Efate 50 m grid bathymetry. 14
Figure 17.	Shaded relief map of the Efate 50 m gridded bathymetry. 15
Figure 18.	Slope angle map of Efate 50 m grid bathymetry. 15
Figure 19.	Preliminary interpretation, submarine geomorphology, Mele Bay. 16
Figure 20.	Major components of the Mele Bay morpho-structure, Efate. 17
Figure 21.	Photo of the survey vessel <i>Turagalevu</i> 19
Figure 22.	SEAFRAME tide gauge datum definition and geodetic levels at Vanuatu. 23
Figure 23.	Location and dates of CTD casts. 25
Figure A1.1.	Conceptual illustration of bathymetric data acquisition with an MBES. 28
Figure A2.1.	SOPAC/EU MBES, Reson 8160, coverage around Efate. 32
Figure A2.2.	Sounding points for MBES and SBES in Port Havannah. 33
Figure A2.3.	Sounding points for MBES and SBES in Mele Bay. 34
Figure A2.4.	Sounding points for MBES and SBES in Forari Bay. 35

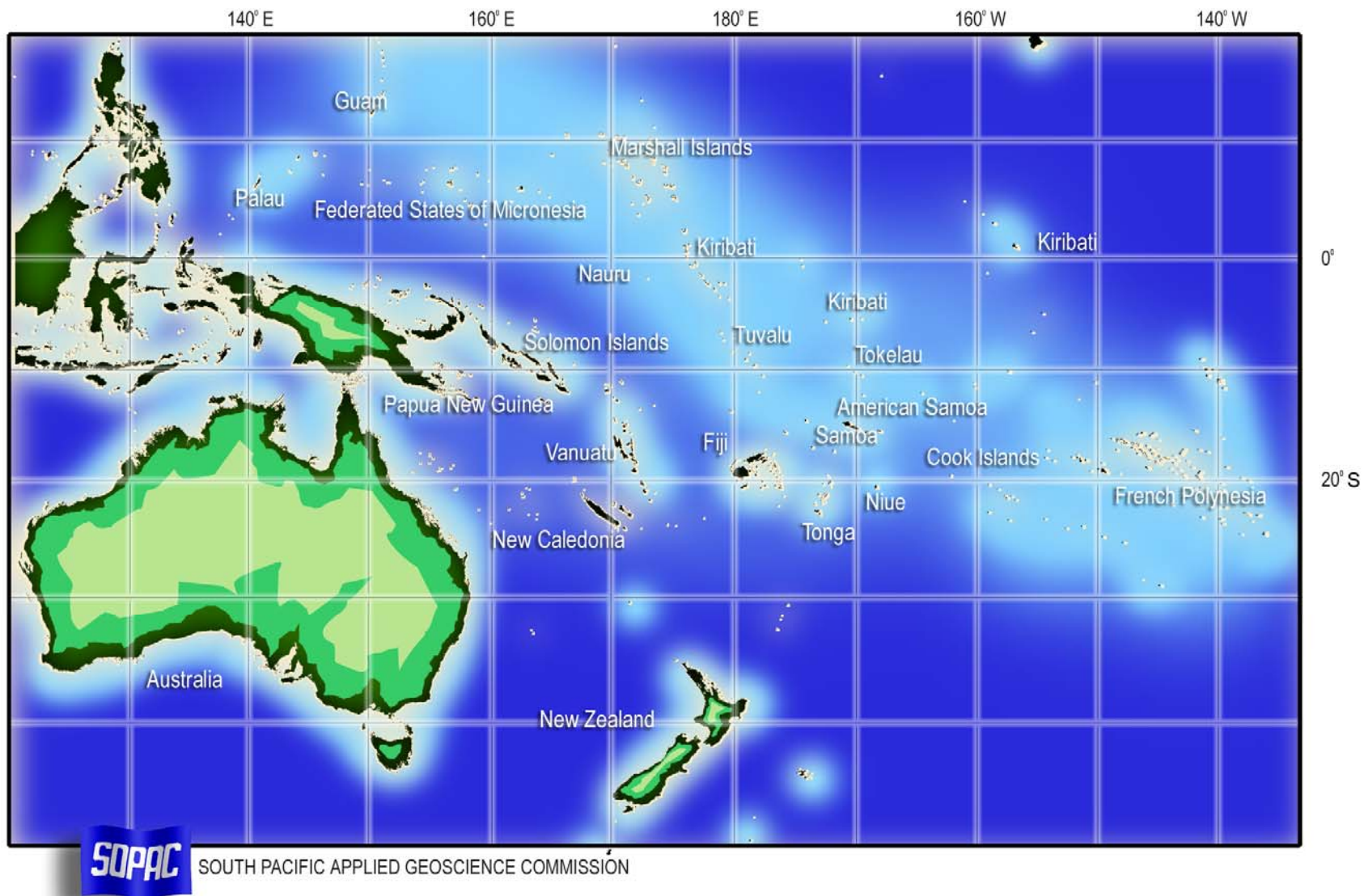


Figure 1. Location map of Pacific Island countries and territories constituting SOPAC.

<i>Acronyms and their meaning</i>	
ACP	African, Caribbean, and Pacific
ADV	Acoustic Doppler velocimeter
ARGO	Array for real-time geostrophic oceanography
ASCII	American standard code for information interchange
CD	Chart datum
CTD	Conductivity – temperature – depth
DTM	Digital terrain model
EEZ	Exclusive economic zone
EU	European Union
GDEM	Generalised digital environmental model
GEBCO	General bathymetry chart of the oceans
GLW	General Lamb wave
GPS	Global positioning system
LAT	Lowest astronomical tide
MBES	Multibeam echosounder
MRU	Motion reference unit
MSL	Mean sea level
NOAA	National Oceanic and Atmospheric Administration
PI-GOOS	Pacific Islands Global Ocean Observing System
RTK	Real-time kinematic
S2004	Global bathymetry grid merging GEBCO and predicted depths from satellite altimeter measurements
SOPAC	Pacific Islands Applied Geoscience Commission
SRTM	Space Shuttle Topography Mission 2000
TAO	Tropical atmosphere ocean array
UTC	Universal time co-ordinated (Greenwich meridian time, GMT)
UTM	Universal transverse Mercator
WGS	World geodetic system

EXECUTIVE SUMMARY

Krüger, J. and Sharma A. 2008: High-Resolution Bathymetric Survey of Efate, Vanuatu. *EU EDF 8 – SOPAC Project Report 110*. Pacific Islands Applied Geoscience Commission: Suva, Fiji, vi + 50 p. + 10 charts.

This report describes a high-resolution bathymetric mapping survey of the seabed surrounding the island of Efate in Vanuatu, by the Pacific Islands Applied Geoscience Commission (SOPAC). This work was initiated by the SOPAC/EU project 'Reducing Vulnerability of Pacific ACP States', which called for an investigation of the nearshore seabed around the island of Efate using a multibeam echosounder (MBES). The survey was carried out over a period of 25 days in August 2003, resulting in the acquisition of over 600 line kilometres of MBES data. The survey achieved good coverage of the seafloor from the inshore area, starting from a minimum depth of 40 m, to an average offshore distance of 10 km, reaching water depths of some 2 000 m. A 15 by 15 km area over a 100–150 m plateau, situated approximately 80 km to the SSW of Mele Bay, was also surveyed.

A review of external sources of available bathymetry was undertaken, and the survey data supplemented with publicly available data. The resultant compilation was used to produce bathymetry charts of Efate at scales of 1 : 100 000 and 1 : 50 000, with more detailed charts of Mele Bay, Forari Bay and Havannah Bay at 1 : 20 000. These new bathymetric maps give a descriptive picture of the ocean bottom terrain, vividly revealing the size, shape and distribution of underwater features. This can serve as the basic tool for scientific, engineering, marine geophysical and environmental studies, as well as marine and coastal resource management.

1. INTRODUCTION

1.1 Background

This report describes a high-resolution bathymetric mapping survey of the seabed surrounding the island of Efate in Vanuatu (Figure 2). The survey was conducted using a mid-ocean depth multibeam echosounder (range of 10–3000 m), and carried out over a period of 25 days in August 2003, resulting in the acquisition of over 600 line-km of multibeam echosounder (MBES) data. The strength of the magnetic field was also continuously logged during the survey using a towed magnetometer. This report presents the results of the MBES survey; the data collected by the magnetometer will be covered elsewhere.

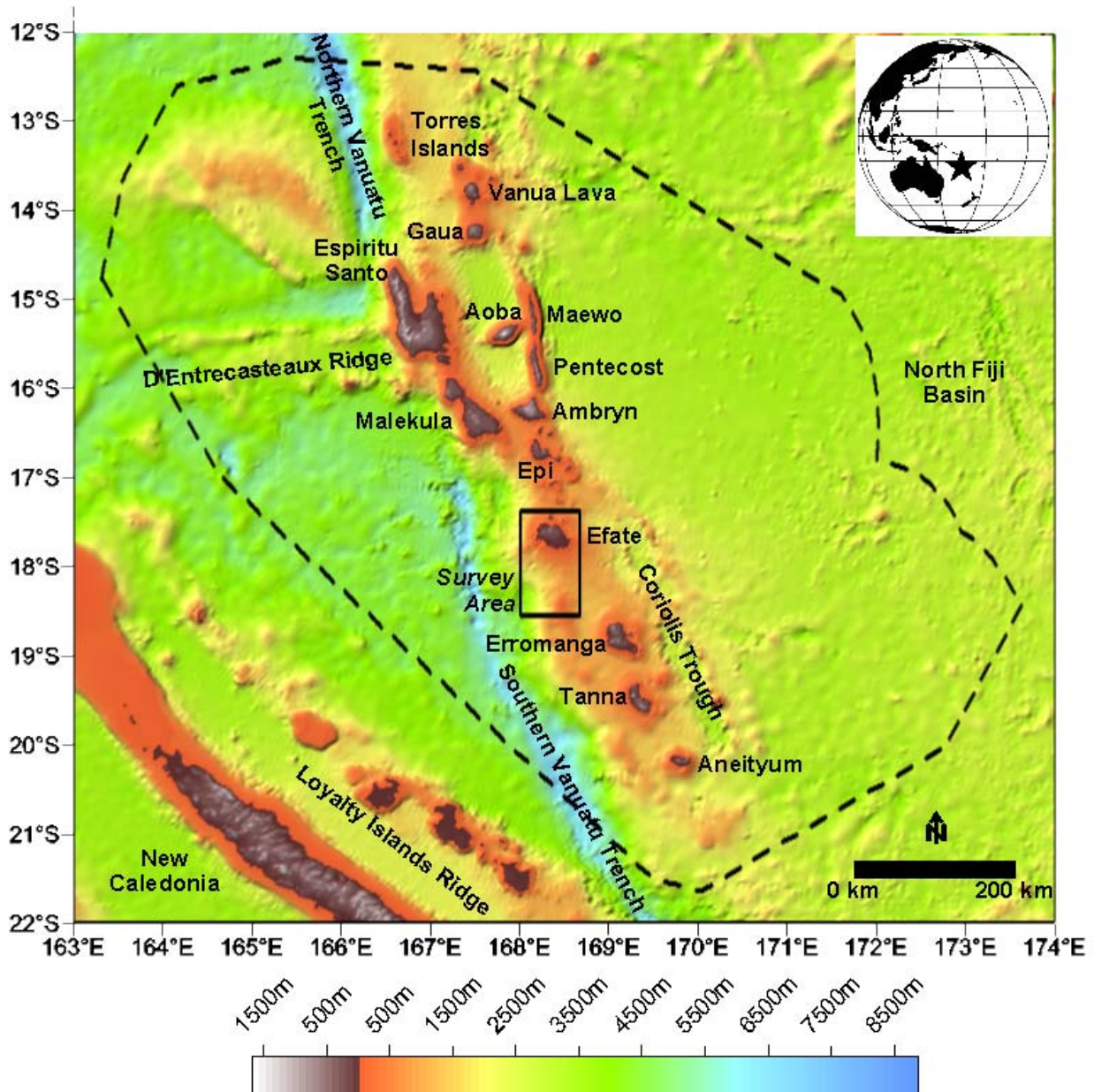


Figure 2. Topography of Vanuatu, showing the islands and approximate position of the EEZ (dashed line – indicative only). Major islands and important geological features are named. The box illustrates the location of the survey area around Efate Island and southern plateau. Bathymetric data are S2004 (described in Marks and Smith 2006).

This work was initiated by the Pacific Islands Applied Geoscience Commission (SOPAC) and European Union (EU) Reducing Vulnerability of Pacific ACP States Project. The seabed mapping was carried out in response to stakeholder requests referenced in Sanday (2003), with the priority mapping areas of Mele Bay, Forari Bay, and Port Havannah (see Figure 4 for location). In addition to the bathymetric maps presented in this report, and their relevance to the SOPAC/EU project, it is envisaged that data from the survey will be used to support future activities in fisheries, tourism, mineral exploration, coastal management, and geo-hazard studies.

1.2 Geographic Situation

Vanuatu is a scattered archipelago of about 80 islands of volcanic origin. The largest islands are Espiritu Santo, Malekula, Maewo, Pentecost, Ambrym, Epi, Efate (main island and administrative centre), Erromanga, Malo, Tanna and Aneityum (Figure 2). Selected geographic facts about the islands are listed in the table below.

Geography of Vanuatu	
Location	In the tropical south-western Pacific Ocean, centred at 16° S and 167° E
Population	186 678 (estimate: Vanuatu Population and Housing Census 1999)
Land area	In total land about 12 190 km ² with a maximum elevation of 1 877 m (Mt Tabwemasana on the island of Espiritu Santo)
Coastline	Comprises features such as fringing reefs, lagoons, and natural beaches. There have been rapid changes in the coastal geography in populated areas associated with increasing reclamation and coastal construction (Tawake 2004)
Tides	Semi-diurnal
Climate	Mainly tropical and feels the influence of the south-east trade winds from May till October. Mostly hot and humid weather, moderated by the southeast tradewinds. The mean annual precipitation varies from 2 300–3 800 mm per annum. The mean temperature is 24 °C. Natural hazards include cyclones, storm surges, coastal flooding, river flooding, drought, earthquakes, landslides, tsunamis and volcanic eruptions
Exclusive Economic Zone	Approximately 710 000 km ²

1.3 Geological Setting

The dominant seafloor feature in Vanuatu's EEZ (Figure 2) is the NNW-SSE trending Vanuatu Trench (New Hebrides Trench). The 7000 m deep trench is the seafloor expression of the eastward dipping subduction zone which marks the present-day boundary between the Indo-Australian plate to the west, and the microplate of the North Fiji Basin to the east (Figure 3). The morphology of the Vanuatu island arc is complex due to its varied tectonic history, with the survey area of Efate belonging to the Central Chain of active volcanism that also includes the Santa Cruz Islands, Banks Islands, Ambae, Ambrym, Epi, Tongoa, Efate, Erromanga, Tanna, and Aneityum (Suckale et al. 2005; Johnson et al. 1992).

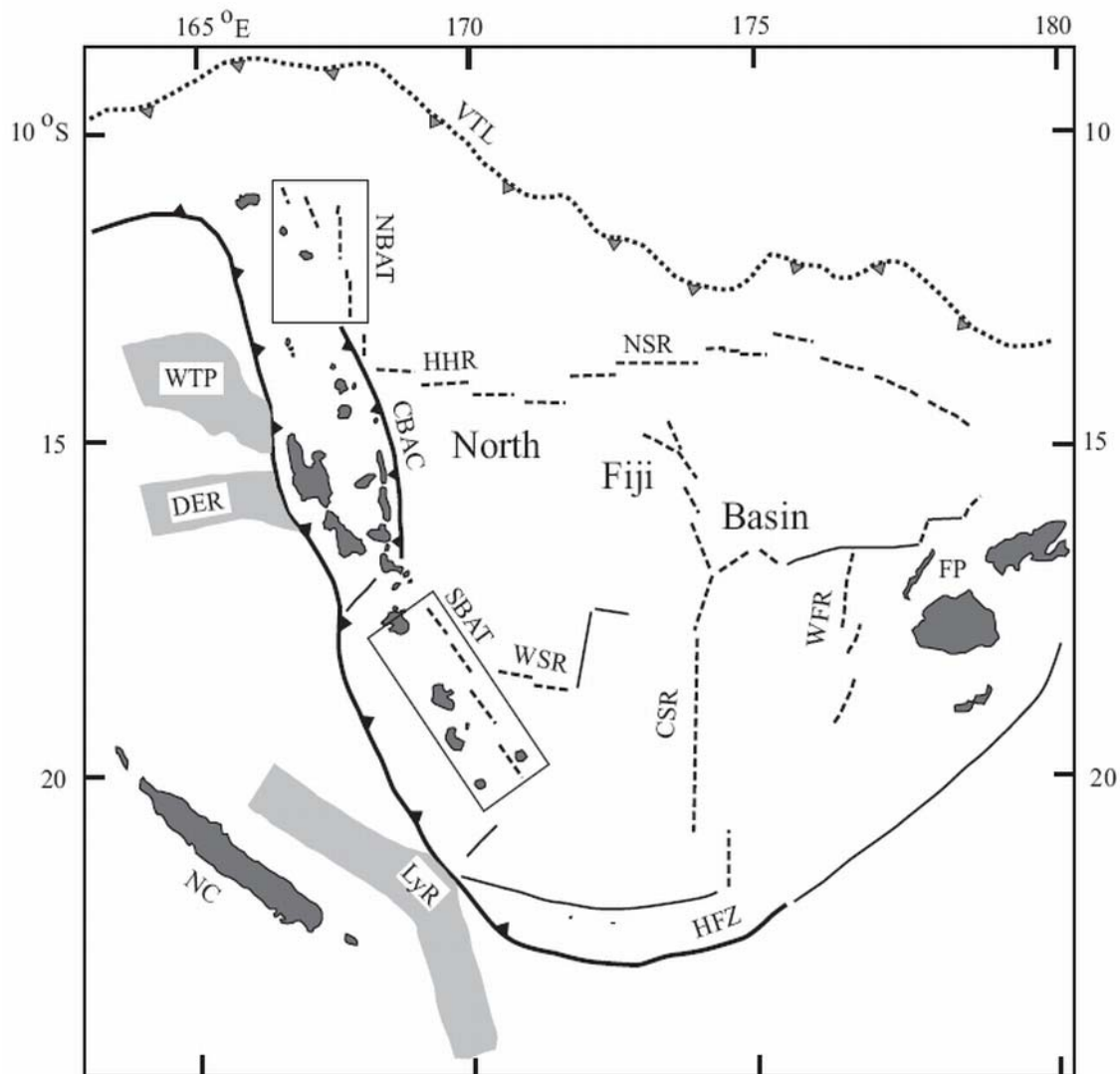


Figure 3. Simplified tectonic elements in the region of the Vanuatu arc and adjacent North Fiji Basin (from Arculus 2006). Barbs on solid lines mark the direction of subduction movement. Dashed lines indicate spreading zones. Transformation zones are marked as solid lines. The dotted line marks the lineament of the inactive Vitiac Trench. Abbreviations: CBAC, Central Backarc Compressional zone; CSR, Central Spreading Ridge; DER, D'Entrecasteaux Ridge; FP, Fiji Platform; HFZ, Hunter Fracture Zone; HHR, Hazel Holme Ridge; LyR, Loyalty Ridge; NBAT, Northern Backarc Troughs; NC, New Caledonia; NSR, Northern Spreading Ridge; SBAT, Southern Backarc Troughs; VTL, Vitiac tectonic lineament or trench; WFR, West Fiji Ridge; WSR, Western Spreading Ridge; WTP, West Torres Plateau.

The Southern Vanuatu Trench is located approximately 100 km west of Efate. Eastward subduction of the Indo-Australian plate beneath the Pacific Plate at this location occurs at a rate of approximately 10 cm/year (Arculus 2006; Suckale et al. 2005). Approximately 100 km to the east of the survey area lies the Vate Trough, which forms part of the backarc Coriolis Troughs with water depths of 2000–3000 m. The trough is currently magmatically active (Arculus 2006), and extension occurs at the rate of 5 cm/year, in a NE-SW direction (Pelletier et al., 1998). To the north Efate is bound by a transverse-arc shear zone extending from the trench west of Efate island to the south of Epi island (Figure 3), marking the junction between the southern Vanuatu backarc troughs and the central backarc compressional zone (Suckale et al. 2005).

The net effect of the tectonic constraints described above is that the survey area, which is part of the southern Vanuatu arc region, is currently experiencing a general clockwise rotation (Pelletier et al. 1998), with an E-W compressive stress regime (Pelletier et al. 1998; Collot et al. 1985).

1.4 Previous Bathymetry Surveys

Bathymetric maps are topographic maps of the sea floor, giving a descriptive picture of the ocean bottom terrain. With an EEZ of approximately 710 000 km², the available bathymetric data is limited, and the exact nature of the seafloor is poorly known. Most bathymetric data originates from sparse single-beam soundings from oceanographic cruises, and, since the early 1970s, from MBES systems as well as satellite-derived predicted depth. However, SOPAC in Suva and the Research Institute for Development (IRD) in Noumea have significant data holdings the study area and these are listed in the table below.

Previous Bathymetry Surveys	
MBES coverage by IRD Nouméa on RV <i>Jean Charcot</i> and RV <i>L'Atalante</i> . (Compiled by B. Pelletier, IRD.)	SEAPSO 1 and 2 cruises (Nov. 1985), Seabeam MBES; SOPACMAPS1 transit, 19/07/1993; CALVA cruise, 12/07 to 17/07/1996; PORMEA transit, 20/07/1996; ALAUF1 transit, 01/03/2000; all with Kongsberg Simrad EM12 Dual MBES, Caribes software, 100 m grid spacing.
MBES coverage by IRD Nouméa on RV <i>Alis</i> . (Chief Scientist: B. Pelletier, IRD.)	TERRALIS cruise, 10/12 to 20/12/2003, Kongsberg Simrad EM1002 Dual MBES, Caribes software, 50 m grid spacing.
MBES coverage by SOPAC. (Compiled by J. Krüger, SOPAC.)	SOPAC cruise by R. Smith on DGWR boat, 29/5 to 8/6/1999, Reson SeaBat 8101 MBES, Reson Software.
SBES soundings. (Compiled by B. Pelletier, IRD, and J. Krüger, SOPAC.)	This dataset is mainly a compilation from IRD Noumea (B. Pelletier) of ship soundings for the area 17–19°S, 167–169°E, including data from various cruises by the French, USA, Japanese, and Australian governments. Particularly cruises by the Royal Australian Navy (RAN) on MV <i>Cape Pillar</i> from 1984 to 89. It also includes nearshore data acquired by IRD RV <i>Alis</i> in 1999 during the NEOTECT cruise. The RAN survey data were digitised at IRD Noumea, from paper charts provided by SOPAC. SOPAC SBES data was acquired by R. Smith, during nearshore surveys in 1990, 1992, and 1997.

This depth data was used to compile a composite bathymetry grid for the survey area. This is presented in the next section.

2. RESULTS

2.1 Bathymetry and Derivatives

Bathymetric data provide information on the depth and morphology of the seafloor, as well as the shape and size of submarine features. The area of seabed covered by multibeam echosounder data during this survey is shown in Figure 4. The survey achieved good coverage of the seafloor from the inshore area, starting from a minimum depth of 40 m, to an average offshore distance of 10 km, reaching water depths of some 2000 m. A 15 by 15 km area over a 100–150 m plateau, situated approximately 80 km to the SSW of Mele Bay was also surveyed. Detailed maps of the achieved coverage are shown in the Appendices.

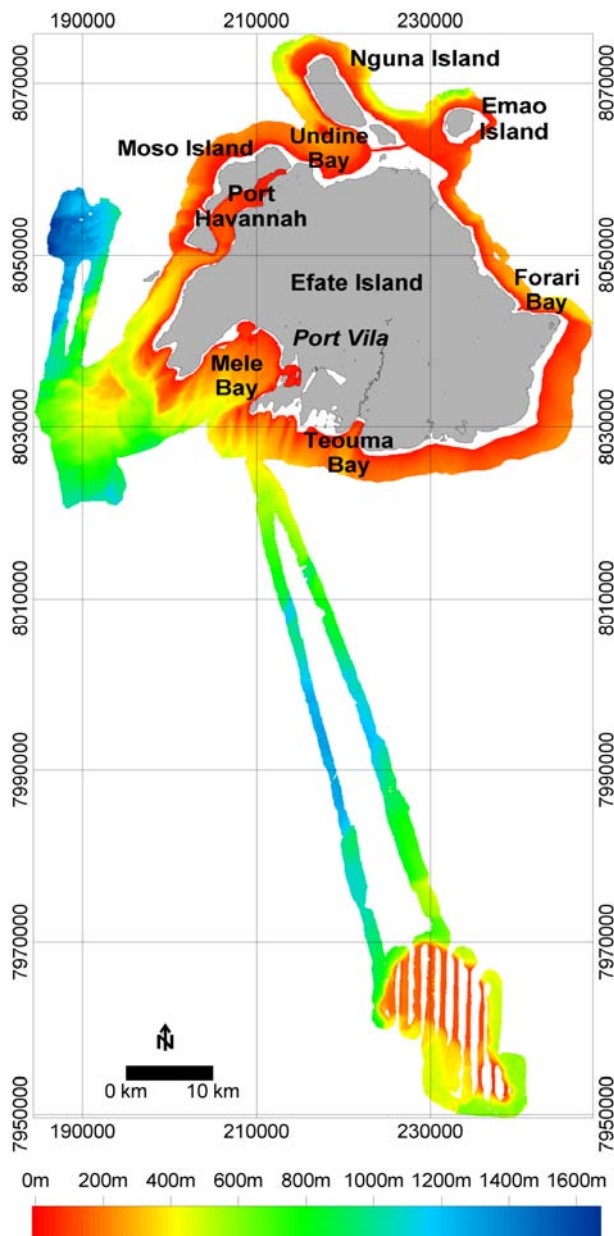


Figure 4. Bathymetric map of SOPAC/EU 50 m-gridded multibeam echosounder data. Depths are in metres. For location see box in Figure 2. The map projection of this and subsequent figures in this report is UTM zone 59 South.

The MBES bathymetry data acquired during this survey are available as a grid file from the SOPAC GeoNetwork site. The gridded data for the priority areas of Mele Bay, Forari Bay, and Port Havannah are shown in the figures that follow as the bathymetric derivatives of slope angle maps, shaded relief maps, and three-dimensional rendered surfaces. All other areas were merged with publicly available bathymetry and are shown on the charts enclosed with this report (see Appendix 4 for details). A preliminary seabed morphology of Mele Bay is presented in Section 2.3.

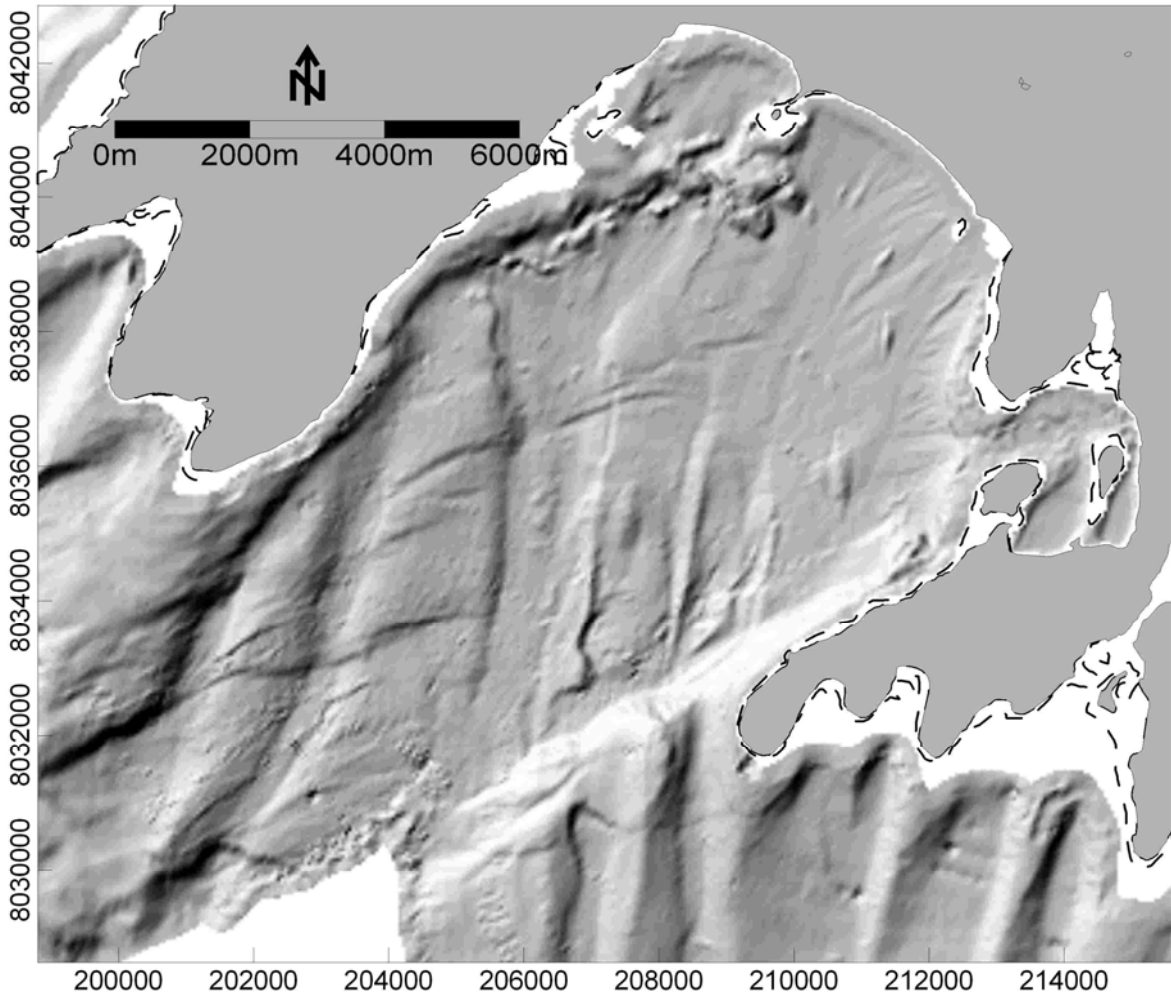


Figure 5. Shaded relief map of Mele Bay. Land is shown in grey. The reef platform is delineated as the dashed black line.

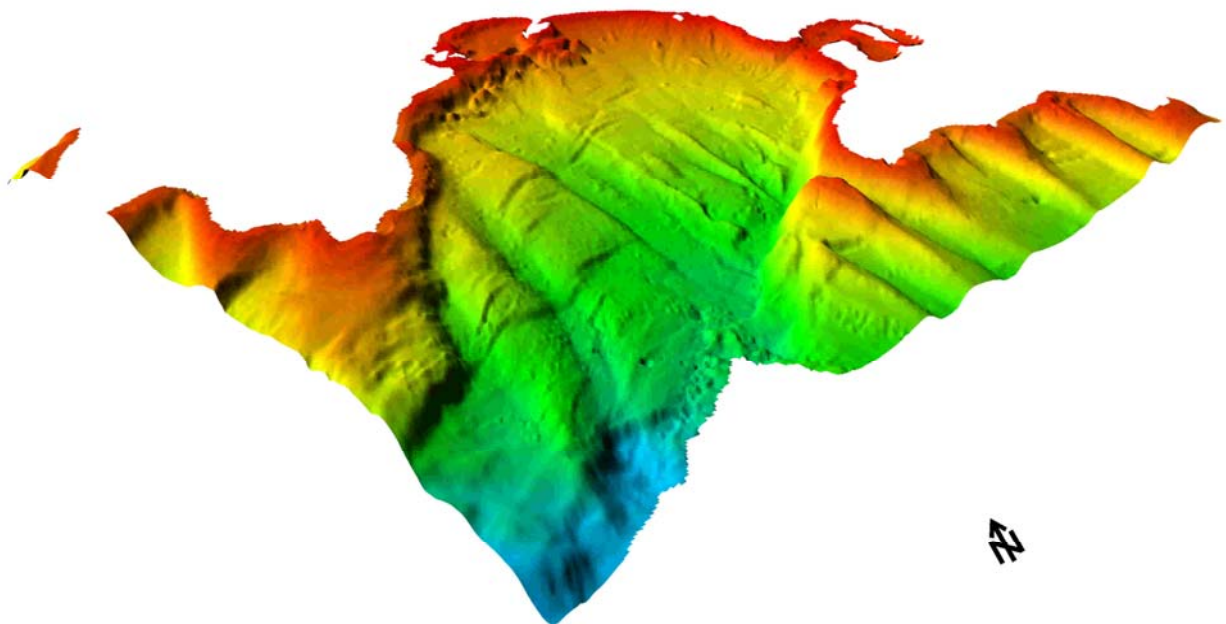


Figure 6. Three-dimensional bathymetry map of Mele Bay. Shallow to deep from red to blue. Two times vertical exaggeration.

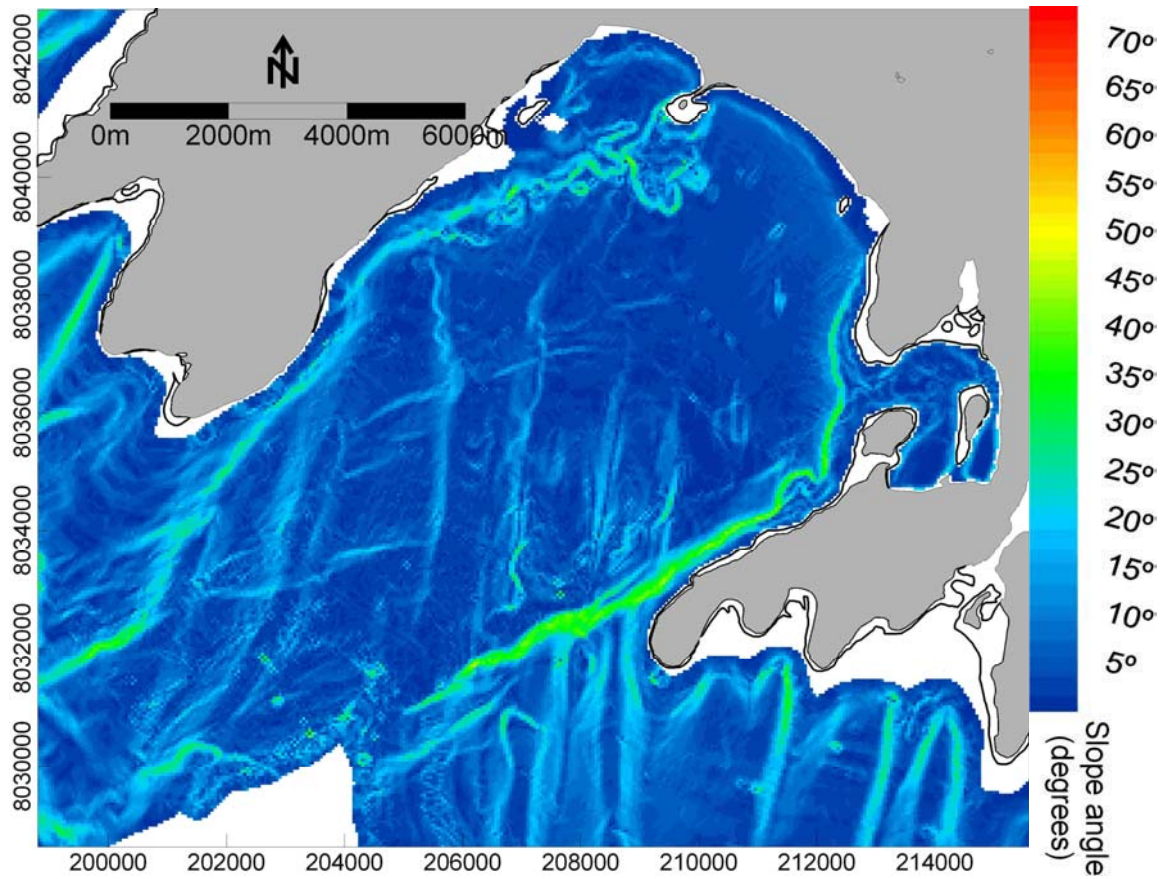


Figure 7. Slope angle map of Mele Bay. Land is shown in grey. The reef platform is outlined as the solid black line.

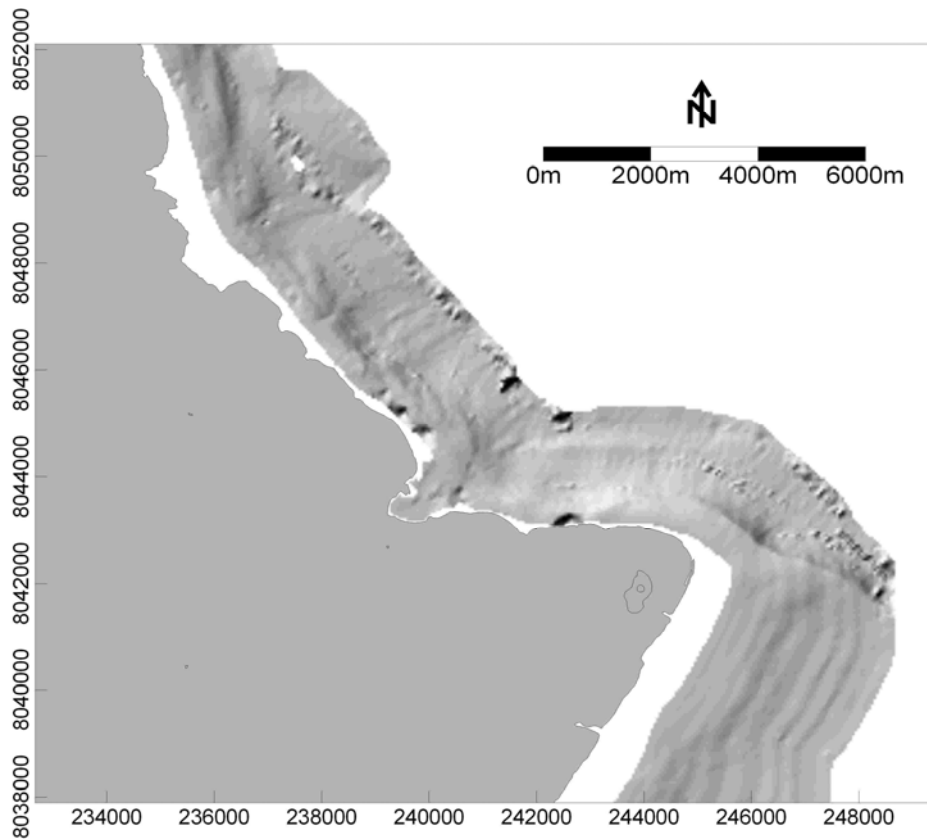


Figure 8. Shaded relief map of Forari Bay. Land is shown in grey.

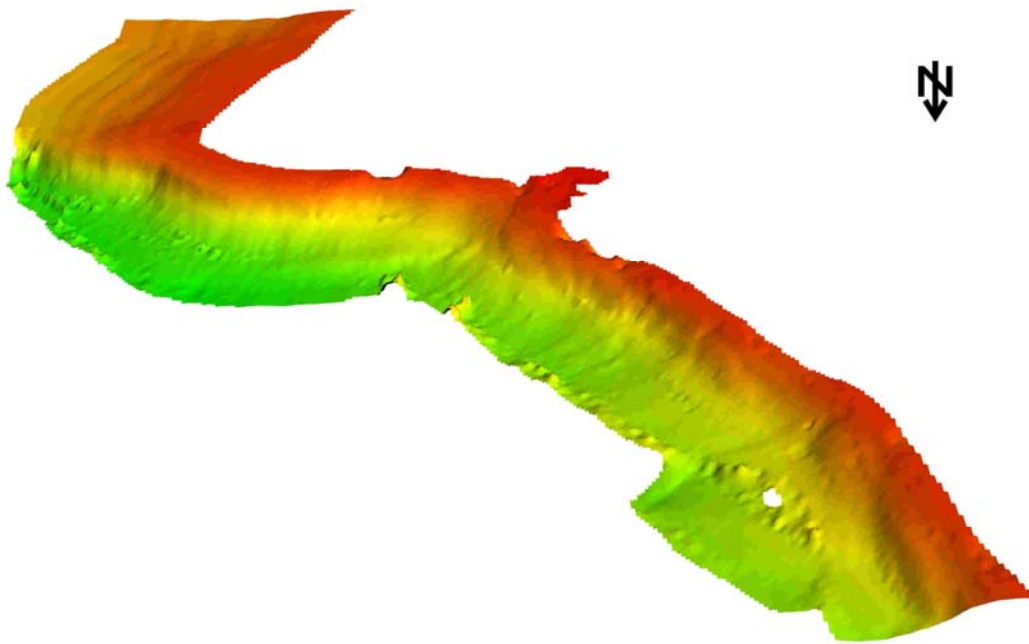


Figure 9. 3-dimensional bathymetry map of Forari Bay. Shallow to deep from red to green. Two times vertical exaggregation.

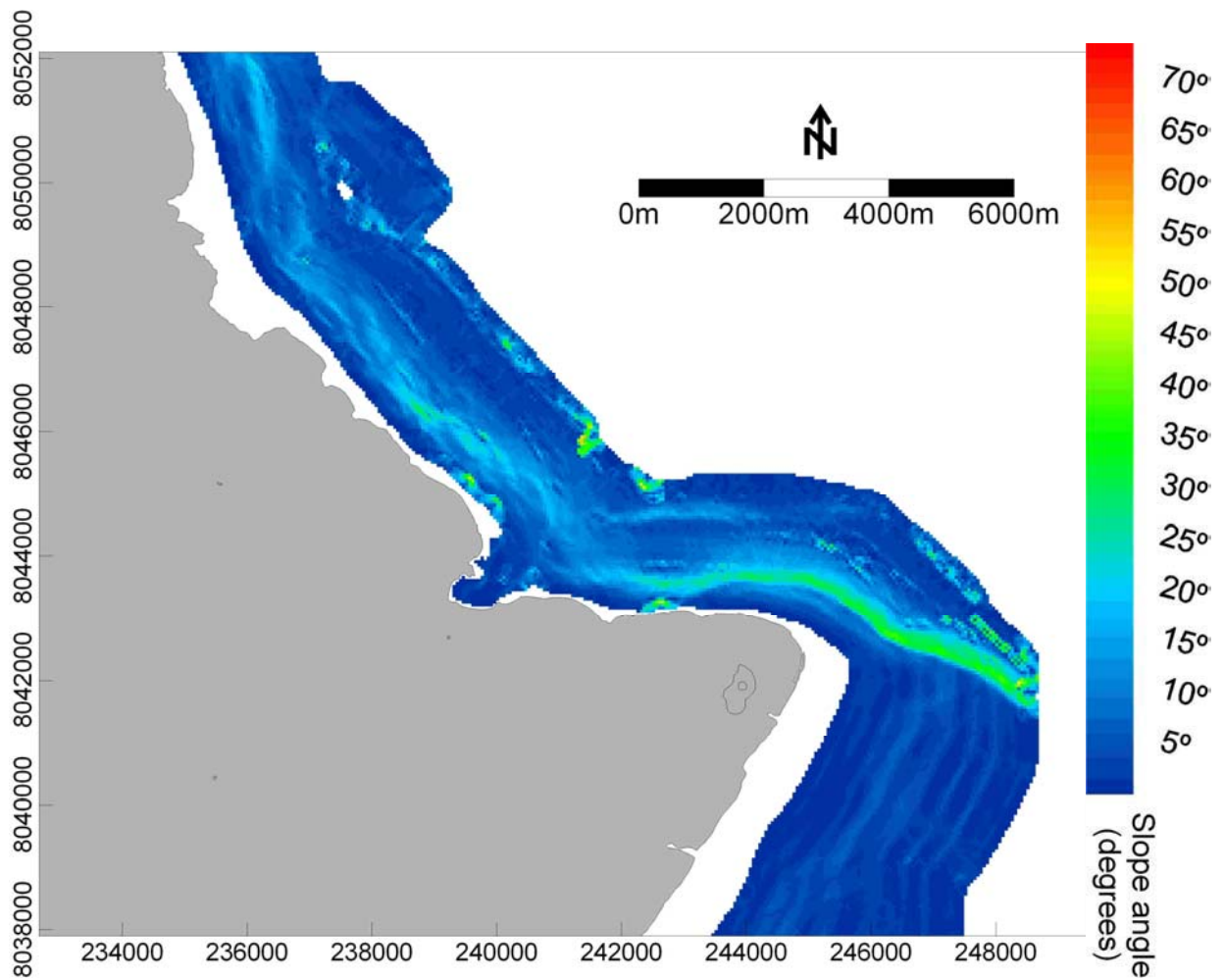


Figure 10. Slope angle map of Forari Bay. Land is shown in grey.

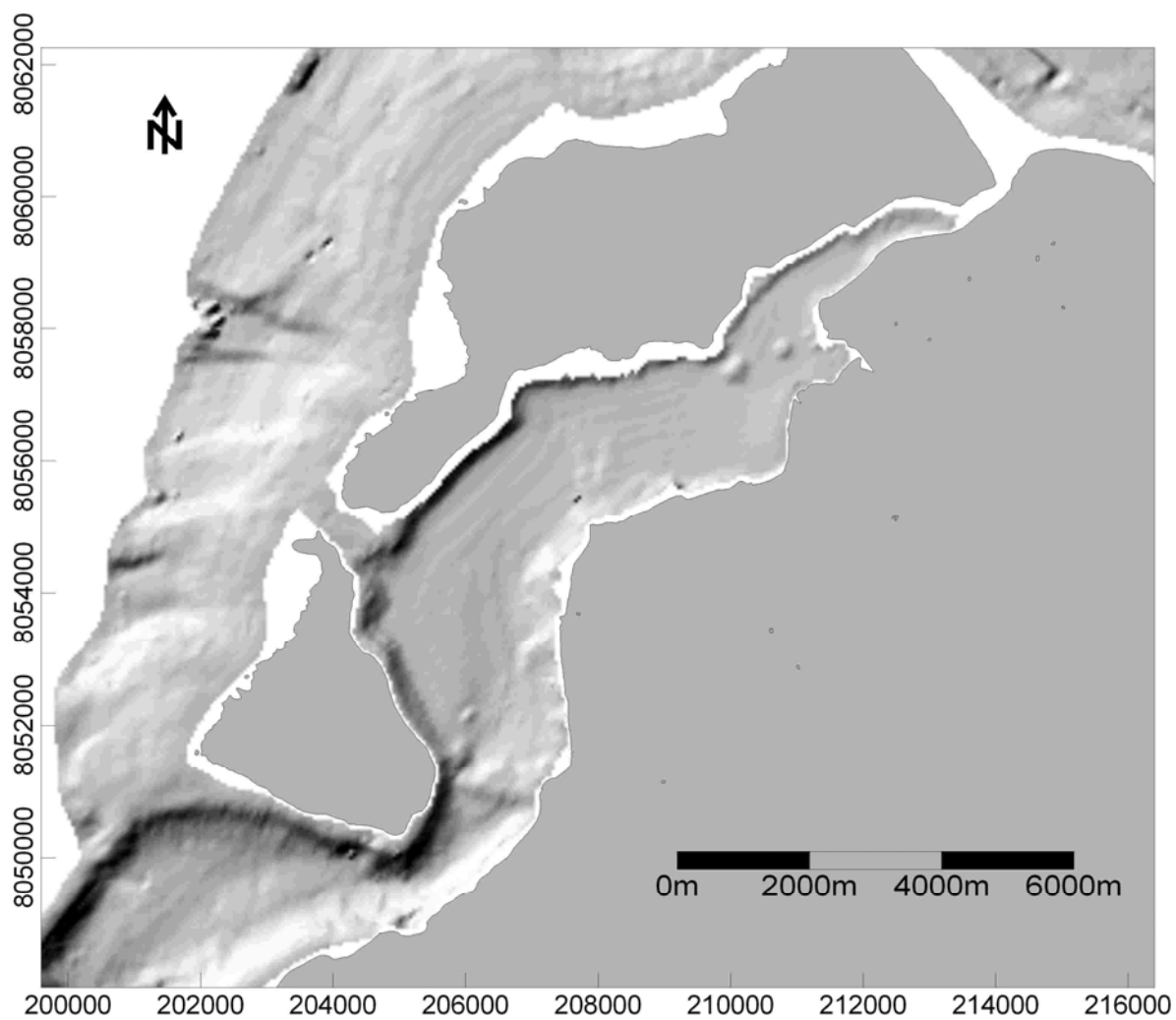


Figure 11. Shaded relief map of Havannah Bay. Land is shown in grey.

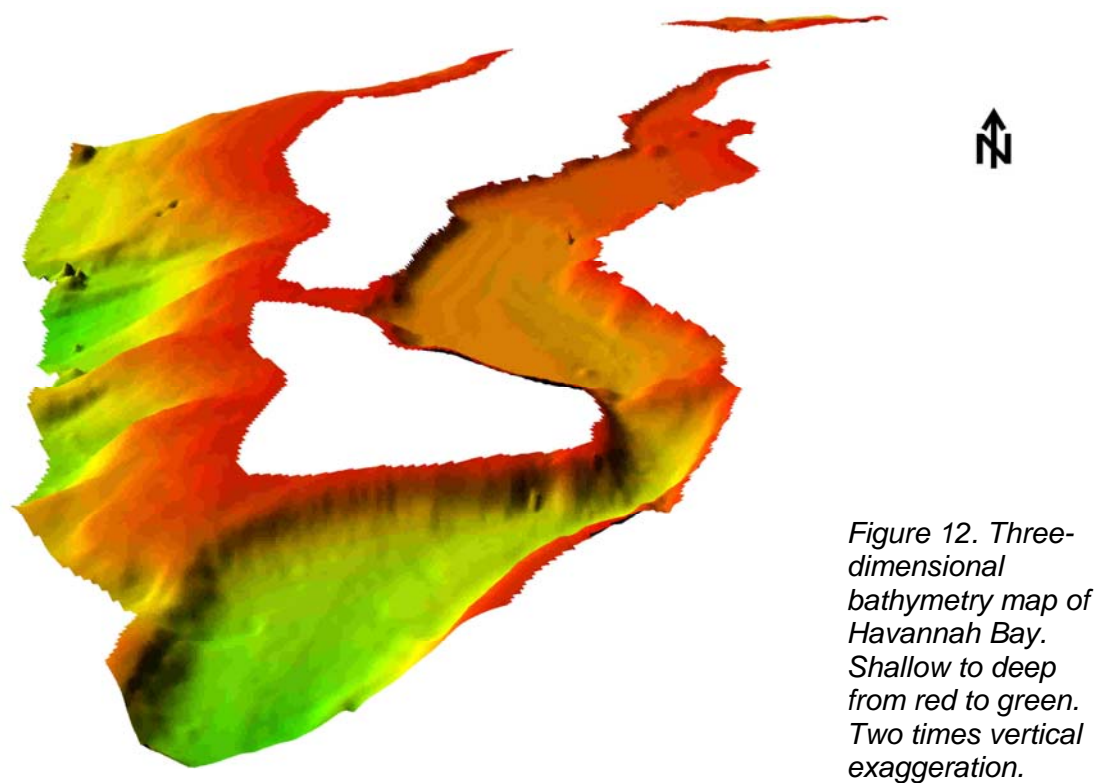


Figure 12. Three-dimensional bathymetry map of Havannah Bay. Shallow to deep from red to green. Two times vertical exaggeration.

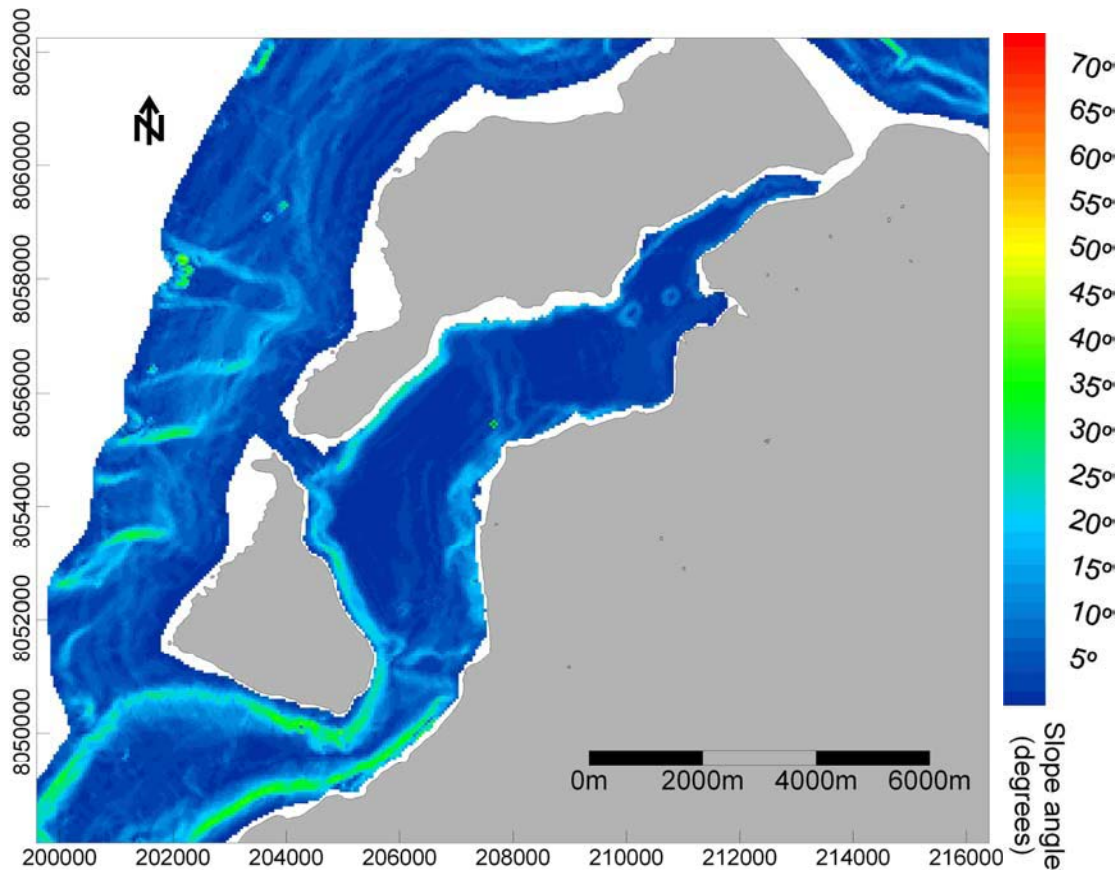


Figure 13. Slope angle map for Havannah Bay. Land is shown in grey.

2.2 Composite Bathymetry

A continuous 50 m bathymetry grid was created using the SOPAC/EU MBES bathymetry together with other available MBES, SBES and land topography (Shuttle Radar Topography Mission, SRTM, <http://www2.jpl.nasa.gov/srtm/>) data as listed in the introductory section 2.1 above, and shown in Figure 14 below. Computation of the grid was done using a hierarchical approach, merging datasets using Golden Software Surfer 8.06 by the following method:

- (1) Created separate MBES, SBES, and SRTM grids, either aggregating (high-resolution data, e.g. nearshore MBES) or re-sampling (sparse SBES soundings) onto a 50 m grid over a 100 x 150 km area.
- (2) Calculated residual surface between SBES and MBES grids.
- (3) Applied low-pass filter to grid (2) in areas with no MBES coverage.
- (4) Added residual grid from step (3) to SBES grid from step (1).
- (5) Replaced land area with SRTM data in final grid, where SRTM is land elevation data from the Space Shuttle Topography Mission 2000, at 90 m grid spacing. Man-hour and computational time for the 100 x 150 km area was about three weeks.

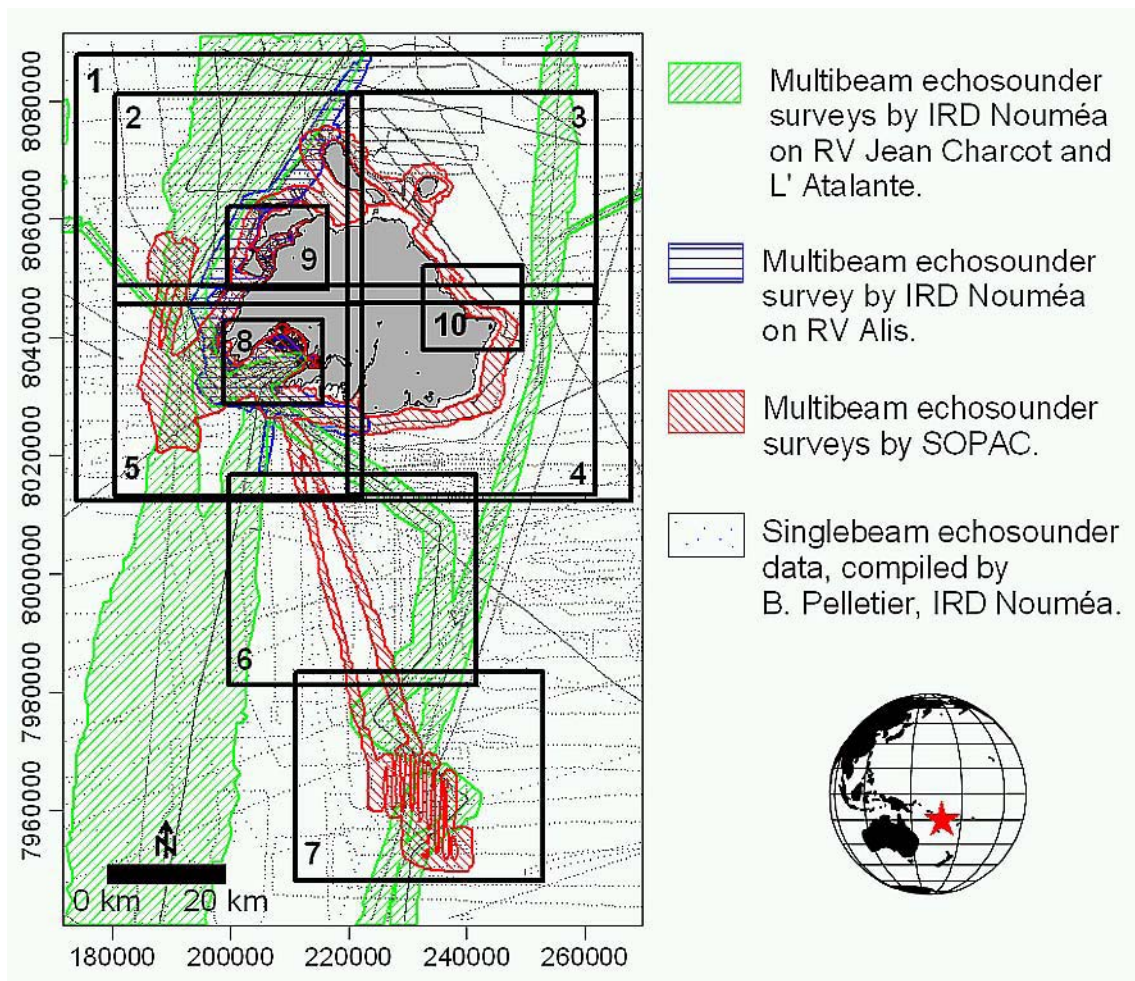


Figure 14. Data source diagram for the 50 m continuous grid covering an area of 100 x 150 km around the island of Efate and the submarine plateau to the south of the island. The black boxes indicate areas covered by the numbered charts enclosed with this report and available from the SOPAC Geonetwork site (see Appendix 4).

The resultant gridded bathymetry is shown in Figure 15, and derivatives of a three-dimensional view, shaded relief, and slope angle, are shown in Figure 16, Figure 17 and Figure 18, respectively. Ten individual A0-sized charts (Appendix 4) with scales ranging from 1 : 20 000 to 1 : 10 000 were made for the areas as shown in Figure 14. Data source diagram for the 50 m continuous grid covering an area of 100 x 150 km around the island of Efate and the submarine plateau to the south of the island are shown in Appendix 2.

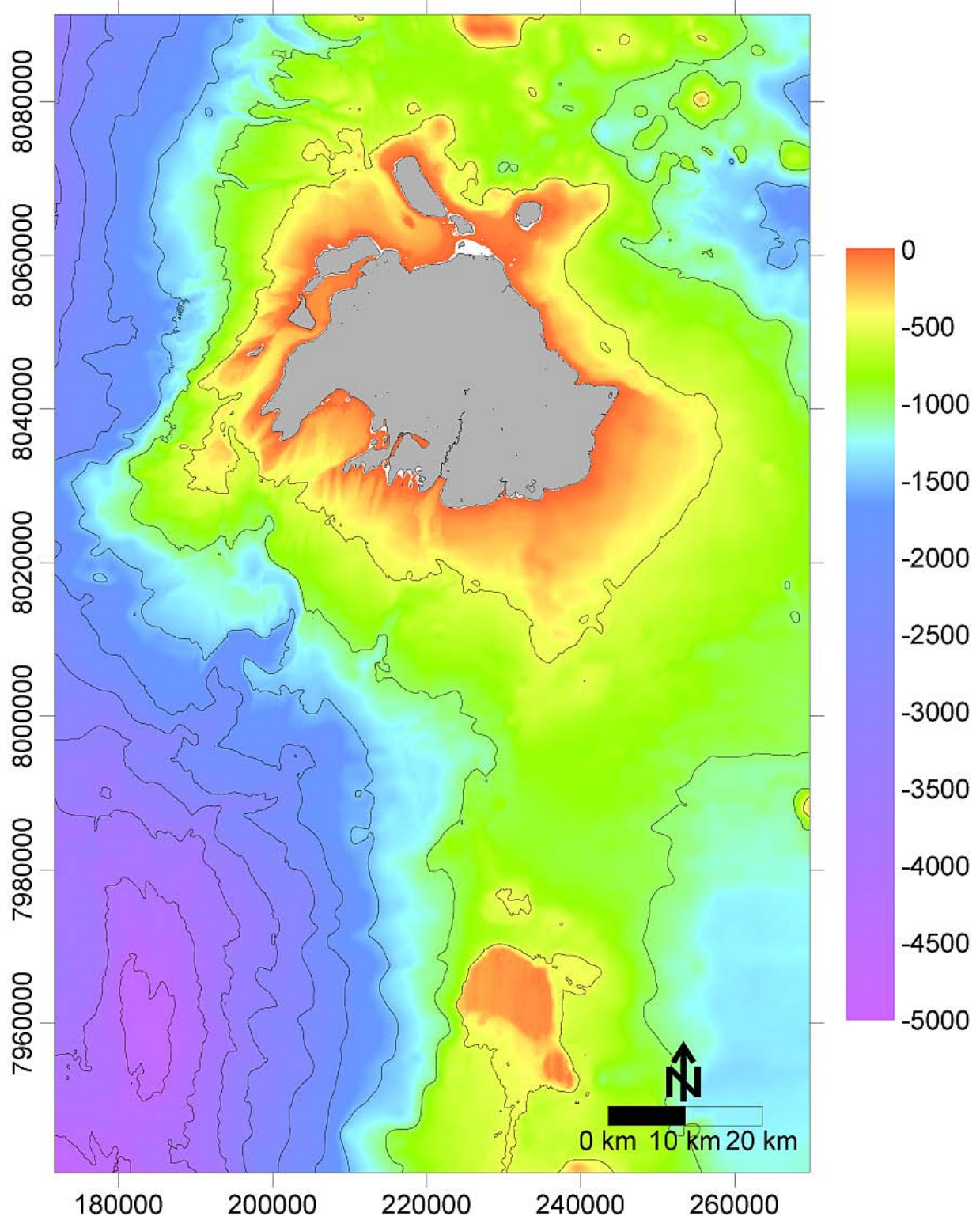


Figure 15. Composite bathymetry of Efate. Depths are in metres below sea level. Isobaths interval is 500 m. Land is shown as grey area, and white areas are reef platforms.

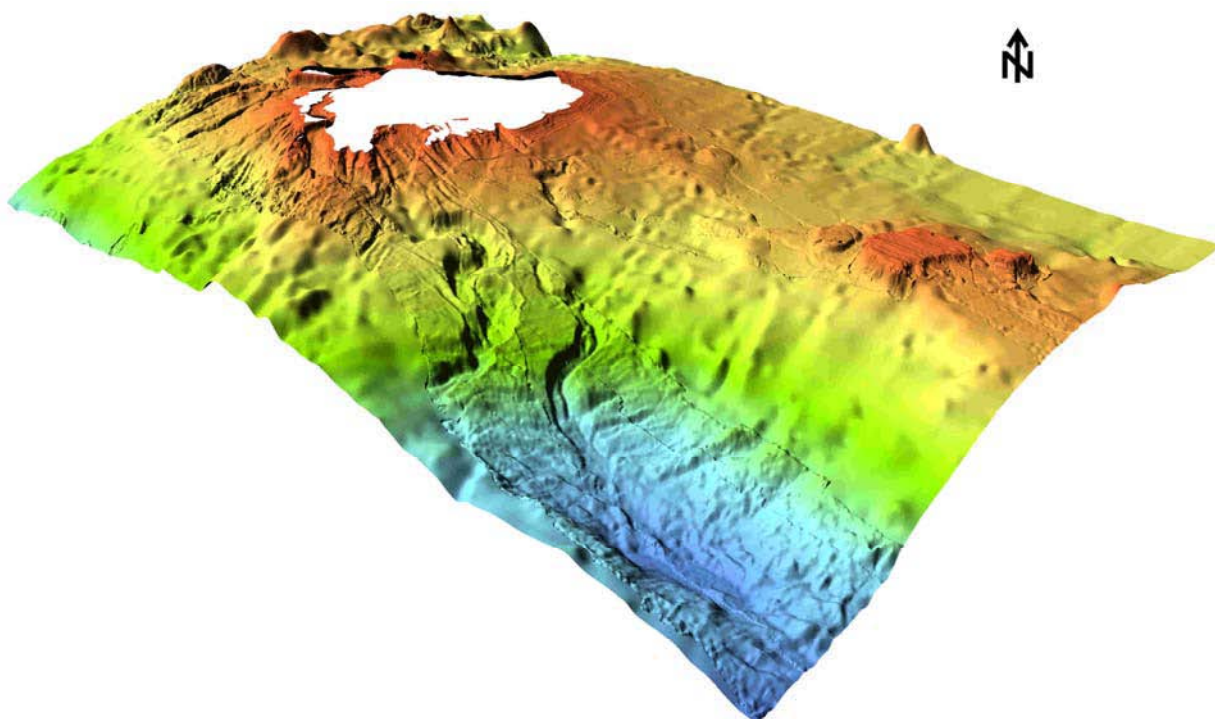


Figure 16. Three-dimensional perspective image of the Efate 50 m grid bathymetry. Shallow to deep from red to blue. Two times vertical exaggeration.

2.3 Morphological Features

The general morphological trend of the seabed around Efate is summarised in the table below. The terminology used to describe submarine features is based on guidelines published by the International Hydrographic Organisation (IHO 2001).

Summary of seabed morphology, Efate	
~0 m	Modern fringing reef and rock platform, up to 50 m wide.
~40 m	Submarine terrace, 500 m wide
60–250 m	Seaward sloping seabed, slope angles 30–40°
250–800 m	Seaward sloping seabed, slope angles 0–20°. Occasional large blocks.
800–1400 m	Numerous seaward convex scarps, slope angles 30–60°, exceeding 60° to the north and northeast.
1400 m to max. survey depths	Variable relief including numerous arcuate scarps, sidewalls, canyons, and flats. Slope angles 0–40°

No additional information such as backscatter, seismic profiles, or ground-truth data (e.g. near-bottom visual observations or direct sampling) for the area was available at the time of writing. However, the bathymetric derivatives were used in addition to the high-resolution bathymetry to provide a description of the submarine morphology of Mele Bay. The preliminary interpretation is presented in Figure 19 and below, and may be refined as additional data become available in the future.

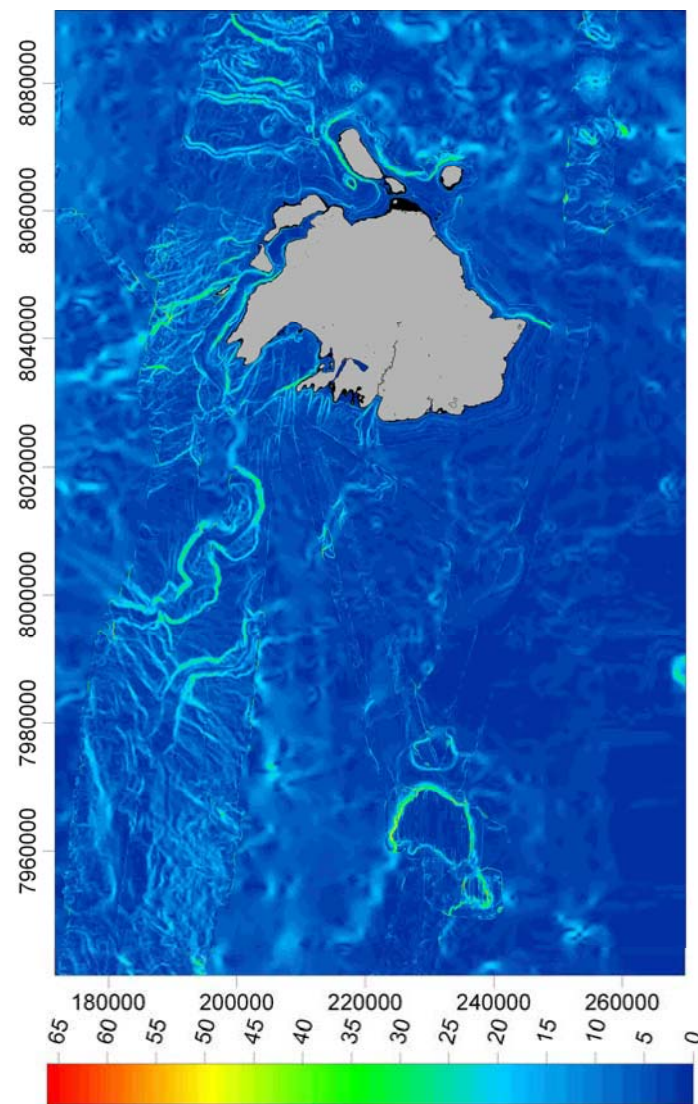
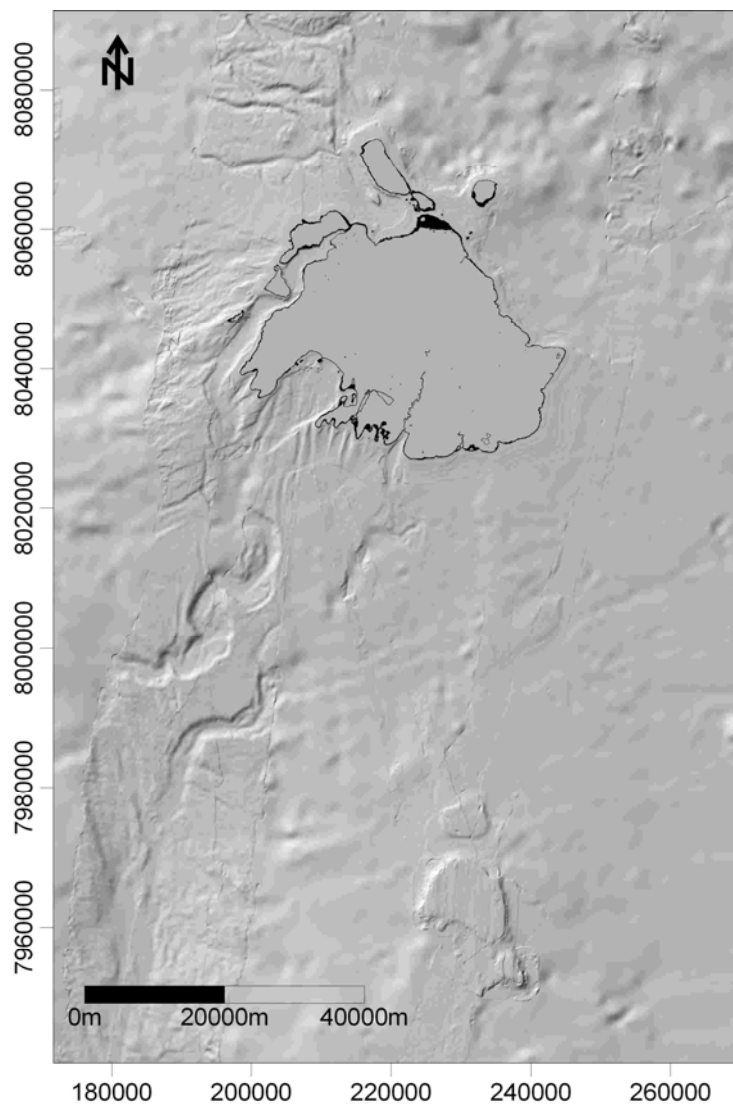


Figure 17 (Left). Shaded relief map of the Efate 50 m gridded bathymetry. Land is shown in grey, with coastline and reef in black.
 Figure 18 (Right). Slope angle map of Efate 50 m grid bathymetry. Land is shown in grey, and reef areas in black.

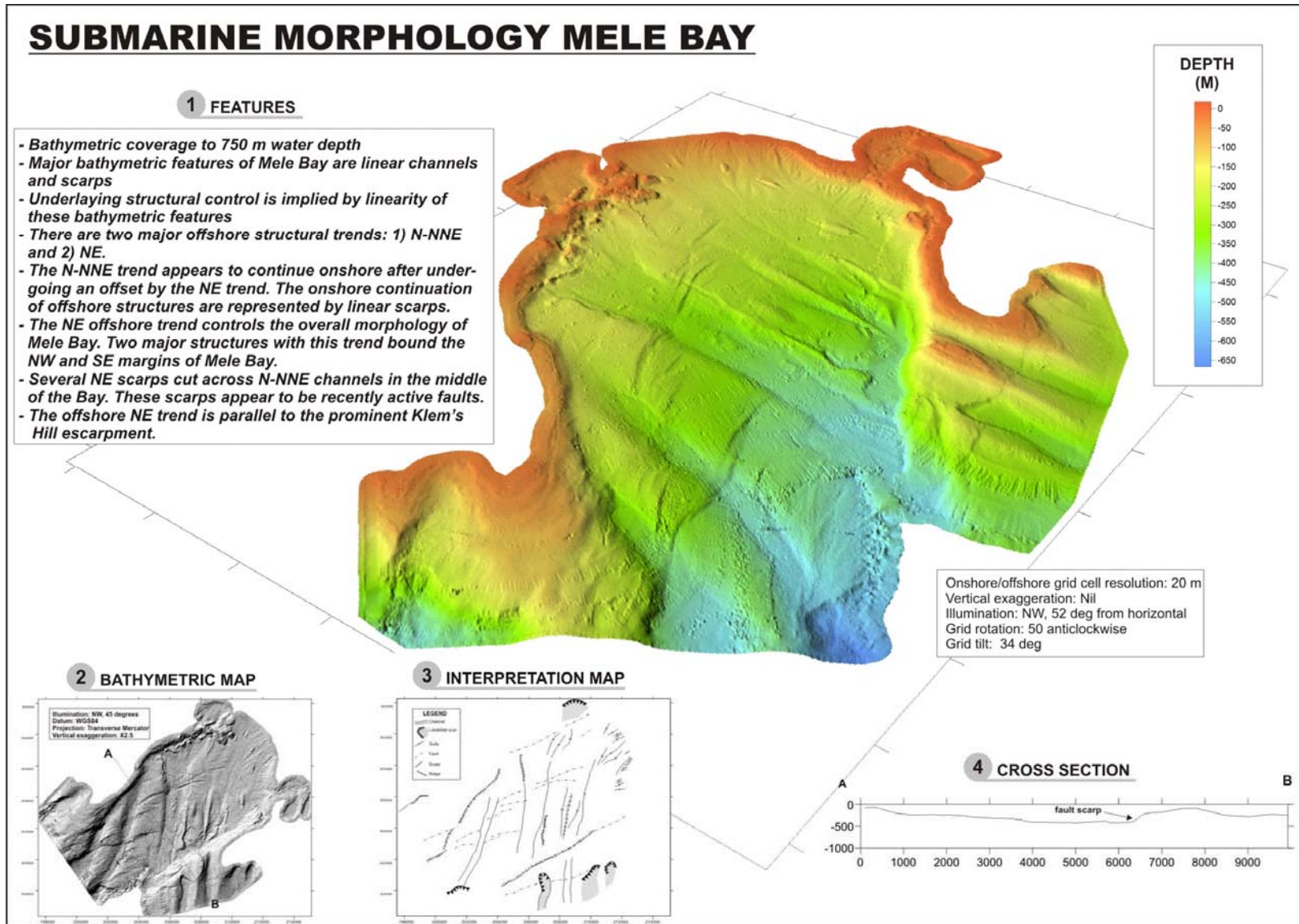


Figure 19. Summary of preliminary interpretation, submarine geomorphology, Mele Bay, Efate. See Figure 20 for details of insets 2 and 3.

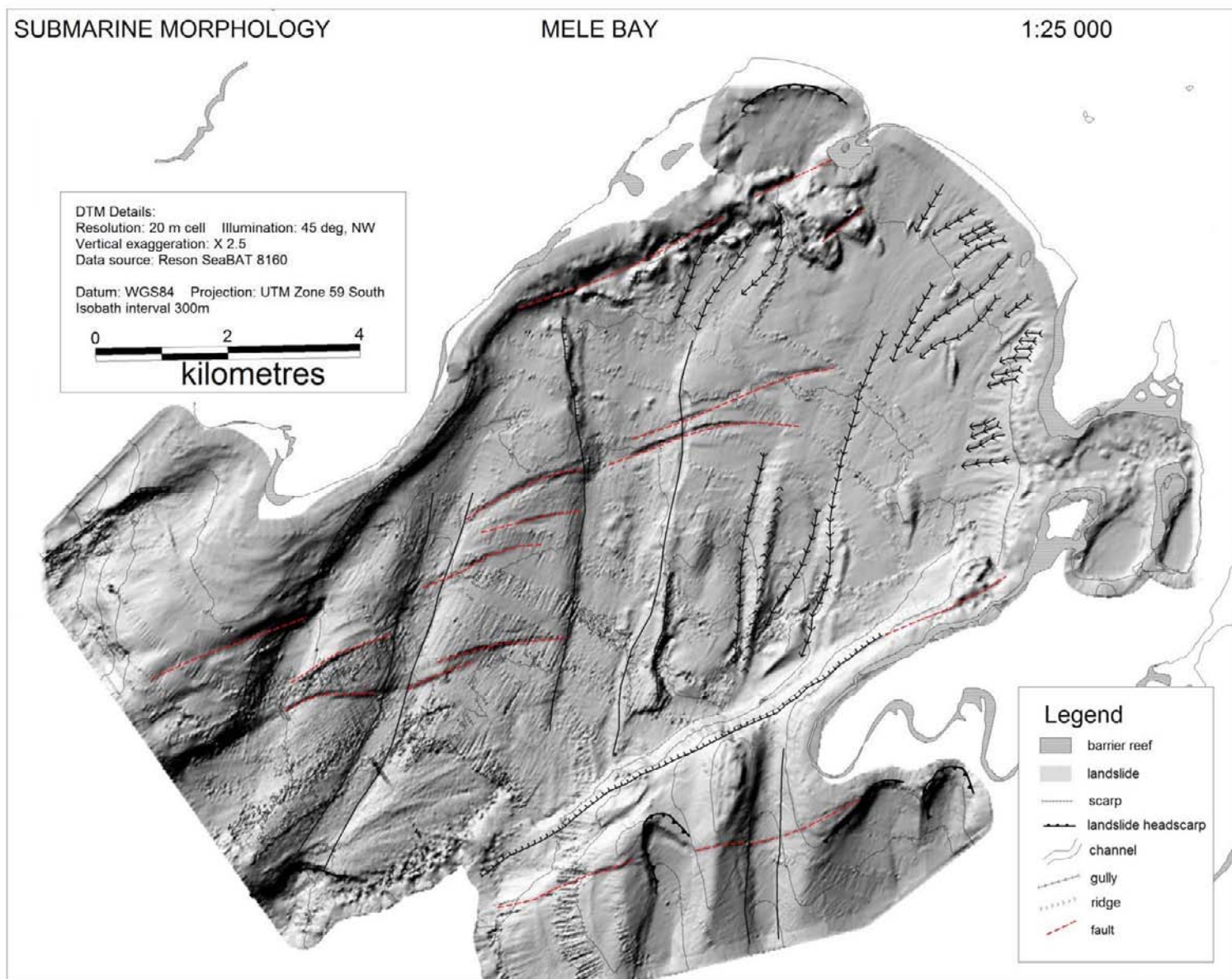


Figure 20. Major components of the Mele Bay morpho-structure, Efate. Backdrop is 20 m grid shaded relief.

3. DATA ACQUISITION AND PROCESSING

3.1 *Fieldwork Summary*

Survey Particulars	
Survey vessel	RV <i>Turagalevu</i>
Fieldwork date	2 to 27 August 2003
Equipment used	Reson 8160 Multibeam Echosounder Geometrics G-881 Magnetometer

All dates and times in this report are given in the local Vanuatu time zone. Results from the magnetometer are presented elsewhere.

3.2 *Field Personnel*

SOPAC	
Benjamin Gouldby	Physical Oceanographer
Quan Chung	Project Technician
Simon Young	Electronics Engineer

Vessel	
Steven Hay	Master
Jon Tikokadavu	Engineer

3.3 *Geodetic Reference System*

The survey results were mapped in terms of the following geodetic reference system:

Geodetic datum	WGS84	
Ellipsoid	WGS84	
	Semi-major axis (a)	6378137.000
	Semi-major axis (b)	6356752.314
	Inverse flattening (1/f)	298.257223563
	Eccentricity sq. (e ²)	0.0066943800
Projection	UTM Zone 59 South	
	Projection type	Transverse Mercator
	Origin latitude	00° 00' 00.0000" North
	Origin longitude	171° 00' 00.0000" East
	Origin false easting	500000.0000
	Origin false northing	1000000.0000
	Scale factor	0.9996000000
	Grid unit	metres

Geodetic transformation	From WGS84 (GPS satellite datum) to UTM 59 South	
	Source coordinate system	WGS84
	Target coordinate system	UTM 59 South
	Transformation parameters	
	dX	0.00
	dY	0.00
	dZ	0.00
	rX	0.00000
	rY	0.00000
	rZ	0.00000
	Scale	0.00000

3.4 Vessel Description and Static Offsets

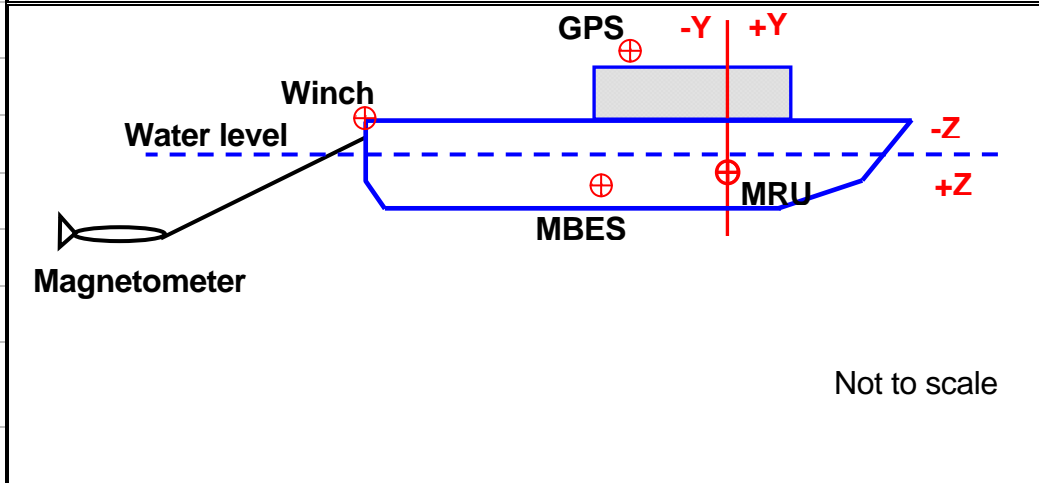
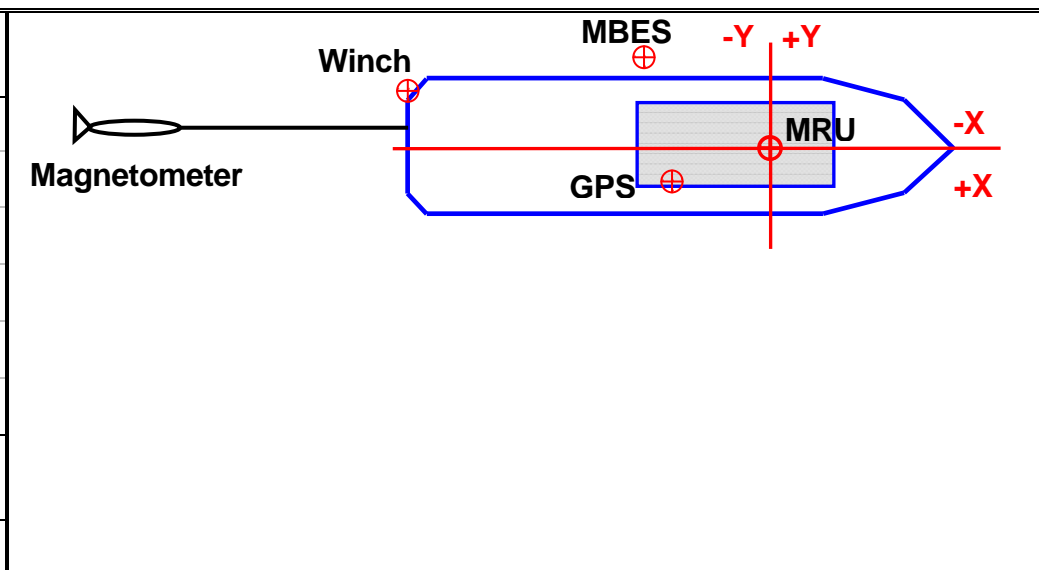


Figure 21. Photo of the survey vessel Turagalevu. The mounting pole for the 8160 Multibeam echosounder transducer can be seen over the port side.

Sensor	X (m)	Y (m)	Z (m)
Reference point at water level	0.00	0.00	0.00
Motion Reference Unit (MRU)	0.00	0.00	-0.28
Positioning Antenna (GPS)	6.04	-2.31	1.54
Multibeam Echo Sounder (MBES)	-2.90	4.33	-0.72
Winch	N/A	N/A	N/A
Magnetometer	-0.15	-58	N/A

Vessel

Name	<i>Turagalevu</i>
Length overall	18 m
Breadth (mid)	6 m
Draft (mid)	1.5 m
Displacement	26 t
Port of registry	Suva
Radiation Call Sign	3DN6531
Classification	Westcoaster, Freemantle, Australia



Not to scale

3.5 Positioning Control

The vessel's reference point (X=0, Y=0, Z=0) was the motion reference unit (MRU) position at the waterline. Positioning was by stand-alone GPS, using an Ashtech Aquarius dual-frequency P-code receiver. A good satellite constellation status was observed throughout the survey. The patch test was conducted during the survey with stand-alone GPS (see details below).

3.6 Survey Computer

The survey computer was a Windows 2000 PC running Navisoft 2.2.2. This computer was used for continuous on-line data logging and computation of positioning and digital bathymetry. The package also provided a line control display for the helm. The on-line operator continuously monitored a range of quality control parameters.

An off-line Navisoft 2.2.2 package was used in the office for replaying and post-processing of track data and bathymetry. An A0 plotter was available for the production of full-size charts (841 x 1189 mm).

3.7 Multibeam Echosounder

A Reson SeaBat 8160 multibeam echosounder (MBES) was temporarily installed on RV *Turagalevu*, and used to provide swathe bathymetry data. A MBES provides high-resolution information about the depth of water from the surface to the seafloor in a water body.

The main instrumental and operating parameters are listed below.

Instrumentation	
Multibeam echosounder	Reson SeaBat 8160
Transducer mount	Port-side pole-mounted
Motion reference unit	TSS DMS 2-05 Dynamic Motion Sensor
Gyro	SG Brown Meridian Surveyor Gyro Compass
Sound velocity probe at transducer	Installed
Operating Parameters	
Transducer Frequency	50 kHz
General water depth	10–2500 m
Average ship's speed	7 knots (3.6 m s ⁻¹)
Transmit Power	Variable 1–16
Pulse length	Variable 0.5–10.0 ms
Horizontal coverage	Approximately two times water depth
No of beams / beam spacing	126 / 1.2 °
Ping rate	Variable
Dynamic Offset Calibration	12/08/2003
Roll correction	0.57
Pitch correction	–16.99
Yaw correction	–0.86
GPS Latency correction	785
Gyro correction	Not determined

The patch test to determine the dynamic offset values was conducted on 12 August, ten days into the survey and after bottom contact with the transducer. This caused significant (visible) misalignment of the over-the-side pole mount and loss in data quality.

3.8 *Multibeam Echosounder Data Processing*

On return to the SOPAC office in Suva, Navisoft 2.2.2 software was used for the post-processing of the MBES survey data. Post-processing is a form of data reduction, which involves checking, calibration, cleaning and preparation necessary to convert raw measurements into a form suitable for analysis, application and presentation. The product of post-processing is in the form of ASCII listings of gridded easting, northing, and depth (XYZ) points. Gridded XYZ points from Navisoft were used in Surfer 8.05 to produce final charts and figures. The processing and chart production sequences are listed below.

Post-processing Sequence	
Phase 1	Correct for sound velocity, tide, GLW and required depth.
Phase 2	Editing and de-spiking using fast de-spiking algorithms which are provided with various filters and options.
Phase 3	Deleting, interpolation, and manual editing of single and multiple points using the editor's interactive tools.
XYZ output	ASCII XYZ files (easting, northing, depth) are in the project coordinate system. The final output consisted of a file that includes all post-processed sounding points, as well as files of reduced points at grid dimensions of 40 m.
Chart Production Sequence	
XYZ to grid	XYZ data are reduced and gridded to approx. 1 mm (0.1%) at the charting scale (e.g. 50 m grid size for a chart scale of 1 : 50 000).
Digital terrain model (DTM)	A surface model is created from the grid. A search radius of approximately three times the grid spacing is used to fill data gaps. The DTM is also blanked against regions that contain no valid data such as land and reef areas.
Chart output	Various levels of smoothing are applied to the DTM and contours to give a realistic impression of the seabed, without removing any real features from the data set.

3.9 *Tidal Information*

Soundings were reduced to the Port Vila tide gauge zero datum defined as approximate lowest astronomical tide (LAT), 0.7500 m below mean sea level (MSL 1973), and 2.8537 m below the fixed height of Benchmark VAN 1 (see Figure 22), using observed water levels from the Port Vila tide gauge provided by the Australian Bureau of Meteorology (<http://www.bom.gov.au/oceanography/>) through the South Pacific Sea Level and Climate Monitoring Project (<http://www.bom.gov.au/pacificsealevel/index.shtml>).

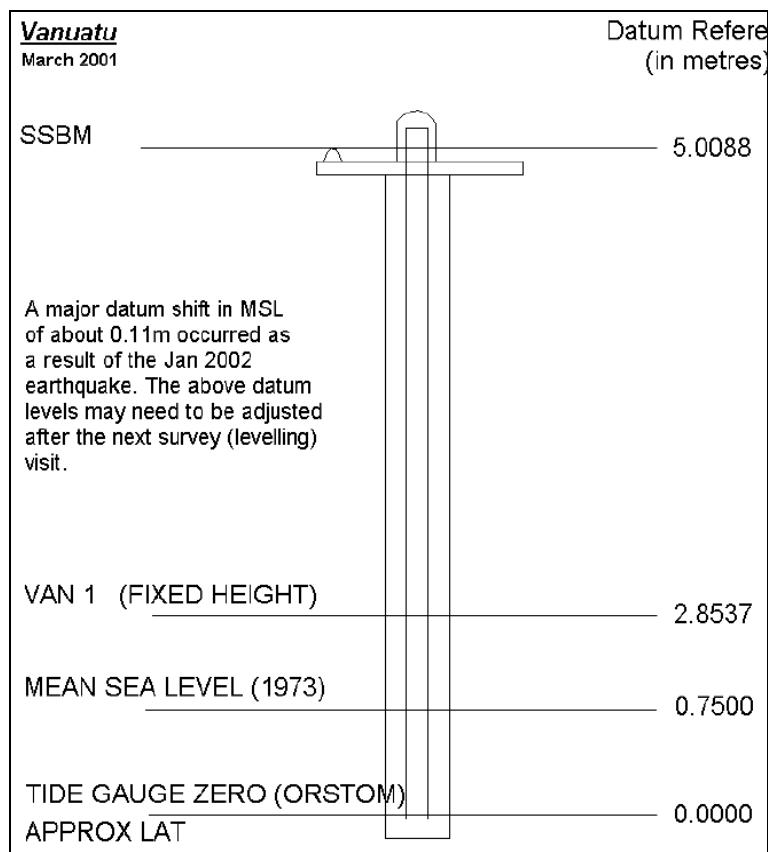


Figure 22. SEAFRAME tide gauge datum definition and other geodetic levels at Vanuatu (from NTFA 2005).

3.10 Sound Velocity Profiling

The accuracy of the depth soundings depends in part on the variation of the speed of sound with water depth. This is because the acoustic beams pass through a water column that has varying properties (causing refraction). The sound speed structure of the water column is determined from the measurement of temperature, salinity and depth (with a conductivity, temperature and depth sensor – CTD). The main instrumental, operational, processing parameters are listed below.

CTD Instrumentation	
Make	SeaBird Electronics
Model	SeaCat 19+ (self-powered, self-contained)
Serial number	4716
Depth rating	3000 m

Operating Parameters	
Sample rate	1 scan every 0.5 s
Maximum depth	Limited to 400 m due to wire rope length
Data recorded	Profiles of conductivity, temperature, and pressure

Data Processing	
Positioning	The profile position was taken at the GPS antenna near the start of the downcast. Vessel drift may have been significant (~500 m) over the duration of the profile.
Data conversion	Converted raw data (.hex) to a .cnv file. The following values are output from the recorded data: Pressure, dbar Depth, m (derived using salt water at local latitude) Temperature, deg C (ITS-90) Salinity, psu (derived) Density, kg m ⁻³ (derived) Sound velocity, m/s (derived using Chen and Millero 1977)
Bin average	Averaged data into 1 m depth bins. No filtering was applied.
Output	Processed data was saved in ASCII text format with the file name date_location_bin.cnv.

The CTD profile details are listed below. The summaries of the CTD profile data in graphical form are shown in Appendix 3.

Profile location	Date	Time	Easting	Northing	Depth (m)
Mele	04/08/03	12:47	208742	8034419	341
Port Havana	05/08/03	17:25	206344	8053869	132
Port Havana	06/08/03	10:51	210405	8057758	43
Undine Bay	07/08/03	09:02	217396	8063416	250
Erueti	08/08/03	11:57	230021	8027655	46
Teouma	09/08/03	09:30	220224	8027673	217
Pango point	10/08/03	10:54	208382	8027715	423
Nguna	11/08/03	09:54	215795	8074874	387
Emao	12/08/03	16:40	230913	8062193	71

As noted above, the on-board CTD probe could only be operated to a maximum depth of 400 m, due to restrictions on the wire rope length. Appropriate sound velocity corrections were therefore limited to soundings of up to 400 m water depth. The CTD sensor was lost on 13/08/2003 near Emao, and no more casts and or sound velocity corrections were performed after this date.

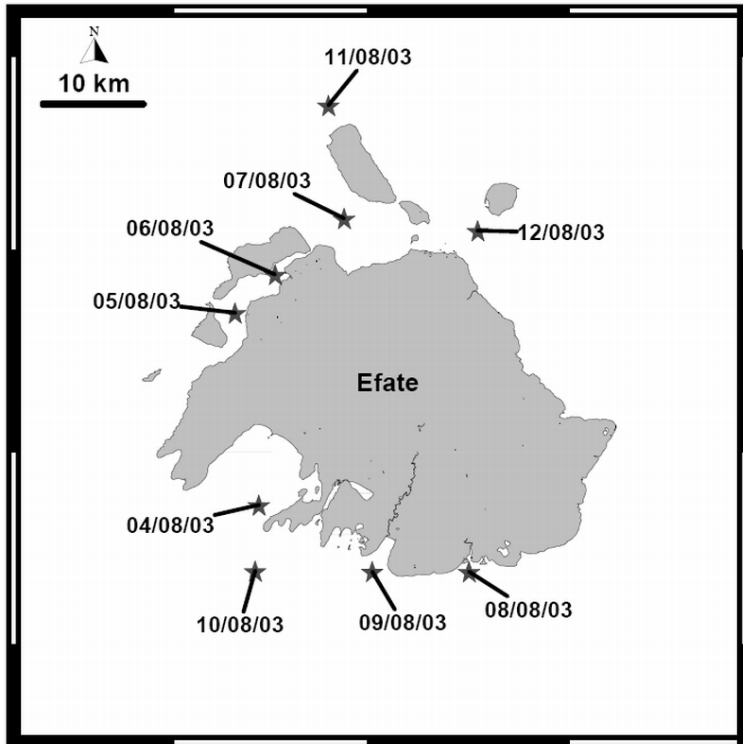


Figure 23. Location and dates of CTD casts. See table above for details.

4. REFERENCES

- Arculus, R.J. 2006. Coriolis Troughs and southern New Hebrides Arc: primary tectonic results from the CoTroVE (SS06/2004) research voyage. Australian Earth Science Convention (AESC), 5 p.
- Chen, C.T. and Millero, F.J. 1977. Speed of sound in seawater at high pressure. *Journal of the Acoustic Society of America*, 32(10), 1357 p.
- Collot, J.Y., Daniel, J. and Burne, R.V. 1985. Recent tectonics associated with the subduction/collision of the D'Entrecasteaux zone in the central New Hebrides. *Tectonophysics* 112: 325–356.
- Department of Land Surveys. 1994. Efate Topographical Series.
- International Hydrographic Organisation (IHO), 2001. Standardisation of undersea feature names, 3rd Edition., International Hydrographic Bureau, Monaco. 42 p.
- Johnson, D.P., Maillet, P.C. and Rice, R.C. 1992. The seabed morphology of the Hazel Holme fracture zone and the New Hebrides arc, northern Vanuatu – Solomon Islands region. *SOPAC Technical Report 138*: 27 p.
- Marks, K.M. and Smith, W.H.F. 2006. An evaluation of publicly available global bathymetry grids. *Marine Geophysical Researches* 27: 19–34.
- NTFA 2005. Pacific Country Report, Sea Level & Climate: Their Present State. National Tidal Facility Australia.
- Pelletier, B., Calmant, S. and Pillet, R. 1998. Current tectonics of the Tonga-New Hebrides region. *Earth and Planetary Science Letters* 164: 263–276.
- Reson, 2002. SeaBat 8160 Multibeam Echo Sounder System operator's manual, v3.00.
- Sanday, R., 2003. Proceeding of the 2nd Vanuatu multi-stakeholder consultations, Melanesian hotel, Port Vila, Vanuatu. *EU-SOPAC Project Report 16*. 33 p.
- Smith, R. 1991. Bathymetry and seabed morphology, Port Havannah, Vanuatu. *SOPAC Technical Report 122*, 20 p.
- South Pacific Sea Level and Climate Monitoring Project (<http://www.bom.gov.au/pacificsealevel/index.shtml>).
- Suckale, J., Grünthal, G., Regnier, M. and Bosse, C. 2005. Probabilistic seismic hazard assessment for Vanuatu. Geoforschungszentrum Potsdam, Scientific Technical Report STR, 73 p. 05/16
- Tawake, A., 2004. Vanuatu – country mission and technical advisory report, coastal management and aggregates assessment in selected parts of south-western Efate island. *EU-SOPAC Project Report 47*, 47 p.
- Vanuatu Population and Housing Census 1999
http://www.pacificweb.org/DOCS/Other%20P.I/Vanuatu/vanu99/Vtu99Pop_Hous2.htm
accessed 12/11/2007.

APPENDICES

Appendix 1 – Statement of Uncertainty and Suitability for Charting

Bathymetric maps are topographic maps of the sea floor. The bathymetric map serves as the basic tool for performing scientific, engineering, marine geophysical and environmental studies. The information presented in this report and enclosed charts are intended to assist persons and authorities engaged in recreation, tourism, marine resource related industries, hydrographic mapping, coastal development, trade and commerce, sovereignty and security, and environmental management. It is therefore important that users be informed of the uncertainties associated with the data and with products constructed from it. The following is an outline of the survey equipment used and the operating principles, including limitations and estimates regarding the data accuracy.

A1.1 Horizontal positioning

The methods used to acquire survey data will affect the final product accuracy. The global positioning system, GPS, uses radio signals from satellites that orbit the earth to calculate the position of the GPS receiver. Stand alone GPS has an estimated accuracy as good as approximately 10 m, depending on satellite configuration and atmospheric conditions. In addition to this, equipment and measurement errors also need to be considered.

A general rule of thumb is that surveys should be conducted with a positioning accuracy of 1 mm at the scale of the chart. Therefore, at a chart scale of 1:10 000, the survey would be required to be accurate to 10 m.

The present S-44 4th Edition Standard of the International Hydrographic Office (IHO) includes a depth-dependent factor that takes into account the added uncertainty of the positions of soundings from multibeam echo sounder systems as water depth increases. The relevant survey orders are listed in Table A1.1, with multibeam surveys conducted by SOPAC generally falling into orders 2 or 3.

Table A1.1. Recommended accuracy of survey orders

Survey order	Application	Recommended accuracy	horizontal
Order 1	Harbours and navigation channels	5 m + 5% of depth	
Order 2	Depths < 200 m	20 m + 5% of depth	
Order 3	Depths > 200 m	150 m + 5% of depth	

For the purpose of this survey, it was assumed that the use of stand-alone GPS provided adequate precision in terms of horizontal position. Therefore, it is not recommended to interpret nearshore data at scales larger than 1 : 10 000, or a grid size smaller than 10 m. For areas with water depths greater than 200 m, a charting scale of at least 1 : 50 000 is recommended.

A1.2 Depth measurements

Bathymetric maps provide information about the depth of water from the water surface to the seabed. Through the use of detailed depth contours and full use of bathymetric data, the size, shape and distribution of underwater features are clearly revealed. The depth is measured using a ship-mounted multibeam echo sounder (MBES). The MBES transducer produces an acoustic pulse designed as a fan that is wide in the across-track and narrow in the along-track direction (Figure A1.1). The swath of seabed covered by this transmit beam is typically more than twice the water depth. The pulse of sound emitted from the MBES travels through the water column and is reflected back as an echo and received as numerous

narrow beams by the receiving elements of the MBES. The measurements are time based, and by using the speed of sound in seawater each time is converted first to a range and then, knowing the beam angle, to a depth. The distance to the seabed is then combined with the movement of the vessel to stabilise it into a real-world framework. This framework is then positioned to provide XYZ soundings for each beam's interaction with the seabed. A series of these swaths are then combined to produce a three-dimensional representation of the seafloor topography.

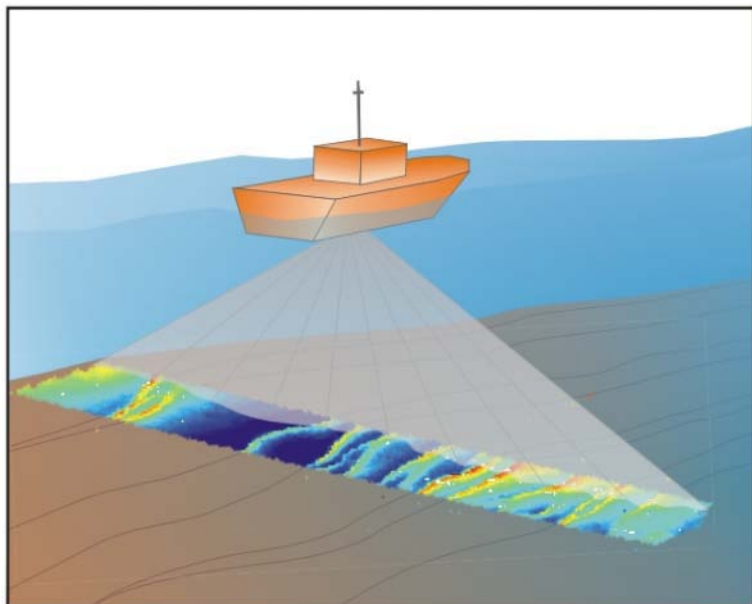


Figure A1.1. Conceptual illustration of bathymetric data acquisition with a multibeam echosounder, MBES (source: <http://www.rcom.marum.de>, accessed 10/01/2007).

The accuracy of the MBES system is critically dependent on the corrections applied for vessel motion (heave, pitch, roll, yaw, and heading). However, the absolute accuracy of single beam and multibeam bathymetry depends on several factors that are not easy to determine. For single beam data, probably the principal errors that may be introduced are due to topographic features falling between survey lines. Multibeam systems give far better coverage.

The S-44 4th Edition Standard of the IHO lists values “a” and “b”, (Table A1.2) that should be introduced into the following equation to calculate the error limits for depth accuracy:

$$\pm \sqrt{a^2 + (b \times d)^2}, \text{ where } d = \text{depth.}$$

Table A1.2. Values for calculating error limits for depth accuracy

Survey order	Application	Constants
Order 1	Harbours and navigation channels	a = 0.5 m, b = 0.013
Order 2	Depths < 200 m	a = 1.0 m, b = 0.023
Order 3	Depths > 200 m	a = 1.0 m, b = 0.023

For example, the IHO recommends that a nearshore coastal survey (Order 2) in water depths of 20 m should have a maximum depth error of ± 1.1 m.

A MBES has, as any other measuring instrument, an inherent limit in its achievable accuracy. The total measurement accuracy, i.e. the uncertainty in the depth and location of the soundings, also depends upon the errors of the auxiliary instruments such as the motion reference unit, the gyro compass, and the measurements of the speed of sound through the

water column. The sea state at the time of the survey also contributes significantly to the quality of the data. The possible accuracy of the measured depths may be estimated by considering the following main error sources.

A1.3 Error budget analysis for measured depths

Measurement	The nadir-beam bottom detection range resolution of the multibeam system has a maximum limit of 0.1 m (Reson 2002). However, multibeam systems are particularly susceptible to errors in the far range (outer beams), and detection is estimated at ± 0.3 m plus 0.5 % of the depth. Errors also include the detection of the sea floor due to local variations of depth within the beam footprint, especially in the outer beams, and a varying density of the bottom material. This may be significant if a relatively low-frequency transducer is used on soft marine muds in shallow water.
Transducer draft	The transducer depth below the water line may be determined to ± 0.1 m. However, the draft of the vessel due to the variability in vessel loading, e.g. fuel and fresh water storage, was not determined. It is estimated that this introduced a water depth independent error of up to ± 0.2 m. Dynamic draft errors, e.g. vessel squat, may also be significant.
Sound velocity	The sound velocity profiles measured by the conductivity-temperature-depth sensor (CTD) probe did not reach full survey depths in waters exceeding 400 m water depths. An inaccurate sound path from the transducer to the bottom and back will affect not only the observed depth of water, but also the apparent position of the observed sounding. This error is presumed to exceed 0.5% of the water depth beyond the direct CTD measurements. In order to minimise this error, ARGO and GDEM data may be used to supplement the CTD data.
Heave	This error is directly dependent on the sea state, the sensitivity of the motion sensor and installation parameters. The MRU installation did not account for the offset distance between MRU, the centre of gravity, and the MBES transducer mount. However, the software was able to perform lever arm calculations and heave compensation during post-processing, and the vertical error is assumed to be significant only in heavy seas.
Tide/water level	Errors due to tides may be significant, especially where predicted tides some distance from the survey area are used. Perhaps ± 0.3 m for uncertainty in tidal datum need to be considered.

From the listing above, it is estimated that the measured depths in 20 m are typically accurate to about ± 1.5 m (± 0.3 m root mean square). However, the data presented in this report should be treated more conservatively since the first ten days of survey data was collected without dynamic offset corrections. Patch test values obtained after this data are of questionable quality as the transducer experienced bottom contact prior to the patch being performed. In addition to this the CTD was lost in the second week of the survey and sound velocity corrections could not be applied after this. The data is visibly poor in areas, with significant amounts of systematic noise. This is especially visible in the data over the southern plateau where the data is deemed to be problematic and of poor quality.

The complete bathymetric model, or digital terrain model (DTM), is based on some form of interpolation between the sampled depths from several survey lines. Consequently, the total uncertainty associated with a bathymetric model will include uncertainties due to horizontal

positioning, and uncertainties introduced by the interpolation process, and will therefore be larger than the depth sounding uncertainty.

A1.4 Multibeam echosounder data density

The density of data used to construct a bathymetric grid is an important factor in its resolution – the denser the data, the higher the resolution that can be achieved. Sounding density is critical in terms of seabed feature detection and delineation. The two main factors that control the potential bathymetric target resolution capability of a multibeam echosounder are the distance between individual soundings (both in the cross-track and along-track dimensions), and the footprint size. The footprint is the area on the seabed covered by the sound pulse. Footprint size is a function of range, beam angle, and receiver and transmitter beam widths. A high sounding density and small footprint will result in higher resolution data. Conversely, the target detection capability is going to decay as a result of a growing projected beam footprint and decreasing data density.

The along-track spacing is controlled by the ping rate, which in turn is limited by the two-way travel time from the source to the seafloor. The maximum across-track spacing depends again primarily on the range, but also on the equiangular beam spacing. The size of the beams received by the MBES system is between one and one-and-a-half degrees. This means that a system mounted on a ship will have an increasing projected footprint size with increasing water depth. The footprint will also be larger at the outer beams than at the centre of the swath, as the range and incident angles increase with distance from the nadir beam. It is possible to have local variations of depth within the beam footprint, causing vertical error and affecting amplitude detection.

Table A1.3 shows a summary of the projected beam footprint size under varying water depths for the two MBES systems currently in use by SOPAC. It should be noted that the higher frequency system (SeaBat 8101) is not appropriate for applications in waters deeper than 200 m. Due to the constant beam width; the sounded area varies according to the depth and slope, which results in a variable data density in the survey area.

Table A1.3. Projected footprint size under varying water depths

Water depth (m)	SeaBat 8160 (deep water) 50 kHz, 126 beams at 1.5 °		SeaBat 8101 (shallow water) 240 kHz, 101 beams at 1.5 °	
	Inner footprint at nadir (m)	Outer footprint at 65° (m)	Inner footprint, nadir (m)	Outer footprint (m)
20	0.5	2.8	0.5	3.5
50	1.3	7.0	1.3	17.6
100	2.7	14.0	2.6	35.3
200	5.3	28.0	5.2	70.6
500	13.3	69.9	N/A	N/A
1000	26.7	139.8	N/A	N/A
1500	40.0	209.8	N/A	N/A
2000	53.4	279.7	N/A	N/A

Table A1.3 above assumes a horizontal seabed, and shows the variation in across-track footprint size with water depth and beam angle. The sounding density and swath width will also vary when surveying steep slopes, or highly incised margins, as the footprint size varies strongly with topography. Therefore, deeper sections have larger projected footprints and

fewer data point. This has the effect that a bathymetric feature whose lateral dimensions are less than the beam footprint size will not be resolved.

It should also be noted that the along-track resolution usually exceeds the across-track resolution due to ping rates, especially in deep water. Since ping rates are limited by the two-way travel time. Rates for water depths of 20 m and 1 500 m are 12.9 and 0.2 pings per second, respectively. Using maximum ping rates, or when surveying in deep water, the same area may be measured with the outer beams for several pings, which may give inconsistent sounding data due to the poor repeatability on uneven seabed.

In order to take into account depth-dependent point density, it is generally accepted to grid bathymetric data at a resolution that is on the order of the average beam footprint size, typically 10% of the water depth.

Appendix 2 – Multibeam Echosounder Coverage

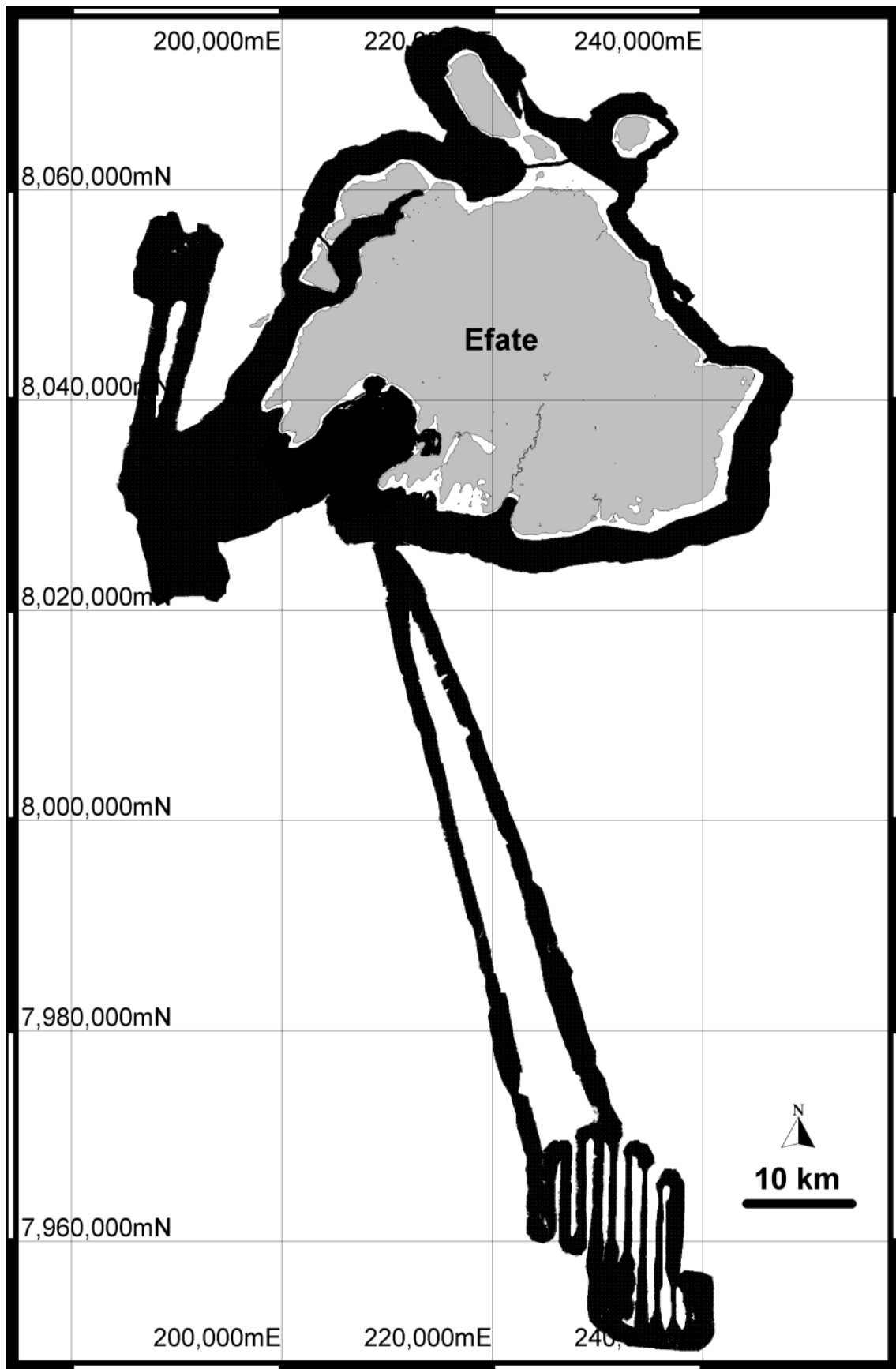


Figure A2.1. Map showing SOPAC/EU MBES, Reson 8160, coverage around Efate on a 40 m grid.



Figure A2.2. Sounding points for MBES (crosses on a 50 m-grid, this report), and SBES (sparse solid circles within bay, Smith 1991) in Port Havannah. Backdrop source map is 1 : 50 000 Efate Topographic Series, Department of Land Surveys, 1994).

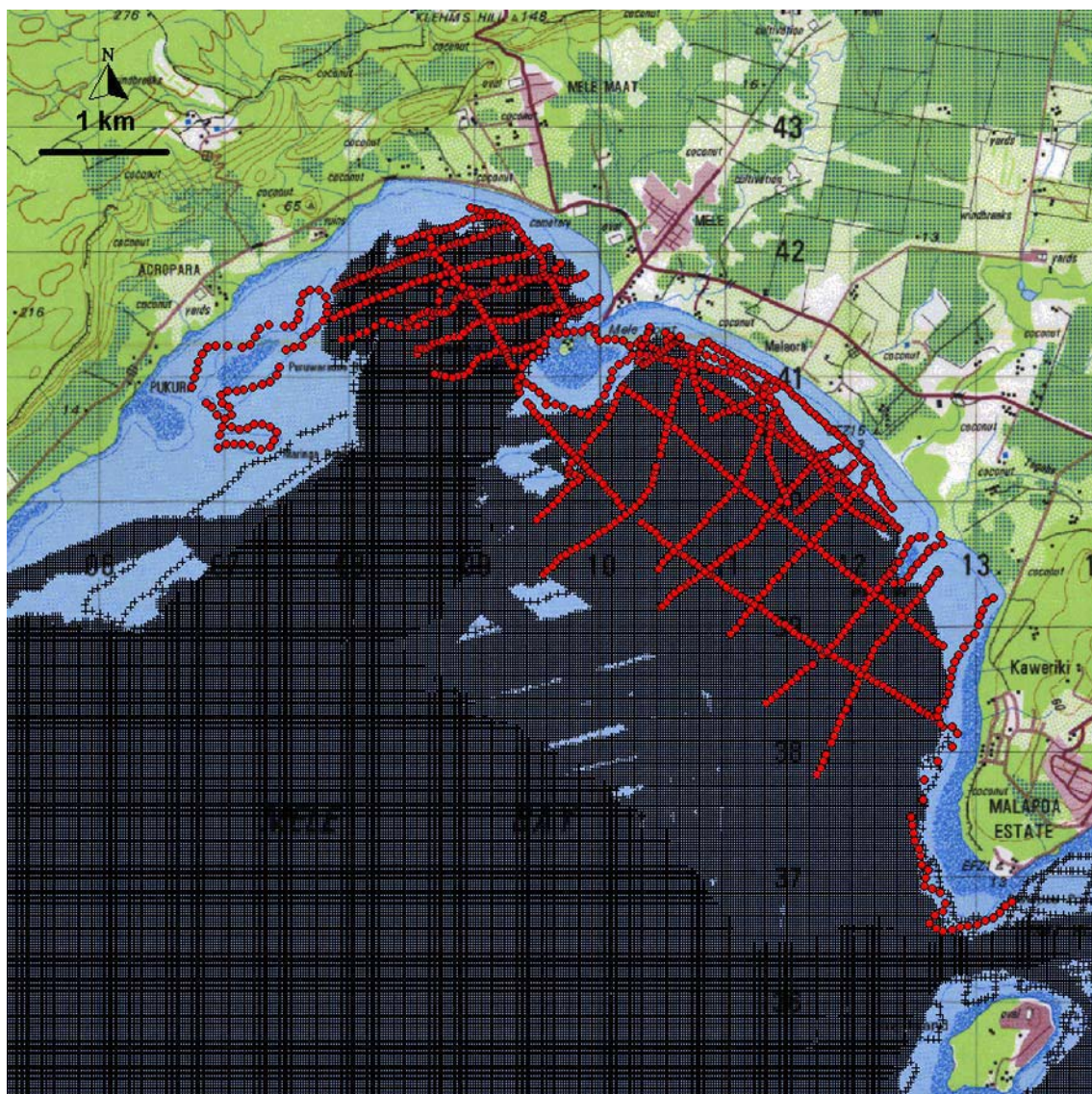


Figure A2.3. Sounding points for MBES (crosses on a 50 m-grid, this report), and SBES (red solid circles, Smith 1991) in Mele Bay. Backdrop source map is 1 : 50 000 Efate Topographic Series, Department of Land Surveys, 1994).

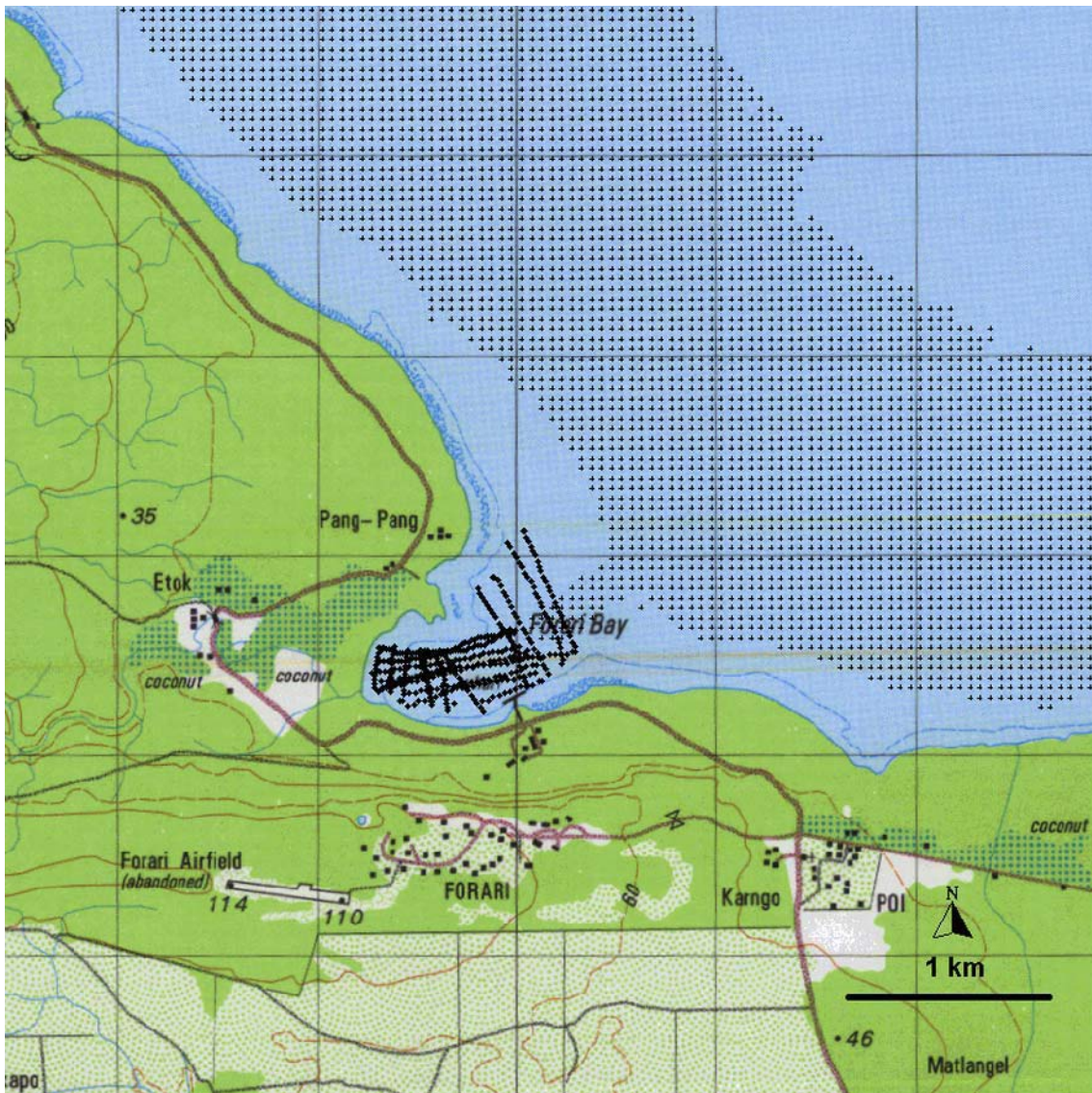
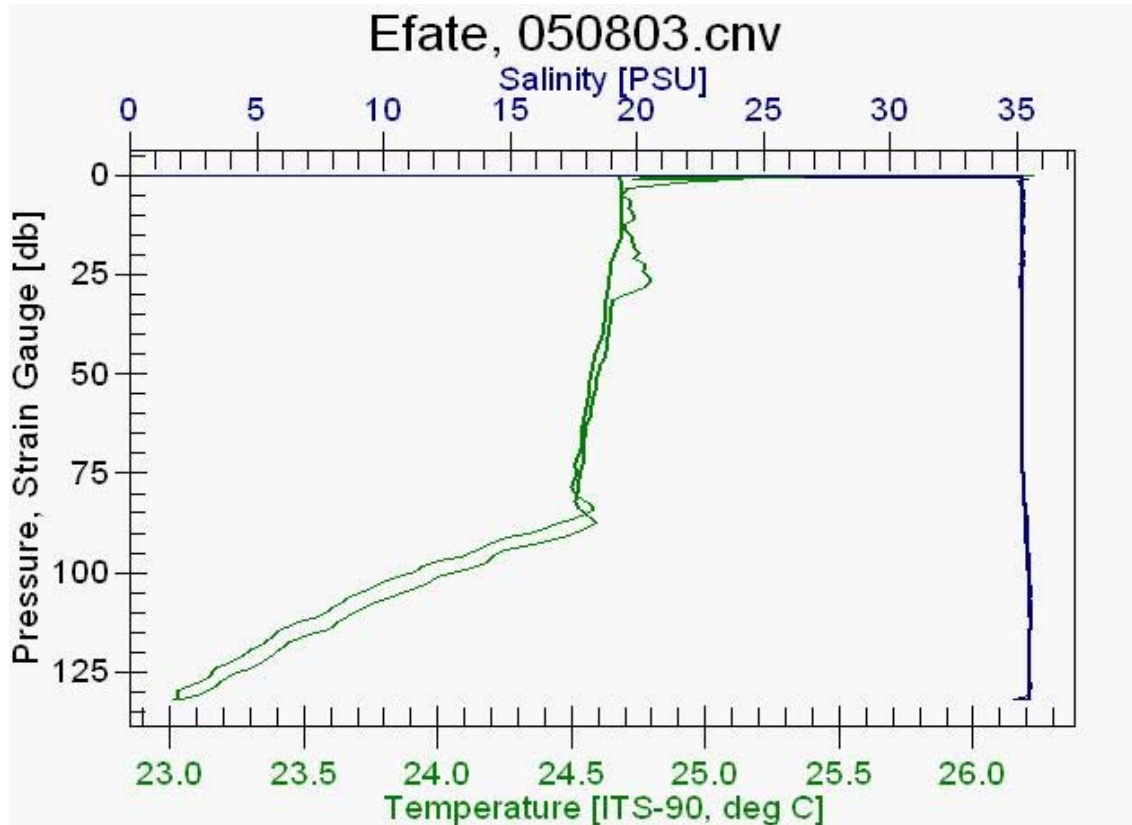
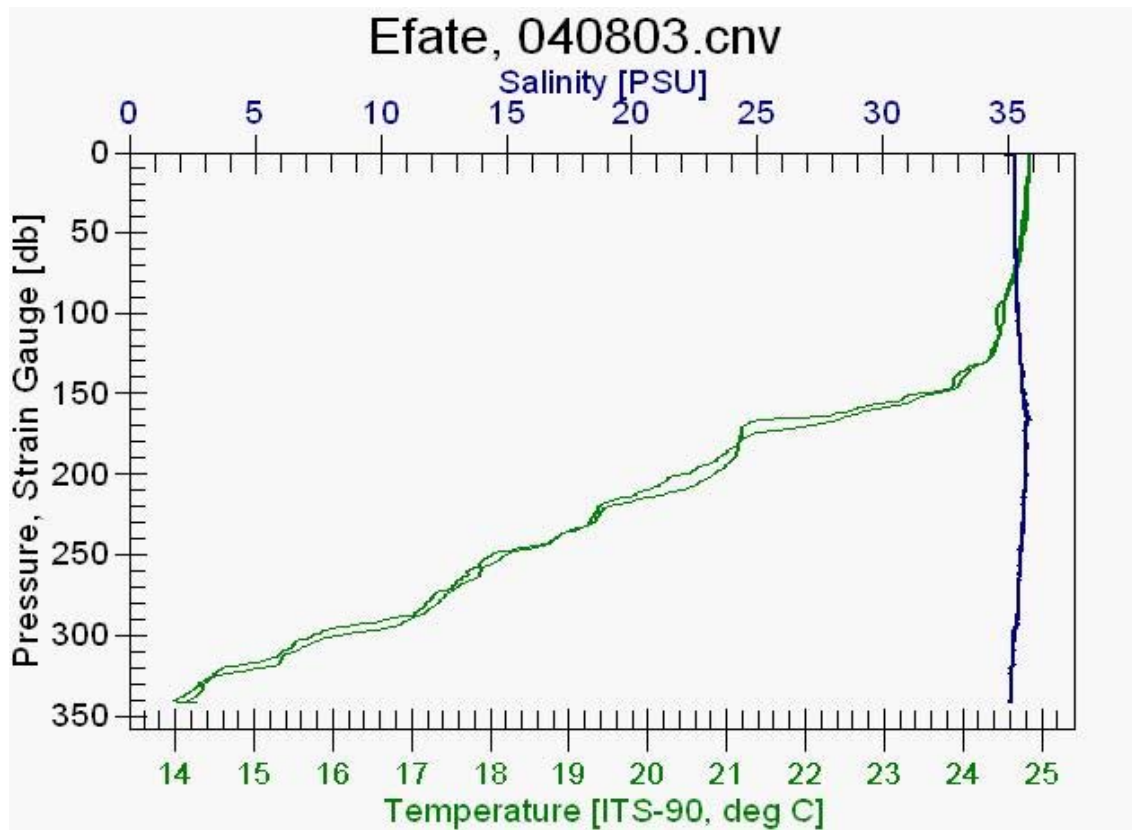
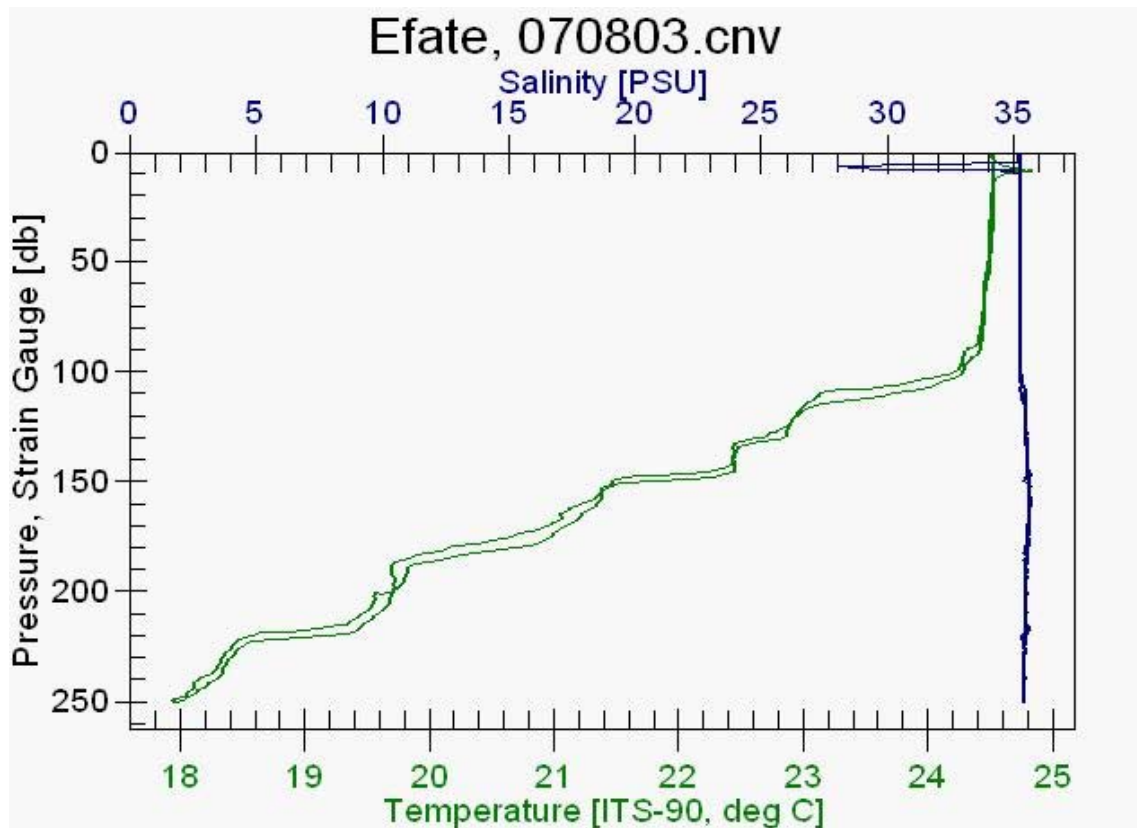
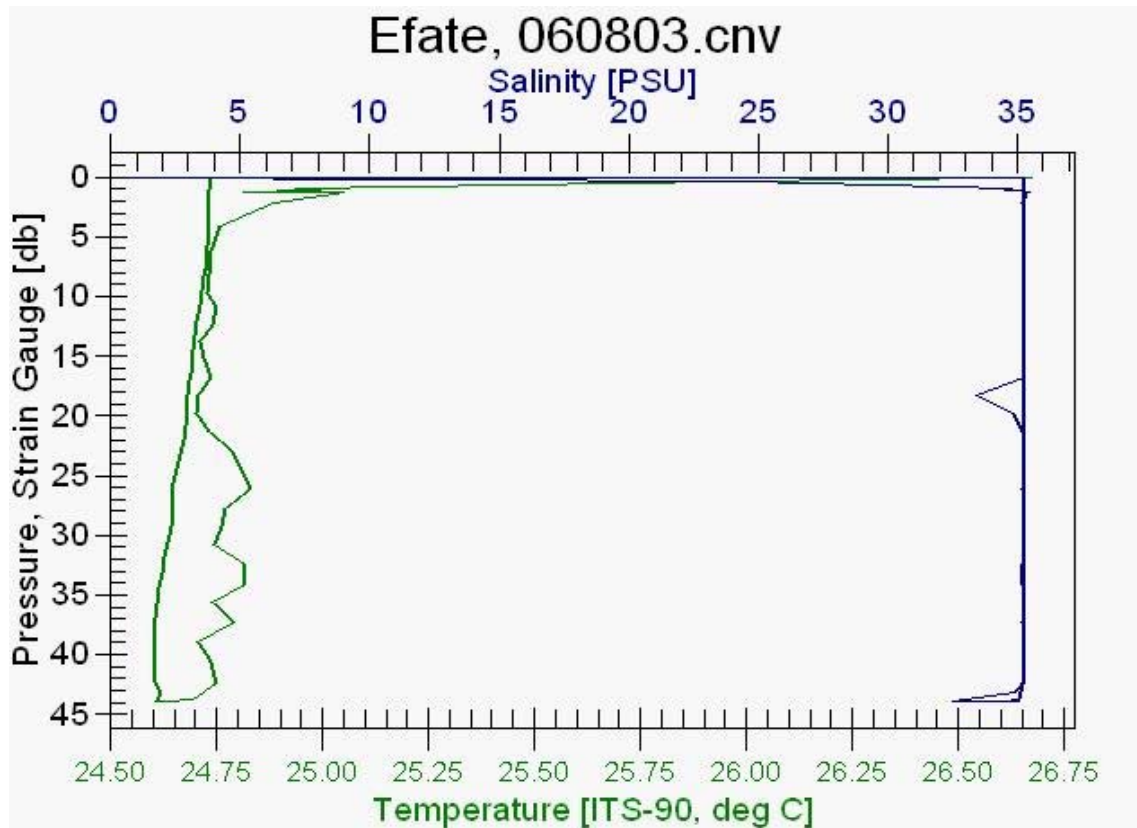
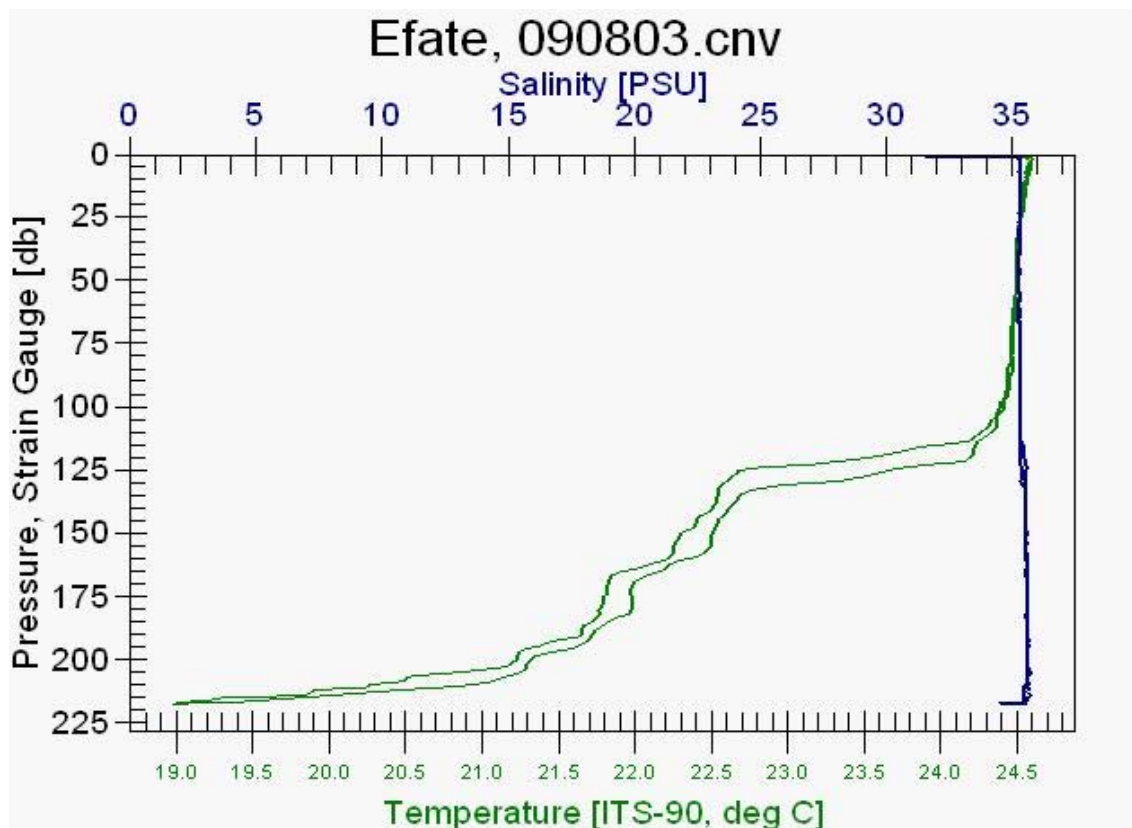
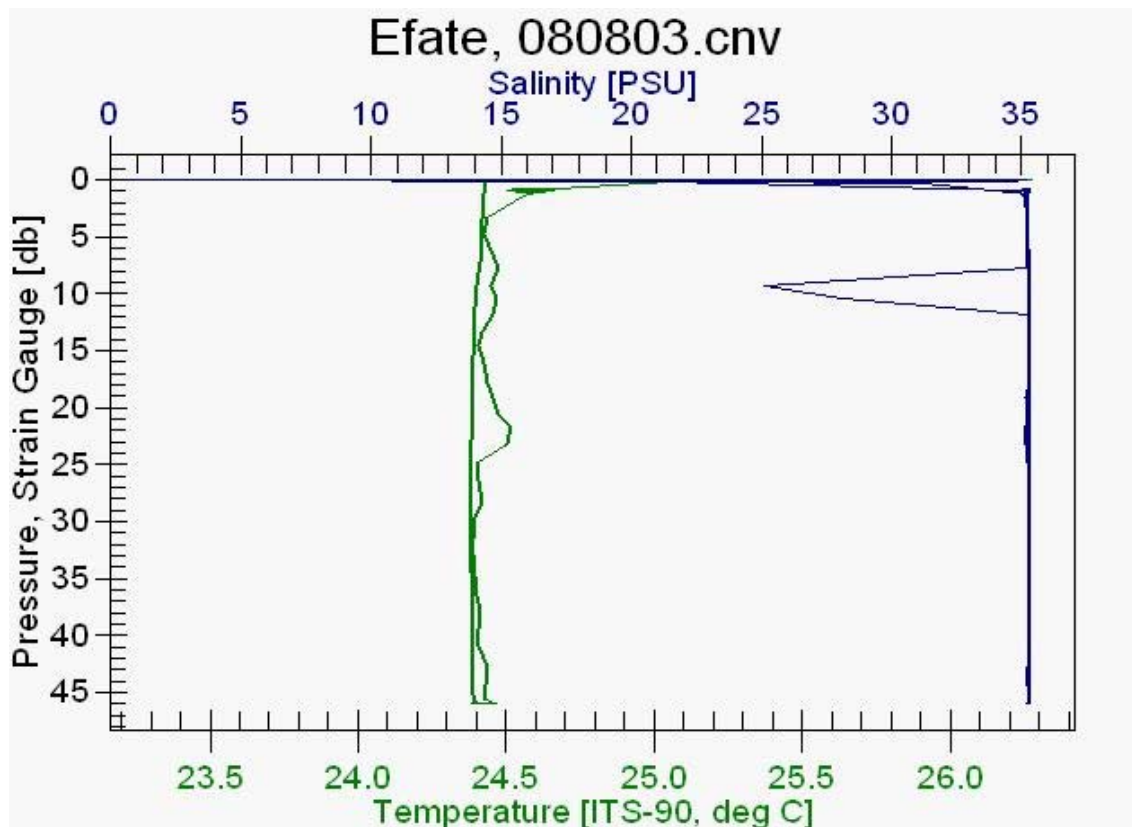


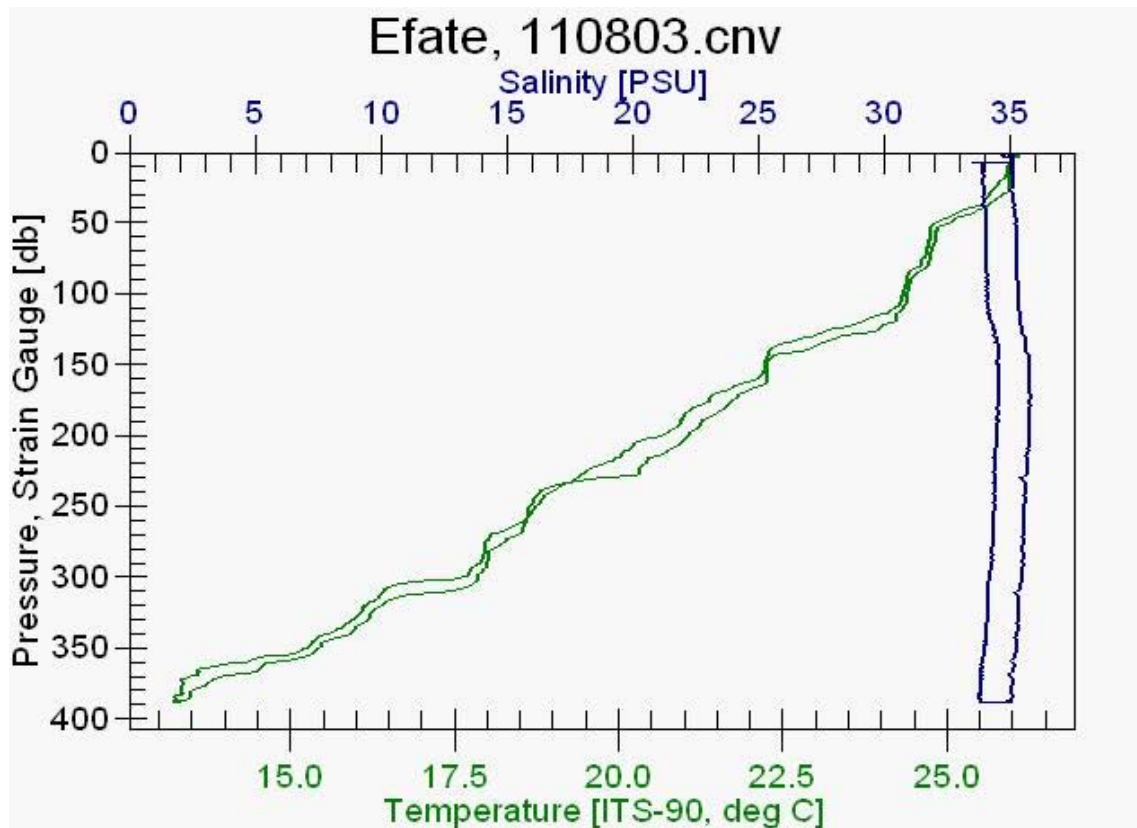
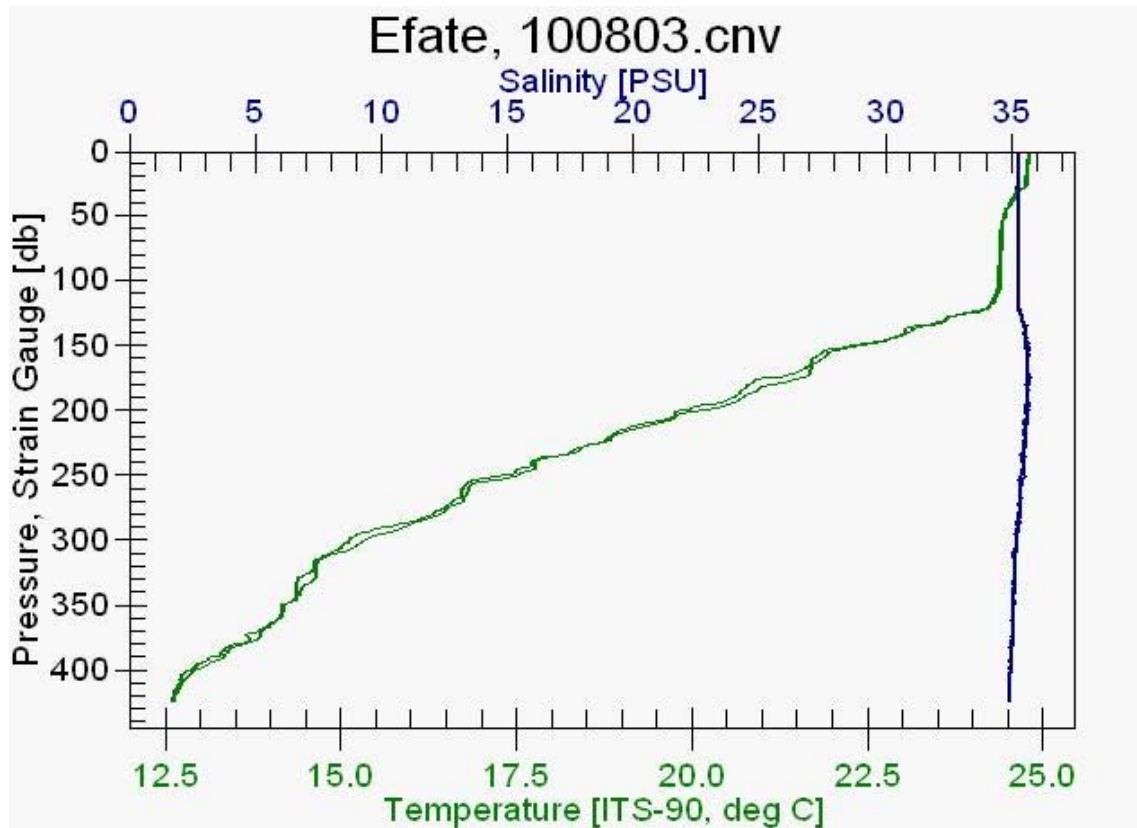
Figure A2.4. Sounding points for MBES (crosses on a 50 m-grid, this report), and SBES (solid circles, Smith 1991) in Forari Bay. Backdrop source map is 1 : 50 000 Efate Topographic Series, Department of Land Surveys, 1994).

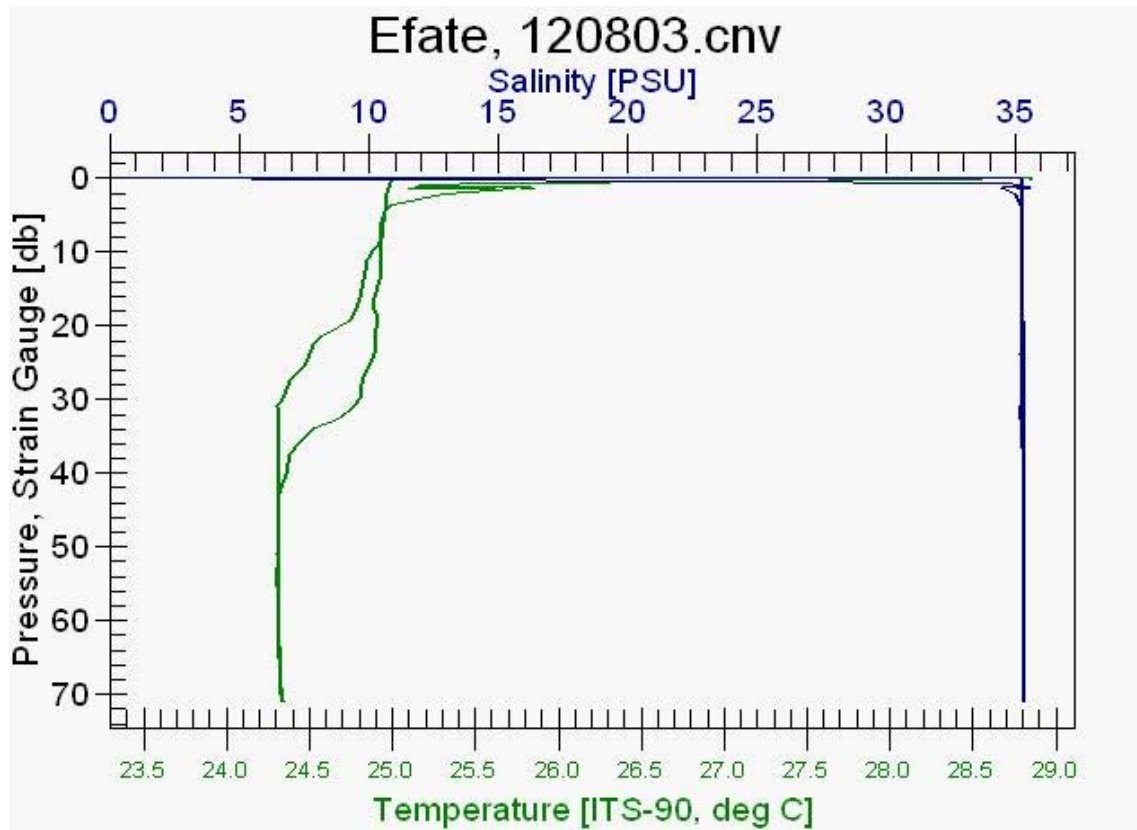
Appendix 3 – CTD Profiles











Appendix 3 – High-resolution A0 Charts, Efate Bathymetry

Charts are available from SOPAC, and can be downloaded from its website (www.sopac.org). Full size is 841 x 1189 mm. (Low-resolution A4 representations follow.)

Chart No	Title	Scale	Drawing No.
1	Efate, Bathymetry chart area 1	1 : 100 000	ER110.1
2	Efate, Bathymetry chart area 2	1 : 50 000	ER110.2
3	Efate, Bathymetry chart area 3	1 : 50 000	ER110.3
4	Efate, Bathymetry chart area 4	1 : 50 000	ER110.4
5	Efate, Bathymetry chart area 5	1 : 50 000	ER110.5
6	Efate, Bathymetry chart area 6	1 : 50 000	ER110.6
7	Efate, Bathymetry chart area 7	1 : 50 000	ER110.7
8	Mele Bay, Bathymetry chart area 8	1 : 20 000	ER110.8
9	Forari Bay, Bathymetry chart area 9	1 : 20 000	ER110.9
10	Havannah Bay, Bathymetry chart area 10	1 : 20 000	ER110.10

Appendix 4 – Line Logs

Date	Data files (.raw .prd)		Data files used		Azimuth	Heading	Speed	start time	end time	Comments
(August)	Revised name	Area	svel(.vel?)	tide(.tid)	(deg. N)	(deg. N)	(knots)	(hours)	(hours)	
2	020803_0001									not to be used
	020803_0002	Mele	none	none	227		7.7			computer crashed with blue screen message check for virus
	020803_0003	Mele	none	none	227		7.5	12:57	3.4	deploy 2 current meters in Teomua bay
	020803_0004	Teomua Bay	none	none	22		7.9	04:04	5.45	
3	030803_0004	P.Vila	none	none	263		8	04:19		maggie dropped for testing low signal message but after then that seemed to be working
	030803_0005	P.Vila	none	none			8	?	13:26	
	030803_0006	P.Vila	none	none			7.5	12:58	13:32	
	030803_0007	Erakor Bay	none	none	266		8	13:32	14:10	
	030803_0008	Mele	none	none	6.34		8.2	14:16	15:28	
4	040803_0009	Mele	none	none			8	08:48	11:11	maggie deployed at 8.25 off at 12.30
	040803_0010	Mele	none	none			8	11:12	11:57	
	040803_0011	Mele	none	none	293		7.9	12:01	12:23	
5	050803_0012	Mele	none	none	285		7.9	09:31	09:52	sound vel not working/pulled maggie in for about 10mins @9.30
	050803_0013	Mele	none	none	297		5.7	09:52	10:00	lose connection
	050803_0014	Matao Pt	none	none	286		8.4	10:00	11:28	
	050803_0015	Port Havana	none	none			8	11:28	13:01	
	050803_0016	Port Havana	none	none			8	13:02	14:31	
	050803_0017	Port Havana	none	none			8	14:32	16:01	
	050803_0018	Port Havana	none	none	0.91		7.8	16:01	17:05	
	050803_0019	Port Havana	none	none	324		7.9	17:08	17:16	

	050803_0020	Port Havana	none	none	11.65		8	17:18	17:25	CTD cast x 206344 y 8053069 17:25
	050803_0021	Port Havana	none	none	40.25		8	17:38	18:01	maggie turned off 17:25
	050803_0022	Port Havana	none	none	44		7.8	18:01	18:15	sound velocity probe noticed not working - dodgy connection
6	060803_0023	Port Havana	none	none			5	07:07	08:21	
	060803_0024	Port Havana	none	none			7.8	08:21	09:19	
	060803_0025	Port Havana	none	none			7.8	09:19	10:25	
	060803_0026	Port Havana	none	none			8	10:26	10:49	CTD cast x 210405.69 y 8057758.16 10.51am
	060803_0027	Moso Island	none	none			8	11:27	14:23	
	060803_0028	Matna Bay	none	none			7.5	14:24	03:07	
	060803_0029	Matna Bay	none	none			7.5	03:08	15:50	
	060803_0030	Nguna Island	none	none			7.5	15:50	16:56	
	060803_0031	Nguna Island	none	none	155		7.4	16:57	18:22	
7	070803_0032	Palao Bay	none	none			7.7	07:10	07:40	
	070803_0033	Undine Bay	none	none			7.9	07:43	08:56	CTD cast x 217396.35 y 8063416.56 9.02am
	070803_0034	Undine Bay	none	none			7.5	09:31	10:49	
	070803_0035	Moso Island	none	none			8.4	10:49	11:52	
	070803_0036	Lelapa Island	none	none			8	11:52	12:16	maggie basestation data downloaded 16.00h battery charged and restarted at 18.54h Vanuatu time sampling interval changed to 600 secondly
	070803_0037	Hillard Channel	none	none			8	12:16	13:43	
8	080803_0038	Pango Point	none	none	175		8.1	07:53	09:40	
	080803_0039	Teoumoa	none	none			7.5	09:41	10:03	
	080803_0040	Teoumoa	none	none			7.5	10:03	10:34	
	080803_0041	Eruti	none	none			7.4	10:34	10:47	

	080803_0042	Soumabal Pt	none	none		7.4	10:47	11:07	
	080803_0044	Soumabal Pt	none	none	272	8	11:35	11:52	
	080803_0045	Eruti	none	none	266	7.8	11:52	11:56	CTD cast x 230021.88 y 8027685.73 11.57am
	080803_0046	Eruti	none	none	86.6	6.3	12:02	12:28	over flow calc
	080803_0047	Teoumoa	none	none	94	6.4	12:30	12:34	lost GPS due to low power
	080803_0048	Teoumoa	none	none	204	7.7	12:39	12:56	
	080803_0049	Teoumoa	none	none		7.1	12:57	13:37	
	080803_0050	Eruti	none	none		6.5	13:37	13:51	
	080803_0051	Eruti	none	none		6.8	13:53	14:26	
	080803_0052	Eruti	none	none		9	14:26	15:14	
	080803_0053	Teoumoa	none	none	262	8.2	15:14	16:11	eternal time out appered at 15.40
9	090803_0054	Pango Pt	none	none	141	7.6	08:15	09:16	CTD cast x 220224.86 y 8027673 9.30am
	090803_0055	Teouma	none	none	141	7.9	09:50	10:22	
	090803_0056	Teouma	none	none		8	10:22	10:35	
	090803_0057	Ereuti	none	none		8	10:35	12:19	
	090803_0058	Manuro Pt	none	none		7.2	12:20	13:54	
	090803_0059	Ereuti	none	none		8	14:00	14:11	
	090803_0060	Ereuti	none	none		8	14:11	14:17	
	090803_0061		none	none		8.5	14:17	14:51	
	090803_0062	Teouma	none	none	322	8.3	14:51	16:00	
10	100803_0063	Pango Pt	none	none	211	7.7	10:00	10:24	CTD cast x 208382 y 8027715 10.25am
	100803_0064		none	none		8	10:41	11:58	
	100803_0065	Ner Pt	none	none	88.91	7.5	11:59	12:43	
	100803_0066	Soumabai	none	none	38	7.6	12:43	14:16	
	100803_0067	Mammo Pt	none	none			14:16	15:43	lost GPS power supply playing up fell to 0.75 volts
	100803_0068	Mangea Rf	none	none		7.4	15:47	17:57	maggie off 5.42pm

11	110803_0069	Matua Bay	none	none	34	7.4	07:14	07:34	computer crashed blue screen saying dumping files. System disc error need system disc to re boot comp.
	110803_0070	Nguna Island	none	none	300	7.7	07:35	07:58	
	110803_0071	Nguna Island	none	none	323	7.7	07:58	08:16	
	110803_0072	Nguna Island	none	none	278	7.1	08:17	09:09	
	110803_0073	Nguna Island	none	none	160	7.5	09:06	09:11	
	110803_0074	Nguna Island	none	none	211	7.6	09:11	09:34	CTD cast x 215795.23 y 8074874 9.37am
	110803_0075	Nguna Island	none	none		8	09:54	10:49	
	110803_0076	Nguna Island	none	none		7.6	10:50	11:33	
	110803_0077	Nguna Island	none	none	148	8	11:33	13:30	
	110803_0078	Nguna Island	none	none	268	7.7	13:30	14:28	
	110803_0079	Undine Bay	none	none	215	8.2	14:28	15:55	
	110803_0080	Undine Bay	none	none	87	7.7	15:55	16:51	hit transducer coming into anchor
12	120803_patch_0081		none	none		8		07:45	pitch and roll and latency yaw
	120803_patch_0082		none	none		8	07:49	08:05	pitch and roll
	120803_patch_0083		none	none		8	08:07	08:32	latency
	120803_patch_0084		none	none		4	08:33	08:44	yaw
	120803_0081		none	none		8	08:46	08:49	
	120803_0082	Passage	none	none		8	08:49	09:33	
	120803_0083	Emao	none	none			09:33	10:57	maggie went out 9.30am
	120803_0084	Mongea Rf	none	none	305	6.1	10:57	11:35	
	120803_0085	Emao	none	none	137	8.3	11:35	12:40	this section has very lumpy bathymetry
	120803_0086	Emao	none	none	157	7.8	13:00	13:48	
	120803_0087	Uranglelei Rf	none	none	109	7.7	13:48	14:11	
	120803_0088	Emao	none	none	194	7.5	14:11	14:45	
	120803_0089	Emao	none	none		7.4	14:45	15:35	
	120803_0090	Emao	none	none		7	15:32	16:09	
	120803_0091	Emao	none	none	358	8.3	16:09	16:30	

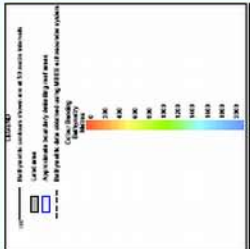
	120803_0092	Emao	none	none	45	8	16:50	17:09	CTD x230913 y 8062193 16.40h
	120803_0094	Emao	none	none	261	7.8	17:09	17:28	
	120803_0095	Emao	none	none	319	8.3	17:28	17:43	
	120803_0096	Emao	none	none	112	7.3	17:44	18:10	
	120803_0097	Emao	none	none	249	7.9	18:10	18:25	
	120803_0098	Emao	none	none	92	7.8	18:27	18:45	
	120803_0099	Emao	none	none	106	7.4	18:47	19:17	
	120803_0100	Emao	none	none	93	7.6	19:17	19:46	
13	130803_0101	Emao	none	none	21	4.0+	06:46	07:56	
	130803_0102	Mangea Rf	none	none	186	7.3	07:56	08:59	
	130803_0103	Eton	none	none	145	7.7	08:59	09:25	
	130803_0104	Mamuro	none	none		7.6	09:25	10:18	
	130803_0105	Forari Bay	none	none		7.8	10:18	12:03	
	130803_0106	Emao	none	none	73	7.9	12:03	13:03	
	130803_0107	Emao	none	none		8.1	13:05	14:00	gyro crashed/ Lost CTD probe cable snapped after getting snagged on the bottom at x 233849 y 8067833 14.12h
	130803_0108	Uranalelei Rf	none	none	256	8.1	15:13	15:54	
	130803_0109	Undine Bay	none	none	232	8	15:55	16:09	
	130803_0110	Undine Bay	none	none	217	7.9	16:10	16:16	
	130803_0111	Undine Bay	none	none	69	8	16:16	17:49	
	130803_0112	Undine Bay	none	none		8	17:50	18:11	
	130803_0113	Undine Bay	none	none		8	18:13	19:41	
14	140803_0114	Port Havana	none	none		7.3	06:42	07:52	got back into P Vila for fuel and water changed one power supply for GPS
15	150803_0115	Erakor	none	none	120	7	07:53	08:34	
	150803_0116	Taumor	none	none	97	7	08:35	09:29	
	150803_0117	Soumanmbal	none	none		8	09:29	10:28	

	150803_0118	Eton	none	none	7.17		7.6	10:28	11:04	
	150803_0119	Manuro	none	none	128		7.6	11:05	12:45	
	150803_0120	Soumanmbal	none	none			7.6	12:45	13:25	
	150803_0121	Meselp	none	none	359		8.6	13:25	14:15	
	150803_0122	Manuro	none	none	179		6.8	14:15	16:04	
	150803_0123	Soumanmbal	none	none	84		7.3	16:04	17:40	
	150803_0124	Manuro	none	none	179		6.7	17:40	17:52	
	150803_0125	Manuro	none	none	145		6.6	18:16	19:24	
	150803_0126	Meselp	none	none	244		7.5	19:24	20:30	
	150803_0127	Soumanmbal	none	none	217		7.8	20:30	22:14	
16	160803_0129	Mele	none	none	262		7.9	07:02	07:12	
	160803_0130	Devil Pt	none	none	282		7	07:47	08:13	
	160803_0131	Devil Pt	none	none	300		7.6	08:15	08:41	
	160803_0132	Devil Pt	none	none	353		7.1	08:42	08:53	
	160803_0133	Devil Pt	none	none	218		7.9	08:56	10:25	
17	170803_0134	Erakor	none	none	143		8	07:39	08:00	gyro crashed in small waves
	170803_0135	Erakor	none	none	271		7.5	08:32	09:33	
	170803_0136	Devil Pt	none	none	271		7.2	09:33	10:07	
	170803_0137	Devil Pt	none	none			7	10:08	11:28	
	170803_0138	Lelepa Island	none	none	286		8	11:35	13:07	
	170803_0139	Moso	none	none	280		7.7	13:07	14:06	
	170803_0140	Lelepa Island	none	none	217		8.5	14:06	15:17	
	170803_0141	Moso	none	none	39		7	15:17	16:27	
	170803_0142	Moso	none	none			8.4	16:27	17:45	
	170803_0143	Lelepa Island	none	none	218		8.2	17:45	18:10	
18	180803_0144	Port Havana	none	none	233		7.6	06:45	06:47	Check if side scan is working and how to use it
	180803_0145	Lelepa	none	none	217		7.2	07:03	09:08	
	180803_0146	Mangea Rf	none	none	130		8.3	10:13	10:43	gyro crashed

	180803_0147	Epao	none	none	135	7.8	11:07	11:15	line further out to sea trying to get to south coast
	180803_0148	Nammro Pt	none	none		7	12:08	13:27	gyro crashed still going south
	180803_0149	Souanbal	none	none	271	7.2	13:27	15:04	
	180803_0150	Teouma Bay	none	none		5	15:23		looking for current meters inshore teouma bay
	180803_0151	Teouma Bay	none	none		7.6	15:50	16:09	
19	190803_0153	Mele	none	none	215	8	10:30	11:00	try to recover patch test file/ HRP not working so canceled
	190803_0154	Pango	none	none	355	8.5	11:01	11:40	
	190803_0155	Devil Pt	none	none	255	7.4	15:39	16:32	
	190803_0156	Paul Reef	none	none	358	8.2	16:32	17:40	
20	200803_0157	Moso	none	none	4.51	7.4	06:40	07:13	
	200803_0158	Moso	none	none	277	7.4	07:13	07:47	
	200803_0159	Moso	none	none		7.1	07:47		
	200803_0160	Mangea Rf	none	none	185	7.7	10:12	10:34	
	200803_0161	Mangea Rf	none	none	90	8.3	10:34	11:50	
	200803_0162	Forari Bay	none	none	9.8	8.5	11:50	13:18	
23	230803_0163	Mele	none	none	30	5.4	13:12	13:27	
	230803_0164	Mele	none	none	7	4.5	13:27	13:33	
	230803_0165	Mele	none	none	280	5.4	13:33	13:42	
	230803_0166	Mele	none	none	312	5	13:42	13:49	
	230803_0167	Mele	none	none	125	4.3	13:49	14:09	
	230803_0168	Mele	none	none	251	4.9	13:59	14:06	
	230803_0169	Mele	none	none	294	5.1	14:09	14:22	
	230803_0170	Mele	none	none	37	4.7	14:24	14:31	
	230803_0171	Mele	none	none	214	4.9	14:33	14:40	
	230803_0172	Mele	none	none	304	4.2	14:41	14:49	
	230803_0173	Mele	none	none	213	5	14:50	14:58	
	230803_0174	Mele	none	none	276	4.5	15:06	14:15	
	230803_0175	Mele	none	none	168	4.5	15:17	15:18	

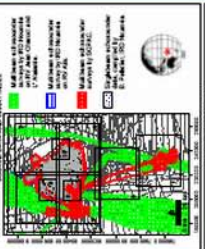
	230803_0176	Mele	none	none	139	7.9	15:23	15:35	
	230803_0177	Mele	none	none	293	8.2	15:35	15:49	
	230803_0178	Mele	none	none	231	7.5	15:49	16:01	
	230803_0179	Mele	none	none	267	8.3	16:01	16:16	
	230803_0180	Mele	none	none	222	7.7	16:17	16:25	
24	240803_0181	Devil Pt	none	none	228	8.1	07:25	08:33	looking for deil point fad
	240803_0182	Fad	none	none	58	7.3	08:33	09:40	
	240803_0183	Fad	none	none	320	7.9	09:36	10:24	
	240803_0184	Fad	none	none	259	7.9	10:26	11:27	
	240803_0185	Fad	none	none	335	8.5	11:34	12:05	
	240803_0186	Fad	none	none	313	7.7	12:11	14:17	
	240803_0187	Seamount	none	none	221	7.1	14:17	16:16	looking for sea mount 366
	240803_0188	Seamount	none	none	191	8.9	16:16	17:26	
	240803_0189	Seamount	none	none	114	6.9	17:27	18:35	
25	250803_0190	Pango Pt	none	none	157	7.4	09:54	12:36	heading to sea mounts 36 miles away
	250803_0191		none	none	161	6.4	12:36	14:36	half way there
	250803_0192	Sea Mount	none	none	179	7.5	14:36	15:45	
	250803_0193	Sea Mount	none	none	6.35	7.5	15:45	16:53	
	250803_0194	Sea Mount	none	none	168	7.4	16:53	18:20	
	250803_0195	Sea Mount	none	none		7.1	18:20	19:30	
	250803_0196	Sea Mount	none	none	92	8	19:30	20:40	
	250803_0197	Sea Mount	none	none	105	7.9	20:40	21:42	
	250803_0198	Sea Mount	none	none	173	7.8	21:42	23:38	
	250803_0199	Sea Mount	none	none	180	7.8	23:38	00:40	26th
	250803_0200	Sea Mount	none	none	355	8.5	00:40	01:20	26th
	250803_0201	Sea Mount	none	none			01:20	02:05	26th
	250803_0202	Sea Mount	none	none	5.59	7.5	02:05		26th
27	270803_0203	Devil Pt	none	none	250	8	07:53	08:55	
	270803_0204	Devil Pt	none	none	90	7.2	09:01	09:45	snippets on

	270803_0205	Devil Pt	none	none	260		7.8	09:48	10:27	snippets on
	270803_0206	Devil Pt	none	none	97		7	10:29	11:10	snippets on
	270803_0207	Devil Pt	none	none	274		8	11:11	11:30	snippets on
	270803_0208	Devil Pt	none	none	44		7	11:32	11:55	
	270803_0209	Devil Pt	none	none	238		7.8	11:57	12:34	snippets off big marlin strike spooled reel
	270803_0210	Devil Pt	none	none	233		8.2	12:38	13:19	sea mount centre and small 188372, 88035210
	270803_0211	Devil Pt	none	none				13:23	13:50	plateau 193361, 8034718
	270803_0212	Devil Pt	none	none	294		7	14:00	14:30	computer crashed running PRD 3D Swath both screens blank but illuminated
	270803_0213	Devil Pt	none	none				14:32	15:00	
	270803_0214	Devil Pt	none	none				15:02	15:00	infill lines
	270803_0215	Devil Pt	none	none				16:05	16:25	
	270803_0216	Devil Pt	none	none	68.1		8.1	16:34	17:03	inbound mele bay



NOTES

- 1) This chart was compiled from the following sources:
 - (a) Sounding Sheet (SS) data from the Hydrographic Survey of the Mediterranean Sea, 1975-1985.
 - (b) Sounding Sheet (SS) data from the Hydrographic Survey of the Mediterranean Sea, 1986-1995.
 - (c) Sounding Sheet (SS) data from the Hydrographic Survey of the Mediterranean Sea, 1996-2005.
 - (d) Sounding Sheet (SS) data from the Hydrographic Survey of the Mediterranean Sea, 2006-2015.
 - (e) Sounding Sheet (SS) data from the Hydrographic Survey of the Mediterranean Sea, 2016-2025.
- 2) The chart is based on the latest available data and is subject to change.
- 3) The chart is based on the latest available data and is subject to change.
- 4) The chart is based on the latest available data and is subject to change.
- 5) The chart is based on the latest available data and is subject to change.
- 6) The chart is based on the latest available data and is subject to change.
- 7) The chart is based on the latest available data and is subject to change.
- 8) The chart is based on the latest available data and is subject to change.
- 9) The chart is based on the latest available data and is subject to change.
- 10) The chart is based on the latest available data and is subject to change.



Scale

1:100,000

Scale bar showing 0, 500, 1000, 1500, 2000 meters.

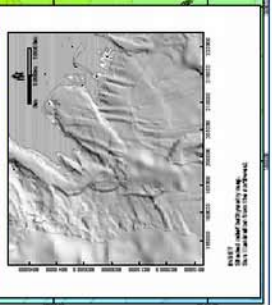
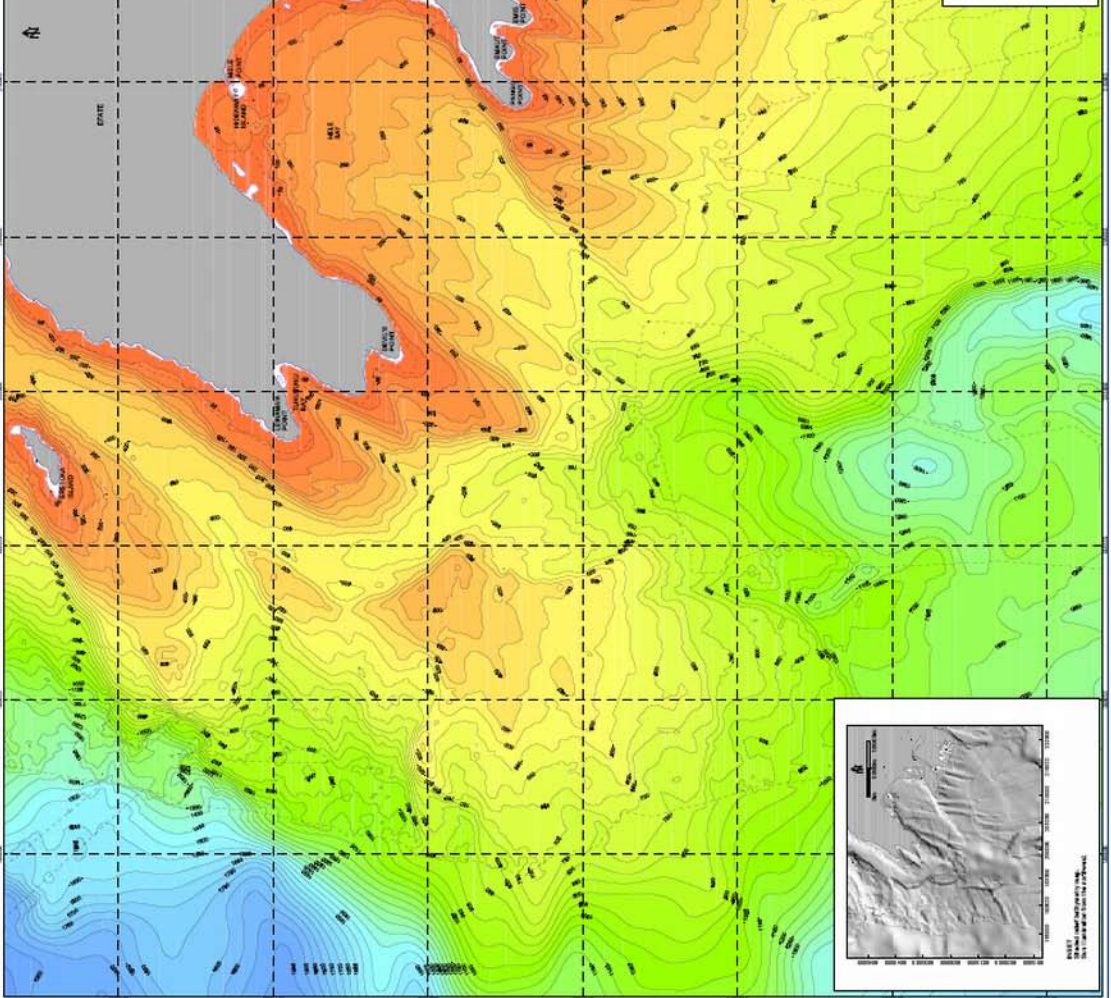
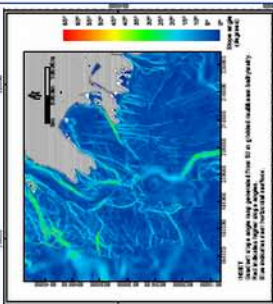
SOPAC IIRD
 International Hydrographic Organization
 Pacific Region

EMN - Chart Area 6

COMPOSITE BATHYMETRY

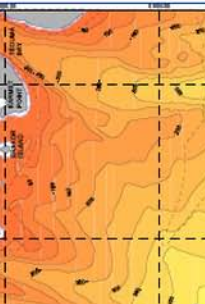
EMN - Chart Area 6

EMN - Chart Area 6



NOTES

- 1) This chart was compiled from the following sources:
 - (a) Sounding Sheet (SS) data from the Hydrographic Survey of the Mediterranean Sea, 1975-1985.
 - (b) Sounding Sheet (SS) data from the Hydrographic Survey of the Mediterranean Sea, 1986-1995.
 - (c) Sounding Sheet (SS) data from the Hydrographic Survey of the Mediterranean Sea, 1996-2005.
 - (d) Sounding Sheet (SS) data from the Hydrographic Survey of the Mediterranean Sea, 2006-2015.
 - (e) Sounding Sheet (SS) data from the Hydrographic Survey of the Mediterranean Sea, 2016-2025.
- 2) The chart is based on the latest available data and is subject to change.
- 3) The chart is based on the latest available data and is subject to change.
- 4) The chart is based on the latest available data and is subject to change.
- 5) The chart is based on the latest available data and is subject to change.
- 6) The chart is based on the latest available data and is subject to change.
- 7) The chart is based on the latest available data and is subject to change.
- 8) The chart is based on the latest available data and is subject to change.
- 9) The chart is based on the latest available data and is subject to change.
- 10) The chart is based on the latest available data and is subject to change.



Scale

1:100,000

Scale bar showing 0, 500, 1000, 1500, 2000 meters.

SOPAC IIRD
 International Hydrographic Organization
 Pacific Region

EMN - Chart Area 6

COMPOSITE BATHYMETRY

EMN - Chart Area 6

EMN - Chart Area 6

LEGEND

- Hydrographic contour lines at 10 and 20 fathoms
- Low area
- Approximate boundary between reef areas

Color Depth Contour Intervals

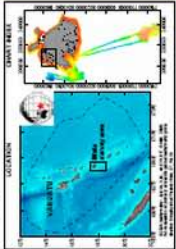
10 fms
20 fms
30 fms
40 fms
50 fms
60 fms
70 fms
80 fms
90 fms
100 fms
110 fms
120 fms
130 fms
140 fms
150 fms
160 fms
170 fms

NOTES

Obtain bathymetric data by 1/2 mile grid in the project area. The data were collected using a single beam echosounder (SBEC) and a dual beam echosounder (DBEC) on the R/V "SOPAC" in 2002. The data were processed using the following program:

DATA PROCESSING SOFTWARE
 NAME: HYDROGRAPHIC DATA PROCESSING SOFTWARE
 VERSION: 2.1.1
 DEVELOPER: J. J. GARDNER
 CONTACT: J. J. GARDNER
 ADDRESS: 1000 N. W. 10th St., Ft. Lauderdale, FL 33304, USA
 PHONE: 754.783.1234
 FAX: 754.783.1234
 E-MAIL: JJGARDNER@FPLA.COM

DO NOT BE USED FOR NAVIGATION



PROJECT CONTACT INFORMATION

Project Name: SOPAC
 Project Number: 020202
 Project Date: 2002
 Project Location: Vanuatu, Pacific Ocean

SCALE

0 10 20 30 40 50 60 70 80 90 100 METERS

PROJECT FUNDING

SOPAC
 PACIFIC OCEAN SURVEILLANCE AND OBSERVATION CENTER
 1000 N. W. 10th St., Ft. Lauderdale, FL 33304, USA
 PHONE: 754.783.1234
 FAX: 754.783.1234
 E-MAIL: JJGARDNER@FPLA.COM

PROJECT TITLE
 VANUATU
 Havanah Bay
 BATHYMETRY

Obtain bathymetric data by 1/2 mile grid in the project area. The data were collected using a single beam echosounder (SBEC) and a dual beam echosounder (DBEC) on the R/V "SOPAC" in 2002. The data were processed using the following program:

