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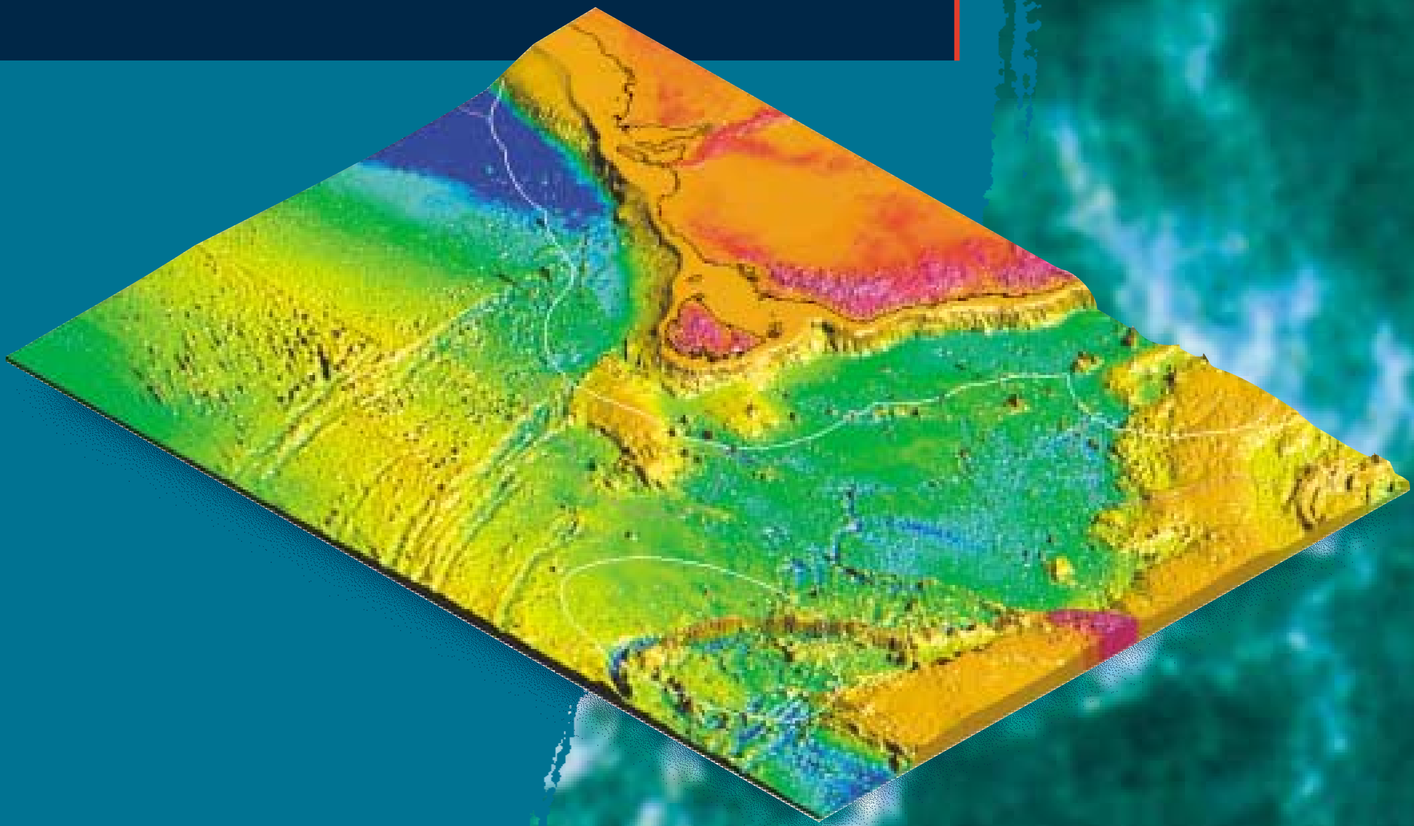
Seafloor mapping of the South–east Marine Region and adjacent waters.

AUSTREA final report:
Lord Howe Island, south-east Australian margin (includes Tasmania and South Tasman Rise) and central Great Australian Bight.

Peter Hill, Nadège Rollet and Phil Symonds.



Australian Geological Survey Organisation / National Oceans Office cooperative project

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Contents

Page
Abstract **8**

Executive Summary **9**

PART A: Introduction and Regional Information **11**

A1. Introduction **11**

A2. Relevance to Australia's Ocean Policy and Marine Science and Technology Plan **12**

A3. AUSTREA Data Acquired and Data Processing **14**
Data Processing 15

A4. Overview of the Geological Setting of the South-east Marine Region **16**

PART B: Main SE Australia Region - Offshore Tasmania, Victoria, Southern NSW and SE South Australia, and South Tasman Rise 21

B1. Geological and Tectonic Framework of Offshore Tasmania and Adjacent Regions of Southeast Australia **21**
Southern NSW, Gippsland and east Tasmanian margins 22
Southern Tasmanian margin and the South Tasman Rise 23
West Tasmanian margin 24
Otway margin 26

B2. AUSTREA Swath Mapping and Underway Geophysics Results **26**
Southern NSW, Gippsland and northeast Tasmanian margins 26
East Tasman Plateau and the South Tasman Rise 29
Southern Tasmanian margin 30
West Tasmanian margin 31
Otway margin 33
3.5 kHz acoustic facies analysis 36

B3. Integration of Regional Seabed Data Sets and Their Analysis **36**

B4. Regional Seabed Character and Geology **36**

B5. Seabed Resources and Potential **39**
Petroleum 39
Deepsea mineral deposits 39
Fisheries 40

PART C: Offshore Lord Howe Island **42**

C1. Geological Background **42**

C2. Seabed Data Sets **43**

C3. Seafloor Morphology and Character **43**

C4. Seabed Resources **44**

PART D: Great Australian Bight **46**

D1. Regional Setting **46**

D2. Morphology of the GAB Marine Park **47**

D3. Previous Geological Sampling Work **47**
  Dredges 47
  Cores 47

D4. New Samples from *Southern Surveyor* Cruise SS01/00 .... **48**

D5. Sedimentology of the GAB Marine Park from Acoustic Facies Mapping **53**
  Oceanography of the Great Australian Bight 53
  Sedimentary facies of the shelf and upper slope of the GAB Marine Park 53
  GAB Marine Park acoustic facies map of the middle and lower slopes 54

D6. Subsurface Geology **55**
  Stratigraphy 56
  AUSTREA-1 seismic lines in the Marine Park 57
  Spatial distribution of post-rift sediments (Late Santonian to Recent) 58
  Tectonic variations across the Benthic Protection Zone 59

D7. Interpretation of the Deep Holes in the Nullarbor Canyon **59**

PART E: Summary of Results **60**

E1. Seabed Resource Potential **60**
  Petroleum 60
  Deepsea mineral deposits 60
  Fisheries 61
  Biodiversity conservation 61

E2. Law of the Sea Implications **62**

E3. Conclusions **62**

E4. Recommendations **62**

E5. Acknowledgments **64**

References **65**

Glossary of Technical Terms **74**

FIGURES

A1. Overview image of offshore southeast Australia, including most of the area covered by the proposed South-east Regional Marine Plan and surveyed by AUSTREA on the Australian margin. 3-D hill-shaded topography, with view to the NNE.

A2. Low-angle 3-D view of the southeast Australian region, looking to the northwest.

A3. 3-D hill-shaded topographic image of the main area covered by the proposed South-east Regional Marine Plan and the focus of this report. View to the northeast.

A4. Location of the South-east Marine Region, areas within the AEEZ and claimable extended continental shelf.

A5. Index map of all the AUSTREA map sheets for the Australian sector of the South-east Marine Region.

A6. Map showing the continental shelf meso-scale regions for Australia.

A7. Physiographic provinces map of the southeast Australian region.

A8. Structural elements of the southern and southeastern margins of Australia showing rift basins.

A9. Gravity anomalies from satellite altimetry, magnetic anomaly and fracture zone identifications, for the Southern Ocean.

A10. Age of the seafloor off southern and eastern Australia.

A11. Plate reconstructions of the Australian-Antarctic region at 43.7, 33 and 26 million years ago, with ocean circulation patterns.

◘

B1. 3-D swath-bathymetry image of the steep, canyoned continental margin of the NSW South Coast, with important sample locations indicated.

B2. Spectacular seafloor topography and canyon systems of the Bass Canyon Complex off Gippsland - image produced from AUSTREA-1 swath data merged with data from AGSO's 1997 Sojourn7 survey and other (non-swath) topographic data sets.

B3. Seismic profile 4 on the Tasman-facing margin north of the Bass Canyon complex- showing Late Cretaceous-early Tertiary graben fill and locally-thick well-stratified Neogene carbonate cover.

B4. Seismic profile 6 in the deepwater Gippsland Basin just north of Bass Canyon - showing at least 2 s twt of sedimentary section and a late Tertiary prograding carbonate wedge incised by canyons.

B5. Seismic profile 15 along a graben off Freycinet Peninsula, east Tasmania, showing a thick, deformed ?Late Cretaceous fill with thin Neogene cover.

B6. View in 3-D of the southeast margin of Tasmania, and parts of the South Tasman Rise and East Tasman Plateau, looking northwest. Large volcanoes are part of the Balleny hot-spot chain. Image produced from merged swath data sets, AUSTREA-1 & -2 and AGSO's 1994 TASMANTE and 1997 Sojourn7 surveys.

B7. 3-D image of Cascade Seamount, a flat-topped submarine volcano (guyot) with numerous cones on its flanks. View to NNE. Prime orange roughy and dory fishing grounds are located along the edge of its summit area.

B8. 3-D image of the southern margin of Tasmania, looking NW, and showing the extensive volcanic terrain and cone fields plus location of the Tasmanian Seamounts MPA. Image produced from merged swath data sets, 1994 AGSO TASMANTE and AUSTREA.

B9. The Tasmanian Seamounts MPA, shown by the pink boundary line, within the field of volcanoes off southern Tasmania. The volcanic cones are typically several hundred metres high.

B10. Seismic profile 16b on the upper continental slope south of Hobart showing a strongly faulted and folded Late Cretaceous or older sedimentary section that outcrops on the sea floor or has no more than a veneer of young cover.

B11. Remarkable systems of downslope canyons, commonly 50-100 m deep, incised into the thickly sedimented continental slope of west Tasmania. 3-D image from merged TASMANTE and AUSTREA-1 swath data.

B12. Seismic profile 16c on the upper continental slope off the southwest tip of Tasmania showing a thick section of the Port Davey Sub-basin and 500 m high planated volcanic cone.

B13. Seismic profile 21 over the Sandy Cape Sub-basin, off northwest Tasmania, showing a thick sedimentary section (at least 2 s twt) with a large buried canyon (Palaeogene fill), and surface canyon development.

B14. Seabed topography south of Kangaroo Island, with spectacular canyon development at the margin. Inferred sediment flow patterns during sea level lowstands. AUSTREA-1 swath-bathymetry merged with regional bathymetry data.

B15. Backscatter imagery draped on 3-D topography – rugged canyon systems south of Kangaroo Island.

B16. Detail of backscatter response from the canyon floors, walls and channel systems within the Murray Canyon complex.

B17. Seismic profile 28 along the upper continental slope south of Kangaroo Island (Beachport Sub-basin) showing the dramatic >2 km relief and incision into the

Tertiary prograding sediment wedge beyond the shelf break. Basement, and probable Cretaceous sediments, are exposed in the canyon walls.

B18. Geological sampling sites (AGSO data base) and bathymetric contours (200 m) for the southeast Australian region.

B19. Topography of the southeast Australian region, colour hill-shaded relief. AUSTREA and other swath data merged with regional gridded data including onshore DEM.

B20. Backscatter imagery over the southeast Australian region. Merge of AUSTREA, TASMANTE and Sojourn7 data sets. Dark areas represent high backscatter levels, light areas low backscatter.

B21. Seabed slope from the gridded swath-bathymetry data for the southeast Australian region.

B22. Seabed aspect from the gridded swath-bathymetry data for the southeast Australian region.

B23. Seabed rock outcrop distribution interpreted from the backscatter imagery for the southeast Australian region.

B24. Seabed structures and geological domains of the southeast Australian region.

◆

C1. 3-D topographic image of the Lord Howe Island/Ball’s Pyramid ‘hot-spot’ volcano, based on the AUSTREA-1 multibeam data below 300 m water depth.

C2. AUSTREA-1 swath-bathymetry off Lord Howe Island and Ball’s Pyramid merged with NATMAP (1982) data for depths shallower than 300 m. The flanks are rugged and steep, and studded with volcanic cones up to several hundred metres high.

C3. AUSTREA-1 backscatter imagery off Lord Howe Island and Ball’s Pyramid. Dark areas represent high backscatter (volcanic cones and steep rocky slopes), while the lighter areas are seafloor sediments (mainly carbonates, including pelagic oozes).

◆

D1. Location of the Great Australian Bight Marine Park and study area covering part of the Benthic Protection Zone.

D2. Bathymetry of the deeper part of GAB Marine Park with seismic reflection transects (AUSTREA-1 cruise, 2000) and geological sample locations (*Southern Surveyor* cruise, 2000).

D3. GAB structural elements.

D4. Generalised stratigraphy of the Bight Basin (after Totterdell *et al*., 2000).

D5. Bathymetry in the GAB Benthic Protection Zone from AUSTREA-1 swath data. The view is to the northeast and shows an area about 80 km across.

D6. Acoustic reflectivity in GAB Benthic Protection Zone recorded during the AUSTREA-1 cruise.

D7. AUSTREA-1 backscatter data in the Nullarbor Canyon.

D8. Some samples recovered during the *Southern Surveyor* cruise.

D9. Sedimentary facies on the GAB shelf.

D10. Acoustic facies types based on 3.5 kHz echo sounder profiles (from Damuth, 1980 and Whitmore & Belton, 1997).

D11. Acoustic facies in the GAB Benthic Protection Zone interpreted from swath imagery (bathymetry and acoustic reflectivity) and along-track 3.5 kHz seismic profiles (AUSTREA-1 cruise, 2000), with fault locations, and sediment sample sites (from *Southern Surveyor* SS01/00 cruise, 2000).

D12. Line-drawing of interpreted AEA1023 and AEA1023A seismic profiles along the GAB Marine Park.

D13. Seismic line showing high reflectivity layer within the Hammerhead sequence, between mid-Campanian and Maastrichtian sediments.

D14. Santonian-Maastrichtian sediment thickness in two-way-time (ms).

D15. Eocene sediment thickness in two-way-time (ms).

D16. Oligocene - Recent sediment thickness in two-way-time (ms).

D17. Set of line-drawings across the Marine Park from west to east (based on AUSTREA-1 seismic reflection profiles). The deformation increases eastwards, towards the Nullarbor Canyon.

D18. Interpreted seismic reflection profile (AEA1023) across a deep hole in the Nullarbor Canyon.

TABLES

D1. AGSO geological sampling sites in the GAB Marine Park, *Southern Surveyor* cruise SS01/00 – locations and preliminary results. 49

APPENDICES

1. Shipboard and post-processed survey data 78

2. Digital products and geological data sets 79

3. UNCLOS Article 76 80

4. Informal terms relating to UNCLOS Article 76 82

5. Geological time scale 83

ABSTRACT

In early 2000 the Australian Geological Survey Organisation (AGSO) completed two major seabed swath-mapping and geophysical surveys of the Australian South-east Marine Region. These surveys, AUSTREA-1 and AUSTREA-2, were commissioned by the National Oceans Office and Environment Australia and were designed to provide important new scientific information on the seabed in this region to assist implementation of Australia's Ocean Policy, and in particular, development of the South-east Regional Marine Plan and establishment of marine protected areas (MPAs) within and adjacent to the South-east Marine Region.

This report, on the AUSTREA surveys and their results off southeast Australia, covers the region from Lord Howe Island in the east, to the central Great Australian Bight (GAB) in the west, to the southern tip of the South Tasman Rise (STR) in the south. Marine protected areas mapped included the Lord Howe Marine Park, the Benthic Protection Zone of the GAB Marine Park and the Tasmanian Seamounts MPA. Mapping of all the major deepsea trawl fisheries off Tasmania (including STR) was completed. The survey lines on the eastern STR are important for Australia's seabed claims under the UN Convention on the Law of the Sea.

The AUSTREA surveys off southeast Australia produced high-resolution maps and images of a large area of seabed (more than twice the size of Tasmania) over which only generalised bathymetry maps were previously available. Spectacular submarine landscapes were revealed - deeply-incised canyon systems, high cliffs, fields of volcanic cones and large isolated volcanic seamounts. Multichannel reflection seismic and 3.5 kHz profiles provided information on the nature and depth of seabed sediments and sedimentary basins in the region, with several potential frontier petroleum basins indicated off Tasmania. Gravity and magnetic profiles produced additional information on the underlying geology, including basement rocks. Underway oceanographic data collected during the surveys will assist further marine research in this region. All the survey data were collected in digital format, readily allowing further processing, enhancement and display.

As part of the study, the AUSTREA swath-bathymetry and backscatter data were merged with earlier surveys and data sets, including major multibeam surveys conducted by AGSO since 1994. A regional interpretation of the merged data sets, in terms of main seafloor structures and geological domains, was completed. The primary and derived spatial seabed data sets can be further interrogated and analysed to predict the distribution of specific sedimentary facies and benthic habitats.

Integrated with pre-existing seabed data sets, the new AUSTREA data provide the basis for future South-east Marine Region deepwater environmental management strategies and the development of the South-east Regional Marine Plan, and also provide framework information to support further biological and physical scientific field studies and research.

Recommendations based on the AUSTREA results indicate a need for further studies of benthos and ecosystems in a number of critical areas in and adjacent to the South-east Marine Region, a need for further research to test techniques for classifying sediment facies and benthic habitats using acoustic methods, and a need for further resource assessments in the frontier deepwater areas - petroleum (including methane hydrates), fisheries and biodiversity.

EXECUTIVE SUMMARY

Between December 1999 and February 2000, the Australian Geological Survey Organisation (AGSO) completed two major seabed swath-mapping and geophysical surveys (AUSTREA-1 and AUSTREA-2) off southeast Australia and on the Macquarie Ridge for the National Oceans Office (NOO) and Environment Australia (EA). Together, these surveys swath-mapped about 260,000 km² of seabed and collected about 21,000 km of geophysical profile data, including 15,000 line-km of reflection seismic data. The survey ship was the 85-m French oceanographic and geoscience research vessel *L'Atalante*. The work was done mainly for marine zone planning and management, for assessment of seabed living and non-living (petroleum and mineral) resources, and geological and biological research, as a major step towards implementation of *Australia's Oceans Policy* and *Australia's Marine Science and Technology Plan*, and in particular, the development of the South-east Regional Marine Plan by the National Oceans Office.

Data collected on the AUSTREA surveys included Simrad EM12D swath-bathymetry and backscatter imagery, 6-channel GI-gun reflection seismic, digital 3.5 kHz sub-bottom profiles, gravity and total field magnetics. Also collected was oceanographic information – expendable bathythermographs (XBTs) to 1800 m depth, and underway acoustic doppler current profiler (ADCP), sea surface temperature and salinity measurements. A full set of shipboard maps was provided to the National Oceans Office, and copies of the digital swath-data are held for NOO at AGSO. Copyright of all data is held by the Commonwealth of Australia. It was agreed that all data from the cruises be jointly managed by AGSO, NOO and EA.

AUSTREA-1 surveyed the southeast Australian sector of the South-east Marine Region from southern New South Wales to Kangaroo Island, including much of offshore Tasmania. The deepwater part of the Great Australian Bight Marine Park was also mapped, as was the proposed marine protected area around Lord Howe Island (now the Lord Howe Marine Park) and the eastern part of the Tasmanian Seamounts Marine Protected Area (MPA) off southern Tasmania. AUSTREA-2 completed the mapping off southeast Tasmania, and surveyed parts of the eastern and central South Tasman Rise (STR) and then completed a major survey of the Macquarie Ridge, mainly south of Macquarie Island. The survey on the southern Macquarie Ridge, and to some extent the work on the eastern STR, was designed to provide information critical for Australia's seabed claims under the UN Convention on the Law of the Sea (UNCLOS).

This report on the seabed of the southeast Australian sector of the South-east Marine Region is based on the new data, and incorporates the results of both AUSTREA surveys north of 50ºS. The study includes the AUSTREA-1 surveys in the Great Australian Bight and off Lord Howe Island. Data from previous AGSO swath-mapping surveys in the region (TASMANTE 1994, Sojourn7 1997) have been merged with the AUSTREA swath-data to allow an integrated analysis. Use has been made of existing geological, geophysical and bathymetric data, as well as the results of earlier scientific work in this region.

Mapping of the volcanic slopes of Lord Howe Island and Ball's Pyramid out to the 12 nautical mile outer limits of the then-proposed marine park, revealed a rugged terrain of volcanic cones, flows and canyons likely to harbour diverse benthic communities. The steep and narrow rifted continental margin off the NSW South Coast was shown to be deeply dissected by canyons and to contain gigantic continental fault blocks, and also volcanic seamounts and ridges of probable synrift origin. The survey completed mapping of the huge

Bass Canyon complex off southeast Victoria, revealing detailed morphology of tributary canyons up to 1000 m deep adjacent to the Gippsland oil fields. Important fishing grounds of the South East Fishery were mapped off Tasmania, including volcanic and carbonate pinnacle terrain off St Helens, volcanic seamounts of the Southern Hills, and the heads of canyon systems incised into the sedimented upper slope off west Tasmania. Mapping of the Tasmanian Seamounts Marine Protected Area, south of Hobart, was completed, with thirty additional volcanic seamounts found just east and north of the MPA. The seismic profiles confirmed the existence of potential frontier petroleum basins off the east, southern and west coasts of Tasmania. Parts of the deeply-canyoned upper and mid slope of the Otway Basin were mapped off northwest Tasmania, Victoria and South Australia. The Great Australian Bight Benthic Protection Zone of the GAB Marine Park was fully surveyed below the 500 m isobath and was shown to be generally a uniform slope, with the gigantic Nullarbor Canyon crossing its southeastern corner, gouged into deformed Late Cretaceous sediments.

AUSTREA-2 completely mapped Cascade Seamount, which in recent years has become a major orange roughy and dory trawl fishery, and found it to be a volcanic guyot 650 m deep with a multitude of small volcanic cones on its flanks. A survey of the summit area of the STR, filling gaps in coverage of AGSO’s 1994 TASMANTE survey, resulted in full coverage of this area which straddles the AEEZ and which has been under considerable fishing, and possibly environmental, pressure from Australian and overseas trawlers in the past few years. The seabed terrain on the STR summit area comprises numerous rocky hills (volcanics and Palaeozoic basement), about 750 m deep, interspersed with patches and plains of pelagic carbonate oozes. The elevated location of this area within a converging circum-Antarctic circulation and the winnowed nature of the sediments suggest strong currents and a prolific benthos on the hills and other rocky outcrop. Several large volcanoes, part of the Balleny hot-spot chain, were mapped on the eastern margin of the STR, as was a volcanic terrain on the southern STR similar to the field of cones on the continental slope of southern Tasmania. A unique and diverse benthos could be expected on the large seamounts (as shallow as 1600 m) and volcanic terrain, but no biological surveys have been done as yet. This southern part of the STR is likely to come under Australian jurisdiction as part of our ‘extended’ continental shelf under UNCLOS, after Australia lodges its claim in 2004.

Part of this study involved the integration of the AUSTREA swath-bathymetry and backscatter data with that of earlier surveys and data sets. A regional interpretation of the merged data sets was completed and provides the basis for further more detailed and targeted studies. The primary and derived spatial (GIS) seabed data sets allow further interrogation and analysis, mapping the distribution of specific sedimentary facies and benthic habitats, and the development of models for sedimentary, oceanographic and biological processes.

This report contains a number of recommendations based on the AUSTREA results and associated regional study.

PART A: Introduction and Regional Information

A1. INTRODUCTION

The Commonwealth Government of Australia, in December 1998, launched *Australia's Oceans Policy* (McEwan, 2000; Davis, 2000) aimed to develop an integrated and ecosystem-based approach to planning and management for all ocean and seabed uses. This is to be achieved through the development of Regional Marine Plans, based on large-scale marine ecosystems covering Australia's marine jurisdiction. The first Regional Marine Plan to be prepared will be for Australia's southeast Exclusive Economic Zone (EEZ) and adjacent extended continental shelf **(Figures A1, A2 & A3)**, encompassing the waters off Victoria and Tasmania, including Macquarie Island, and parts of southern New South Wales (NSW) and eastern South Australia **(Figure A4)**.

The Regional Marine Plans need to be developed on the basis of sound knowledge of the region's physical and biological features. This is emphasised in *Australia's Marine Science and Technology Plan* (1999), a companion document to the *Ocean's Policy,* outlining scientific implementation priorities and strategies. Accessible and accurate information on bathymetry, seabed structure and processes and high resolution maps are basic tools in a wide range of planning and management options. Using multi-beam arrays, modern acoustic survey methods allow high-resolution maps and images of large areas of the seabed to be generated quickly and cost-effectively. AGSO pioneered the use of such systems in Australian waters, including parts of the South-east Marine Region (Exon *et al*, 1994; Hill *et al*, 1998, Exon & Hill, 1999). However, large areas of the offshore South-east Marine Region remained poorly mapped.

In mid-1999 an opportunity arose to charter France's premier oceanographic and geoscience research vessel, the 85-m *L'Atalante*. This vessel, owned by IFREMER (Institut Français de Recherche pour l'Exploitation de la Mer) is equipped with one of the most powerful multibeam swath-mapping systems available, the Simrad EM12D. It also operates a wide range of other state-of-the-art geophysical and oceanographic systems, including 6-channel GI-gun seismic, digital 3.5 kHz sub-bottom profiler, gravity meters, magnetometer, and acoustic doppler current profiler.

AGSO was commissioned by Environment Australia (EA) and the newly-established National Oceans Office (NOO) to undertake a comprehensive and cooperative seabed mapping program off southeast Australia using N/O *L'Atalante*.

This survey program, named AUSTREA (AUSTRalia Environment Australia), was completed as two cruise legs AUSTREA-1 and AUSTREA-2. The AUSTREA-1 cruise (AGSO Survey 222) concentrated on the Australian South-east Marine Region **(Figures A1 & A2)**, while AUSTREA-2 (AGSO Survey 223) mapped an area off southeast Tasmania and completed a major survey on the Macquarie Ridge, mainly to define jurisdiction limits under the United Nations Convention on the Law of the Sea (UNCLOS). *L'Atalante* left Noumea on 18 December 1999 at the start of AUSTREA-1 and finished the survey in Hobart on 11 January 2000. AUSTREA-2 began from Hobart on 15 January and ended at Bluff, New Zealand, on 9 February 2000. Survey information, data acquisition parameters and preliminary results of these surveys are contained in the respective cruise reports: Hill *et al.* (2000) - AUSTREA-1, and Bernardel *et al.* (in press) - AUSTREA-2. These two reports are outputs of NOO-AGSO Cooperative Project OP2000-SE01.

Together, these two surveys swath-mapped about 260,000 km² of seabed and collected about 21,000 km of geophysical profile data, including 15,000 line-km of reflection seismic data. Off southeast Australia, the main areas surveyed were:

- submarine slopes of Lord Howe Island (covering the then-proposed marine protected area out to 12 nautical miles, now the Lord Howe Marine Park)
- continental slope off the NSW South Coast
- offshore Gippsland Basin and Bass Canyon complex (to extend the area swath-mapped by AGSO in 1997 - Hill *et al.*, 1998; Exon *et al.*, 1999)
- deep-sea fishing grounds off east, south and west Tasmania (to extend the area swath-mapped by AGSO in 1994 (Exon *et al.*, 1994; Exon *et al.*, 1997b) and 1997 (Hill *et al.*, 1997a))
- submarine volcanoes south of Tasmania, including the eastern part of the Tasmanian Seamounts Protected Area (Koslow & Exon, 1995; Koslow & Gowlett-Holmes, 1998; MPA declared in May 1999)
- the deeply-canyoned continental slopes off northwest Tasmania, southwest Victoria and Kangaroo Island
- the Great Australian Bight Benthic Protection Zone of the GAB Marine Park (Environment Australia, 1999; Slater, 1999)
- Cascade Seamount on the East Tasman Plateau
- the summit area of the South Tasman Rise (STR), partly swath-mapped by AGSO in 1994, and recently the focus of significant demersal trawl fishing activity, accompanied by an international fishing dispute (Caton & McLoughlin, 2000).
- the eastern margin of the STR.

This report, based on the new data, provides an initial synthesis and assessment of the physiography, structure and facies of the seabed within the southeast Australian sector of the South-east Marine Region, with reference to environmental and resource significance. This study includes all the areas listed above, covering the results of both AUSTREA surveys north of 50ºS. Data from previous AGSO swath-mapping surveys in the region (TASMANTE 1994, Sojourn7 1997) have been merged with the AUSTREA swath-data to allow an integrated analysis. The report is part of the final output of NOO-AGSO Cooperative Project OP2000-SE01.

A2. RELEVANCE TO *AUSTRALIA'S OCEAN POLICY* AND *MARINE SCIENCE AND TECHNOLOGY PLAN*

This report results from an agreement between the National Oceans Office (NOO) and the Australian Geological Survey Organisation (AGSO) under Cooperative Project OP2000-SE01. The relevant schedule details the cooperative arrangements and falls within the framework of the *South-east Regional Marine Plan*, which forms part of *Australia's Oceans Policy*.

Australia's Oceans Policy, directed at developing an integrated and ecosystem-based approach to planning and management for multiple-use of Australia's offshore areas, was supplemented in June 1999 by the release of the *Australia's Marine Science and Technology Plan* (MSTP), which is concerned with developing a better understanding of the nature of Australia's vast marine jurisdiction and to build a sound information base to support the Regional Marine Plans. Specifically, the MSTP aims to:

- advance understanding of the form and structure of the seabed;
- advance understanding of the ocean's thermal characteristics, current patterns and chemistry, and its role in Australia's weather and climate;
- advance understanding of the marine species and ecosystems, and their behaviour over time;
- assist environmental conservation; and
- support the ecologically sustainable long term planning and management of our marine resources and environments.

The MSTP comprises three programs – (i) understanding the marine environment, (ii) using and caring for it, and (iii) building the infrastructure for (i) and (ii). Primary objectives are listed for each of these programs. The AUSTREA surveys and scientific outputs relate directly to a number of these, namely:

- ☐ to characterise and better understand the geological framework and evolution of Australia's continental margin and adjacent ocean basins;
- ☐ to define the boundaries of Australia's Marine Jurisdiction;
- ☐ to map the form and nature of the seabed of Australia's Marine Jurisdiction;
- ☐ to improve understanding of the principal physical and chemical oceanographic processes in Australia's coastal and open ocean waters;
- ☐ to understand marine biodiversity and biological processes in Australia's oceans;
- ☐ to understand the dynamics of Australia's marine habitats and ecosystems;
- ☐ to define, research and explore regions in Australia's Marine Jurisdiction that are potentially important to the petroleum and minerals industries; and
- ☐ to improve the productivity and sustainability of wild harvest fisheries, and to improve understanding of the relationship between fished stocks and the ecosystems that support them.

Earlier AGSO swath surveys on Australia's southern margin have also addressed the above objectives (Stagg *et al*., 2000).

In order to oversee implementation of *Australia's Oceans Policy* and, in particular, the Regional Marine Planning process, the National Oceans Office (NOO) was formed in December 1999 as an Executive Agency under the *Public Service Act 1999 (Cwth).* Development of the *South-east Regional Marine Plan* began formally in April 2000 and is expected to take about three years. The South-east Marine Region includes marine areas off Victoria, Tasmania (including Macquarie Island), southern New South Wales and eastern South Australia. Broadly, the South-east Marine Region includes all of the waters and seabed within the 200 nautical mile limit of the Exclusive Economic Zone (EEZ), stretching from Kangaroo Island, encompassing waters off Tasmania and Victoria, through to latitude 36°

48'S on the New South Wales coast, and then offshore to the east-northeast **(Figure A4)**. The planning region includes the extended continental shelf beyond the EEZ, to which Australia will be claiming certain rights under the United Nations Convention on the Law of the Sea.

A3. AUSTREA DATA ACQUIRED AND DATA PROCESSING

Data acquisition systems, data acquisition parameters, data quality and data coverage on the AUSTREA cruises are fully described in the post-cruise reports (Hill *et al.*, 2000; Bernardel *et al.*, in press).

Data types (all digitally recorded) included the following:-

Simrad EM12D multibeam swath-bathymetry and backscatter imagery
The EM12D (Pohner & Hammerstad, 1991) was the main seabed mapping system on board, providing detailed bathymetric and backscatter ('reflectivity') images of the sea floor while the ship was underway, generally at 10 knots. Bathymetric soundings are captured by the 162 sonar receive beams that fan out athwartships beneath the vessel, with backscatter intensity information processed out from the return signals at several times the spatial resolution of the bathymetric data.

The swath width of the system is about 7 times the water depth, out to a maximum of about 20 km. The ping (transit pulse) rate is proportional to water depth because the sonar echoes take longer to return from deep water. Ping rates are usually in the order of a few seconds in shallow water (several hundred metres deep) to about 15 seconds in the deep ocean. Because of these factors, the swath-width and mapping rate (km^2 per hour) is less in shallower water, but this is compensated by a higher spatial resolution (both cross-track and along-track).

Apart from pure depth, the bathymetric data provide important information on the geological structure of the seabed, and the backscatter data provide information on the nature of the seabed. Strong backscatter usually indicates rocky outcrop, and weak backscatter indicates soft sediment (Augustin *et al*., 1996).

6-channel GI-gun reflection seismic
The seismic source for this system comprised 2 GI airguns towed just behind the ship, emitting an explosion of compressed air every 10 seconds. The seismic echoes returning from the sea-bottom and underlying sediment and rock strata were recorded by a 6-channel hydrophone receiver, 300 m long, towed about 200 m behind the ship (to minimise noise from the ship).

The seismic profiles recorded provide a image (in cross-section) of the sedimentary strata (soft and lithified sediment) and underlying basement to a depth of up to several kilometres. The information is very important for mapping sedimentary basins, determining their structure and evolution, and for assessing petroleum potential.

3.5 kHz sub-bottom profiles
This system is a high-resolution seismic profiler. It operates somewhat between a normal echo-sounder and a standard seismic reflection system. It produces high resolution images of the seabed and sub-bottom sediment layers, both vertically and along-track, but because of the relatively high operating frequency its depth penetration is limited. During the AUSTREA surveys the 3.5 kHz profiler produced excellent images of sediment layers beneath the sea

floor to depths of almost 100 m in places (particularly in the deep ocean basins floored by soft pelagic oozes).

Gravity

L'Atalante had two operational marine gravity meters on board, and these provided underway measurements of the earth's gravitation field. The gravity field varies from place to place as seafloor relief changes and as the density structure of the sediments and basement rocks beneath the seabed changes. Sedimentary basins are generally of lower density than enclosing basement rocks, so it is possible to map the extent and depth of such basins by modelling techniques based on the gravity profiles.

Total field magnetics

A sensor, measuring the total magnetic field of the earth, was towed 230 m behind the ship (beyond the magnetic influence of the ship). Because rocks and sediments vary in their magnetic properties, largely due to varying magnetite content and magnetisation direction during formation, the magnetic profiles recorded can be used to assist mapping of the seabed geology and structure. Igneous rocks, including volcanics such as basalts (forming seamounts and oceanic crust), are usually strongly magnetic, and exhibit a pronounced signature in the profiles.

Oceanographic data

XBTs (expendable bathythermographs - thermistor sondes connected to shipboard instruments by fine copper wire) were launched from the ship twice a day on average. These probes measured sea temperature to 1800 m depth, and were vital for correcting the EM12D multibeam for ray-bending effects (sound velocity in the water column varies with depth, temperature and salinity). The data are also very useful for oceanographic studies.

Sea surface temperature and salinity measurements were continuously recorded during the cruises. Also continuously recorded were ocean current data using an ADCP (acoustic doppler current profiler). This instrument operated at frequencies of 75 and 300 kHz and recorded current information to depths of about 560 m.

Data processing

Most of these shipboard data sets require sophisticated editing and processing to reduce them to a form suitable for interpretation and display. The multibeam (bathymetry and backscatter) data were processed on board and a full set of maps, contours and imagery, of the new data was produced. A full set of these on high quality film media, opaque and transparent, were lodged with NOO after the cruises. An index map of all the AUSTREA map sheets for the Australian sector of the South-east Marine Region is provided **(Figure A5)**. A preliminary stack of the 6-channel seismic data was done on board, and final processing of these data was recently completed at AGSO. Processing of all the gravity and magnetics data is nearing completion.

A summary of data processing done on *L'Atalante* and progress on post-processing of the geophysical data at AGSO is provided in **Appendix 1**.

For the main part of the South-east Marine Region, the Australian sector, taken in this study to be bounded by 136ºE, 152ºE, 36ºS and 50ºS, further processing, merging and display of bathymetry and backscatter data sets has been undertaken **(see sections B3-B4)**. An important part of this has been the merging of the major swath data sets generated by AGSO's TASMANTE (1994) and Sojourn7 (1997) surveys with those of AUSTREA-1 and AUSTREA-2.

A4. OVERVIEW OF THE GEOLOGICAL SETTING OF THE SOUTH-EAST REGION[*]

In terms of the regional marine planning, the South-east Marine Region includes all areas within Australia's marine jurisdiction that lie off Victoria, Tasmania, eastern South Australia, southern New South Wales and Macquarie Island (legally considered part of Tasmania). The region lies between lines **(Figure A4)** that extend from the outer limit of the 200 nautical mile Australian Exclusive Economic Zone (AEEZ) to just south of Kangaroo Island off South Australia in the west, and to approximately 36° S off New South Wales in the east, where the boundary is extrapolated from the northern limit of the Twofold Shelf meso-scale region (IMCRA, 1999). Consequently, the South-east Marine Region includes all areas of water, seabed and sub-soil that lie landward of the 12 nautical mile Territorial Sea limit (includes waters within a State or Territory, and the 3 nautical mile Coastal Waters) and within the AEEZ, and adjacent areas of seabed and subsoil that lie within the extended continental shelf beyond the AEEZ, as defined under Article 76 of the United Nations Convention on the Law of the Sea (UNCLOS; **Appendices 3 & 4**; UNCLOS, 1983).

The South-east Marine Region encompasses thirteen of the IMCRA (1999) meso-scale shelf regions **(Figure A6)** – eastern part of Eyre (EYR), Coorong (COR), Otway (OTW), Franklin (FRA), Davey (DAV), Bruny (BRU), Freycinet (FRT), Boags (BGS), Central Bass Strait (CBS), Central Victoria (CVA), Victorian Embayments (VES), Flinders (FLI) and Twofold Shelf (TWO), as well as the Sub-Antarctic (incorporating the South Tasman Rise) and Macquarie Island marine domains of the AEEZ. It includes parts of the Southern Ocean and the Tasman Sea, as well as Bass Strait. It is a physically complex region extending through 24 degrees of latitude (36-60°S) and 30 degrees of longitude (135-165°E), encompassing a variety of climatic zones, seafloor types and oceanographic conditions, and therefore a diverse range of marine habitats. The southeast part of Australia contains Australia's highest population density, and the coastline of the South-east Marine Region forms the home and recreational area for a large percentage of the population.

The bathymetry, geology and tectonic evolution of the main physiographic elements of the South-east Marine Region **(Figure A7)** are described in more detailed in the AUSTREA-1 and 2 cruise reports (Hill *et al.*, 2000 and Bernardel *et al.*, in press, respectively). To the west of Tasmania the continental margin varies from about 130-450 km in width where it faces the 5000 m deep oceanic South Australian Basin and Abyssal Plain. The narrower part of the margin from South West Cape in Tasmania, to Cape Jaffa in South Australia, consists of a 30-60 km wide shelf to about 200 m depth; a relatively steep, 100-150 km wide canyoned and gullied slope from 200-3500 m; and, in places, a smoother 50 km wide lower slope that is commonly bound on its outer edge by northwest-trending ridges of continental bedrock (Hill *et al.*, 1997c). Further west, the broad margin of the central Great Australian Bight consists of a 200 km wide shelf, and a broad slope province containing the 200 km wide, 300-2500 m deep Ceduna Terrace. South of Tasmania the margin can be more than 550 km wide. Here the 40 km wide shelf is separated from the triangular-shaped 1000-3000 m deep, current-swept, continental South Tasman Rise by the 3500 m deep South Tasman Saddle **(Figure A3)**. Off

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[*] For reference, a geological time scale is provided in **Appendix 5**

southeast Tasmania the margin is also up to 400 km wide because of the circular 2000-3000 m deep continental East Tasman Plateau. This plateau is surmounted by the Cascade Seamount, which rises to within 650 m of the sea surface. The East Tasman Plateau is separated from the upper slope by the 3500 m deep East Tasman Saddle **(Figure A3)**, and from the South Tasman Rise by the partly oceanic 4000-4500 m deep L'Atalante Depression (**Figure A3**; Royer & Rollet, 1997; Exon *et al.*, 1997a).

Off northeast Tasmania, eastern Victoria and southern NSW the margin is only about 60-80 km wide, and consists of a narrow (20-40 km) shelf and a steep (3-10°), 40-50 km wide canyoned slope. The 80 km wide WNW-trending Bass Canyon complex dissects the slope from depths of 2000-4000 m to the east of the 250 km by 500 km broad shelfal depression that forms Bass Strait. In the South-east Marine Region, the eastern margin lies adjacent to the 4200-4600 m deep oceanic Tasman Basin and Abyssal Plain. The Tasman Basin separates the Australian margin from the 750-3000 m deep continental Lord Howe Rise and Challenger Plateau. Major volcanic seamounts and guyots on the western margin of Lord Howe Rise, within the Tasman Basin, and south of the East Tasman Plateau, form parts of the hot-spot related Lord Howe, Tasmantid (CPCEMR, 1991), and Balleny Seamount Chains (Sutherland, 1994), respectively **(Figure A7)**.

Southeast of the Tasman Basin, Macquarie Island surmounts a system of narrow (generally less than 25 km), 500-2000 m deep ridges and adjacent troughs 5000-6500 m deep that form the Macquarie Ridge Complex **(Figure A7)**. This NNW-NNE-trending oceanic ridge complex extends north from the Australia-Pacific-Antarctic triple plate junction at about 62° S 160° E, to the Alpine Fault System of New Zealand's South Island, a distance of some 1600 km. In the north, the Macquarie Ridge Complex is separated from the large continental Campbell Plateau to the east by the Solander Trough, which joins to the south with the oceanic Emerald Basin.

East-west oriented ridge segments within the Australia-Antarctic Basin correspond to the Southeast Indian Ridge seafloor spreading system **(Figure A7)**, along which new oceanic crust is being created during the separation of Australia and Antarctica. Associated north-trending ridge-trough systems that run between Australia and Antarctica are oceanic fracture zones (eg. George V, Tasman and Balleny Fracture Zones) - transform faults that mark the flow-lines along which Australia and Antarctica drifted apart. Other more subtle NW- and NE-trending lineaments in the Tasman Basin also correspond to the extinct spreading ridge and transform faults, respectively. The irregular NE-trending ridge complex at the southern end of the Tasman Basin, that includes Resolution Ridge, corresponds to the boundary between the older oceanic crust of the Tasman spreading system, and younger oceanic crust of the Southeast Indian and Pacific-Antarctic spreading systems to the south.

The arrangement of physiographic provinces and features described above is largely the result of the progressive rifting and breakup of Gondwanaland since the Late Jurassic (~160 Ma), and separation of the various continental fragments during the creation of new ocean floor by seafloor spreading, possibly from about the Cenomanian (95 Ma) in places, but certainly from the Campanian, to the present day. The most recent syntheses of basin and margin development off southern and eastern Australia are contained in Symonds *et al.* (1996) and Stagg *et al.* (1999). The sedimentary basins of the South-east Marine Region **(Figure A8)** are largely the product of a protracted episode of Mesozoic extension within eastern Gondwanaland, which led to development of the 'Southern Rift System' (SRS; Willcox & Stagg, 1990) and ultimately to breakup of the supercontinent into the Australian and Antarctic Plates. The SRS, containing the Bremer, Bight, Otway, and Sorell Basins, extends for more than 4000 km, from Broken Ridge in the far west, to the South Tasman Rise in the southeast, with a major splay passing through the Bass and Gippsland Basins of the Bass Strait region. There is no direct evidence for rift basins of this age in New Zealand or beneath Lord Howe Rise, and, in fact, New Zealand and New Caledonia were active convergent margins at this time (Bradshaw, 1989) driven by the oblique subduction of the Phoenix Plate. The Southern Rift System began to form about the same time as Callovian-Oxfordian (~160 Ma) breakup off northwest Australia, on a trend that was roughly perpendicular to the convergent plate boundary of the proto-Pacific.

The central southern Australian margin to the west of Kangaroo Island is underpinned by the Proterozoic Fraser-Albany and Gawler cratonic blocks and overlying Proterozoic (eg. the Polda Trough; **Figure A8)** and Palaeozoic (eg. the Kanmantoo Trough) intracratonic basins. Old cratonic blocks do not exist further east, and during most of the Palaeozoic to early Mesozoic eastern Australia was a convergent margin associated with periods of oblique subduction represented by northwest trending, parallel belts of volcanic arc, forearc basin and subduction complex successions (Korsch & Totterdell, 1996) of the Tasman Fold Belt. Thus, in the east, 'basement' underlying the present-day margin and its conjugates is likely to comprise an amalgamation of these convergent terranes. A short-lived Middle Jurassic tholeiitic magmatic event (175±18 Ma; Hergt *et al*., 1989) formed the Tasmanian dolerite province as part of a long, linear flood basaltic belt within Gondwanaland that stretched from southern Africa (Karoo province) through Antarctica (Ferrar province) to Australia (Tasman province) (Elliot, 1992). This magmatism probably represents the initial stages of Gondwana breakup along eastern Australia.

The extension history of the SRS is complex and poorly understood, with the azimuth of the earliest Late Jurassic-Early Cretaceous phase of extension (> 160 Ma) thought to be NW-SE in the central Great Australian Bight (Etheridge *et al*., 1989) with perhaps associated strike-slip and oblique extensional basin systems developing in the nascent Otway, Bass and Gippsland Basins. A younger Tithonian (> 145 Ma) NNE-SSW extension azimuth has been suggested for the Otway Basin (Hill *et al*., 1995), and Moore *et al.* (2000) suggest that this phase produced a new east-west basin system that overprinted the earlier phase and linked the Gippsland Basin, the onshore-nearshore Otway Basin and perhaps the Duntroon Sub-basin **(Figure A8)**. From the Barremian-Cenomanian (120-95 Ma) the southeast Australian basin system (Otway, Bass and Gippsland) was flooded with volcanogenic sediments, which are thought to have an eastern provenance (Hill *et al*., 1995). These sediments may indicate the existence of a Barremian-Cenomanian extensional/transtensional magmatic province off eastern Australia along the line of incipient Tasman Sea breakup (Bryan *et al*., 1996; Symonds *et al*., 1996). This province may now lie largely on the Lord Howe Rise. A final phase of Cenomanian-Santonian (~95-85 Ma) rifting created NW-SE and N-S extensional and transtensional rift trends in the deepwater Otway-Sorell Basins, offshore Gippsland Basin, Bass Basin, and on and adjacent to the South Tasman Rise (STR), East Tasman Plateau (**Figure A8**; Moore *et al*., 2000), and margins of Lord Howe Rise. This phase of extension, which preceded seafloor spreading to the south and east of Australia, is also represented by significant lower crust/upper mantle thinning that produced the continent-ocean transition zone in the central Great Australian Bight (Sayers *et al*., in press) and by tectonism/magmatism on the South Island of New Zealand (Laird, 1994).

Breakup, and the start of seafloor spreading and the creation of new ocean crust in the South-east Marine Region, were initially thought to have commenced in the central Great Australian Bight during a period of very slow spreading (<1-2 cm/yr, full rate; Cande & Mutter, 1982; Veevers, 1986) from the Cenomanian - Middle Eocene (magnetic anomaly 34y-21y; ~95-47

Ma; **Figure A9**). Recently, on the basis of new deep-seismic and magnetic data, Sayers *et al.* (in press) suggested that new ocean crust only began to form about 83 Ma (early Campanian), about the same time as in the Tasman Basin to the east **(Figure A9)**, although spreading was considerably faster here. Spreading accelerated (4-5 cm/yr) south of Australia in the Middle Eocene (anomaly 18, ~40 Ma) and continues at about this rate to the present day. No anomalies older than Middle Eocene have been identified off the Otway and west Tasmania margins **(Figures A9 & A10)** indicating that seafloor spreading propagated eastwards from the Great Australian Bight. During seafloor spreading the western sector of the STR **(Figure A8)** initially slid past western Tasmania as part of the Antarctic Plate. However, during the Late Palaeocene to Early Eocene it rifted away from Antarctica and became welded to the central sector of the STR. The Antarctic plate began to move rapidly southward relative to the Australian plate in the Middle Eocene forming the Tasman Fracture Zone **(Figure A7)** along the western margin of the STR. The Antarctic plate cleared the STR in the early Oligocene (~33 Ma; **Figure A11b**), significantly affecting ocean circulation both regionally and globally.

Seafloor spreading between eastern Australia, the East Tasman Plateau, the STR and the Lord Howe Rise/Challenger Plateau **(Figure A10)** began in the Campanian (anomaly 33, ~83 Ma; Hayes & Ringis, 1973; Gaina *et al.*, 1998), propagated north along the eastern Australian margin and ended abruptly in the Early Eocene (anomaly 24, ~55 Ma). The complex ocean floor between the STR, Macquarie Ridge and Antarctica has recently been re-examined by Cande *et al.* (2000). They recognise Australia-West Antarctic spreading from the Middle Eocene-Late Oligocene (anomaly 20-8, ~46-26 Ma) off the STR **(Figure A9b)** and the Ross Sea that indicates extension between East and West Antarctica. At the same time, Australia-Pacific spreading orthogonal to that in the Tasman Basin occurred in the area of south Tasman ocean crust south of Resolution Ridge and in the Emerald Basin (Wood *et al.*, 1996; Cande *et al.*, 2000), both of which now straddle and are offset by the Macquarie Ridge. The Macquarie Ridge Complex marks the seismically active Australia-Pacific plate boundary that links north to the Alpine Fault of New Zealand, and south with the Southeast Indian and Pacific-Antarctic spreading ridges at the Macquarie triple junction **(Figures A9b & A10)**. Massell *et al.* (2000) suggest that the present-day, right-lateral strike-slip boundary along the Macquarie Ridge coincides with the relict spreading centre responsible for creating the south Tasman/Emerald Basin oceanic crust. Pure strike-slip motion, transpression and possibly under-thrusting (incipient subduction) have probably occurred along various segments of the Macquarie Ridge Complex during at least the last 10 Ma (Massell *et al.*, 2000).

An important aspect of the plate kinematic evolution of the South-east Marine Region is the opening of the Tasmanian Gateway and the development of the modern oceanic circulation system as Antarctica cleared the South Tasman Rise in the early Oligocene (~33 Ma; **Figure A11)**. This development of the Antarctic Circumpolar Current (ACC) is critical both to global climate evolution and to the modern marine ecosystems of the region. With the Tasmanian Gateway closed during the Middle Eocene (43.7 Ma; **Figure A11a**) weak gyral circulation is inferred in the highly restricted Australo-Antarctic Gulf south of Australia, and the Antarctic margin further east is influenced by the warm East Australian Current (Shipboard Scientific Party, 2000). During the earliest Oligocene (33 Ma; **Figure A11b**) the Tasmanian Gateway opened to deepwater circum-Antarctic circulation, and this began to decrease the influence of the East Australia Current on the Antarctic margin. During the Late Oligocene (26 Ma; **Figure A11c)** the Gateway was fully open expanding the Antarctic Circumpolar Current (ACC) and rapidly increasing decoupling of the East Australian Current from the Antarctic margin (Shipboard Scientific Party, 2000). This produced cooling of Antarctica and some ice sheet formation, contributing significantly to global cooling. With the opening of the Drake Passage off South America in the Neogene and strengthening of the ACC through the widening

Tasmanian Gateway, global cooling and thermohaline circulation intensified leading to the arrival of the current “Icehouse” world by about 15 Ma. This is the environment in which the South-east Marine Region’s diverse ecosystems have developed.

PART B. Main SE Region – Offshore Tasmania, Victoria, Southern NSW and SE South Australia, and South Tasman Rise

B1. GEOLOGICAL AND TECTONIC FRAMEWORK OF OFFSHORE TASMANIA AND ADJACENT REGIONS OF SOUTHEAST AUSTRALIA

The southern and eastern margins of Australia, including the Tasmanian margins, result from the continental fragmentation, since 160 Ma, of eastern Gondwana formed by the Australian and Antarctic continents, New Zealand and the large undersea Campbell and Challenger Plateaus and the Lord Howe Rise (Müller *et al.,* 2000). During the extension between Australia and Antarctica several basins developed from the Late Jurassic until the Late Cretaceous (Willcox & Stagg, 1990). Three continental extension phases are recorded. The first extension, from the Late Jurassic (> 160 Ma) into the Early Cretaceous, was in the Great Australian Bight (GAB), along a NW-SE trend. This led to the formation of strike-slip motion in the nascent Otway Basin and along the Tasmanian margin. The second extension, in the Early Cretaceous, produced a stretching with a NNE-SSW trend in the southeast Australian basins (Otway, Bass, Gippsland) which probably produced a structural overprinting in the GAB basin. The last minor extensional phase preceded seafloor spreading in the Late Cretaceous in the GAB (Cande & Mutter, 1982; Sayers *et al.,* in press) and produced wrenching on the Tasmanian margin.

The continent-ocean boundary in the GAB is dated as 95 Ma (Cenomanian; Veevers, 1986). Recent studies based on interpretation of deep-seismic transects across the continent-ocean boundary (Sayers *et al*., in press), indicate that initial spreading may not have occurred until the Santonian (83 Ma). Subsidence studies along the southern Australian margin, as well as the conjugate pattern of seafloor magnetic anomalies off Australia and Antarctica show that seafloor spreading propagated eastward from the GAB towards Tasmania (Mutter *et al*., 1985). It is believed that seafloor spreading began in the Late Cretaceous at a very slow rate (< 1 cm/yr, full rate), continuing into the Early Eocene, but increasing somewhat to a slow rate (~2 cm/yr) from then into the Middle Eocene (Cande & Mutter, 1982). Spreading accelerated dramatically (to 4-5 cm/yr) in the Middle Eocene (ca. chron 18, 45 Ma; Weissel & Hayes, 1972; Cande & Mutter, 1982; Veevers *et al*., 1991). This event coincided with a major reorganisation of plate boundaries in the Indian Ocean (Royer, 1992). Though breakup probably initiated in the Maastrictian-Paleocene (Hill *et al.,* 1997c), we believe that no major spreading occurred in the Otway Basin and off west Tasmania until the Middle Eocene.

Rifting along the eastern margin of Australia, Tasmania and the STR, probably began in the mid Cretaceous. The opening of the Tasman Sea, between Lord Howe Rise/Challenger Plateau and Australia, started in the Late Cretaceous (chron 33; ~80 Ma), along an ENE-WSW direction (Hayes & Ringis, 1973; Weissel & Hayes, 1977; Shaw, 1989). Seafloor spreading propagated from south to north along the eastern Australian margin. The oldest magnetic anomalies (chron 33) identified in the Tasman Sea are located just east of the East Tasman Plateau. Further south, lack of magnetic anomaly profiles prevents any exact dating of the oceanic crust lying east of the STR. However, plate reconstructions at chron 33 bring the western slopes of Challenger Plateau next to the STR (Molnar *et al*., 1975). Seafloor spreading in the Tasman Sea stopped abruptly in the Early Eocene (chron 24/23, 55-50 Ma), probably when the Australian-Antarctic and Pacific-Antarctic spreading systems connected south of the STR.

Because of the change in trend of the southern Australian margin, the geodynamic context changes progressively from purely extensional in the Great Australian Bight, to transtensive in the Otway Basin, and then purely strike-slip on the western Tasmanian margin (Willcox *et al.*, 1989). The abrupt termination of the major basins and the development in "en echelon" basins along the continental shelf on the western Tasmanian margin can be explained by the existence of major transform fault zones.

Southern NSW, Gippsland and east Tasmanian margins

The Gippsland Basin developed as a transtensional rift ~140 Ma during fragmentation of the East Gondwana supercontinent (Willcox *et al.*, 1992), filling with mainly volcanogenic sediment sourced from an Early Cretaceous magmatic rift system, the Whitsunday Volcanic Province (Veevers, 2000), which lay to just to the east and extended northward. The southeast Australian region was uplifted at ~100 Ma as a prelude to continental breakup about 20 million years later, when the Lord Howe Rise separated from eastern Australia and Tasmania, along an ENE-WSW direction, thereby creating the Tasman Sea. Opening began adjacent to the East Tasman Plateau at ~83 Ma and ended at 55-50 Ma (Royer and Rollet, 1997; Gaina *et al.*, 1998).

Basement on this part of the Australian margin comprises Palaeozoic rocks of the Lachlan Foldbelt. In northeast Tasmania basement rocks comprise folded quartzwacke turbidites of the Mathinna Group (Ordovician to Early Devonian), which have been intruded by Devonian granites that outcrop extensively in the area. The Late Carboniferous-Triassic Tasmania Basin, up to several kilometres thick, covers much of southeast Tasmania and probably extends offshore. The basin has been heavily intruded by Jurassic dolerites. These have been exhumed by erosion and, like the granites to the north, now form extensive outcrop. Tertiary volcanics occur throughout east Tasmania. The basalts have an age range of 58-16 Ma (Sutherland, 1989). The East Tasman Plateau (ETP) is a continental block (Exon *et al.*, 1997a) that subsided below sea level during margin development. Dredging has recovered metasediments and Neoproterozoic orthogneiss. The ETP generally lies at 2000-3000 m depth, but is topped by a late Eocene basaltic volcano, Cascade Seamount (Quilty, 1997), that rises to 650 m below sea level and is thought to be part of the Balleny hot-spot trace (Lanyon *et al.*, 1993).

The Gippsland Basin has been Australia’s major oil-producing province for 30 years. It contains up to 14 km of Late Jurassic-Cainozoic section in an ESE-trending depocentre (Willcox *et al.*, 1992; Megallaa, 1993). The sediments comprise the Late Jurassic-Early Cretaceous Strzelecki Group (non-marine, southern margin syn-rift), Late Cretaceous Golden Beach Group (non-marine, Tasman syn-rift), Late Cretaceous-Eocene Latrobe Group (mainly non-marine, sag phase, and the main petroleum producer), and the Oligocene and younger Seaspray Group (marine carbonates). Faulting and erosion have exposed much of the basin sequence in the Bass Canyon complex on the continental margin.

Good control of the seismic stratigraphy is available in the Gippsland Basin from the many wells, at least on the shelf and down to the upper Latrobe Group. Farther north, off NSW and farther south, off east Tasmania, no offshore drilling control exists on the margin. Some control on the deepwater seismic stratigraphy comes from DSDP Site 283 about 250 km east of the ETP (Kennett *et al.*, 1975). It was drilled in 4756 m of water to a depth of 592 m and bottomed in altered basalt. The sediments recovered were all abyssal clays. The section was

Early Paleocene to Late Eocene, apart from the top 13 m which was Late Miocene-Pleistocene.

The continental shelf off southern NSW and east Tasmania is 20-40 km wide. It is largely non-depositional at present. Surface sediments comprise quartz sands (mainly nearshore), muddy quartzose/calcareous sediments, and bryozoan sands and gravels (Davies, 1979; Jones & Davies, 1983). To the west, grain size decreases towards the centre of Bass Strait and carbonate muds predominate here (Blom & Alsop, 1988). Beyond the shelf edge, the continental slope falls relatively steeply to abyssal depths at 3-10°. Off southeast Tasmania, the continental slope falls to the East Tasman Saddle (between the Tasmanian mainland and the ETP), which lies at a depth of 3200 m and is located about 60 km out from the shelf edge. Off the southern NSW and northeast coasts of Tasmania, the continental slope is mainly steep and rugged and drops down to the relatively flat surface of the Tasman Sea abyssal plain at depths of ~4200-4600 m. Off Tasmania, the continental slope is about 80 km wide in the south, narrows to about 40 km in the north off southern Flinders Island, and then broadens again towards the Gippsland Basin.

The southern NSW and east Tasmanian margins formed by the stepping down seaward of large basement blocks (Colwell *et al.*, 1993; Hill *et al.*, 1998). The fault zone is 60-110 km wide, with one of the narrower sections being off northeast Tasmania. The faults appear to be largely high-angle. The continent-ocean boundary (COB) underlies the rise and generally coincides with the 4200 m isobath off Tasmania, and probably the 4600 m isobath off southern NSW. Adjacent Campanian oceanic basement lies beneath the abyssal plain at a depth of 7.5-8.0 seconds twt (two-way time, see Glossary of Technical Terms), and is overlain by 2.0-2.5 km of relatively flat-lying sediments that onlap the continental basement blocks to the west. In the deepwater Gippsland Basin and south to about 40° 30'S, the upper continental slope is underlain by a complex set of rift basins that are controlled by conjugate WNW faults (parallel to faults within the Gippsland Deep and also Bass Canyon) and NNE faults (margin-parallel). A narrow N-S trending rift graben, well-defined in satellite gravity images, is located beneath the upper slope off Freycinet Peninsula. Structural trends on the basement highs to the east are NW-NNW (rift direction) and NE-ENE (transfer direction). Similar narrow graben are present beneath the continental slope off southern NSW (Colwell *et al.,* 1993).

The ETP is dominated by Eocene hot-spot volcanic intrusions and constructions (Cascade Seamount and a 2200-m high seamount on its northeast margin). Volcanics occur in the post mid-Eocene basinal section, suggesting that minor further volcanism continued after the hot-spot activity. The continental basement surface beneath the ETP appears to have been planated (?sub-aerial erosion), then tilted and faulted as the margin subsided. Up to 2 km of post-rift section is present in the East Tasman Saddle. The underlying synrift section appears to contain considerable volcanics (Hill *et al.*, 1998).

The shelf and upper slope along the southern NSW and east Tasmanian margins are underlain by a wedge of Late Oligocene-Quaternary seaward-prograding carbonate sediments 500-1000 m thick (Colwell *et al.,* 1993; Hill *et al.,* 1998).

Southern Tasmanian margin and the South Tasman Rise

The South Tasman Rise (STR), located south of Tasmania, is a large submarine plateau of continental origin with its culmination at roughly 750 m. It is surrounded on three sides by Late Cretaceous and Palaeogene oceanic crust. Seismic, swath-bathymetry and magnetic data were collected in 1994 during AGSO's survey aboard R/V *L'Atalante* (Exon *et al.*, 1994), west of Tasmania, the STR and ETP. Dredge and core samples were taken by AGSO in 1995 with the R/V *Rig Seismic* (Exon *et al.*, 1995). These data, together with new satellite gravity data, have allowed a revised tectonic review and a synthesis of the geology south of Tasmania (Exon *et al.*, 1997b).

The initial NW-SE extensional direction between Australia and Antarctica clearly implies that the STR, south of Tasmania, was not originally at its present location relative to Australia, as it would have obstructed the Antarctic plate. Linked to Tasmania by thinned continental crust, the STR is composed of two distinct terranes (Royer & Rollet, 1997). A western domain, limited to the east by a transform margin along the Tasman Fracture Zone and to the east by a 170°-oriented boundary at 146°E, was initially attached to Antarctica. The western terrane rifted away from Antarctica in the Late Paleocene/Early Eocene and underwent severe wrench deformations as the Antarctic plate moved southward relative to the Australian plate. Shear motion continued to shape the Tasman Fracture Zone transform margin until the Early Miocene (chron 6B, 23 Ma) after which the Southeast Indian Ridge axis cleared the western edge of the South Tasman Rise. An eastern domain, limited to the west by a boundary at 146°E, rifted away from Tasmania and the East Tasman Plateau.

The STR was affected by NW-SE strike-slip motion in the Late Cretaceous, and N-S extension and strike-slip motion in the Tertiary. Basins on the STR are fault-controlled, and are believed to contain Late Cretaceous to Early Oligocene detrital non-marine and shallow-marine sedimentary rocks, and Late Oligocene and younger bathyal to pelagic chalk and ooze. The basins contain fault structures, and are prospective for petroleum in the long term, but only the central area is in water depths that are presently favourable to drilling.

West Tasmanian margin

The continental margin off west Tasmania is about 200 km wide and covers an area of about 100,000 km². The continental shelf is about 30 km wide in the south and more than 55 km wide in the north. Much of the margin has a thick cover of late Mesozoic and Cainozoic sediments, forming the Sorell Basin (Willcox *et al.*, 1989; Hill *et al.*, 1997c) and the contiguous southernmost part of the Otway Basin. There are four depocentres of the Sorell Basin beneath the shelf: the King Island, Sandy Cape, Strahan and Port Davey Sub-basins (Moore *et al.*, 1992).

The margin comprises a shallow continental shelf, a continental slope with variable relief due to canyon development and uplifted fault blocks, and an abyssal plain at about 5000 m depth underlain by early Tertiary oceanic basement. Cretaceous depocentres on the shelf and upper slope are typically of half-graben or v-shaped geometry, deep and narrow, and appear to be of transtensional origin. These depocentres are located within relatively shallow Precambrian to early Palaeozoic basement and contain 2-4 s twt (~2.0-5.5 km) of section. Sediment thickness beneath the continental slope is generally 2-5 s twt. The lower continental slope is characterised by a highly-faulted zone of uplifted basement blocks. This zone, about 60 km wide, commonly contains two main ridges 30-40 km apart. Seismic profiles across this structural high generally show a profusion of diffractions, particularly at depth, suggesting considerable igneous intrusion. A strong, angular mid-Cretaceous (?Cenomanian) unconformity in the Sorell Basin is believed to coincide with uplift of the Otway Ranges and the eastern Otway Basin generally. The Late Cretaceous and older section has undergone significant deformation, mainly with normal faulting, ranging from near-vertical to low-angle listric and generally dipping seaward, but reverse faulting and gentle to moderate folding are also evident. Though most faults extend only to the top of the Cretaceous, minor faulting extends into the Palaeogene in some areas, particularly the nearshore part of the margin (including the Sorell Fault Zone parallel to and near the coast) and adjacent to the Tasman Fracture Zone in the south. Early Tertiary oceanic basement outboard of the high has a comparatively thin sediment cover of mainly less than 1 km, and is exposed on the seafloor in places.

Petroleum exploration in the region dates back to the 1960s, during which time a broad, sparse seismic data set was acquired. More recent exploration activity (early 1980s, Amoco; early 1990s, Maxus) has been concentrated in the Strahan Sub-basin off the central west coast of Tasmania. Only four exploration wells have been drilled on the margin, two of which (Clam-1 and Cape Sorell-1) are in the Sorell Basin. Petroleum has been generated in the Sorell Basin, at least in the Strahan and Sandy Cape Sub-basins. Indications include live oil in Cape Sorell-1, high concentrations of thermogenic hydrocarbons recorded in geochemical surveys (Whiticar *et al*., 1985; Exon *et al*., 1989), and direct hydrocarbon indicators (flat-spots) in Strahan Sub-basin seismic sections (Conolly & Galloway, 1995).

The only known onshore part of the Sorell Basin occurs as a 500-m thick extension known as the Macquarie Harbour Graben. The sediments, which outcrop extensively on the northern shore of Macquarie Harbour, consist of early Eocene mudstones and sandstones with thin coal seams, overlain by Plio-Pleistocene gravels and sands. The Eocene beds are interpreted as having been deposited in marginal marine and sandy braidplain environments.

Geological sampling of the seafloor off west Tasmanian, mainly by dredge and corer, has provided invaluable geological information and control on seismic interpretation. Sampling cruises conducted in the area include, (i) RV *Sonne* Survey SO36C of 1985 over the west Tasmanian margin and South Tasman Rise, (ii) BMR Survey 67 of 1987 in the Otway Basin and over the far northern west Tasmanian margin, (iii) BMR Survey 78 of 1988 over the west Tasmanian margin, and (iv) AGSO Survey 147 of 1995 over the west Tasmanian margin, South Tasman Rise and East Tasman Plateau.

One of the most important results of the sampling programs has been the discovery of Late Cretaceous shallow-marine sediments exposed on fault blocks on the lower continental slope, in water depths of about 4000-4500 m. This implies substantial subsidence and crustal thinning since these sediments were deposited. In addition, the recovery of Paleocene and early-mid Eocene marginal marine sediments on the mid- and lower slope suggests that full open-marine conditions were not established until the late Eocene. These conditions resulted from post-breakup thermal subsidence of the margin about a hingeline at the present coast, combined with a reduction in the sediment supply.

In summary, the Sorell Basin developed in the latest Jurassic to earliest Cretaceous in a transtensional tectonic setting within the Southern Rift System (Willcox & Stagg, 1990), the zone of initial extension between the Australian and Antarctic cratons. Rifting was followed in the Aptian-Albian by low-energy sag-fill or late-rift deposition. Uplift and erosion in the Cenomanian coincided with the onset of Tasman Basin rifting to the east. Marine deposition first commenced in the Late Cretaceous, and occurred in elongate downwarps (such as the southeast continuation of the Eastern Voluta Trough) and in narrow, fault-controlled depocentres on the upper margin. The last major wrenching episode was in the Maastrichtian-Paleocene, at the time of breakup (Hill *et al*., 1997c). Thick Palaeogene prograding sequences were deposited, first in the north and then farther south, as the margin collapsed and spreading moved relatively south. Minor wrenching, mainly by reactivation of older structures, continued into the Palaeogene due to shearing as the Australian and Antarctic continental plates separated in a N-S direction. The Palaeogene wrench reactivation was confined mainly to the upper margin (including the Sorell Fault Zone) and far south of the Sorell Basin, and was associated with transform movement along the Tasman Fracture Zone and its extension to the north.

Otway margin

The Otway Basin comprises two rifts that overlap temporarily and spatially (Moore *et al.*, 2000). The late Jurassic to mid Cretaceous rift generally trends east-west beneath onshore and nearshore areas, and formed during the early stages of extension between Australia and Antarctica. The mid Cretaceous to early Cenozoic rift trends northwest-southeast to north-south beneath the continental slope and rise, and formed during the later stages of Australia-Antarctica rifting in an overall sinistral transtensional setting. No oceanic crust older than Middle Eocene has been identified adjacent to the Otway Basin (Royer & Rollet, 1997). This may be the case for the whole margin from south of Kangaroo Island to south of the South Tasman Rise. This would imply that the Otway Basin and west Tasmanian margin was a strike-slip or transtensional plate boundary for much of the Late Cretaceous to Early Eocene and that large-scale emplacement of oceanic crust did not commence until the onset of fast seafloor spreading. The Late Cretaceous Otway Basin would have had a conjugate margin either in Antarctica (probably George V Coast) and possibly also partly in the western sector of the South Tasman Rise (Royer & Rollet, 1997).

The continental slope sector of the Otway Basin contains the main part of the sediment volume of the basin (~8 km in thickness). This basin can be subdivided into three sub-basin elements from NW to SE, the Beachport, Morum and Nelson Sub-basins, separated by north-south trending structural highs (Moore *et al.*, 2000). The structural style and relative thickness of sedimentary sequences varies widely between the basin elements, reflecting the complexities of a mixed rifted/strike-slip margin setting.

Key aspects of the stratigraphy of the Otway Basin have been described recently (eg., Kopsen & Scholefield, 1990; Partridge, 1997). A review of the palaeontology of 36 wells in two states and the re-sampling and re-evaluation of the type sections of the early part of the Late Cretaceous in Victorian wells, resulted in significant changes in dating (Partridge, 1997). Broadly, the stratigraphy can be divided onto three phases : (1) the first rift phase Otway Supergroup (Berriasian to Albian), (2) the second rift phase Shipwreck and Sherbrook Groups (Turonian to Maastrichian), and (3) the post rift transgressive/regressive clastic cycles of the Wangerrip Group (latest Maastrichtian to early Middle Eocene), and carbonates and siliciclastics of the Eocene to Recent Nirranda and Heytesbury Groups. The southeastern end of the Otway Basin is continuous with the Sorell Basin on the western margin of Tasmania.

B2. AUSTREA SWATH MAPPING AND UNDERWAY GEOPHYSICS RESULTS

Parts of this section are drawn from Hill *et al.* (2000).

Southern NSW, Gippsland and northeast Tasmanian margins

The continental margin off southern NSW and northern Gippsland (Colwell *et al.*, 1993) is relatively narrow, only 50-70 km wide. The margin broadens out to a large embayment off

Gippsland, the Bass Canyon complex (Hill *et al.*, 1998), which is about 150 km across. The continental slope generally has a slope of 4.5°-10° (between the 1000-4000 m isobaths). The adjacent Tasman Basin is 4200-4850 m deep, and flat-lying - the result of sediment infilling over the 80 million years since the basin opened.

The entire margin is steep, often rugged, and cut by canyons **(Figure B1)**. A ?late Tertiary sediment wedge extends from the shelf to water depths of mainly 2000-3000 m. The lower continental slope is generally less sedimented and more rugged, exposing or at least reflecting, much of the margin's underlying rift structures.

Apart from the extraordinary topography associated with the Bass Canyon **(Figure B2)**, a change from north to south in the geomorphological character of the margin is evident. In the north (from off Newcastle to just south of Montague Island (at ~36° 15'S), the upper continental slope is relatively smooth and sedimented, with a number of canyons 200-600 m deep running either downslope (incising sediment cover), or with a N-S or E-W orientation, the latter probably controlled by rift or transfer faults. Many of the canyons are 1.5-4 km wide, with some as wide as 8 km - such as the ~N-S canyon off Batemans Bay. Three 200 m local highs on the slope off Newcastle may be volcanic cones or pinnacles left by erosion.

The southern part of the margin, from near Montague Island to Gabo Island, shows a more complex geomorphology **(Figure B1)**. The sediment wedge on the upper slope is highly and extensively dissected by gullies, V-shaped valleys and small canyons, typically 1-2 km wide and 50-200 m deep. Erosion may have been accentuated by the relatively steep slope at the toe of the wedge, ~17°. The seismic profiles **(Figure B3)** show up to 700 m of eroded Tertiary section above a strong unconformity. The lower slope (~2500-4500 m depth) also shows unusual structural complexity. The seabed is rugged, with wide canyons and scarps hundreds of metres high. It is probably largely basement outcrop, though the seismic suggests up to 1.5 s twt of rift sedimentary section in places on the lower slope. In the north, off Montague Island, large seamounts and a prominent N-S ridge (all ~600-800 m relief) were mapped on the mid-lower slope. Dredging **(Figure B1)** suggests that these could be part of the igneous Mt Dromedary complex, intruded during rifting of the margin at ~100 Ma (Hubble *et al.,* 1992; Colwell *et al.,* 1993). In the far south (~37° 43'S), a larger, 20-km long and 800-m high ridge, also oriented N-S, was mapped on the lower slope. This could also be of rift-related volcanics, but may be a more conventional rift block. Magnetic anomalies, some up to +200-300 nT, recorded along this southern section of the margin may be evidence of rift intrusions or older magnetic basement.

The mapping done in the deepwater Gippsland area **(Figure B2)** is an extension of AGSO's survey by *Melville* in 1997 (Hill *et al.*, 1998; Exon *et al.*, 1999) during which the main Bass Canyon was completely mapped. AUSTREA-1 considerably extended the survey coverage to the north by multiple lines, and added a single swath to the existing coverage in the west and southwest.

In the north, the head of Everard Canyon (Conolly, 1968; known as the 'Big Horseshoe' in the fishing industry) and its course to the south were mapped in detail. This canyon, which runs roughly N-S, is 4 km wide and has cut a sinuous path up to 600 m deep into the Tertiary sediment wedge north of Bass Canyon. Its confluence with the Bass Canyon is farther west than mapped by Conolly (1968). Farther west, the canyon head, known as 'Little Horseshoe', is about 400 m deep. One of the deepest gorges in the Bass Canyon complex is located at the extreme western end of the complex **(Figure B2)**, where 'West Canyon' has cut into the margin of the Tertiary wedge. The gorge here is 1000 m deep and lies at the junction of three deep canyon arms that come from the south/southwest. The outer slope of the Tertiary wedge between this area and the 'Little Horseshoe' to the north is quite steep, ~16°, and as is the case on the far southern NSW margin, the slope is strongly eroded by downslope runnels. The upper continental slope on the southwest of the Bass Canyon complex is cut by several other canyons, 100-400 m deep, including 'Southwest Canyon" and 'South Canyon'. A little farther south is Flinders Canyon (Conolly, 1968), which runs southeast. 'South Canyon' has cut a deep gorge below the shelf edge, and it appears that before this gorge was cut, the upper part of this canyon linked into Flinders Canyon, transporting sediment from the shelf to the southeast rather than to the east/northeast as in the more recent past.

The seismic profiles north of Bass Canyon **(Figure B4)** show up to 1.0 s twt (~1.0 km) of mainly Neogene section (carbonates of the Seaspray Group), above a further 1.2 s twt of Latrobe Group and older section in places. Total visible section is thus 2.2 s twt, about 2.5 km. The Neogene section is well-stratified but commonly erosionally truncated and cut by canyons, and marked by a strong unconformity at its base. The section shows extensive evidence of cut and fill, indicating that erosion and canyon development was a common occurrence at intervals throughout the Neogene as the carbonate wedge prograded outward. A large magnetic anomaly (~+300 nT) was recorded on the upper slope to the north of the middle of Bass Canyon. The seismic profiles here show a highly disturbed deep section, possibly intruded volcanics of Oligocene-early Miocene age. A large high-standing block, 15 km across and on the mid continental slope at 38° 15'S 150° 11'E, is composed of basement rocks. Its steep, Tasman-facing margin strikes NNE and is line with a prominent scarp farther south off the northern Gippsland margin, in about 3500 m water depth. This structure is likely to be a major normal fault created during Tasman rifting.

Northeast of Flinders Island, Flinders Canyon opens out into a broad embayment, into which a number of smaller canyons also feed. A large WNW-trending graben was mapped in this area by Hill *et al.* (1998), and the AUSTREA-1 seismic profiles confirm its presence. This structure contains at least 1.8 s twt (~2.0 km) of sediments. However, disturbed section in the middle of the graben (where crossed by the AUSTREA-1 lines) and a coincident 250 nT magnetic anomaly indicate volcanics, probably Oligocene-early Miocene, as interpreted north of Bass Canyon. Sailfish-1 well drilled on the shelf just to the west, bottomed in mid Tertiary volcanics, which may be part of the same suite.

The northeast Tasmanian margin (from off Flinders Island to off Freycinet Peninsula) is about 36-90 km wide from the shelf edge to the base of the continental slope, which roughly coincides with the 4000 m isobath. The narrowest section of the margin lies opposite Banks Strait, the main passage between the northeast tip of the Tasmanian mainland and Cape Barren Island. Here the mean slope (between the 1000 m and 4000 m isobaths) is 5.8°. The AUSTREA-1 transit line off northeast Tasmania was run on the upper continental slope, between water depths of 600 m to 2000 m, with the main intention of extending the swath coverage achieved during AGSO's 1997 *Melville* survey upslope.

Of special interest was the St Helens Hill and St Patricks orange roughy deepsea fishery (Kloser *et al.,* 1996), swath-mapped in 1997 and further investigated by CSIRO on *Southern Surveyor* in 1999 (Hill, 1999). AUSTREA-1 mapped North Hill, located northeast of St Helens Hill, in detail for the first time. This 300-m high volcanic cone, with its summit 900 m deep, is a significant assembly location for orange roughy aggregations, and hence an important fishing ground. Though no other large cones were mapped, the backscatter imagery suggests further scattered volcanic outcrop (flows etc) in the area of North Hill, including about 12 km to the north. A series of magnetic anomalies, to 200 nT, were recorded. There are also indications of extensive volcanic seabed terrain farther north on the steep, rugged and strongly canyoned continental slope east of Banks Strait, and this is supported by the 1997 swath data collected farther downslope. Canyon development here may have been enhanced by the strong currents that are known to flow through Banks Strait, and this passage may also be a major river drainage outlet during periods of sea-level lowstand.

The seismic profiles off northeast Tasmania show a strongly eroded and canyoned surface sequence which is up to 500 m thick, well-stratified and presumed to be Neogene carbonate progrades. A depocentre off northern Cape Barren Island (Hill *et al.*, 1998) coincides with a northwest-trending ?fault-controlled embayment and canyon 250-m deep, and contains at least 1.5 s twt of section. Off Freycinet Peninsula, where Hill *et al.* (1998) delineated a N-S-trending rift graben, the AUSTREA-1 profile, an axial strike line, indicated at least 1.8 s twt of graben fill **(Figure B5)**. An eroded Neogene sequence 0-400 m thick unconformably overlies a thick deformed sequence that may be Late Cretaceous in age.

East Tasman Plateau and the South Tasman Rise

The areas mapped off southeast Tasmania, including the STR and East Tasman Plateau, are of high relief with a number of large hot-spot volcanoes rising more than 1000 m above the sea floor **(Figure B6)**. A preliminary account of the AUSTREA-2 results in this area, in terms of morphology, is given in Bernardel *et al.* (in press).

On the continental slope off southeast Tasmania, the new swath coverage (AUSTREA-1 & 2) with earlier Sojourn7 data reveal a central region dominated by canyons, and a mid-slope terrace to the north and south. Several of the canyons commence at the shelf break in about 200 m of water, and are deeply incised to water depths of about 1500 m on the slope. A narrow mid-slope terrace at 43° 20'S represents a more gradual slope gradient from 1200 m to 1700 m depth. To the north, a second, wider mid-slope terrace extends from about 41° 30'S to 42° 20'S, and is characterised by a decrease in slope gradient from about 1300 m to 2000 m.

The newly mapped area includes Cascade Seamount **(Figure B7)** centred at 43° 55'S 150° 30'E, and the broad L'Atalante Depression **(Figure B6)** which lies at abyssal depths (~4000 m) between the East Tasman Plateau (ETP) and South Tasman Rise (STR). The western side of the ETP is marked by an N-S trending escarpment along 149° 25'E, and a seamount cluster at the bottom of the saddle between the ETP and Tasmania. To the southwest, the STR slope into the L'Atalante Depression is gradual and relatively featureless. The slope off Tasmania, into the L'Atalante Depression, is marked by several minor canyons, small ?volcanic cones, and a moderate E-W trending escarpment at about latitude 44° 45'S.

Cascade Seamount **(Figure B7)** is a large seamount, slightly elongate in a N-S direction, that rises from the ETP at about 2500 m to a summit at about 650 m below sea level. The summit area is a broad dome, suggesting sub-aerial exposure and subsequent erosional planation in the past. Its flanks are covered by many small cones and minor ridges. The lower flank of the seamount extends to the southeast as a large lobe.

The AUSTREA-2 survey involved filling in gaps in TASMANTE swath coverage on the summit area of the STR, as well as several passes on its eastern flank during which two major seamounts were completely mapped. The fill-in survey on the summit area of the STR indicated an average depth of ~1000 m, with several minor buildups peaking within 750 m of the sea surface. To the east, the mapped flank has a moderate to gentle gradient and is incised by several SW-NE trending canyons. The two seamounts, centred at about 46° 35'S 149°

30’E (top at 2030 m) and 46° 50’S 149° 30’E (top at 1600 m), are joined by a saddle. Both summits are rounded, suggesting sub-aerial exposure in the past. Their square-shaped outlines suggest structural control during their genesis.

Mapping of the southern STR involved a single swath along the base of its eastern flank to map the foot-of-slope (FoS) for UNCLOS boundary definition purposes. Several seamounts were mapped, including a large one, 1830 m deep and centred at approximately 47° 20’S 150° 40’E. This seamount has a flat top and is star-shaped in plan view, suggesting early sub-aerial exposure and structural control, respectively.

Southern Tasmanian margin

The continental slope off southern Tasmania has a rough and varied terrain. Some large E-W trending ridges lie near its base, and a number of canyons incise its western half, but most spectacular are the numerous (> 100) volcanic cones, some 500-600 m high, that rise above its surface **(Figure B8)**. The shallower cones are deep-sea trawl fishing grounds for orange roughy and this area forms an important component of the South East Fishery. The recently declared Tasmanian Seamounts MPA lies on the mid slope **(Figures B8 & B9)**. The 1994 TASMANTE swath survey mapped almost all the area covered by the MPA, except a very narrow section along its eastern boundary. This, and an adjacent area to the east, was fully mapped by AUSTREA-1.

The following account presents the AUSTREA survey results, with emphasis on the seismic, for the southern Tasmanian margin.

Previous seismic profiling along the southeast and southern margins of Tasmania is sparse and there is no well control. This section is characterised by the preservation of thick sedimentary successions (~2 s twt) beneath the mid-slope. The rift basin off Freycinet Peninsula/Schouten Island occupies a mid-slope terrace at 1-2.3 km depth, with a gentle east to southeast gradient. A large magnetic anomaly - 400 nT in amplitude - occurs over this basin. Width at half height is 8 km, indicating a source depth of more than several km.

Further south, the seismic profile follows the mid-slope, and the sedimentary package described above onlaps a topographic and structural high, which is seismically amorphous or with sparse discontinuous reflectors - this is either basement or an older sediment package. The latter is suggested by the absence of significant positive gravity response.

Southeast of Bruny Island, the section **(Figure B10)** consists mainly of a folded and faulted succession, with a flat-lying veneer, 0-0.3 s twt thick, unconformably overlying it. These successions occupy a well-developed terrace at 1300-1500 m depth, with an abrupt northern and eastern edge rising 400 m above the lower slope. The folds are parallel in style and probably tectonic rather than compactional, and have a wavelength (apparent) of ~8 km. Dips on fold limbs are up to about 15 degrees (unmigrated, apparent). The base of this succession is not resolved, but lies at least 1.6 s twt below the sea floor. The flat-lying veneer has been eroded at the present sea floor, and has been removed completely (exposing the flat-lying unconformity surface) over large areas. Steep ?normal faults appear to displace the veneer and its basal unconformity as well as the folded sequence between. A 200 nT magnetic spike with a width at half height of 8 km suggests depth to magnetic basement of at least several km.

Correlation of the folded succession **(Figure B10)** is problematic. Possibilities include the Late Carboniferous to Triassic Tasmania Basin succession (Parmeener Supergroup), lower

Palaeozoic Wurawina Supergroup and a Cretaceous-Palaeogene rift succession. The structural style is dissimilar to the first two alternatives, and there is no indication on the magnetic profile of the presence of thick Jurassic dolerite sills which are ubiquitous in the onshore Tasmania Basin succession. A Cretaceous-Palaeogene rift succession is therefore considered most likely. This is supported by the coring of late Campanian sediments on the continental slope off Storm Bay (Harris *et al.,* 1999).

The AUSTREA-1 seismic profiles in the area of the MPA show sparse, discontinuous packages of gently dipping reflectors, presumably representing sediments of unknown age, down to at least 2.5 s twt in places. This is mostly unconformably overlain by a cover sequence with continuous flat-lying reflectors, 0.1-0.3 s thick. The continuity of this succession is interrupted by numerous abrupt topographic highs (volcanic cones), up to several hundred metres high and several km wide at the base. Reflections are obscured beneath the volcanoes, making it difficult to determine the age relationships of the sediments and volcanics. However, sediments appear ponded on the upslope sides of the volcanoes in many places, suggesting the upper sediment package is at least in part younger than the volcanoes.

The seismic profiles directly south of Tasmania (south of South Cape) are oriented along the slope in water depths of 500-1000 m, and show a flat-lying sedimentary succession up to 0.6 s twt thick, with strong, parallel reflectors on a prominent unconformity. This sequence is eroded at the present seafloor by canyons that almost reach the unconformity in places. In places below the unconformity there are less regular, sub-horizontal reflectors, and these coincide with gravimetrically low and magnetically quiet intervals, suggesting at least one narrow basin extending more than 0.6 s below the unconformity, with its true extent obscured by the seafloor multiple. Elsewhere the along-slope traverse is magnetically spiky and gravimetrically high, supporting an interpretation of shallow basement. The cover sequence becomes thinner to the west, at least in part because of erosion, and underlying basement is exposed in places.

Only a few of the volcanoes are manifested as significant magnetic anomalies, the largest volcano-coincident anomaly being a 50 nT spike.

West Tasmanian margin

Off southwest Tasmania, the AUSTREA-1 lines comprised two lines that run along the shelf edge or just seaward, continuing the TASMANTE coverage into shallower water. The survey was expanded off northwest Tasmania, where no swath coverage existed. Off the central and northeast western margin of Tasmania, the swath data revealed remarkable systems of downslope canyons, extending from the shelf edge to abyssal depths of the lower continental slope **(Figure B11)**. The canyons have been cut into a sedimented slope, are mainly about 100 m deep and many are more than 60 km long. The canyon systems appear to diverge from the major rivers flowing into the sea off west Tasmania. During periods of low sea-level during the Pleistocene, they would have flowed across the exposed continental shelf, perhaps partly cutting into it and eroding it. The sediment load dumped into the mouths of the canyons would have produced further canyon downcutting during sediment transport downslope.

Seismic results

Offshore of western Tasmania, a number of regional seismic lines have been recently interpreted by Hill *et al.* (1997c) and Moore *et al.* (1992). A close seismic grid has been shot in the Strahan Sub-basin by Maxus (1991) and Amoco. Two wells have been drilled in the Sorell Basin.

On the upper continental slope south of Maatsuyker Island, the surficial sediment package has been removed by erosion, and with exposures of probable basement. A planated volcano (guyot) rises ~500 m above the basement surface, to about 450 m below sea level **(Figure B12)**. This is relatively large in comparison to the other volcanic cones surveyed, but has little or no magnetic response. Its interior is seismically featureless, similar to the underlying 'basement' (which may likewise consist of volcanics). Immediately north of the guyot, the sedimentary cover reappears, 0.2 s thick, with a mostly strongly reflective basal unconformity and containing strong flat-lying parallel to wavy reflectors. The sediment surface has been eroded by small canyons. About 10 km northwest, gravity begins to drop steeply and magnetics becomes quiet, and discontinuous gently north-dipping reflectors below the prominent shallow unconformity probably represent fill of the Port Davey Sub-basin **(Figure B12)**. Farther north, a thicker package of more coherent reflectors in the Port Davey Sub-basin is at least 1.6 s twt thick (obscured by seafloor multiple below this depth). A shallow prominent reflector (0.3-0.4 s twt below the seafloor) can be picked, probably corresponding to the unconformity observed in the data directly south of Tasmania. Correlation with profile 8 of Hill *et al.* (1997c) at 43° 28'S, indicates this surface corresponds to their Oligocene unconformity.

At the northern edge of the Port Davey Sub-basin, the sediments dip southward away from the steep flank of a structural high - possibly in part faulted - coinciding with a sharp northward rise in gravity. The basement high between the Port Davey and Strahan Sub-basins is marked by a broad gravity high and a number of strong magnetic anomalies, the largest 400 nT in amplitude and ~2 km wide at half height. The sequence with the prominent shallow unconformity in the Port Davey Sub-basin continues over this high, where it is up to 0.4 s twt thick with the basal unconformity possibly resting directly on basement. Numerous canyons erode almost to this unconformity. The Strahan Sub-basin is seen in the geophysical profiles as a large gravity low, with quiet magnetics, and at least 1.8 s twt of sediment. In the southern part of the sub-basin, traversed in relatively deep water, the shallow unconformity cannot be differentiated, but in the northern part, shot at the top of the slope, there is a strong reflector at 0.6 to 0.7 s twt which probably correlates with the interpreted Oligocene unconformity of Hill *et al.*'s (1997) profiles 6 and 7. The reflectors within the Oligocene and younger succession are wavy and channelled-looking in this sector. A gravity high and a 100 nT magnetic anomaly probably reflect a basement high separating the Strahan and Sandy Cape Sub-basins, but this is not seen on seismic because of the shallow water depth and consequent shallow seafloor multiple.

In deeper water north of Granville Harbour, at least 2.6 s twt of sediment is evident in the Sandy Cape Sub-basin and contiguous southern Otway Basin. The inferred Oligocene to Recent sequence rapidly thins downslope and northward and pinches out at the seafloor at the southern end of the Sandy Cape Sub-basin. In the Sandy Cape Sub-basin, at least as far north as 40°S, several sequences can be distinguished, and probably correspond to the Cretaceous, Paleocene, Eocene, and largely Neogene packages of Hill *et al.* (1997c). The gently folded and faulted ?Cretaceous succession is generally characterised by less continuous, weaker reflectors than the younger sediments. Off Temma Harbour, the ?Cretaceous and ?Paleocene are gently draped over a seismically amorphous possible basement high with a strongly reflective top, 1-1.2 s twt below seafloor. Close-spaced (2 km) tensional south-dipping faulting associated with northerly dip of rotated fault blocks is seen in the ?Cretaceous in the profiles off Cape Grim (nothwest tip of Tasmania), while an angular unconformity at the base of the ?Paleocene is seen over much of the sub-basin. The ?Palaeogene succession is mainly 0.2-0.4 s twt thick, and characterised by strong, parallel reflectors. The upper, largely Neogene, succession, 0.2-0.4 s twt thick, has a strongly reflective basal unconformity. Erosional features are common in the Tertiary section of the Sandy Cape Sub-basin. **Figure B13** shows a buried canyon, 0.5 s deep into the top of the ?Cretaceous. The succession is also eroded by numerous canyons at the present sea floor, with some flat-floored, having been eroded down to the unconformity which is presumably the upper contact of a more resistant ?Eocene unit.

Otway margin

The northwestern boundary of the Otway Basin is a steep continental slope. This slope is dissected by a series of submarine canyons (von der Borch, 1968; von der Borch *et al.*, 1970). Du Coédic, Murray and Sprigg Canyons **(Figures B14 & B15)** are particularly large features, each with relief in excess of 1500 m (Figure B17). The general trend is NE-SW, but each canyon shows particular features.

The Du Coédic Canyon (between 136°E-136° 30’E) has a main axis trending 070°-080°. It is bounded to the southeast by an escarpment 3000-4700 m deep, parallel to the main axis. The northern border is formed by a steep slope from 2000 m down to 4500 m which is incised by numerous NE-SW trending narrow canyons, each about 1 km wide. They are all connected to the main large (7.5 km wide) 070°-080° canyon. Farther east, before the Murray Canyon, a small canyon exists with a general NE-SW trend. It is 8 km wide and incises the slope, from 2500 m down to 4000 m water depth.

The Murray Canyon (between 136° 50’E-137° 10’E; **Figures B14 & B16**) comprise two main tributaries generally trending NE-SW with a prominent N-S trend on the lower slope, around latitude 37°S. The two tributaries are 8-10 km wide and incise the slope from 2500 down to 4800 m deep. The Murray Canyon is bounded to the west by the Beachport Sub-basin with a N-S trend. This sub-basin forms a plateau between 500-1500 m deep. It is bounded to the south by a NW-SE escarpment from 1500 m down to 2500 m deep. The plateau is bounded to the east by the Sprigg Canyon **(Figure B14)**. The Sprigg Canyon (between 137° 40’E-137° 50’E) is mainly N-S trending and exhibits a distinct 90° bend in its upper reaches. This canyon is 5 km wide and incises the slope from 2500 m down to 4500 m deep. It marks the western border of the Morum Sub-basin. AUSTREA-1 data confirm Seabeam imaging data already acquired in the Sprigg Canyon (Von der Borch *et al.*, 1993) and show that this canyon is floored by relatively reflective material indicating a degree of surface roughness of the canyon-floor units. This observation suggests that the back-scattering material represents canyon-floor sediments. It is uncertain whether or not these three main canyons are currently active sediment conduits. Two trends are particularly present in these canyons, 070°-080° and N-S, suggesting some form of tectonic control. These features seem to have recorded, respectively, the first stage of spreading between Australia and Antarctica and the accommodation movement during this event. The fact that later features have not been obliterated by pelagic sedimentation suggests either that faulting may still be active along the complex northwestern margin of the Otway Basin or that sedimentation rates in the region are abnormally low.

To the east, AUSTREA-1 data recorded swath-bathymetry in water depths of 1000-2000 m, crossing three sub-basins from west to east. These sub-basins have been described recently by Moore *et al.* (2000): the Morum Sub-basin (between 137° 50’E and 140° 30’E), the Discovery Bay High (between 140° 30’E and 141° 20’E), and the Nelson Sub-basin (between 141° 20’E and ~144°E). Five large canyons are present in the Morum Sub-basin and trend roughly NE-SW. They are between 3 km and 13 km wide and between 300-900 m deep. The third canyon to the east (between 139° 10'E and 139° 25'E) is located on the prolongation of the George V Fracture Zone. This fracture zone has been identified more to the south and is commonly interpreted as a main transform fault in the Antarctic-Australian Basin. The Discovery Bay High is characterised by six narrow (5 km wide) canyons close together, generally N-S trending and around 1000 m deep. To the east, the canyons on the Nelson Sub-basin are located at wide intervals, 300 m deep on average, and progressively change trends from 020° to 060°-070°.

Seismic and potential field interpretation

In the Otway Basin hydrocarbon exploration has historically concentrated onshore and in the nearshore parts of the basin. The main depocentre lies beneath the continental slope. All exploration wells are located onshore or on the continental shelf, and deepwater sampling is limited to a number of dredges and seabed cores recovered from outcrops on the continental slope and rise (Exon, Williamson *et al.*, 1987; Exon *et al.*, 1992; Heggie *et al.*, 1988). In 1994-95, AGSO acquired a deep-seismic data set in the basin (Survey 137; Blevin *et al.*, 1995), from the continental shelf out to oceanic crust, in waters from offshore South Australia to offshore Tasmania. These data provide the first complete transects of the offshore Otway Basin and image the structure down to sub-Moho depths beneath the continental slope (Moore *et al.*, 2000).

The AUSTREA-1 profiles cross the basin parallel to the margin and image consecutively the four major domains of the basin, which are from west to east, the Beachport Sub-basin **(Figure B17)**, the Morum Sub-basin, the Discovery Bay High and the Nelson Sub-basin.

The Beachport Sub-basin, between the Murray and the Sprigg Canyons, has a seismic facies composed of small discontinuous reflectors without any dominant orientation, covered by a veneer (not more than 0.2 s twt) of layered sub-horizontal series. The deepest facies shows a strong contrast, with the western facies, composed of a thick (more than 1 s twt) layered series localised in the Murray Canyon **(Figure B17)**. On the basis of seismic character correlations with the Otway Basin, it is likely that the section largely comprises Otway and Shipwreck/Sherbrook Group equivalents, while the overlying veneer consists of Cainozoic sediments.

This Beachport Sub-basin is correlated with a positive magnetic anomaly of 200 nT and a positive gravity anomaly of 90 mGal. These anomalies suggest either volcanic intrusion along the fault planes or a deep magnetic source emplaced during the first stage of spreading. In the second hypothesis, the nature of the magnetic source could be either magmatism or serpentinite, as has been suggested recently in the GAB, at the continental-ocean boundary (Sayers *et al.*, in prep.).

The first canyon east of the Sprigg Canyon seems to be the location of a tectonic deformation. In fact, the acoustic facies on both side of the canyon are different and they are separated by an angular unconformity dipping slightly to the southeast (apparent dip of 5° using an acoustic velocity of 2.3 km/s for the Tertiary series (Finlayson *et al.*, 1997)). On the west side, we observe a layered series strongly deformed by numerous faults which is overlain by a thin series (no more than 0.3 s twt) deposited on an erosional surface. In contrast, on the east flank of the canyon, the sedimentary series is layered, folded sub-horizontally and is deposited on an erosional surface. The deeper sequence is strongly deformed by faulting. To the east, this underlying series becomes progressively tilted to the northwest, parallel to the margin. In different wells, drilled on the northern flank of the Morum Sub-basin, this deep series has been identified as Cretaceous Shipwreck and Sherbrook Group sediments. The Cretaceous section beneath the continental slope has been strongly eroded, and Cainozoic sediments overlying the Eocene unconformity are relatively thin (< 2 s twt).

The eastern side of the canyon coincides with a broad 15 mGal gravity low, which correlates well with a Tertiary sedimentary deposit up to 1.4 s twt thick. The section here contains normal faults dipping to the southeast, at the base of the Tertiary. East of Beachport, on profile 21, a broad 60 nT magnetics high correlates with a less reflective seismic facies within the deeper sequence (Late Cretaceous) that extends up to the erosional surface (Eocene unconformity). It is likely that these low amplitude reflectors beneath a strong and chaotic reflector at the top are due to volcanic intrusion along the fault planes.

It is possible that the faults may have been reactivated recently as is suggested by five young faults observed at the prolongation of the George V Fracture Zone. They affect all sequences from the surface, through the Tertiary and down to the upper Cretaceous. Their fault throws increase towards the south, more than 100 ms twt or around 100 m in depth, taking 2.1 km/s for the acoustic velocity of the upper Tertiary. The latest stage of faulting has also been described in the Sorell Basin (Hill *et al.*, 1997c) and on the South Tasman Rise (Exon *et al.*, 1997b). This suggests that the faulting in the south may have lasted into the early Tertiary. Steep-sided canyons that deeply incise the Cretaceous section show that the slope is undergoing active erosion.

Continuing to the east, the Morum and Nelson Sub-basins are separated by the Discovery Bay High. The seismic data suggest that the deeper series which can be correlated with the Shipwreck/Sherbrook Group sections is relatively uniform in thickness (more than 2 s twt) folded sub-horizontally and less intensely faulted than to the northwest and southeast. The Tertiary sediments are thin (less than 0.2 s twt) to absent. The eastern flank of the high is intensively affected by canyon incisions, down to 1-1.2 s twt deep. The canyons are guided by faulting with small fault throws, perpendicular to the margin.

The Nelson Sub-basin does not have a structural boundary between the major depocentre of the southeastern Otway Basin and the Sorell Basin to the south. Above the multiple, the Nelson Sub-basin is composed of two distinct sedimentary facies. The upper series is formed by layered and strong reflectors and is not more than 0.8 s twt thick. It is deposited on an erosional surface affected by deep valley incisions down to 0.4 s twt deep. The underlying series is less reflective and is highly folded over a thickness of more than 2 s twt. The upper series can be interpreted as Tertiary sediments, while the underlying series can be interpreted as Late Cretaceous section. The structural style and the acoustic character of sedimentary fill are different to that of the Morum Sub-basin to the northwest. The deepest series begins to show strong deformation in horst and graben from 142° 30’E to the western Tasmanian margin.

Along the ship’s track, the continental slope of the Otway Basin is marked by quiet magnetics (except in the Beachport and a part of the Morum Sub-basins) and gravity anomalies which mimic the topography of the sea bottom (except in the Beachport and a part of the Morum Sub-basins). The free-air gravity anomalies mainly reflect changes in seabed topography rather than expressing influences of deeper crustal layers.

3.5 kHz acoustic facies analysis

An interpretation of seafloor character based on analysis of 3.5 kHz profiles and acoustic imagery was done on the AUSTREA-1 survey data and can be found in the post-cruise report (Hill *et al.,* 2000). A detailed analysis of much of the South Tasman Rise and offshore west Tasmania, based on AGSO's 1994 TASMANTE cruise, has been already been done (Sheet 12 in Hill *et al.* (1997b), Whitmore & Belton (1997), Müller *et al.* (1997)). Further post-graduate work is being done on the AUSTREA data at the University of Sydney and the results are expected to become available as student theses.

B3. INTEGRATION OF REGIONAL SEABED DATA SETS AND THEIR ANALYSIS

As part of this study, integration of major data sets for the region, including the merging of the major swath data sets generated by AGSO's TASMANTE (1994) and Sojourn7 (1997) surveys with those of AUSTREA-1 and AUSTREA-2, has been undertaken.

The following is a list of the main processing and display tasks completed:-

- Swath-bathymetry from AUSTREA-1, AUSTREA-2, TASMANTE and Sojourn7 surveys merged, gridded and displayed.
- Backscatter imagery from AUSTREA-1, AUSTREA-2, TASMANTE and Sojourn7 surveys merged, gridded and displayed.
- The new, merged swath-bathymetry data set has been merged with existing gridded topographic data sets to provide continuous coverage over the region. The existing data sets used include, (1) Tasmanian region grid, 0.0025° cell size, 140-152°E 37-51°S (Bernardel, 1997), (ii) Australian onshore digital elevation model GEODATA 9 SECOND DEM (Caroll, 1996), and (iii) AGSO Australian regional grid, 0.01° cell size (based on cruise data within AGSO's marine data base and predicted bathymetry derived from satellite altimeter measurements (Smith & Sandwell, 1994) – to fill small gaps in coverage at the northwest and northeast corners of the map area.
- Terrain analysis was done on the swath bathymetry data sets, with maps of various seabed attributes such as seafloor slope and aspect produced.
- 2-D and 3-D images of the seafloor, whole area and selected parts, were produced - 2-D colour hill-shaded relief images, 3-D colour-coded topography, 3-D topography draped with backscatter imagery.

A listing of the digital products is provided in **Appendix 2.**

B4. REGIONAL SEABED CHARACTER AND GEOLOGY

The AGSO geological data base for the South-east Marine Region comprises several thousand data points, representing geological stations and their details such as survey references, station number, location, sampling method or device, and a description of the sediments or rocks recovered. A condensed version of the information contained in the AGSO data base has been produced for the purposes of this regional study **(Appendix 2)**. The condensed version contains the following information for each station: station number, station alias, latitude, longitude, sampling method/device, main facies (rock, gravel, sand, silt or mud/clay), and a brief geological description of the main components of the sample recovered. **Figure B18** shows the distribution of geological sampling stations off southeast Australia, the sampling methods used and the main facies recovered.

The merged bathymetry for the Australian sector of the South-east Marine Region is shown as 200 m contours in **Figure B18** and as a hill-shaded colour-coded topographic image in **Figure B19**. Backscatter imagery for the same region, comprising a merge of the AUSTREA-1, AUSTREA-2, TASMANTE and Sojourn7 data sets is presented in **Figure B20**.

The gridded bathymetry data from the swath surveys (AUSTREA, TASMANTE and Sojourn7) were processed in ER Mapper to generate images of seabed slope **(Figure B21)** and seabed aspect **(Figure B22)**.

A subset of the regional backscatter data set **(Figure B20)** covering the spectacular canyons on the margin south of Kangaroo Island is shown in **Figures B15 & B16** as a drape on 3-D topography. These images illustrate the variations in backscatter intensity from features such as rock faces on escarpments and canyon walls (strong backscatter), lag deposits and outcrop in canyon thalwegs (strong backscatter), clay/silt-filled channels (weak backscatter), and pelagic sediment drape (weak backscatter).

As indicated above, areas of the seafloor that produce high backscatter are generally hard surfaces such as rock outcrop, or perhaps coarse clastic sediments such as gravels (Augustin *et al*., 1996). From the known distribution of seabed geology and sedimentary facies (eg. from sampling cruises such as Exon *et al*. (1995), conducted post TASMANTE swath-mapping) it appears that there is good correlation between rocky outcrop and high backscatter returns (seen as dark areas in **Figure B20**) in this study area off southeast Australia. A map of interpreted seabed outcrop **(Figure B23)** was prepared based on the backscatter response over the region **(Figure B20)**. In preparing the map, care was taken to avoid misinterpreting artefacts in the backscatter imagery. Such artefacts include:- spurious response from the nadir zone (area directly beneath the ship from which acoustic returns are dominated by specular reflections, and so is effectively a backscatter blind zone), shadow zones behind high-standing topography, accentuated returns from ship-facing submarine cliffs or very steep slopes, and poor balance between starboard and port backscatter levels on some lines due to technical problems during acquisition. Also taken into consideration was the fact that high backscatter intensity can come from manganese nodule pavements, even when buried beneath several metres of pelagic sediment, as appears to be the case on the abyssal plain immediately south of the STR (Exon, 1997).

A synthesis of all the data sets available - including topography, backscatter imagery, sampling results and a knowledge of interpreted sub-bottom geology from the network of seismic lines over the region - enabled a broad regional framework of seabed geological facies and main seabed structures to be produced **(Figure B24)**.

The principal seabed geological domains are:-

- the continental shelf, extending from the shore to the abrupt change in slope at its edges, in water depths of 200-250 m
- the continental slopes, and slopes on the adjacent submerged continental plateaus (South Tasman Rise and East Tasman Plateau), extending from the shelf break at ~250 m to ocean depths of 4000-4500 m
- the adjacent abyssal plains lying in water depths of ~4000-5500 m.

The continental shelf off southeast Australia is underlain by two main sediment types - carbonate sediments and siliceous sediments (mainly quartz sands), plus lithological facies comprising a mix of the two. This allows a zonation of the continental shelf on the basis of carbonate/silica content, with three categories mapped out, (i) predominantly carbonates, (ii) mixed carbonates/siliciclastics (roughly equal percentages), and (iii) mainly siliciclastics (largely quartz sands). The three sediment types have been mapped out using the sampling information in the AGSO data base **(Figure B18)**, and a number of other sources (some of which contributed to the data base) – Jones & Davies (1983), Davies (1979), Blom & Alsop (1988), Harris *et al*. (1991), Harris (1994) and Gostin *et al.* (1988).

The continental slopes show a physiography mostly controlled by the tectonic processes of margin development, with faulted rift blocks and fracture zones commonly exposed on the seabed or mantled by no more than a thin or patchy sediment cover. This is the case off southeast Australia because the margins have been largely sediment starved, with little terrigenous input since formation. The bulk of young sediments on the continental slopes are fine-grained hemipelagic carbonates (partly derived from the shelf) and nanno-foram oozes. The latter form most of the sediment cover on the STR and East Tasman Plateau. The exposed basement and rocks mainly comprise late Proterozoic to Palaeozoic metasediments, granites, gneisses and schists. Spectacular rift topography is seen on the continental slope south of Kangaroo Island, off the southern NSW and off east Tasmania **(Figures B19 & B21)**. The Tasman Fracture Zone that forms the western margin of the STR is the scar left as Antarctica broke away from Australia and slid past the STR over a period of about 15 million years beginning about 45 Ma. The large continental blocks and ridges off west and southwest Tasmania **(Figure B19)** are the products of wrench movements along a NW-SE oriented plate boundary.

The continental slope of the Otway and northwest Tasmanian margins is wider and of lower gradient than elsewhere off southeast Australia, and this is due to the considerable extension of continental crust here during the rifting process prior to breakup. The slope is almost entirely sediment covered, and extensively incised by downslope canyons, particularly off western Victoria and northwest Tasmania. Major canyons are present elsewhere on the steeper parts of the margin where basement rocks are exposed (eg. south of Kangaroo Island, off northeast Tasmania, Gippsland and southern NSW, but here they are controlled by the basement structures and so follow more erratic paths. The canyons appear to be relatively inactive at present, but would have been active during the Pleistocene when the shelves were exposed and being eroded. A 50-km wide scar on the upper continental slope of southwest Tasmania appears to have been formed by a massive submarine slump or landslide (Hill *et al.*, 1997c).

Extensive volcanic terrain, including numerous volcanic cones, occupies the continental slopes south of Tasmania, off southeast Tasmania and in the St Helens Hill area off northeast Tasmania **(Figure B24)**. Similar volcanic terrain is located on the summit area of the STR and at its southern end. Recent Ar-Ar dating of an olivine basalt sample from St Helens Hill (Hill, 1999) gave an age of 45-50 Ma (Middle Eocene).

The abyssal plains off southeast Australia are of low to moderate relief. The abyssal plain in the Tasman Sea appears to be relatively flat and covered by pelagic sediments - nanno-foram mud and ooze. Turbidite deposits, originating from slope failures (slumps and debris flows) from higher on the continental slope and from the shelf edge (Jenkins & Keene, 1992), probably underlie the continental rise and margins of the abyssal plain (Colwell *et al*., 1993). In the Southeast Indian Ocean, adjacent to the Otway margin, the abyssal sediments appear to be similar to those adjacent to the lower slope/rise in the Tasman Sea, except that off the Otway margin large ?volcanic seamounts and blocky hills (up to several hundred metres high), at and seaward of the continent-ocean boundary (COB), protrude through the sediment cover. Farther south, to the west and south of the STR, a remarkable ‘abyssal hill’ E-W seafloor spreading fabric, cut by N-S fracture zones, is observed. Sediment cover of nanno-foram mud/oozes appears to be patchy and thin, with oceanic crust (tholeiitic basalts) exposed over large areas, and probably swept free of sediment by strong bottom currents.

B5. SEABED RESOURCES AND POTENTIAL

Petroleum

The Gippsland Basin is a mature oil and gas province, and was, until very recently, the highest oil producing basin in Australia. Reserves are declining and expected to continue to do so. To counter this decline, exploration and production is extending into the deeper water parts of the basin. In 1999 subsea production began from the Blackback field in 395 m of water.

Petroleum exploration is active in the Bass Basin and offshore Otway Basin, with several permits in each. Gas/condensate discoveries have been made. A petroleum exploration permit is currently held over the Strahan Sub-basin off west Tasmania, where Cape Sorell-1 well had oil shows.

The AUSTREA seismic lines crossed a number of poorly explored parts of the Tasmanian margin. The profiles provided new data, and confirmed the presence of significant sediment thickness (>1.5 km), and thus at least some petroleum potential, in the Port Davey and Sandy Cape Sub-basins of the west Tasmanian Sorell Basin, and also off southern Tasmania, east Tasmania (rift basin off Freycinet Peninsula) and northeast of Cape Barren Island.

The South Tasman Rise (STR) contains deep wrench basins with up to 6 km of sedimentary section, but they lie in deep water on the flanks of this continental block, and so their prospectivity is reduced. Nevertheless, because drilling and development technology has kept up with the global trend to explore deeper and deeper fields (1500 m depths now not considered exceptional (Thomas, 2000)), acreage will probably be released on the STR in the next few years.

Potential gas hydrates have recently been recognised on and adjacent to the STR (Stagg *et al.*, 2000). Bottom simulating reflectors (BSRs) have been identified in seismic profiles within small sedimentary basins on the STR and also beneath the L’Atalante Depression. They suggest the presence of considerable volumes of free methane gas and methane in the form of crystalline hydrates within the section. Though no economic way of extracting the methane from such deposits has yet been devised, they nevertheless represent a potential resource, though very long term at present.

Deepsea mineral deposits

The main deepsea mineral deposits that may be of long term commercial mining interest are metal-rich ferromanganese crusts and nodules. The main metals of economic interest in such deposits are Co, Cu and Ni. No significant mineral exploration has taken place offshore in the South-east Marine Region. It is conjectured that there may be some potential for placer deposits in relatively shallow water on the continental shelves, particularly tin (cassiterite) off

Tasmania (where it has been mined at a number of locations throughout the state), possibly gold, and perhaps heavy mineral sands off southern NSW, Gippsland and northeast Tasmania. Geochemical analysis of heavy minerals in selected surface samples of shelf sediments off eastern Victoria and Tasmania (Jones & Davies, 1983) revealed no economically important concentrations.

The most comprehensive study of the ferromanganese deposits in the region has been that by Exon (1997). Unusually thick ferromanganese crusts, up to 20 cm thick, are present on rocky outcrops off west Tasmania and on the STR in water depths of 1500-4500 m. Those from within the oxygen-minimum zone (<2000 m) average 0.8% Co, which compares very favourably with other locations in the world that are highly prospective (eg. Marshall Islands). However, the highest Co contents are from crusts only 2-4 cm thick, as compared to a suggested cut-off thickness of 4 cm. Exon (1997) recommends that further prospecting for Co-rich crusts should concentrate on outcrops in water depths of 1000-2000 m on the eastern STR and southern Tasmanian margin.

Manganese nodule fields are common on the abyssal plains off Tasmania and the STR, and also occur in deep water on the STR (shallowest recovery was at 2400 m). Nodules dredged from the STR were commonly from areas of rocky outcrop, and were mostly smooth and very large (5-10 cm diameter). Though apparently abundant, the nodules from both the STR and adjacent abyssal areas are of low metal grade (averaging 0.14% Cu, 0.26% Ni, 0.20% Co) and are presently not of economic interest (Exon, 1997).

Fisheries

Seafloor morphology and structure have major influences on where commercial fisheries are located and the type of fish species that are to be found there. Orange roughy, a deepwater species commonly found in the depth range ~500-1200 m, aggregate above the surface of seamounts and other high-standing terrain on the seafloor, while blue grenadier aggregate in canyon heads at and below the continental shelf edge during spawning. Longline fishers for pelagic species such as tuna and billfish often target waters above deep seamounts because of the upwelling produced by such features.

The AUSTREA swath surveys completed the detailed mapping of major and commercially important deepsea fishing grounds in the South-east Marine Region (Tilzey, 1994). These included:-

- St Helens Hill/St Patricks grounds off northeast Tasmania (orange roughy)
- Cascade Seamount on the East Tasman Plateau (orange roughy/dory)
- Southern Hills south of Tasmania (orange roughy/dory)
- South Tasman Rise trawl fishery on the summit area (Caton & McLoughlin, 2000, pp.205-207) (orange roughy)
- Canyon systems off west Tasmania (blue grenadier).

Detailed seabed maps and images are now available to help manage these fisheries and to assist biological research and protection of the benthic habitats. Possible new deepsea fisheries may exist, particularly in the more remote regions such as the southern STR. Here large seamounts, as shallow as 1600 m depth, have been mapped and there is also a deep volcanic terrain similar to that found in the Southern Hills area on the southern continental slope of Tasmania. Orange roughy are one species likely to be found, and the southern STR may also host other species such as Patagonian toothfish. Upwelling of currents over the large deeper seamounts may attract pelagic species such as tuna.

PART C: Offshore Lord Howe Island

Lord Howe Island and the rock pinnacle, Ball's Pyramid 23 km to the south **(Figure C1)**, are subtropical volcanic islands located on the Lord Howe Rise, about 700 km northeast of Sydney. They are part of NSW. Lord Howe Island has a coral reef claimed to be the southernmost in the world. Mount Gower, the highest point on Lord Howe Island, is 875 m above sea-level. The spire of Ball's Pyramid rises almost vertically (~70º slopes) above the sea surface to a height of 552 m. A number of rocky reefs and islets are located up to 5 km off the main islands. The Lord Howe Marine Park (Commonwealth waters) was declared on 21 June 2000. The Marine Park extends from 3 to 12 nautical miles around Lord Howe Island, Ball's Pyramid and their adjacent islands.

Up to the time of cruise planning in the second half of 1999, detailed maps of the submarine flanks of the islands did not exist, and it was agreed between NOO/EA and AGSO that a survey should be conducted if possible, given that *L'Atalante* would be transiting through the area on its way from Noumea to southern NSW.

The survey off Lord Howe Island was run as a circuit of Lord Howe Island and Ball's Pyramid, on average 3 nautical miles out from the 300 m isobath. The swath width was about 11 km, with the half-swath downslope being greater than that upslope, as is normal. A line was then run through the deepwater channel between the two islands. The survey was completed in 13 hours. Depths mapped were in the range ~300-3000 m. Most of the deepwater area of the then-proposed MPA around Lord Howe Island and Ball's Pyramid (extending out to 12 nautical miles) was mapped. Bearings taken during the survey suggested that the location of Ball's Pyramid as shown on the Australian Hydrographic Office (AHO) Chart AUS 213 may be about 400 m out, plotting to the northeast of the chart position.

The Australian Hydrographic Office recently produced a new chart of the Lord Howe Island area, Chart AUS 610. The new AUSTREA-1 swath-bathymetry has been included in the compilation of this chart. This followed a request from the AHO to AGSO for the data, a request approved by NOO.

C1. GEOLOGICAL BACKGROUND

Lord Howe Island and Ball's Pyramid, located on the western margin of the Lord Howe Rise, are the eroded, subaerial parts of volcanic edifices that were constructed by hot-spot volcanic activity about 6-7 Ma over a period of about half a million years (McDougall *et al.*, 1981).

They form part of the N-S oriented Lord Howe hot-spot chain of coral-capped guyots that runs the length of the northern Tasman Sea, younging to the south, and paralleling the Tasmantid seamount chain about 300 km to the west (CPCEMR, 1991). These chains formed by erupting basaltic rocks as the Australian lithospheric plate drifted northwards at ~7 cm/year over a mantle plume, in a similar way that Hawaiian chain of shield volcanoes and seamounts evolved.

The Lord Howe Rise is a N-S trending ribbon of continental crust that became detached from the eastern Australian continent about 80 Ma (Weissel & Hayes, 1977; Royer & Rollet, 1997) through rifting and seafloor spreading, forming the Tasman Sea basin. This spreading ceased about 52 Ma. The Dampier Ridge, west of Lord Howe Island, is also believed to be a sliver of continental crust formed during the same phase of lithospheric extension. The Lord Howe

Basin that separates the two ridges has a basement of oceanic or highly extended lower continental crust. The Gower Basin, a rift basin on the western Lord Howe Rise to the north and northeast of Lord Howe Island, contains horst and graben structures with a sediment fill of up to 4500 m in places, and has medium to long-term petroleum potential (Symonds & Willcox, 1989). A geological framework study of the Gower Basin is underway at AGSO at present (Willcox & Sayers, in prep.).

The rocks exposed on Lord Howe Island are mainly basaltic volcanics – lava flows, volcanic breccias, and cross-cutting dykes and other intrusions. Much of the low lying areas of the island consist of beach and dune deposits and a widespread calcarenite, consisting of coralline algae fragments, and less abundant coral, foraminifera and molluscs. The calcarenite is aeolian in origin, and was probably deposited around the flanks of the volcano during periods of low sea level in the Pleistocene, blown there by winds off the surrounding carbonate platform that would have been subaerially exposed at the time (McDougall *et al.*, 1981; Thompson *et al.*, 1987).

C2. SEABED DATA SETS

The new AUSTREA-1 swath data sets **(Figures C2 & C3)** now provide the best and most detailed information on the seabed off Lord Howe Island/Ball’s Pyramid in deep water below 300 m depth. The 1:250,000 NATMAP chart (NATMAP, 1982) and Australian Hydrographic Office charts provide detailed bathymetry above that depth.

New seabed sediment sample and trackline bathymetry data were acquired recently by a research cruise of R/V *Franklin* (Woodroffe & Jones, 1998). 73 grab samples and 3 successful piston cores were obtained around Lord Howe Island and Ball’s Pyramid, mostly from the island platforms. All but one sample, a piston core, were from water depths shallower than 158 m. This core, from 760 m on the western flank between the two islands, yielded very fine muddy sand, of presumed carbonate composition. The sampling on the platform showed that a rim at 25-35 m depth consisted of a hard substrate dominated by coralline algae and attached epifauna. The inner part of the platform (<40 m depths) consisted of fine- to medium-grained carbonate sand. No volcanic detritus was found in the grab samples.

C3. SEAFLOOR MORPHOLOGY AND CHARACTER

Lord Howe Island and Ball’s Pyramid are each surrounded by a platform or shelf **(Figure C2)** that is mainly 30-50 m deep, with an edge at 60-70 m depth, at which the seafloor begins to descend steeply (NATMAP, 1982). The platforms extend about 10 km offshore, and have total area of about 750 km^2.

The composite edifice **(Figure C1)** is about 90 km in a NNW-SSE direction and about 50 km WSW-ENE, and lies in water depths of 1800 m (ENE side) to ~3500 m (WSW side). The edifice is rhomboidal in shape **(Figure C2)**, with NE-SW and NNW-SSE trends, suggesting basement structural control of the volcanism. The NNW-SSE long axis parallels the Tasman Basin rift and seafloor spreading structures.

The swath data **(Figure C1)** show the submarine flanks of these volcanic islands to be rugged and steep, commonly 10-20°, and steeper in places. The terrain includes down-slope flow structures (probably debris flows of coarse sediment or old lava flows), canyons and numerous volcanic cones and pinnacles, many 150-300 m high. At least 20 parasitic cones are evident in the imagery, with a cluster of several in the deep channel between the islands on the southwest flank of the composite edifice. The largest flow 'chute' is 8 km wide and located on the WSW side of Ball's Pyramid. At least one cone (200 m high) occurs on the relatively flat adjacent Rise, about 47 km east of Lord Howe Island **(Figure C2)**. The submarine slopes of Lord Howe Island and Ball's Pyramid appear to be mostly rocky volcanic outcrop, with only thin patches of sediment. The complex substrate on the seamount flanks suggests the existence of diverse ecosystems, perhaps similar to those found on the Tasmanian seamounts.

The Lord Howe Basin to the west, between the Lord Howe Rise and Dampier Ridge, is 4050 m deep and generally flat-bottomed, except for a large ?volcanic seamount that rises steeply from the middle of the basin to 2800 m or shallower (only the northern part of the seamount was mapped). Where crossed, the continental Dampier Ridge is 80 km wide and rises to 2000 m. The western side appears to be underlain by en echelon N-S-oriented fault blocks. About 90 km northeast of Lord Howe Island large gravity anomalies (+30-40 mGal) were recorded near two local topographic culminations, and these probably reflect significant positive basement relief.

The 3.5 kHz profiles indicate that the sea floor around Lord Howe Island and Ball's Pyramid consists of extreme topography and basement outcrop (acoustic facies type IIIA (Hill *et al.*, 2000; Whitmore & Belton, 1997)). The shallow channel between Lord Howe Island and Ball's Pyramid shows some very coarse sediments (type IIB). To the west of Lord Howe Island, depth increases rapidly and thick pelagic sediment (type IB) blankets the basin floor, with penetration to at least 50 m by the 3.5 kHz echosounder. As in places east of Lord Howe Island, volcanics commonly emerge through the sediment cover and appear as discrete areas of intense reflectivity in the imagery.

C4. SEABED RESOURCES

The Gower Basin to the north and northeast of Lord Howe Island has medium to long-term petroleum potential (Symonds & Willcox, 1989; Willcox & Sayers, in prep.). This is because of, (i) its thick sedimentary section (up to 4 s twt), making maturation of hydrocarbons possible, (ii) its conjugate location in plate reconstructions and similarities to the Gippsland Basin and Durroon Sub-basin (in Bass Strait off northeast Tasmania), and (iii) reasonable water depths of ~1000-1500 m, making exploration drilling feasible using modern technology. No petroleum potential is expected in the vicinity of the islands (at least within 12 nautical miles) because of the thick pile of volcanic rocks and the structural disruption of possible underlying basin sediments by the intrusive activity.

Ferromanganese crusts on deep ocean substrates generally contain small amounts of Cu, Ni and Co (mainly less than 1%). Crusts on the flanks of the Lord Howe Island/Ball's Pyramid seamount may be of long-term resource interest, particularly if cobalt rich. But little sampling information is available. Cobalt-rich crusts on seamounts generally lie at depths of 1000-2000 m, corresponding to the oxygen minimum zone (Exon, 1997).

In relation to fisheries, the Lord Howe Island region presently comes under the East Coast Deepwater Trawl Fishery, the Eastern Tuna and Billfish Fishery and the South East Fishery (non-trawl sector) (Caton & McLoughlin, 2000). A Lord Howe Island Exclusion Zone is in place to protect the interests of local fishing operators and the fishery, and is also designed to protect World Heritage values of the Lord Howe Group. The fisheries exclusion zone applies to all mainland fishing within 12 nautical miles, and trawling is excluded within 25 nautical miles of the Island. Orange roughy are the main deep-trawl species fished on the Lord Howe Rise, but presently it is a comparatively small domestic fishery. Though trawling is now banned, the rugged nature of the Lord Howe Island/Ball’s Pyramid flanks suggests that these slopes would be a hostile environment for demersal trawling in any case, resulting in significant loss of bottom gear.

PART D: Great Australian Bight

Australia has some of the most diverse and unique marine life in the world. The establishment of a representative system of marine protected areas on the Australian margins is widely regarded, both nationally and internationally, as one of the most effective mechanisms for protecting biodiversity.

The Great Australian Bight Marine Park in the Great Australian Bight (GAB) **(Figure D1)** was declared on 17 April 1998 to protect the southern right whale and the Australian sea lion and a representative strip of the unique benthic environment. The total area of the Park is 19,769 km^2, and includes two overlapping areas, the Marine Mammal Protection Zone and the Benthic Protection Zone (BPZ). The Marine Mammal Protection Zone is in the Head of Bight, adjacent to the State Marine National Park, from three nautical miles to approximately 12 nautical miles offshore. The BPZ is 20 nautical miles wide and stretches south from the edge of the State Park to the edge of the Exclusive Economic Zone of Australia (AEEZ) at 200 nautical miles. The BPZ is designed for the protection of the unique and diverse bottom dwelling fauna and flora and the seabed sediments. Both areas include the waters, seabed, and the subsoil beneath the seabed to a depth of 1000 meters below the seabed.

The work carried out for this report focused on the Benthic Protection Zone, swath-mapped in January 2000 during the AGSO/NOO/EA AUSTREA-1 cruise **(Figure D2)** on the research vessel *L'Atalante*. Data used for this study include swath-bathymetry, backscatter data, 3.5 kHz echo-sounder and 3-fold seismic reflection profiles acquired during AUSTREA-1 (Hill *et al.*, 2000).

The results of this cruise have significantly increased the scientific understanding of Australia’s offshore marine environment and assisted in planning a sediment sampling program for a subsequent cruise using the CSIRO research vessel *Southern Surveyor* in May 2000 (SS01/00; CSIRO, 2000). This 47-day cruise, conducted over 3 legs, was jointly supported by the National Oceans Office, CSIRO, EA and AGSO. The purpose of this cruise was to refine techniques for mapping and classifying marine benthic habitats and also to sample geological features in the GAB Marine Park. Geological samples recovered during the SS01/00 cruise also contributed to a better understanding of the geophysical data.

D1. REGIONAL SETTING

The Great Australian Bight is part of the Southern Ocean which developed as a result of the separation of Australia and Antarctica in the Late Mesozoic to Cainozoic. The area is underlain by a large sedimentary basin, the Bight Basin, which contains up to 15 km of sediments of Late Jurassic to Recent age **(Figure D3)**. The Bight Basin is further sub-divided into the Eyre, Recherche, Ceduna and Duntroon Sub-basins. The greatest sediment thickness occurs in water depths greater than 200 m, in the Ceduna Sub-basin. The Bight Basin formed in the Late Jurassic **(Figure D4)** in response to the breakup of eastern Gondwanaland, as part of a developing rift valley that stretched from the southwest of Western Australia to Tasmania in the southeast. A more detailed description of the geological history of the Bight Basin is given in section D6 of this report.

D2. MORPHOLOGY OF THE GAB MARINE PARK

Swath-mapping in the GAB Marine Park **(Figure D5)** shows that the margin is gently sloping down to about the 2500 m isobath and is relatively featureless, except for two volcanic(?) pinnacles less than 100 m high and up to 700 m across that protrude above the sediment surface near the 1750 m isobath **(Figure D2)**. Below 2500 m, to a depth of more than 5000 m, the margin is steeper, faulted, and heavily canyoned. The canyons are approximately parallel, ENE-trending and appear to be tectonically controlled. The swath data have revealed that, associated with the canyons, particularly the Nullarbor Canyon and in other locations in deep water, are giant holes, up to 5 km across and about 500 m deep. These features are unusual, and their nature is undetermined. It is possible that the holes are produced by escaping fluids, and if so, they may host chemosynthetic organic communities.

Acoustic backscatter imagery **(Figure D6)** gives some indication of the nature of the sediments and their distribution on the shelf, continental slope and continental rise. Where the sediments are relatively soft, the backscatter is low and the images appear relatively light in the imagery. Where the sediments are harder, the acoustic response is more reflective and darker in the imagery. In **Figure D6**, we observe that the upper slope is mainly covered by soft, recent sediments. However, the lower slope indicates harder sediments outcropping, especially in the Nullarbor Canyon which incises older rocks that may once have been more deeply buried **(Figure D7)**. Samples recovered from the seafloor contribute to the ground-truthing of acoustic images.

D3. PREVIOUS GEOLOGICAL SAMPLING WORK

Dredges

Two existing dredge stations are located in the marine park, both in the Nullarbor Canyon. They were acquired during AGSO (BMR) Surveys 66 and 102 in 1986 (Davies *et al.*, 1986) and 1991 (Feary *et al.*, 1991), respectively, using R/V *Rig Seismic*. The first dredge (66DR05) did not reach the sea bed, while the second one (102DR03) recovered Campanian to Maastrichtian mudstone, claystone and siltstone, as well as Quaternary nannofossil ooze, at a water depth of 4180-3660 m.

The calcareous and terrigenous rocks in the 102DR03 dredge were recovered from the lower slope of the Ceduna Terrace. They represent various sedimentary environments, from terrigenous, shallow water estuarine/lagoonal and mud flats to deeper water, purely calcareous shelf. The Late Cretaceous ages for the terrigenous mudstones and siltstones indicate that these rocks are correlatives of the Hammerhead Supersequence (Potoroo Formation; **Figure D4)**. The calcareous rocks are time equivalents of the Dugong Supersequence (Wilson Bluff Limestone; **Figure D4)**. The shelfal carbonates dredged during AGSO (BMR) Survey 102 support the general open marine conditions postulated for the Bight Basin from the Early Eocene to the Middle Oligocene.

Cores

One core (66GC050) was taken in the marine park area during AGSO (BMR) Survey 66 (Davies *et al.*, 1986). This core, from 1134 m water depth in the central part of the Ceduna Basin, (34° 02.305' S, 130° 41.483' E), measured 247 cm in length and recovered pelagic calcareous ooze with several sandy horizons.

D4. NEW SAMPLES FROM THE SOUTHERN SURVEYOR CRUISE SS01/00 (MAY 2000)

The sparseness of existing sediment data required the collection of further geological samples to ground-truth the acoustic units observed in geophysical data, and to investigate palaeoenvironmental conditions in the last 50,000 years.

As part of the *Southern Surveyor* cruise SS01/00, AGSO sampled sea bottom sediments from water depths of 500 to 5300 m, in two stages **(Figure D2; Table D1)**. Stage 1, in water depths of 500 to 2500 m included five stations sampled every 500 m along one of the AUSTREA-1 seismic profiles, using an 8 m long gravity corer (GC01 to GC05). The aim was to investigate long-term changes in sedimentary, water column, and climatic conditions. Stage 2 included four cores located in the deep holes, in water depths of 3000 to 5300 m Siting of the core locations was based on detailed swath-mapping, seismic data and 3.5 kHz profiles. These cores were collected to investigate the sediments in the deep holes, with two cores taken from the canyon axis (GC07, GC08) and two from the western edge of the canyon (GC06, GC09). In addition, old detrital sediments (probably Late Cretaceous) were sampled at three dredge locations, two in the deep holes, and one on a submarine scarp (DR01-DR03).

Most of the sediments obtained from the shelf and the slope consist of unconsolidated and reworked calcareous sands and muds **(Figure D8)**. The samples were described on board the *Southern Surveyor* **(Table D1)**, and bagged for further laboratory analysis. The core samples will be analysed to contribute to an interpretation of the palaeoclimatic history of the region, and to provide acoustic velocity information.

Black mud and mudstone were found at the base of the four cores taken from the deep holes, and in all three dredges. Preliminary investigations indicate that these muds are of Cretaceous or Palaeogene age. Only a thin veneer of recent ooze (about 2 cm) was recovered at the surface, proving that recent sediments have been eroded or were not deposited in the holes. In the deepest hole, the sediments recovered at 1.5 m below the seabed (dark grey mud at ~5250 m) have been analysed and the foraminifera indicate a Santonian-Campanian age.

Table D1. AGSO geological sampling sites in the GAB Marine Park, *Southern Surveyor* cruise SS01/00 – locations and preliminary results

Cores/Grabs	Time	Latitude	Longitude	Depth	Length of recovery	Observations
GC01 + GR01	1h + 1h	33º 27.954' S	130º 48.79' E	480 m	5.22 m	**Target**: Quaternary sediments **Recovery**: nanno ooze in core **Recovery in the Core Catcher:** Green beige sandy mud with bioclasts (shells and pteropods). Uniform sample.
GC02	30'	33º 51.131' S	130º 48.645' E	999 m	4.2 m	**Target**: Quaternary sediments **Recovery in the Core Catcher**: Grey firm nanno-foraminiferal ooze. ~2% sand fraction. Some dark marbling.
GC03	37'	34º 35.067' S	130º 45. 80' E	1506 m	3.35 m	**Target**: Quaternary sediments **Recovery in the Core Catcher**: Cream-grey nanno-foraminiferal ooze ~2% sand fraction. Firm consistency. Some darker marbling, maybe due to some Fe content. Soupy ooze at the top of the core
GC04	40'	34º 51.403' S	130º 43.280' E	2012 m	5.01 m	**Target**: Quaternary sediments **Recovery at the top of the core**: Pinky-beige nanno-foraminiferal ooze ~1% sand fraction (GB, ORB). Colour and texture uniform throughout the sample. **Recovery in the Core Catcher:** Light grey nanno-foraminiferal ooze. Colour is not uniform throughout the sample, with areas of lighter mud and some dark marbling.
GC05	50'	35º 01.788' S	130º 40.082' E	2518 m	4.49 m	**Target**: Quaternary sediments **Recovery in the Core Catcher:** White-beige nanno mud with firm consistency; uniform colour and consistency.
GC06	1h	35º 04.401' S	130º 50.357' E	2666 m	0.45 m	**Target**: recent sediments or Late Cretaceous **Recovery in the Core Catcher:** Dark brown soft mud with pyrite(?) and light green-brown mud. At the boundary of the dark component and the green-brown one, a transitional brown mud is observed with many bioclasts associated.
GC07	1h40'	35º 10.134' S	130º 49.007' E	3278 m	0.2 m	**Target**: recent sediments or Late Cretaceous **Recovery in the Core Catcher**: 3 different muds types. The main component is a dark brown mud with Fe discolouration and a brittle texture. The second mud is a dark-beige mud with a more cohesive texture. The third mud seems to be a mixture of the two. Nanno ooze at the top of the core.
GC08	2h20'	35º 35.899' S	130º 37.032' E	5250 m	1.5 m	**Target:** recent sediments or Late Cretaceous **Recovery in the Core Cutter**: **A-** Black mud with different harder mudclasts of various types (some are rust coloured, others are black). The sample contains a small amount of grey mud.

						Recovery in the Core Catcher: Firm plastic grey mud with green-black fluid mud
GC09	2h	35º 24.36' S	130º 39.596' E	4600 m	0.05 m	**Target**: recent sediments or Late Cretaceous **Recovery in the Core Cutter**: **A-** Grey-black compacted mud with considerable amount of bioclasts including hardened worm tubes, hardened shells, and biogenic hash mixed throughout the sample. **B-** Hard marl with some inclusions with shiny ?pyrite. **Recovery in the Core Catcher:** White lithified sub-angular mudstone. One surface has a thin Fe-Mg (?) crust. Evidence of bioclasts in the mudstone. Colour: cream to rust; hardness <2 but other surfaces are harder (have deformed the core cutter). **Recovery at the bottom of the core:** 3 different mud types. A green-brown mud is the main component; also present is a dark beige mud, and in lesser amount, a brown-orange mud. The darker mud is more fluid and contains some unidentified dark clasts. **Recovery at the top of the core:** A softer, more watery sample than from the bottom of the core. 2 mud types, each containing dark mudclasts.

Dredges	**Time**	**Start**			**End**			Observations
		Latitude	**Longitude**	**Depth**	**Latitude**	**Longitude**	**Depth**	
DR01	2h30'	35º 08.029' S	130º 48.267' E	3220 m	35º 07.746' S	130º 48.076' E	2735 m	**Target**: recent sediments or Late Cretaceous. (*AUSTREA-1* cruise) line Aea1022 between 5.00-4.40 **Recovery**: 35 kg **A**. Beige planktonic nanno and foraminiferal ooze. Less than 1% sand fraction obelina(?) and agglutinated benthic species. Some discolouration layers were apparent in the ooze. The colour is similar to the mudstone. Two different consistencies: fluid and coherent mud. **B**. Sub-angular and sub-rounded dark grey-brown cobbles of semi-lithified mudstone. Size average: 10x5 cm. The clasts have a plastic texture. Contain oxidised Fe(?) layers. Some parts of the mudstone are much darker, almost black, with a more plastic consistency. A 4 cm tube structure, transparent, associated with the sample and evidence of bioturbation. A small number of darker brown clasts, less than 1 cm across, were found in the mud. Some cream-coloured mud within the clasts may have been incorporated during the dredging process.
DR02	5h	35º 20.038' S	130º 35.795' E	4350 m	35º 17.275' S	130º 36.662' E	*3850 m*	**Target**: recent sediments or Late Cretaceous. (*AUSTREA-1* cruise) line Aea1023 between 12.30-12.50. **Recovery**: 20 kg **A.** Pinky beige nanno-foraminifera ooze. Less than 1% of sand fraction (planktonic foraminifera, and agglutinated forams). Sticky mud. **B.** Sub-angular and sub-rounded mudstone cobbles, which display two colour variations, rich brown (Fe alteration) and a dull brown-green (no internal structure). Cobble sizes ~9x8 cm.
DR03	3h30'	35º 35.99' S	130º 37.042' E	5248 m	35º 34.587' S	130º 37.055' E	4850 m	**Target**: recent sediments or Late Cretaceous. **Recovery**: 5 kg **A**. Two-toned, soft foram and nanno ooze (pinky beige and a lighter shade). Several clasts were washed from the ooze: a) sub-angular mudstone, size: 2.5x1.5 cm with a thin Mg-Fe (?) crust < 0.1 cm, b) Fe crust ~ 0.4 cm thick. **B**. Three types of mudstone: a) dark brown to green-brown mudstone with fine Fe layers parallel to the fabric, sub-angular;

								b) chocolate brown mudstone, with mudclasts of varying texture and colour. c) rich chocolate brown mudstone angular with many inclusions of high reflectance. One cleavage plane. Some Fe discolourations. **C**. A single, slightly-elongate, pyramid-shaped cobble (11x8x7 cm). Smooth angular rock with concentric layers of FeMg(?) crust. Dense, weighing 840 g.

Total time for all the samples = 22h37'

Post-cruise geoscience studies of the samples from the GAB, and also from the previous *Southern Surveyor* legs, will include general sedimentology, and studies of foraminifera (Andrew Smith, Melbourne University).

D5. SEDIMENTOLOGY OF THE GAB MARINE PARK FROM ACOUSTIC FACIES MAPPING

The Great Australian Bight has been recently recognised as an ideal location to study the history of global climatic and oceanographic changes along the southern temperate Australian coastline (James *et al.*, in prep.). Sedimentological studies indicate that major oceanographic changes, such as glacial extremes and the opening and closing of the Indonesian gateway, are reflected in geochemical records preserved in sediment-producing organisms. The lack of fluvial inputs to the Bight region has been a major factor in preserving this record. The present arid climate and the prevailing low continental relief has meant that only minor terrigenous sediments are transported onto the wide continental shelf, thus permitting the growth of carbonate-secreting organisms and leading to the accumulation of bioclastic debris uncontaminated by fluvial inputs (Gostin *et al.*, 1988).

Oceanography of the Great Australian Bight

The GAB faces the cold Southern Ocean, 500 km north of the Subtropical Convergence Zone (northern boundary of the Antarctic Circumpolar Current flow; Rintoul *et al.*, 1997) and is located in the sub-equatorial arid belt. In the Ceduna area, the water is cold inshore, with seasonal localised up-welling offshore (James *et al.*, in prep.). The waters are strongly affected by seasonality, principally as a series of eastward-moving winter low pressure systems give way to a large summer high pressure cell. In the summer, currents are generally anti-clockwise, flowing northward along the Eyre coast and west across the GAB. The prevailing westerlies generate an east-flowing current at the shelf edge (Godfrey *et al.*, 1986) and a near-shore longshore current. Winter current directions are generally clockwise.

The middle shelf experiences fluctuations in water composition. In spring, waters over the shelf are 17ºC and isothermal. In summer, the surface waters begin to warm significantly as the GAB plume (high temperature cell in the GAB) moves eastward, while at the same time sub-thermocline waters become cold through up-welling. Shelf water stratification weakens and disappears during autumn and winter, when the saline, nutrient-depleted GAB plume waters cover the entire Ceduna sector. The influence of this water body on sedimentation is profound. Sediments are all relics of ancient sediment production/accumulation. However, a prominent tongue of bryozoan-rich modern sediment extends inboard some 60-70 km from the normal edge of the Bryozoan (sand) facies (B) **(Figure D9)**, and traces the zone of summer upwelling onto the shelf (James *et al.*, in prep.). Summer up-welling is also important for the growth of bryozoans on the outer shelf and upper slope, east of the GAB Marine Park area. The Marine Park is located at the junction between the Eyre sector where deposition is interpreted as reflecting year-round down-welling (a combination of off-shelf transport and reduced in-place production in the Quaternary sediments) and the Ceduna sector where the sedimentation is influenced by the seasonal up-welling (James *et al.*, in prep.).

Sedimentary facies on the shelf and upper slope of the GAB Marine Park

The GAB is the largest sector of the southern Australian continental margin displaying cool-water carbonate sedimentation ranging from locally warm-temperate inboard to cooltemperate outboard (Feary & James, 1998; James *et al.*, in prep.). The northern part of the shelf is covered by warm-water, tropical photozoan carbonate sediments, while the southern half is a region of temperate, cool-water, heterozoan carbonate deposition. This cool-water southern shelf is the largest area of such sedimentation in the modern world. Located in the sub-tropical arid climatic belt, it has no source of terrigenous clastic sediment, consequently almost all of the deposits are carbonates. The sediments have both sub-tropical and temperate attributes (James *et al.*, in prep.).

The sediments on the shelf and upper margin in the Marine Park are a mixture of latest Pleistocene intraclasts and Holocene biofragments. In this region, active inshore sedimentation limits mid-shelf sediment production, inhibited by the presence of the GAB Plume. Seasonal up-welling generates local bryozoan-rich sedimentation well onto the shelf. The sediments down to 500 m depth can be divided into eight facies (James *et al.*, in prep.; **Figure D9)**: Quartzose Skeletal Sand and Gravel (T1), Mollusc-Intraclast Sand (MR), Intraclast Sand (R), Intraclast-Mollusc Sand and Gravel (RM), Intraclast-Bryozoan Sand (RB), Spiculitic Branching Bryozoan Mud (SB), Delicate Branching Bryozoan Sand and Gravel (BB) and Spiculitic Mud (M).

The facies partition on the shelf, particularly within the zone of wave abrasion (shallower than 60 m water depth), indicates that the rocky substrate produces sediment that is mostly swept away by an energetic hydrodynamic environment. In deeper environments, sediments are moved, but not continuously, at least during winter months (James *et al.*, in prep.). The angularity of Holocene bio-fragments and lack of fine particles argues for winnowing and off shelf transport as the major physical process.

GAB Marine Park acoustic facies map of the middle and lower slopes

Acoustic facies mapping has been used to produce a map of Recent deposits in the GAB Marine Park and to deduce processes controlling their deposition. The 3.5 kHz acoustic response of surface sediments was utilised to recognise predicted sedimentary facies (eg. Damuth, 1980). Information from along-track 3.5 kHz profiles, confirmed with full swath-bathymetry and acoustic backscatter data, allows facies maps to be produced between ship tracks.

Seven acoustic facies types were recognised in the GAB Marine Park. These can be attributed to different bedforms and sediment types according to the acoustic facies types determined from 3.5 kHz echo sounder profiles **(Figure D10**, modified from Damuth, 1980 and Whitmore & Belton, 1997):

Facies IA	sharp continuous single echo with no sub-bottom reflectors;
Facies IB	sharp continuous echo with up to 20 continuous, parallel sub-bottom reflectors, on typically flat to gently undulating seafloor;
Facies IIA	sharp to semi-prolonged, continuous echo with discontinuous, parallel sub-bottom reflectors);
Facies IIB	semi-prolonged to prolonged echo with no sub-bottoms;
Facies IIIA	large (>100's m) overlapping, irregular, prolonged hyperbolic echoes;
Facies IIIC	smaller (<100's m), overlapping, irregular, semi-prolonged to prolonged hyperbolic echos;
Facies IIID	small, regular overlapping hyperbolae tangential to the seafloor.

On the upper margin, from 500 to 2500 m deep, and on the continental slope, from 2500 to more than 5000 m deep, six distinct acoustic facies (IB, IA, IIB, IIID, IIA, IIIA) have been sampled by six gravity cores (Figure D11; GC01, GC02, GC03, GC04, GC05, GC06). The three other cores and the three dredges from the slope and the Nullarbor Canyon (GC07, GC08, GC09, DR01, DR02, DR03) support the distinction of more subtle variations on the backscatter data (between high and medium reflectivity on the lower slope; acoustic facies G1, G2).

Seven principal acoustic facies are observed down the slope, corresponding to undisturbed sediments on the upper slope, to interpreted turbidites on the middle slope, and topography and scarps on the lower slope:

- Facies IB, interpreted as undisturbed pelagic and hemipelagic ooze, occurs in water depths of 500 to 1650 m;
- Facies IA, interpreted as a firm plastic mud, is located principally on the upper slope between 500 and 1500 m water depth, in four NE-SW trending narrow bands of 4-5 km width, in shallow submarine canyons that incise only the surficial sediments (less than 200 m deep);
- Facies IIB, interpreted as sand/silt turbidites, extends down to water depths of 2050-2200 m and often shows marked relief;
- Facies IIID, interpreted as small regular bed-forms, occurs in water depths of 2200 to 2400 m;
- Facies IIA, interpreted as fine distal turbidites with minor pelagics, is observed in water depths of 3000-3100 m;
- Facies IIIA, interpreted as extreme topography (scarps), occurs in 3100 to 4300 m water depth;
- Facies IIIC, interpreted as marked topography (scarps, canyons and basement outcrop), occurs in water depths of 4300 to 5500 m.

A distinction has been made in the backscatter interpretation **(Figures D6 & D11)** between high reflectivity (in the middle of the Nullarbor Canyon) and medium reflectivity (mainly west of the canyon). This variation in intensity appears to be linked to variation in thickness of the recent sediments. These sediments are thin to absent in the middle of the canyon (<2 cm) and thicker (<10 cm) on the sloping flanks.

The samples from the axis of the Nullarbor Canyon (two cores) recovered a very thin veneer of recent deposits overlying older sediments (Late Cretaceous or Palaeogene mudstone in GC07 and dark-grey mud in GC08). West of the canyon, two cores and one dredge (GC0206, GC09, DR02) also recovered mudstone and dark-grey mud of Late Cretaceous or Palaeogene age, as well as limestone of probable Eocene-Oligocene age.

In summary, the echo-types, verified by sediment samples, distinguish a smoothed and carbonate-dominated upper slope and a steeper, faulted and siliciclastic lower slope in the GAB Marine Park

D6. SUBSURFACE GEOLOGY

The deeper structure underlying the Benthic Protection Zone has been interpreted using six 3-fold seismic reflection profiles acquired during the AUSTREA-1 cruise. The NNE-trending profiles run downslope, more or less parallel to the Marine Park boundaries, between water depths of 1000 m to more than 5000 m **(Figure D2)**. The interpretation builds on recent work by AGSO's Southern Margin Frontiers project which conducted a regional study of the Bight Basin in 1998-2000 (Totterdell *et al*., 2000). The project was based on the interpretation of petroleum exploration wells in the Bight Basin and a grid of seismic lines in the Bight Basin that included newly acquired data sets (DWGAB and HRGAB surveys) covering the Ceduna Sub-basin and extending into the Eyre and Duntroon Sub-basins, supplemented by selected, mostly reprocessed data from the Eyre, Recherche and Ceduna Sub-basins, and two deep seismic transects across the continental shelf (AGSO Survey 199). The study permitted development of a basin evolution history (Totterdell *et al*., 2000) which is summarised below.

Stratigraphy

Two petroleum exploration wells in the Bight Basin provide control on basement and sedimentary cover. Esso Jerboa-1 well, in the Eyre Sub-basin, and Shell Potoroo-1 well, on the northern margin of the Bight Basin, penetrated extensive Mesozoic to Cenozoic sections. Six sequences were intersected and consist of: (a) Middle to Late Jurassic sands, (b) Berriasian to Barremian sand-prone lacustrine sediments, (c) Aptian non-marine claystones and shales, (d) thin Albian marine shale-prone sediments, (e) Cenomanian marine interbedded shales, claystones and sandstones, and (f) Tertiary open-marine carbonates.

The geological history of the Bight Basin can be divided into three major phases **(Figure D4)**, reflecting the evolution of the basin from an intracratonic rift basin to a passive margin basin (Stagg *et al*., 1991; Totterdell *et al*., 2000). They include a Late Jurassic period of rifting, an Early to Late Cretaceous period of thermal subsidence that culminated in continental breakup, followed by a second phase of thermal subsidence in the Late Cretaceous to Tertiary. Recent studies based on interpretation of deep seismic transects across the continent-ocean boundary and a revised interpretation of magnetic anomalies (Sayers et al, in press) indicate that initial seafloor spreading in the GAB may not have occurred until early Campanian (~ 80 Ma). A period of slow spreading in the Late Cretaceous to middle Eocene was followed by faster seafloor spreading from the middle Eocene onwards. This change to fast spreading caused the collapse of most of the outer continental margin into deepwater environments and a widespread marine transgression (Stagg *et al*., 1990; Willcox & Stagg, 1990; Totterdell *et al*., 2000; Norvick & Smith, 2000) that resulted in the establishment of open marine carbonate sedimentation.

Extensive half graben systems were filled with fluvial and lacustrine clastic sediments (Sea Lion and Minke supersequences). The syn-rift successions are overlain by widespread Berriasian to Albian fluvio-lacustrine to marine sediments of the Southern Right and Bronze Whaler supersequences. The onlapping sag-fill geometry of these Early Cretaceous packages in the Eyre, Ceduna and inner Recherche sub-basins suggests that they were deposited during a period of thermal subsidence. Accelerated subsidence commencing in the Late Albian led to the deposition of the marine shales of the Blue Whale supersequence, followed by a period of gravity-controlled faulting and deformation in the Cenomanian. The White Pointer supersequence is characterised by growth strata associated with a series of listric faults that sole out in underlying ductile over-pressured shales of the Blue Whale supersequence which acted as a décollement. Open marine conditions during the Turonian-Santonian (Tiger supersequence) were followed by the development of massive shelf margin delta complexes in the Late Santonian-Maastrichtian (Hammerhead supersequence). The progradational to aggradational stratal geometries within the Hammerhead supersequence suggest initial high rates of sediment input that subsequently waned during this period. An overall transgressive phase of sedimentation in the early Tertiary (Wobbegong supersequence) was followed by the establishment of open marine carbonate shelf conditions from the Early Eocene onward (Dugong supersequence).

AUSTREA-1 seismic lines in the GAB Marine Park

The seismic data acquired during the AUSTREA-1 cruise allowed an infill of the existing seismic line grid over a narrow part of the Bight Basin, combining AGSO's previous profiles and petroleum exploration data. The new data sets permit more accurate mapping of tectonic features in this area and validate previous suggestions by other authors (Willcox & Stagg, 1990; Norvick *et al*., 2000; Totterdell *et al.*, 2000; Sayers *et al*., in prep.).

The Benthic Protection Zone extends oceanwards across the outer edge of the Ceduna Sub-basin on the upper slope, the continental slope and the continental rise. On the upper slope **(Figure D11)**, from 500 m down to 1300 m water depth, the sedimentary sequences are undisturbed. Below 1600 m depth, small scarps (about 15 m high) are observed on the 3.5 kHz echo sounder. As these features are unrelated to deeper structures, they might be associated with recent gravity sliding.

The main zone of tectonic deformation in the shallow subsurface occurs about 260 km from the coast. These structures are half-grabens approximately 15 km wide and under about 1000 m of Tertiary-Recent sediments. On the continental slope, the normal faults become more abundant, are more closely spaced and, downslope, progressively reach the surface, at about 2800 m depth. At the base of the slope, at about 4000 m water depth, the structures are toe-thrusts.

The geology of the tectonic and sedimentary sequences underlying the Benthic Protection Zone are illustrated in the NNE-SSW–oriented transect AEA1023- AEA1023A **(Figure D12,** location **Figure D2)**. The cross-section shows that the sedimentary succession consists of a prograding wedge of Tertiary carbonates and siliciclastics sediments that overlies a thick cover of Cretaceous sediment. From the bottom to the top of the cross-section, the following succession is observed **(Figure D12;** geologic time-scale - **Appendix 5)**.

- Sediments of Early Cretaceous and Cenomanian age (Southern Right to White Pointer sequences) represent “acoustic basement” on the AUSTREA seismic lines.
- Turonian-Santonian, mostly fine-grained, marine sediments were deposited during a period of increased subsidence rates possibly caused by a second phase of extension in the outer basin.
- Campanian-Maastrichtian post-rift sediments that are mainly composed of massive deltaic and shelf margin complexes deposited during the period of slow seafloor spreading. Within the Hammerhead supersequence, between the mid-Campanian and Maastrichtian successions, a highly reflective layer is observed on the upper slope **(Figure D13)**. This facies extends seawards to the first set of faults intersecting seafloor, about 260 km from the coast (this boundary is indicated by a dashed black line in **Figure D11)**. The depth of these strong reflections is relatively uniform across the upper slope (at about 2.8-3.3 s two-way time) but they seem to be younger in age oceanwards. In fact, they are located just above the mid-Campanian boundary in the northeast and migrate progressively upwards to just beneath the Maastrichtian boundary towards the southwest. This migration in space and time can be attributed to the progradation of a deltaic shelf plain. The acoustic facies of this layer is composed of discontinuous strong reflections, interpreted as coaly deposits within distributary channel sandstone and delta plain mudstone.

- Paleocene-Early Eocene sequence (Wobbegong) of marginal marine to deltaic sandstone. Strong basal unconformity is an eroded and faulted surface. The sequence is absent beneath the mid continental slope, and relatively thin (<200 m) beneath the upper slope.
- Eocene angular unconformity which marks the onset of faster seafloor spreading at about 43 Ma.
- Middle Eocene to recent carbonate sediments that were deposited in a cool-water to temperate environments.

The main structures are graben and half-grabens with listric normal faults on the upper continental slope and associated toe-thrusts at the base of the slope. At least three phases of faulting are observed - Santonian, Late Campanian and Maastrichtian. After the Maastrichtian, the GAB margin subsided progressively. The growth faults sole out at the base of the Turonian unit where shaly layers form a décollement for the overlying sediments. This deformation occurred after the deposition of the Campanian sediments and before the Eocene unconformity. It most likely occurred at the end of the post-breakup thermal sag phase, during Maastrichtian deposition.

Spatial distribution of post-rift sediments (Late Santonian to Recent)

The spatial distribution of post-rift sediments (Late Santonian to Recent) underlying the Marine Park gives some indication about variations in subsidence rates since continental breakup in the Bight Basin. Data generated by AGSO's Southern Margin Frontiers project combined with the new data set acquired in the GAB Marine Park allows the mapping of the thickness of three sequences **(Figures D14 to D16)**: (1) Late Santonian to Maastrichtian sediments (Hammerhead sequence) deposited during the period of slow seafloor spreading, (2) Middle Eocene to Oligocene sediments (lower Dugong sequence) deposited after the onset of faster seafloor spreading, and (3) Oligocene to Recent sediments (upper Dugong sequence).

Sedimentation during the upper part of the Late Cretaceous **(Figure D14)** was mainly into an older depocenter, between Australia and Antarctica, with up to ~3 s twt (~3 km) of sediments deposited. The isopachs show that the Late Cretaceous basin was controlled by WNW-trending features, sub-parallel to transform faults associated with early movement between Australia and Antarctica (Willcox & Stagg, 1990). Around this older depocentre, the Santonian-Maastrichtian sediment thickness is relatively uniform at 500 ms twt.

During the Eocene **(Figure D15)**, the deposition was locally relatively high on the continental rise (up to 2.5 s twt, or 2.4 km based on an acoustic velocity of 1.9 km/s), but lower in the old depocentre. This observation is consistent with the dramatic decrease in sediment influx in the early Tertiary, which resulted in the establishment of a sediment-starved shelf. The acceleration of seafloor spreading in the mid-Eocene then led to subsidence of the margin and the development of an aggradational carbonate shelf (up to 250 ms twt or 230 m thick).

Post-Oligocene sediments **(Figure D16)** are uniformly distributed on the shelf and on the continental slope with thicker deposits in the Ceduna Sub-basin and on the continental slope (up to 750 ms twt thick, or up to 650 m based on an acoustic velocity of 1.7 km/s). They thin progressively seawards (less than 100 ms twt, or 90 m thick). These sediments were also deposited in rapidly increasing water depth during the fast spreading episode that started in mid-Eocene.

Tectonic variations across the Benthic Protection Zone

A series of line drawings based on seismic profiles (AUSTREA-1 cruise) across the Benthic Protection Zone **(Figure D17)** illustrates variations in structure and sedimentary succession in the marine park, from west to east. The profiles show a distinct increase in deformation over a short distance (about 80 km) towards the Nullarbor Canyon. The continental slope becomes steeper and more faulted towards the east, where the faults reach the surface and cut the slope into small steps, similar to the fault-scarp that was sampled during the *Southern Surveyor* cruise (DR02 on the line AEA1023, **Figure D12)**. In and adjoining the Nullarbor Canyon, the listric normal faults are conjugate to the toe-thrusts and create depressions at the surface like the deep holes observed in the Nullarbor Canyon. This increase in deformation eastwards is associated with an increase in sediment thickness towards the centre of the Ceduna Sub-Basin. This is consistent with a gravity-slide mechanism, i.e. the thicker the sedimentary cover, the more deformation is expected.

D7. INTERPRETATION OF THE DEEP HOLES IN THE NULLARBOR CANYON

Based on the new AUSTREA-1 data, combined with geological samples recovered during the Southern Surveyor SS01/00 cruise, a mechanism for the formation of the deep holes in the Nullarbor Canyon is proposed.

The deep structure below one of the deep holes is shown on the AUSTREA-1 seismic profile, AEA1022 **(Figure D18)**, a N-S cross-section through the Nullarbor Canyon. The deep hole appears to be tectonically controlled by a large number of faults, grouped as a negative flower structure. Such a feature is usually associated with transtensional movement. Therefore, it is suggested that some strike-slip movement occurred on a feature localised in the Nullarbor Canyon, probably during the onset of slow seafloor spreading, in the Campanian or Maastrichtian. These transtensional faults appear to have been reactivated recently to create new faults that reach the surface. The faults sole out at the base of Turonian shales, which form a décollement for the younger growth faults. Movement on the décollement surface was gravity-driven and it is suggested that the growth faults initiated the surface depressions of the holes. The marine shales are likely to be over-pressured (Totterdell *et al.*, 2000), allowing water to escape along the newly created faults. An observed lateral variation in the acoustic facies beneath (fuzzy facies) and beside (clear facies) the holes might be associated with fluid seepage. The water escape may have prevented new deposition of younger sediments in the holes. The hypothesis of fluid release will be tested by a cruise of the R/V *Franklin* in early 2001 (Cruise FR01/01, Chief Scientist Dr Ray Binns of CSIRO Exploration & Mining). Deep contour currents in this region may also contribute to shaping the holes and keeping them clear of sediments.

PART E. Summary of Results

E1. SEABED RESOURCE POTENTIAL

Petroleum

The Gippsland Basin is well explored with major production from multiple oil and gas fields in the central part of the basin, on the continental shelf. Exploration and development is extending into the deeper parts of the basin beyond the shelf edge. As shown by the AUSTREA-1 seismic survey, extensions, or sub-basins of the Gippsland Basin occur to the north and south, and it is likely that these will receive more exploration attention in the future.

In the offshore Otway Basin, development of the Minerva gas field is going ahead, and it is likely that development of the La Bella and Troas gas fields will follow. Exploration of the offshore Otway is continuing in a number of permit areas. The AUSTREA-1 seismic data, collected on the poorly-surveyed mid-upper continental slope, will assist the exploration effort and contribute to understanding the structure and development of this basin. Exploration is also continuing in a number of permits in the nearby Bass Basin, and development of the Yolla gas field is likely in the near future.

Off western Tasmania, an exploration permit is held over the Strahan Sub-basin of the Sorell Basin. Other, poorly explored parts of the Tasmanian margin were crossed by the AUSTREA survey, and were shown to be underlain by basins with significant sediment thickness (>1.5 km) and petroleum potential. These include the Port Davey and Sandy Cape Sub-basins off southwest and northwest Tasmania, respectively, and also unnamed basins off southern Tasmania, east Tasmania (rift basin off Freycinet Peninsula) and northeast of Cape Barren Island.

The STR, with its deepwater wrench basins containing up to 6 km of sediment fill, has medium to long term petroleum potential. The same applies to the Gower Basin northeast of Lord Howe Island, but no potential is likely close to the island. BSRs identified over extensive areas of the STR, and also on the northeast Lord Howe Rise, indicate the presence of methane hydrates in the sedimentary section (upper few hundred metres). Such gas hydrate accumulations may be of long term resource potential.

Though few wells have been drilled in the Great Australian Bight, the Bight Basin is considered to have promising petroleum potential. Thick basin development was confirmed by the AUSTREA-1 seismic profiles. The Bight Basin has been the subject of recent work by AGSO (Totterdell *et al*., 2000) and formed the basis of the 1999 Acreage Release in that area. Three exploration permits have been taken up, and these lie over or adjacent to the Benthic Protection Zone.

Deepsea mineral deposits

Dredge sampling has shown that extensive manganese nodule fields are present on many parts of the abyssal plain in the South-east Marine Region, and that nodules are large and apparently abundant on rocky areas of the STR below 2400 m water depth (Exon, 1997). The metal grades are sub-economic at present, however. The swath backscatter images and relief maps indicate areas of rocky seabed where nodules are likely to be present. High backscatter intensity from much of the abyssal seafloor adjacent to the southern STR suggests the presence of extensive manganese nodule pavements, exposed or perhaps covered by up to several metres of pelagic sediment. Though not of direct commercial/mining interest, knowledge of the distribution of these deposits is nevertheless of environmental importance.

Crusts of relatively high Co content occur on rocky substrates on the STR in water depths of less than 2000 m, and have economic potential. But the sampling data base is small, and more prospecting is required to quantify the potential. The target zone would be the oxygen minimum between water depths of 1000-2000 m. Areas of high backscatter intensity, indicating hard bottom/rocky substrate, are the most promising for further investigations. High Co crusts have been confirmed on the STR, but other parts of the continental margin with little or no sediment cover may host Co-rich ferromanganese crusts, including the continental slope south of Tasmania, off Kangaroo Island and off NSW. The flanks of large seamounts such as Cascade, Lord Howe Island/Ball’s Pyramid, and those mapped by AUSTREA off the eastern margin of the STR, may also have potential.

Fisheries

AUSTREA completed the swath-mapping of most of the major and commercially important deepsea fishing grounds in the South-east Marine Region, including:- St Helens Hill/St Patricks grounds off northeast Tasmania (orange roughy), Cascade Seamount on the East Tasman Plateau (orange roughy/dory), Southern Hills south of Tasmania (orange roughy/dory), South Tasman Rise trawl fishery on the summit area (orange roughy), canyon systems off west Tasmania (blue grenadier).

The detailed seabed maps and images produced will assist development of management plans for these fisheries so that fish stocks can be exploited in a sustainable way, yet ensuring that the ecosystems and benthic habitats are protected. The detailed maps of the bottom terrain will allow fishers to minimise loss and damage of bottom gear and will assist development of fishing techniques to minimise damage to the fragile benthic ecosystems often found on seamounts and other deepsea terrain.

Biodiversity conservation

The AUSTREA surveys, together with results of other recent AGSO multibeam surveys, now provide images and maps, unprecedented in detail, of the seabed landscape over much of the Australian sector of the South-east Marine Region, particularly in the deepwater frontier below about 300 m. The data reveal a tremendous diversity in physical environments, with a great range of terrain types and bottom substrates. The region also lies at the confluence of three major ocean current systems, the Antarctic Circumpolar Current, the East Australian Current and the Zeehan Current (Rintoul, 2000; Cresswell, 2000). Hence this region can be expected to host a wide diversity of ecosystems and biota, as has been shown by targeted deepwater biological studies such as that by CSIRO on the volcanic ‘hills’ south of Tasmania, in the area of the new MPA.

The new maps and images of existing MPAs will allow focussed studies of species, biological dynamics and habitats within these areas. The new high-resolution seabed data has allowed the identification of localised features that may be of special conservation value, such as the isolated volcanic(?) pinnacles on the sedimented mid continental slope of the GAB BPZ.

The new survey data will be vital for planning future biological and environmental research studies aimed at understanding the nature and ecology of the seabed communities that inhabit this frontier area, and the conservation of their biodiversity.

E2. LAW OF THE SEA IMPLICATIONS

The AUSTREA-2 survey along the eastern margin of the STR has provided important new FoS, 2500 m isobath, and sediment thickness information that will help define the outer boundary of the extended Continental Shelf, and so Australia's seabed jurisdiction under UNCLOS **(Appendices 3 & 4)**. Australia's claim, due to be submitted to the UN in 2004, will probably be for most, if not all, of the southern STR **(Figure A4**; Bernardel, 1999). If accepted, Australia will be responsible for managing and safeguarding the ecological health of the seabed in this area, and this will probably require the monitoring and control of seabed operations, including current activities such as demersal trawling (eg. for orange roughy) and potential future activities such as oil drilling.

E3. CONCLUSIONS

This report, based on the AUSTREA surveys, presents an analysis of seafloor morphology and geology for the offshore southeast Australian region south to 50°S, including the South Tasman Rise, offshore Lord Howe Island and the GAB Marine Park. This study encompasses all the AUSTREA-1 survey and the southeast Tasmania and South Tasman Rise parts of AUSTREA-2. These surveys were designed to complement data coverage of earlier surveys in the region, notably the AGSO TASMANTE and Sojourn7 swath-surveys. Integration of the various data sets has resulted in a detailed data base for much of the South-east Marine Region.

The new data, integrated with the pre-existing seabed data sets, provide the basis for developing environmental management strategies and the South-east Regional Marine Plan, and also provide framework information to support future biological and physical scientific field studies and research.

E4. RECOMMENDATIONS

The AUSTREA swath, geophysical and oceanographic data comprise a wealth of information that a report such as this cannot hope to cover completely. It is anticipated that the data will be used extensively in the future for environmental planning and further scientific research, covering a multitude of both local and regional aspects of the South-east Marine Region marine environment.

Following from this study, some recommendations for future work are detailed below:-

- continue to research seabed sedimentary processes (eg. Harris *et al*., 1999) and geological framework and development (eg. Exon et al., 1997b, Hill *et al*., 1997c, Hill *et al*., 1998) within the South-east Marine Region using the new AUSTREA swath data, earlier surveys and future targeted surveys. Such studies, aimed at a full understanding of the offshore geology, and its past and present dynamics, are vital for future support of environmental planning and management.

- ☐ continue work to assess the petroleum potential of frontier basins within the South-east Marine Region. The new seismic data collected during the AUSTREA surveys have helped considerably to define and delineate a number of these frontier basins, particularly off Tasmania and on the STR, but further work is needed to integrate all the data now available, and to plan additional surveys on parts of the margin where vital information is lacking.
- ☐ conduct further research to test and refine techniques for rapidly and cost-effectively classifying seabed sediment facies and benthic habitats using acoustic single and multibeam systems (eg. 3.5 plus kHz profiling and multibeam backscatter recording), with pilot studies on parts of the continental shelves (as done recently by CSIRO Marine Research on cruise SS00/01) and on the continental slope, using ground-truthing control and calibration (seabed sampling and video). More seabed samples are required in the South-east Marine Region to improve sediment classification and to allow a more robust analysis of acoustic facies distribution and relationships between habitat and species.
- ☐ produce a complete, fully corrected and processed bathymetry data base for the South-east Marine Region, and generate detailed gridded data sets for seabed analysis and display. This data base would include all the AUSTREA swath data which are of excellent quality, swath data from earlier surveys, all ship trackline data, point soundings (largely from hydrographic maps and sample stations), and bathymetry data from petroleum industry seismic surveys (2-D & 3-D).
- ☐ conduct studies of the benthos, based on the new detailed swath maps, in a number of critical areas within or adjacent to the AEEZ. These are areas where seabed exploitation (including bottom trawling) and other commercial activities are encroaching on pristine seabed terrain and systems. Such work would be along the lines of studies conducted by CSIRO Marine Research on the seamounts off southern Tasmania. More use of video recording of the seabed is suggested, as is the application new technology involving tools such as ROVs (remotely operated vehicles) and manned submersibles. Areas where such surveys and assessments may be needed include:- (i) seamounts and hills on the summit area of the STR, on the flanks of Cascade Seamount, in deep water areas east and northeast of St Helens Hill, (ii) the tops of the large seamounts off the northeast margin of the STR, (iii) the heads of canyon systems off west Tasmania, (iv) the upper continental slope of the Gippsland Basin.
- ☐ investigate the distribution and extent of gas hydrates in the region as a future potential resource, particularly on the STR where BSRs have been identified. This may require further reflection seismic, seabed geochemistry and drilling.
- ☐ swath-survey the southern STR, where only sparse coverage exists at present, to identify and map all areas of high-standing topography, including seamounts, so that an assessment of the benthos can be made. A seismic survey run concurrently would allow assessment of petroleum potential at the same time.
- ☐ assess fisheries potential and conduct exploratory fishing in the more remote regions, particularly the southern STR where large seamounts and volcanic ‘hills’ terrain were mapped.
- ☐ assess conservation potential and conduct biological sampling in the newly surveyed or more remote regions, particularly the STR where large seamounts and volcanic ‘hills’ terrain were mapped.

E5. ACKNOWLEDGMENTS

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Glossary of Technical Terms

Many of these definitions are sourced from Kennett (1982) - a standard text on marine geology and seafloor processes, Sheriff (1991) - exploration geophysics encyclopedia (Society of Exploration Geophysicists), and Kearey (1993) – encyclopedia of earth sciences.

ACC: Antarctic Circumpolar Current, the world's most voluminous ocean current, which flows clockwise around Antarctica.

Acoustic: sonar or sound signal travelling through water or other medium.

AEEZ: Australian Exclusive Economic Zone, the marine zone within a 200 nautical mile radius of Australia's coastal baseline where Australia has complete jurisdiction over the resources of the water column, seabed and subsoil.

ARC/INFO^{TM}: trademark software product of Environmental Systems Research Institute (ESRI) able to perform a large suite of Geographical Information System (GIS) mapping and processing functions.

Basalt: fine-grained, dark-coloured volcanic rock rich in ferromagnesian minerals. The compositional equivalent of gabbro and dolerite. It forms the upper layers of oceanic crust.

Benthic: living on the bottom of the sea.

Benthos: marine organisms living on the seafloor.

Biodiversity: the variety of all life forms: the different plants, animals and micro-organisms, the genes they contain and the ecosystems they form.

Breakup: the point at which extensional rifting of continental crust results in the appearance of volcanic and igneous material (ie. oceanic crust) along an extensive lineament and the commencement of continental drift between the opposing sides.

Caraibes^{TM}: multibeam sonar processing and display software developed by IFREMER, and used on *L'Atalante* and at AGSO.

COB: continent-ocean boundary. The boundary or zone off a continent where continental rocks (eg. granites, metasediments) end and oceanic crust (basalt) begins – developed by rifting of a continent and then seafloor spreading, forming the ocean basin.

Contour currents: ocean bottom-water circulation, which often follows depth contours. Stratification in the water column tends to force the currents along contours rather than up and over topography. They are best developed in areas of steep topography, especially at the continental margins where the bottom topography extends through the greatest thickness of the water column.

Debris flows: gravity-induced, down-slope movements of mixtures of coarse and fine debris and water, resembling the flow of wet concrete.

Demersal: Relating to the sea floor. Demersal species are those living on, or closely associated with, the sea floor.

Dolerite: medium-grained igneous rock the compositional equivalent of basalt and gabbro. They often occur as dykes and sills.

Ecosystem: A dynamic complex of plant, animal and microorganism communities and their non-living environment interacting as a functional unit.

EEZ: the Exclusive Economic Zone refers to the marine zone within a 200 nautical mile radius of a coastal state’s baseline where the coastal state has complete jurisdiction over the resources of the water column, seabed and subsoil.

Eocene: geological epoch of the Tertiary period, extending from about 55 to 34 million years in the past (see Appendix 5)

ER Mapper™: trademark product of image processing software by Earth Resource Mapping Pty Ltd.

Facies: the sum total of features such as sedimentary rock type, mineral content, sedimentary structures, bedding characteristics and fossil content, which characterise a sediment as having been deposited in a given environment.

FoS: foot-of-slope. Base of the continental slope.

Hot-spot: oceanic volcanoes sourced by a magma source beneath the crust in the upper mantle. Generally associated with chains of volcanoes representing the direction of plate motion over the stationary volcanic source.

IFREMER: Acronym for French marine science institute with headquarters in Brest, *Institut Français de Recherche pour l’Exploitation de la Mer*.

IMCRA: Interim Marine and Coastal Regionalisation for Australia (Technical Group), Environment Australia.

Isobath: A contour line joining points of equal depth of the sea floor.

kHz: unit of one thousand Hertz (cycles/second), referring to the frequency of a transmitted acoustic signal. Multibeam systems generally operate at frequencies of between 10 kHz (deep-water systems) and 200 kHz (shallow-water systems).

Listric: style of faulting in which the fault surface that becomes less steep as one goes deeper, becoming nearly horizontal at some depth. Rotation is involved in this type of faulting.

Ma: million years ago (before present).

Manganese seafloor deposits: the accumulation at the seafloor of primarily manganese, but also iron, copper, nickel and cobalt. These elements are precipitated out of the water column and accrete in an oxidised state as nodules, crusts or thin coatings on rocks. In many areas of the seafloor they exist as pavements of nodules and are in sufficient quantities to make them of economic interest. Although prevalent at the seabed interface they also occur as buried deposits where sediment accumulation rates have been higher.

Marine Protected Area (MPA): An area of sea especially dedicated to the protection and maintenance of biological diversity, and of natural and associated cultural resources, and managed through legal or other effective means.

mGal: milligal, unit of acceleration used with gravity measurements (equals 10^{-5} m/s^2). At the earth's surface on the equator, gravity is about 978,000 mGal; at the poles it is ~0.5% stronger.

Miocene: geological epoch of the Tertiary period, extending from about 24 to 5 million years in the past (see Appendix 5).

Multibeam: acoustic mapping system involving multiple acoustic beams fanning out across the path of the ship so that a swath-like portion of seafloor is ensonified and mapped.

Nautical mile (nm): unit of distance equivalent to 1 minute of the great circle of the earth, equals 1.852 km.

nT: nanotesla, unit of magnetic flux density (field strength). The earth's magnetic field varies from about 30,000 nT at the equator to 60,000 nT at the poles.

Orange roughy: orange-coloured deepsea fish species *Hoplostethus atlanticus*, very important commercially and trawled on seamounts off southeast Australia.

Patagonian toothfish: fish species *Dissostichus eleginoides* occurring around most sub-Antarctic islands and submarine plateaux. They grow to over 2 m length and 100 kg in weight, and are predatory, feeding mainly on mid-water fish and squid as well as benthic animals.

Petrosys^{TM}: mapping and basin analysis software system by Petrosys Pty Ltd, Adelaide, South Australia

Placer: a mineral deposit formed by the sorting and washing action of water. Usually a dense mineral such as gold or cassiterite (tin).

Pleistocene: geological epoch from 2 million to 10,000 years ago, corresponding to a period of major glaciations on earth.

Seafloor spreading: the mechanism by which new oceanic lithosphere is created at an oceanic ridge (spreading centre) between diverging plates. Typical spreading rates are 1-10 cm/year.

Seamount: large conic-like submarine edifice, usually a volcano, rising above the sea floor. Called guyot if the top is planated.

Sedimentology: the physics and chemistry of sediments and sedimentary rocks. Refers to sediment grain characteristics, mineral composition, depositional processes and environments.

South Tasman Rise: large elevated submarine massif south of Tasmania cored by continental rock and containing sedimentary basins. Formed during Australian-Antarctic separation.

Spreading fabric: the alternating ridge-valley morphology developed on bare oceanic crust as a result of its formation along linear mid-ocean spreading centres.

Strike-slip: differential horizontal (or wrench) motion along a fault. Termed right-lateral if the displacement of the far block is to the right when viewed from either side, and vice versa for left-lateral motion.

Subduction: the tectonic process at the boundary between two converging lithospheric plates in which one plate moves downward beneath the other.

Tectonics: the study of the processes by which the earth's crust has attained its present structure.

Transpression: tectonic strike-slip motion with a component of compression between the opposing segments of crust.

Transtension: tectonic strike-slip motion with a component of extension between the opposing segments of crust.

Turbidites: the sediments deposited by turbidity currents, which are marked by graded bedding, moderate sorting and well-developed primary structures.

Turbidity currents: short-lived, powerful, gravity-driven currents consisting of dilute mixtures of sediment and water of density greater than the surrounding water, the motion of which is maintained by internal turbulence.

Twt: two-way time. The depth of an event or horizon, or the thickness of a geological unit, as measured in two-way reflection time in a seismic section. For example, given an average seismic velocity of 2000 metres/second (typical for relatively young, upper crustal sediments), 1 second twt represents 1 km depth or thickness.

UNCLOS: acronym for the *United Nations Convention on the Law of the Sea*, a 1982 treaty providing for the means to define and regulate a coastal state's marine jurisdiction. Australia ratified it in 1994, thereby giving it until 2004 to justify its relevant claim. See also Appendices 3 & 4.

APPENDICES

Appendix 1.
Shipboard and Post-processed Survey Data

Details of the data types, system and survey parameters, survey coverage, monitor records acquired and shipboard data products are available in the cruise reports for AUSTREA-1 and AUSTREA-2 (Hill *et al.*, 2000 and Bernardel *et al*., in press, respectively). A summary of the data collected, and the status of post-cruise processing at AGSO is provided below. All primary digital data sets were taken off the ship on Exabyte tape, and much of the data are now on disk on AGSO's computer and data base systems. Detailed maps of the cruise navigation, bathymetry and backscatter imagery have been lodged with NOO as 1:250,000 map sheets (see Figure A5 for sheet locations). These map sheets include Nos. 4 (Lord Howe Island) to 20 (GAB Marine Park) from AUSTREA-1, and 251 (southeast Tasmania) to 255 (southern STR) from AUSTREA-2.

Navigation

Precise differential GPS navigation data were collected throughout the cruises (positional accuracy ~1 metre). The data required minimal processing on board because of their high quality, and were reduced to final navigation as Caraibes *.nvi files. Time-annotated ship's tracks were displayed on the 1:250,000 maps produced on board (Figure A5).

Simrad EM12D multibeam swath-bathymetry and backscatter imagery

The EM12D data were recorded on the ship's ARCHIV data acquisition system and processed to Caraibes-compatible data formats. Further processing and editing was done to enhance data quality and to ensure that optimum sound velocity corrections had been applied. The data were then gridded, 150-200 m grid spacing for bathymetry and ~50 m for backscatter, and displayed as maps and images. Detailed maps at 1:250,000 scale of bathymetry contours (generally 50 m contour interval) and backscatter imagery (sheet locations in Figure A5) were prepared on board, and copies of these were provided to NOO.

6-channel GI-gun reflection seismic

The seismic data were converted to SEG-Y format after acquisition, and processed to produce a preliminary stack of the data. These stacks were displayed on film, mainly so that an initial interpretation of the data could be made. The SEG-Y field data were subsequently fully processed (stacked and migrated) at AGSO. All the processed AUSTREA-1 and AUSTREA-2 data have been loaded into a GeoFrame project for interpretation.

3.5 kHz sub-bottom profiles

On board *L'Atalante* the 3.5 kHz data were recorded in SEG-Y format and profiles recorded on high-quality opaque strip-chart film. The digital data volumes are huge, and so redisplay of the digital data has not been practical for regional studies. All 3.5 kHz interpretation work so far has been on the hardcopy monitor records, and this has been efficient and very satisfactory.

Gravity

The raw gravity data collected by the two gravity meters on the ship are currently undergoing final processing at AGSO. The processing involves converting the relative gravity values measured on board to absolute values from the gravity ties to shore base stations made while the ship was in port, correcting for meter drift, correcting for ship's heading and latitude, making a correction for recording delay, editing to remove bad or noisy data, and finally filtering and resampling.

Total field magnetics

Processing of the raw shipboard data is underway at AGSO. The data require digital editing and spike removal, reduction to magnetic anomaly values (subtracting a global IGRF reference field), correction for distance of the sensor behind the navigation reference point on the ship, filtering and resampling.

Oceanographic data

XBTs (expendable bathythermographs) were launched twice a day and sometimes more often, depending on sea temperature variability (affected by ocean currents and gyres) and survey program. The digitally recorded temperature–pressure data were converted to sound velocity-depth profiles, and used to correct the EM12D data for refraction (ray-bending) effects and time–to-distance (depth) processing. The XBT data are also very useful for oceanographic studies, and contribute to the regional data base.

Digital logging of sea surface temperature and salinity was done throughout the cruises, as well as continuous recording of ocean current data using the 75/300 kHz ADCP (acoustic doppler current profiler).

All the oceanographic data are held on tape at AGSO at present, but will be made available to marine science organisations such as CSIRO Marine Research and the Australian Oceanographic Data Centre as required.

Appendix 2.
Digital Products and Geological Data Sets

Below is a listing of all the primary and derived digital data sets constructed as a result of the study leading to this report. These data sets form the basis for most of the images presented in the figures. The other data sets from AUSTREA are described in Appendix 1 and elsewhere in this report, and also in the post-cruise reports (Hill *et al.*, 2000 and Bernardel *et al.*, in press).

Spatial Gridded Data Sets

ER Mapper grid format (can be converted to ARC/INFO).

- AUSTREA-1 and AUSTREA-2 merged bathymetry for the southeast Australian region bounded by 136ºE, 152ºE, 36ºS and 50ºS.
- Merged bathymetry for the above region - merge of all AUSTREA swath-bathymetry, the main earlier swath surveys in the region (TASMANTE (1994) and Sojourn7 (1997)), and other AGSO regional bathymetry data sets (including Bernardel (1997), and use of satellite predicted bathymetry (Smith & Sandwell, 1997) in some areas of sparse ship coverage).
- Merged AUSTREA-1 and AUSTREA-2 backscatter imagery for the southeast Australian region bounded by 136ºE, 152ºE, 36ºS and 50ºS. and stored as values between 0 and 255 reflecting intensity levels.

- Merged backscatter imagery for the above region - merge of all AUSTREA imagery and that of the main earlier swath surveys in the region (TASMANTE (1994) and Sojourn7 (1997)).
- Terrain slope (degrees) – from the merged AUSTREA swath-bathymetry over the region bounded by 136ºE, 152ºE, 36ºS and 50ºS.
- Terrain aspect (degrees azimuth) – from the merged AUSTREA swath-bathymetry over the region bounded by 136ºE, 152ºE, 36ºS and 50ºS.

Spatial Vector Data Sets

ER Mapper vector or Petrosys vector/culture files (can be converted to ARC/INFO cover).

- Contours – line contours for any depth constructed on demand from the bathymetry grid.
- Submarine volcanic cones – point data showing the interpreted distribution of these features.
- Canyons, seafloor escarpments, main fracture zones – polyline data showing the interpreted distribution of these features.
- Seabed sediment and bedrock outcrop distribution (including volcanic terrain and hot-spot volcanoes) – polygons outlining the interpreted distribution of seafloor sediments/outcrop.

Seabed geological sample data set (AGSO data base) – station location and brief geological description

This is a sub-set of information in AGSO’s marine data bases and was prepared for the South-east Marine Region especially for this study. It represents several thousand data points (sample sites), and can be provided as an Excel spreadsheet, simple ASCII file or Petrosys culture file.

Appendix 3.

United Nations Convention on the Law of the Sea (UNCLOS) 1982, Article 76

Article 76: Definition of the continental shelf

1. The continental shelf of a coastal State comprises the seabed and subsoil of the submarine areas that extend beyond its territorial sea throughout the natural prolongation of its land territory to the outer edge of the continental margin, or to a distance of 200 nautical miles from the baselines from which the breadth of the territorial sea is measured where the outer edge of the continental margin does not extend up to that distance.

2. The continental shelf of a coastal State shall not extend beyond the limits provided for in paragraphs 4 to 6.

3. The continental margin comprises the submerged prolongation of the land mass of the coastal State, and consists of the seabed and subsoil of the shelf, the slope and the rise. It does not include the deep ocean floor with its oceanic ridges or the subsoil thereof.

4. (a) For the purposes of this Convention, the coastal State shall establish the outer edge of the continental margin wherever the margin extends beyond 200 nautical miles from the baselines from which the breadth of the territorial sea is measured, by either:

   (i) a line delineated in accordance with paragraph 7 by reference to the outermost fixed points at each of which the thickness of sedimentary rocks is at least 1 per cent of the shortest distance from such point to the foot of the continental slope; or

   (ii) a line delineated in accordance with paragraph 7 by reference to fixed points not more than 60 nautical miles from the foot of the continental slope.

   (b) In the absence of evidence to the contrary, the foot of the continental slope shall be determined as the point of maximum change in the gradient at its base.

5. The fixed points comprising the line of the outer limits of the continental shelf on the seabed, drawn in accordance with paragraph 4 (a) (i) and (ii), either shall not exceed 350 nautical miles from the baselines from which the breadth of the territorial sea is measured or shall not exceed 100 nautical miles from the 2,500 metre isobath, which is a line connecting the depths of 2,500 metres.

6. Notwithstanding the provisions of paragraph 5, on submarine ridges, the outer limit of the continental shelf shall not exceed 350 nautical miles from the baselines from which the breadth of the territorial sea is measured. This paragraph does not apply to submarine elevations that are natural components of the continental margin, such as its plateaux, rises, caps, banks and spurs.

7. The coastal State shall delineate the outer limits of its continental shelf, where that shelf extends beyond 200 nautical miles from the baselines from which the breadth of the territorial sea is measured, by straight lines not exceeding 60 nautical miles in length, connecting fixed points, defined by coordinates of latitude and longitude.

8. Information on the limits of the continental shelf beyond 200 nautical miles from the baselines from which the breadth of the territorial sea is measured shall be submitted by the coastal State to the Commission on the Limits of the Continental Shelf set up under Annex II on the basis of equitable geographical representation. The Commission shall make recommendations to coastal States on matters related to the establishment of the outer limits of their continental shelf. The limits of the shelf established by a coastal State on the basis of these recommendations shall be final and binding.

9. The coastal State shall deposit with the Secretary-General of the United Nations charts and relevant information, including geodetic data, permanently describing the outer limits of its continental shelf. The Secretary-General shall give due publicity thereto.

10. The provisions of this article are without prejudice to the question of delimitation of the continental shelf between States with opposite or adjacent coasts.

Appendix 4.
Informal Terms Relating to UNCLOS Article 76

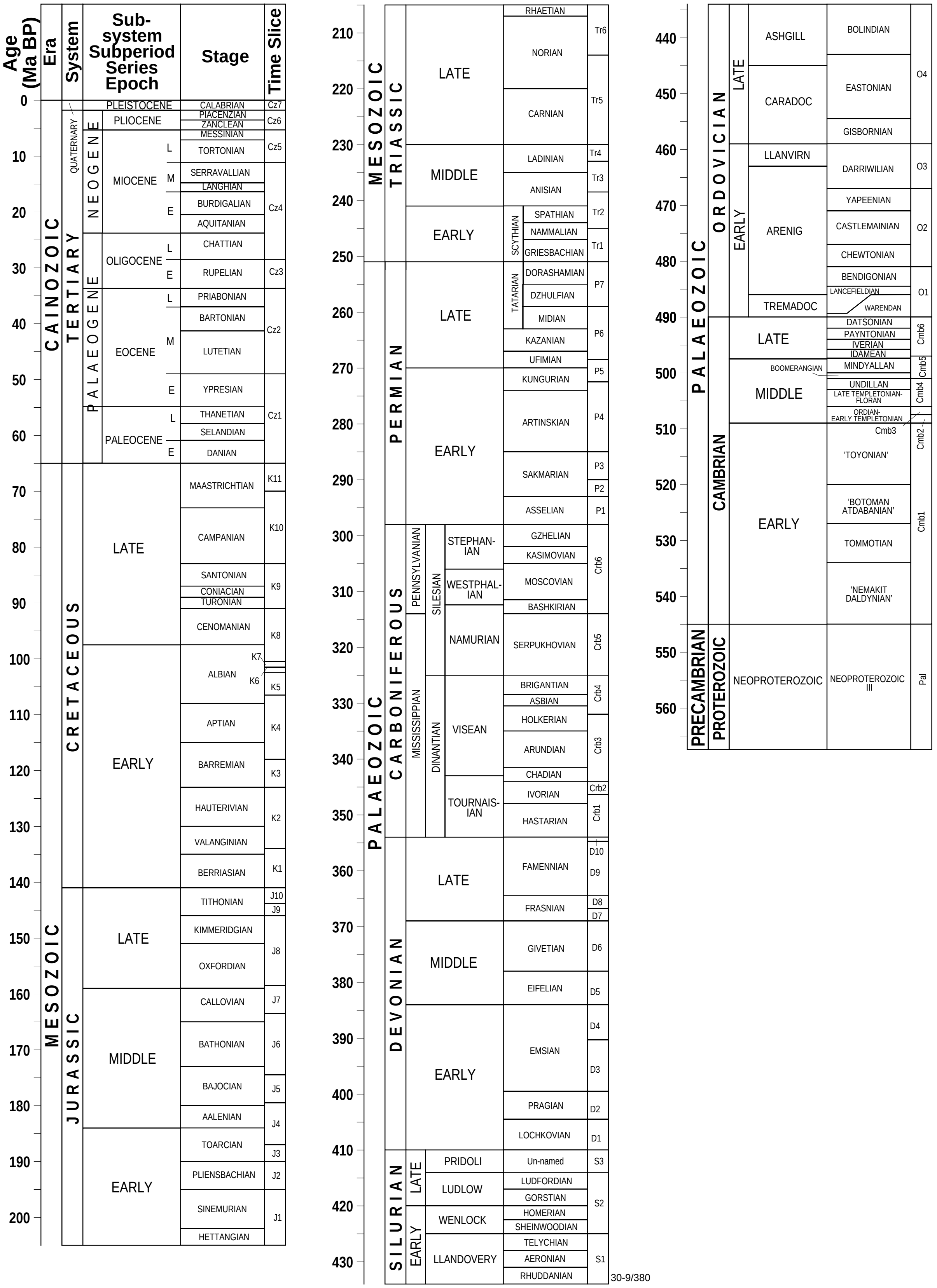
Application of Article 76 of United Nations Convention on the Law of the Sea (UNCLOS) raises several concepts and terms which will be referred to frequently in interpretations of seismic/bathymetric survey lines for the purposes of 'legal' Continental Shelf (CS) definition. Following are simplified definitions of the more important terms that we commonly use. Some aspects of the application of Article 76 remain unclear, and will only be resolved following further deliberation by the Commission on the Limits of the Continental Shelf.

Firstly, a *Hedberg arc* may be drawn, with a radius of 60 nautical miles, from an interpreted foot-of-slope (FoS) position. The location at which this arc intersects the seaward extension of the survey line is called the *Hedberg point.* With a series of FoS positions established around a continental margin, at a spacing of less than 120 nautical miles, a series of intersecting Hedberg arcs may then be constructed. Clearly, as the spacing between survey lines (and therefore, the FoS positions) decreases, the envelope of the intersecting Hedberg arcs approaches a 60 nautical mile buffered locus of the FoS, except in some cases where the latter contains embayments. This is part of the reason for AGSO's 'safe minimum' approach, where we aim to space survey lines ~30 nautical miles apart, where logistically possible. The final outcome, the true *Hedberg Line* (the informal name for the line that defines the outer edge of the 'legal' continental margin, as contained in Article 76, paragraph 4(a)(ii), of UNCLOS), is constructed by joining selected points on the Hedberg arcs by straight lines, not more than 60 nautical miles long. This would normally be done in a manner so as to maximise the size of the enclosed 'legal' continental margin. This true Hedberg Line will normally only intersect the survey line at the Hedberg point where the locus of the FoS points is a straight line. Such situations are unusual in the context of CS beyond 200 nautical mile, since it is normally associated with irregularly shaped marginal plateaus.

Secondly, a *Sediment Thickness point* may be determined, by interpretation of a seismic survey line (or possibly by drilling), where the 1% sediment thickness criterion is satisfied. That is, the point at which the thickness of sedimentary rocks is at least 1% of the shortest distance from such point to the FoS. In contrast to the Hedberg arc, this is strictly a single point, which may be joined to adjacent Sediment Thickness points to form the *Sediment Thickness Line* (the informal name for the line that defines the outer edge of the 'legal' continental margin, as contained in Article 76, paragraph 4(a)(i), of UNCLOS), or to selected points on Hedberg arcs, again by straight lines, not more than 60 nautical miles in length.

Finally, the fixed points (not more than 60 nautical miles apart) comprising the line which defines the outer limits of the CS, may not lie beyond one or other of two cut-offs. The first cut-off is 350 nautical miles from the baseline (informally called the *350 nautical mile cut-off line*), and the second is 100 nautical miles beyond the 2500 m isobath (informally called the *isobath cut-off line*). The former is purely a geometrical construction from the Territorial Sea baselines, whereas the latter depends on definition of the 2500 m isobath.

Appendix 5.
Geological Time Scale



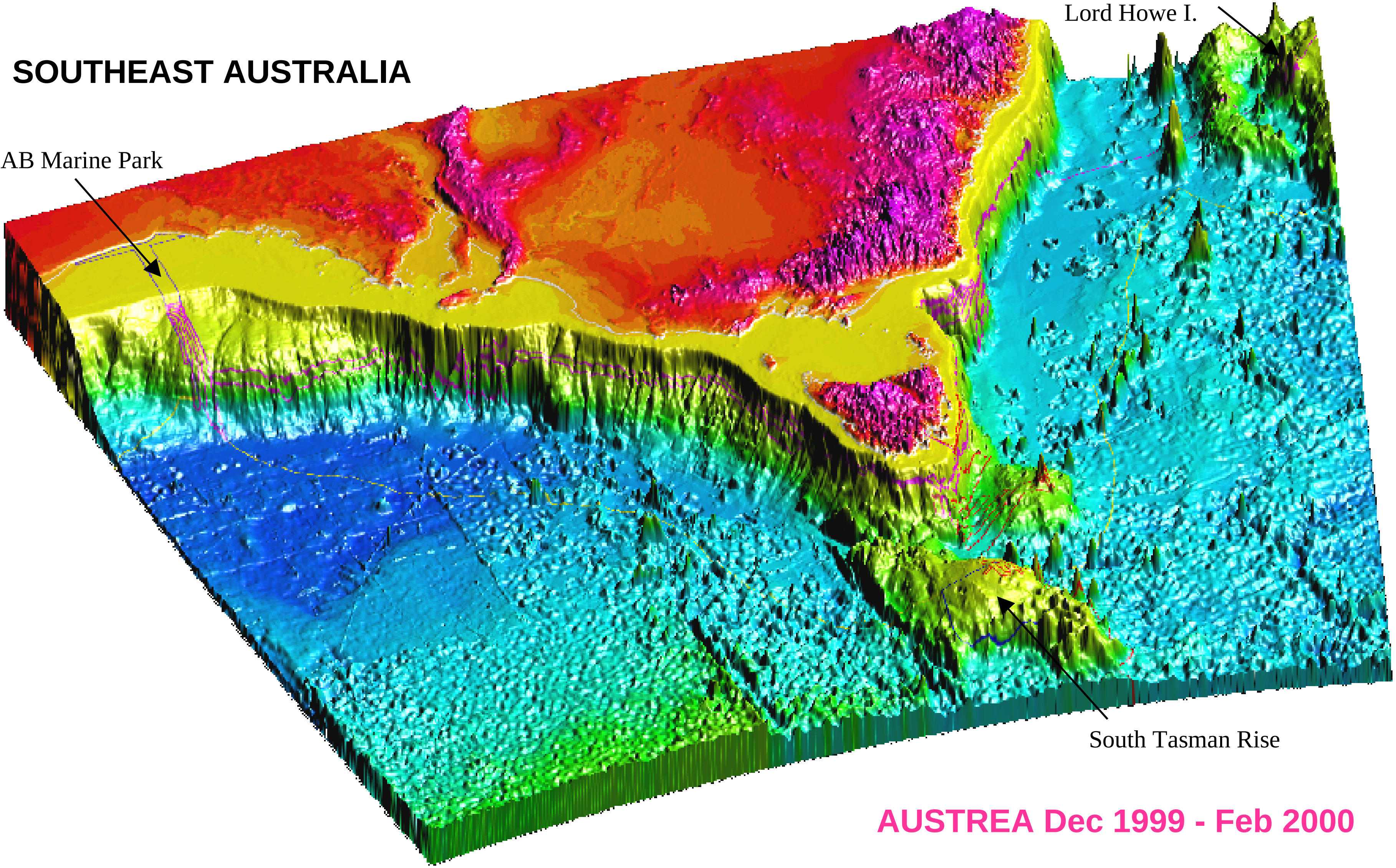


Figure A1. Overview image of offshore southeast Australia, including most of the area covered by the proposed South-east Regional Marine Plan and surveyed by AUSTREA on the Australian margin. 3-D hill-shaded topography, with view to the NNE. AUSTREA-1 lines (in dark pink) and AUSTREA-2 lines (in red) draped on the topography.

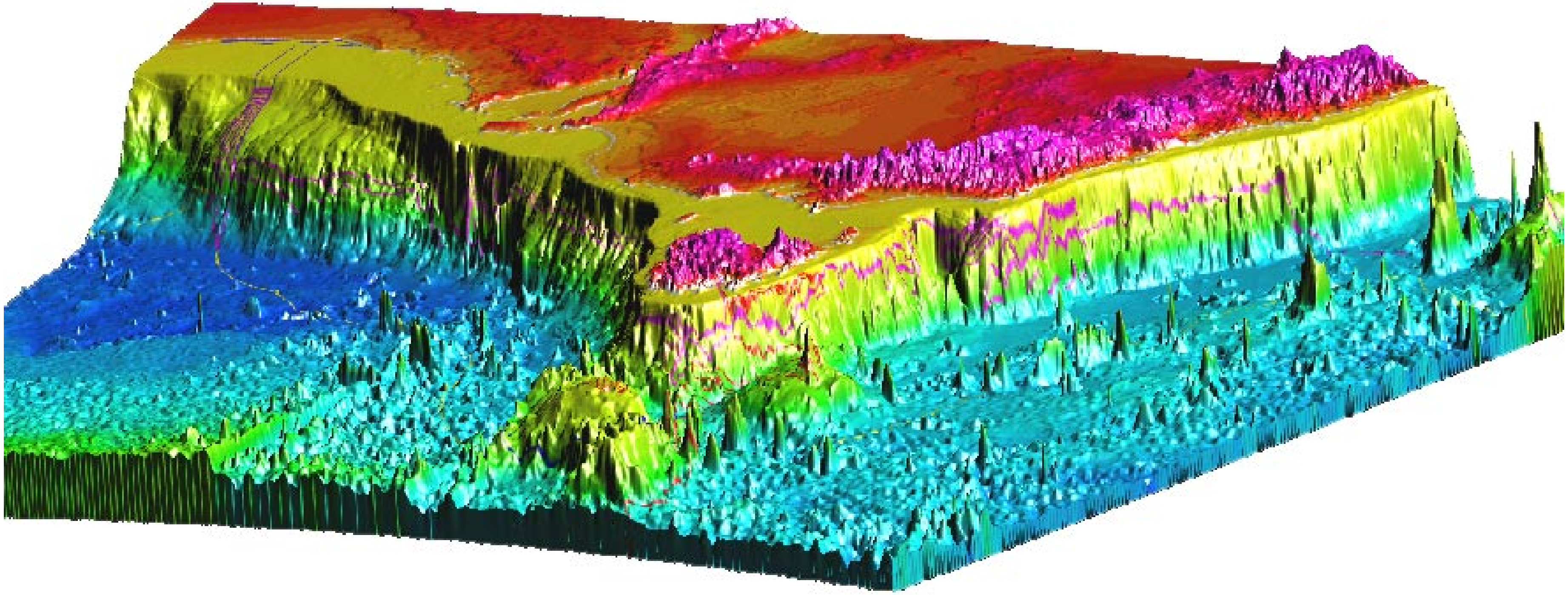


Figure A2. Low-angle 3-D view of the southeast Australian region, looking to the northwest.

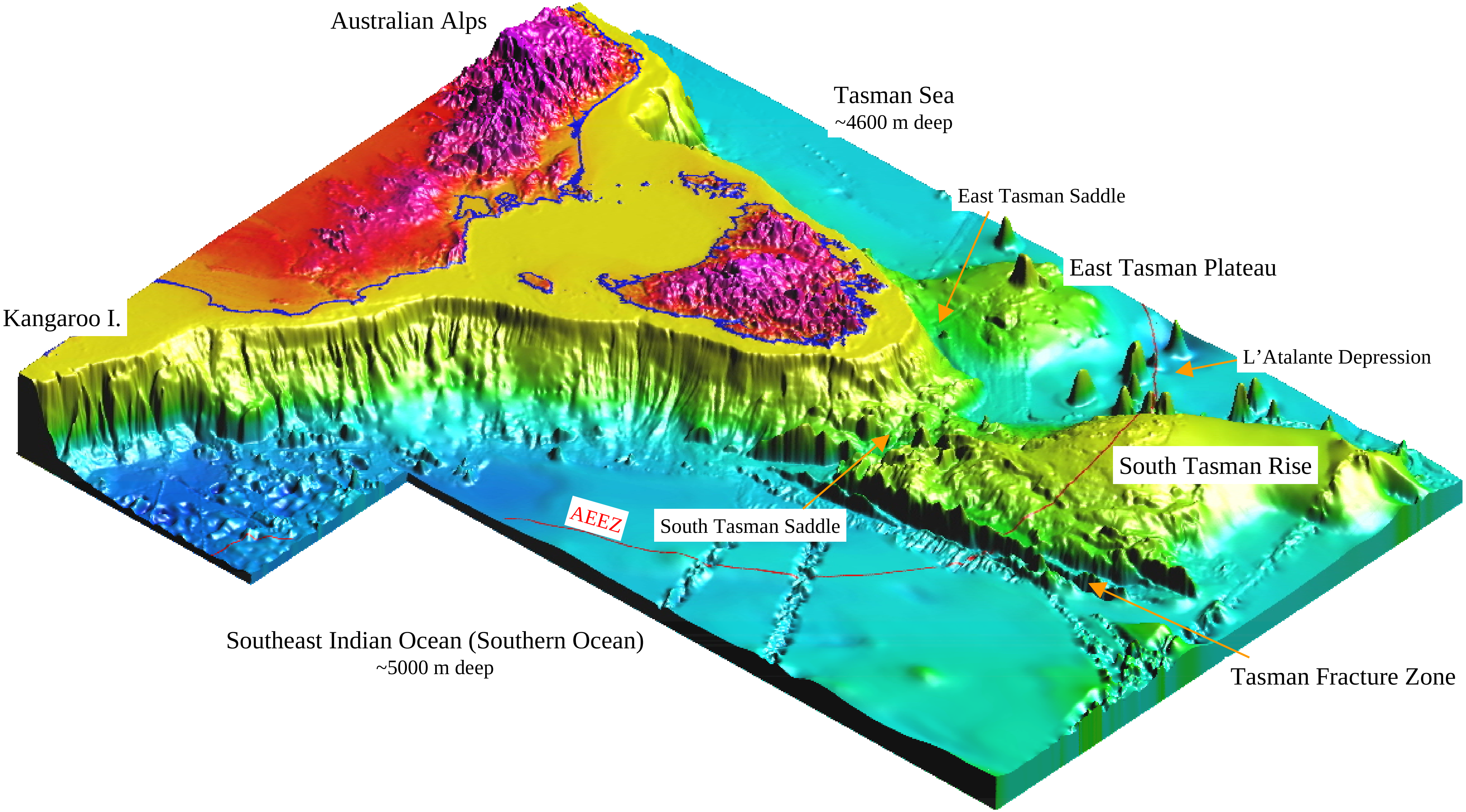
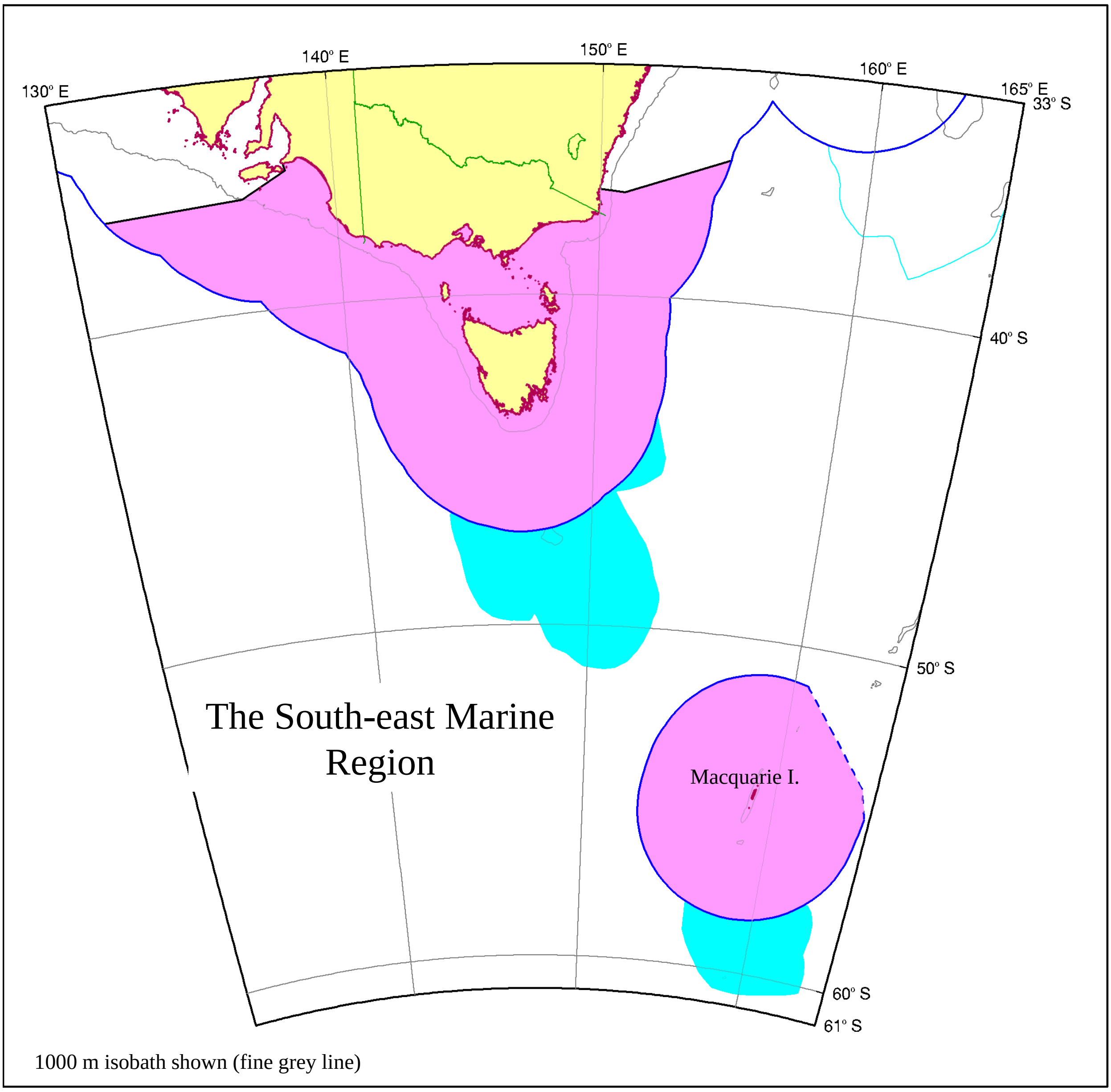


Figure A3. 3-D hill-shaded topographic image of the main area covered by the proposed South-east Regional Marine Plan and the focus of this report. View is to the northeast.



🟪 Areas within the EEZ 200 nautical mile limit

🟦 Areas of claimable extended continental shelf

Figure A4. Location of the South-east Marine Region, areas within the AEEZ and claimable extended continental shelf. Eastern and western boundaries off Australia based on information from the National Oceans Office January 2001.

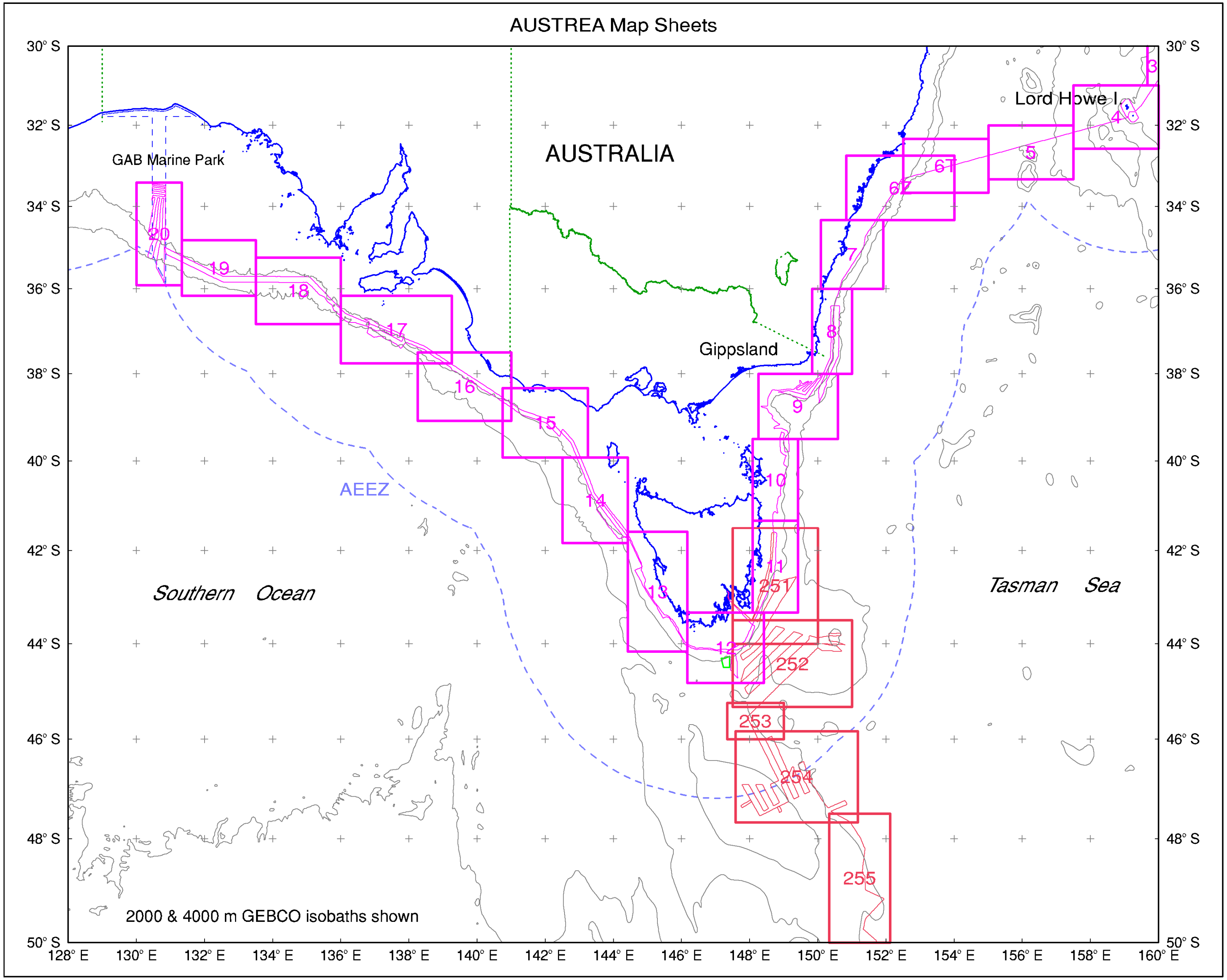
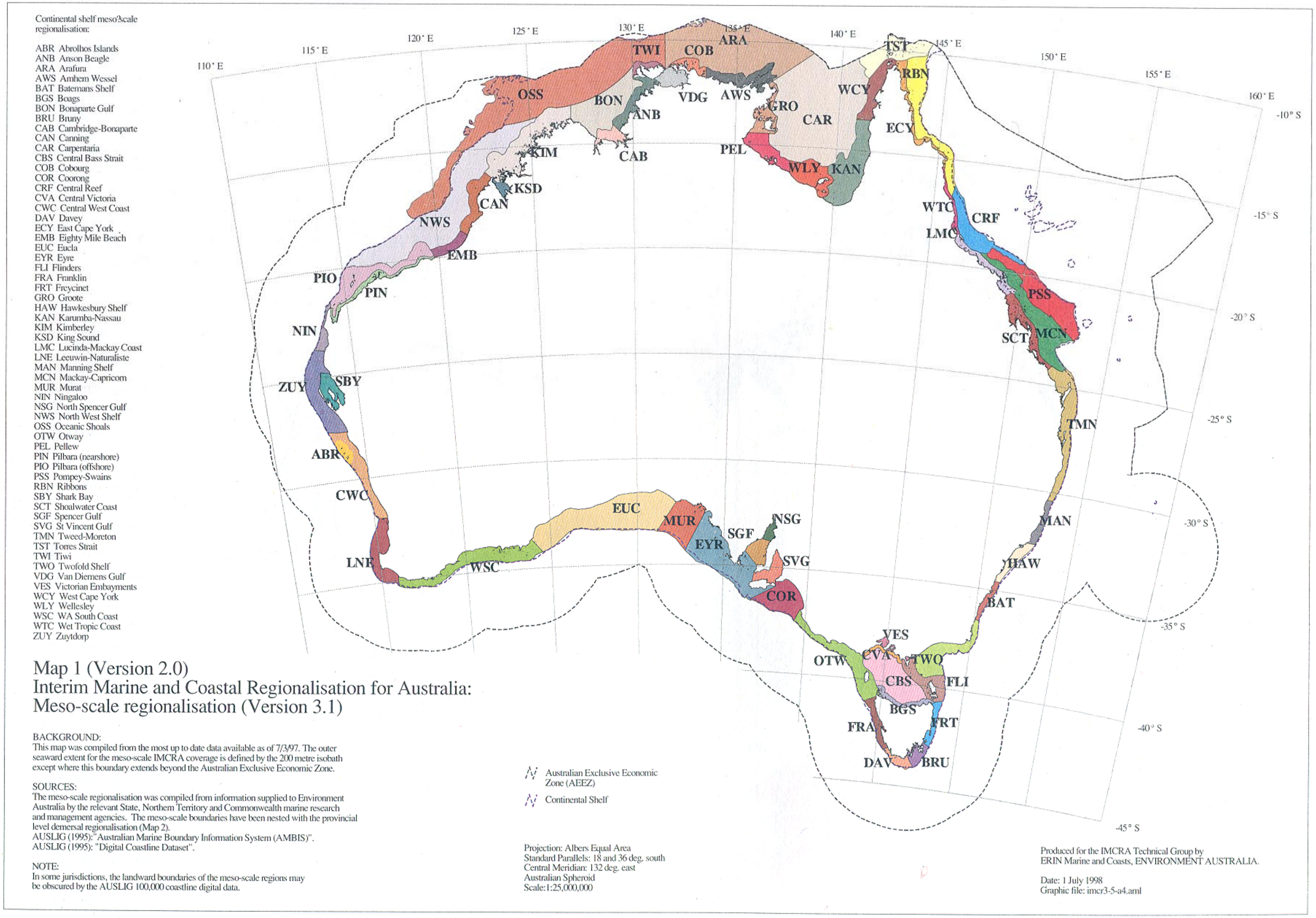


Figure A5. Index map of all the AUSTREA sheets for the Australian sector of the South-east Marine Region. AUSTREA-1 in dark pink, AUSTREA-2 in red.



Continental shelf meso?scale regionalisation:

ABR	Abrolhos Islands
ANB	Anson Beagle
ARA	Arafura
AWS	Arnhem Wessel
BAT	Batemans Shelf
BGS	Boags
BON	Bonaparte Gulf
BRU	Bruny
CAB	Cambridge-Bonaparte
CAN	Canning
CAR	Carpentaria
CBS	Central Bass Strait
COB	Cobourg
COR	Coorong
CRF	Central Reef
CVA	Central Victoria
CWC	Central West Coast
DAV	Davey
ECY	East Cape York
EMB	Eighty Mile Beach
EUC	Eucla
EYR	Eyre
FLI	Flinders
FRA	Franklin
FRT	Freycinet
GRO	Groote
HAW	Hawkesbury Shelf
KAN	Karumba-Nassau
KIM	Kimberley
KSD	King Sound
LMC	Lucinda-Mackay Coast
LNE	Leeuwin-Naturaliste
MAN	Manning Shelf
MCN	Mackay-Capricorn
MUR	Murat
NIN	Ningaloo
NSG	North Spencer Gulf
NWS	North West Shelf
OSS	Oceanic Shoals
OTW	Otway
PEL	Pellew
PIN	Pilbara (nearshore)
PIO	Pilbara (offshore)
PSS	Pompey-Swains
RBN	Ribbons
SBY	Shark Bay
SCT	Shoalwater Coast
SGF	Spencer Gulf
SVG	St Vincent Gulf
TMN	Tweed-Moreton
TST	Torres Strait
TWI	Tiwi
TWO	Twofold Shelf
VDG	Van Diemens Gulf
VES	Victorian Embayments
WCY	West Cape York
WLY	Wellesley
WSC	WA South Coast
WTC	Wet Tropic Coast
ZUY	Zuytdorp

Map 1 (Version 2.0)
Interim Marine and Coastal Regionalisation for Australia:
Meso-scale regionalisation (Version 3.1)

BACKGROUND:
This map was compiled from the most up to date data available as of 7/3/97. The outer seaward extent for the meso-scale IMCRA coverage is defined by the 200 metre isobath except where this boundary extends beyond the Australian Exclusive Economic Zone.

SOURCES:
The meso-scale regionalisation was compiled from information supplied to Environment Australia by the relevant State, Northern Territory and Commonwealth marine research and management agencies. The meso-scale boundaries have been nested with the provincial level demersal regionalisation (Map 2).
AUSLIG (1995):"Australian Marine Boundary Information System (AMBIS)".
AUSLIG (1995): "Digital Coastline Dataset".

NOTE:
In some jurisdictions, the landward boundaries of the meso-scale regions may be obscured by the AUSLIG 100,000 coastline digital data.

Australian Exclusive Economic Zone (AEEZ)

Continental Shelf

Projection: Albers Equal Area
Standard Parallels: 18 and 36 deg. south
Central Meridian: 132 deg. east
Australian Spheroid
Scale:1:25,000,000

Produced for the IMCRA Technical Group by
ERIN Marine and Coasts, ENVIRONMENT AUSTRALIA.

Date: 1 July 1998
Graphic file: imcr3-5-a4.aml

Figure A6. Map showing the continental shelf meso-scale regions for Australia (taken from IMCRA, 1999).

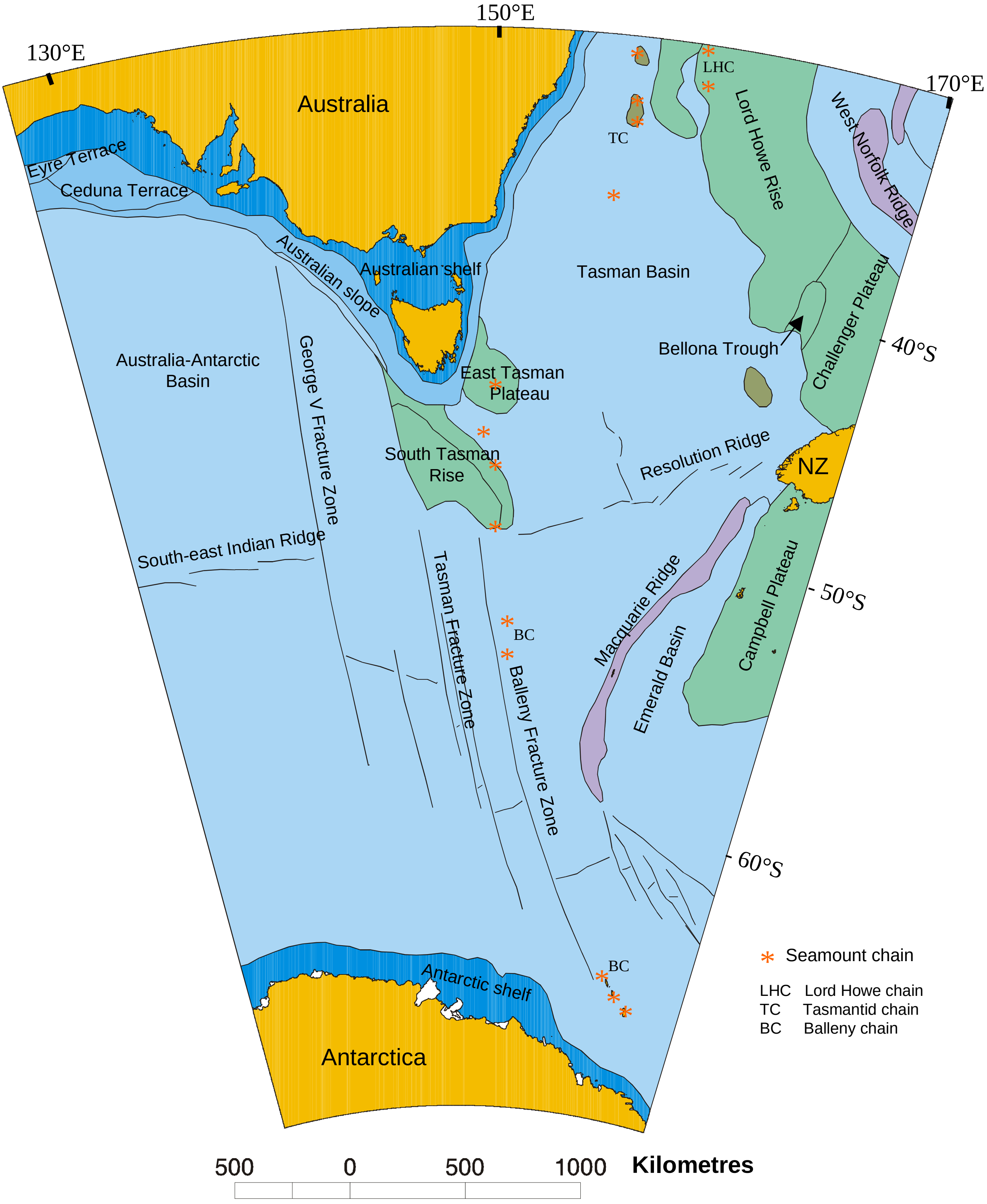


Figure A7. Physiographic provinces map of the southeast Australian region.

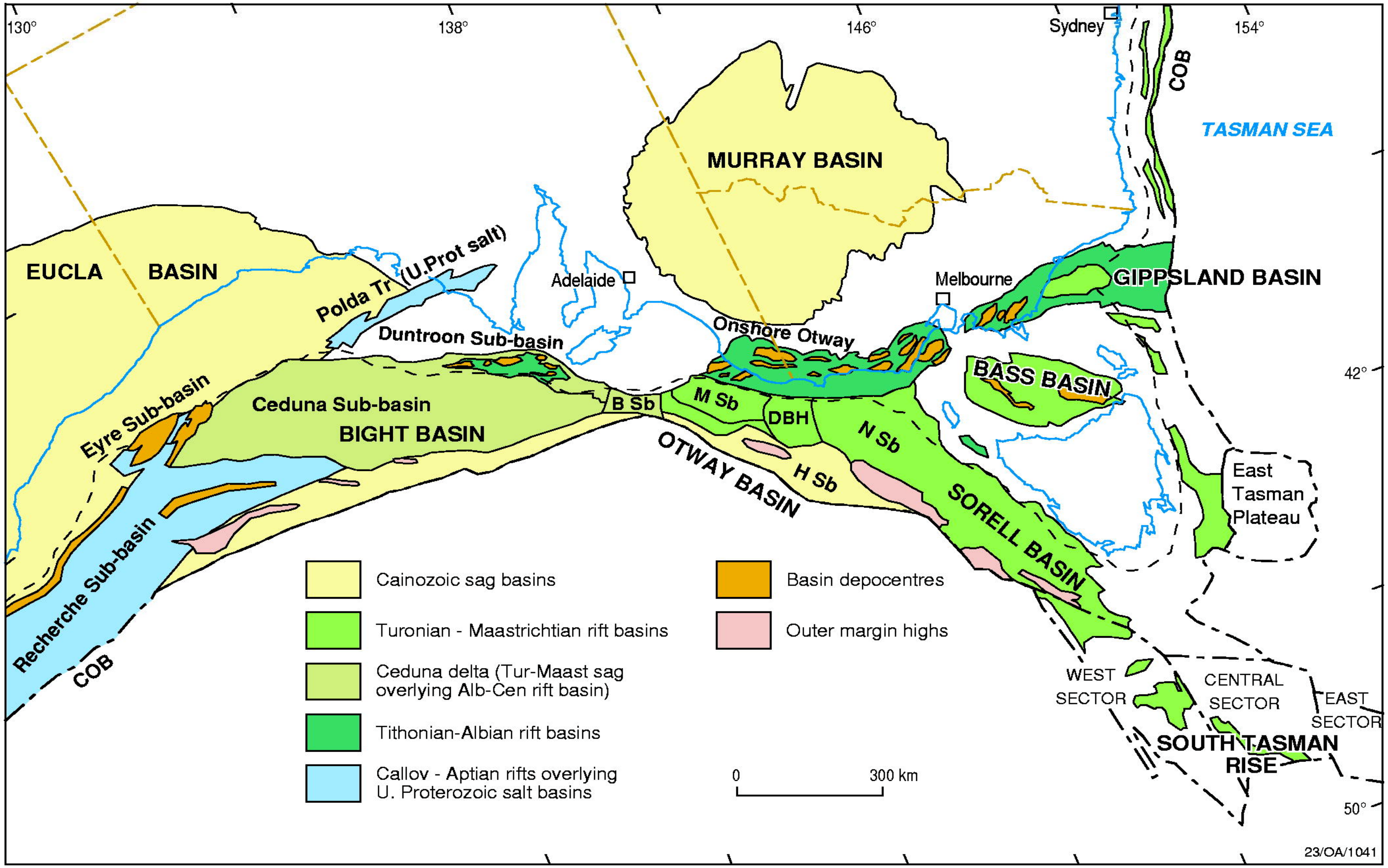


Figure A8. Structural elements of the southern and southeastern margins of Australia showing the distribution of Early and Late Cretaceous rift basins. COB - continent-ocean boundary; B Sb - Beachport Sub-basin; M Sb - Morum Sub-basin; DBH - Discovery Bay High; N Sb - Nelson Sub-basin; H Sb - Hunter Sub-basin. After Moore *et al*. (2000).

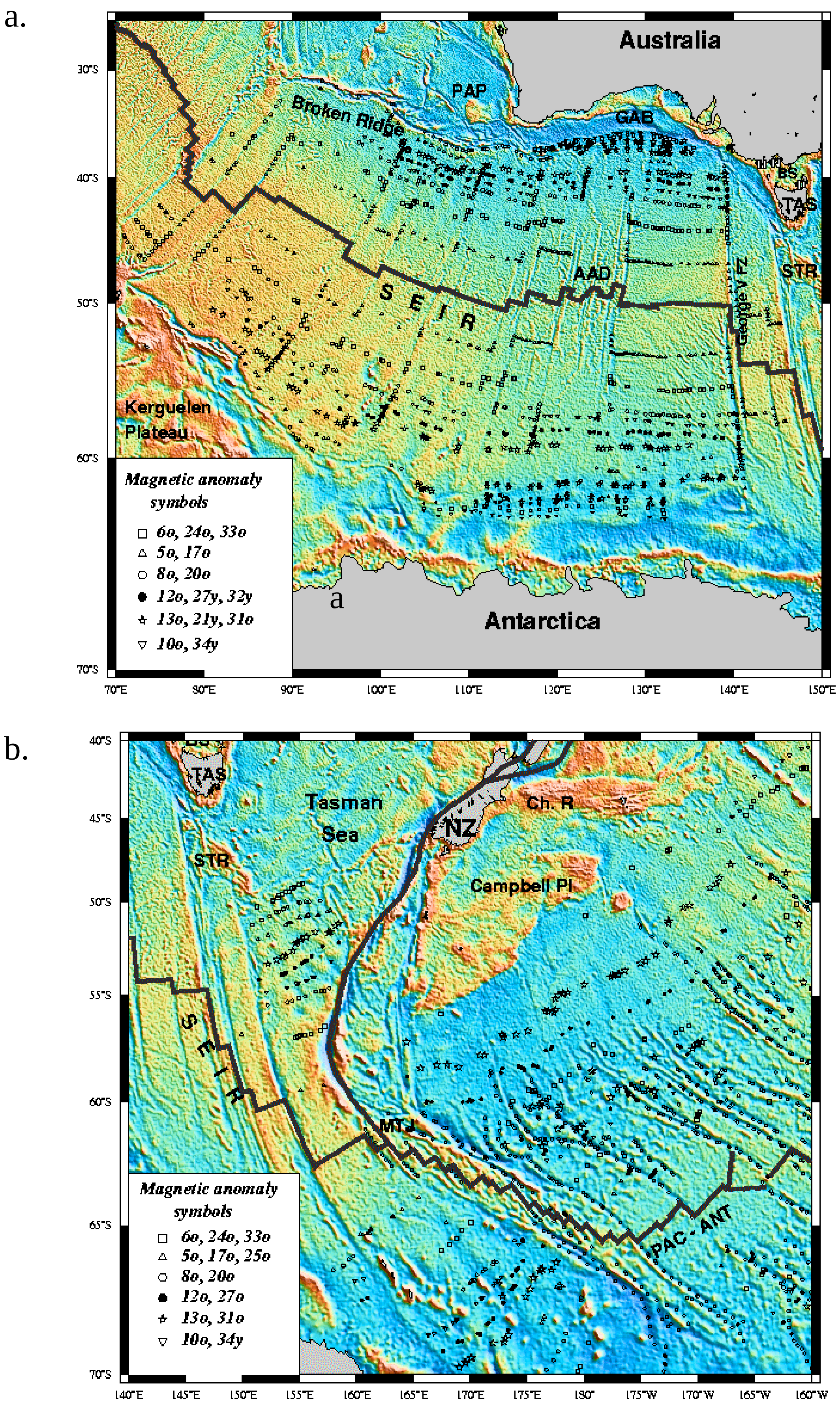


Figure A9. Gravity anomalies from satellite altimetry overlain by seafloor spreading magnetic anomaly and fracture zone identifications for (a) the region between Australia and Antarctica and (b) the Macquarie Ridge region. After Müller (2000).

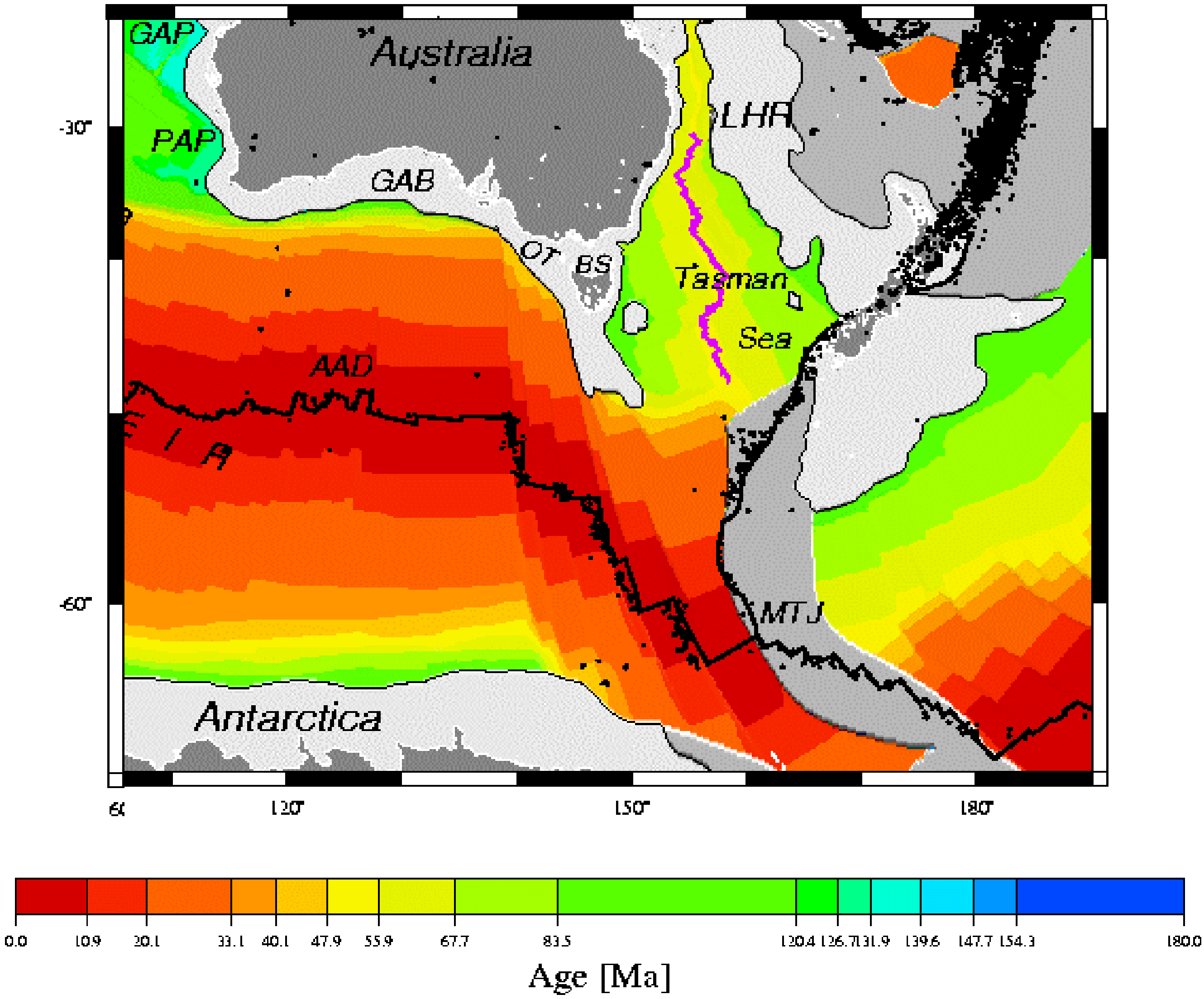


Figure A10. The age of the ocean floor off southern and eastern Australia. Shows extinct (pink line) and active seafloor spreading ridges (black line) and earthquakes (black dots). GAP - Gascoyne Abyssal Plain; Pap - Perth Abyssal Plain; GAB - Great Australian Bight; OT - Otway Basin; BS - Bass Strait; LHR - Lord Howe Rise; SEIR - South East Indian Ridge; AAD- Australian-Antarctic Discordance; MTJ - Macquarie Triple Junction. Medium grey areas represent oceanic crust with complex structure or poorly-defined magnetic lineations. Modified from Müller *et al.* (1997).

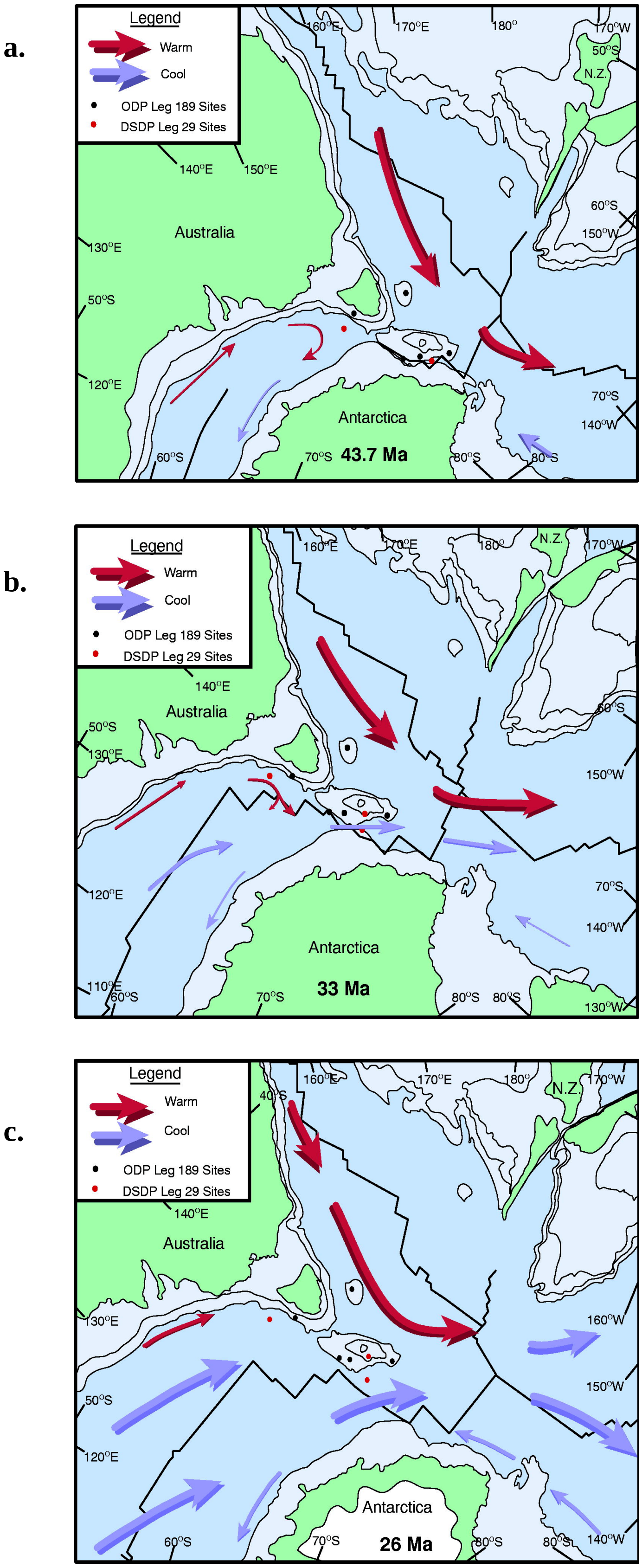


Figure A11. Plate reconstructions of the Australian-Antarctic region at 43.7, 33 and 26 million years modified from Cande *et al.* (2000). Shows the inferred surface-water circulation of the Australian-Antarctic region from the (a) middle Eocene (43.7 Ma) with the Tasmanian Gateway closed; (b) earliest Oligocene (33 Ma) with the Gateway starting to open; (c) late Oligocene(33 Ma) with the Gateway open and expansion of the Antarctic Circumpolar Current. After Shipboard Scientific Party (2000).

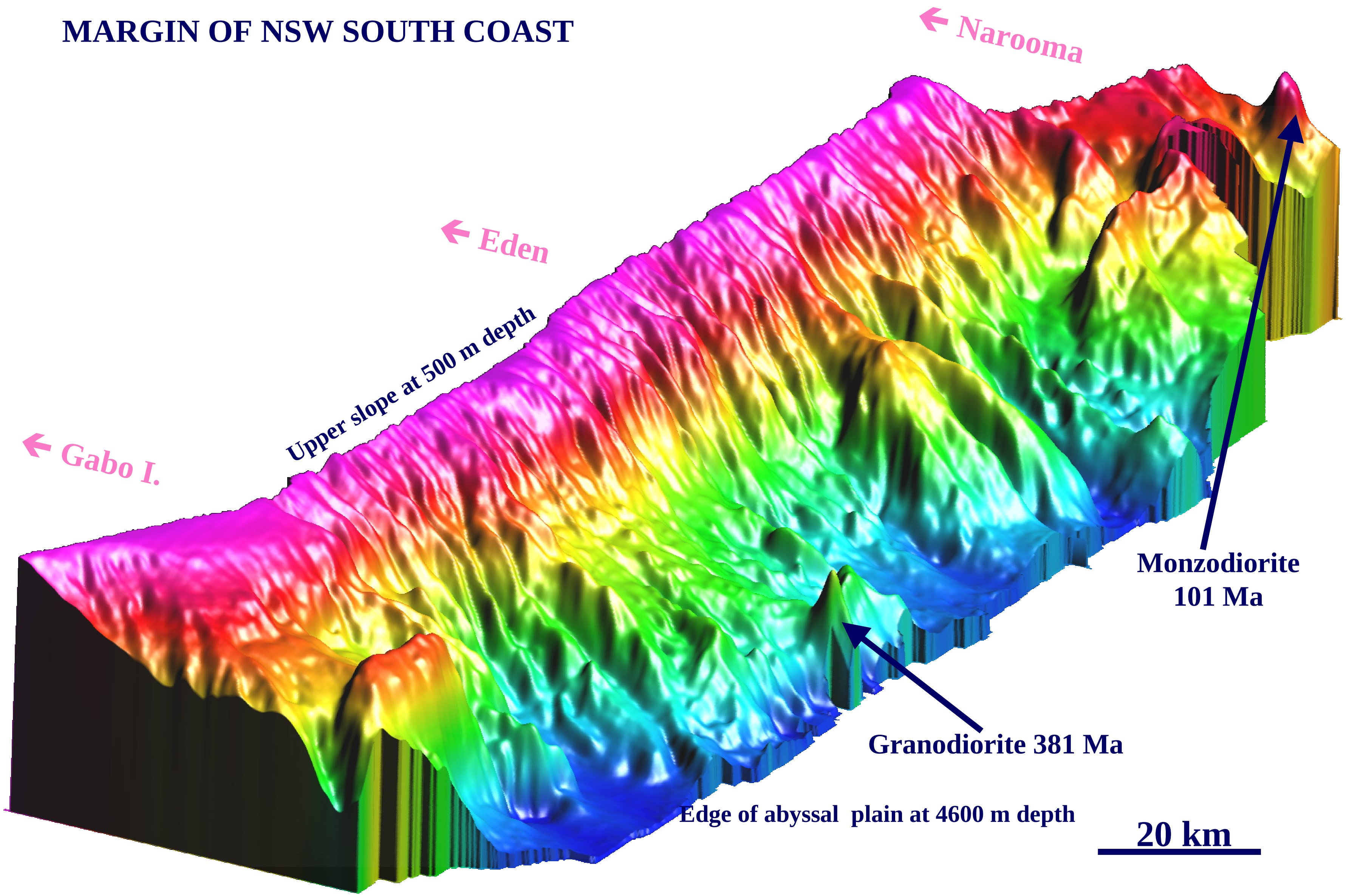


Figure B1. 3-D swath-bathymetry image of the steep, canyoned continental margin of the NSW South Coast, with important sample locations indicated.

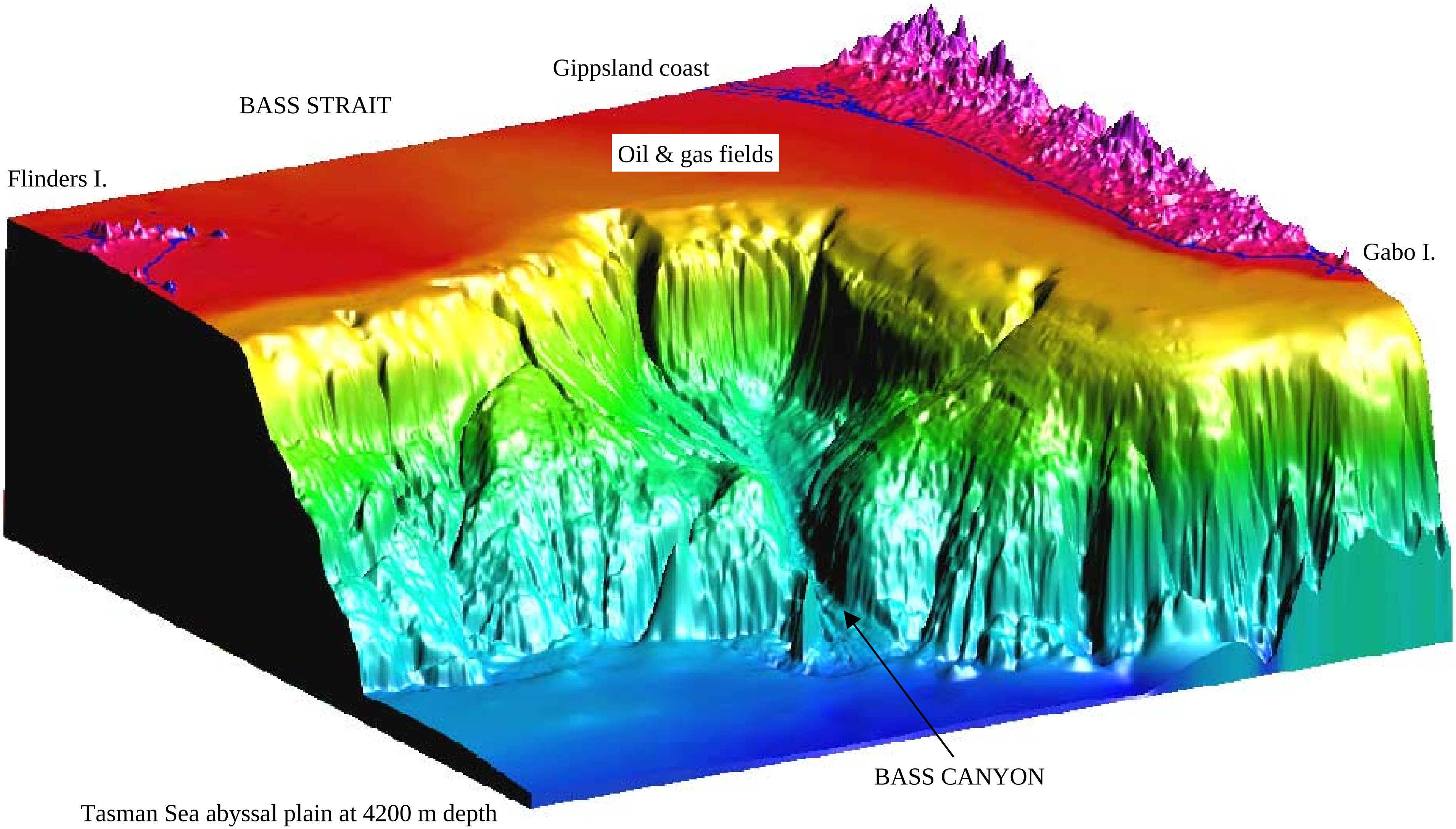


Figure B2. Spectacular seabed topography and canyon systems of the Bass Canyon Complex off Gippsland - image produced from AUSTREA-1 swath data merged with data from AGSO's 1997 Sojourn7 survey and other (non-swath) topographic data sets.

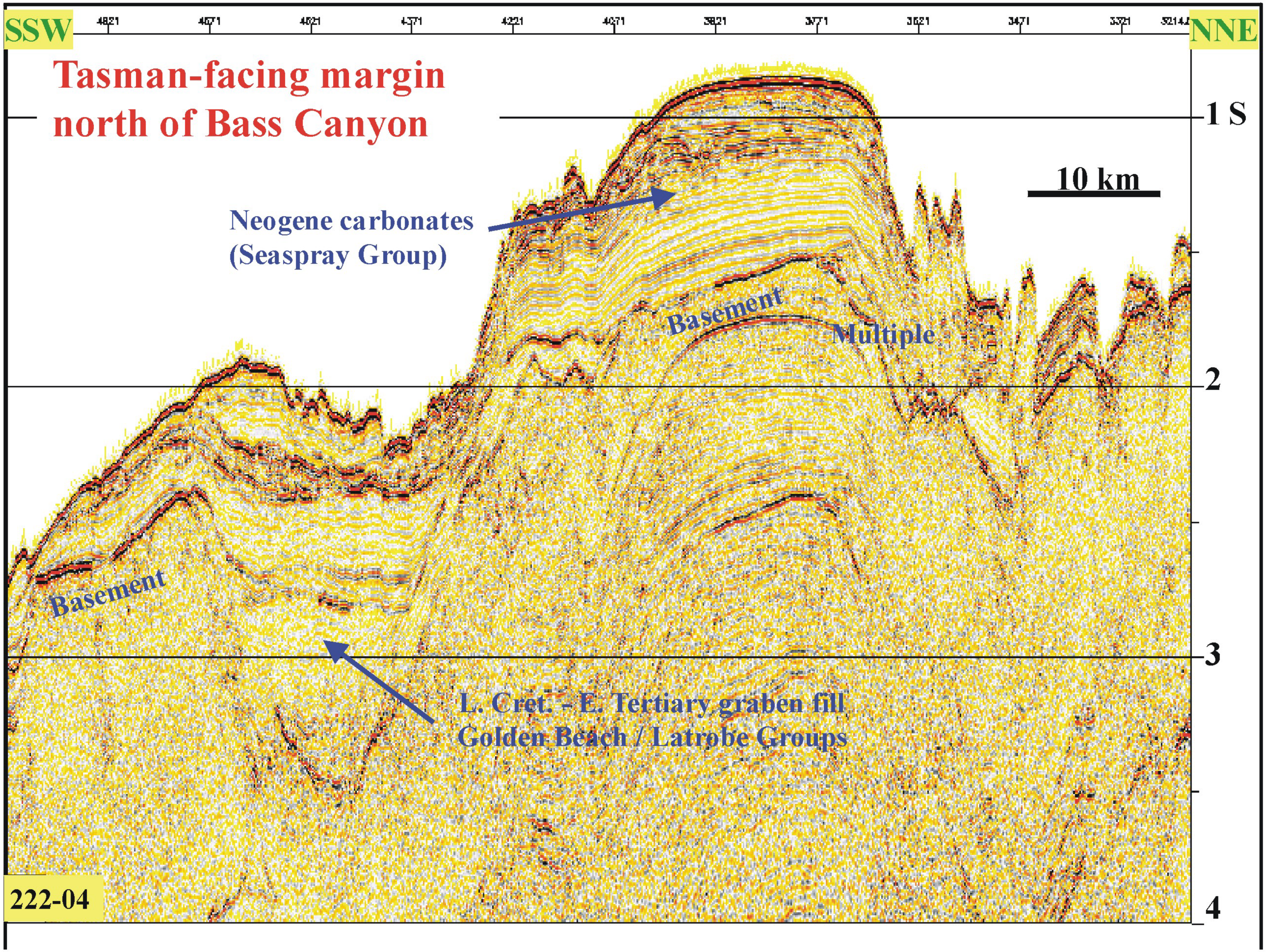


Figure B3. Seismic profile 4 on the Tasman-facing margin north of the Bass Canyon complex- showing Late Cretaceous-early Tertiary graben fill and locally-thick well-stratified Neogene carbonate cover. Structures in Hill *et al.* (2000), Figure 10.

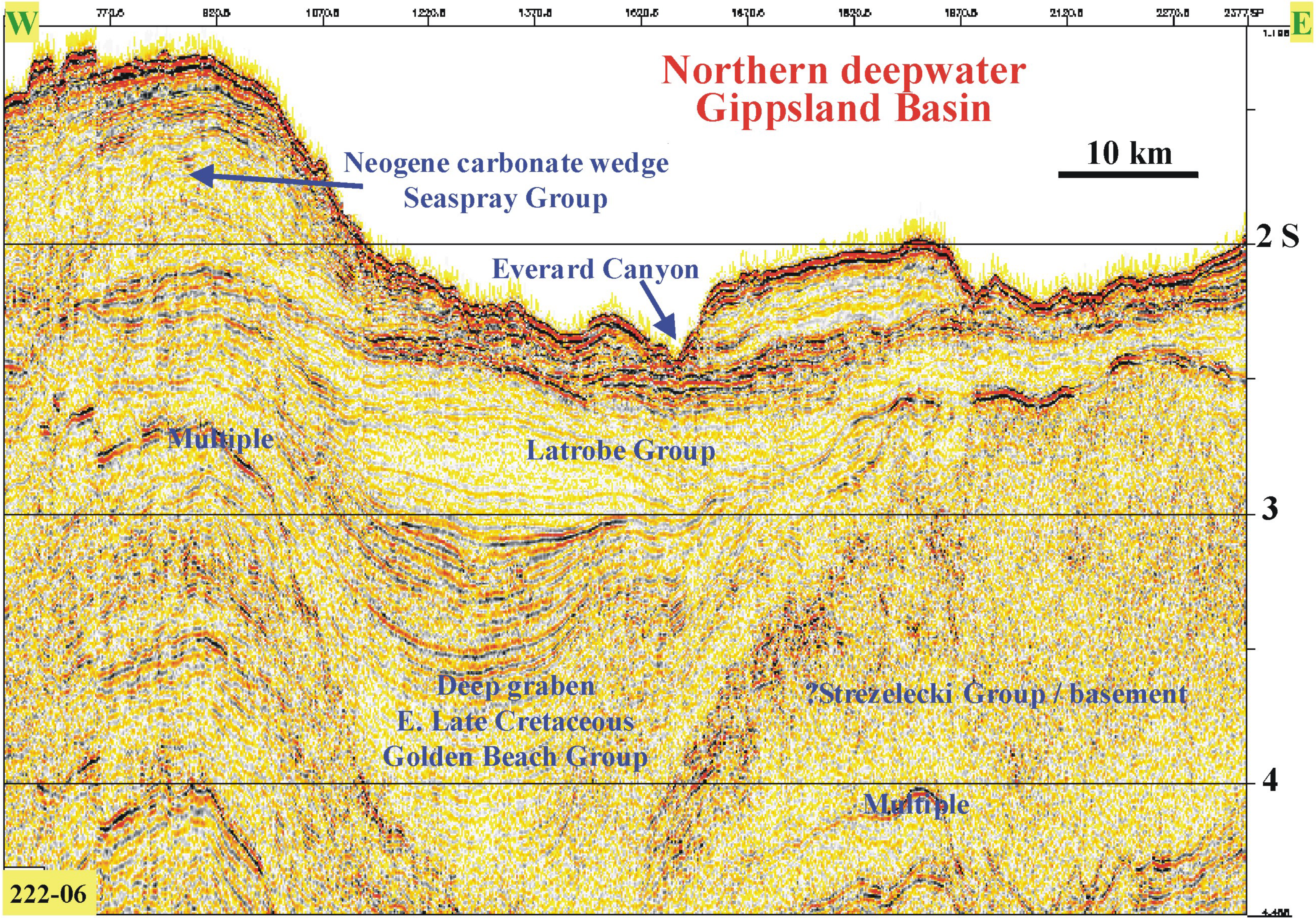


Figure B4. Seismic profile 6 in the deepwater Gippsland Basin just north of Bass Canyon - showing at least 2 s twt of sedimentary section and a late Tertiary prograding carbonate wedge incised by canyons. Structures in Hill *et al.* (2000), Figure 11.

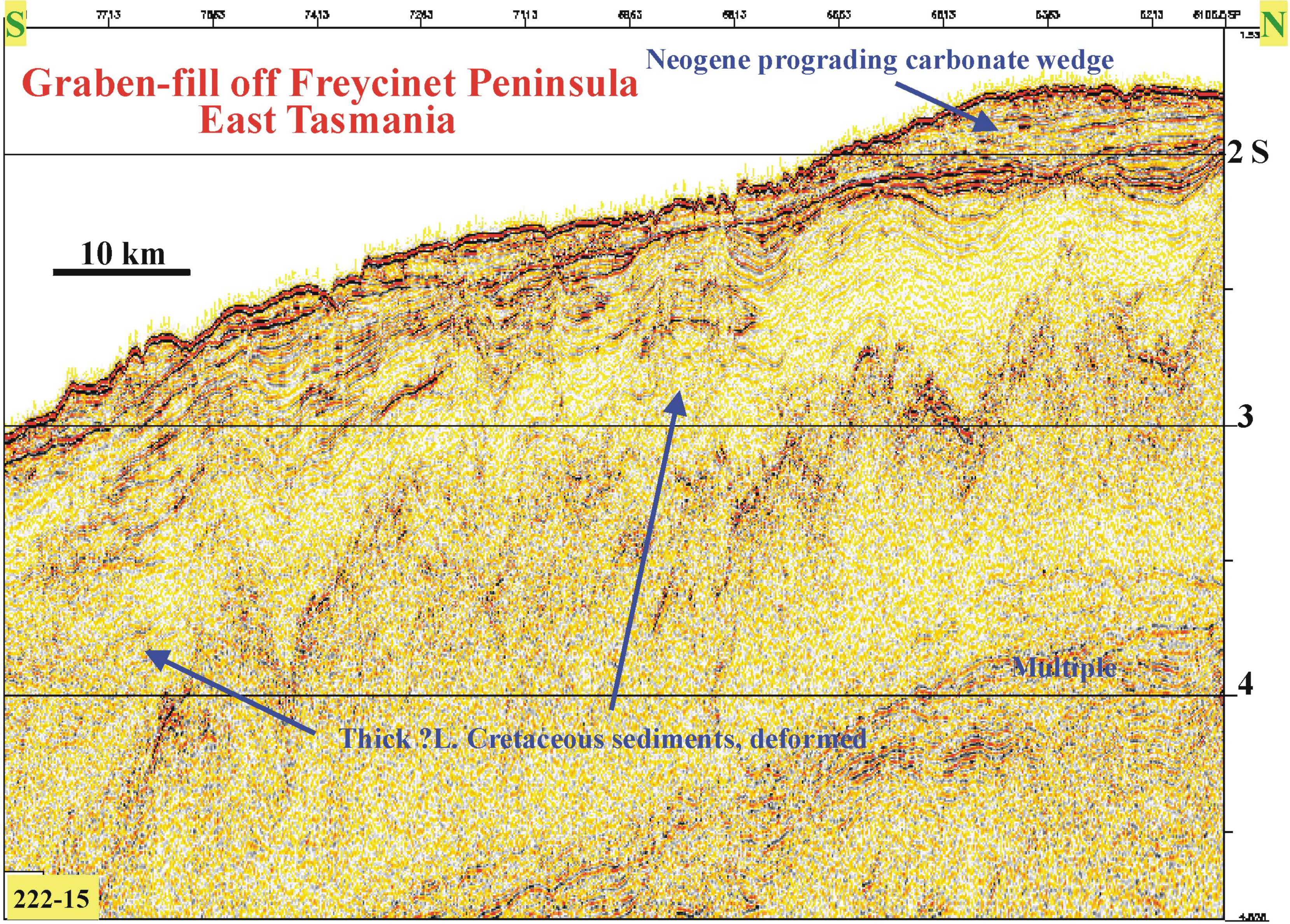


Figure B5. Seismic profile 15 along a graben off Freycinet Peninsula, east Tasmania, showing a thick, deformed ?Late Cretaceous fill with thin Neogene cover. Structures in Hill *et al.* (2000), Figure 12.

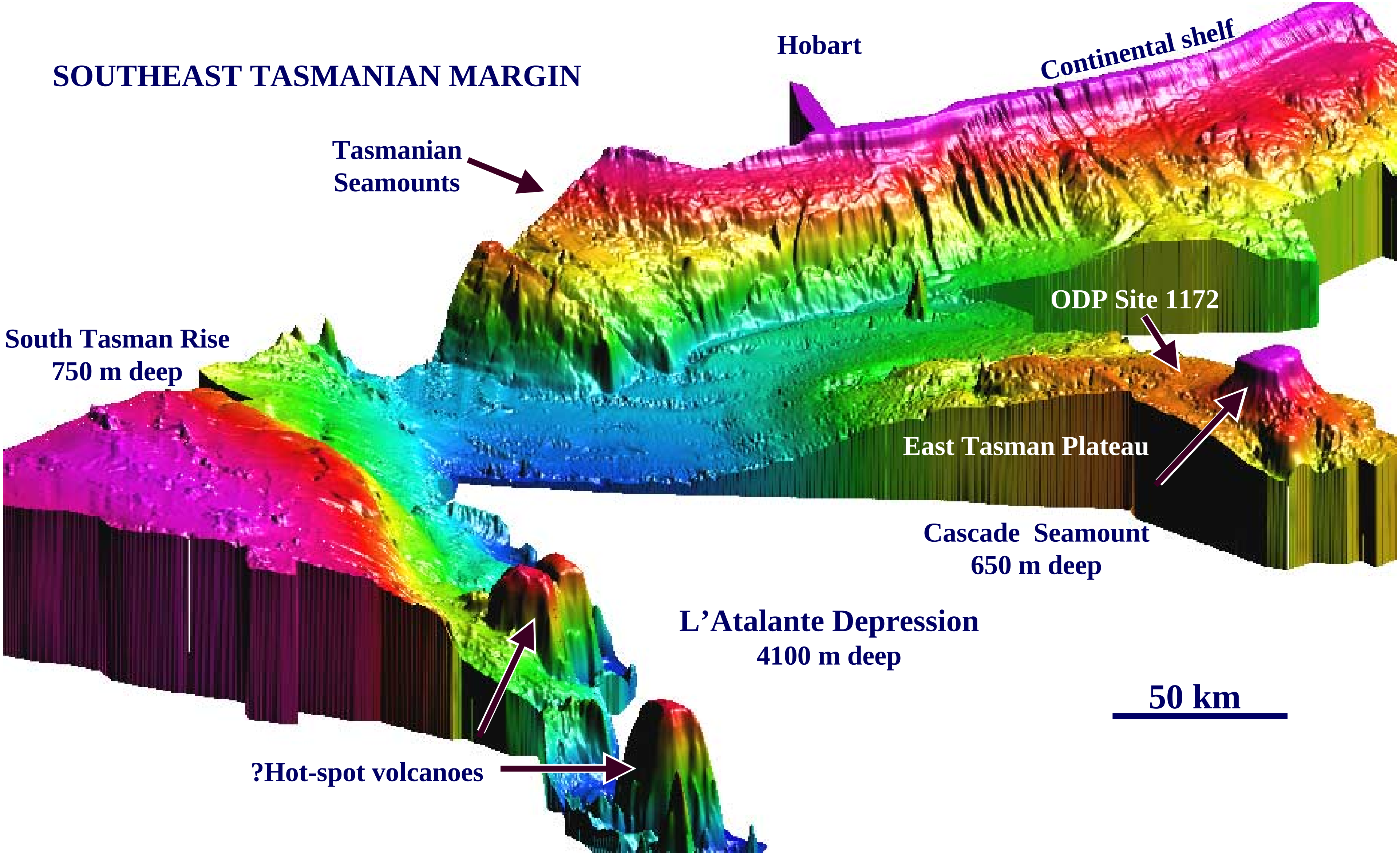


Figure B6. View in 3-D of the southeast margin of Tasmania, and parts of the South Tasman Rise and East Tasman Plateau, looking northwest. Large volcanoes are part of the Balleny hot-spot chain. Image produced from merged swath data sets, AUSTREA-1 & -2 and AGSO's 1994 TASMANTE and 1997 Sojourn7 surveys.

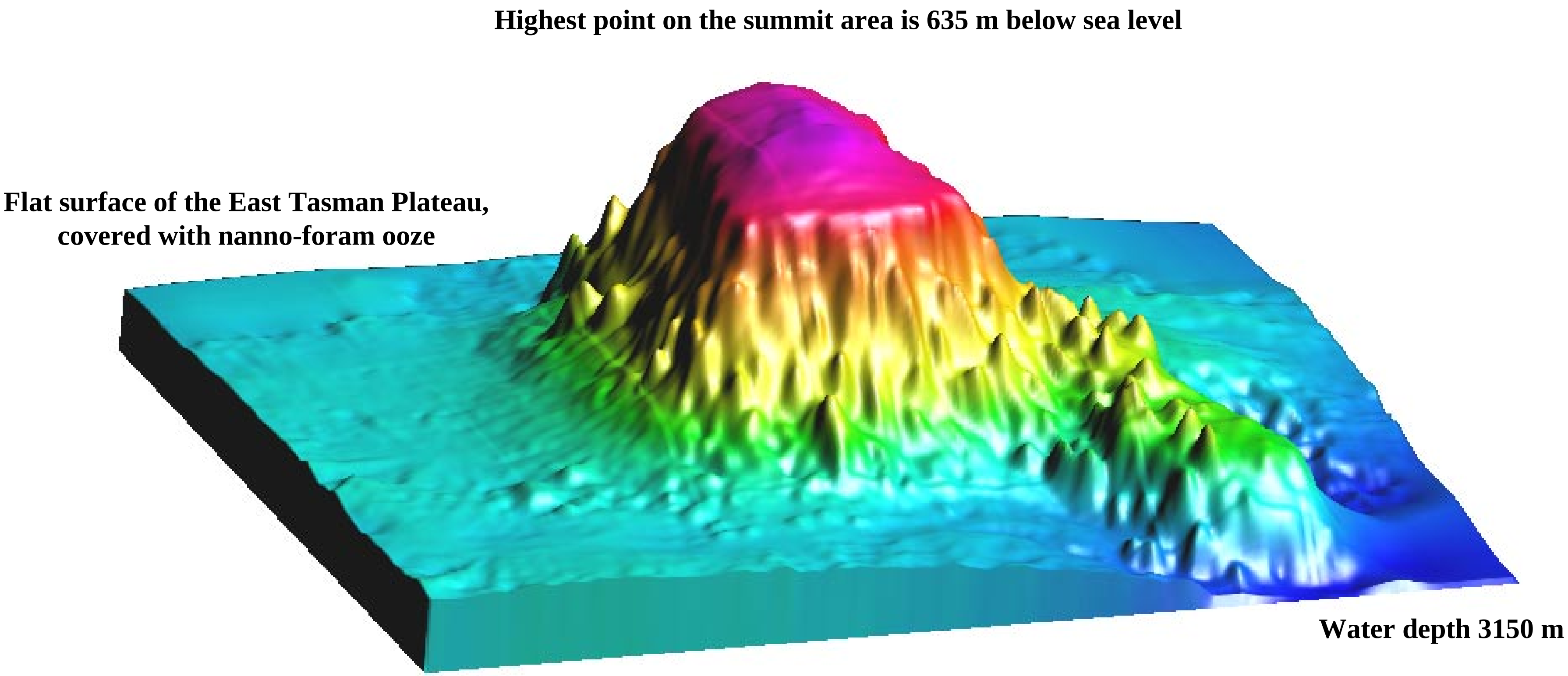


Figure B7. 3-D image of Cascade Seamount, a flat-topped submarine volcano (guyot) with numerous cones on its flanks. View to NNE. Prime orange roughy and dory fishing grounds are located along the edge of its summit area.

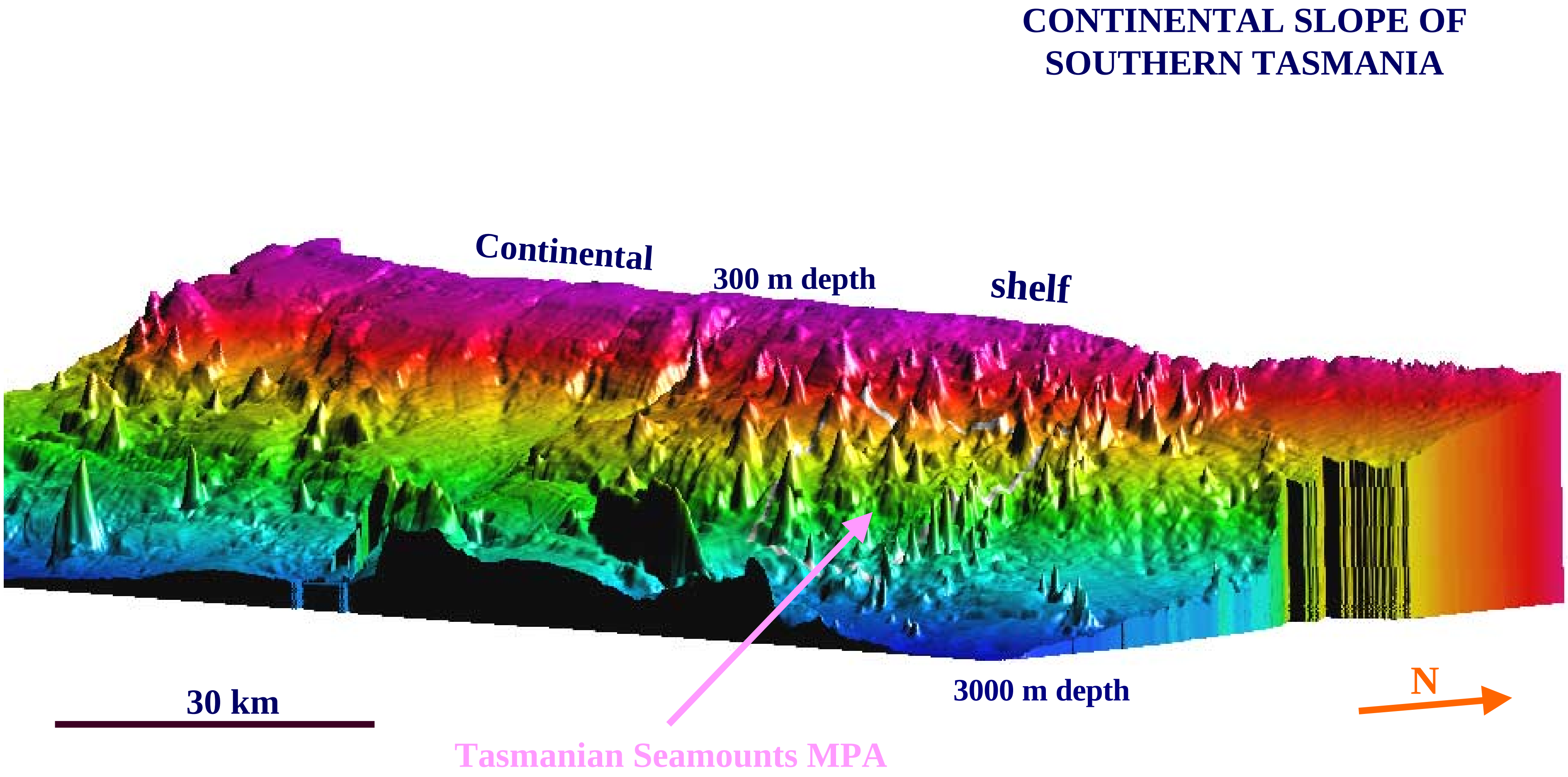


Figure B8. 3-D image of the southern margin of Tasmania, looking northwest, and showing the extensive volcanic terrain and cone fields plus location of the Tasmanian Seamounts MPA. Image produced from merged swath data sets, 1994 AGSO TASMANTE and AUSTREA.

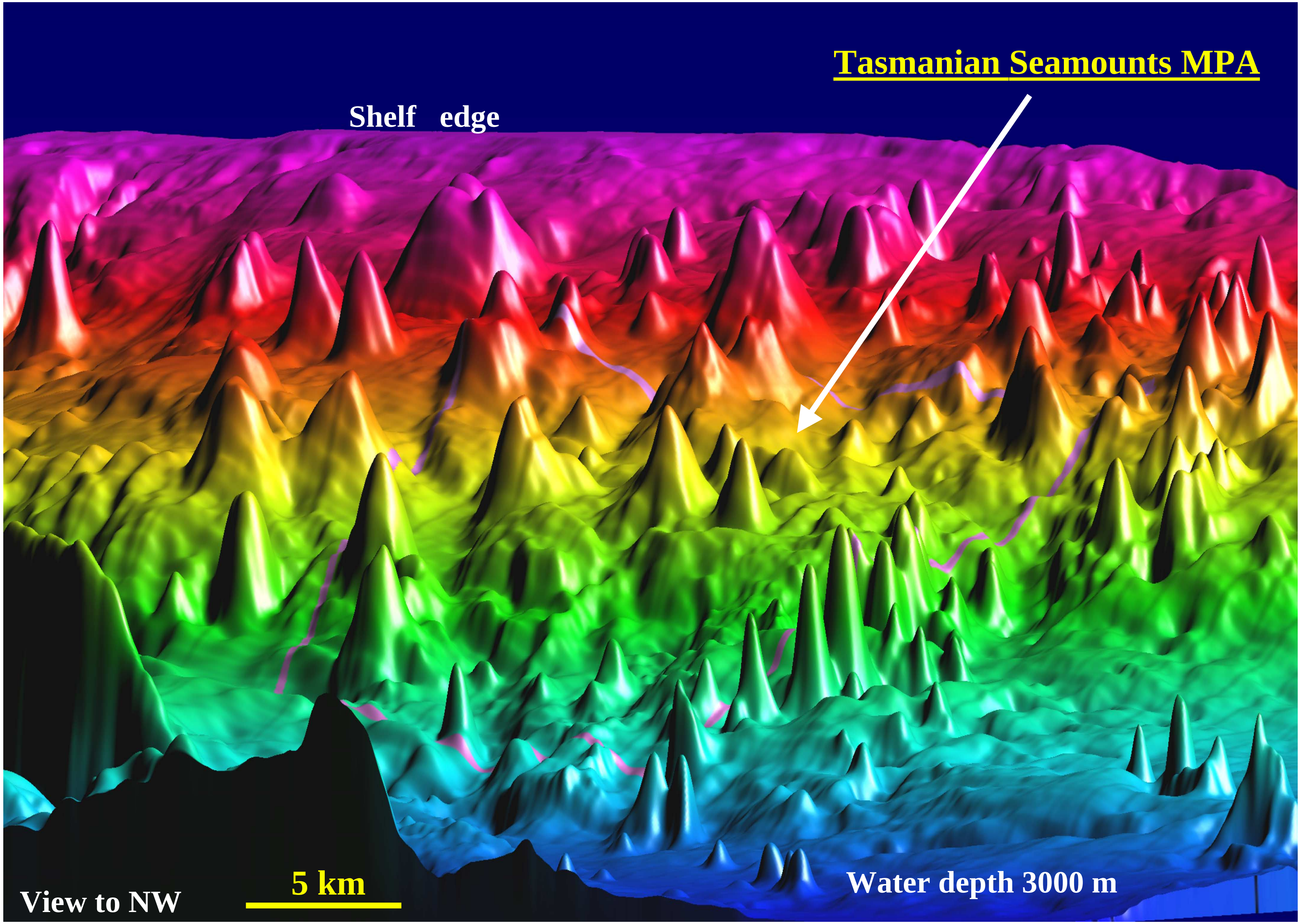


Figure B9. The Tasmanian Seamounts MPA, shown by the pink boundary line, within the field of volcanoes off southern Tasmania. The volcanic cones are typically several hundred metres high.

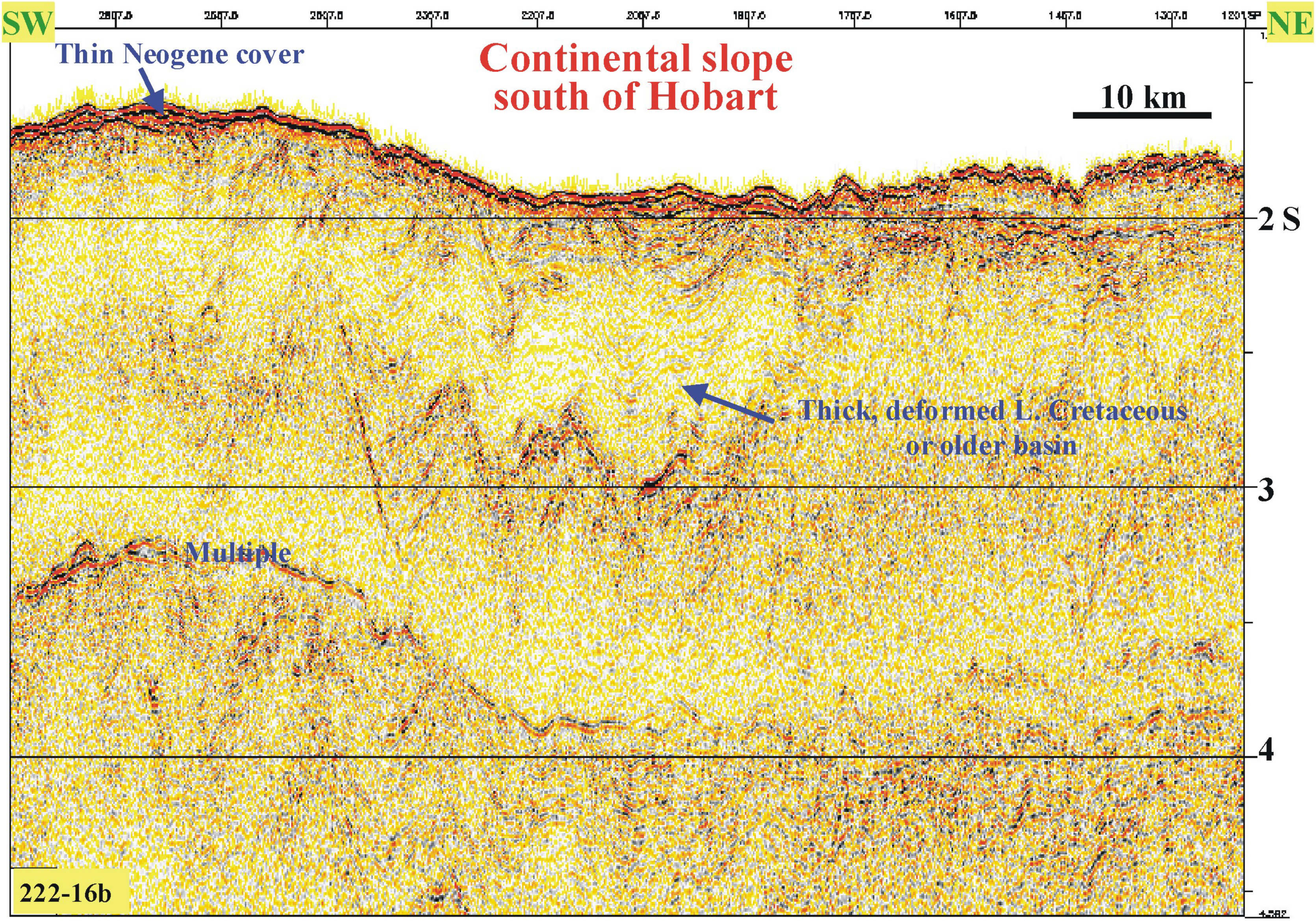


Figure B10. Seismic profile 16b on the upper continental slope south of Hobart showing a strongly faulted and folded Late Cretaceous or older sedimentary section that outcrops on the sea floor or has no more than a veneer of young cover. Structures in Hill *et al.* (2000), Figure 13.

CANYONS OFF WEST TASMANIA

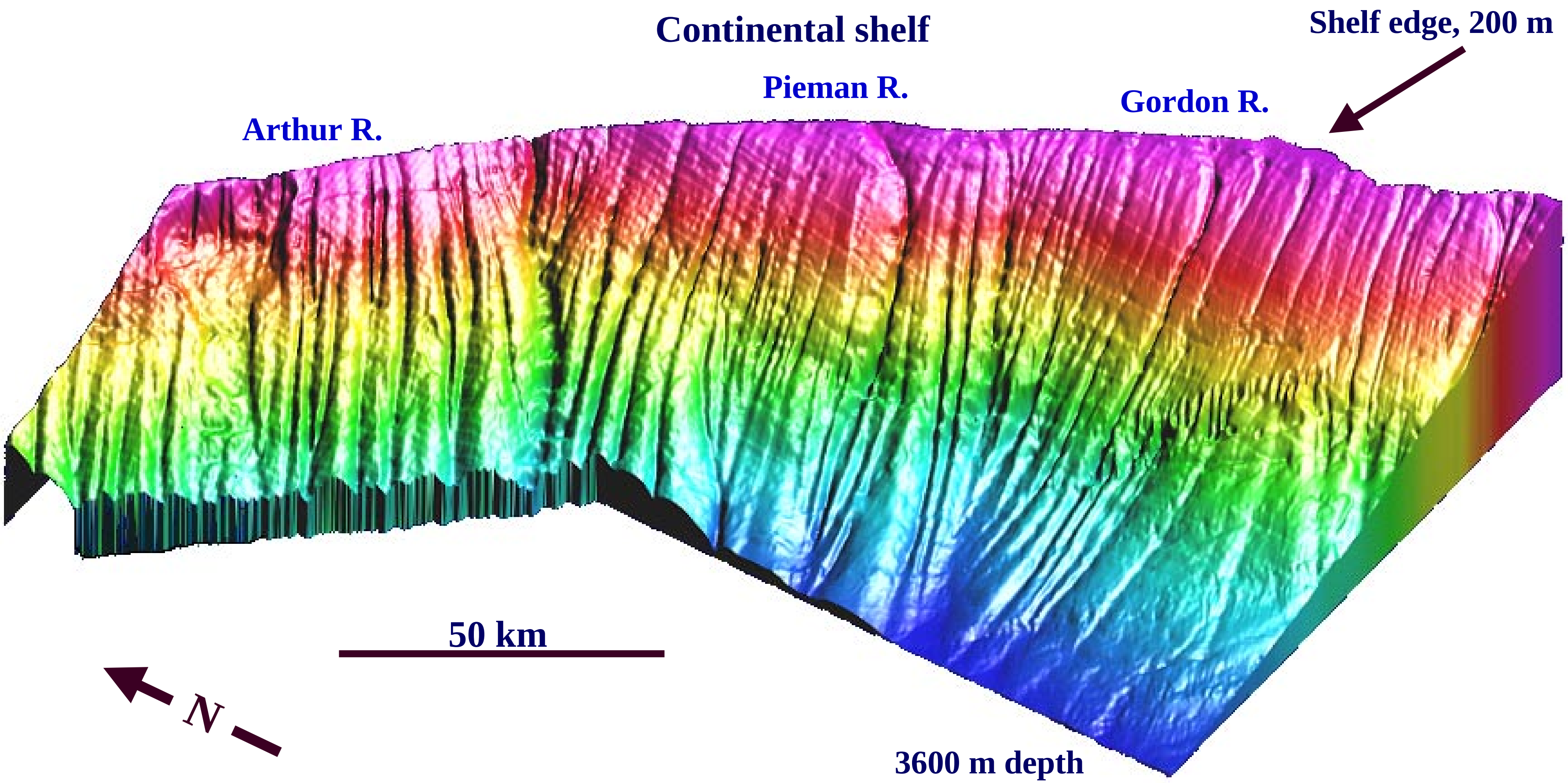


Figure B11. Remarkable systems of downslope canyons, commonly 50-100 m deep, incised into the thickly sedimented continental slope of west Tasmania. 3-D image from merged TASMANTE and AUSTREA-1 swath data.

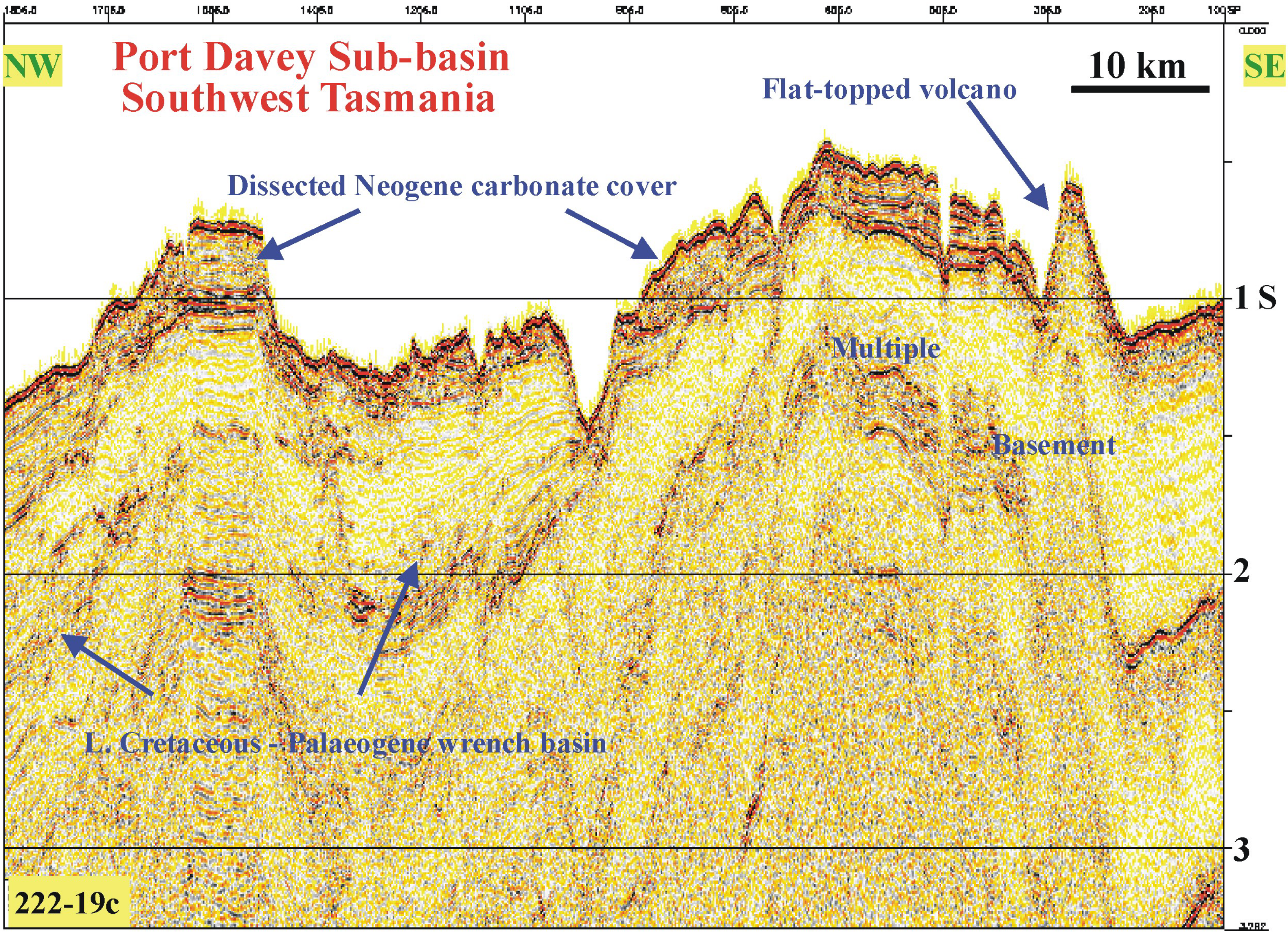


Figure B12. Seismic profile 16c on the upper continental slope off the southwest tip of Tasmania showing a thick section of the wrench-formed Port Davey Sub-basin and 500 m high planated volcanic cone.

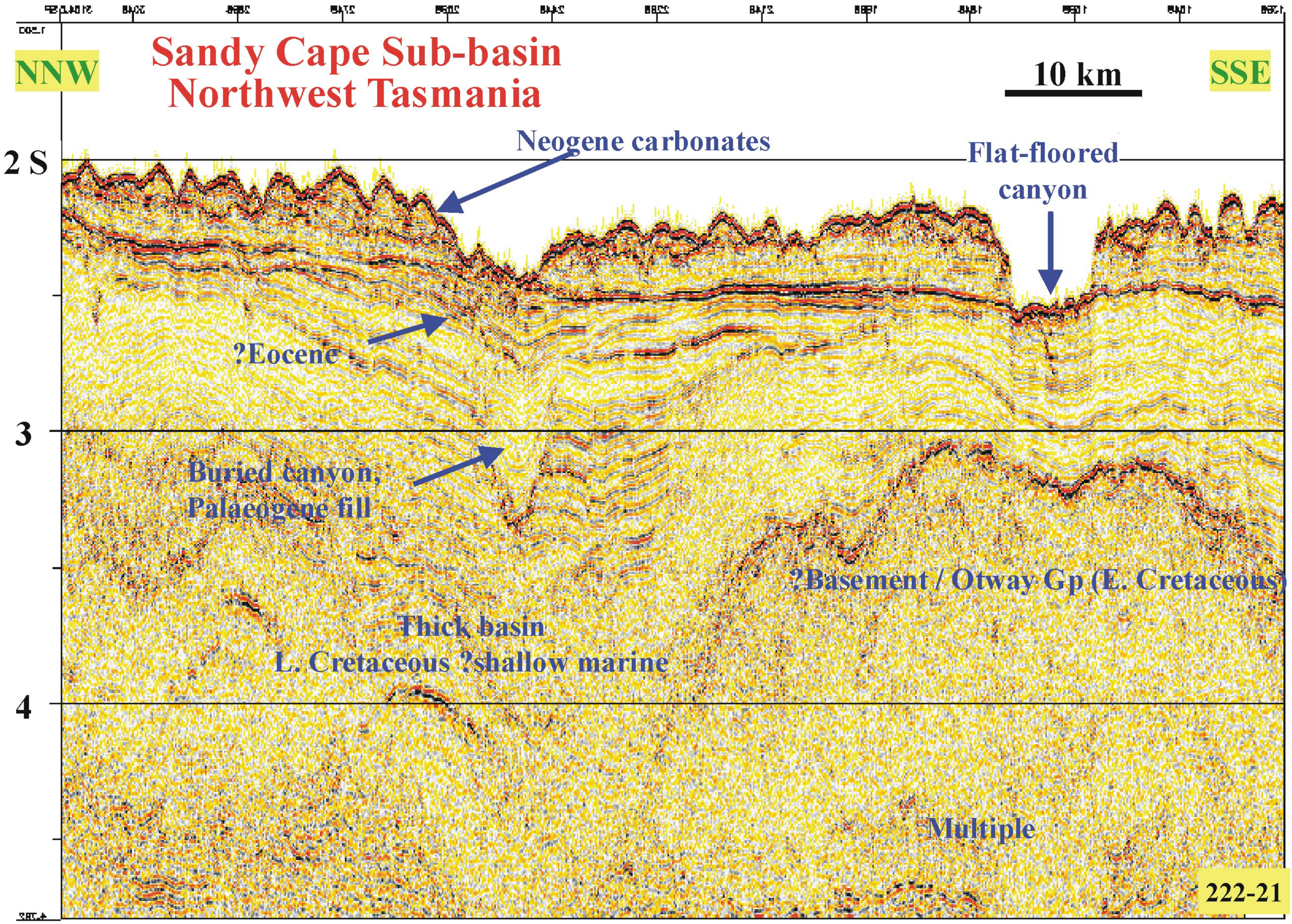


Figure B13. Seismic profile 21 over the Sandy Cape Sub-basin, off northwest Tasmania, showing a thick sedimentary section (at least 2 s twt) with a large buried canyon (Palaeogene fill), and surface canyon development. Structures in Hill *et al.* (2000), Figure 14.

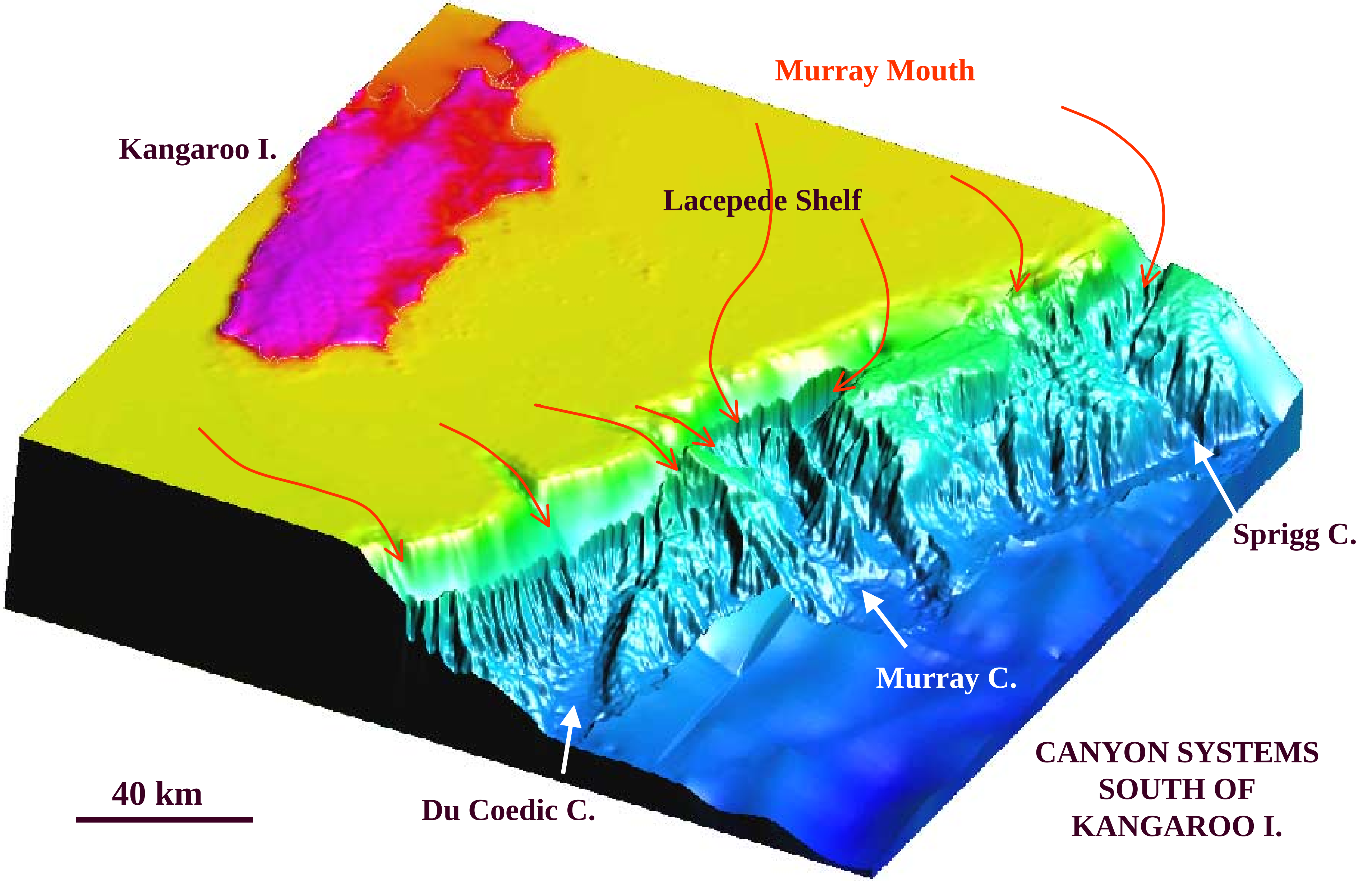


Figure B14. Seabed topography south of Kangaroo Island, with spectacular canyon development at the margin. Inferred sediment flow patterns during sea level lowstands. AUSTREA-1 swath-bathymetry merged with regional bathymetry data.

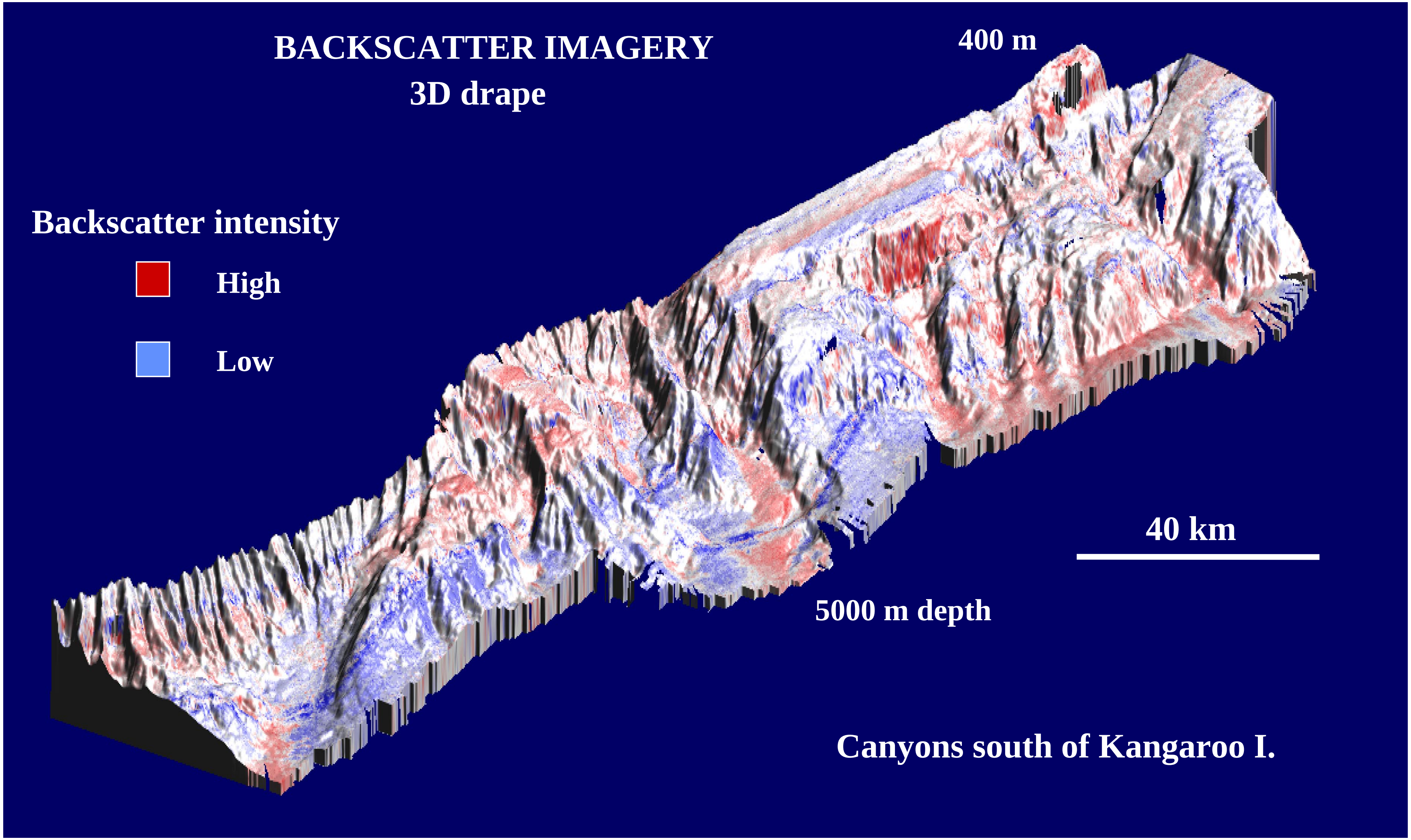


Figure B15. Backscatter imagery draped on 3-D topography – rugged canyon systems south of Kangaroo Island.

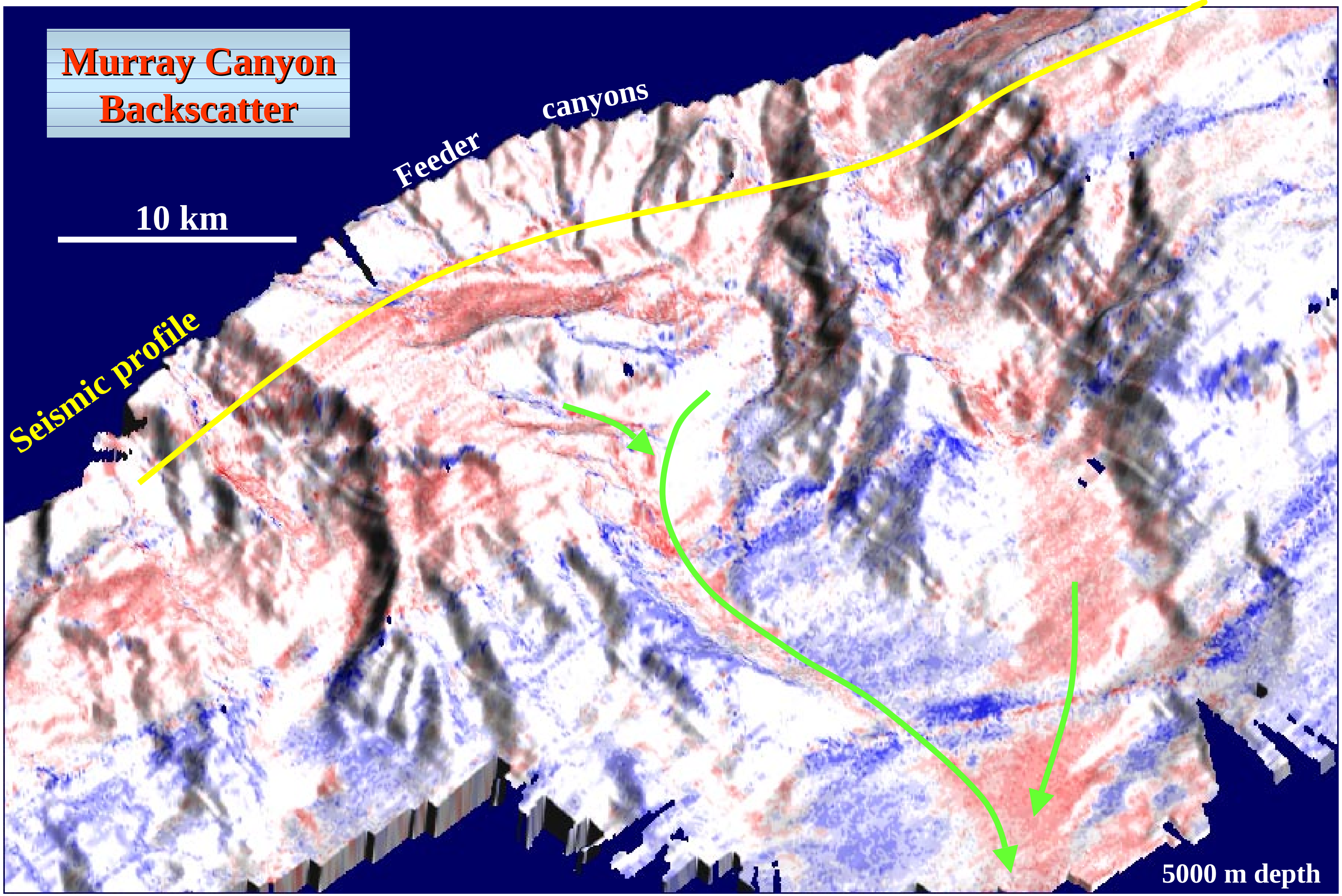


Figure B16. Detail of backscatter response from the canyon floors, walls and channel systems within the Murray Canyon complex. Red is high backscatter and blue is low. Yellow line shows location of seismic profile in Figure B17.

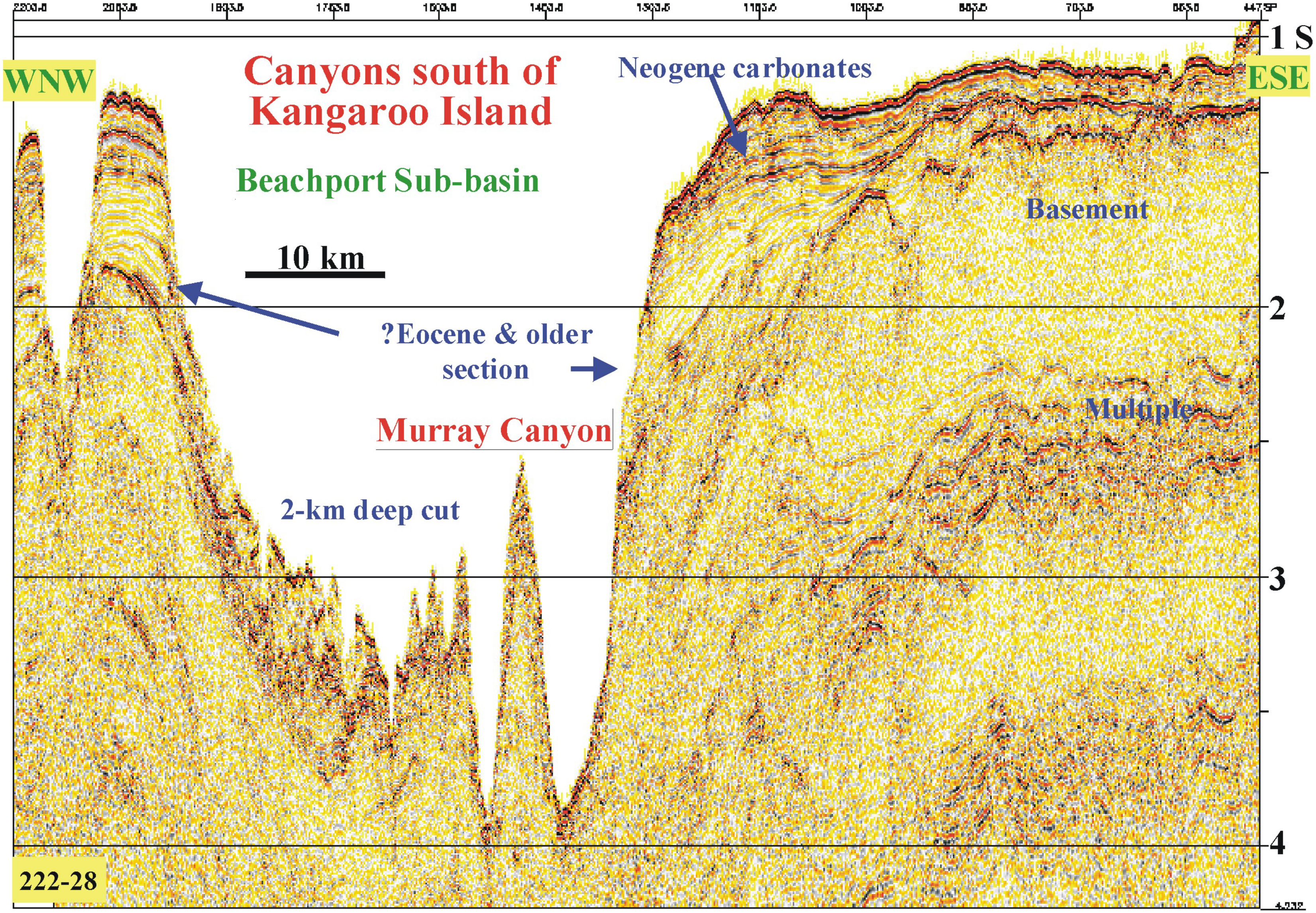
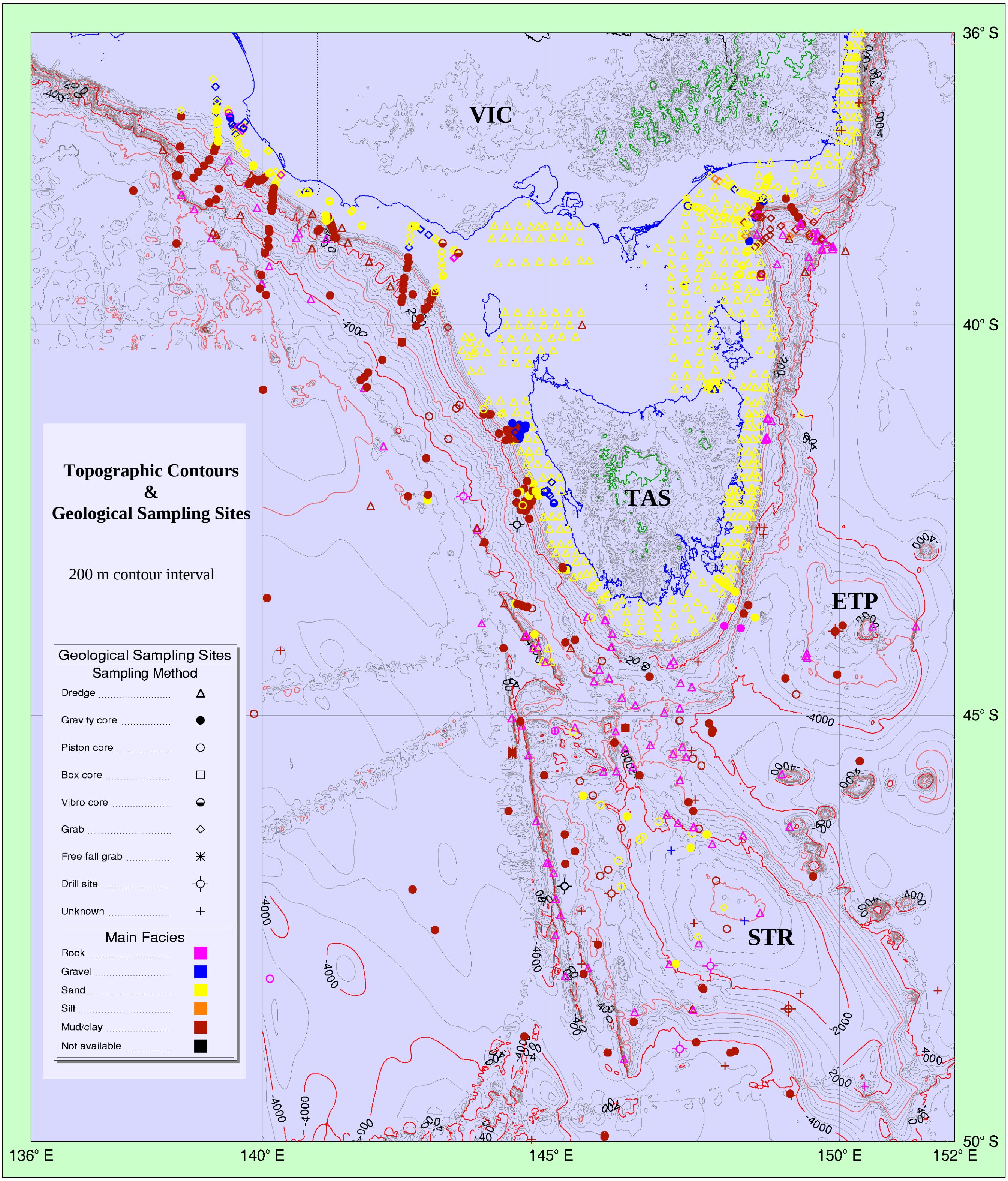


Figure B17. Seismic profile 28 along the upper continental slope south of Kangaroo Island (Beachport Sub-basin) showing the dramatic >2 km relief and incision into the Tertiary prograding sediment wedge beyond the shelf break. Basement, and probable Cretaceous sediments, are exposed in the canyon walls.



VIC: Victoria TAS: Tasmania ETP: East Tasman Plateau STR: South Tasman Rise

Figure B18. Geological sampling sites (AGSO data base) and bathymetric contours (200 m) for the southeast Australian region.

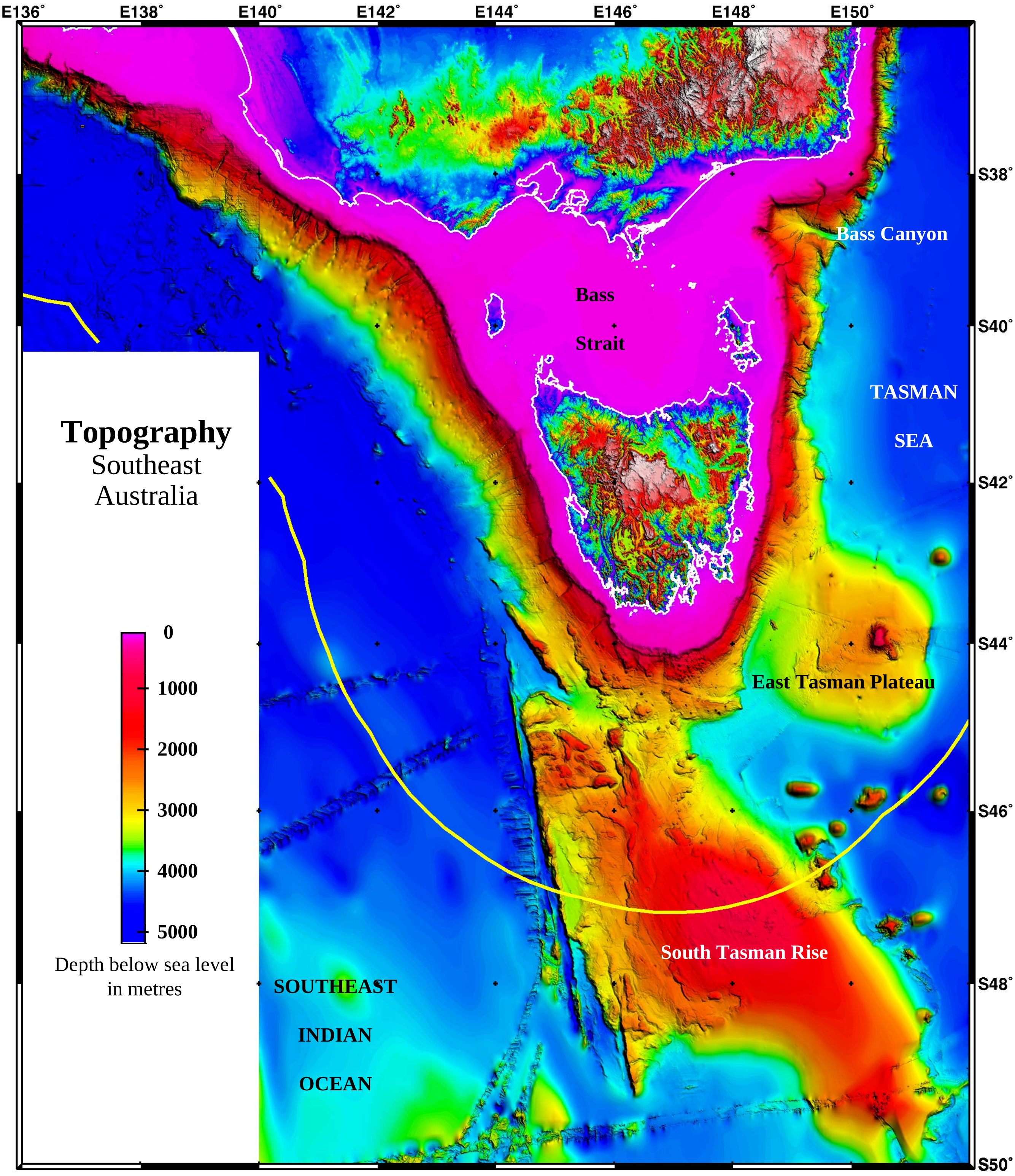


Figure B19. Topography of the southeast Australian region, colour hill-shaded relief. AUSTREA and other swath data merged with regional gridded data including onshore DEM (Carroll, 1996).

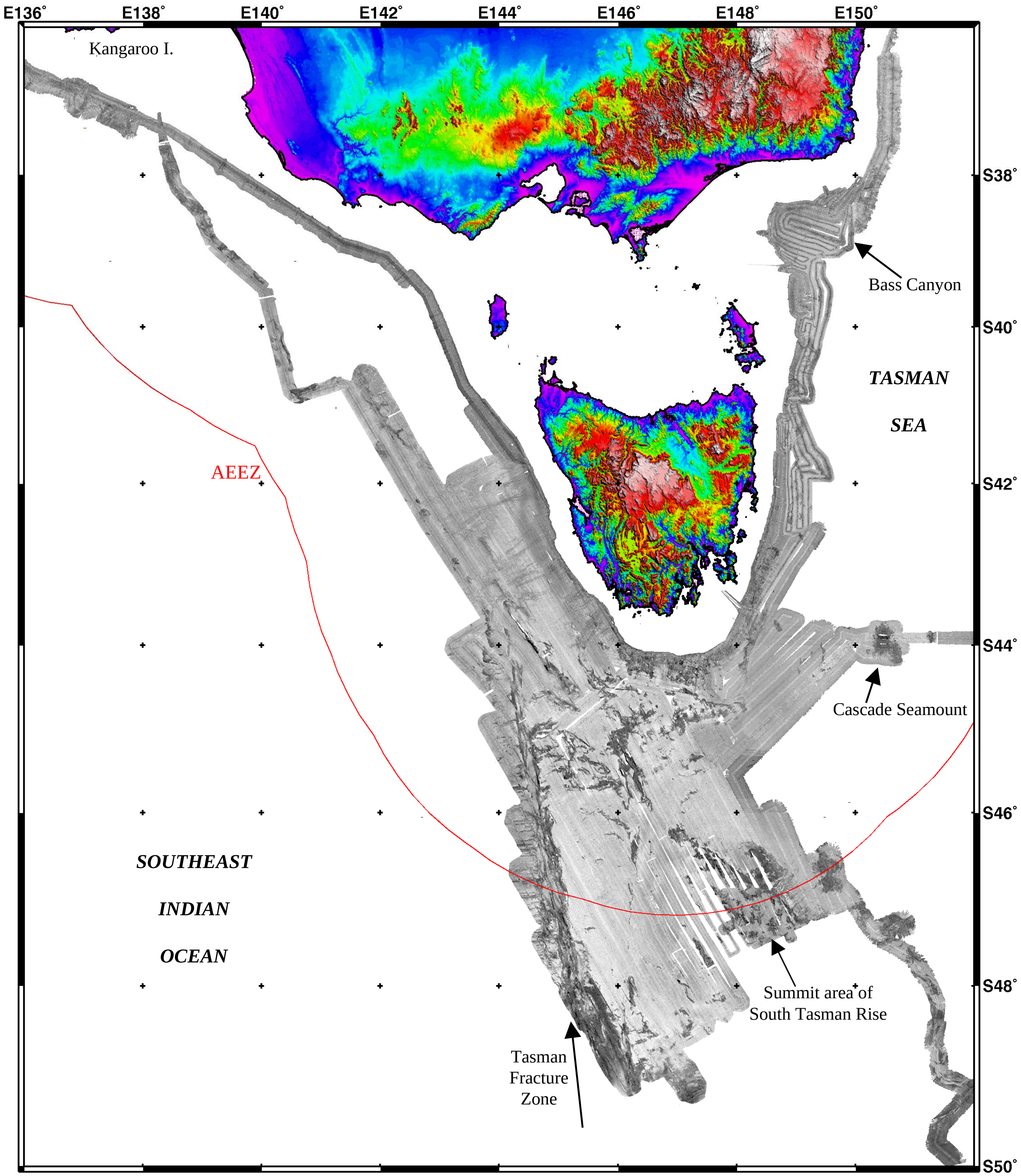


Figure B20. Backscatter imagery over the southeast Australian region. Merge of AUSTREA, TASMANTE and Sojourn7 data sets. Dark areas represent high backscatter levels, light areas low backscatter.

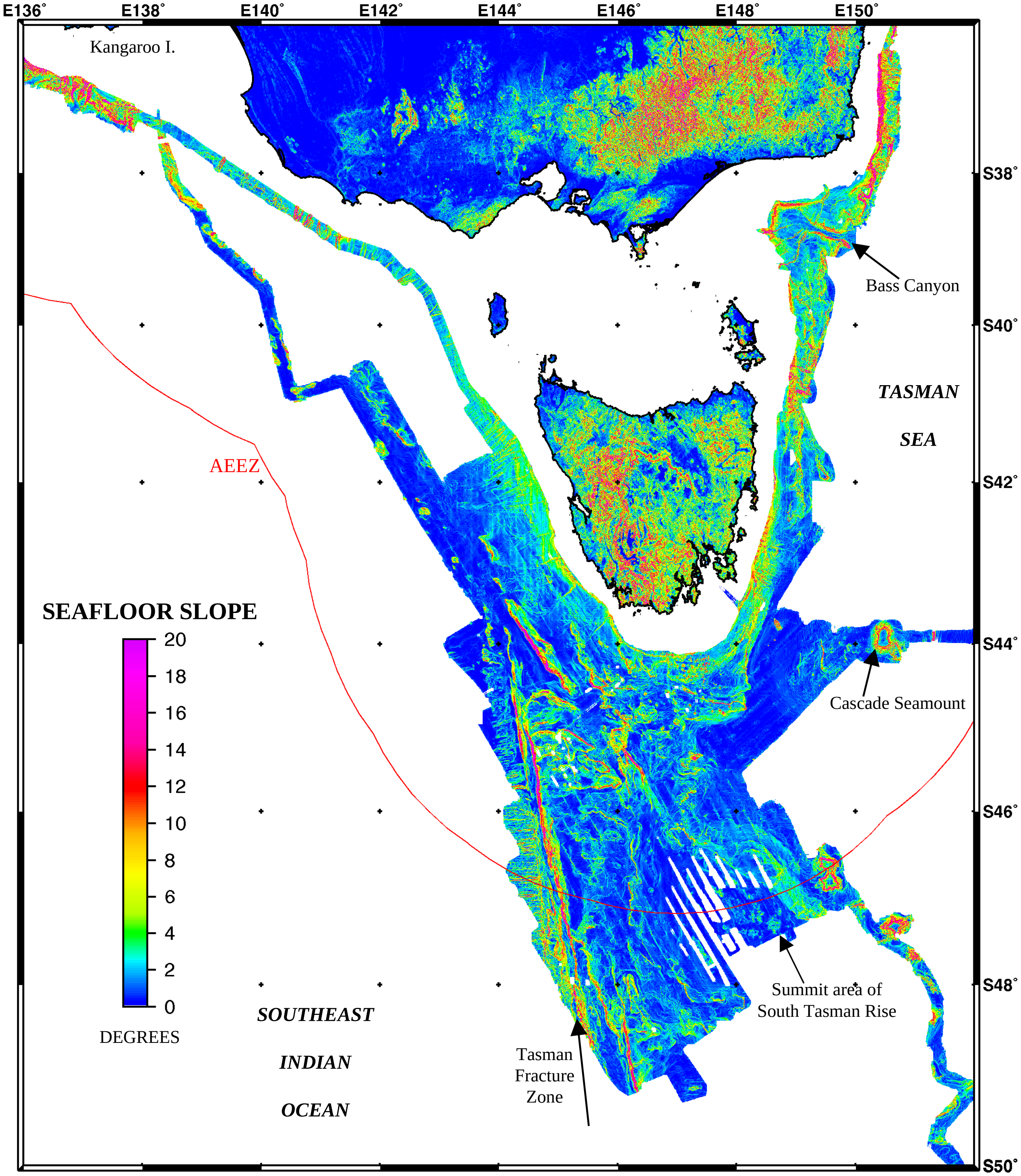


Figure B21. Seabed slope from the gridded swath-bathymetry data for the southeast Australian region.

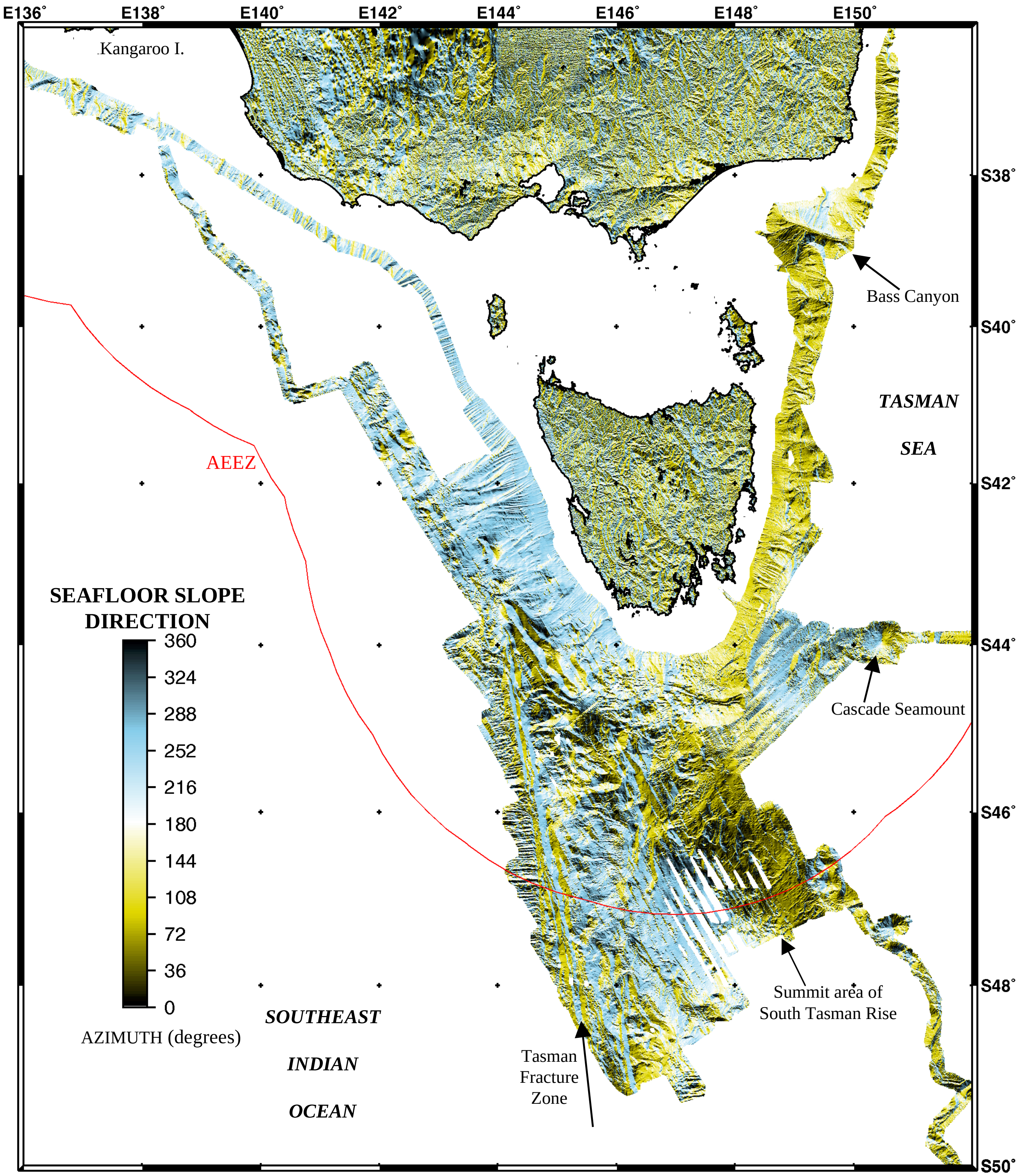


Figure B22. Seabed aspect from the gridded swath-bathymetry data for the southeast Australian region.

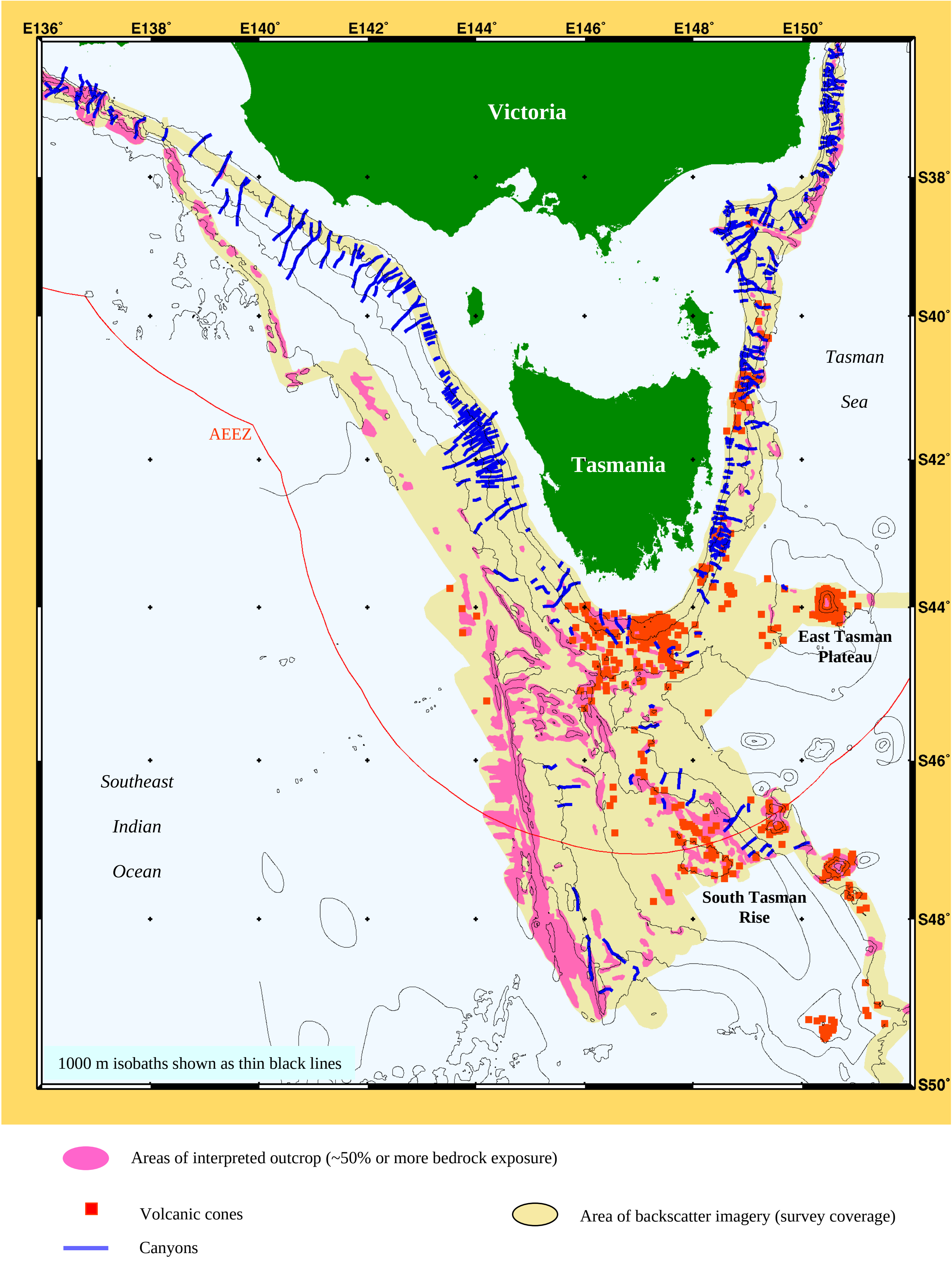


Figure B23. Seabed rock outcrop distribution interpreted from the backscatter imagery for the southeast Australian region.

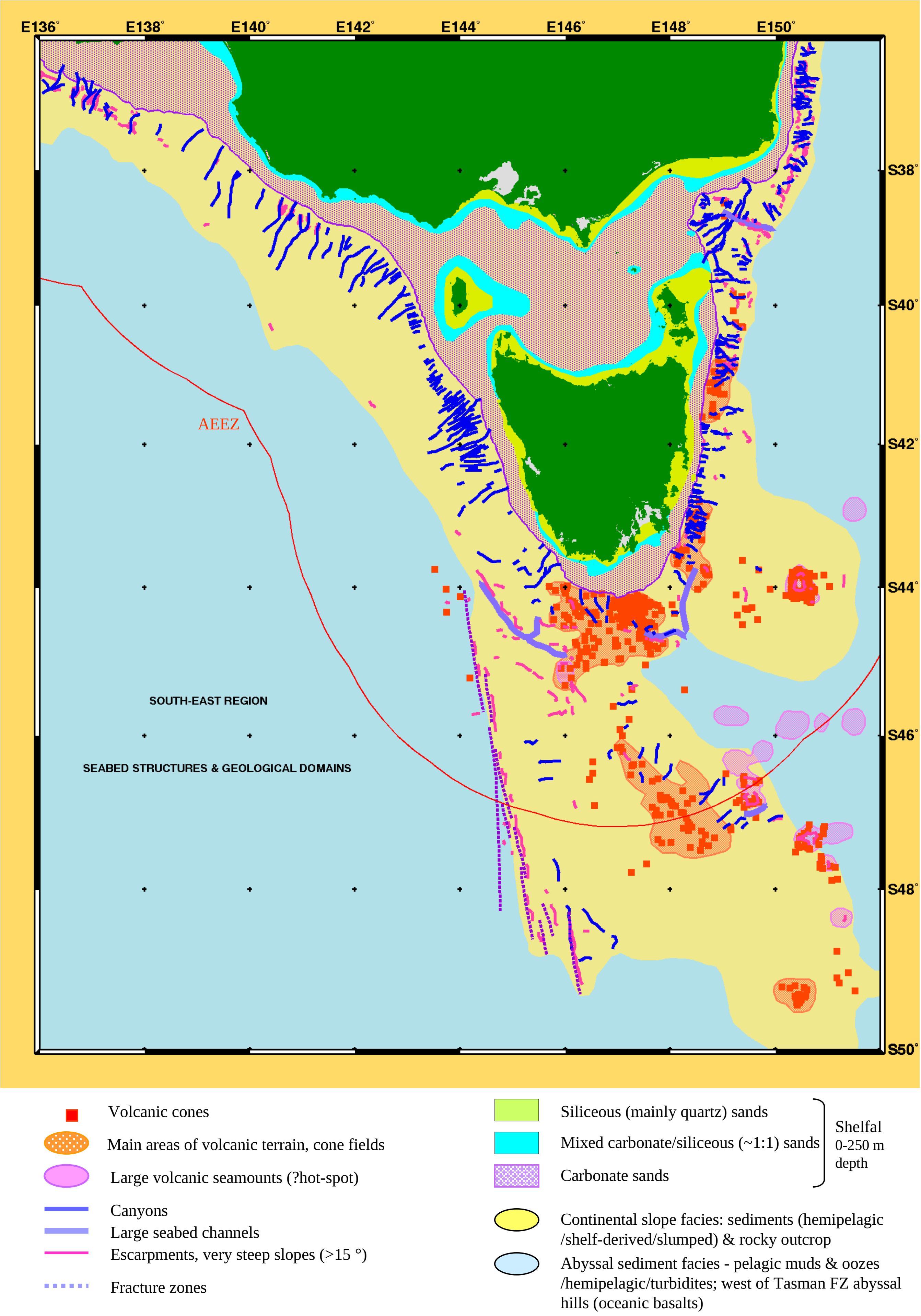


Figure B24. Seabed structures and geological domains of the southeast Australian region.

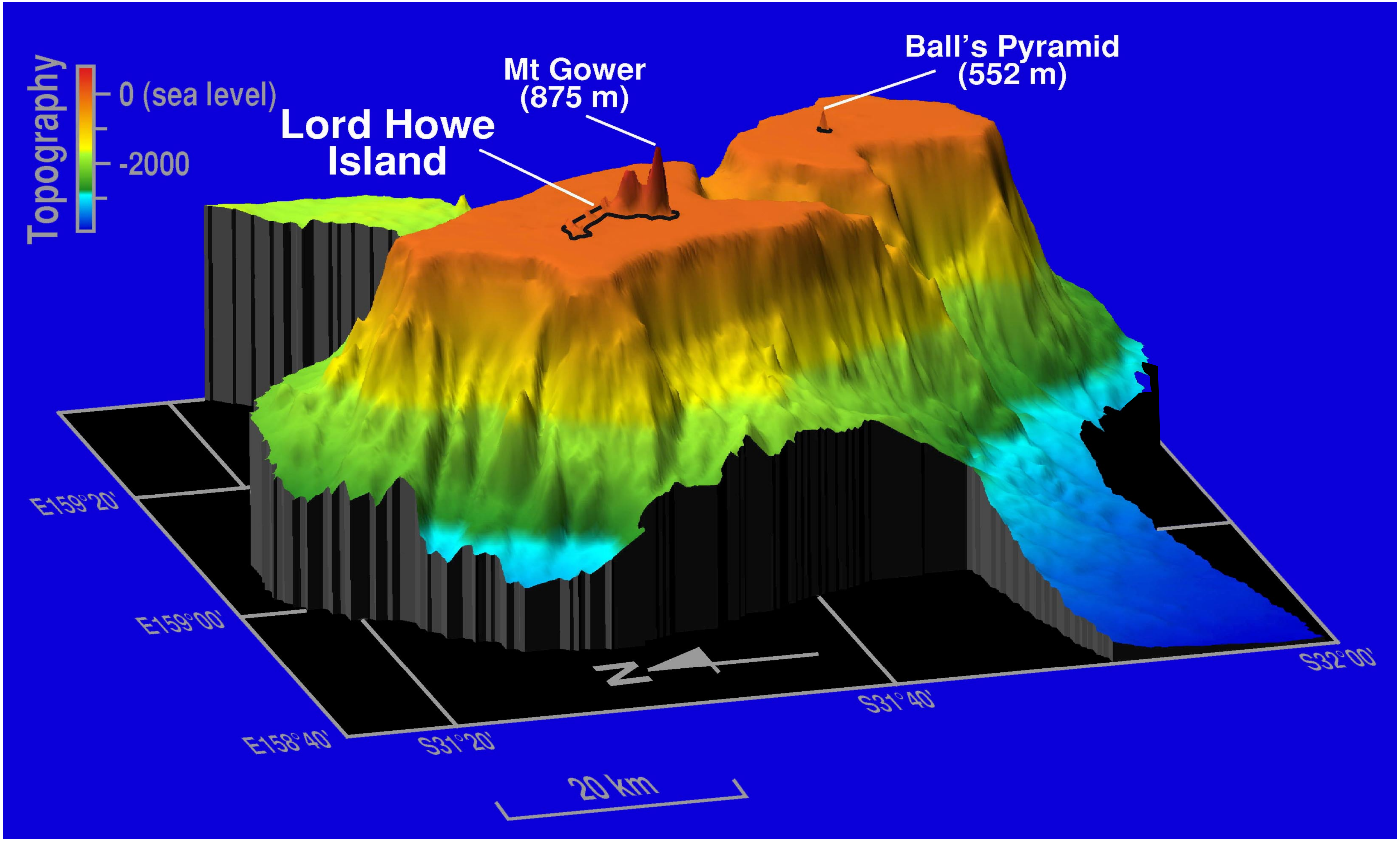


Figure C1. 3-D topographic image of the Lord Howe Island/Ball's Pyramid 'hot-spot' volcano, based on the AUSTREA-1 multibeam data below 300 m water depth.

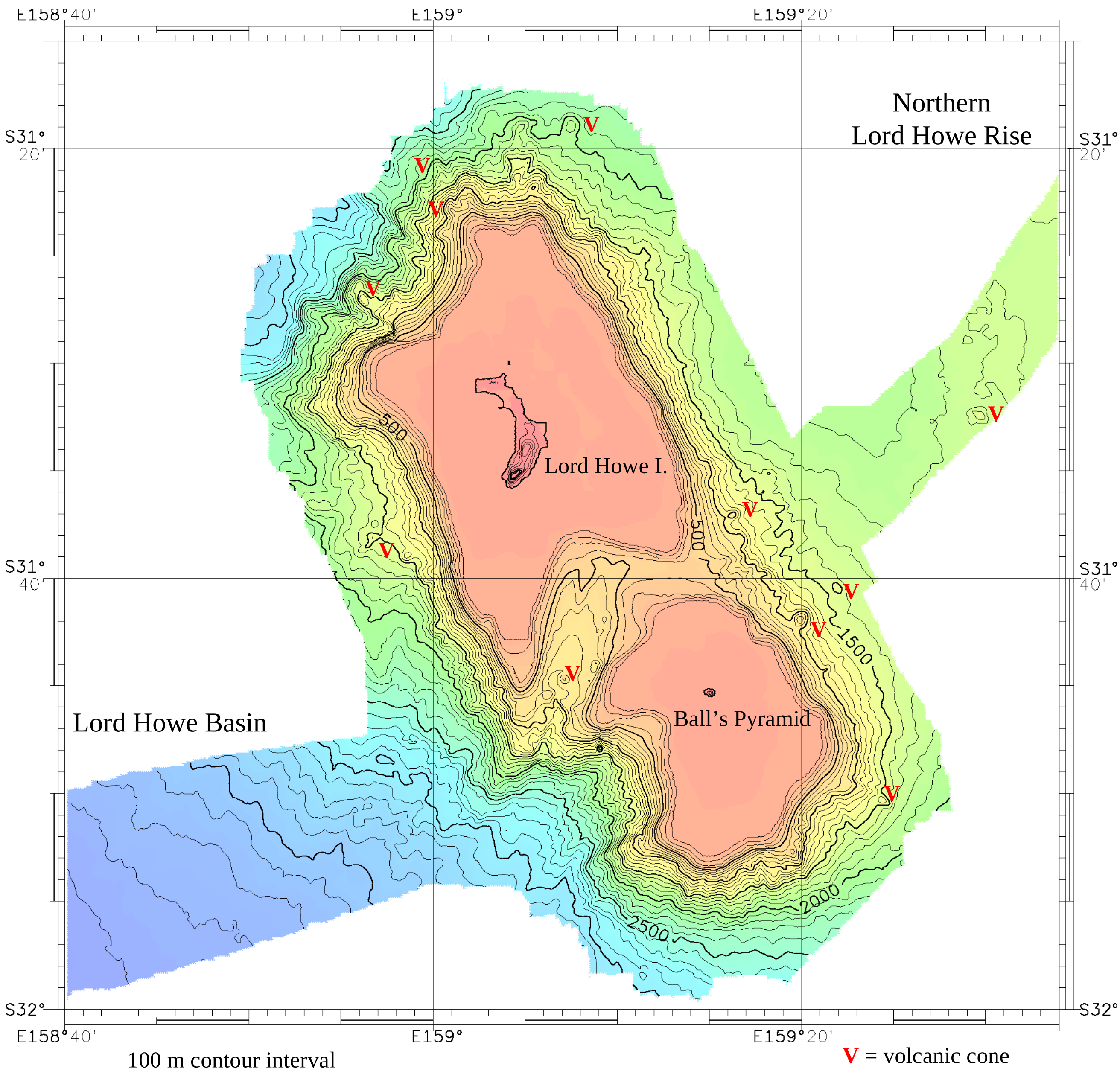


Figure C2. AUSTREA-1 swath-bathymetry off Lord Howe Island and Ball's Pyramid merged with NATMAP (1982) data for depths shallower than 300 m. The flanks are rugged and steep, and studded with volcanic cones up to several hundred metres high.

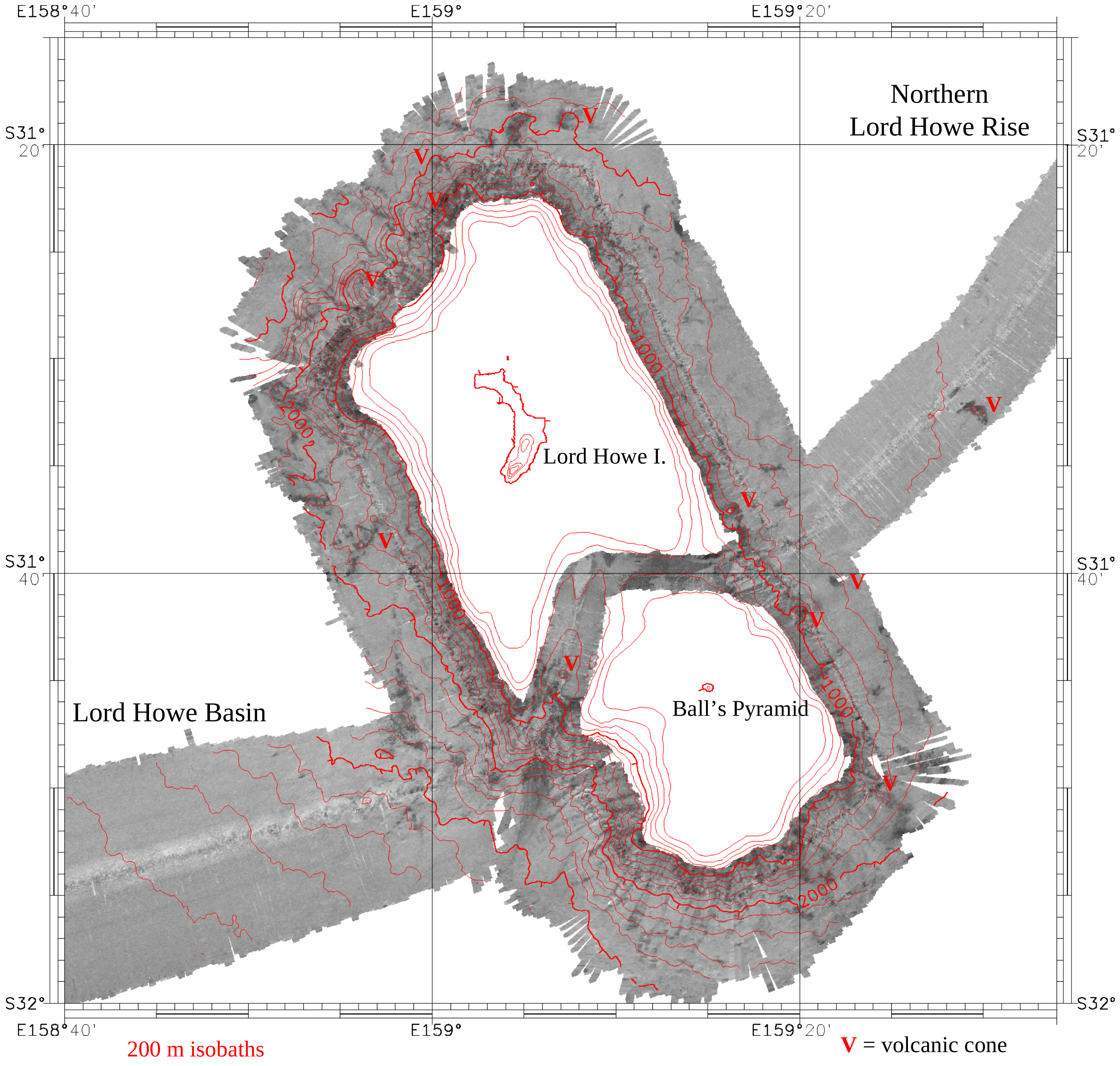


Figure C3. AUSTREA-1 backscatter imagery off Lord Howe Island and Ball's Pyramid. Dark areas represent high backscatter (volcanic cones and steep rocky slopes), while the lighter areas are seafloor sediments (mainly carbonates, including pelagic oozes).

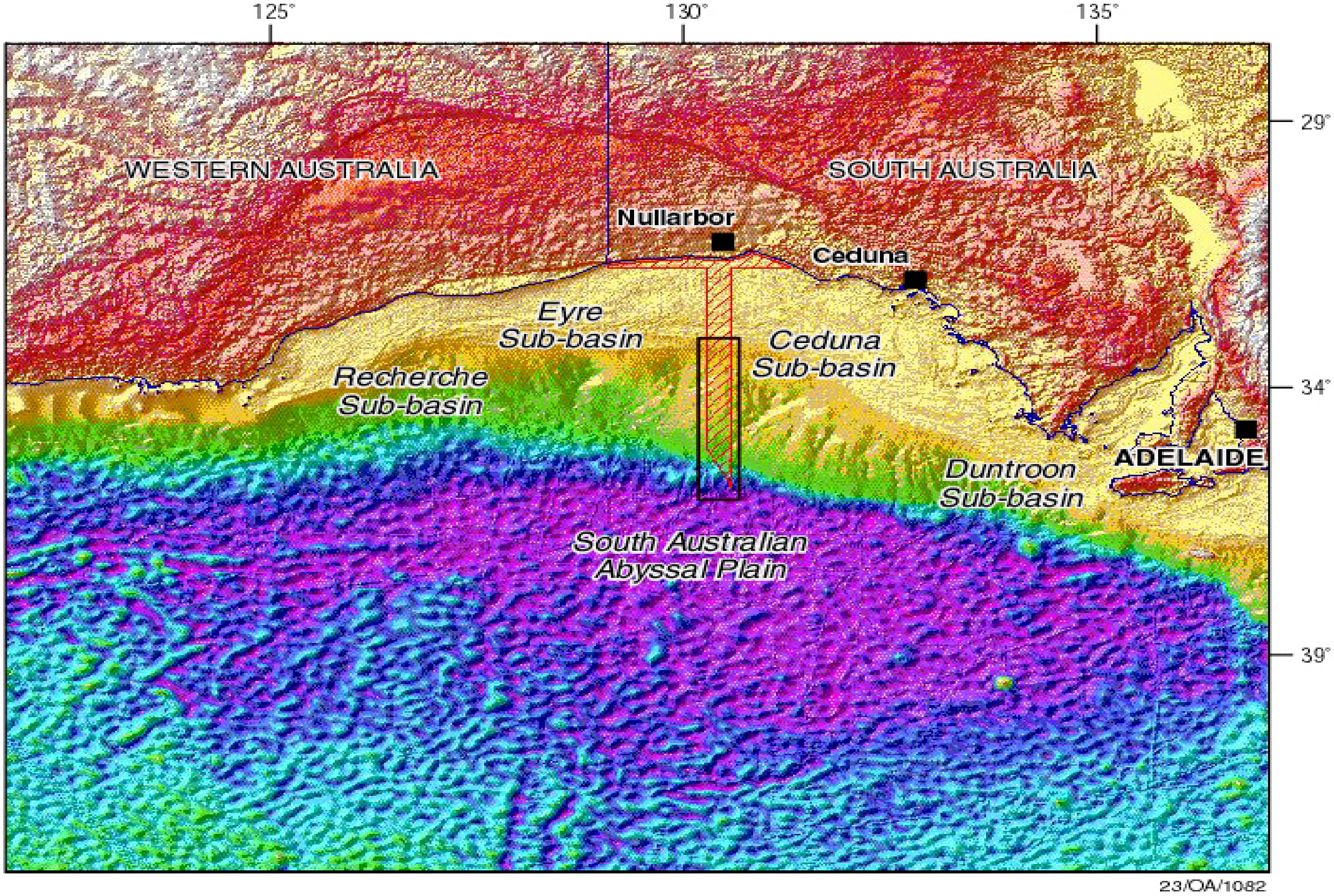


Figure D1. Location of the Great Australian Bight Marine Park (striped red area) and studied area (black rectangle) covering part of the Benthic Protection Zone (bathymetry map from Petkovic *et al*., 1999).

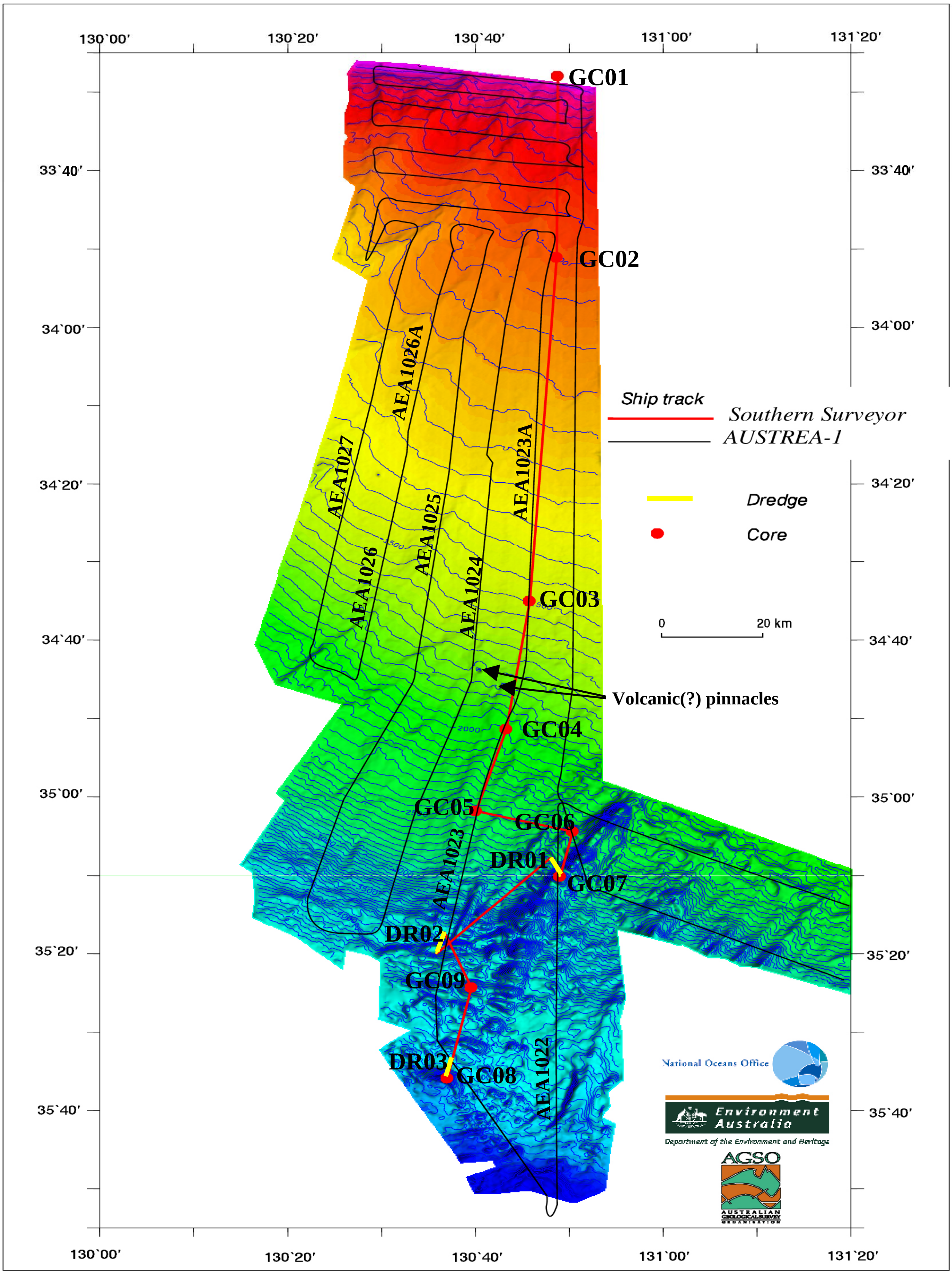


Figure D2. Bathymetry of the deep part of GAB Marine Park with seismic reflection transects (AUSTREA-1 cruise, 2000) and geological sample locations (*Southern Surveyor* cruise, 2000).

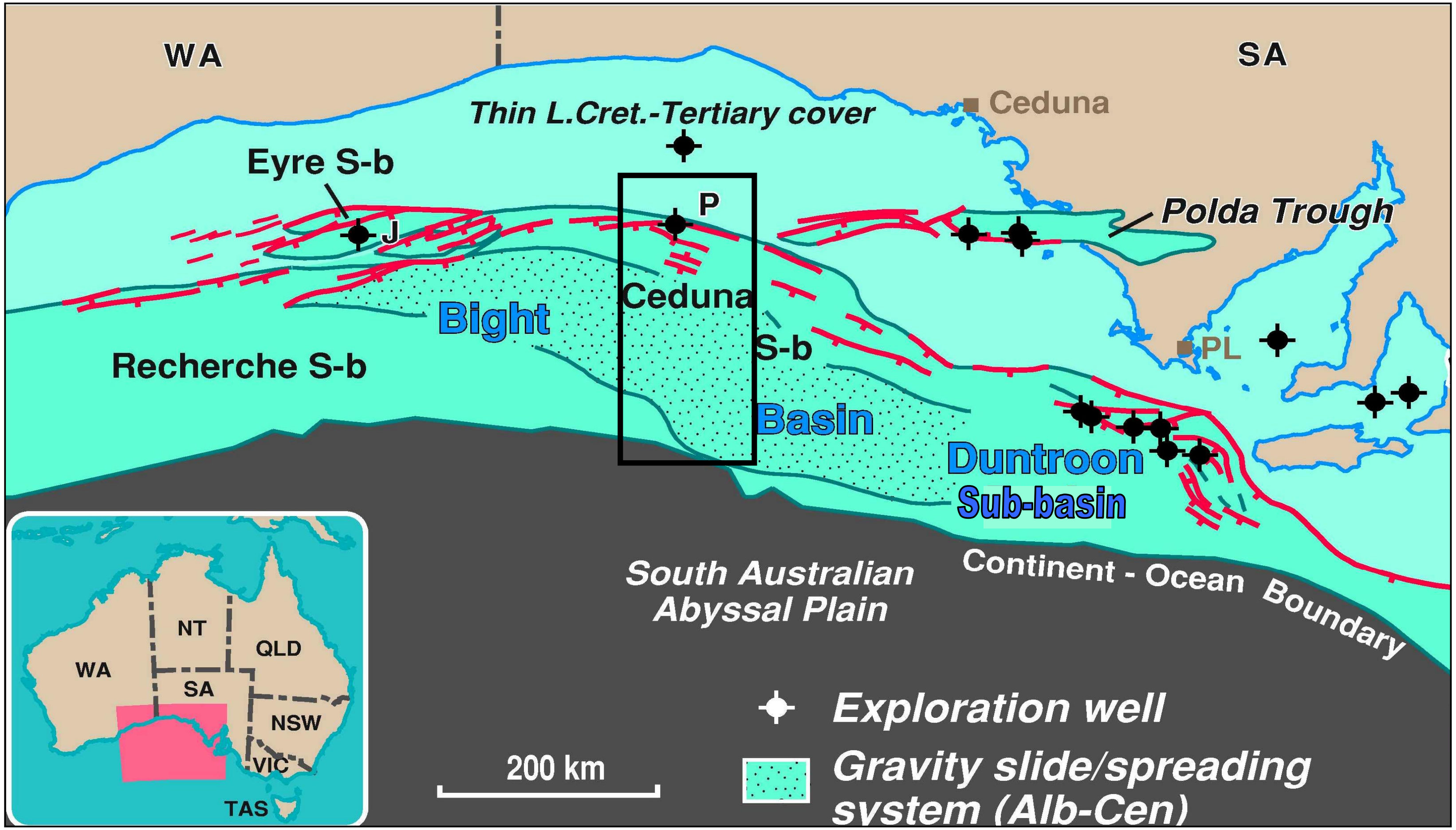


Figure D3. GAB structural elements (after Totterdell *et al*., 2000). J: Esso Jerboa-1 well; P: Shell Potoroo-1 well. The black box indicates the AUSTREA-1 study area over the deepwater GAB Marine Park.

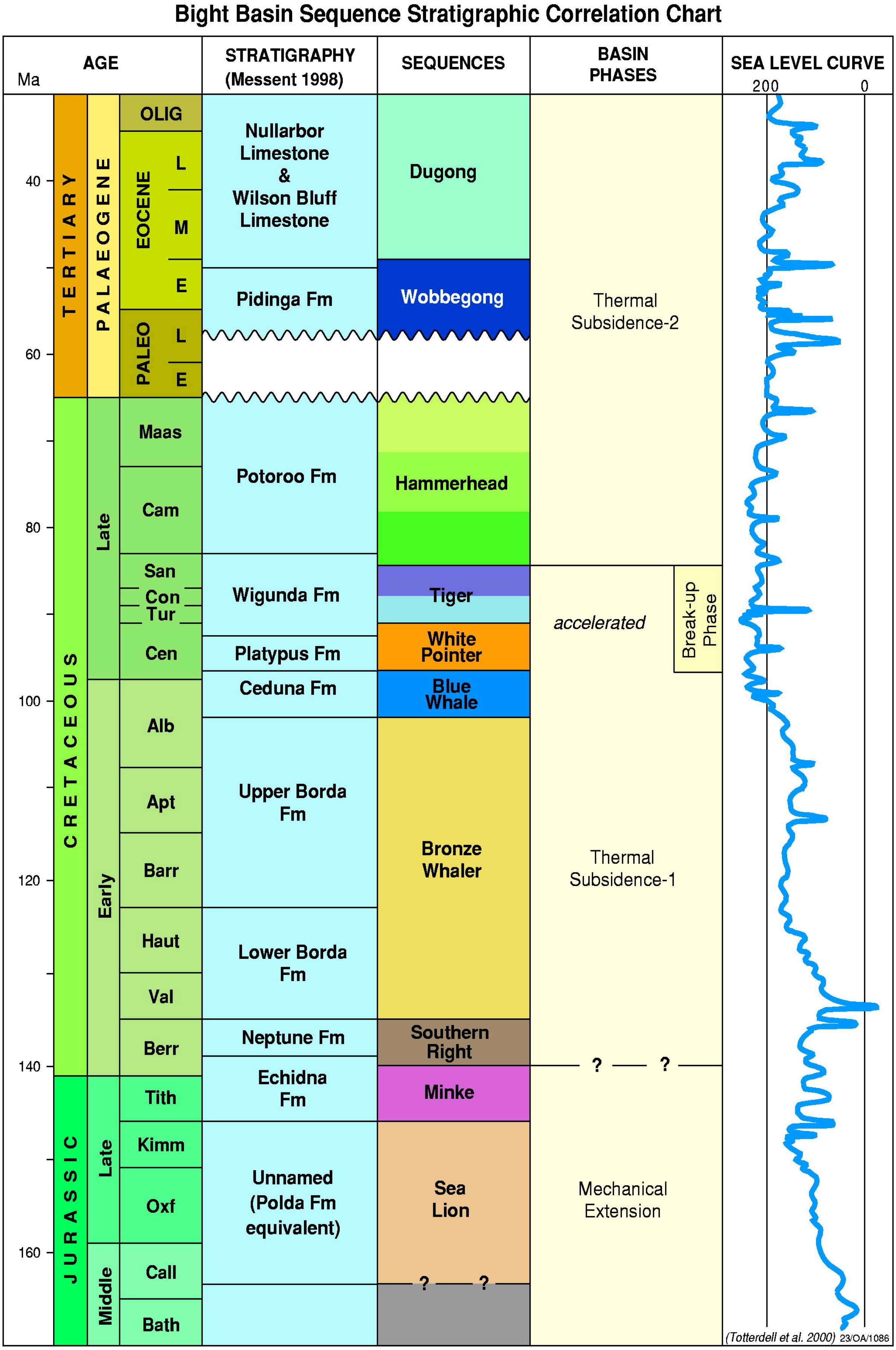

Bight Basin Sequence Stratigraphic Correlation Chart

Figure D4. Generalised stratigraphy of the Bight Basin (after Totterdell *et al*., 2000).

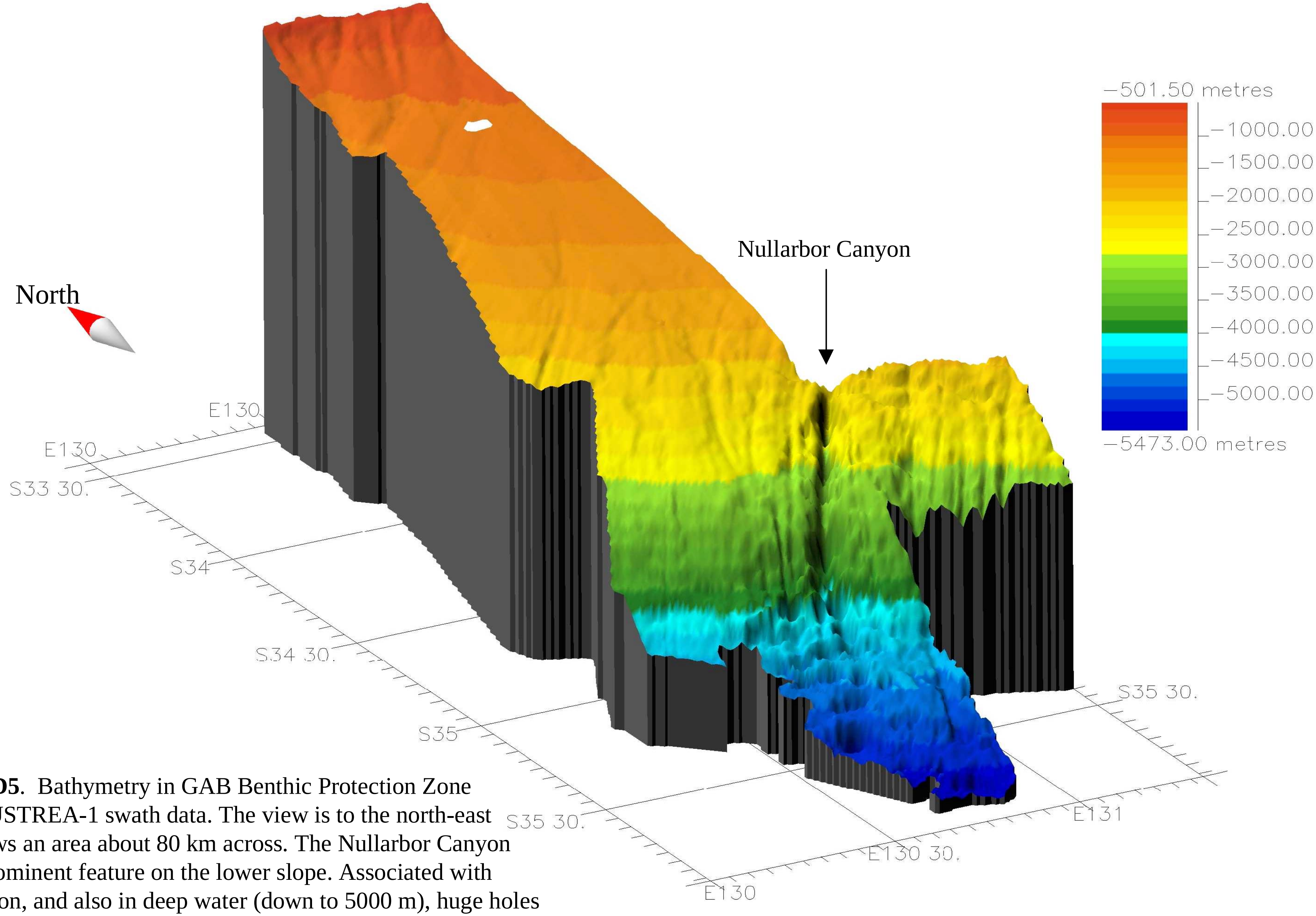


Figure D5. Bathymetry in GAB Benthic Protection Zone from AUSTREA-1 swath data. The view is to the north-east and shows an area about 80 km across. The Nullarbor Canyon is the prominent feature on the lower slope. Associated with the canyon, and also in deep water (down to 5000 m), huge holes are observed, up to 5 km across and 500 m deep.

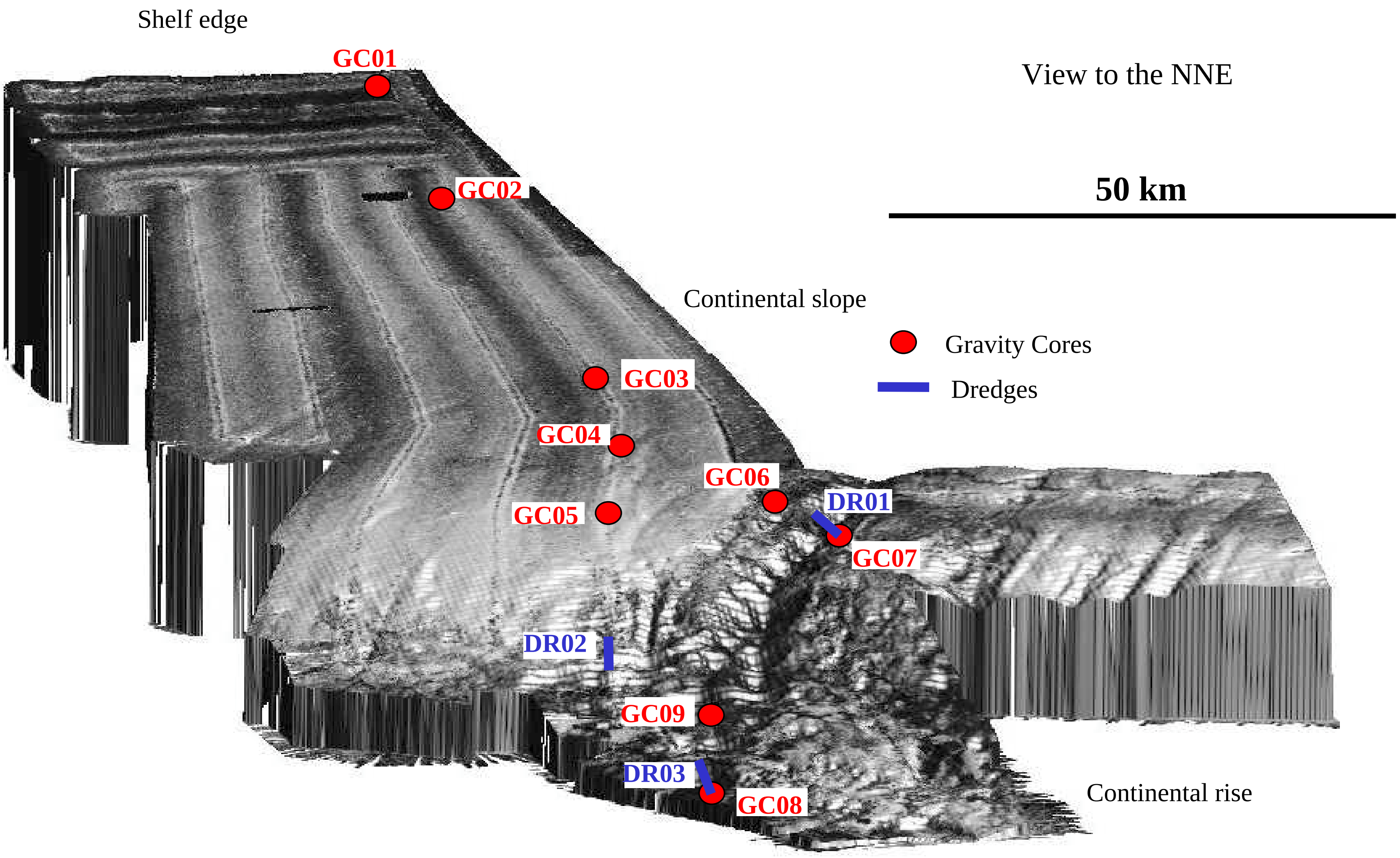


Figure D6. Acoustic reflectivity in GAB Benthic Protection Zone recorded during the AUSTREA-1 cruise.

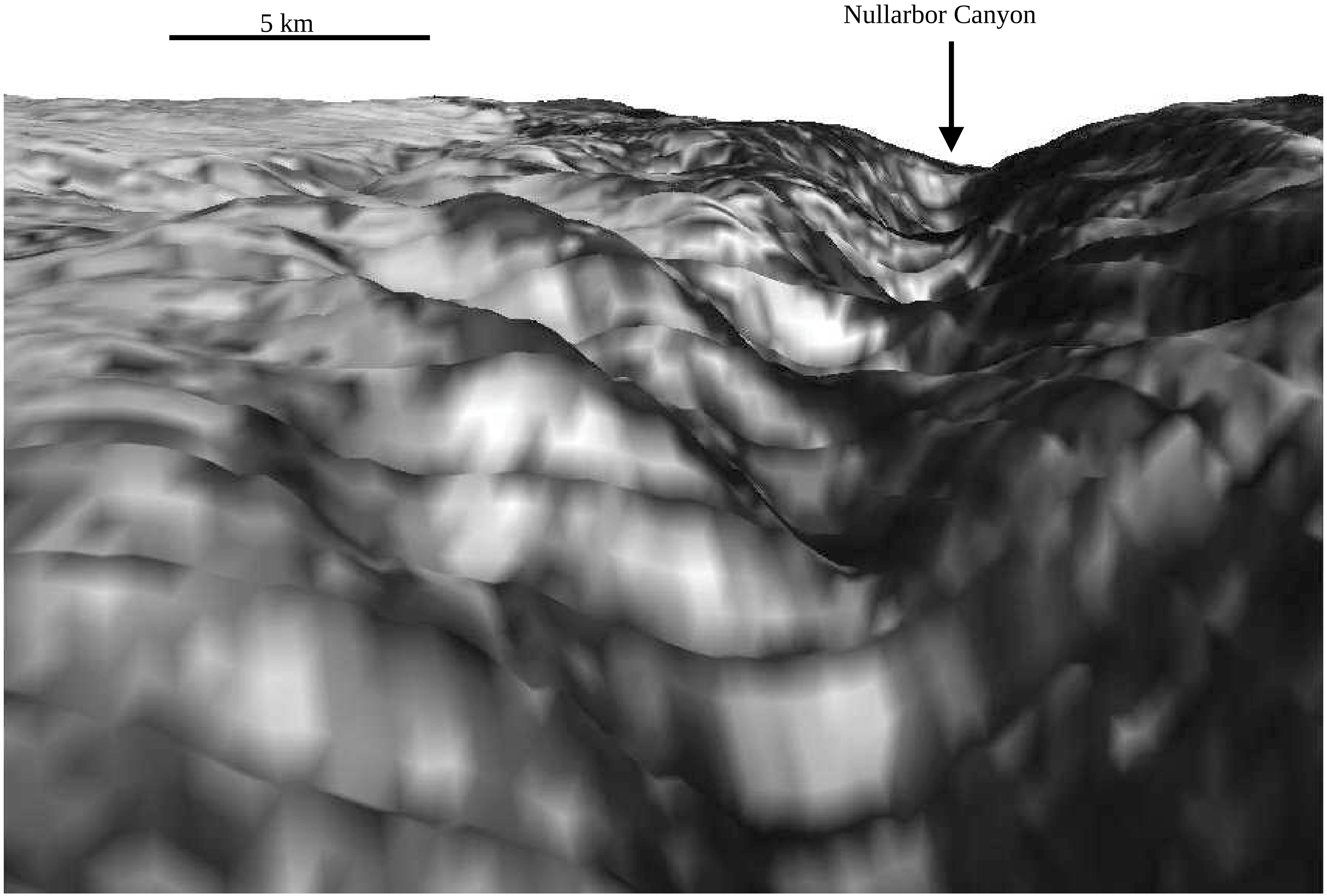


Figure D7. AUSTREA-1 backscatter data; the view is towards the upper part of the Nullarbor Canyon.

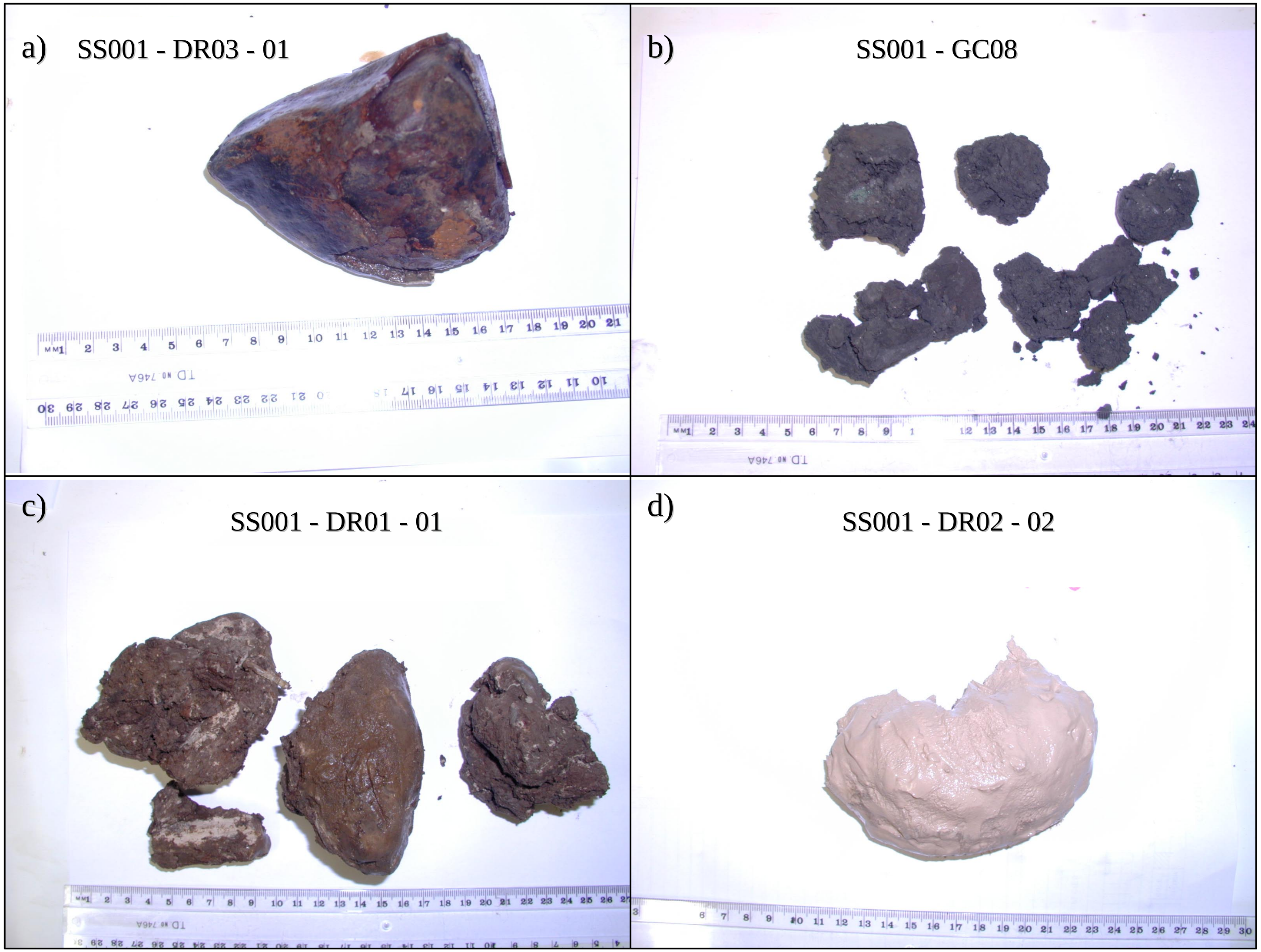
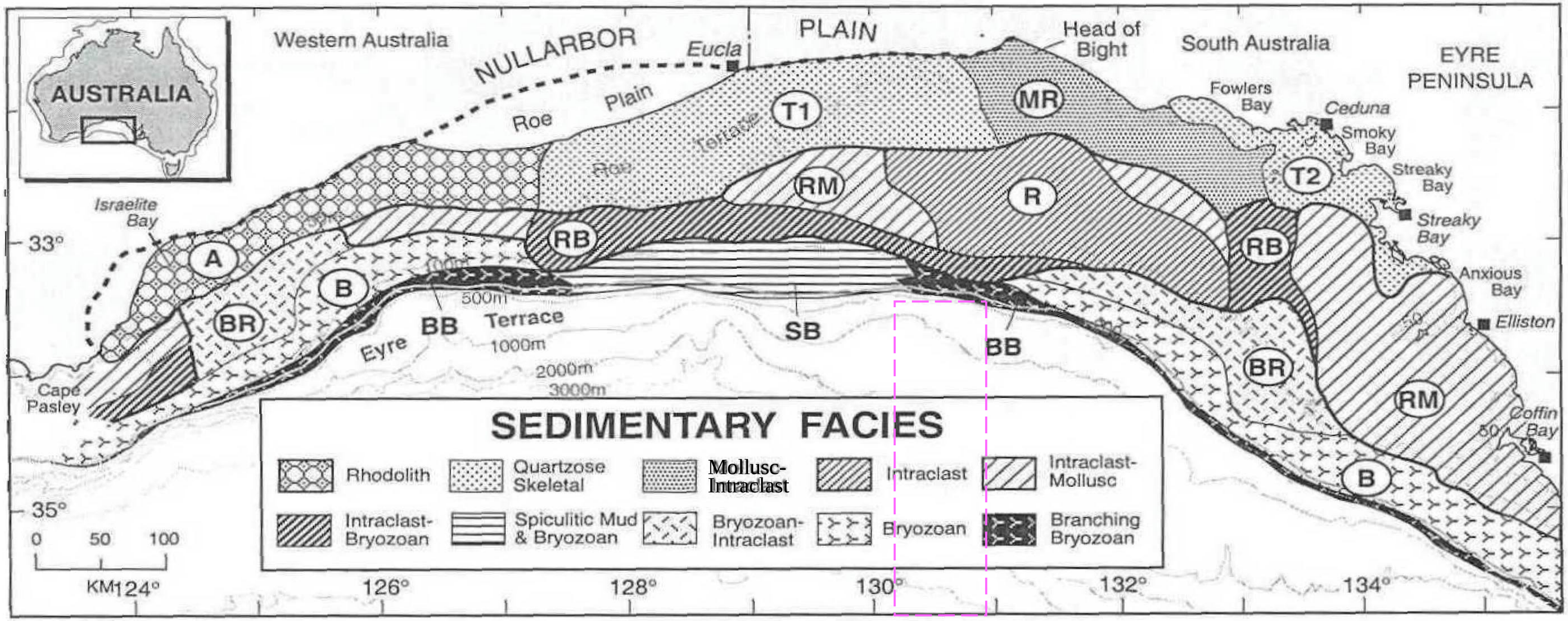
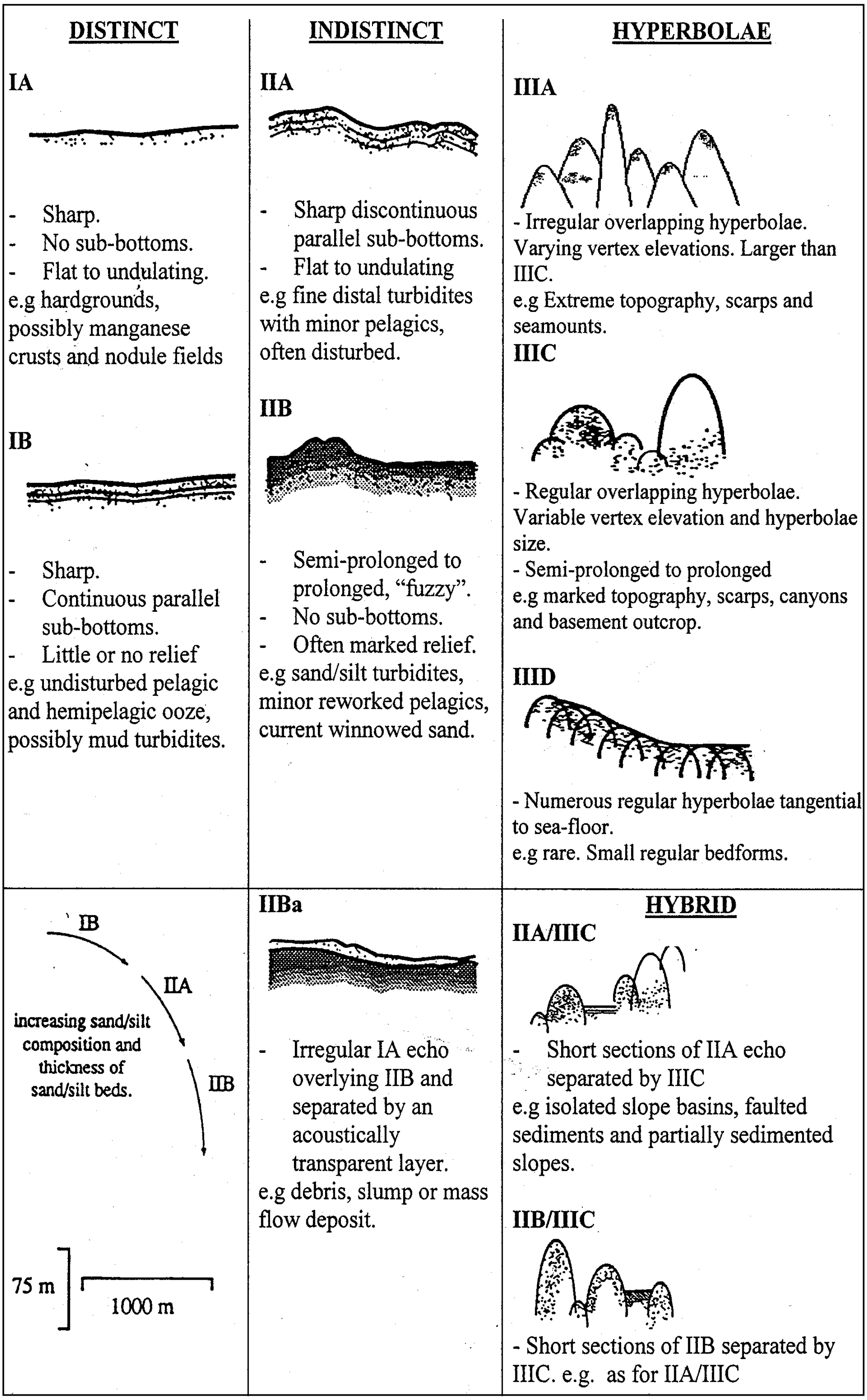


Figure D8. Some samples recovered during the *Southern Surveyor* cruise (see locations on Figure D2) : **a**) Pyramid-shaped cobble with concentric layers of Fe-Mn crust, from dredge site 3 (DR03) in the deepest hole of the Nullarbor Canyon, in water depth of 5250 m; **b**) Black mud with harder mudclasts of different types (some have a rust colour, others are black), from core site 8 (GC08), in the deepest hole of the Nullarbor Canyon at a water-depth of 5250 m; **c**) Sub-rounded brown cobbles of semi-lithified mudstone with Fe oxidation layers and evidence of bioturbation, from dredge site 1 (DR01) in one of the shallow holes in the Nullarbor Canyon, at a water-depth of 3220 m ; **d**) Pinky-beige Quaternary nanno-foraminiferal ooze, from dredge site 2 (DR02) on the continental slope, on the western side of the Nullarbor Canyon, at a water-depth of 4350-3850 m.



Area of present study

Figure D9. Sedimentary facies on the GAB shelf (from James *et al*., in prep.).



DISTINCT	INDISTINCT	HYPERBOLAE
IA - Sharp. - No sub-bottoms. - Flat to undulating. e.g hardgrounds, possibly manganese crusts and nodule fields	**IIA** - Sharp discontinuous parallel sub-bottoms. - Flat to undulating e.g fine distal turbidites with minor pelagics, often disturbed.	**IIIA** - Irregular overlapping hyperbolae. Varying vertex elevations. Larger than IIIC. e.g Extreme topography, scarps and seamounts.
IB - Sharp. - Continuous parallel sub-bottoms. - Little or no relief e.g undisturbed pelagic and hemipelagic ooze, possibly mud turbidites.	**IIB** - Semi-prolonged to prolonged, “fuzzy”. - No sub-bottoms. - Often marked relief. e.g sand/silt turbidites, minor reworked pelagics, current winnowed sand.	**IIIC** - Regular overlapping hyperbolae. Variable vertex elevation and hyperbolae size. - Semi-prolonged to prolonged e.g marked topography, scarps, canyons and basement outcrop. **IIID** - Numerous regular hyperbolae tangential to sea-floor. e.g rare. Small regular bedforms.
IB IIA increasing sand/silt composition and thickness of sand/silt beds. IIB 75 m 1000 m	**IIBa** - Irregular IA echo overlying IIB and separated by an acoustically transparent layer. e.g debris, slump or mass flow deposit.	**HYBRID** **IIA/IIIC** - Short sections of IIA echo separated by IIIC e.g isolated slope basins, faulted sediments and partially sedimented slopes. **IIB/IIIC** - Short sections of IIB separated by IIIC. e.g. as for IIA/IIIC

Figure D10. Acoustic facies types based on 3.5 kHz echo sounder profiles (from Damuth, 1980 and Whitmore & Belton, 1997).

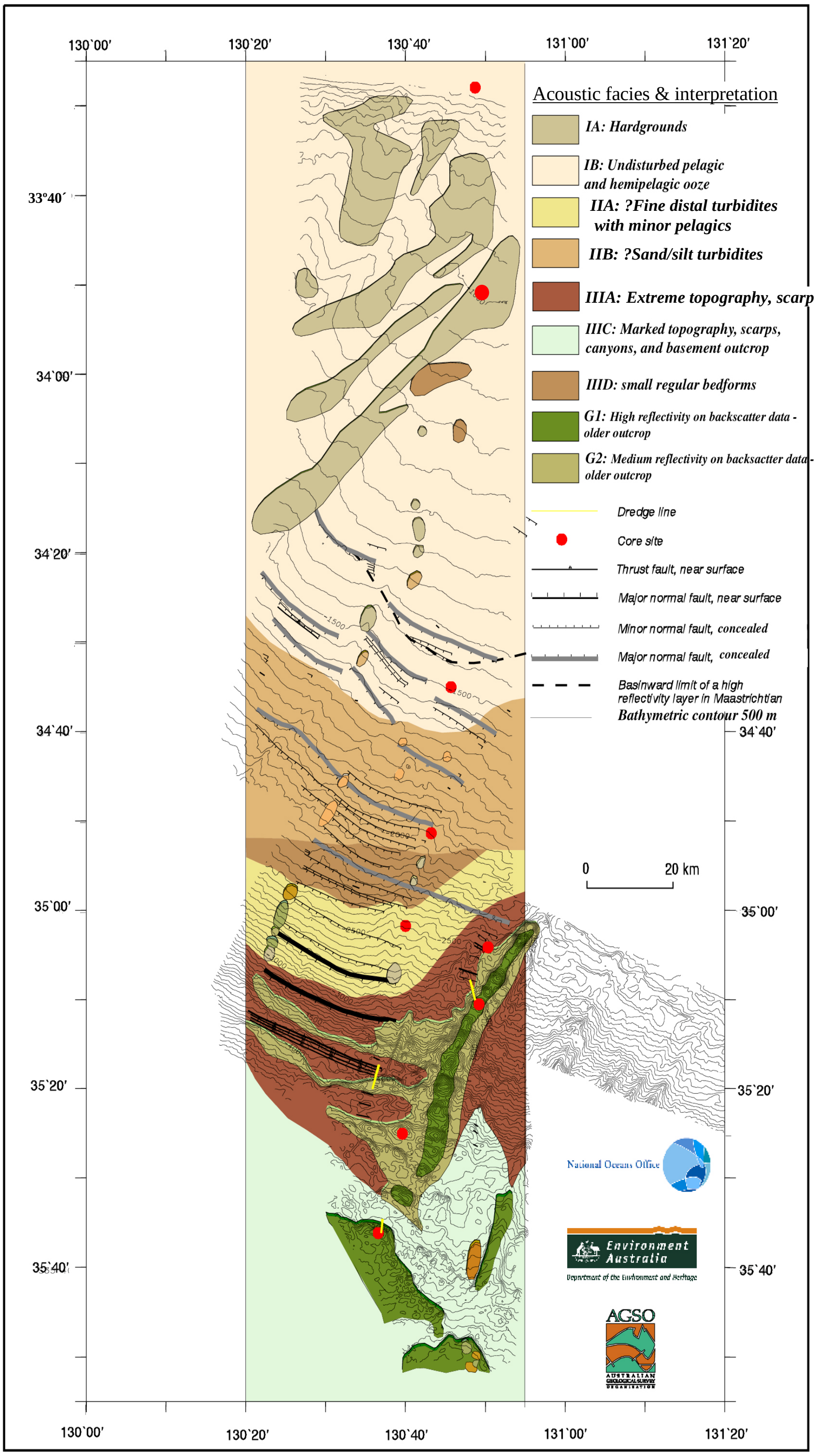


Figure D11. Acoustic facies in the GAB Benthic Protection Zone interpreted from swath imagery (bathymetry and acoustic reflectivity) and along-track 3.5 kHz seismic profiles (AUSTREA-1 cruise, 2000), with fault locations, and sediment sample sites (from *Southern Surveyor* SS01/00 cruise, 2000).

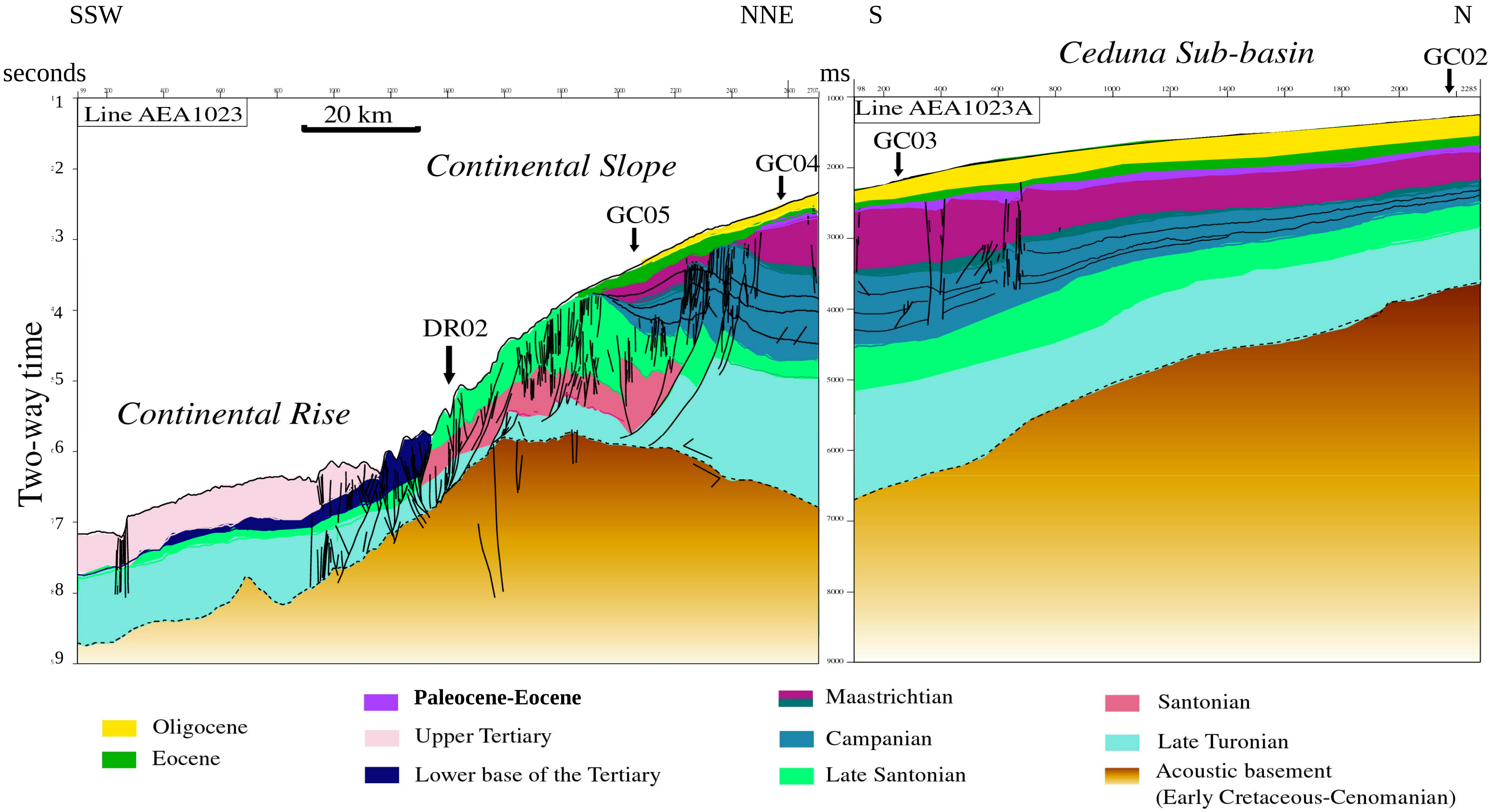


Figure D12. Line-drawing of the AEA1023 and AEA1023A seismic profiles along the GAB Marine Park - see Appendix 5 for an explanation of geological ages.

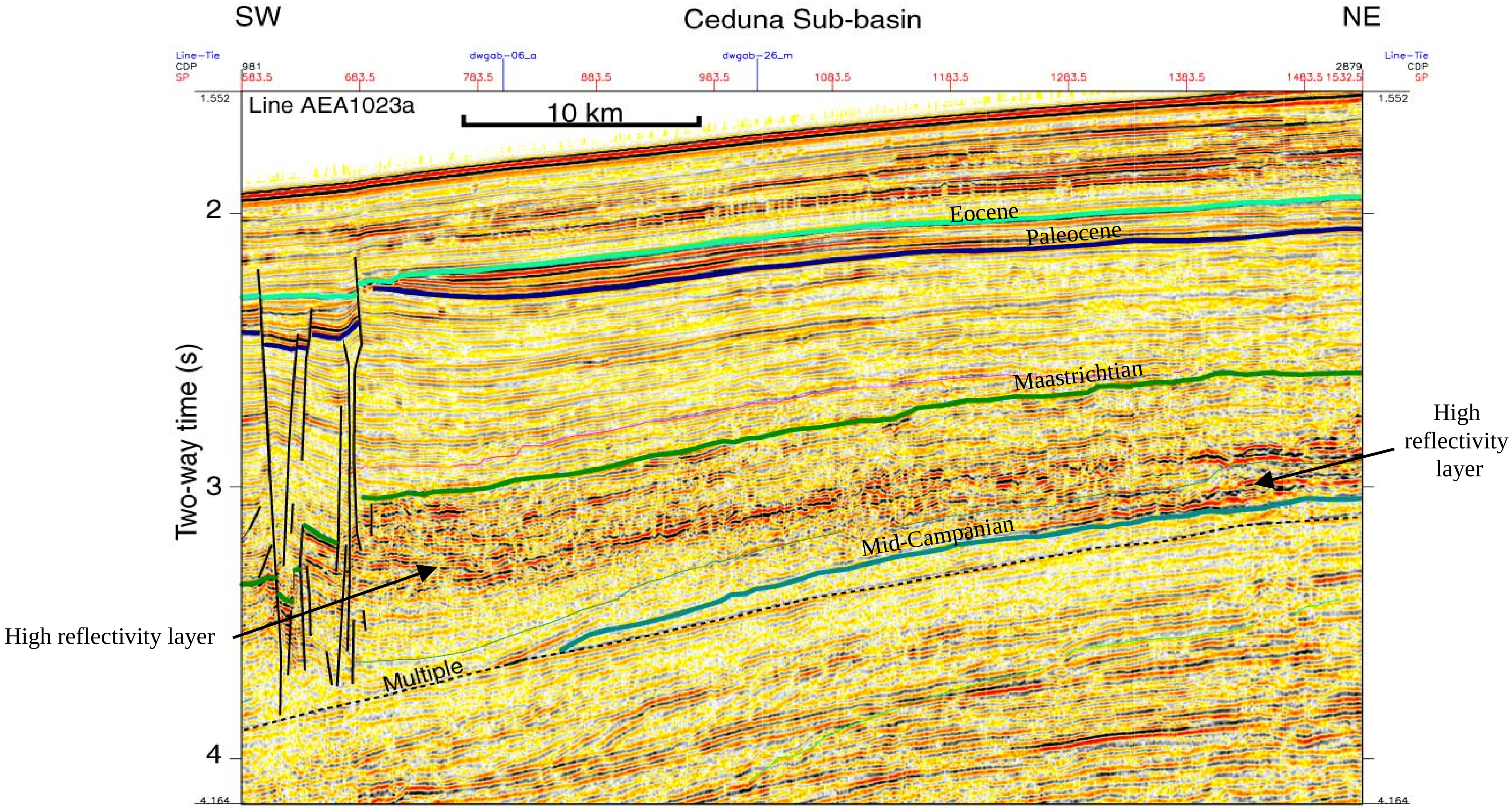


Figure D13. Presence of a high reflectivity layer within the Hammerhead sequence, between mid-Campanian and Maastrichtian sediments.

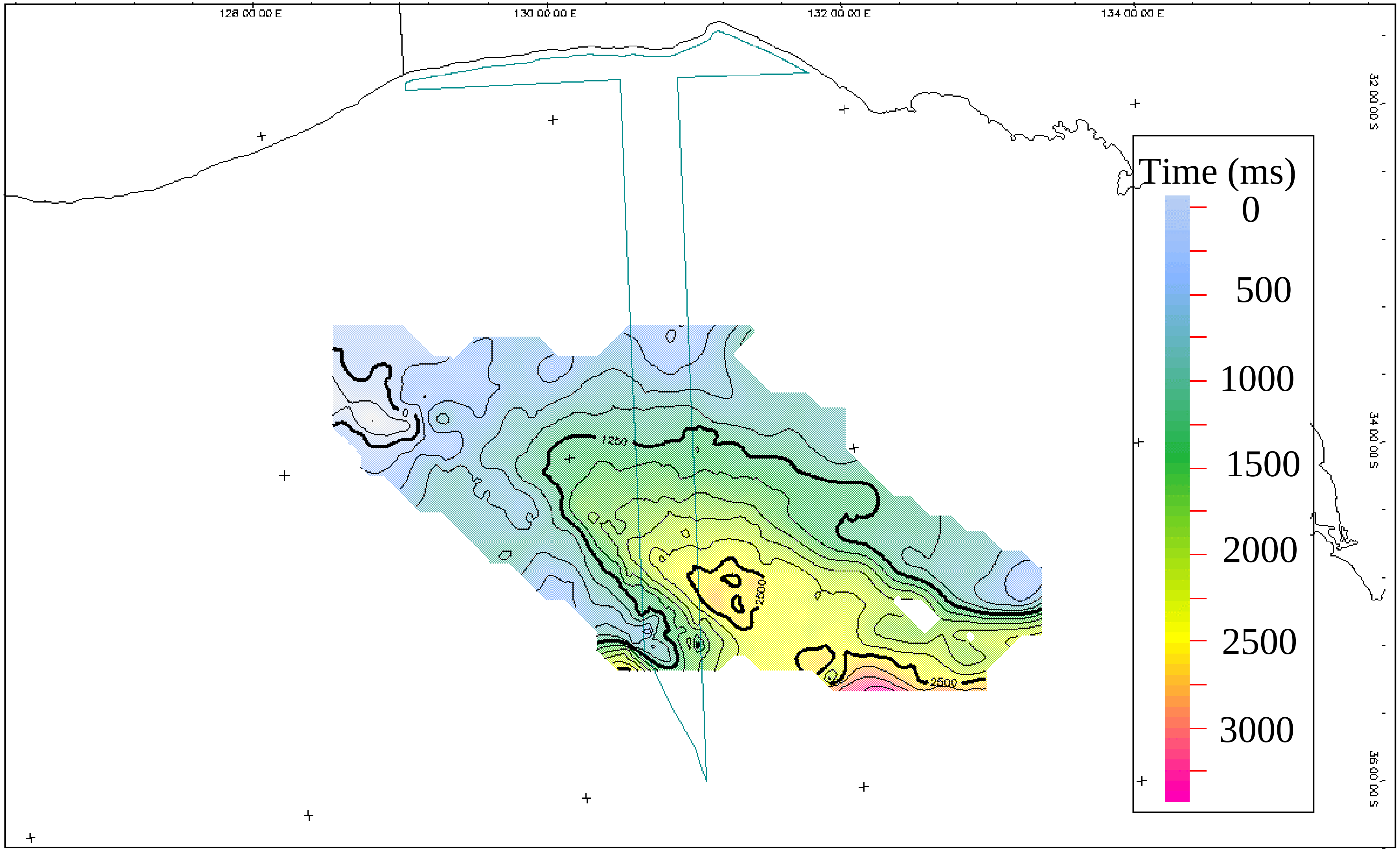


Figure D14. Santonian-Maastrichtian sediment thickness in twt (ms). Sequence thickens offshore into old depocentre.

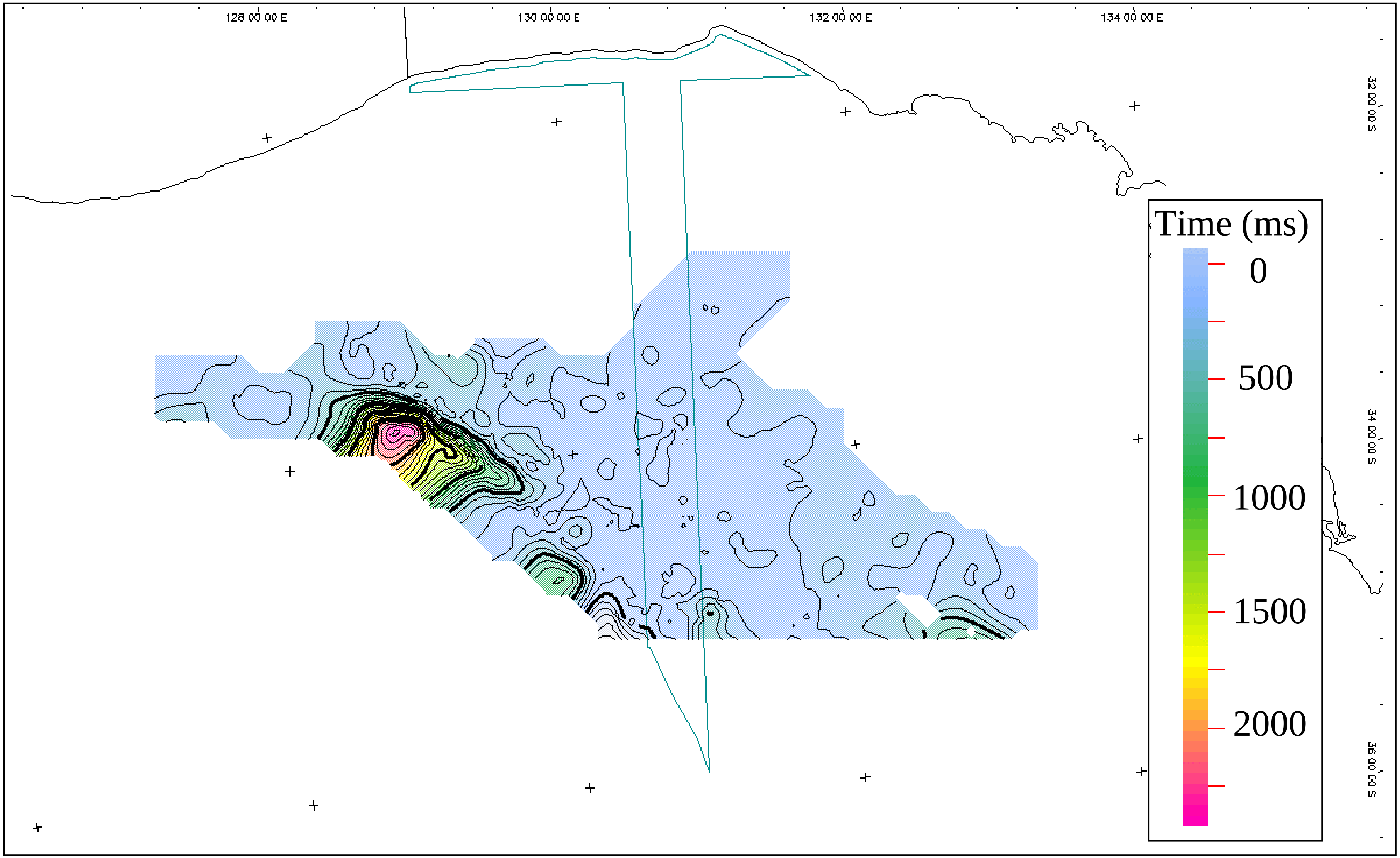


Figure D15. Eocene sediment thickness in twt (ms). Deposits are thick on the continental rise to the west.

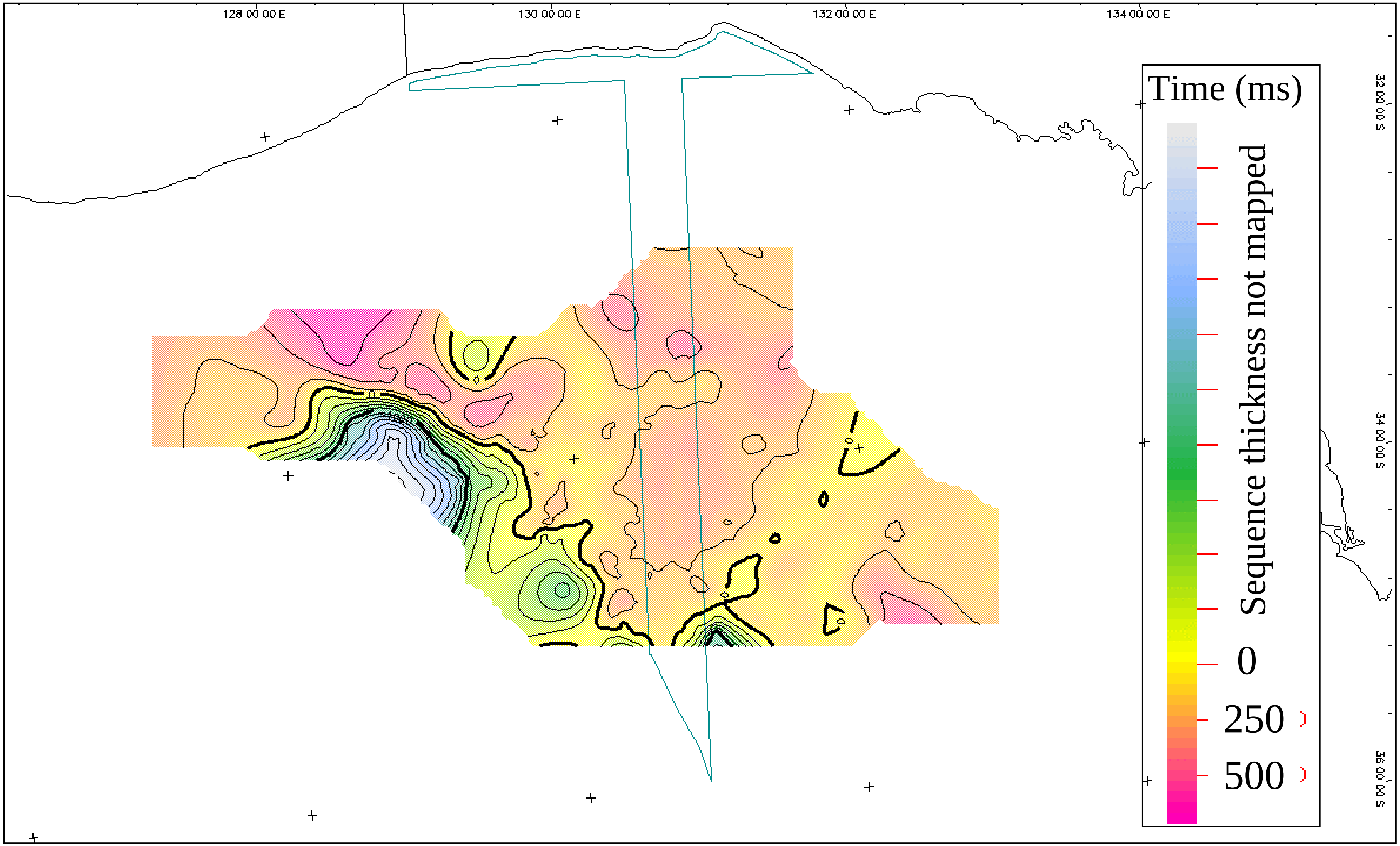


Figure D16. Oligocene - Recent sediment thickness in twt (ms). Deposits are thick on the continental slope.

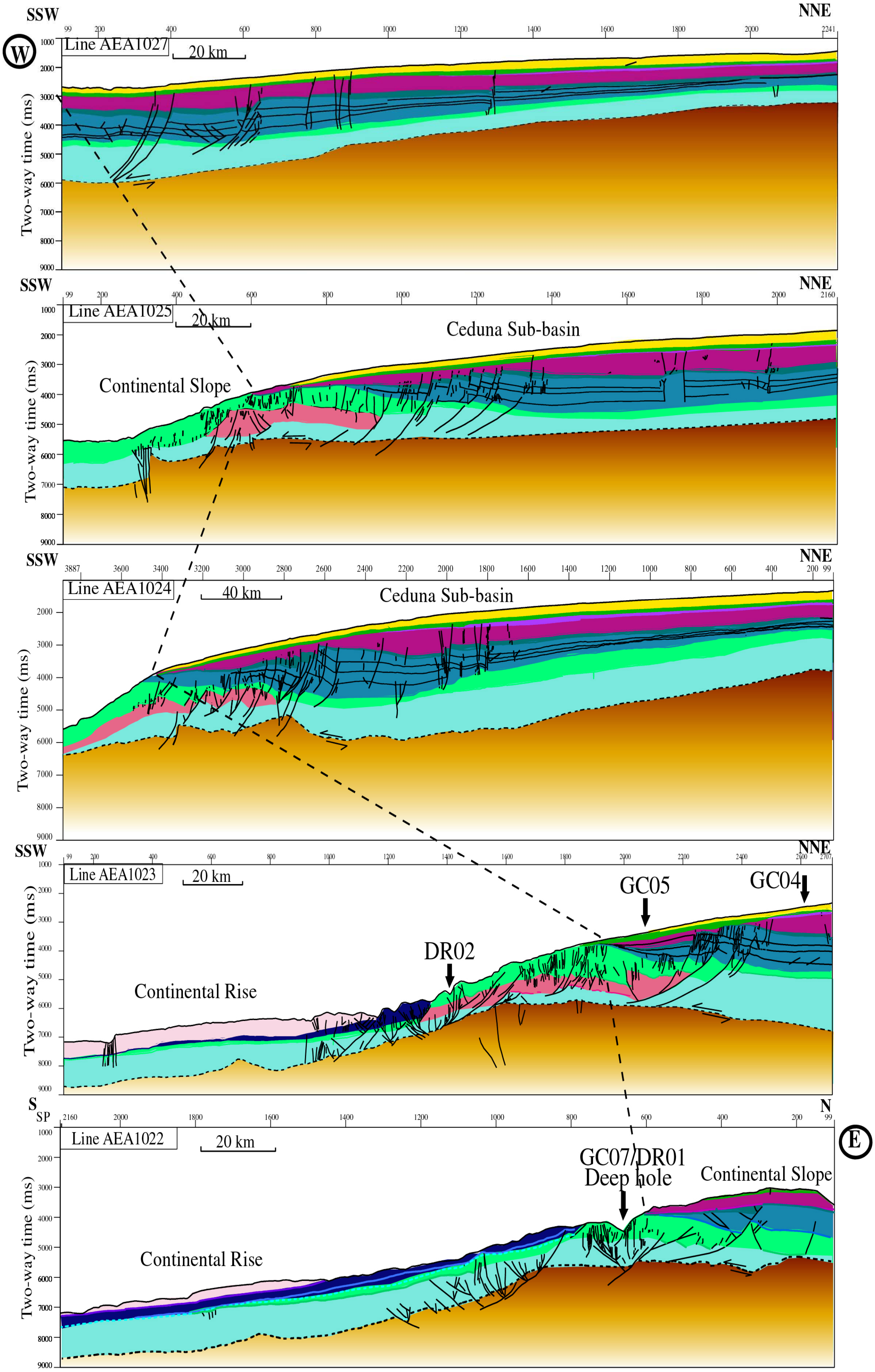


Figure D17. Set of line-drawings across the Marine Park from west to east (based on AUSTREA-1 seismic reflection profiles). The deformation increases eastwards, towards the Nullarbor Canyon.

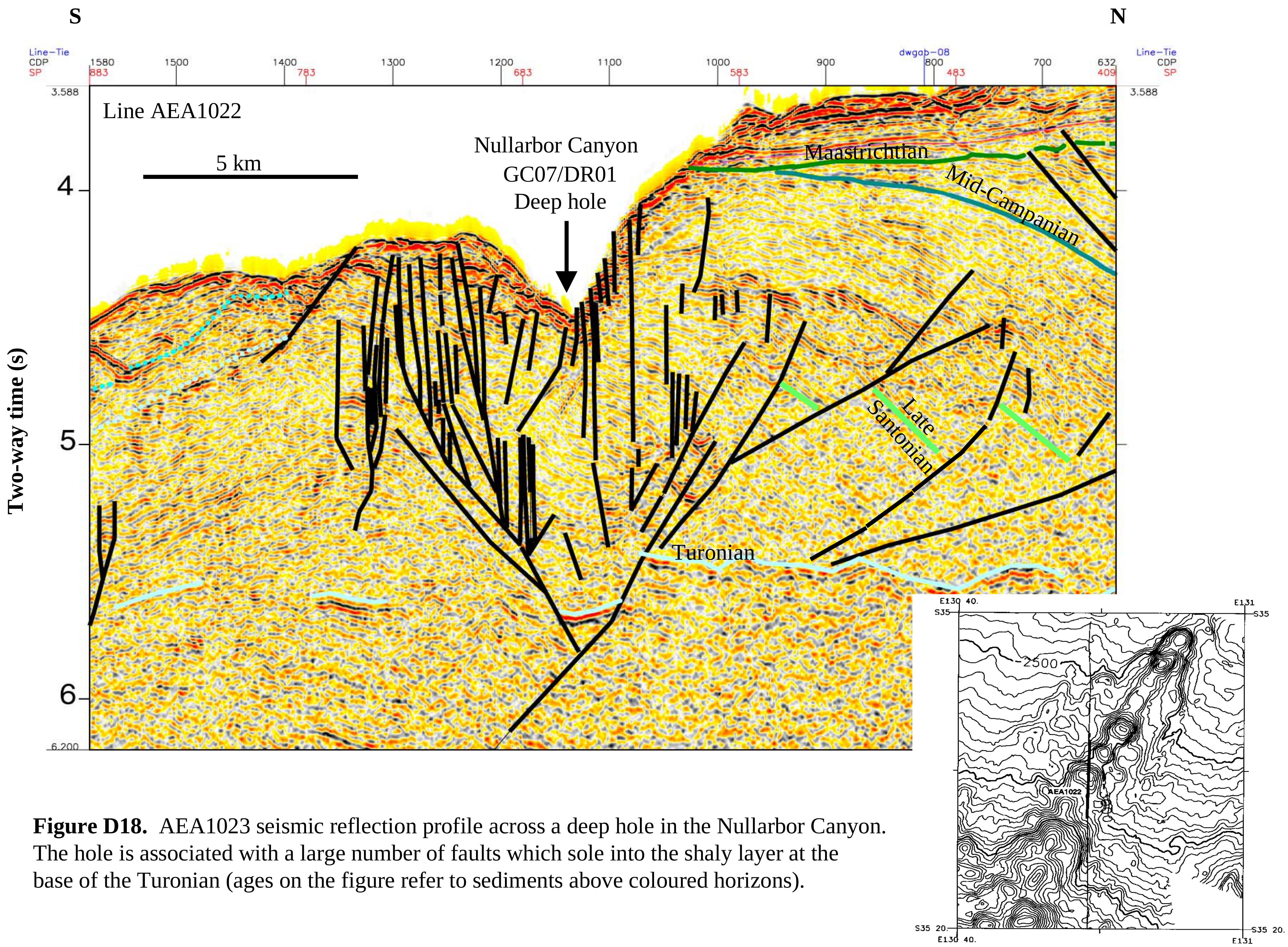


Figure D18. AEA1023 seismic reflection profile across a deep hole in the Nullarbor Canyon. The hole is associated with a large number of faults which sole into the shaly layer at the base of the Turonian (ages on the figure refer to sediments above coloured horizons).