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OFFSHORE SYDNEY BASIN AND NSW CONTINENTAL MARGIN GEOCHEMISTRY AND SEDIMENTOLOGY: NATURAL PROCESS, ANTHROPOGENIC CONTRIBUTIONS AND NON-RENEWABLE RESOURCES

by

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Offshore Sydney Basin and NSW Continental Margin Geochemistry and Sedimentology: Natural Processes, Anthropogenic Contributions and Non-renewable Resources.

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Executive Summary

This proposal describes a multi-institutional, multi-disciplinary, 28 day survey, to be conducted aboard the BMR research vessel Rig Seismic on the NSW continental margin, between Wollongong, Sydney and Newcastle during September-October of 1992.

The survey includes personnel from the Environment Management Unit of the Sydney Water Board; Sydney University, Depts. of Geography, Geology and Geophysics, the Ocean Sciences Institute, the Geological Survey of New South Wales, and the Program in Marine Geosciences and Petroleum Geology from the BMR. Partial funding for the survey is being provided by the Sydney Water Board and Sydney University.

The overall primary objectives include:

1. To collect baseline environmental data on the distribution and chemical compositions of sediments (with special reference to anthropogenic materials), which will be used for environmental monitoring purpouses in the coastal zone.

2. To provide appropriate scientific data re the juxtapositon of renewable and non-renewable resources on the continental margin, and the discharge of wastes (human and industrial) from various activities to the coastal zone. These data are one essential aid in managing coastal zone activities adjacent to Australia's major population centre.

3. To provide new information related to non-renewable resources (hydrocarbons, seafloor minerals and marine sands and aggregates) present in the offshore Sydney Basin.

The projects to be conducted include :

(i) Quaternary and Contemporary sedimentation and geochemistry on the continental shelf.

(ii) The record of Quaternary climate change preserved in sediments on the continental slope

(iii) Easterly changes of sedimentary facies and thermal history of the Permo-Mesozoic Sydney basin rocks.

(iv) Contaminants in continental shelf sediments.

(v) Geochemical characterisation of continental shelf sediments-with special reference to nutrients, nitrogen and phosphorus.

(vi) Continuous geochemical tracer studies of ocean outfalls and estuary/ocean exchanges (with special reference to light hydrocarbons).

The timetable for the survey is shown in Table 1.

TABLE OF CONTENTS

1. Introduction

The major metropolitan areas of Australia are located at the coastline. The Governments responsible for managing these expanding communities are under increasing pressures to provide for both the energy, material, recreational and environmental needs and expectations of these communities.

The offshore Sydney Basin is currently being explored for hydrocarbon resources in an effort to provide for the future energy needs of metropolitan Sydney. The continental shelf of the NSW coastline contains minerals, and sands and aggregates that may be used for construction materials. Furthermore, the discharge of industrial and human wastes, via rivers, estuaries, stormwater runoff and ocean outfalls to the coastal zone places increasing stresses upon both the renewable resources, and the recreational facilities of the coastal zone.

The management of these, often competing, activities and interests requires (in part) adequate scientific data on the non-renewable and renewable resources and naturally occurring processes, such that an adequate balance may be found to sustain these varieties of activities and interests.

This proposal describes a multi-institutional (Bureau of Mineral Resources(BMR), Program in Marine Geoscience and Petroleum Geology; Environment Management Unit of the Sydney Water Board (SWB); the Depts. of Geography, Geology and Geophysics and Ocean Sciences Institute (OSI) of Sydney University (SU), and the Geological Survey of NSW (GSNSW)), multidisciplined program to be conducted aboard the Rig Seismic during 1992. The survey is focussed on the continental shelf off Sydney, but includes data collection between Wollongong and Newcastle.

The SU/GSNSW/OSI/BMR program and the SWB/BMR program components are described separately (for logistical purpouses), although the scientific objectives and activities are integrated, as suggested in Figure. 1.

2. Offshore Sydney basin: stratigraphic and environmental investigations of the shelf and slope (A joint program between SU, GSNSW, OSI and the BMR).

This work involves three principal components of an integrated study which provide an understanding of the geological aspects most involved with human use of the offshore area of the Sydney Basin (hydrocarbons, minerals and waste disposal).

2.1 Quaternary and contemporary sedimentation and geochemistry on the continental shelf.

2.2 The record of Quaternary climate change on the continental slope.

2.3 Easterly changes of sedimentary facies and thermal history of Permo-Mesozoic Sydney Basin rocks on the continental slope.

Australian Research Council (ARC) funding is being requested for post-cruise analyses, interpretation and reporting.

2.1 Quaternary and Contemporary Shelf Sedimentology and Geochemistry.

Significance

This project will document Quaternary stratigraphic patterns across the entire shelf width. To date, no vibrocores have been collected on the mid and outer shelf of the Sydney Basin and the Quaternary stratigraphy of the area is completely unknown.

Early BMR surveys (Marshall, 1979; Davies, 1979) delineated the broad-scale distribution of surface sediments, but subsequent geological investigations have been restricted to the more accessible inner shelf. Consequently, mechanisms of sedimentation, especially barrier development at lower sea levels, are poorly understood.

The present study area occupies an important transition zone where along-shelf sediment budgets change. Rates of littoral sediment transport have varied regionally along the shelf over time and also across the shelf during sea level oscillations (Roy & Thom 1981; 1991). As a result, the northern NSW shelf is more sediment- and mineral-rich than the southern shelf (Jones & Davies 1979; Hudson & Ferland 1987; Roy 1990; Roy & others 1991). Temporal and spatial changes in sediment budgets and barrier development throughout the Quaternary are thought to be a key factor in the formation of heavy mineral beach placers. Thus, our results will provide a linkage between existing models of sedimentation and mineralisation on the inner shelf, and those for the mid and outer shelf. The study will also provide a geological framework for the geochemical work discussed below.

A geologically controlled geochemical baseline study is justified on legal, health, environmental and scientific grounds. The central NSW coast is the most densely urbanised and industrialised area in Australia. Waste from Newcastle, Sydney, Wollongong and Port Kembla have been discharged into the ocean for 100 years and, as a result, adjacent continental shelf sediments have become contaminated with heavy metals and organic residues. Davies (1974, 1979) found arsenic concentrations up to 0.18mg/g off Wollongong. Birch & Davey (submitted.) and Batley (CSIRO, pers. comm., 1990) have also identified high levels of Ni, Cu, Zn, Pb and Hg in surficial sediments off Sydney. Historical background and present baseline contaminant levels in NSW shelf sediments are not known. Mid-shelf mud accumulations (Fig. 2) will contain an historical and regional record of the impact on

the environment of human settlement. Because contaminants originate from three metropolitan centres and shelf water movements are energetic, along-shelf mixing of the contaminated sediments is expected. The contaminants will also act as a tracer indicating modern sediment dispersal pathways.

Potentially polluted mid shelf muddy sediments coincide with commercial fishing grounds which supply fish and crustacea to the metropolitan markets. The levels of restricted substances in the sediments, and the possibility of fish feeding on contaminated benthos in the same areas, will be of interest to the NSW Departments of Natural Resources (Fisheries Division) and Health.

The results of this research component would have direct significance to the following government and industrial programs: a. commercial mineral exploration (Cable Sands Pty Ltd); b. sand and gravel (marine aggregate) exploration (Metromix Pty Ltd); c. laying of submarine telecommunications cables (AOTC Ltd); d. monitoring of the new Sydney deep water sewage outfalls (SPCC, FRI); e. dumping of dredge spoils off Newcastle and Sydney; f. coastal engineering and erosion studies, especially in the vicinity of harbours and port facilities (Public Works Dept.); g. future siting and evaluation of (sewage) ocean outfalls (Water Board); h. geochemical investigation of pollutants in sediments off Wollongong (Jones & Ohmsen, Univ. Wollongong).

Objectives

Sedimentology of Quaternary Shelf Sediments

1. To map the Quaternary sediments of the continental shelf so as to develop an evolutionary stratigraphic model characterising transgressive and regressive sedimentation on a high energy, sediment-starved shelf;

2. to document the resource potential (heavy minerals and marine aggregate) and the geotechnical properties of the mid and outer shelf sediments;
3. to test hypotheses that shelf sediment dispersal and deposition is significantly controlled by the East Australian Current (EAC); and
4. to verify a computer model describing responses of coastal sediments to changing sea levels in mid and outer shelf environments (Roy, Cowell & Jones, 1989).

Geochemistry of Contemporary Shelf Sediments

1. To delineate the nature, concentration and provenance of organic and metallic contaminants in surficial shelf sediments located adjacent to the urban and industrial centres of Wollongong, Sydney and Newcastle;
2. to establish present baseline and historical background data sets and construct a contaminant stratigraphy for the mid shelf sediments;
3. to study the nature and mechanisms of fixation and release of contaminants from marine sediments; and
4. to use assemblages of contaminants to identify sources and dispersal pathways for suspended sediments on the open shelf; and
5. provide a regional framework for other, more restricted environmental studies.

Research Program

Shelf work covers an area of 11,000 km^2 and involves approximately 660 line km of high resolution seismic. The way-points for the seismic data collection are summarised in Table 2. Approximately 50 vibrocores are to be collected from 9 across-shelf traverses (Fig. 2). The station locations for vibrocoring are shown in Table 3. The depth range for vibrocoring is up to 200 m, but is dependent on shelf current strength; maximum penetration is 6 m. The coverage is designed to

investigate regional along-shelf and across-shelf trends in both Quaternary and contemporary shelf sediments.

Analyses of the shelf data will be carried out at the University of Sydney, and a number of other specialist laboratories. Geophysical data will be interpreted to delineate surficial facies and stratigraphic sequences, side-scan data will be used to indicate sediment dispersal pathways, and Quaternary shelf evolution will be based on seismic and core data. Vibrocore analysis will consist of four phases:
a. Core processing (splitting, logging, resin peels, x-ray, sub-sampling of vibrocores) (Birch, Roy); b. Sedimentological analyses (microscopy, grain size, organic carbon and carbonate, macro- and micro-faunal identification, mineralogy, XRD) to characterise environments of deposition (Birch, Roy, Albani); c. Geochemical analyses for environmental baseline study (organochlorines, metals and organic carbon) (Birch, Batley); d. Dating (C^{14}, Thermoluminescence (T/L), Pb^{210}) of selected core intervals to establish chronologies and rates of sedimentation (Birch, Roy).

Geochemical analyses require that vibrocores be chill-stored prior to analysis; facilities exist onboard the 'Rig Seismic' and at the University of Sydney. Trace metals (8 elements), organochlorines and 'light end' hydrocarbons will be examined vertically in a number of cores to determine rates of sedimentation and mixing, and in the top-most interval of all vibrocores to represent regional 'modern day' contamination.

Light hydrocarbons have very recently been identified as a tracer for sewage plumes in the water column off the Sydney outfalls. High concentrations of C1-C6 were found in the bottom-waters, suggesting a sediment source contribution for these hydrocarbons to the water column. The current work will test one hypothesis that these organics may be released from the surficial sediments, becuse of increased

(anthropogenic) loads of particulate organic matter, from the ocean outfalls (or elsewhere), to the surface sediments.

Sequential partitioning will be performed on a limited number of specially selected samples to identify the chemical phase with which metals and organics are associated. The most appropriate digestion procedure will be guided by the results of this study. Organic and inorganic chemical analyses will be undertaken on a size-normalized basis, either by physical separation, or statistically using independent size data.

2.2 Record of Quaternary Climate Change preserved in sediments on the Continental slope.

Significance

Marine sediments of the upper slope contain a record of surface water productivity and sea level oscillations for the late Cenozoic. The fluctuations in magnetic susceptibility in the sediments can be correlated with oxygen isotope values to measure ice volume, and indirectly sea levels. A core collected in May 1991 from 2400 m water depth contains cyclical layering which may be related to an intensification of the oxygen minimum zone (OMZ) during sea level lowstands. Both productivity and the OMZ are related to upwelling and the intensity of the EAC. The switching on and off of this current is a function of climate and, on a longer time span, the northward motion of the Australian plate. During periods of high productivity the O_2 minimum is intensified and benthic organisms are excluded, allowing organic-rich sediment to be preserved on the slope. Past changes in the intensity of the OMZ most likely correlate to sea level and ocean current circulation. These cycles can be studied for high frequency climatic fluctuations.

The deposition in the sediments of varying amounts of organic matter results in a variety of diagenetic reactions which drive the dissolution and precipitation of minerals. Redox sensitive trace elements are particularly influenced by variations in organic matter preservation rates, and the relative abundances of some trace elements (down-core) has been shown to be indicative of varying rates of organic matter preservation. Also, the mass accumulation rates of trace elements and organic carbon and calcium carbonate may be used to document periods of varying oceanic productivity. While a variety of geochemical indicators have been used to document these cycles, they provide no clues as to causal mechanisms. One such mechanism may be variations in the vertical nutrient structure in the water column - an oceanographic phenomena that can be examined by the use of carbon isotopic studies of benthic and planktonic forams preserved in the sediments. This approach has provided some promising results on G/I (glacial/interglacial) variations in oceanic productivity and nutrient profiles in the northeastern Indian Ocean related to variations in the Leuwin Current off Western Australia.

Data from the Sydney slope will extend to the south the climatic record obtained from samples collected off the Queensland coast (Ocean Drilling Program (ODP) Leg 133). Also, major and trace elements data from these cores will provide terrigenous and biogenic mass accumulation rates (at key climatic periods), further our knowledge of geochemical tracers and proxy indicators for oceanographic processes, and extend our observations from the northern NSW coastline phosphorite sediments.

Objectives.

1. To document climatic oscillations in the Quaternary (and possibly Neogene) by sampling cyclical units in sediment cores from the slope.

2. To examine Quaternary variations in carbon (organic and carbonate) fluxes (oceanic productivity) sediment accumulation rates and terrigenous inputs (continental weathering) related to glacial/interglacial cycles and variations in the EAC.

Research Program

For the paleoclimate studies, a coring transect will be taken on the upper- and mid-slope (500 - 3500 m) offshore of Sydney where 100% cover by SEABEAM bathymetry is available at 50 m isobaths. This allows sampling to avoid areas of topographic complication (scarps and slides), and to target ponded sediment sites with a record of Quaternary sedimentation. Neogene sediments may occur near the surface in the heads of canyons. Six metre gravity (or piston) cores will be used to sample the unconsolidated sediments. The proposed locations of cores are summarised in Table 4 and Figure 3.

Petrographic and textural studies will be performed on the cores. X-radiography, magnetic susceptibility, oxygen/carbon stable isotopes, micropaleontology and carbonate/carbon contents will be used to characterise sediment cycles in the cores. In addition, major and trace element compositions will be determined (XRF), mass accumulation rates of terrigenous and biogenic materials (carbon as both organic and carbonate), will be determined and specific detailed geochemical analyses (e.g., uranium, thorium and biogenic silica, phosphorus and select trace metal contents) will be examined as proxy indicators of variations in organic carbon inputs. G/I changes in the vertical nutrient profiles will be examined with detailed isotopic studies of benthic and planktonic forams (jointly with Woods Hole Oceanographic Institution).

2.3 Easterly changes of Sedimentary facies and thermal history of Permo-Mesozoic Sydney Basin Rocks.

Significance

Onshore exposures and borehole records in the Sydney Basin indicate important changes of facies towards the east of the basin particularly in thicknesses, marine influence and volcanic supply (Herbert 1980). In view of the current exploration activity for petroleum in the offshore basin extension and there being no published data on the Permo-Triassic sequence offshore, it is important that such changes be investigated. One glaring unknown at present is the extent and depth to which the Sydney Basin sequence extends beneath the continental shelf/slope. Our study will contribute answers to these questions and help in assessments of the hydrocarbon prospectivity.

The opportunity exists to sample Sydney Basin strata and overlying sequences by dredging continental slope outcrops (Figs. 2 & 4). This is due to the fact that the NSW continental slope (western rifted margin of the Tasman Sea) is remarkably sediment-starved. Recent work based on GLORIA acoustic imagery, multibeam bathymetry and seismic data show that pre-rift strata crop out as ridges and scarps and in canyons at various levels on the slope (Fig. 1; Jenkins & others, submitted.; Jenkins 1991).

Upper Cretaceous and Cenozoic strata which also crop out on the slope will contain a syn- and post-rift history of the margin, particularly its subsidence. For example south of Sydney, dredging during the May 1991 'Franklin' cruise sampled Paleocene shelf-facies glauconite sandstones at 700-2000m water depth. Previous dredging had sampled Upper Cretaceous shoreline facies on the lower continental slope at 3000m water depth (Marshall 1990) and also Eocene units.

Our study will provide data by which to test tectonic models of upper plate detachment rifting. The NSW passive margin has been interpreted as an upper plate margin by Etheridge & others (1989) who claim their model can predict the morphology, structure, uplift/subsidence history and thermal evolution of such margins. Thus, our work will contribute to the debate on symmetric 'pure shear' versus asymmetric 'simple shear' rifting: a primary objective of several large international programs including the ODP ('Long Range Plan 1989-2002', 1990, p. 72).

Diagenetic studies of dredged samples would determine if lateral changes of heating or burial took place in the east of the basin (>100km from present boreholes). Samples of basement rocks and sediments from the slope will provide significant new data on the burial/uplift, erosional and thermal history which has been a long-standing problem in southeastern Australian geology (Branagan 1983; Middleton and Hunt 1989). A thermal event leading to uplift is thought to have occurred between 80 and 100 Ma (Ollier 1982; Moore & others 1986). High vitrinite reflectance values for onshore sequences suggest the presence of at least 1km of cover but no remnants of that cover have been found in the surface geology. Evidence for continuing Triassic/Jurassic sedimentation in the basin and its subsequent removal, comes from the Lower Triassic Narrabeen Group using fluid inclusions, stable isotopes and authigenic illite ages (Bai & others 1991) which suggest high heat flow at 91-146 Ma (coincident with rifting) and removal of >1km of section.

Objectives

1. To define stratigraphic facies change in the Permian-Mesozoic Sydney Basin sequence out to 100km east from the present coast; and

2. To define diagenetic, thermal and subsidence history of the easternmost Sydney Basin.

Research Program

Fifteen areas for dredging on the slope, in water depths of 900-4800m (Fig. 2), have been identified using existing seismic data, multibeam bathymetry and acoustic imagery. The proposed dredge stations are summarised in Table 5. Site surveys during the BMR cruise will pin-point the precise sampling targets within each dredging area. The Sydney University team has conducted numerous successful sampling cruises over the NSW continental slope, chiefly south of Sydney (Hubble & others, In press; Jenkins & others submitted.; 'RV Franklin' 5/91 cruise report).

Petrographic and textural studies will be performed on the dredge samples from the slope. The laboratory program for the rock samples is:
a. Petrographic descriptions of sedimentology, provenance and diagenesis (Jenkins & Keene); b. SEM and stable isotope analysis of quartz overgrowths and clay-carbonate cements to determine diagenetic sequence (Keene with ARC/Univ./CSIRO Centre for Isotopic Studies - CIS); c. XRD to identify mineral species (Jenkins); d. study of fluid inclusions trapped in quartz overgrowths for burial P/T conditions (Keene with CSIRO facilities); e. palynology & foram biostratigraphy (Helby, Albani); f. vitrinite reflectance (Facer); g. apatite fission-track (commercially, Keene); and h. K-Ar dating of illite cements and glauconites (commercially, Keene).

3. Geochemical, Sedimentological and Oceanographic Processes Controlling the Distribution of Anthropogenic materials on the Continental Shelf offshore metropolitan Sydney. (A joint program between SWB and the BMR)

3.1 Contaminants in Coastal Sediments.

Significance

Concentrations of contaminants in marine sediments can be used to trace the source and the extent of persistent compounds within the marine environment. Contaminants in sediments may be present in concentrations higher than those in the overlying water column; these higher concentrations can provide a higher resolution and enhanced accuracy when determining dispersion patterns. Bottom sediments are not only a repository or 'sink' for contaminants, but under some conditions may also act as a source to the surrounding environment.

Sydney coastal waters receive contaminants from stormwater runoff, industrial discharges and sewage treatment effluent. Rivers and lagoons may also be an important source of input into the Sydney coastal zone since they effectively concentrate and release the combined input of their extended catchments at a single point.

The Environment Management Unit of the Sydney Water Board has previously surveyed areas of the Sydney coastline to characterise contaminants in sediments. Samples were collected in an area extending from Curl Curl to Botany Bay and to a distance of 7 km offshore. The program was designed to examine the impact of the major ocean outfalls on contamination of coastal sediments. Levels of heavy metals and organochlorine pesticides and PCBs have been measured. During 1992 these areas will be sampled again to begin to assess annual and longer-term variations.

Although a picture of contaminant distribution in the nearshore zone is beginning to emerge, it is possible that contaminants may be accumulating further offshore, moved there by sediment resuspension and transport where they become adsorbed to the finer

silt-clay sediments present in deep water at the edge of the continental shelf. Some contaminants are highly correlated with the presence of fine sediment particles (unpublished data). As the near shore regions off Sydney are primarily sandy sediments, contaminants could be transported further offshore where they may gradually accumulate. In order to assess whether contaminants are accumulating at the edge of the continental shelf, baseline information is required.

There is virtually no previous information available by which to make an assessment of the impact of pollution sources on the fine sediments at the edge of the continental shelf.

Objectives.

1. To determine the concentrations of select heavy metals (cadmium, copper, chromium, lead, zinc, iron, nickel, mercury, arsenic and selenium in sediments of the continental shelf.

2. To determine the concentrations of organic toxicants in sediments of the continental shelf between Broken Bay and Port Hacking.

Research Program

Sediment samples will be collected from Rig Seismic from four transects running east-west from Broken Bay, near Port Jackson and Botany Bay and south of Port Hacking to examine in detail, trends offshore of the Sydney region. Locations of each of the proposed sampling sites are detailed in Table 6., and shown n Figure 5. This program will be integrated with the sediment work on geochemical processes described below.

Sediments will be analysed for heavy metals, organochlorine pesticides, PCBs, total organic carbon and grain size distribution.

Heavy metal analysis will be carried out using acid oxidative digestion followed by flame atomic absorption spectrometry (AAS). The metals to be analysed are Cd, Cu, Cr, Pb, Zn, Fe, and Ni. Other metals, Hg, As, and Se, will be analysed after acid oxidative digestion by cold vapour AAS for Hg and hydride generation for As and Se.

At select stations, pore water manganese concentrations will be measured at sea. Manganese, a redox sensitive metal, is remobilised under 'reducing' conditions, but remains trapped in sedimentary particles in 'oxic' sediments. Because manganese is a scavenger (from seawater and sediment pore fluids) of several of the metals proposed to be measured here, the locus of remobilisation (dissolution) and removal (precipitation) reactions of sedimentary manganese across the shelf may be a primary control on the concentration or dispersion of toxicant metals on the shelf.

Samples for organochlorine analysis will be sonicated three times with dichloromethane and acetone, concentrated to 5ml, and solvent exchanged to n-hexane. Clean-up will be carried out on a fluorisil column, eluting the first fraction (I) with n-hexane and the second (I) with 2% acetone in n-hexane. Both fractions will be concentrated to 2ml. Gas chromatography will be on 30 metre capillary columns using an electron capture detector. Estimates of detection limits will be based on a minimum peak height/area of three times background. The pesticides analysed for are DDT, DDD, DDE, BHCs (alpha, beta, and gamma), heptachlor, heptachlor epoxide, hexachlorobenzene, chlordane (alpha, gamma, and total), dieldrin, aldrin and PCBs.

Analysis of organic carbon will be carried out on a total carbon analyser by the method of Sandstrom et al.(1986).

3.2 Geochemical characterisation of sediments: organic carbon and sedimentary nutrients (nitrogen and phosphorus).

Significance.

The effects of long term, low level input of organic carbon and nutrients (particularly nitrogen and phosphorus) through urban point source discharges to a high-energy coastal zone are poorly understood. Mathematical models are largely inadequate to predict long term impacts due to the complex behaviour and numerous pathways affecting fate and distribution of nutrients within the coastal zone.

Inorganic nutrients such as nitrogen and phosphorus may be absorbed by microorganisms within the water column or sediments. They may accumulate in sediments or be resuspended under various oceanographic conditions. Long term, low level input of organic compounds to the water column has the potential to radically alter water column food chain structure. It is necessary to begin now to collect baseline data on these coastal processes and to set up experiments through which to predict the impact of sewage material on coastal microbial communities.

Much of the concern on impacts of nutrients in the marine zone has been generated by evidence associated with areas of relatively enclosed water bodies such as fiords and low-energy coastal zones. There are certainly eutrophication problems in many of these areas. However, the research from these systems is largely inapplicable to the Sydney region given its open ocean, high energy environment. Thus, we need to gather data on the potential for eutrophication specific to the Sydney region.

Sydney Water Board research programs associated with assessing effects of nutrients in the coastal zone include measurements of microbial activity and nutrient transformations within the water column and sediments in the coastal zone off

Sydney. The sediment work includes assessing current rates of benthic nutrient fluxes, microbial production and biomass and physico-chemical status. Manipulative experiments are being carried out to determine the effect of additional sewage loads on these processes in sediments.

Objectives.

1. To characterise shelf sediments as to their physico-chemical features such as porewater nutrient concentration gradients, redox profiles, dissolved oxygen penetration, grain size distribution and porosity and their solid phase chemistry including TOC (total organic carbon), TON (total organic nitrogen), TP (total phosphorus) and TOP (total organic phosphorus).

2. To determine, from porewater nutrient concentrations, background sediment flux rates for the nutrient species (ammonia, nitrate, nitrite, phosphate and silicate).

3. To estimate rates of benthic aerobic metabolism from sediment oxygen profiles.

4. To examine processes of light hydrocarbon generation and consumption in surficial sediments, hence evaluate the use of light hydrocarbon measurements as 'early warning signals' of anthropogenic carbon inputs.

Research Program

This work will be carried out concurrently with the sediment collection for contaminant analysis. Due to logistical constraints on core processing times, not all sites where sediment cores are collected for contaminant analysis will be profiled for geochemistry. However, sampling will be stratified so that cores are sampled across a number of sediment types for this part of the project.

Subcores from Soutar box-cores will be processed at sea, and porewaters separated from the sediments by centrifuging in a refrigerated centrifuge. Oxygen in sediments will be determined by carefully inserting a microelectrode into the sediments at millimetre intervals. Nutrients, nitrate, ammonia, phosphate and silicate and pore water manganese will be determined at sea via colorimetric methods. Light hydrocarbons will be measured by conventional 'headspace' techniques.

This work will be carried out (in part) in collaboration with Dr. R. Johnstone of the Aquatic Ecology Dept. at the University of Stockholm. Dr. Johnstone has considerable expertise in this area and has carried out similar investigations into eutrophication processes in the Baltic region.

3.3 Continuous geochemical tracers of ocean outfalls and estuary/ocean exchange processes (light hydrocarbons).

Significance

Pollutant sources may be identified and dispersion (of pollutants) mapped using a variety of techniques. Some of these include the use of microbiological indicator species, visual techniques such as the tracking of dyes or indirect methods such as the measurement of dispersion characteristics using information from current meters.

Recent trials conducted by the Bureau of Mineral Resources (BMR) has shown that analysing oceanic waters for light hydrocarbon content provides a useful method for characterising pollutants from various sources. A schematic of the continuous profiling capability aboard Rig Seismic is shown in Figure 6. These trials were conducted between Botany Bay and North Head. A vertical profile indicted a thick plume of hydrocarbons centred at about 40-45 m water depth (Fig. 7). Also,

hydrocarbon signals were detected from each of the three deepwater ocean outfalls, and off the entrance to Botany Bay and from within Port Jackson (Fig 8a,b). By characterising these source types according to their hydrocarbon signal it may be possible to determine the source of hydrocarbons in the coastal water masses, and its subsequent dilution from that source.

Furthermore, the continuous profiling capability aboard Rig Seismic (approximately 200 line km of data can be collected daily) allows for near synoptic representations of plume dispersion (over relatively small areas) to be generated.

This component will attempt to identify and characterise the hydrocarbon signals from a number of possible major pollutant sources along the Sydney coastline. The distributions of light hydrocarbons in seawater provide a complementary set of information for other components of the program such as the contaminants in biota and sediments.

Objectives.

1. To determine the concentrations and distributions of light hydrocarbons around the ocean outfall sites located at Malabar, North Head and Bondi.

2. To determine the concentrations and molecular compositions of light hydrocarbons entering the coastal zone from major estuaries, Port Jackson, Botany Bay, Broken Bay and Port Hacking.

Research Program

A combination of continuous towing of the submerged 'towfish' (Fig. 6) at several depths and vertical profiles at known point sources will be used to characterise

hydrocarbon distribution patterns. The focus of the profiling will be at entrances to the major estuaries, and around the SWB ocean outfall sites. The final locations for the vertical profiles of hydrocarbons in the water column and the way-points for the horizontal profiling of hydrocarbons in the coastal zone are still being resolved, and will require approval for operating in confined locations.

4. Project Synthesis

The overall program is a co-ordinated effort from at least three major organisations. While all projects have clearly defined responsibiliites for their execution, the synthesis will be coordinated, as suggested in Figure 1.

Regional patterns in Quaternary geology and stratigraphy shown in the shelf vibrocores will be interpreted in terms of long-term sediment budget and sea level changes. This model will provide a framework to describe deposition and dispersal of contemporary sediments. Provenance and dispersion will be addressed by use of statistical analysis and computer simulation modelling. The data and results have implications for non-renewable resources including seafloor minerals, gravels and sands and also for environmental monitoring.

The geochemical data on sediment compositions (metals and organics) and the geochemical characterisation (nutrients, nitrogen and phosphorus) of sediments will be interpreted in terms of dynamic geochemical mass balances (schematically illustrated in Fig. 9), such that an understanding of the natural processes (and rates of input, removal and internal recycling reactions) controlling concentrations and distributions can be developed. Within this framework, anthropogenic contributions and contaminants can be identified and quantified. Some part of the geochemical study could be identified as suitable topics for Ph.D research.

The continuous geochemical tracer work quantifying light hydrocarbon distributions in seawater around the deep ocean outfall sites and the entrances to estuaries will be used to:- help identify possible 'sources' of various hydrocarbons in the coastal zone; examine the conservative/non-conservative behaviour of light hydrocarbons in seawater and, assess the use of light hydrocarbons in estimating dilution and dispersion processes within plumes. The geochemical process studies of sediments (above) and the light hydrocarbon distributions in seawater have implications for environmental monitoring and management.

Synthesis of the basin studies will involve: a. stratigraphic correlation of samples to onshore sequences using lithostratigraphy, paleontology and seismic; b. relating the samples to the structure of the rifted margin, (e.g., downfaulting, paleoshelf erosion) by reference to seismic and bathymetric data; c. analysis of eastwards changes in lithostratigraphic and diagenetic character; and d. synthesis of analytical results in terms of diagenetic history (burial, heatflow, uplift and erosion). These results have implications for hydrocarbon resources.

5. References

Anderson, R.Y., Gardner, J.V. & Hemphill-Haley, E. 1989. Variability of the late Pleistocene-early Holocene oxygen-minimum zone off northern California. *In* Aspects of Climate Variability in the Pacific and the Western Americas, Peterson, D.H. (ed.), American Geophysical Union, 75-84.

Bai, G., Keene, J.B., Eadington, P.E., Hamilton, P.J. & MacDougall, I. 1991. Fluid flow history of Early Triassic Narrabeen Group sandstones of the Southern Sydney Basin. Aust. Soc. Explor. Geophys., 8th Conf & Geol. Soc. Austr. Explor. Symp., Sydney, Feb., 1991, 122.

Birch, G.F. & Davey, S. (submitted) Spatial and temporal distribution of heavy metals on the continental shelf off Sydney, NSW, Australia. Aust. J. Mar. Fresh. Res.

Branagan, D.F. 1983. The Sydney Basin and its vanished sequence. J. Geol. Soc. Aust., 30, 75-84.

Davies, P.J. 1974. Arsenic in sediments on the continental shelf of southeast Australia. Search, 5 (8), p. 394-395.

Davies, P.J. 1979. Marine Geology of the continental shelf off southeast Australia. Bur. Min. Res. Aust. Bull., 195.

Etheridge, M.A., Symonds, P.A. & Lister, G.S. 1989. Application of the detachment model to reconstruction of conjugate passive margins. Am. Assoc. Petrol. Geol., 46, 23-40.

Facer, R.A., Cook, A.C. & Beck, A.E. 1980. Thermal properties and coal rank in rocks and coal seams of the Southern Sydney Basin, New South Wales: a palaeogeothermal explanation of coalification. Int J. Coal Geol, 1, 1-17.

Herbert, C. 1980. Depositional development of the Sydney Basin, pp 11-52 In Herbert, C. & Helby, R. (Eds) A Guide to the Sydney Basin. Bull. NSW Geol. Surv., 26.

Hubble, T.C.T., Packham, G.H., Hendry, D.A. & McDougall, I. (In press). Granitic and monzonitic rocks dredged from the southeast Australian continental margin. [Aust. Jl Earth Sci.]

Hudson, J.P. & Ferland, M.A. 1987. Seismic results from the inner continental shelf of the Twofold Bay/ Disaster Bay region, southern NSW. Geol. Sur. NSW, Report No.1987/093, 55 p.

Jenkins, C.J. 1991. Acoustic backscatter imagery of the steep and thinly sedimented continental margin of Southeast Australia. Fifth Circum-Pacific Energy and Mineral Resources Conference and Exhibition (Hawaii), American Association of Petroleum Geologists, 48-49.

Jenkins, C.J., Lawrence, M.W. & Hughes Clark, J.E. (Subm.). GLORIA Imagery and Geology of the Sediment-starved Continental Margin of SE Australia. [Mar. Petrol. Geol.].

Jenkins, C.J. & Hubble, T.C.T. (In press.). The Natsushima Ridge: Splinter of the Tonga Arc in the Lau Basin. [Mar. Geol.].

Jenkins, C.J., Packham, G.H., Hubble, T.C.T., Quilty, P. & Adams, C.J. (Subm.). Trace of the Balleny Hotspot in the Tasman Sea and Southern Ocean from 70 Ma to present. [Nature].

Jones, H.A. & Davies, P.J. 1979. Preliminary studies of offshore placer deposits, eastern Australia. Marine Geology, v. 30, p. 243-268.

Marshall, J.F. 1979. The development of the continental shelf of northern New South Wales. BMR Jl Aust. Geol. Geophys., 4, 281-288.

Marshall, N.G. 1990. Campanian dinoflagellates from southeastern Australia. Alcheringa, 14, 1-38.

Middleton, M.F. & Hunt, J.W. 1989 Influence of tectonics on Permian coal-rank patterns in Australia. Int. J. Coal geol., 13, 391-411.

Moore, M.E., Gleadow, A.J.W. & Lovering, J.F. 1986. Thermal evolution of rifted continental margins: new evidence from fission tracks in basement apatites from southeastern Australia. Earth & Plan. Sci. Letts., 78, 255-270.

Ollier, C.D. 1982. The great escarpment of eastern Australia: tectonic significance. Jl geol. Soc. Aust., 29, 12-23.

Roy, P.S. 1990. Placer minerals in continental shelf sediments, South Eastern Australia. *In* Placer Deposits - A Symposium. Univ. NSW, Sydney, 163-182.

Roy, P.S. & Thom, B.G. 1981. Late Quaternary marine deposition in New South Wales and southern Queensland - an evolutionary model. Jl Geol. Soc. Aust., 28, 471-489.

Roy, P.S., Cowell, P.J. & Jones, R.A. 1989. Modelling coastal changes in response to rising sea level. IGBP Planning Workshop on sea-level change and the Australian coastline. Aspendale, Melbourne, 2-3.

Roy, P.S. & Thom, B.G. 1991. Cainozoic shelf sedimentation model for the Tasman Sea margin of southeastern Australia. *In* Williams, M.A.J. et al. (eds.), The Cainozoic in Australia: A Re-Appraisal of the Evidence, Geol. Soc. Aust., Spec. Publ. No. 18, 119-136.

Roy, P.S., Zhuang, W.-Y. & Bryant, E.A. 1991. Interglacial and drowned interstadial barriers in SE Australia. INQUA XIII Internat. Congress, Abstracts, p. 310.

Sandstrom M.W., Tirendi, F. & Nott, A. 1986. Direct determination of organic carbon in modern reef sediments and calcareous organisms after dissolution of carbonate. Marine Geology 70, 321-329.

6. Equipment Required.

2.1 Sydney Univ/BMR Continental shelf geology and geochemistry.

(i). High resolution marine seismic (e.g., uniboom) suitable for defining surficial shelf lithofacies to a sub-bottom depth of c. 50 m, to be towed at a steady speed of up to 4.5 knots.

(ii). DSTO 3.5 kHz subbottom profiler (provided by OSI) may be able to identify presence of surficial mud on shelf.

(iii). Electric vibrocorer with penetration capability of up to 6 m or better and water depth capability of at least 160 m. It is anticipated that both the 2 m and 6 m frame will be used (BMR to supply, but GSNSW vibrocorer to be used as backup).

(iv). GPS/SatNav navigation with real - time plotting.

(v). Gravity corer (up to 6 m) and sediment 'grabs' (BMR)

(vi). Box corer (BMR supplied).

2.2 Sydney Univ./BMR Continenal slope coring.

(i). High resolution seismic - water gun/s, single channel streamer (600m), digital recording at high rate <0.5msec, highpass (?>300Hz) filtered chart record in addition to wideband (OSI & BMR equipment);

(ii.) 3.5kHz subbottom profiler (OSI to borrow from DSTO), to be towed at side of ship 12m deep, up to 8kts but over slope 5kts;

(iii). Piston Corer (OSI supplied);

(iv). Gravity corer (BMR supplied);

(v) GPS/SatNav navigation with real-time plotting;

(vi) 12.5kHz echosounder.

2.3 Offshore Sydney Basin Stratigraphy and Thermal History

(i). Box-chain and pipe dredges (OSI supplied; BMR backup), to be used in tandem;

(ii) 3.5kHz subbottom profiler (OSI to borrow from DSTO), to be towed at side of ship 12m deep; up to 8kts, but 5kts over slope;

(iii). Dredging winch/A-frame 20 T capable;

(iv) Tensionmeter, wire out and wire angle measurement on the dredging A-frame block (BMR supplied), plotted to a chart recorder or screen;

(v) GPS/SatNav navigation with real-time plotting;

(vi) 12.5kHz echosounder.

3.1 and 3.2 Contaminants in and Geochemical characterisation of sediments

(i) Box corer (BMR)

(ii) Vibrocorer (2 m, BMR), sediment grabs (BMR)

(iii) Portable microwave transponder navigation system (SWB)

(iv) Specialised analytical equipment for separating pore fluids and analyses of pore fluids and sediments (SWB). BMR will supply a refrigerated highspeed

centrifuge, UV-VIS spectrophotometer (pore water Mn analyses) and gas chromatograph.

3.3 Continuous geochemical profiling

(i) BMR will supply all equipment for the continuous geochemical profiling.

(ii) SWB will provide vertical current profiling equipment and logistics for when these measurements are conducted simultaneously with the vertical profiles of light hydrocarbons from Rig Seismic.

List of Tables

Table 1. Timetable for the survey.

am 07- pm 09 September	Rig Seismic port call in Sydney for loading of all scientific equipment.
pm 09 September	Rig Seismic departs Sydney to begin 12 day survey with SWB scientists. (approximately 8 days seafloor sampling and 4 days continuous seawater geochemistry)
21 September	Disembark SWB scientists and embark SU scientists by helicopter. 16 day survey with SU scientists (approximately 4 days very high resolution seismic, continuous geochemical profiling, sub-bottom, gravity and magnetic profiling on the continental shelf; 6 days sampling sediments of the continental shelf; 6 days coring and dredging samples from the continental slope).
am 08 October.	Rig Seismic arrives Sydney - end of survey - unloading of scientific gear begins immediately.
pm 09 October	Rig Seismic departs next survey.
17 December (date to be finalised)	Proposed date for post-survey meeting and finalisation of survey Record.

Table 2. Way-points for high resolution seismic data collection on the NSW continental shelf.

Line No.	Way Point	Latitude (^{O}S)	Longitude (^{O}S)
	0/1	34^{O}51.5'	150^{O}49.0'
1			
	1/2	34^{O}51.3'	151^{O}06.5'
2			
	2/3	34^{O}25.5'	150^{O}56.5'
3			
	3/4	34^{O}29.7'	151^{O}14.2'
4			
	4/5	34^{O}04.6'	151^{O}12.0'
5			
	5/6	34^{O}11.0'	151^{O}26.0'
6			
	6/7	33^{O}50.4'	151^{O}17.6'
7			
	7/8	33^{O}57.0'	151^{O}36.5'
8			
	8/9	33^{O}33.4'	151^{O}22.6'
9			
	9/10	33^{O}44.4'	151^{O}46.4'
10			
	10/11	33^{O}14.6'	151^{O}37.8'
11			
	11/12	33^{O}26.0'	152^{O}02.0'
12			

	12/13	$32^{O}55.0'$	$151^{O}50.0'$
13			
	13/14	$33^{O}09.6'$	$152^{O}19.7'$
14			
	14/15	$32^{O}38.0'$	$152^{O}15.1'$
15			
	15/16	$32^{O}51.5'$	$152^{O}37.4'$
16			
	16/17	$32^{O}26.5'$	$152^{O}34.0'$
17			
	17/+	$32^{O}31.3'$	$152^{O}51.5'$

Table 3. Station locations for seafloor sampling as part of the SU/BMR, sedimentology and environmental geochemistry continental shelf sampling program between Newcastle and Wollongong.

The following 50 sampling sites have been pre-selected on the basis of existing bathymetry and limited seismic data.

Sample Site Number & Priority			Latitude	Longitude
1	A	1	34°51.4'	150°50.0'
	B	2	34°51.4'	150°53.1'
	C	1	34°51.4'	150°57.0'
	D	1	34°51.4'	151°01.5'
	E	2	34°51.4'	151°04.8'
3	A	2	34°25.7'	150°57.2'
	B	1	34°26.5'	151°00.5'
	C	1	34°27.0'	151°03.5'
	D	1	34°27.9'	151°06.9'
	E	1	34°29.0'	151°11.2'
5	A	1	34°05.0'	151°13.0'
	B	1	34°06.6'	151°16.4'
	C	2	34°08.0'	151°19.3'
	D	1	34°09.2'	151°22.0'
	E	2	34°10.5'	151°25.0'
7	A	1	33°51.5'	151°21.0'
	B	1	33°52.7'	151°24.1'
	C	2	33°53.2'	151°25.8'

	D	1	33°54.0'	151°28.0'
	E	1	33°55.0'	151°31.0'
	F	1	33°56.1'	151°34.0'
9	A	2	33°34.0'	151°24.0'
	B	1	33°35.8'	151°27.5'
	C	1	33°37.8'	151°32.0'
	D	1	33°39.5'	151°35.6'
	E	1	33°41.4'	151°39.6'
	F	2	33°43.3'	151°44.0'
11	A	2	33°15.5'	151°39.4'
	B	1	33°17.1'	151°43.0'
	C	1	33°19.5'	151°48.1'
	D	2	33°21.6'	151°52.6'
	E	1	33°24.0'	151°58.0'
13	A	1	32°55.6'	151°51.4'
	B	1	32°57.4'	151°55.2'
	C	1	32°59.3'	151°59.0'
	D	1	33°01.2'	152°03.0'
	E	2	33°03.5'	152°07.5'
	F	1	33°05.5'	152°11.4'
	G	2	36°07.9'	152°16.4'
15	A	2	32°39.0'	152°16.5'
	B	1	32°40.9'	152°19.8'
	C	1	32°43.9'	152°24.7'

	D	2	$32^{O}46.9'$	$152^{O}29.7'$
	E	1	$32^{O}50.0'$	$152^{O}34.9'$

Sample Site Number & Priority			Latitude	Longitude
17	A	2	$32^{O}26.8'$	$152^{O}35.3'$
	B	2	$32^{O}27.6'$	$152^{O}38.8'$
	C	2	$32^{O}29.2'$	$152^{O}44.0'$
	D	2	$32^{O}30.6'$	$152^{O}49.1'$

Table 4. Station locations for coring sediments of the NSW continental slope; environment and climate change program.

Water Depth (m)	Position
600m,	$33^{o}52'S$; $151^{o}46.5'E$ 5.5nm transit
1000m	$33^{o}55'S$; $151^{o}52'E$, 3.5nm transit
1500m	$33^{o}57'S$; $151^{o}55.4'E$ 4.5nm transit
2000m	$33^{o}59'S$; $152^{o}00'E$ 3.5nm transit
2500m	$34^{o}01'S$; $152^{o}04'E$ 5nm transit
3100m	$34^{o}04'S$; $152^{o}09'E$

12 hours on site coring, 6 hours seismic (30nm) + 1hour streaming, 3 hours transit time between stations; 3 hours share of overall transit; total= 24 hours

Suggested procedure:

(i) complete 3.5kHz profiler traverse from 200m to 3500m;

(ii) return to coring sites on transect, conduct a gravity core/piston core at each;

(iii) stow in fridge at $2\text{-}4^{o}$.

Table 5a. Target locations for proposed seafloor dredging operations, NSW continental slope: Sydney Basin stratigraphy. (Final dredge sites will be selected from those below).

SeaBeam sites are from the map of J.E. Hughes Clarke (1990); BMR Seismic lines are from the 1972 BMR Continental Margins Survey, monitor records.

1. Lower reaches of Sydney Canyon: N wall and S-directed basement ridge at mouth; offshore of Botany Bay.

   SeaBeam: 34^{o}16'S 152^{o}02'E to 34^{o}18'S 152^{o}03'E, 3800-4100m, 14-20^{o} gradient

2. Lower Slope: SSW-NNE directed steep slope leading to abyssal plain; offshore of Port Jackson.

   SeaBeam: 34^{o}03'S 152^{o}17'E to 34^{o}15'S 152^{o}08'E, 3500-4700m, 14-30^{o} gradient

3. Rear wall of very entrenched canyon between two basement blocks; offshore of Port Jackson.

   SeaBeam: 33^{o}52'S 152^{o}22'E to 33^{o}56'S 152^{o}20'E, 3800-4400m, 15-20^{o} gradient

4. Lower slope; offshore of Broken Bay.

   SeaBeam: 33^{o}28'S 152^{o}30'E to 33^{o}34'S 152^{o}24'E, 2800-4000m, 15-20^{o} gradient

5. Mid-slope, offshore of Newcastle-Port Stephens.

   Seismic, BMR 12/041 12.140915

   32^{o}49'S 152^{o}53'E, 1800-2100m, 25^{o} gradient

6. Lower-slope, offshore of Newcastle-Port Stephens.

   Seismic, BMR 12/041 12.140800-0730

   32^{o}50'S 153^{o}07'E to 32^{o}51'S 153^{o}09'E, 3000-3750m, 10^{o} gradient

7. Mid-slope, offshore of Gosford.

Seismic, BMR 12/033 12.071700

$33^{O}11'S$ $152^{O}47'E$, 2850-3750m, 20^{O} gradient

8. Lower-slope, offshore of Gosford.

Seismic, BMR 12/033 12.071940

$33^{O}10'S$ $153^{O}09'E$, 4120-4870m, 20^{O} gradient

9. Mid-slope, offshore of Newcastle.

Seismic, BMR 13/010 13.050055

$33^{O}03'S$ $152^{O}46'E$, 2250-3230m, 10^{O} gradient

10. Lower-slope, offshore of Bulli.

Seismic, BMR 15/034 15.050610-0630

$34^{O}18'S$ $151^{O}56'$-$152^{O}00'E$ to $34^{O}18'S$ $151^{O}54'E$, 3150-3980m, 10^{O} gradient

11. Lower-slope, offshore of Bulli.

Seismic, BMR 15/034 15.050700-0712

$34^{O}18'S$ $152^{O}08'E$, 4050-4870m, 15^{O} gradient

12. Upper slope, offshore of Gosford.

Seismic, United Geophysical shots 6325-6320

$33^{O}34'S$ $152^{O}18'E$, 2400-2700m

13. Pinnacles, offshore of Newcastle

NSW FRI 8810 soundings 17-5-1988: 38-39, 43-44, 51-52, 60-63

$32^{O}53$-$56'S$ $152^{O}43$-$48'E$; 950-1107m

14. Peak, offshore of Newcastle:

NSW FRI 8810 soundings 17-5-1988: 62

$32^{O}52.0'S$ $152^{O}46.5'E$, 950-1033m

15. Upper slope basement ridges

Seismic, BMR 12/029 12.072355-0005

$33^{O}48.5'S$ $152^{O}04'E$, 1500-1950m

Table 5b. Top priority slope dredging sites

Area:	Position: (lat deg.S;lon.deg E)	Depths:	Dredgings
13	32°53-56'S 152°43-48'E	950-1107m	2
9	33°03'S 152°46'E	2250-3230m	2
7	33°11'S 152°47'E	2850-3750m	2
	(Waypoints 33°22'S 152°33'E & 33°24'S 152°42'E		?2)
4	33°28'S 152°30'E to 33°34'S 152°24'E	2800-4000m	2
12	33°34'S 152°18'E	2400-2700m	2
15	33°48.5'S 152°04'E	1500-1950m	2
3	33°52'S 152°22'E to 33°56'S 152°20'E	3800-4400m	2
2	34°03'S 152°17'E to 34°15'S 152°08'E	3500-4700m	4
11	34°16'S 152°02'E to 34°18'S 152°08'E	3800-4870m	2
10	34°18'S 152°00'E to 34°18'S 151°54'E	3150-3980m	4

Table 6. Station locations for the SWB/BMR seafloor sampling program between Broken Bay and Port Hacking.

Site No.	Sample Type	Latitude	Longitude
1	G, BC, VC	33°37.55'	151°23.92'
2	G, VC	33°37.55'	151°26.22'
3	G, VC	33°37.55'	151°30.52'
4	G, VC	33°37.55'	151°33.82'
5	G, BC, VC	33°37.55'	151°37.12'
6	G, VC	33°37.55'	151°40.42'
7	G, VC	33°37.55'	151°43.72'
8	G, BC, VC	33°37.55'	151°47.O2'
9	G, VC, BC	33°48.75'	151°41.91'
10	G, VC	33°48.75'	151°38.53'
11	G, VC	33°48.75'	151°35.15'
12	G, BC, VC	33°48.75'	151°31.77'
13	G, VC	33°48.75'	151°28.39'
14	G, VC	33°48.75'	151°25.01'
15	G, BC, VC	33°48.75'	151°21.63'
16	G, VC, BC	33°59.95'	151°18.32'
17	G, VC	33°59.95'	151°21.72'
18	G, VC	33°59.95'	151°25.12'
19	G, BC, VC	33°59.95'	151°28.52'
20	G, VC	33°59.95'	151°31.92'
21	G, BC, VC	33°59.95'	151°35.32'
22	G, VC, BC	34°11.15'	151°26.80'
23	G, VC	34°11.15'	151°23.40'
24	G, VC	34°11.15'	151°20.00'

25	G, BC, VC	34°11.15'	151°16.60'
26	G, VC	34°11.15'	151°13.20'
27	G, VC	34°11.15'	151°09.80'
28	G, BC, VC	34°11.15'	151°06.40'

List of Figures.

9. Schematic of simplified geochemical mass balance indicating major inputs, exports and internal recycling pathways.

Appendix 1

Selected bibliography of relevant continental margin geology (supplied by Sydney University)

Barron, J., Larsen, B & others (incl Jenkins, C.J.). 1989. ODP Leg 119, Kerguelen-Heard Plateau and Prydz Bay, Antarctica. Proc. Ocean Drilling Progr. Rep. 119, 1-942.

Birch, G.F. 1990. Phosphorite deposits on the South African continental margin and coastal terrace. *In* Phosphate Deposits of the World. V. 3, Neogene to Modern Phosphorites, W.C. Burnett & S.R. Riggs (eds.). Cambridge Univ. Press.

Davies, H.L., Keene, J.B., Hashimoto, K., Joshima, M., Stuart, J.E. & Tiffin, D.L. 1987. Bathymetry and canyons of the Western Solomon Sea. Geo-Marine Letts 6(4), 181-192.

Davies, H.L., Honza, E., Tiffin, D.L., Lock, J., Okuda, Y., Keene, J.B., Murikami, F. & Kisimoto, K. 1987. Regional setting and structure of the Western Solomon Sea. Geo-Marine Letts 6, 153-160

Eckert, J.M., Keene, J.B., Leggett, K.E.A. & Williams, K.L. 1989. Coprecipitation of manganese from marine sediment pore waters for X-ray fluorescence spectrometry. Anal. Chim. Acta 222, 169-175

Flemming, B.W. & Birch, G.F. 1990. Jahresbilanz der terrigen sediment zufuhr zum kustennahenschelf des sudlichen Afrika. Haupt. samml. Deutch. Geol. Gessell. Vom 3-6 Oct. Bremen, Germany.

Hambrey, M.J., Larsen, B., Ehrmann, W.U. & the ODP Leg 119 Shipboard Scientific Party (incl. Jenkins, C.J.) 1988. Forty million years Antarctic glacial history yielded by Leg 119 of the Ocean Drilling Program. Polar Record 25, 99-106.

Harris, P.T., Pattiaratchi, C.B., Cole, A.R. and Keene, J.B. (In press). Evolution of subtidal sandbanks in Moreton Bay, Eastern Australia. Mar. Geol.

Honza, E., Davies, H.L., Keene, J.B. & Tiffin, D.L. 1987. Plate boundaries and the evolution of the Solomon Sea region. Geo-Marine Letts, 6, 161-68.

Jenkins C.J. & Alibert C. 1991. Sedimentary and Metamorphic Rock Clasts from the Cenozoic Diamictons of Sites 739-743 in Prydz Bay, East Antarctica. In: Barron J., Larsen, B. & others 1989. Proc. Ocean Drilling Progr., Sci. Results, 119, 133-141.

Jenkins, C.J. & Keene, J.B. 1992. Submarine slope failures on the south-east Australian continental slope. Deep-Sea Res, 39, 121-136.

Jenkins C.J. (In press). Abyssal sediment drifts, erosion and history of bottom-water flows in the Tasman Sea southwest of New Zealand. Aust. J. Earth Sci.

Malikides, M., Harris, P.T., Jenkins, C.J. & Keene, J.B. 1988. Carbonate sandwaves in Bass Strait. Aust. Jl Earth Sci. 35, 303-311.

McArthur, J.M., Thomson, J., Jarvis, I., Fallick, A.E. and Birch, G.F. 1988. Eocene to Pleistocene phosphogenesis off western South Africa. Mar. Geol., 85, 41-63.

Roy, P.S. (in press). Shell hash dating and mixing models for palimpsest marine sediments. Radiocarbon, 33.

Roy, P.S. & Connell, J. 1991. Climate change and the future of atoll states. Jl Coastal Res., 7, 1057-1075.

Roy, P.S. & Thom, B.G. 1991. Cainozoic shelf sedimentation model for the Tasman Sea margin of southeastern Australia. *In* The Cainozoic in Australia: a Re-appraisal of the Evidence, M.A.J. Williams & others (eds.), Geol. Soc. Aust. Spec. Publ. No. 18, 119-136.

Thom, B.G. & Roy, P.S. 1988. Sea-level rise and climate: lessons from the Holocene. *In* Greenhouse Planning for Climate Change, G.I. Pearman (ed.), Melbourne, CSIRO Publ., 177-188.

Tiffin, D.L., Honza, E. and Keene, J.B. 1987. A multi-national multi-parameter Marine study of the western Solomon Sea and region. Geo-Marine Letts, 6, 175-180.

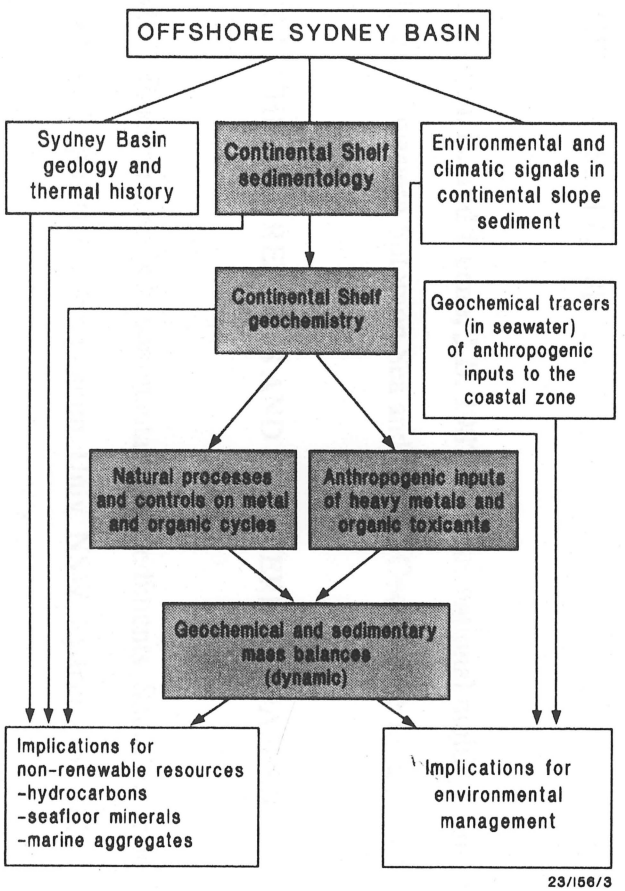
RELEVANT TECHNICAL REPORTS AND UNREFERREED PAPERS

Roy, P.S. 1990. Placer minerals in continental shelf sediments, South Eastern Australia. *In* Placer Deposits - A Symposium. Univ. NSW, Sydney, 163-182.

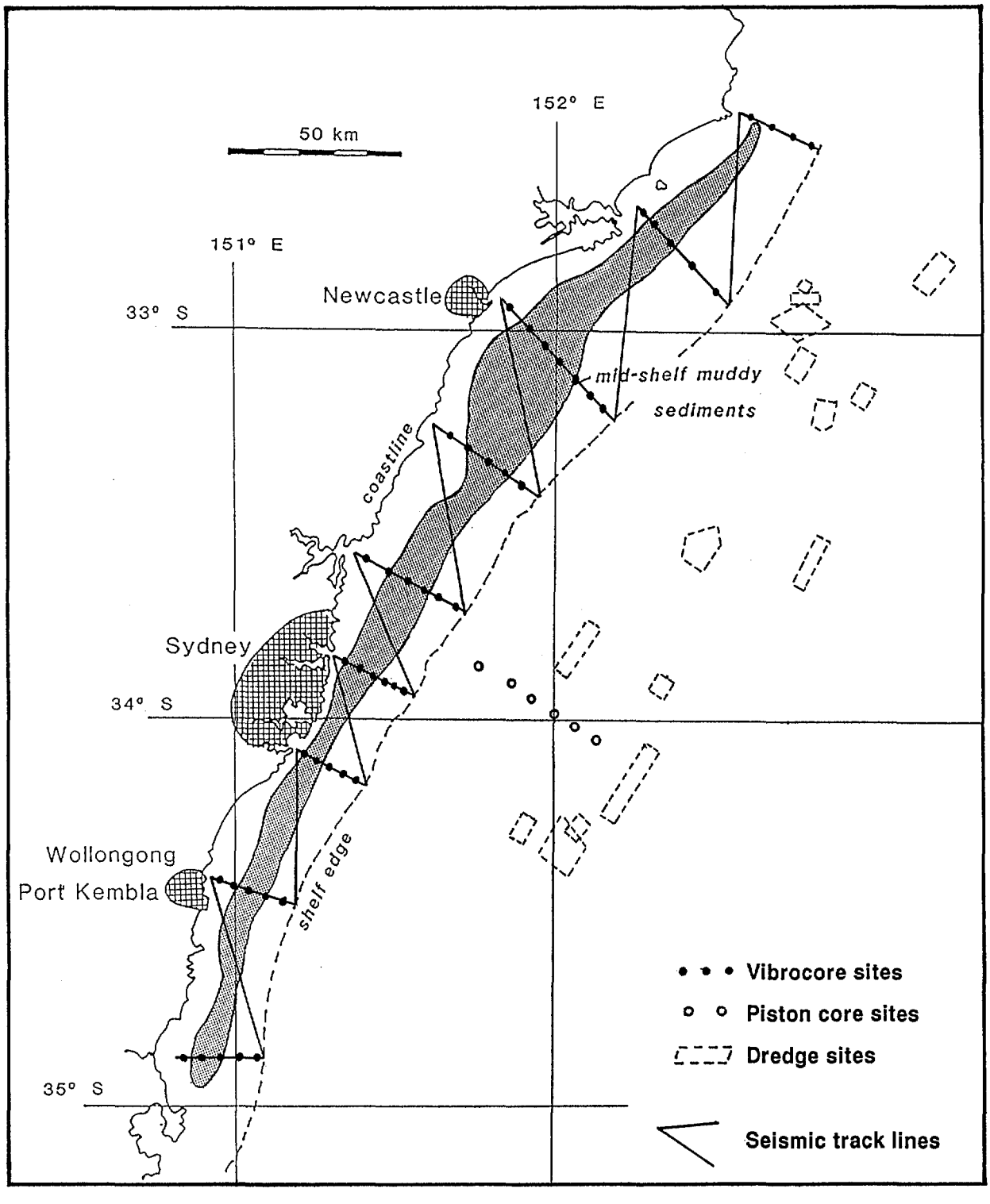
Roy, P.S., Cowell, P.J. & Jones, R.A. 1989. Modelling coastal changes in response to rising sea level. IGBP Planning Workshop on Sea-level Change and the Australian Coastline. Aspendale, Melbourne, 2-3.

Roy, P.S. & Ferland, M.A. 1987. Seismic results from the inner continental shelf of the Shoalhaven/ Jervis Bay/ Ulladulla region, southern NSW. Geol. Sur. NSW Report, GS 1987/191, 33 p.

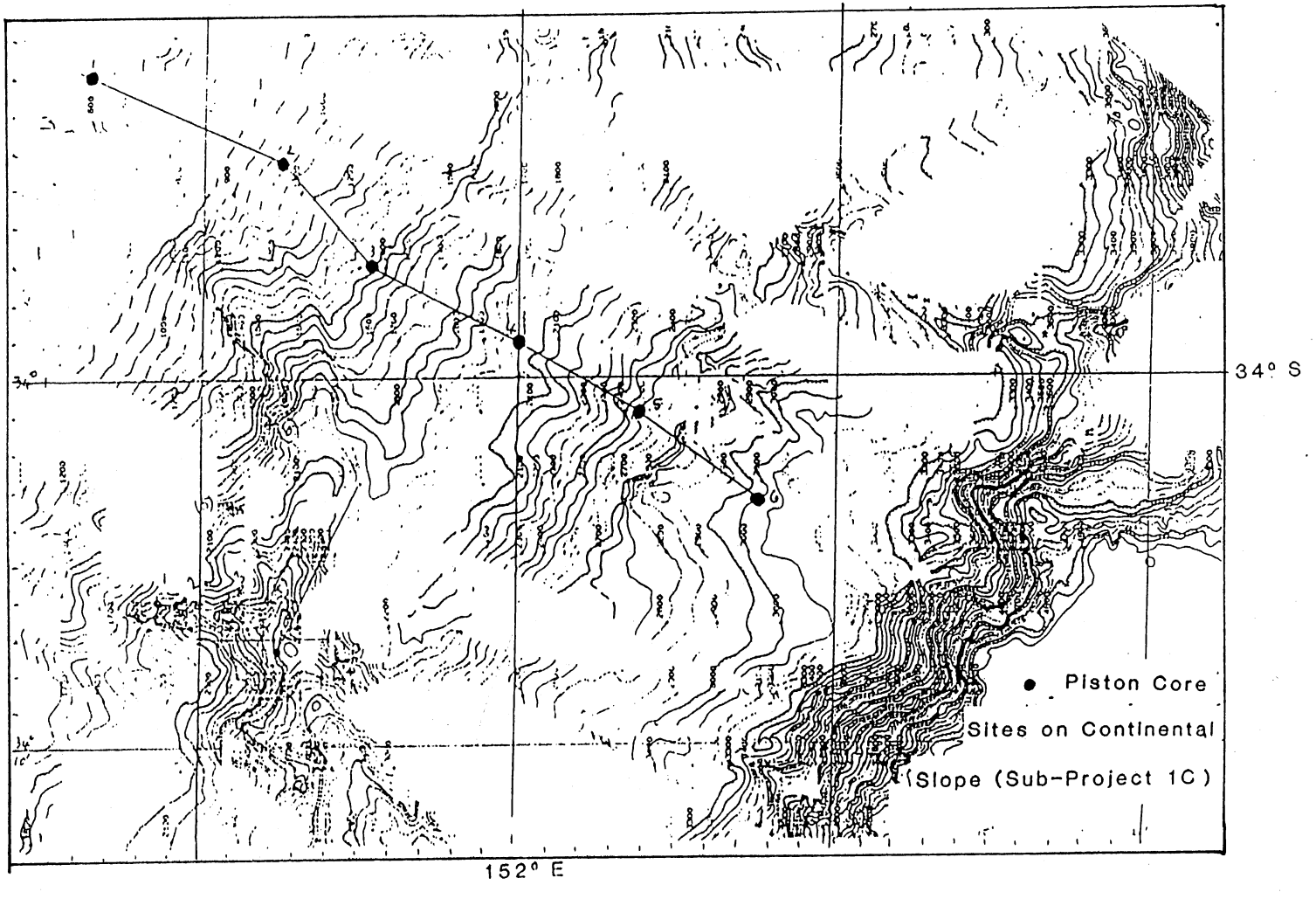
Roy, P.S. & Hudson, J.P. 1988. Seismic results from the continental shelf, southern NSW: Narooma - Montague Island - Bermagui area. Geol. Sur. NSW Report, GS 1987/094, 65 p.



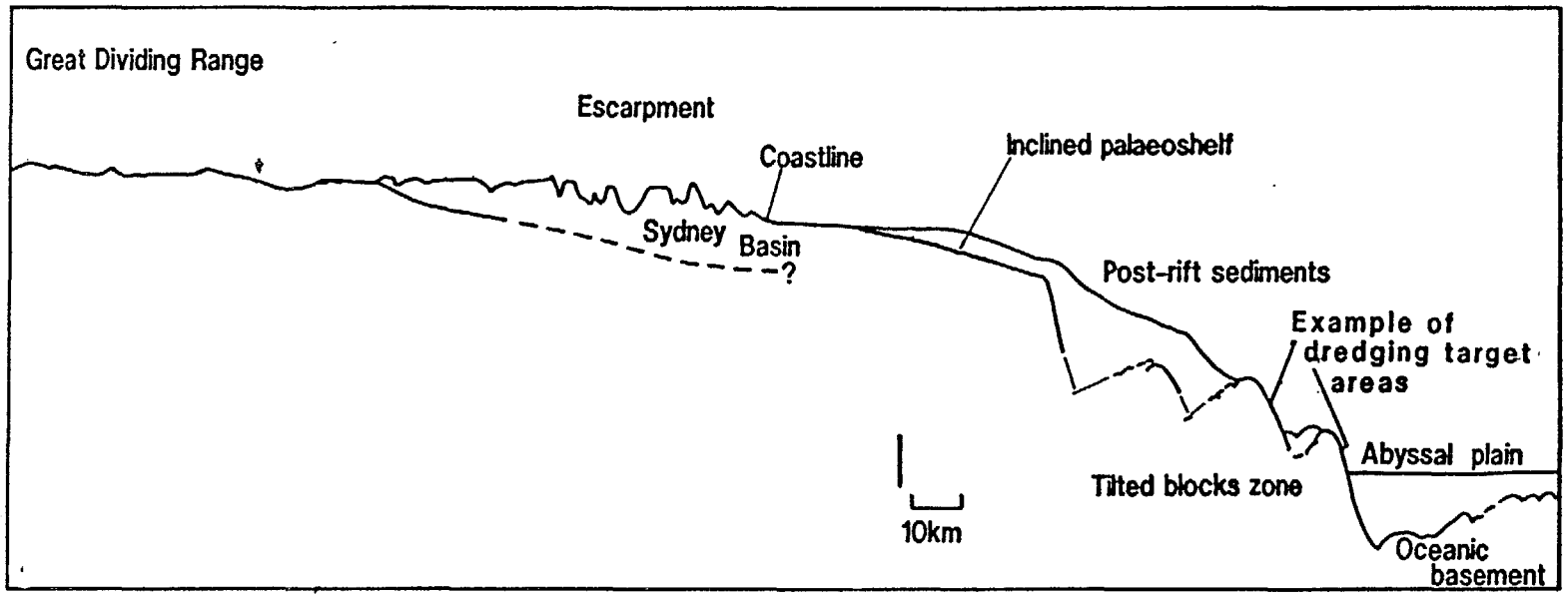
1. Schematic diagram summarising the major project activities and linkages between project components.



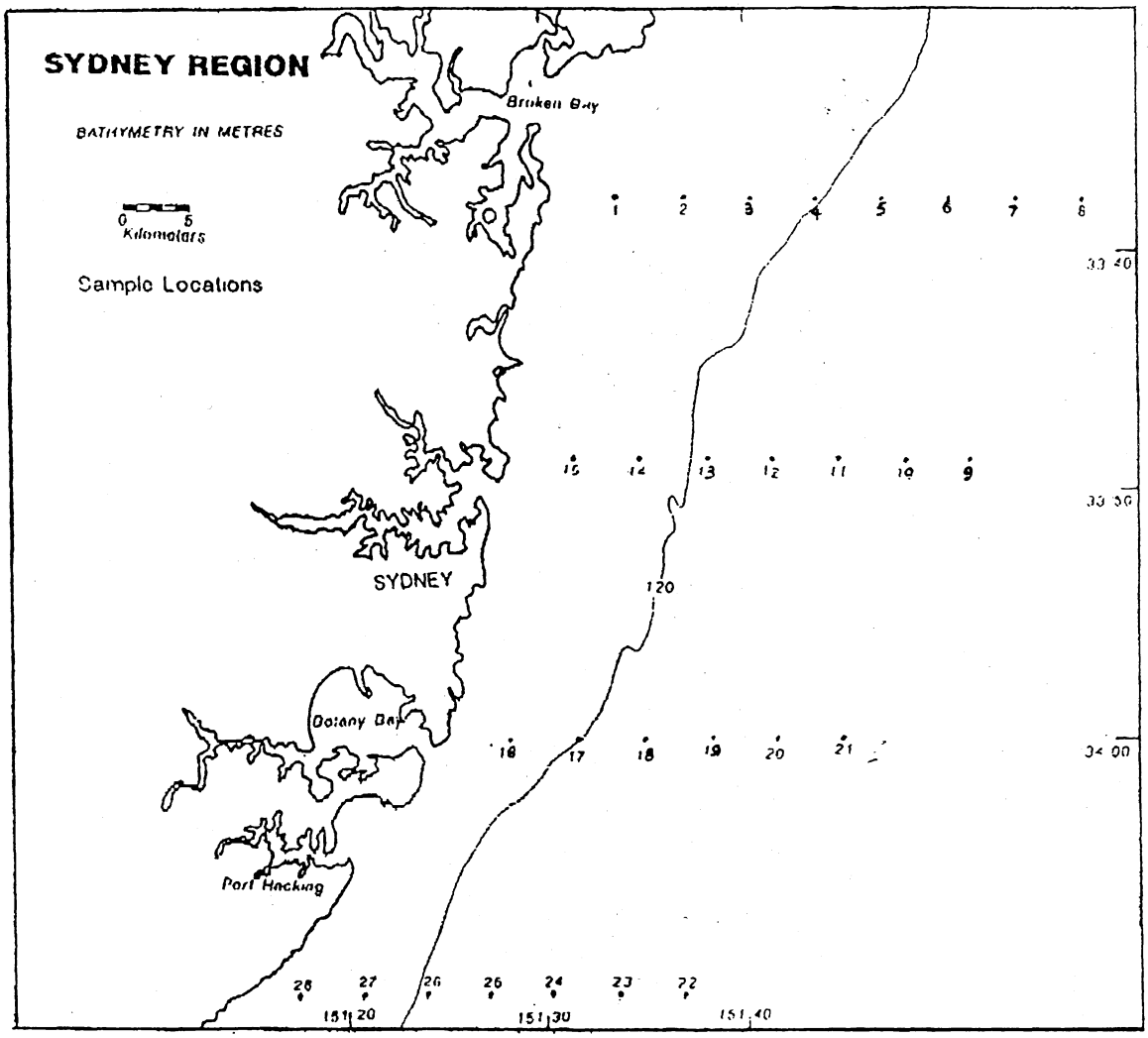
2. Map of the continental shelf of central NSW showing the proposed locations for the high resolution seismic survey, the cross-shelf coring transects and proposed dredge targets on the slope.



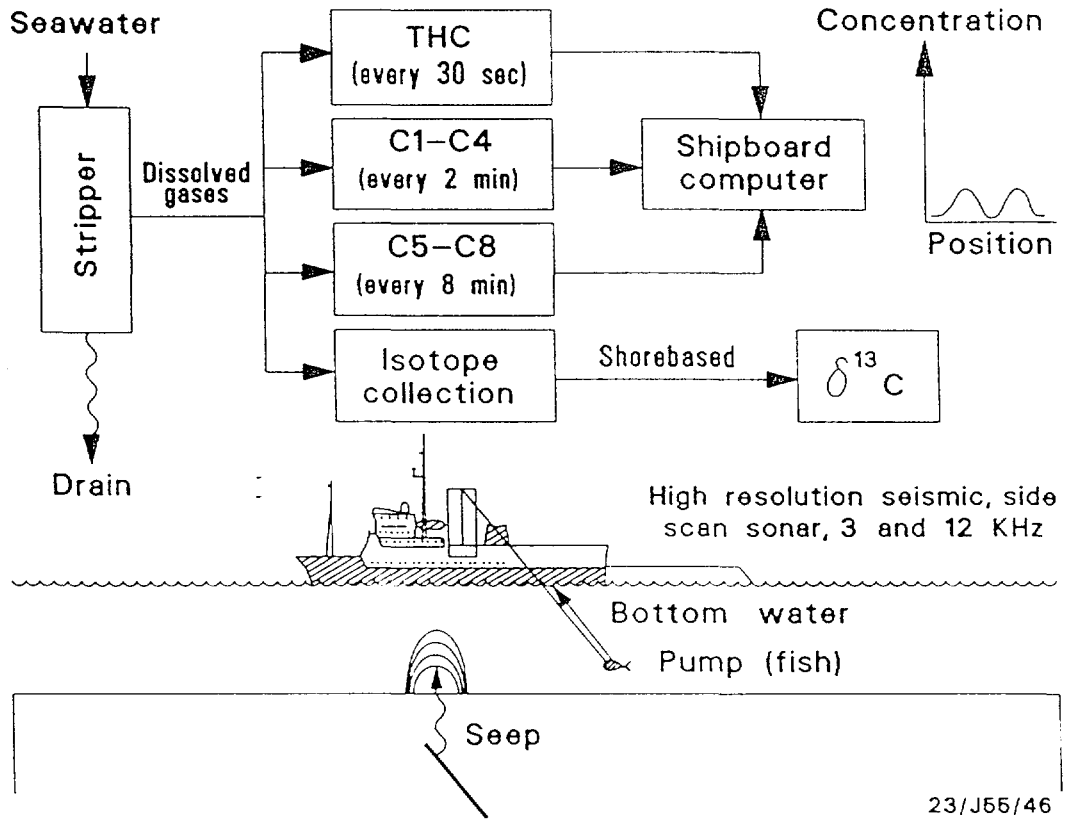
3. Map showing the locations and bathymetry of proposed piston/gravity core locations on the continental slope.



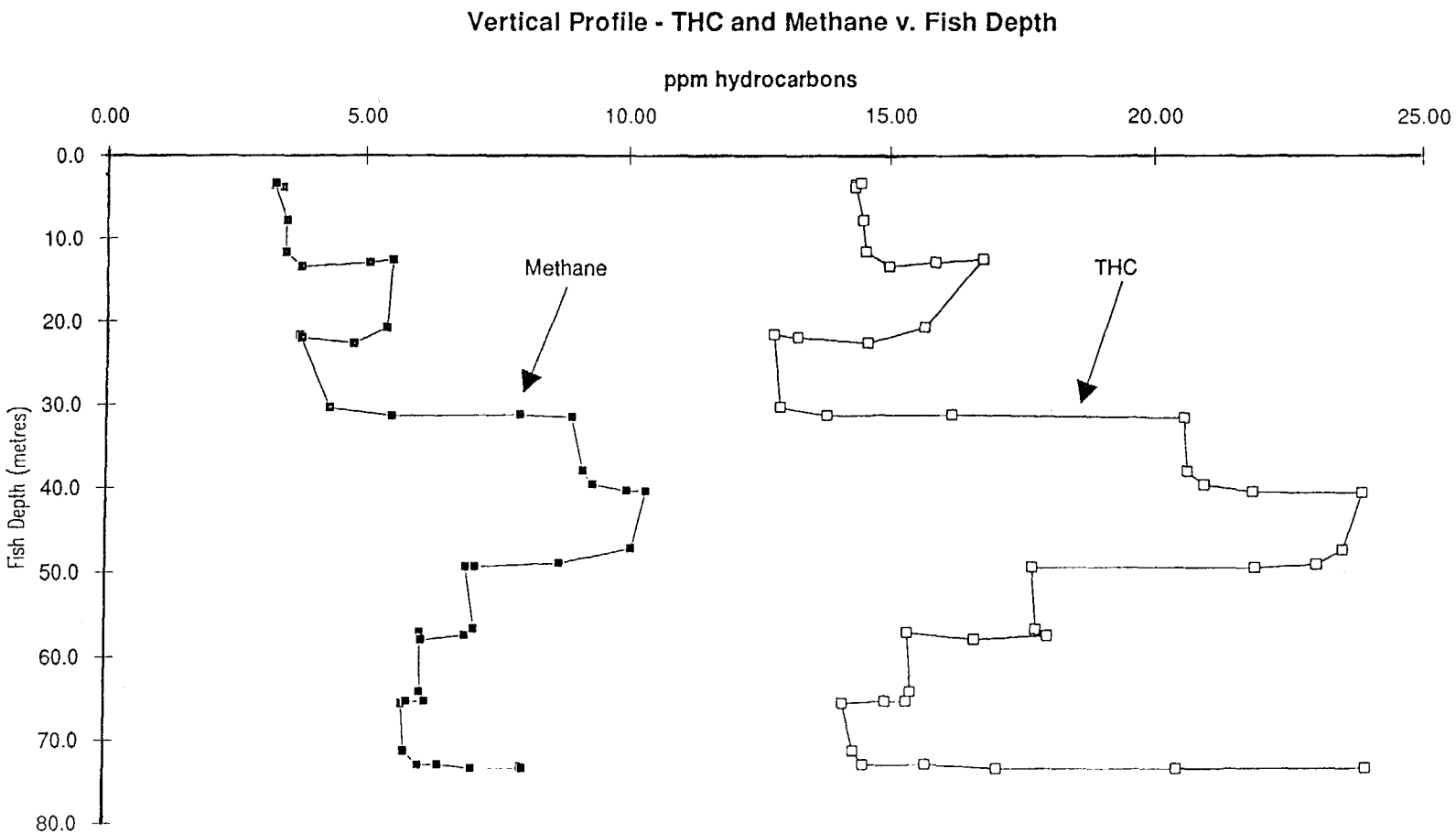
4. Figure of proposed dredging targets.



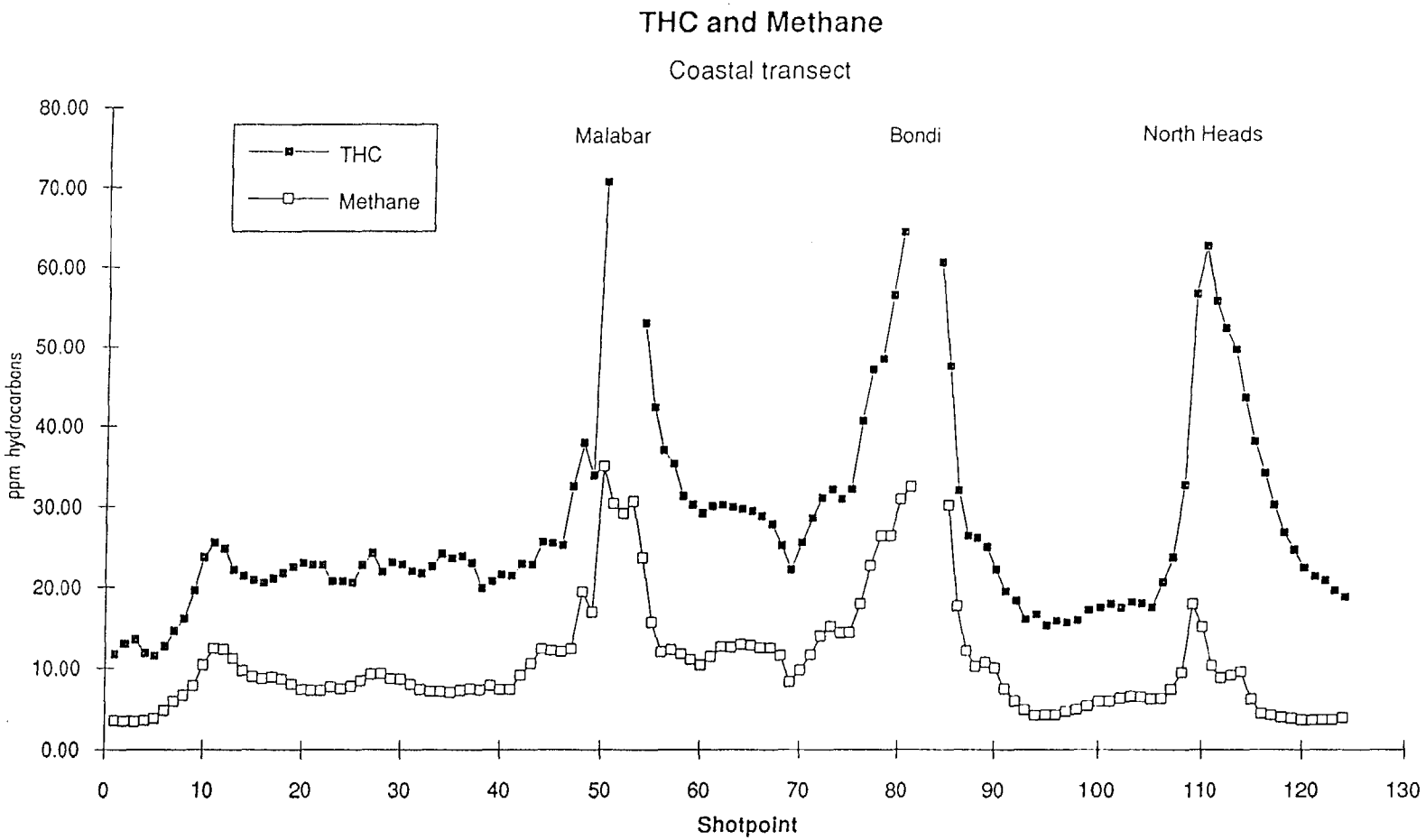
5. Map of the proposed SWB vibrocoring transects.



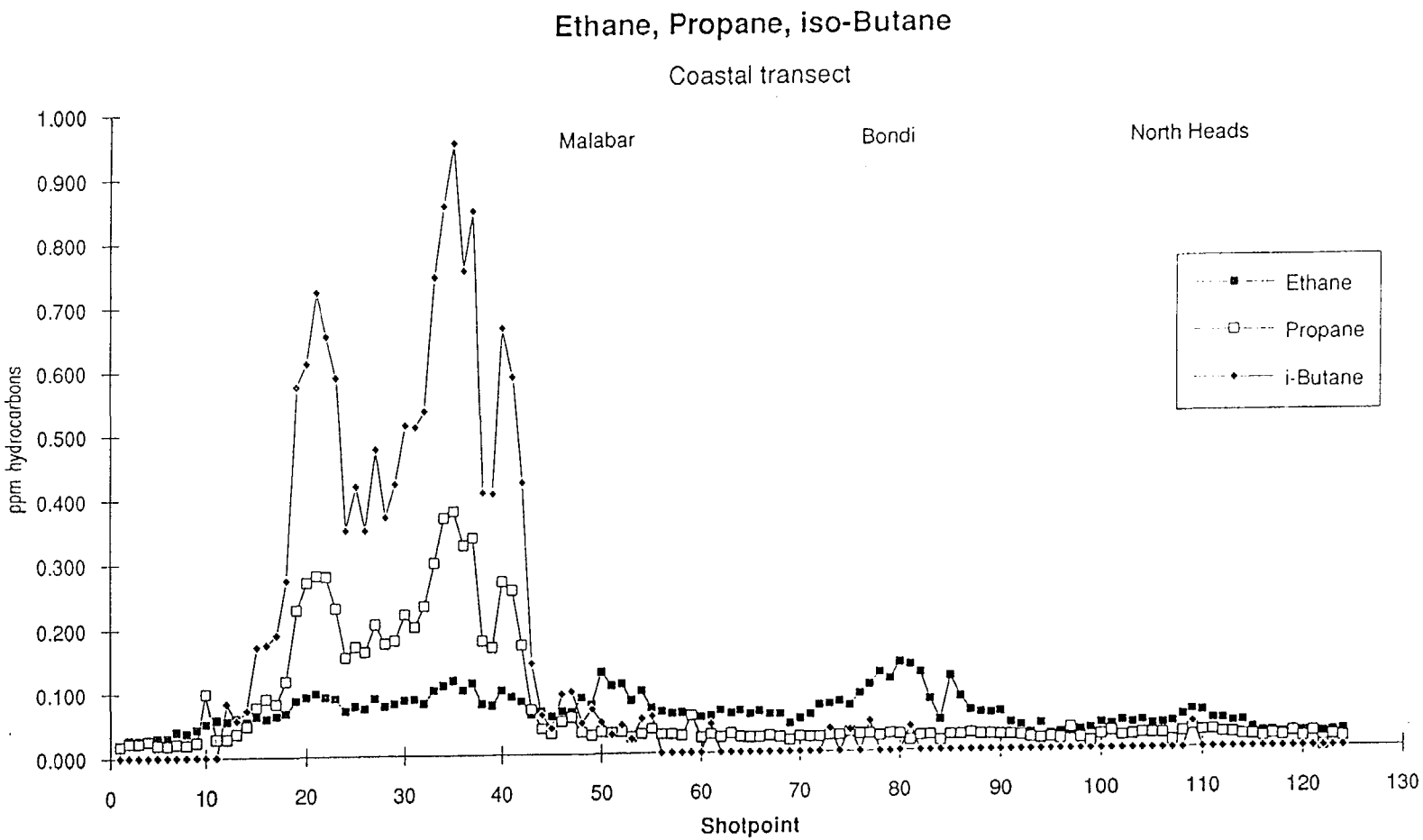
6. Schematic of the continuous profiling equipment aboard Rig Seismic, and the onboard gas extraction and light hydrocarbon gas analysis sequence.



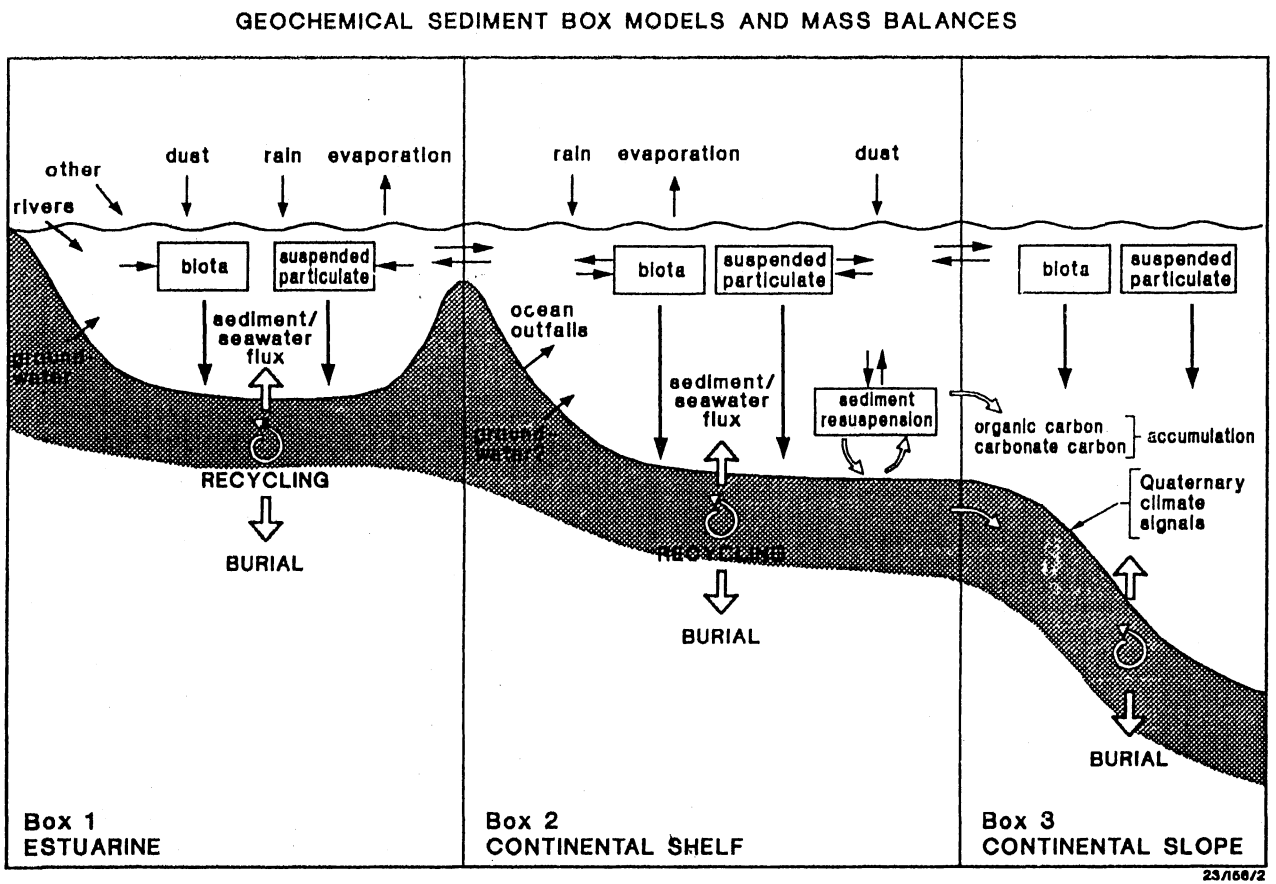
7. Vertical profile of methane and THC south of Malabar, off the entrance to Botany Bay.



8a. Total hydrocarbons (THC) and methane in seawater in the viciniites of the SWB ocean outfall sites off Sydney.



8.b Ethane, propane and butane concnetrations in seawater in the vicinities of the SWB ocean outfall sites off Sydney.



9. Schematic of simplified geochemical mass balance indicating major inputs, exports and internal recycling pathways.