THE NERC MARINE CENTRES' STRATEGIC RESEARCH PROGRAMME 2007-2012

Theme 5: Continental Margins and the Deep Ocean

The deep ocean and the seafloor beneath it are the largest yet least known environments on our planet. They profoundly influence the way in which the Earth reacts to climate change, provide vital resources, and can cause natural catastrophes (with significant risks to the UK). A better understanding of the biodiversity and resource potential of the deep ocean, its geophysics and its complex interactions with the global carbon cycle are all urgently required.

Theme 5 comprises two Research Units and eight Work Packages:

Continental margins (National Oceanography Centre, Southampton).
Theme Leader: Doug Masson dgm@noc.soton.ac.uk

WP 5.1	Physical controls on the benthic ecosystems of continental margins
WP 5.2	Causes, frequency and prediction of geohazards such as landslides and tsunamis
WP 5.3	Physical processes regulating the transport of sediments to the deep ocean
WP 5.4	Transport of fluids from the sub-seafloor to the seabed and their part in carbon fluxes
WP 5.5	Application of scientific knowledge to the management of ocean resources (UNCLOS)
WP 5.6	The General Bathymetric Chart of the Oceans (GEBCO)

Biogeochemistry of the deep ocean (National Oceanography Centre, Southampton)
Theme Leader: Doug Masson dgm@noc.soton.ac.uk

WP 5.7	Twilight zone dynamics
WP 5.8	Benthic system dynamics

Theme 5: Continental Margins and the Deep Ocean

Strategic setting

The deep ocean, which lies between the sunlit layer of the sea and the abyssal seafloor, is a vast fluid universe. It is the largest (yet least explored) single habitat for life on our planet, occupying ~1.3 x10^9 km^3; it is also the largest reservoir for carbon in the Earth system. Understanding the ocean's capacity to store anthropogenic CO_2 is now essential since this affects the global climate as well as marine food chains, biodiversity and, ultimately, human existence. While the deep ocean receives material from overlying waters, it is also the main source of nutrients that fuel new production in the surface ocean. These processes are poorly known, but are thought to strongly influence the annual variability in the magnitude and type of biological productivity. In addition to providing resources - hydrocarbons and minerals, as well as fisheries - the deep ocean can also bring catastrophe, such as the 2004 Indian Ocean tsunami. It is therefore unsurprising that the dark, cold, remote frontier of the deep ocean is one of NERC's six priority themes for potential investment – and that it has been highlighted as of strategic importance by all the major global change and biodiversity programmes.

The range of remarkable discoveries made only recently (coral mounds, microbial diversity in the ocean's interior, hydrothermal vents and cold seeps) indicates the scope for further important revelations and the role of novel technology, such as Autonomous Underwater Vehicles (AUVs), high-resolution sidescan sonar and Remotely Operated Vehicles (ROVs), in making them. The pace of such technological developments reflects the rapidly increasing human exploitation of the deep ocean (Fig 1). Yet scientific knowledge of the deep ocean lags behind our ability to sustainably use its resources: we need to assess not only direct human impacts, arising from deep-sea fishing and hydrocarbon extraction, but also indirect impacts, such as increasing ocean acidity, with knock-on effects for calcareous plankton, sediments and benthic fauna.

Theme 5 addresses all NERC's current science priority areas - climate change, Earth's life-support systems, and sustainable economies (NERC, 2002). It also addresses new concerns identified in recent gap analyses, such as: What are the sources, sinks and transport processes of carbon within the Earth system? How will marine species adjust to climate and environmental change? What is the diversity of (marine) microbial assemblages, and what are their dynamics, community interactions and evolutionary processes? What unexplored sources of biodiversity can we find within the deep ocean? What are the environmental risks of exploiting gas hydrates as an energy source?

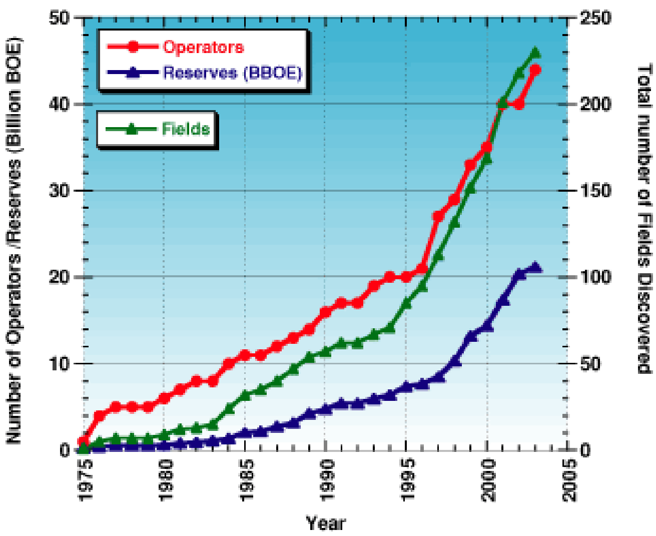


Fig. 1. Example of the increase in deep water oil production from 1975 to 2005. This mirrors the growth of deep ocean resource exploitation worldwide and across all industries.

Much UK deep-ocean research is already embedded in European programmes; e.g. in FP VII planning, in guiding the Euroceans and MarBEF EU networks, and in coordinating HERMES (Hotspots Ecosystem Research on the Margins of European Seas; EU large integrated project). Apart from ensuring a UK science contribution to European policy making, such partnerships mobilise much larger resources than can be generated by a single research group or by national collaborations, providing additional (and essential) multi-disciplinary information. At the international level, Theme 5 will provide data and understanding for IGBP environmental change programmes, the UN Convention of Biological Diversity (CBD), and the Census of Marine Life. Theme 5 will also advise new legislation being formulated through the UN Law of the Sea (UNCLOS) for resource use and environmental protection.

Main science aims

The overall aim of Theme 5 is to deliver coordinated, multidisciplinary research on the functioning of the deep ocean from the photic zone to the sub-seabed, encompassing biology, physics, geology, chemistry and mathematical modelling. Such an integrated deep-sea programme is unique in the UK and will ensure the provision of knowledge essential for underpinning UK policy in conserving marine biodiversity, controlling the effects of global change, managing ocean resources in a sustainable manner, and mitigating the effects of geohazards.

The specific objectives of Theme 5 are:

- To understand the processes controlling the vertical flux of carbon between the base of the photic zone and the seabed and to quantify this flux.
- To quantify fluxes of carbon and fluids from the sub-seabed into the deep ocean and their contribution to global carbon budgets.
- To determine how the carbon flow interacts with deep-ocean pelagic and benthic communities in the open ocean and on the continental slope.
- To investigate how benthic ecosystems on continental margins and in the deep ocean respond to spatial and temporal variation in environmental parameters.
- To understand the causes, frequency and predictability of submarine geohazards.
- To apply scientific knowledge to the sustainable management of the ocean and its resources.

Theme 5 combines two Research Units, on Continental Margins and on the Biochemistry of the Deep Ocean. Ultimately the science of the two activities will be combined, but because the methods of study and the resources needed are largely different, the work has been planned within two groups.

In Continental Margins, the physical processes regulating the transport of sediment will be investigated as well as the transport of hydrocarbons and aqueous fluids from the seafloor. The effect of both of these major processes on the landscape ecology of the continental slope will be assessed. In addition, the causes, mechanisms and frequency of submarine geohazards will be studied, particularly those that potentially could have a devastating effect on coastal communities, such as earthquake and landslide-induced tsunamis. Carbon flux from the geosphere into the ocean will be assessed. The information will be used to advise on whole ecosystem management strategies, including policy issues relating to Marine Protected Areas and international treaties on the development of open ocean resources.

In Biogeochemistry of the Deep Ocean, we will study the flux of particles through the ‘twilight zone’ in order to reduce the large uncertainties in our knowledge of the magnitude of the downward flux in various biogeochemical provinces of the global ocean. The twilight zone is a large biogeochemical reactor influencing the supply of nutrients to the euphotic zone and the fate of materials consigned to the deep seafloor. Theme 5 will study how zooplankton and microbes repackage and breakdown particles, and how these processes influence carbon transfer. Direct observations and experimental approaches will provide data to drive stoichiometric models of heterotrophic OM utilisation. The impact on the deep-sea benthos of repackaged OM, and the of part of surface production that by-passes twilight zone processes, will be assessed by analysing global patterns and through ROV *in situ* experimentation. Proven modelling expertise in upper ocean systems will be extended to benthic ecosystems utilising the information generated by bentho-pelagic coupling observations and experimental approaches.

Centre contributions

Theme 5 will be implemented by the National Oceanography Centre, Southampton (NOC), capitalising on the strengths of NOC scientists in the physics, biogeochemistry, biology and modelling of the ocean’s interior, and the geology and biology of ocean margin systems. These researchers are used to working closely together and across discipline boundaries, through previous multidisciplinary projects for NERC (e.g. Biophysical Interactions and Controls on Export

Production, BICEP), industry (e.g. Atlantic Margin Environmental Survey, AMES), government departments (e.g. MOD studies on sedimentary environments in the Arabian Sea) and Europe (e.g. HERMES). In addition to continuing collaborations with other NERC marine Centres and BGS (not requiring Oceans 2025 support), opportunities are identified for UK university involvement in Theme 5 through the SOFI initiative, together with new posts to strengthen NOC's combination of skills and expertise, and its position as one of the top five oceanographic institutions in the world.

Continental margins

Background

Human exploitation of continental margins is progressing at a rapidly increasing rate. Hydrocarbons are being extracted from deep-sea sites, new communication cables are being laid and bottom trawling now occurs to >1500 m. We are now beginning to understand connections between sub-surface geological processes – fluid flow, gas hydrates, and microbial activity – and seabed processes and ecosystems, but much more research into this component of the Earth system is necessary. This Research Unit extends from subsurface to seabed processes (including benthic ecosystems), and includes the interactions of physical oceanography with topography, that lead to a complex jigsaw of ocean margin ecosystems. Temporal variations in these processes, particularly from large-scale episodic events, create further complexity. Knowledge of sedimentary processes on continental margins is needed to provide modern analogues for hydrocarbon reservoirs, whilst a wider geophysical context is needed to assess the risk of natural hazards such as tsunamis, generated by offshore earthquakes and landslides, that threaten coastal communities.

Scientific aims and objectives

The overall aims are:

- to investigate how ecosystems, sedimentary systems and subsurface fluid flow on continental margins respond to spatial and temporal variations in environmental parameters
- to examine the consequences of such change for sustainable use of resources on continental margins.

Detailed rationale, specific objectives, approach and methodologies are given in the six interlinked Work Packages below.

WP 5.1 Physical controls on the benthic ecosystems of continental margins

The classical view of the deep-ocean floor as a gently sloping, sediment-draped, continental margin leading to a flat and featureless abyssal plain - all unaffected by human activities - has been overturned in the last few decades, principally through the use of novel technology. Deep-towed sidescan sonar and ROVs have enabled the deep ocean to be studied in fine detail, particularly in areas of complex terrain. UK and European agencies are committed by international agreements to achieve sustainable management of deep-ocean natural resources. These actions must be underpinned by sound science. Current advice on sustainable management issues has developed through the science of 'landscape ecology'. Truly integrated multidisciplinary research is now needed to understand how organisms are distributed in a complex environment, how their distributions affect the flow of energy, materials and bioresources, and how ecological functions are influenced by natural and human factors. NOC's team of benthic biologists, working in concert with geologists, physical oceanographers and modellers, are uniquely placed to tackle deep-ocean landscape ecology and take an international lead in its application to policy issues. NOC has already made substantial contributions to this topic area (e.g. Bett *et al* 2001; Masson 2001), including the discovery of novel and important habitats in UK waters, such as deep-sea barchan dunes and the coral-topped Darwin Mounds (Wynn *et al* 2002; Masson *et al* 2003). In WP 5.1, we will extend observations of ecological patterns in relation to environmental variables by using ROVs to test experimentally the hypotheses generated by these patterns.

<u>*Landscape ecology of continental margins.*</u> Recent technical innovations have led to remarkable scientific discoveries, such as giant coral mounds and methane-seeping mud volcanoes, on continental margins across the World (Freiwald *et al* 2004). The EU HERMES Integrated Project, led from NOC, has developed a comprehensive strategy for the study of Europe's continental margin. Particular attention is being given to canyon systems because they fast-track material, including pollutants, from land and shelf seas into the deep ocean (Puig *et al* 1999) and they play an important role in carbon storage (van Weering *et a*l 2001). NOC is also interested in other areas of the UK continental shelf (deep-water Exclusive Economic Zone), with additional funding from new national initiatives arising from the Atlantic Margin Environmental Surveys (AMES; Bett 2001).

Canyons characterise more than half of the European margin and far exceed their terrestrial equivalents in extent and depth. They may be important 'hotspots' of biodiversity and biomass (Rogers *et al* 2003). Episodic 'flushing' of canyons mobilises large amounts of sediment and associated material (Khripounoff *et al* 2003) overwhelming benthic ecosystems over a wide area of the abyss as well as the canyon floor (Thomsen *et al* 2002). The frequency of such events and associated particle fluxes are largely unknown, as are the rates of recolonisation of the impacted ecosystems. Canyons are complex systems, highly variable in terms of their hydrography, sedimentology, biogeochemistry and biology, and each with its own characteristics. To create useful policies for whole ecosystem management there is a clear need not only for a concerted effort to compare canyons from different biogeochemical provinces and different topographic settings, but also for co-ordinated, multidisciplinary projects relating the fauna to the environmental variables that regulate their distributions, i.e. their landscape ecology.

We will undertake a comprehensive study of the landscape ecology of canyons on the European Atlantic Margin, focussing on two groups of canyons with contrasting morphologies, activities and biogeochemical provinces: a) the Gollum Channel System and the Whittard and Dangeat Canyons (the principal canyon feature in UK waters) to the southwest of Ireland; and b) the Nazare, Cascais and Setubal Canyons off the Iberian coast. An initial investigation of the Iberian canyons was carried out in 2005 (Weaver *et al* 2005), this work will continue in 2006 (RRS *Charles Darwin* cruise 179) leading to a major effort with the ROV *Isis* in 2007. Work to the southwest of Ireland will be undertaken with partial support from HERMES and a NERC standard grant to be submitted in the summer of 2006. The specific objectives of WP 5.1 are:

i) To describe the physical environment of each canyon system - its bathymetry, the distribution of substratum / sediment facies, physical oceanography (see WP 5.3) - at scales that relate to the distribution of distinct biological communities, and to assess the relative 'activity' of each canyon, both by direct monitoring and from the sediment record.

ii) To describe the major ecological components of each canyon system and, by reference to the physical parameters, to investigate and ground-truth the distribution of distinct biotic communities within each canyon. By comparing different canyons, and by comparing canyon and adjacent open slope environments, we will assess: a) successional status in relation to canyon activity; b) level of canyon endemism; and c) species turnover (beta-diversity) along the European margin.

iii) To synthesise the physical and ecological information leading to an understanding of the landscape ecology of canyon systems relevant to their environmental management. This objective includes identification and mapping of environmental management units (e.g. biological communities / habitats), and identification of key environmental controls on present biological distributions and the relative vulnerability (susceptible or resilient) of the various canyon ecosystem components.

<u>*Experimental ecology.*</u> Practical difficulties have led to deep-sea biology being dominated by observation of ecological patterns. However, many aspects would be better addressed by direct experiment and some can only be tackled in this way. This is notoriously difficult in the deep sea, not only because sophisticated technology is needed, but also because experimentation is best conducted as a series of iterative steps. Through the SERPENT project (www.serpentproject.com), NOC has

access to stand-by time in commercial ROV activities, working with the oil and gas industry. This has provided unprecedented opportunities for *in situ* experimental ecology, as well as a proving ground for technologies to be used with the UK ROV *Isis*. We will employ *in situ* incubation chambers to study the physiology of deep-water fauna, and to determine recolonisation rates on the continental margin in relation to natural and man-made disturbances. We will transplant fauna in different environmental settings to measure how environmental factors, such as temperature, pressure and current speed, influence growth and vital life processes such as reproduction. We will use the knowledge gained to advise on best practice in deep-water industries, for the public appreciation of science and the sustainable management of the UK deep-water environment.

WP 5.2 Causes, frequency and prediction of geohazards such as landslides and tsunamis

The recent UK government report 'The role of science in physical natural hazard assessment' (NHWG 2005) highlighted submarine earthquakes, landslides and the eruption or flank collapse of volcanic islands as natural hazards of global significance. All these hazards can also generate tsunamis that may increase the area affected by a single disaster to an entire ocean basin. The 2004 Asian tsunami, which killed around 300,000 people in 40 countries around the Indian Ocean, was a graphic example of this. The report also noted that, although scientific knowledge of natural hazards had expanded greatly over recent decades, the understanding of different hazards and potential impacts remains variable. Questions to be addressed in WP 5.2 include: What is the frequency of landslides on continental margins? How do we quantify the landslide and tsunami risk posed (to the UK and elsewhere) by volcanic oceanic islands, such as the Canary Islands?

Frequency of catastrophic events. Deep-sea sediments (debris flows and turbidites) record catastrophic events that affect basin margins and can be used to predict the frequency of such events in a particular area. Theme 5 scientists already have a strong reputation in using this technique; for example, showing that the Canary Island landslide record is better preserved in sedimentary basins hundreds of km from the islands than it is on the islands themselves (Wynn & Masson 2003). But many uncertainties remain. Whilst most historical submarine landslides have been triggered by earthquakes, other suggested triggers, particularly those related to climate/sea level change, weak layers in the sediments, and the dissociation of subsurface gas hydrates (see WP 5.4), are poorly understood.

To address these issues we will perform a systematic analysis of catastrophic events preserved in the sediment record along the eastern Atlantic margin from the UK south to the Canary Islands to examine variations in the frequency of such events with latitude. This will involve the acquisition of new sediment cores in poorly sampled areas (such as off NW Iberia and the Bay of Biscay) and a re-evaluation of archive cores (from the NERC BOSCORF archive) from better known areas such as off NW Africa. We will also link to BGS studies of landslide frequency north of the UK. The study area will include areas of continental margin from a range of geological/ sedimentological environments: glacially-influenced in the north, river-influenced at mid latitudes and arid off NW Africa (Weaver *et al* 2000). The tectonic setting varies from the stable passive margins of NW Europe, earthquake prone SW Iberia and the volcanically influenced Canary Islands. We will analyse event frequency over a period of at least 50,000 yr, to include a complete glacial-interglacial cycle so that the effects of changing sea level are fully documented. In this way we will be able to separate the effects of tectonic environment, sedimentological setting and climate/sealevel changes and gain a better understanding of how each of these affects slope stability.

Tsunami generation. Although tsunamis are generally associated with the active continental margins of the Pacific Ocean, they also present a threat to UK and European coasts. Past examples include the Lisbon tsunami of 1755, which killed tens of thousands of people along the west coasts of Iberia and NW Africa and reached SW England (Baptista *et al* 1998), and the pre-historic Storegga tsunami, caused by a giant landslide, which devastated the coasts of Norway and eastern Scotland (Bondevik *et al* 2005). In addition, the threat of tsunamis generated by collapse of volcanic islands, such as the Canaries, cannot be neglected (see below).

While there is little doubt that the ultimate cause of the Lisbon tsunami was a magnitude 9 earthquake on the Azores-Gibraltar plate boundary, there has been speculation that the extreme wave heights experienced at Lisbon might also reflect a landslide tsunami generated locally on the continental slope immediately west of Lisbon (McGuire 2005). Previous work at NOC has shown that a turbidite deposit, dated at 1755, exists in the deep basin west of Portugal, and that it originated from the continental slope. However, the location of the slope failure (or failures) that contributed to the turbidite is unknown.

To address this problem we will collect additional geophysical (swath bathymetry and sidescan sonar) data from the Portuguese margin, where limited existing data already show areas of apparently recent landslide activity. Data acquisition will be undertaken with WP 5.1, co-funded by the EU HERMES programme. Sediment cores will also be collected to date the mapped landslides, and numerical modelling will be used to assess whether any observed landslide might have been capable of generating a significant tsunami. Existing cores from the margin and deep basin will be examined both to assess landslide (and earthquake) frequency on this margin and to test whether any 'tsunami signal' can be seen in the deep basin turbidite; e.g. sediment suspended as a result of the tsunami impact on the coast may have been carried across the narrow continental shelf and contributed to the density current that ultimately deposited the turbidite in the deep basin. This is part of a wider objective to investigate to what extent gravity-driven sediment flow deposits in the deep ocean basins can yield information about the slope processes that generated the gravity flows. We are developing this technique for the Canary Islands, where it seems possible to distinguish deposits resulting from large flank landslides, small sediment failures on the submarine island flanks and volcaniclastic events generated by floods on the islands or direct interaction of lavas entering the ocean. Further development of this work, to model tsunamis from reconstructed landslide scenarios, would seem suitable for SOFI support; for example, as a studentship.

Tsunamis resulting from great earthquakes (e.g. the 2004 Indian Ocean tsunami) can have truly catastrophic results. Most great earthquakes occur where two plates converge, with earthquake size related to the ruptured plate boundary length. The factors controlling rupture length and the failure frequency of particular segments need to be understood. This will be mainly addressed in a recently funded NERC Consortium award in which Masson and Wynn are Co-PIs. Our contribution here will focus in particular on event frequency, where we have recognised expertise.

Volcanic island landslides. Much has been made of the potentially devastating tsunami that might result from the collapse of the Cumbre Vieja volcano in the Canary Islands. However, this prediction is based on poorly constrained modelling and is widely disputed (Masson *et al* in press). In geological terms, a landslide's tsunamigenic potential is determined by its behaviour during initial failure. Current models for Cumbre Vieja use a simple approach, modelling the landslide as a single, rapidly accelerating block (Ward & Day 2001). The offshore sediment record suggests otherwise, since volcaniclastic turbidites associated with Canary Island landslides typically exhibit multiple fining upward sediment sequences, suggesting that the landslide proceeds more slowly by retrogressive failure (Wynn & Masson 2003). The rate of retrogression needs to be accurately constrained in order to produce realistic landslide and tsunami models. To achieve this we will perform detailed sedimentological, petrological and geochemical analysis of the multiple landslide generated turbidites to accurately define the source of each sub-unit within the landslide source area. Sedimentological and geochemical analysis will be used to assess the contribution from slope sediments, superficial volcanic products and intrusive igneous rocks in each sub-unit, with the aim of constraining the sequence of events in the source area and hence the failure mechanism. Most of this work will be performed using existing sediment cores (from the NERC BOSCORF archive) but some additional cores will be required. A tsunami modelling programme to investigate a range of volcanic island landslide scenarios will also be initiated. This will provide a reality check on the models published to date where the main aim seems to have been to find the most extreme scenario. The modelling project will require recruitment of a numerical geologist at post-doctoral level.

WP 5.3 Physical processes regulating the transport of sediments to the deep ocean

Sediment sequences on continental margins hold a record of the processes which deposited them, including gravity flows, along-slope transport by oceanographic currents and settling of pelagic material. Deciphering this record can help us understand the relative importance of the various processes, many of which are episodic (and almost impossible to study as they happen) yet of fundamental significance to the sustainable use of continental margins. That is because they influence the distribution of benthic ecosystems, redistribute carbon and pollutants from the land and shelf seas to the deep ocean, and give insights into the formation of buried sedimentary rocks such as those that form hydrocarbon reservoirs. This WP focuses on the physical processes controlling sediment transport through canyons, and gravity flows and their deposits. It builds on current work funded by the EU HERMES project and industry sponsors, and will use information on modern sediment deposits to increase our understanding of the structure of hydrocarbon reservoirs.

<u>*Physical controls on sediment transport through submarine canyons.*</u> Submarine canyons are one of the main conduits through which sediment passes from the continental shelf, across the continental margin, and into the deep ocean. However, when sealevel rose at the end of the last glaciation, many canyons lost their connection to sediment sources that were active at low sealevel. As a consequence, some canyons, such as Setubal Canyon on the Portuguese margin, became largely inactive; others, such as Nazare Canyon, have been transformed into sediment traps that are presently accumulating large volumes of sediment (Eurostrataform 2006); whilst a third group, such as Whittard Canyon in the Bay of Biscay, remain active as major sediment transport conduits (Zaragosi *et al* 2000). The variable nature of present day canyons is only just becoming apparent and remains little understood. What processes bring sediment into the canyon? What drives episodic sediment transport processes (e.g. turbidity currents) and how often do they occur? How do canyons interact with ocean currents? What influences, beneficial or otherwise, do sediment transport processes exert on canyon benthic ecosystems? (linked to WP 5.1).

To address these questions we will undertake sediment coring, current measurements and video observations in canyons on the Iberian and northern Bay of Biscay margins. Recent and long-term (glacial-interglacial) sedimentation rates and processes will be determined, as will the driving mechanisms of present-day processes. Existing cores from off Iberia, held at the BOSCORF facility (with additional cores to be collected in 2006), will form the initial dataset. An ROV cruise planned for 2007 will allow precisely located video observations to be made of the canyon floor and to position instruments such as Bathysnap time-lapse camera systems, current meters and sediment corers in the canyon axis. A later research cruise (2009) will target canyons in the Bay of Biscay, with the major objective being a comparison between these active canyons and the less active Iberian margin canyons. This will improve knowledge of the timing of events, fluxes and ‘energy’ within the canyons, leading to a better understanding of how sedimentation influences benthic ecosystems and providing a clear link to the complementary HERMES programme.

Physical oceanographic processes, such as internal tides, along-slope currents and down-slope cascading, are likely to play a major role in controlling sediment transport within canyons and to influence the distribution of biological communities. For example, the upper and lower boundaries of the Mediterranean outflow on the western European margin are associated with cold-water corals and large sponge aggregations (De Mol *et al* 2005). While the physical mechanisms for this remain unclear, it is plausible that density differences could focus or redistribute internal wave energy at these locations. Over much of the ocean margin the gradient of the continental slope is close to the angle of energy propagation of semi-diurnal internal tides (near ‘critical’), suggesting that the shape of continental margins is determined by internal tide characteristics (Cacchione *et al* 2002). Movement of sediment within canyons may be an important part of this process. Typically, the side walls of canyons are steeper than the critical slope for internal tides resulting in trapping of energy in the canyons, while the slope along the canyon axis is less than critical, reflecting energy up towards the canyon head where it may cause intense mixing (Carter & Gregg 2002). Where the bottom slope is near critical, nonlinear processes (e.g. formation of bores; Hosegood *et al* 2004) can occur. In addition, Heathershaw *et al* (1987) showed that internal tidal currents at the shelf break can be strong enough to transport sediment off-shelf, towards the canyon heads. However, the role of these processes in transporting sediment within the canyons is unclear. Do they result in a downslope transport of material, or just re-suspension and stirring within the canyon? What determines the magnitude of internal wave energy in the canyons?

This part of WP 5.3 will quantify advection, energy dissipation and bottom stresses in canyons and relate these to sediment movement. To achieve this we will observe currents and hydrography in and adjacent to canyons with profiling moorings, ADCPs and current meters. Precise placement of instruments in the axis of canyons on the Iberian margin will be possible during the planned ROV *Isis* cruise in 2007. On the same cruise, CTD and microstructure (turbulence) measurements will be made across the Mediterranean Water on the slope. In the laboratory, idealised numerical simulations, driven by tidal currents or density flows with smooth and canyoned slopes, will be performed and the results compared with field data.

Deep-water gravity flow processes and deposits. Large-scale gravity flows (e.g. debris flows and turbidity currents) are among the most dramatic deep ocean events, with individual flows capable of transporting sediment >1500 km (Wynn *et al* 2002). Despite their significant geohazard potential (see WP 5.2), our understanding of flow processes is limited, mainly due to the difficulty in directly monitoring them. Studies of modern gravity flow deposits are more advanced and provide needed analogue data for deep-water hydrocarbon reservoirs, most of which are hosted in gravity flow deposits (e.g. sands transported by turbidity currents). This is particularly significant given the rapidly increasing importance of deep-water hydrocarbon exploration.

Our main aim is to investigate key deep-water environments - distal fan deposits, submarine channels and basin floor sequences - where the need for new data is greatest. Many hydrocarbon reservoir rocks were originally deposited in a distal fan setting, but the depositional processes leading to reservoir quality, sand-rich deposits are poorly understood. The interpretation of new geophysical image and sediment core datasets from the edge of the Rhone Fan, to be collected in 2006, will give new insights into distal fan settings. Comparison with existing data from the Mississippi and Speculobe Fan fringes will provide a data continuum between sand-dominated systems, mixed sand-mud systems, and sand-poor systems. A research cruise to the Nile Fan in early 2009, funded by an oil industry consortium, will focus primarily on sand body distribution in sinuous channel environments, a key reservoir target in many hydrocarbon provinces. Spectacular 3D images of such channels are now commonplace (e.g. Deptuck *et al* 2003), but there is urgent need for high-resolution planform and cross-sectional data of their internal architecture, calibrated with targeted coring. The Nile Fan cruise will also look at gravity flow geohazards. Finally, ongoing research in topographically simple settings such as basin floors will enable us to unravel complex flow processes, e.g. those responsible for generating poor reservoir quality ‘linked debrites’ (Talling *et al* 2004), which are a common component of hydrocarbon reservoirs in the North Sea and Gulf of Mexico. This work will link closely to WP 5.2, where the frequency and trigger mechanisms of gravity flow events will be investigated. A new staff position in numerical modelling will be created to support gravity flow process modelling.

WP 5.4 Transport of hydrocarbons and aqueous fluids from the sub-seafloor to the seabed and their part in carbon fluxes

Understanding subsurface fluid flow and its surface expression is vital to the safe exploitation of the marine environment, with implications for climate change and the sustainable management of marine bioresources. Unlike many geological processes, fluid flow phenomena can operate on short time scales and can influence the environment we are living in today (Berndt 2005). WP 5.4 will address the following crucial questions: How does focused fluid flow control benthic ecosystems? What is the mobility of marine gas hydrates and do they play a role in climate change? How do gas hydrate dynamics affect submarine slope stability?

The role of cold seeps for benthic ecosystems. Large communities of unique chemosynthetic organisms have been reported from active mud volcanoes and large pockmarks above petroleum reservoirs (Sibuet & Olu-Le Roy 2003). Such ecosystems are also breeding grounds for some fish species. There is substantial geophysical evidence (Berndt 2005) for further seabed seepage fuelled by other processes such as sediment dewatering, volcanic intrusions, and gas hydrate systems. These systems are common: thus it is important to assess their relevance for biodiversity, total biomass and ecosystem functioning on a margin-wide scale. We propose to conduct a multi-disciplinary cruise to a suitable site (the Hatton Bank off the UK or the Gjallar Ridge off mid-Norway) to map the pathways of the seeping fluids, to determine the origin, quantity, and composition of gas and fluids, and to determine their effects on benthic ecosystems. This cruise will include: a) seismic data collection with NOC's new 3D seismic system to map the fluid pathways, pore water geochemistry in order to determine the origin of the fluids and to quantify their flux rates; b) bottom water geochemistry to determine how much methane the benthic ecosystem is absorbing, and c) sampling of the benthos, to determine species composition, biomass and nutritional status. Integration of the data will provide an assessment of the relevance of these systems which is crucial for deciding which chemosynthetic ecosystems should be protected, e.g. from deep-sea trawling.

Fluid flow and climate change. Carbon flux from the geosphere into the ocean and the atmosphere is usually neglected in climate modelling on the assumption that this flux is both low and constant with time. However, recent work shows that the flux was substantial during several periods of the Neogene (Millo *et al* 2005). This is supported by recent IODP drilling and ice core data that revealed significant variations in atmospheric carbon isotope composition that are closely linked to atmospheric temperature variations (Thomas *et al* 2002). However, the total flux rate and the composition of gases reaching the ocean and eventually the atmosphere are still unknown and the subject of heated debate (Judd 2003). There are large uncertainties in assessing the total amount of gas hydrate in the marine environment and the mobility of the gas hydrate reservoir, although the latest mass balancing studies indicate that present day warming might release 2000-4000 Gt of carbon (Archer & Buffet 2005). Without constraining gas hydrate dynamics further, these fluxes and climate models have significant uncertainties. We propose an assessment of present and past carbon fluxes from gas hydrate systems using data collected by the HERMES project (e.g. Storegga Slide region, Gulf of Cadiz, Barents Sea), available industry-sponsored seismic data, and data that will result from an International Polar Year cruise off Svalbard. We will collect sediment cores to calibrate the seismic results using geoacoustic and geochemical laboratory experiments that will provide better estimates of free gas and gas hydrate concentrations in the sediments.

Another important carbon flux from the geosphere to the atmosphere is carbon released from organic rich sediments during volcanic intrusions (Svensen *et al* 2004). This may have been the dominant carbon flux-generating mechanism during the formation of large igneous provinces. It is crucial to quantify this process, because the only other documented climate change of a similar scale to the present was in the early Eocene and possibly linked to sill intrusions. Therefore, all climate models that are based on the early Eocene analogue require further geological validation. We have submitted an IODP proposal to investigate relict hydrothermal vent structures linked to the early Eocene thermal maximum on the Norwegian Margin (Planke *et al* 2005). We propose to extend this work by investigating the effect of present volcanic activity on degassing of marine sediments at a site where volcanic activity occurs in a sedimentary environment, e.g. the Knipovitch Ridge/Svalbard margin interception. Combined seismic and geochemical work would allow quantification of the amount of carbon released in relation to the amount of volcanic material emplaced. So far, such estimates are entirely based on the geochemical signature of fossil systems.

Gas hydrates and slope stability. Fluid entrapment in the subsurface can lead to significant over-pressures that reach lithostatic pressure under gas hydrates (Hornbach *et al* 2004). As the stability of sediments depends on the effective stress, the distribution of pore fluids plays a major role in slope stability. We propose to investigate over-pressures under gas hydrates, to constrain their role in slope stability, using a variety of techniques. Increases in sedimentary pore pressures due to gas hydrate dissociation are likely to be particularly severe in polar and boreal areas subject to relatively rapid global warming, such as the Fram Strait. Similar conditions on the mid-Norwegian margin after the last glacial maximum coincided with the Storegga Slide and its associated tsunami. A landslide in the

Fram Strait would trigger a tsunami that could affect human populations and offshore installations around the North Atlantic basin. We propose to evaluate the seismic data collected within the IPY project for pore pressure variations using the method of Hornbach *et al* (2004) and seismic inversion to develop future slope stability scenarios. This work could be further developed through SOFI; for example, by a PhD studentship.

WP 5.5 Application of scientific knowledge to the management of ocean resources

The governance of ocean space in terms of resource use and environmental protection falls within the international statute of the United Nations Convention on the Law of the Sea (UNCLOS). UK government departments (FCO, DTI and Defra) require specialised technical advice from marine experts in a range of disciplines in order to develop and monitor UK maritime policy in this legal framework. Theme 5 will deliver independent, high-quality scientific advice on territorial sovereignty, marine scientific research, resource management, and the preservation of the marine environment. Much of this advice focuses on continental shelf and margin settings, where demand for both living and non-living resources pushes exploration and exploitation into increasingly deeper waters. Specific issues are likely to include: advice on the limits of the legal UK continental shelf; support for technical negotiations with neighbouring coastal states on overlapping territorial claims; and advice to the UN International Seabed Authority relating to the deep seabed beyond national jurisdiction. In particular, the 2009 UNCLOS deadline for securing the sovereignty of states to shelf areas beyond 200 nautical miles means that NERC, via the NOC, will be asked to provide the legal-technical interface for UK claim submissions to the UN for both mainland and overseas territories.

While a core group of staff work full-time on UNCLOS issues, other staff with expertise in geophysics, seafloor surveying and benthic biology are able to provide independent, policy-relevant advice on deep-sea biodiversity, bioprospecting, bioharvesting and marine environmental protection. Large volumes of geophysical data already collected during government-commissioned surveys on UK margins in the North and South Atlantic are currently the subject of cross-Centre (NOC/BGS) interpretation and publication. Finally, the recognition of NOC as a world leader in the field of technical advice for shelf delimitation has led to significant external support for UNCLOS-related work from governments of other coastal states, as well as requests for training. More than 80 delegates from 38 countries have now attended the annual week-long workshop initiated in 2001.

WP 5.6 The General Bathymetric Chart of the Oceans (GEBCO)

An accurate estimate of bathymetry is the basis for much oceanographic research and for the utilisation of ocean resources. It is a prerequisite for developing a capability to predict basin scale processes and expand knowledge of factors influencing environmental and ecosystem change. The GEBCO activity represents an international commitment by NERC and the UK to the Intergovernmental Oceanographic Commission (IOC) and the International Hydrographic Organization (IHO) to contribute to the generation and public dissemination of the most authoritative bathymetric dataset for the world's oceans. It is fully consistent with one of the defining characteristics of NERC science, namely the requirement to undertake long-term survey, mapping and data management, and is in the vanguard of maintaining the UK's involvement in deep-ocean exploration on a global scale.

The main aim, based on a consortium of international contributions, is to develop, maintain and update an accurate, authoritative and high-resolution digital bathymetry. Through the efforts of NOC and BODC an atlas containing a global one-minute interval grid and accompanying contours was published in 2003 (www.bodc.ac.uk/projects/international/gebco). To date, more than 2000 copies of the GEBCO CD-ROM have been distributed to organisations in more than 100 countries. This has gained NERC significant international recognition and enabled NERC and UK scientists to acquire rapid and easy access to the best quality information. Increasing data submission and sophisticated data collection techniques means that there is now a real impetus and opportunity for significant improvement in areas of very poor data coverage.

NERC's contribution comprises the GEBCO International Liaison and Bathymetric Editor at NOC, and the GEBCO Digital Atlas Manager based at BODC. International Liaison work involves the acquisition of high-resolution digital data from national archives and commercial contractors for inclusion in future GEBCO products. Bathymetric Editor activities include primary compilation of data into maps and grids, and participation in international bathymetric working groups. The Digital Atlas Manager at BODC (support sought under NF1) is responsible for receiving and quality-controlling new data; updating the Atlas bathymetry; providing user support and answering enquiries about data sets; ensuring delivery and appropriate licensing of data through CD-ROM and the web; data archiving; and providing feedback from users to the GEBCO community. The merging of satellite-altimeter derived depths into the GEBCO digital acoustic database, which is currently being discussed by GEBCO's Guiding Committee, will produce a better product in remote areas, and is likely to become a priority for future GEBCO updates.

Summary research plan for WP 5.1 – 5.6

All WPs will run through the full 5 year programme, but with important peaks in activity for WP 5.1-5.4 related to the cruise-based fieldwork schedule. See also Gantt chart in concluding material. Key sites for fieldwork are expected to include (from north to south along the continental margin of the NE Atlantic): the Svalbard margin, Hatton Bank, the northern margin of the Bay of Biscay, the Portuguese margin and the North African margin around the Canary Islands. As currently known or anticipated, the continental margins field programme will consist of:

Interpretation of data collected pre-April 2007: 2006 RRS *Charles Darwin* cruises 178/9, Gulf of Cadiz and Iberian Margin, mud volcanoes and canyons; 2006 TTR cruise, Rhone Fan

Cruise programme:

2007	ROV cruise to Iberian margin canyons and mud volcanoes in Gulf of Cadiz
2008	Coring cruise, record of catastrophic events in deep basins along European margin.
2009	ROV cruise to Bay of Biscay canyons
2010	Sampling/geophysics/biology cruise to study fluid flow on Hatton Bank
2011	A follow-up canyons cruise

Other cruises: 2007/8 Svalbard margin, gas hydrates/geohazards, (funded, IPY consortium); 2008 Sumatra, Geohazards (funded, NERC consortium); 2008/9 Nile fan, sediment transport (possible industry consortium)

Summary of deliverables for WP 5.1 – 5.6

- Understanding slope morphology, sediment facies, sediment transport, oceanography and biogeochemistry sufficiently to allow 1st order prediction of biological community distribution.
- Identification of environmental management units (biological communities/habitats), key environmental controls on biological distributions, and the vulnerability of various ecosystems.
- Quantifying the frequency of catastrophic events related to natural hazards in the NE Atlantic.
- Improved models for tsunami generation associated with landslides.
- Quantification of bottom stresses and energy associated with internal waves and tides in canyons
- Understanding the oceanographic characteristics of varied sediment transport regimes in canyons
- Assessing carbon release from gas hydrates to the atmosphere in response to global warming.
- Quantifying carbon flux from active mud volcanoes and understanding of their plumbing.
- Quantifying carbon fluxes from volcanic sill intrusions and sediment dewatering systems.
- Preparation of UK continental shelf claims beyond 200 nautical miles.
- Continued capacity building for overseas governments in UNCLOS issues.
- Provision of global digital bathymetry, updated as new data becomes available, web access to dataset and the IHO/IOC gazetteer.

Biogeochemistry of the deep ocean

Background

Without understanding the dominant processes occurring in the deep ocean and their variability, it is impossible to evaluate the oceans' responses to global change. Our lack of understanding of the biota and biogeochemistry of the deep ocean has been highlighted as strategically important by IGBP, SCOR, IOC and WCRP, and by a wide range of international global change research activities and initiatives, including IMBER, CLIVAR, GLOBEC, DIVERSITAS, Census of Marine Life, ICOMM, EurOceans and MarBEF.

Whilst the deep ocean is a challenging habitat in which to work, NOC scientists are used to delivering high quality, multidisciplinary field-based research programmes in the pelagic and benthic realms. The novelty of Theme 5 lies in coordinated, quantitative research involving physics, chemistry, biology, and modelling of the deep ocean from the base of the euphotic zone to the abyssal seafloor. This Research Unit focuses on the biogeochemical dynamics of the deep ocean water column and the resultant impact on underlying benthic communities. These issues are not addressed in an integrated way elsewhere in the UK, and the programme therefore has a unique national role in providing underpinning knowledge required by policy makers for international agreements on conserving deep ocean biodiversity, the management of deep ocean bioresources, and the role of the global ocean in climate change.

Scientific aims and rationale

The deep ocean is Earth's inner space, and most of it remains unexplored. This important reservoir in the Earth system receives a rain of material from the more turbulent surface layer across the seasonal thermocline and into the twilight zone (TZ). There it is transformed biogeochemically, partly returning as nutrients to fuel production in the surface layer, and partly continuing downwards to reach the seabed (Fig 2).

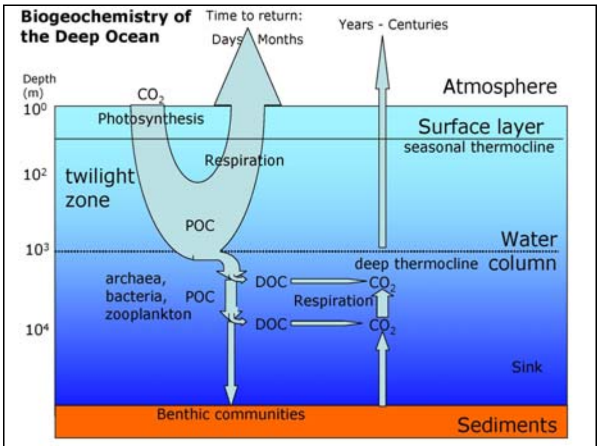


Fig 2: A simplified 1-D scheme of deep ocean biogeochemistry showing the vertical flux of carbon through water column layers and to the benthos.

Whether material in the TZ refluxes upwards or continues downwards depend on various complex biogeochemical processes with important implications. The magnitude of carbon received by the TZ is a variable fraction (2-50%) of that fixed annually by primary production (Buessler 1998). The carbon that passes the main ocean thermocline is locked out of contact with the surface mixed layer, and hence the atmosphere, for centuries to millennia. Part of downward flux fuels the diversity of life on the deep-ocean floor. Although the importance of the deep ocean is recognised, few coordinated measurements and experiments have been made there – and our understanding of its biogeochemistry is still in its infancy (Treguer *et al* 2003).

Our overall aim is to understand the processes controlling the downward flux and fate of carbon and associated elements and how changes in these processes impact on life in the deep ocean.

Objectives, approach and methodologies

Specific objectives are:

i) to determine how the properties of the TZ are structured by surface ocean processes

ii) to quantify and model the rates of downward flux and biogeochemical transformations of biogenic matter in the TZ

iii) to determine how ocean biogeochemical provinces map onto the structure and function of deep-ocean communities

We will combine skills in biology, chemistry, physics and modelling in a framework of intensive, field-based process studies and spatially extensive research cruises in the North and South Atlantic. The research will be closely linked with Theme 2, which will provide the necessary data on inputs from the sunlit layer, through working often with shared resources (cruises and personnel). The work will be delivered by two work packages, each of which is subdivided to address specific issues.

WP 5.7 Twilight zone dynamics

The surface ocean has been partitioned into discrete functional provinces (Longhurst 1998) with particular biogeochemical characteristics (Ducklow 2003). In the Atlantic between 50°N and 50°S, Longhurst (1998) identified six provinces based on physical forcing and primary production. Links between these contrasting production regimes and the underlying deep ocean have not been studied in any detail. Some conceptual approaches, e.g. the bifurcation model, show how surface water production might relate to export (Legendre & Le Fevre 1989), but this is complicated by evidence for strong decoupling between the magnitude of production and particulate export (Buessler 1998).

Physical dynamics of twilight zone. We will combine the latest technology and observational techniques to tackle the physically driven pathways to, from and through the deep ocean. On transects, we will test the hypotheses that the TZ is dominated by 3D eddy transports (Allen 2005) stirring the TZ and exchanging water across the permanent thermocline, while below there is a more quiescent weakly stratified environment dominated by slow mode barotropic flows, interrupted by topographic features over which increased velocity shear leads to enhanced diffusive mixing.

In process studies (detailed below), high spatial resolution (10-20 km) observations will be made to resolve the 3D baroclinic flows associated with mesoscale eddy structures that penetrate the deep ocean. These measurements will be made in repeated area surveys (c. 6 box surveys per cruise of 200 km length scale), using a CTD and SeaSoar (Allen *et al* 2005). SeaSoar surveys (with optical plankton counter and FRRF to 500 m) will be carried out between CTD surveys to > 800 m. We will focus on 12 depth horizons over the top 800 m, measuring temperature, salinity and biogeochemical parameters, with HCFC (Smythe-Wright *et al* 1996) measurements to trace water history using new high sensitivity GC-MS (Rhein *et al* 2002). Vessel mounted ADCP (VM-ADCP) will be used to map upper ocean currents and to derive the geostrophic stream functions required to solve the Omega equation and calculate downward velocities.

For Atlantic Meridional Transect (AMT) studies, biogeochemical measurements made under SO1 will be complemented by improved physical measurements to match those of process study cruises. Using VM-ADCP, boundaries between upper ocean water masses, edges of eddies and unstable fronts will be determined by the position of current jets and compared with near real-time satellite images. This will allow a reconstruction of upper ocean pseudo-density sections to ‘interpolate’ between CTD stations (McDonagh *et al* 2006). We make two first order assumptions: that the AMT CTD stations sample all the major water masses; and that any barotropic component to the geostrophic flow is large scale and of slow mode variability. We will estimate the significance of the latter from lowered ADCP profiles on the CTD stations.

A sparse array of full depth CTD and lowered ADCP (LADCP) profiles will be carried out as part of the process studies and in long-term observation programmes. At these CTD stations, CFC measurements will also provide us with information regarding the lateral transport of water (Smythe-Wright & Boswell 1998) and help constrain the overall movement of particles from the surface to the deep ocean. The LADCP profiles will be used to examine the variability in vertical diffusivity in the deep ocean where weak stratification and steep topography can lead to diapycnal diffusivities of $K_p > 10^{-3}$ $m^2 s^{-1}$, two orders of magnitude greater than previously inferred ‘typical’ deep ocean values (Naveira Garabato *et al* 2004a, b; Polzin *et al* 2002). Where internal waves break over particularly sharp topography of the mid-Atlantic ridge, we expect significant turbulence to reach high up into the TZ and possibly even ventilate the photic zone. (Note: sea-trials are planned for AutoSub6000 in 2007. However, WP 5.7 does not rely on AutoSub6000; it will be exploited for deep ocean studies using separate funding.)

<u>*Particle flux through the twilight zone.*</u> Our understanding of deep ocean biogeochemistry, community structure and function can be improved by reducing uncertainties in the magnitude of downward flux, and how this changes with depth, region and time. In addition to carbon, this improved understanding must include all limiting elements and the wide variety of complex organic molecules that support life in the deep ocean. Large uncertainties in published data make such quantification a major challenge. The simplest way to estimate these fluxes is to use sediment traps that collect settling material in time series collectors. Deep (>2000m) traps yield reliable measurements but flux data from fixed traps at shallower depths are affected by stronger hydrodynamic flow and attract large numbers of live plankton that contaminate the samples (Lampitt 1989). The material collected suffers from substantial dissolution of components (Antia 2005). To overcome these problems, we have recently developed highly successful free-drifting traps (PELAGRA) that provide data on the variations in flux with depth of a wide variety of biological and chemical components of the settling material.

Budget calculations of naturally occurring radioisotopes and from oxygen profiles, provide a complementary approach to quantifying flux. The different particle-reactive behaviour and range of half-lives of these radionuclide tracers make them versatile tools for studying particle-related processes in the ocean. Thorium isotopes, with half-lives suitable for use in different parts of the water column, are particularly useful (Clegg *et al* 1991). Depth-related oxygen consumption of the water column may be used to estimate respiration/ remineralisation throughout the deep ocean. We will quantify oxygen consumption at different depths in the water column. Direct measurements of flux below the TZ will be extrapolated upwards based on remineralisation rates at various depths in the TZ. These will be calculated using estimates of oxygen consumption in the water column and measurements of oxygen concentration and estimates of the time since the water was in contact with the atmosphere. Based on tritium:helium ratios (Jenkins 1998) and concentrations of CFC (Doney & Bullister 1992), the oxygen utilization rate can be calculated (Falkowski et al 2003). This approach yields fluxes integrated over large space and time scales but provides no information on how the particles are transported or their chemical characteristics.

PELAGRA will be used in process cruises to quantify the downward particle flux at key depths at primary stations. Also on AMT cruises, we will use ^{234}Th to estimate export flux from the epipelagic zone and hence supply to the top of the TZ (~200m depth) and ^{228}Th to estimate fluxes throughout the TZ. ^{230}Th will be used to quantify the trapping efficiency of sediment traps below the TZ. To characterize the nature of the material settling out of the surface ocean, we will use ^{210}Po affinity to POC with ^{210}Pb affinity to biogenic silica to understand ballast export (Friedrich & Loeff 2002). The comparative study of ^{234}Th, ^{228}Th, ^{210}Po and ^{210}Pb will complement studies on the role of various ballast materials in enhancing fluxes. ^{7}Be will be used as a natural tracer for mixing processes of water from the surface ocean (Kadko & Olson 1996). This radiogeochemical approach will better constrain the budgetary calculations of the particle-reactive radionuclides through the deep ocean as well as its interactions with the surface ocean.

<u>*Twilight zone biogeochemistry.*</u> The TZ extends from the base of the euphotic zone to ~1000 m depth. It is characterized by sinking particles (Burd *et al* 2002), abundant archaea (Karner *et al* 2001), active bacterioplankton (Fuchs *et al* 2005), bacteriovorous protists (Gowing *et al* 2003) and migrating zooplankton (Angel 1989). Phototrophic cyanobacteria have been recorded throughout the TZ over much of the Atlantic (Zubkov & Burkill submitted); as these organisms are also heterotrophic (Zubkov *et al* 2003) they may play an active biogeochemical role. The TZ is a biogeochemical hotspot with heterotrophy, respiration and remineralisation (Treguer *et al* 2003) as well as a specialized food web (Cho *et al* 2000) that retains all the DOC and 90% of the particulate matter produced in the euphotic zone (Treguer *et al* 2003).

Within the TZ, zooplankton and microbes repackage and breakdown particles, remineralising organic compounds to CO_2 or by dissolution to DOC. The flux decrease with depth reflects the demands of the TZ community. Whether zooplankton or microbes dominate this process is unclear, although both can account for 100% of the decrease (Treguer *et al* 2003). As well as affecting material cycling through ingestion, zooplankton transport material downwards during diel vertical migration. This migratory flux can account for 4-34% (locally 70%) of the sinking flux measured by sediment traps (Ducklow *et al* 2001). Although their trophic structure is poorly characterised, simple models demonstrate that TZ communities can profoundly effect particle transformations and fluxes (Jackson & Burd 2001). Better models of the TZ require more information on microbes and zooplankton within this zone. The TZ therefore acts as a biogeochemical filter, transforming and degrading sinking particles. Many particles settle slowly, but some, such as those generated in the spring bloom, are fast-tracked to the deep seafloor (Billett et al 1983).

Does microbial remineralization of organic matter in the TZ control the quantity and composition of particle downflux into the deep ocean? This question will be addressed with *in situ* incubations to measure TZ remineralisation in conjunction with enumeration and characterisation of micro-organisms inhabiting the TZ. A rig will be deployed with sets of incubation bottles closed at discrete depths within the TZ. The bottles will be injected with isotopic tracers (e.g. ^{13}C and ^{15}N labelled organic molecules), incubated *in situ* from several days to weeks and finally injected with fixating agents before being collected for isotopic elemental analysis on board and ashore. As well as avoiding pressure changes that may influence experimental results, this approach avoids trans-formation of polymers that are thought to be important (Chin *et al* 1998). The microbial community will be phylogenetically characterised in conjunction with rate measurements to identify the dominant microbial groups, prokaryotes and protists. Appropriate molecular identification techniques are being developed and employed partly via the NERC microbial metagenomics consortium.

For comparison with the microbial community, we will address the role of zooplankton in the TZ by measuring biomass and size spectra using a video plankton camera system and laser optical plankton counter (LOPC),verified with physical samples from closing nets. Community energy demand will be estimated from the size spectra and allometric relationships (e.g. Peters 1983) to quantify the role of zooplankton in TZ C flux.

Modelling the twilight zone system. Processes mediating remineralisation of organic carbon in the deep ocean are so poorly known that modelling studies tend to parameterise them using empirical curve fits of particle flux as a function of depth (Martin *et al* 1987). More recently, Jackson & Burd (2002) included bacterial degradation and zooplankton consumption in a theoretical model of downward particle flux in the water column. Although this approach provides mechanistic insights, the relative roles of microbes and zooplankton in carbon degradation are controversial. Banse (1990) calculated that zooplankton respiration rates below 200 m accounted for 50-100% of the observed decline in downward particle flux at two Pacific sites, while other authors consider that remineralisation is dominated by microbial processes (Cho & Azamm,1988; Turley & Mackie 1994).

For the TZ zone, our modelling approach will focus on particles and their utilisation by zooplankton and bacteria, and on comparing model output with data. Particulate OM will be divided into size classes corresponding to the size spectra of sinking particles, which has consequences for their depth penetration into the ocean. Production and consumption of dissolved OM will also be represented, following Anderson & Williams (1999). Both C and N will be included as model currencies, using appropriate stoichiometric models of heterotrophic OM utilisation. Ecosystem models will be tested and analysed in 1D using ecosystem testbeds (Theme 9). The most appropriate will then be used in 3D using the Harvard Ocean Prediction System (HOPS) model, focussed on the fine-scale survey work proposed around the PAP site (SO2). Pelagic biology, which provides the export flux, will be developed in this model as part of Theme 2 then extended to the TZ to determine the relationship between TZ processes and variability in the euphotic zone. Climate sensitivity (wind forcing, heating) tests will also be undertaken to examine their impact on export.

WP 5.8 Benthic system dynamics

The deep seabed is linked to processes in the upper water column by the downward OM flux. Benthic communities integrate processes over space and time, and so large-scale faunal changes reflect major processes occurring in the overlying water column. Strong coupling between surface primary production and the seafloor (Lampitt *et al* 2001) profoundly influences these communities (Billett *et al* 2001; Gooday 2002) and hence carbon recycling (Bett *et a*l 2001). Specialized linkages may exist between the deep-sea benthos and sea surface primary production. For example, bio-essential carotenoids, synthesized by cyanobactertia but not by deep-sea benthic organisms, may regulate life processes on the seafloor (Wigham *et al* 2003; Hudson *et al* 2004). We recently compared abyssal benthic communities at two adjacent sites under different production regimes off the Crozet Islands (Southern Ocean). The Crozet eutrophic community resembled North Atlantic eutrophic faunas more closely than an oligotrophic community 240 km away (Wolff *et al* in press). These observations confirm the close link between phytoplankton and the benthos, with the latter providing the ultimate measure of OM flux and the crucial gateway for carbon burial (Smith & Kaufmann 1994).

Benthic community models are less developed than pelagic ecosystem models (Ebenhoh *et al* 1995). Most seafloor modelling has focused on early diagenesis (Kelly-Gerreyn *et al* 2005) via bioturbation coefficients (Soetaert *et al* 1996). Benthic models are limited by the difficulty of quantifying biological processes (e.g. respiration and ingestion) due to sampling constraints and problems involved in extrapolating species-specific measurements to community level processes (Blackford 1997). Models of the size structure of benthic communities (Kaariainen *et al* submitted) that use the close relationship between body size and most biological functions offer a promising approach; these assume that organisms of the same size have similar bioenergetics regardless of identity. Models can be constrained by biomass measurements and *in situ* pulse-chase experiments that yield respiration and radiolabelled food ingestion rates.

To understand how changes in the biogeochemistry of the water column and the dynamics of the flux of OM affect the structure and dynamics of deep-sea benthic ecosystems at the global scale we will study a) benthic community structure, life history traits and the biogeochemistry of organisms at a variety of contrasting biogeochemical provinces in the World Ocean; and b) use *in situ* incubation experiments to test the effects of changes in OM flux (quantity / quality) on life processes (respiration, reproduction, excretion, growth) of deep-sea organisms.

*Bentho-pelagic coupling – global patterns***.** On AMT cruises, we will assess broad-scale changes in benthic communities with biogeochemical provinces using seafloor photography to determine megabenthic composition and standing stock. The megabenthos of comparable abyssal localities (6-8 sites) in the North and South Atlantic will be quantified using the NMFD SHRIMP (Seabed High Resolution IMaging Platform). Owing to low standing stocks in oligotrophic regions we will undertake 6 hr surveys to generate reliable quantitative data. These data will be related to surface ocean and water column biogeochemical measurements to determine how oceanic processes map to the seafloor. Bathysnap time-lapse camera systems will be deployed for periods of up to one year to provide data on temporal variation in the benthos and the flux of organic matter to the seafloor (Bett *et al* 2001). These data will also make a substantial contribution to understanding global patterns in biodiversity of particular relevance to the international Census of Marine Life programme.

Building on the recent discovery of very similar communities in eutrophic regions of the NE Atlantic and Crozet Islands, we will investigate similar hotspots of productivity through collaborations with international and UK universities and institutions (e.g. NE Pacific with the Monterey Bay Aquarium Research Institute). Molecular phylogenetics and biochemical analyses will clarify reasons for benthic community characteristics revealed by our recent research which appear to be related to the overlying biogeochemical province (Wolff *et al* in press).

Experimental biogeochemistry of the deep-ocean floor. In order to test hypotheses derived from observed patterns, we will use the UK ROV *Isis* to conduct experiments at PAP (see below) on two dedicated benthic cruises. Repeated access to commercial ROVs through the SERPENT project will facilitate hypothesis testing and will be used to refine experimental techniques prior to the *Isis* expeditions. We will conduct *in situ* incubation experiments using food radiolabelling, respiration, size fractionation and proteomic techniques. We will examine how the composition of organic matter (i.e. food quality: diatom, dinoflagellate, prymnesiophyte, cyanobacteria detritus) affects different benthic species. A proteomics analysis will pinpoint proteins that correlate with detritus of different origin and whether the response varies between benthic species.

Modelling deep-ocean benthic processes. We will build on our recent modelling using body size based allometric relationships (for ingestion, respiration, defecation and mortality) to understand controls on observed benthic biomass distributions for meio- and macro-fauna (Kaariainen *et al* submitted). The model will be expanded to include the megabenthos, which may dominate deep-sea benthic processes (Billett *et al* 2001). Historic and ongoing data collection at PAP will initially be used to establish and test the model, then new reliable data on benthic process rates, derived from *in situ* incubation experiments, will be used to refine the models' parameters. Ultimately, we will couple benthic models to ecosystem models developed under Themes 2 and 9, to investigate how variability in surface ocean and water column processes affects deep-ocean benthic ecosystems.

Research plan for WP 5.7 – 5.8

We will focus on the Porcupine Abyssal Plain (PAP) site where there is much background information from previous studies and continuous environmental data at hour/day resolution [Theme 10 (SO2) linked to a European ocean observatory]. We will visit PAP annually to maintain this unique time-series. Additional multidisciplinary expeditions will include a major process study in 2009, comprising two back-to-back cruises on which we will study the biogeochemistry of the deep ocean at PAP. This will comprise a full water column and seafloor study, in order to: a) investigate spatial (50 x 50km) and temporal (2 month) variability in water column biogeochemical (physics, biology, chemistry) and benthic properties, centred around the observatory; b) relate inputs from the surface water production (Theme 2 data), to the passage of material, microbial activity, zooplankton grazing and particulate degradation dynamics in and through the TZ; c) carry out ROV-based experiments on the benthic communities to determine their trophic, reproductive and respiratory activity in relation to bulk carbon and key molecules; and d) model the downward flux processes. As the ROV procedures are new, these will require development prior to 2009. This will be done using 'free' access to commercial ROVs through the SERPENT project enabling us to develop and refine techniques in continental margin settings prior to our major effort in the deep ocean. To compare the PAP site with a low latitude oligotrophic site, we will conduct a second process study (2011) in the North Atlantic Subtropical gyre with Theme 2.

For our latitudinal studies, we will use the 2007 AMT (SO1) and annual short term visits to PAP to develop and refine relevant TZ skills and then use them to study the TZ dynamics in the North and South Atlantic underneath contrasting surface water production regimes. In 2008 we will deploy SHRIMP on AMT to generate benthic data to complement the TZ studies along the AMT transect and to extend AMT to South Georgia for comparisons with the 2006 Crozet study. AMT activity will be made in conjunction with Theme 2 to make the links with surface water productivity. As PAP will form the first station on each annual AMT cruise, this will provide continuity of data at this site.

Deliverables for WP 5.7 – 5.8

These will include: a) assessment of spatial variability and interrelationships between TZ processes and benthos with surface water biogeochemical provinces between 50°N and 50°S in the Atlantic; b) fine temporal resolution of connectivity between ocean surface, TZ and benthos at PAP; c) improved parameterisation of deep ocean mixing processes; d) understanding whether microbes or zooplankton dominate particle degradation in the TZ; e) long-term trends in the quantity and quality of export flux at PAP and its effect on the structure of the abyssal benthic community; f) *in situ* ROV deployed chambers and results from organic detritus experiments using various phytoplankton groups on benthic communities; g) large-scale ocean basin comparisons in biodiversity and ecosystem functioning (linked to participation in the Census of Marine Life field programme, CeDAMar); h) ecosystem model of the TZ, coupled to HOPS, assessing the relative roles of bacteria and zooplankton and climate sensitivity; and i) models for understanding how water column fluxes impact on benthic ecosystems.

Theme 5 Synthesis and Concluding Material

Oceans 2025 links and wider synergies

The wide knowledge base of the multidisciplinary Theme 5 research team (from the NOC Ocean Biogeochemistry & Ecosystems, Geology &Geophysics, and Ocean Observation & Climate groups) will be augmented not only through links to other Oceans 2025 Themes (Table 1), but also with large international projects and many academic and industry partners in the UK and Europe (Table 2).

Table 1. Main links between Theme 5 and other parts of Ocean 2025

Theme 1	Ocean models, global sea level response to climate change. For example, estimates of bottom water temperature are essential for modelling the behaviour of gas hydrates and possible greenhouse gas emissions from the subsurface (WP 5.4).
Theme 2	Carbon flux in the deep ocean is clearly heavily influenced by production in the surface layers of the ocean, in effect leading to a process continuum between biogeochemistry of the upper ocean (Theme 2), the twilight zone, the abyssal ocean and the seabed (Theme 5).
Theme 3	Much of the sediment that accumulates on continental margins comes from the continental shelf, e.g. sediment fluxes within many submarine canyons are largely determined by sediment input from the shelf at the canyon head. Water exchange between the shelf and slope (e.g. cold water cascades) may significantly influence slope and canyon sedimentation.
Themes 4 and 6	Much of Theme 5 (e.g. WP 5.1, 5.8) is aimed at the understanding of ecosystems and biodiversity and will lead to strong links with Themes 4 and 6.
Theme 8	Technology is key to operating in the challenging environments of continental margins and the deep ocean (e.g. submarine canyon investigation using precisely-deployed ROV; use of Autosub 6000 for bio-geochemical measurements in the Twilight Zone and to revolutionise observations of the deep seabed).
Theme 9	Theme 5 biogeochemical, biological (e.g. at PAP) and oceanographic measurements (e.g. in canyons) will be used to validate predictive models
Theme 10	Much of the biogeochemical research will take place at PAP SO2 gaining great benefit from the long-term records of oceanographic processes and communities there. The marine observatory is set to become the flagship tool in ocean science, with a major EC programme on the horizon. Theme 5 scientists are already established in steering this through the ESONET programme.
BOSCORF	Access to the huge archive is sediment cores held in the national repository is vital to our planned work on geohazards (WP 5.2) and sedimentary processes (WP 5.3).
NF1: BODC	GEBCO, access to historical datasets, management of new data

Table 2. Main science collaborations between Theme 5 and other research groups (UK and international)

UK

British Antarctic Survey	Molecular genetics and microbiology
British Geological Survey (BGS)	Law of the Sea (UNCLOS), where BGS will contribute to NOC led documentation of territorial claims around the UK and overseas territories. Mapping of UK offshore territory, where NOC will contribute data collected during environmental assessment work to the BGS led mapping initiative. Geohazards, e.g. NOC and BGS will collaborate in the study of the Sumatran subduction zone recently funded through a NERC Consortium Grant.
SAMS (as HERMES partner)	Cold-water corals, benthic biology
Univ of Aberdeen (OceanLab)	Deep-ocean fish populations; lander-based in situ experimental techniques
Univ of Bristol	Comparison of modern continental sedimentary systems and the rock record
Univ of Leeds	Experimental studies of gravity flows (turbidity currents and debris flows), using scaled models of real events observed on continental margins.
Univ of Liverpool	Detailed organic chemistry of flux material and benthic organisms

International

EU Framework 6 Integrated Project ‘HERMES’	‘Continental Margins’ derives huge benefit from close ties with the EU HERMES project (45 partners including 6 in the UK). These links bring a wide range of expertise and added value, including organic geochemistry, sediment microbiology and gas hydrate modelling
EU MarBEF network	Marine biodiversity and ecosystem function; 55 European partners (7 UK)
Monterey Bay Aquarium Research Institute, USA	Long-term time series observations of abyssal benthos and collaborations on the use of ROV-based in situ experimental techniques
Max Planck Inst, Bremen	Molecular microbiology

Theme-wide Stakeholder relevance and Knowledge Transfer

Stakeholder relevance and Knowledge Transfer are built-in to Oceans 2025: all the Marine Centres involved have, and will continue to obtain, both private sector and governmental funding for applied research that meets specific user needs. Such commissioned research is not presented here although it is the direct consequence of previous NERC strategic funding. Oceans 2025 will provide the underpinning capabilities, expertise and facilities to continue to make that possible in future, whilst also delivering data, information and understanding directed at current national needs. The results of Theme 5 are of direct relevance to and will inform:

- UK Government, EC and international policy makers, including the UN
- NGOs with interests in environmental issues
- UK industries (hydrocarbons, fisheries, bioresources, telecommunications)
- The general public.

A thorough understanding of the deep-sea environment is a pre-requisite for the development of an ocean governance policy for the UK and Europe as a whole. This requirement is recognised in NERC's delivery plan 2005-08 that called for "new knowledge in the areas of water management, biodiversity and ecosystems to enable better stewardship of the environment" (NERC, 2005). It is also recognised in 'Science for Sustainable Marine Bioresources' (Barange, 2005) that "underpinning interdisciplinary knowledge of the functioning of the UK's (marine) ecosystems" is necessary "to develop sustainable exploitation strategies for marine bioresources", compatible with conservation and industry needs. Exploitation of ocean resources also includes non-renewables, such as oil and gas, which need to be exploited with minimal damage to the environment.

Policy decisions extend to the need to mitigate against global change and catastrophic geohazard events. Understanding the influence of ocean carbon fluxes on global climate change is fundamental to our ability to predict such change. For example, carbon fluxes from the sub-seabed are entirely neglected from current climate change models for the simple reason that we do not know what these fluxes are. Research at NOC contributes to geohazard policymaking where recent reports have also highlighted that "greater support should be given to the improvement of scientific and technical methods and capabilities for risk assessment, monitoring and early warning" (NHWG, 2005). Policy issues will also be addressed in the EC forum through the HERMES Policy Panel (EU environmental agencies, NGOs and scientists), ensuring that all European governments are aware of, and can act on, state-of-the-art advice concerning the natural environment of Europe's offshore territories.

Outreach and knowledge transfer will build on existing commitments to publicise our science and ensure best practice by UK offshore industry. We will seek to publish our most important results both in peer-reviewed scientific journals and through the popular press. We will contribute to public outreach through our Classroom@sea initiative (www.soc.soton.ac.uk/CHD/classroom@sea/). Biological samples will be made available to the wider science community through the NOC Discovery Collections, as will sediment cores through BOSCORF. Large-scale studies of benthic communities will feed knowledge directly to the Census of Marine Life programme, CeDAMar (Census of the Diversity of Abyssal Marine Life), while the long-term studies at PAP are of key significance to MarBEF (Marine Biodiversity and Ecosystem Functioning; EU network), particularly the DEEPSETS (Deep-sea & Extreme Environments, Patterns of Species and Ecosystem Time Series) project. In addition to routine data banking with BODC, the benthic biological data will be banked with OBIS (Ocean Biogeographic Information System). Theme 5 will form part of the UK contribution to IGBP/SCOR IMBER programme and also to the EU ESONET, MERSEA, CARBOCEAN and OceanSITES programmes.

We will work closely with industry to ensure knowledge transfer and training in areas such as environmental assessment and protection, hydrocarbon reservoir modelling through the use of modern analogues, offshore geohazards and deep-water sedimentology. Industry co-funding will be sought wherever possible. The SERPENT programme (www.serpentproject.com), which makes industry ROVs available for science at no cost to science, is a great example of how industry-science cooperation can benefit both partners. In particular, unique, high quality still and video images from ROV missions (archived in a web-accessible SERPENT database currently in development) will be invaluable to the public understanding of our science.

Table 3. Examples of policy/application issues and stakeholders in relation to Theme 5 science

Policy/application issues	Main stakeholders with interests	Relevant Theme 5 science
The marine carbon cycle and its impact on global climate change	All policy makers and members of the public	Biogeochemical cycles; seabed fluid flow
Geohazard awareness, contributions to policy documents and mitigation (e.g. Natural Hazards Working Group, 2005)	EU and UK government, offshore industry	Causes, mechanisms and frequency of submarine geohazards
United Nations Convention on the Law of the Sea (UNCLOS)	UK government	Provision of scientific backing for UK territorial claims
Sustainability use of the marine environment and conservation of vulnerable ecosystems	EU and UK government, NGOs	Understanding of marine ecosystems (e.g. Darwin cold water coral mounds) to allow their vulnerability to be addressed
Better understanding of marine sediments leading to improved oil exploration and recovery	Oil industry	Sedimentary process studies leading to better understanding of oil reservoir rocks
CO_2 sequestration/disposal	Policy makers, energy sector	Deep-ocean ecosystem function; fluid flow pathways
Defence ('battle space')	UK MoD	Water column and seabed structure and processes

Strategic Ocean Funding Initiative (SOFI)

SOFI opportunities for wider engagement in Theme 5 are envisaged in the following areas:

- Modelling tsunamis from reconstructed landslide scenarios (e.g. via a studentship)
- Gas hydrate/slope stability geotechnical studies (e.g. via a studentship).
- Tracing bioessential molecules through the water column and into the benthos.
- Ageing of deep ocean waters via $^3H/^3He$ concentrations.
- DOC and specific dissolved molecule chemistry link to microbiology studies (with Theme 2)
- Microbiology, organic geochemistry, taxonomy and *in situ* experimentation.
- Proteomics and other molecular biology approaches.

Summary of Theme-wide outcomes

Continental margins

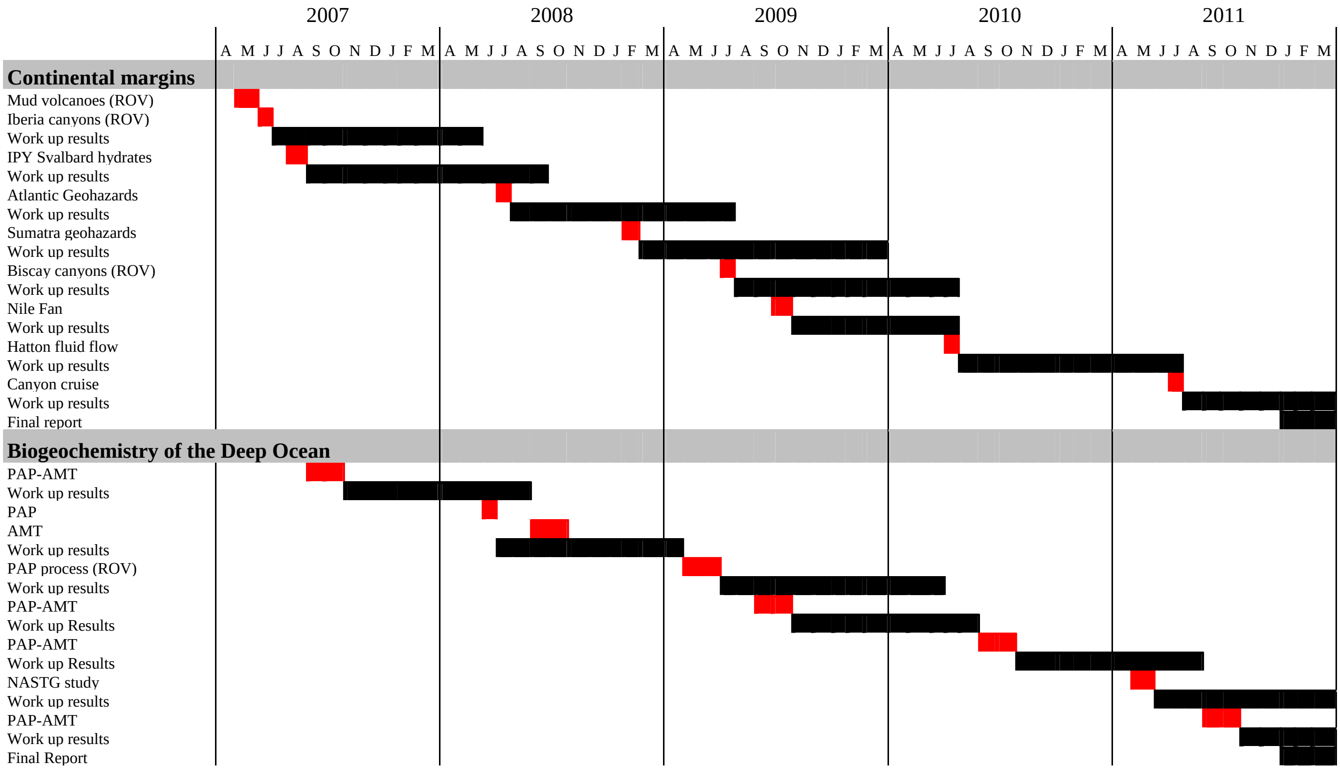
- Understanding margin morphology, sediment facies, sediment transport, oceanography and biogeochemistry in detail sufficient to allow prediction of biological community distribution, with identification of environmental management units (biological communities/habitats), key environmental controls on biological distributions, and the vulnerability of margin ecosystems.
- Quantification of the frequency of catastrophic events related to submarine natural hazards in the eastern North Atlantic, with improved models for tsunami generation associated with landslides.
- Quantification of bottom stresses and energy associated with internal waves and tides in canyons, and understanding of the differences in physical oceanography of different canyon systems.
- Assessment of carbon release from marine gas hydrates to the atmosphere in response to global warming. Quantification of carbon flux from high-flux and low-flux end members of active submarine mud volcanoes, volcanic sill intrusions and sediment dewatering systems.
- Preparation, presentation at the UN, and defence of UK continental shelf claims beyond 200 nautical miles. Four mainland and overseas territories submissions will be made by May 2009. Provision of continued international capacity building for overseas governments in UNCLOS issues, through workshops, training programmes, commissions and consultancies.
- Provision of global digital bathymetry as a one minute interval grid with bathymetric contours and trackline control datasets updated as new data becomes available. Web access to the gridded bathymetry dataset and the IHO/IOC gazetteer of geographic names of undersea features.

Biogeochemistry of the deep ocean

- Ocean-scale (50°N - 50°S Atlantic) comparison of known surface water biogeochemical provinces with novel measurements of underlying twilight zone process dynamics and deep-sea floor ecosystems; associated assessment of deep-ocean biodiversity
- High-resolution temporal study of connectivity between ocean surface and deep-ocean processes (TZ dynamics and benthic responses) at PAP, with SO2.
- A direct assessment of the relative contributions of microbes and zooplankton to total particle degradation processes in the twilight zone.
- Maintenance of unique long-term observation of trends in the quantity and quality of export flux at PAP and its effect on the structure and function of the PAP benthic community.
- The development of ROV-deployed *in situ* experimental techniques and their implementation to derive reliable quantitative data on life process rates on the deep-ocean floor.
- An ecosystem model of the twilight zone, and models linking surface ocean, twilight zone and deep-ocean benthic responses.

Theme 5 schedule 2007-12

Proposed Theme 5 fieldwork is summarised below (cruises are the shorter bars, marked in red).



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Acronyms

ADCP	Acoustic Doppler Current Profiler
AMT	Atlantic Meridional Transect
BGS	(NERC) British Geological Survey
BODC,	(NERC) British Oceanographic Data Centre
BOSCORF	(NOC) British Ocean Sediment Core Research Facility
Carboceans	Marine carbon sources and sinks assessment
CBD	(UN) Convention on biodiversity
CeDAMar	Census of the Diversity of Abyssal Marine Life
CLIVAR	Climate Variability and predictability
CTD	Conductivity Temperature and Depth probe
DEEPSETS	Deep-sea & Extreme Environments, Patterns of Species and Ecosystem Time Series
Defra	(UK) Department of Trade and Industry
DIEPS	Deep-water Industry, Environment, Policy and Science
DIVERSITAS	(ICSU) International biodiversity programme
DOC	Dissolved Organic Carbon
DTI	(UK) Department of Trade and Industry
EC	European Commission
ESONET	(EU) European Sea Floor Observatory Network
EU	European Union
EurOceans	(EU) European Network of Excellence for Ocean Ecosystems Analysis
FCO	(UK) Foreign and Commonwealth Office
FTE	Full Time Equivalent (=1 person year)
GEBCO	General Bathymetric Chart of the Oceans
GLOBEC	Global Ocean Ecosystem Dynamics project
HEI	Higher Educational Institution
HERMES	(EU) Hotspot Ecosystem Research on the Margins of European Seas
HOPS	Harvard Ocean Prediction System
HPLC	High Performance Liquid Chromatography
ICOMM	International Census of Marine Microbes
IGBP	International Geoshpere-Biosphere Programme
IHO	International Hydrographic Organization
IMBER	Integrated Marine Biogeochemistry and Ecosystem Research
IOC	(UN) Intergovernmental Oceanographic Commission
IODP	Integrated Ocean Drilling Program
KT	Knowledge Transfer
LOPC	Laser Optical Plankton Counter
MarBEF	Marine Biodiversity and Ecosystem Functioning (EU Network of Excellence
MERSEA	Marine Environment and Security for the European Area
MPA	Marine Protected Area
MOD	(UK) Ministry of Defence
NASTG	North Atlantic Sub-Tropical Gyre
NERC	Natural Environment Research Council
NF	(Oceans 2025) National Facility
NGO	Non-Governmental Organisation
NMFD	(NOC) National Marine Facilities Division
NOC	National Oceanography Centre Southampton
OBIS	Ocean Biogeographic Information System
OceanSITES	Ocean Sustained Interdisciplinary Time-series Environment observation System
OM	Organic Matter
PAP	Porcupine Abyssal Plain
PELAGRA	lagrangian trap sediment trap
ROV	Remotely Operated Vehicel
SAMS	Scottish Association for Marine Science
SASTG	South Atlantic Sub-Tropical Gyre
SCOR	Scientific Committee on Oceanic Research
SERPENT	Scientific and Environmental ROV Partnership using Existing iNdustrial Technology
SHRIMP	Seabed High Resolution IMaging Platform
SO	(Oceans 2025) Sustained Observation
SOES	(NOC) School of Ocean and Earth Science
SOFI	(Ocean 2025) Strategic Ocean Funding Initiative
TTR	Training Through Research
TZ	Twilight Zone
UN	United Nations
UNCLOS	UN Convention on the Law Of the Sea
UNEP	UN Environment Programme
WCRP	World Climate Research Programme
WP	(Oceans 2025) Work Package