2005 program

RV Southern Surveyor

MARINE NATIONAL FACILITY

CSIRO

voyagesummary SS06/2005

SS06/2005

Biogeochemical processes, effects and signatures of hydrocarbon and ground-water seepage within a tropical, carbonate-rich system: Australia's Timor Sea.

Itinerary

Begin loading AIMS equipment, Sunday, 30 May 2005.
Depart Darwin 1000hrs, Tuesday, 31 May 2005.
Steam to Cartier Trough, the Cornea Seep Site, and Sahul Shoals region for research work.
Arrive Darwin 0700hrs, Thursday 23 June 2005 and unload vessel

Principal Investigators

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Scientific Objectives

1. Determine the ecological importance of submarine seeps in the Timor Sea (all).

2. Estimate the flux of greenhouse gases from the seafloor to the atmosphere (Brunskill, Burns).

3. Determine variations in century and millennial scale burial rate of carbon, metals, and other signals of climate change and ENSO events (Brunskill, Opdyke).

4. Test hypotheses about interactions of seep oil and methane with biota, and how this effects biodiversity in this region (Burns, Rees, Wasmund)

5. Test geological predictions of the locations of submarine vents (Opdyke, Cortese).

6. Map and discover trends in locations of submarine seeps on the seafloor (Cortese, Opdyke).

7. Determine the variations and controls on primary production and respiration of water column plankton (McKinnon).

8. Determine the reasons for the low abundance of coral on the shoal mound tops, and determine the rate of growth and age of coral and limestone on the mound tops (Opdyke).

Voyage Objectives

1. Discover seeps of methane, oil, and brines on the seafloor, using wheelhouse sounder showing bubble plumes, seismic transects, swath mapping, surface and near bottom water sampling, and sediment coring tools. Gas chromatographic measurements of methane in water will be done in the ship laboratory.

2. Obtain sediment cores from soft and hard bottom seafloor, and subsample the cores carefully for hydrocarbon and inorganic chemical measurements, and preserve samples for analyses in our home laboratories.

3. Obtain samples of relict and living biota from the seafloor in association with submarine seeps, using sled dredges, rock dredges, Smith-MacIntyre Grab, and near-bottom water samples.

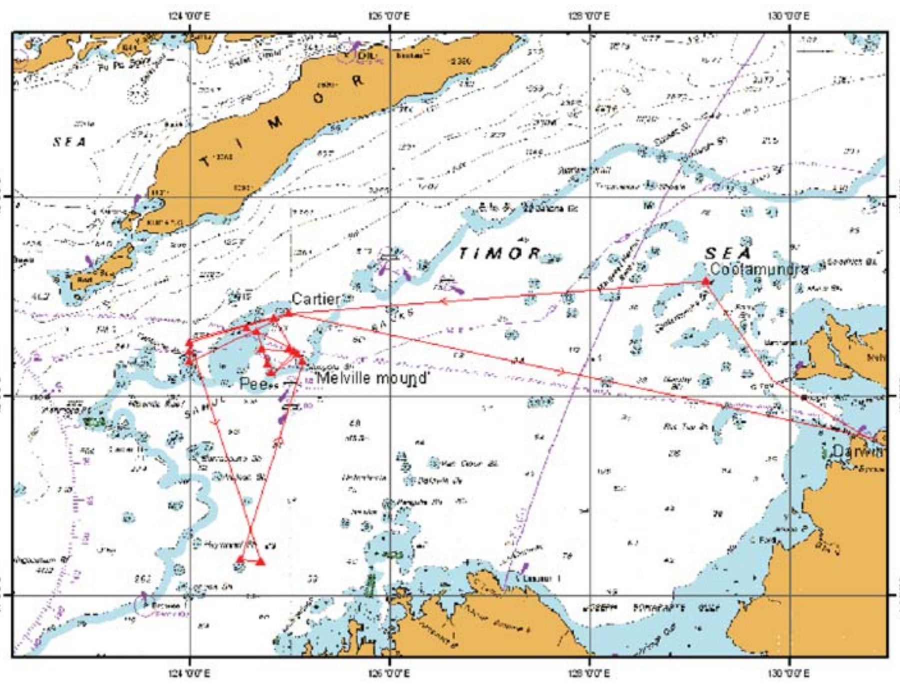
4. Use the swath mapping and seismic tools on the ship to locate best sites for biological and chemical sampling of the water column and seafloor.

5. Measure the daily consumption and production of oxygen in the water column to estimate primary production and respiration. Also to sample the zooplankton, which consume the products of primary production.

6. Obtain drill cores of living and dead corals from the tops of shoal mounds, to measure the history of hydrocarbon abundance, and the age of the mound tops.

Voyage Track

RV Southern Surveyor 31 May - 23 June 2005



Results

1. Determine the geochemical & ecological importance of submarine seeps in the Timor Sea.

According to the swath maps and sub-bottom profiles of the Cornea Seep Site (at 13º 39.26' S and 124º 42.68' E.), the dimensions of the active seepage plume region are approximately 500 x 1400 m in a football shape with the long axis running NW and SE. Positioning CTDs, our large Niskin Cage, grab samplers, and towed cameras into the seafloor source of the vent bubble plumes involved considerable micro-navigation using the 120 kHz sounder signal, as the active vents are probably in a very small area (perhaps 10 m^2, the area of the 120 kHz sounder cone). The active seep area was a dome-shaped feature about 4 m higher than the surrounding sandy seafloor at 84 m water depth. The seepage dome was likely composed of microbially precipitated $CaCO_3$, as a result of anaerobic methane oxidation and sulfate reduction. The hardground dome was opaque to our seismic profiler, so we could not see any structure below the hard cemented surface. Other smaller seep plumes were observed from the 120 kHz sounder to the NW, north and NE from this dome, but they were much smaller in intensity. A heavily weighted Smith-MacIntyre Grab sampler brought up chunks of darkly stained biogenic skeletal carbonate rubble, and many "vent tubes" of outside diameter 2-4 cm and inside aperture diameter 0.8 to 1.2 cm. Some of these "vent tubes" could be seen in a vertical position and lying horizontal on the rough seafloor from a towed camera sled. We will have these "vent tubes" examined by polychaete worm specialists, and for geochemical tracers of likely vent minerals (siderite, pyrite, barite). Microbiological samples were obtained of the seafloor rubble, and these will be tested for hydrocarbon metabolic capacity and various genetic tracers (sRNA, FISH) by Ken Wasmund. Attempts to core this hardground with a Kasten corer failed, and some sort of a drill corer would be required to penetrate this cemented dome. Some (but not all) of the CTD profiles in the Cornea Seep Site show increasing temperature and rapidly declining O2 near the sediment surface. Some of the water samples from near the hardground surface had alkalinities that were higher, and pH was lower, than in normal seawater in the Timor Sea.

Vent bubble plumes were most active (as observed from the EK500 120 kHz sounder, and the presence of bubbles at the surface) at low tide. We were able to observe and collect 10-110 ml of bubble gas rising from deep water to the surface with our "bubble catcher". These samples were analysed by Dr K. A. Burns, using flame ionization detector gas chromatography on board the ship. Most bubble samples were nearly pure methane, with trace levels of ethane, propane, and two unknown unsaturated gases. Samples of this gas have been preserved for carbon stable isotopic measurements. CO_2 was not detected in the bubble gas samples, or perhaps the CO_2 peak was obscured by the very small ethane peak area. Dissolved methane measurements were done, sampling equilibrated headspace gas in the ship's GC lab, and micromolar concentrations were found. Small (5-10 cm) globules and filaments of apparently light crude oil were observed from a small workboat, and some were collected for hydrocarbon analyses at AIMS. Towed camera still photographs and videos, operated by Max Rees, show abundant benthic organisms (solitary corals, bryozoans, gorgonians, ophiuroids) and many species of fish in the vicinity of the bubbling seeps, whereas the abundance of benthic organisms was much lower outside the seep zone in adjacent sandy sediment. Slightly elevated hardgrounds usually have more abundant macrobenthos, so this is not clear evidence of macrobenthic enhancement by seep fluids and methane. Grab samples of the seafloor in the seep zone did not provide any living macrobenthic organisms.

About 10 miles to the north of the hardground seep dome, there were palaeochannels filled with soft sediment that we collected with the Smith-MacIntyre Grab sampler and our kasten corer. One of these soft sediment sites had relatively high hydrocarbon concentrations, as estimated by Dr. K. A. Burns, using UVF of solvent extracts of the sediment. None of the sediment samples directly in the seep site had above-background UVF detectable hydrocarbon concentrations in the sediment, but the sediment on the dome is very coarse gravel and sand, and would not be expected to retain hydrocarbons. As the tide moves the vent bubble plumes down-current, it was often difficult to back-track the large bubble plumes to their seafloor source. A small sediment trap array was deployed on a mooring over the largest vent bubble plume, with one trap array near the sea surface, and a deeper trap 10 m above the seafloor. The shallow trap array was recovered well, but the deep trap came up tangled in the mooring wire sideways. These samples will be analysed at AIMS by Dr. K. A. Burns for hydrocarbon composition. Several CTD profiles and Niskin sample profiles for nutrients (Dave Terhell) and radium isotopes (John Pfitzner) did not show large signals related to the seafloor vent fluids. Balloons attached to the Niskin bottle top ports did collect some methane gas, and we suspect this is due to degassing of the water during retrieval, or simply bubbles in the water that do not dissolve into the warm seawater.

We investigated two deep mounds on the southern margin of the Cartier Trough (Max's Mound at 11° 38.119' S. and 125° 06.105 E. at 223 m water depth, and Melville Mound at 11° 37.282'S. and 125° 07.4' E.). These hard-topped mounds are 50-100 m higher than the surrounding sandy seafloor, and may be active, sealed, or relict submarine seep sites. The tops of these mounds could not be sampled with our Smith-MacIntyre Grab or Kasten corer. Rock dredge samples from the tops of these mounds provided good samples of the "vent tubes" similar to those collected from the Cornea Seep Site. The rock dredge also collected some fossilized and recently-living molluscs, sand dollars, sea urchins, solitary corals, one large mammal bone, as well as some large (20-35 cm) chunks of darkly colored carbonate rubble. Towed camera views of the tops of these mounds revealed a sparse biota dominated by brightly colored ophiouroids and solitary corals. The camera also showed images of large dark coloured and very hard lava-like elevations on top of these deep mounds. At other locations in deep water regions of the Cartier Trough, from 200 to 500 m water depth, we found no evidence of high methane or hydrocarbon content in sediment samples.

The other major source of nutrients to this continental shelf ecosystem would be from upwelling of deep Timor Sea water, below 300 m, where we found nutrient concentrations to be a factor of 10-30 times higher than in the euphotic zone (0-100 m), where planktonic algal growth may be limited by both N and P.

We consider this part of the investigation to be successful. The major new information is that the submarine seeps at Cornea provide methane bubbles that reach the surface of the sea and enter the atmosphere. This methane flux to the sea and atmosphere is an important addition to the carbon budget for this region, and a contribution to the natural greenhouse gas budget needed to understand current global warming models. Seafloor photographic images suggest an enrichment of normal biota on the seep domes, but there is no evidence yet for unusual cold seep fauna or microbial communities, nor a great fluid flux (including nutrients and radium isotopes) from these methane bubble seeps.

2. Estimate the flux of greenhouse gases between the seafloor and the atmosphere.

The amount of coal, oil, gas, and wood that has been burned by global human activities over the last several centuries is semi-quantitatively known, but only half of the resulting combustion product (CO_2) is found in the atmosphere. Most of the missing fossil fuel carbon is probably in the ocean (dissolved, or as particulate inorganic or organic carbon in the water and coastal sediments), but the data to support this global carbon budget is not complete, especially in SE Asia and tropical Australia. Because the tropical ocean is warm, it cannot dissolve much atmospheric CO_2, and microbial decomposition of organic matter is more rapid than in temperate and polar zones. Part of our goal here is to establish the exchange rates of CO_2 and CH4 between the ocean and the atmosphere, to determine whether the Timor Sea is sucking carbon out of the atmosphere, or adding greenhouse gases to the atmosphere.

The AIMS bubble catcher was successful in capturing samples of bubbles rising from the seafloor at the Cornea Seep Site, 1-4 cm in diameter, and often occurring in 1-2 minute spurts of 10-30 silvery bubbles close together. Most bubble catching was done half a mile from the ship, in a rubber work boat, with the outboard engine off. Bubble gas flux from the sea surface to the atmosphere was in the range 0.5 to 1 liter of CH_4 m^{-2} day^{-1}, assuming two 3 hour periods of low tide flux/day. Most of the bubble samples were >99% methane, so this would be a flux from the sea to the atmosphere of approximately 0.021-0.21 moles CH_4 m^{-2} day^{-1}. If vent pipes were evenly distributed over the area of the hardground as defined by swath and seismic mapping (540,000 m^2), then the Cornea Seep may be delivering to the atmosphere 11-110 Moles of CH_4 per day, or 173-1,730 kg/day.

Photosynthetic fixation of carbon dioxide by algae in the euphotic zone sequesters atmospheric carbon, but most of this daily CO2 algal fixation is respired by the algae at night, or is rapidly decomposed by microbial processes. Carbon fixation by photosynthetic algae in excess of respiration & decomposition reactions in the euphotic zone was estimated by Dr. A. D. McKinnon, by measurement of 24 hour oxygen production and consumption rates, yielding net primary production (NPP) of 0.16 Moles C m^{-2} day^{-1} for the Cornea Seep Site. A control site on the inner continental shelf that was not associated with gas seeps had even higher NPP of 0.57 Moles C m^{-2} day^{-1}, so there is little evidence that the gas seeps at Cornea provide nutrients for photosynthetic algal growth. NPP in blue water of the northern Cartier Trough and west of the Sahul Shoals was much lower (-0.019 to 0.033 Moles m^{2} day^{-1}. One site in the central northern part of Cartier Trough (Trap Site 1, Station 3) was heterotrophic, where respiration & decomposition processes exceeded photosynthetic carbon fixation by algae. These rates of carbon fixation by algae (= reduction of atmospheric carbon dioxide to algal organic matter) are of the same order of magnitude as the methane fluxes from the seafloor to the atmosphere. If the greenhouse gas heat trapping capacity of methane is 20 times that of carbon dioxide, then the Cornea Seep Site region is a net source of greenhouse gas, although it is a small area.

Sequestration of carbon in the ocean can also be estimated by the removal rate of organic carbon to our sediment traps (over a 20 day deployment period). These sediment trap samples will be dried and weighed at AIMS, and part of them will be analysed for organic and inorganic carbon, nitrogen, phosphorus, and selected major and minor/trace elements. The other half will be used to estimate all of the different hydrocarbon fractions, some of which are normal biogenic lipids formed by living biota, and some of which are similar to petroleum composition. Measurements of bomb radiocarbon and stable isotopes of carbon on these sediment trap samples may allow interpretations of the fraction of modern atmospheric (and fossil fuel) carbon that is being removed from the ocean via particle sedimentation.

Kasten cores taken on this voyage will allow another estimate of carbon removal rate from seawater. AIMS radiochemical measurements of the uranium series nuclides in sequential sections of the sediment cores can sometimes be used to estimate the rate of sediment accumulation over the last several centuries. Additional millennial scale dating of these sediment cores can be done from oxygen and carbon isotopes in foraminifera picked from each core slice. Chemical measurements of organic and inorganic carbon, N, P, and other elements on these same sediment core slices will give us a view of century/millennial scale variations in the geochemical composition of the sediment, and the burial (= removal) rate of organic and carbonate carbon. Previous work in this region by Brunskill & Opdyke (and others) suggest that some of our longer Kasten Cores probably provide 10,000 to 50,000 years of sedimentation history.

We consider this part of our research at the Cornea Seep Site to be very successful, as we were able to measure several of the fluxes of CO_2 and CH_4 between the seafloor, sea surface, and atmosphere. We were surprised at the large bubble flux of methane at the sea surface over this small area, and we found it interesting that the methane flux to the atmosphere was in the same order of magnitude as carbon fixation by photosynthetic algae in the euphotic zone over the seep site. We will be able to add other measures of this carbon cycle when we have organic and inorganic carbon removal rates from the sediment traps and sediment cores. Improvement in knowledge of this cycle will likely require a drill corer that can penetrate the hardground seafloor of these seeps, allowing access to the microbiological and geochemical properties of the top 2-3 meters of the seeping seafloor. Deep water mounds in the Cartier Trough will require further exploration of their association with submarine vents. Similar "vent tubes" were found ontop of 200 m mound tops, suggested that gas vents have been present in the past on the southern rim of the Cartier Trough, and perhaps all of the large oceanic shoals in this region.

3. Determine variations in century and millennial scale burial rate of carbon, metals, and other signals of climate change and ENSO events.

Nine sediment cores were collected by Brunskill, Zagorskis & Pfitzner, with two failure sites to the NE part of Cartier Trough, and two failed core attempts at the Cornea Seep site. Two Kasten cores from soft sediments in a palaeochannel a few miles north of the Cornea Seep site had elevated concentrations of UVF detectable hydrocarbons, and one of these cores will be analysed at AIMS to obtain more information on the components of the hydrocarbon fractions. Our coring equipment could not penetrate the hard (and probably gas rich) seafloor at the Cornea Seep Site.

Kasten coring efforts in Cartier Trough were successful, especially due to guidance from Bradley Opdyke's interpretations of the sub-bottom profiler transects. A thick wedge of soft Holocene sediment was found thinning seaward, eastward & westward, from the southern margin of Cartier Trough. This wedge of sediment allowed good cores of 2-3 m length to be obtained, for estimations of sediment accumulation rate, organic carbon and inorganic carbon burial rates, and variations in concentrations & burial rates of hydrocarbons, trace elements, and episodes of dust inputs during periods of Australian aridity over the past millennia. Sediment cores were sliced, subsampled, frozen & sacked on the ship. We obtained pore water samples from most of our cores, which will be analysed at AIMS for the major and minor elements. We can estimate century scale sediment accumulation rate from excess ^{210}Pb, ^{137}Cs, ^{241}Am in these cores by gamma spectrometry at AIMS. Subsamples will be picked for foraminifera by Dr. Opdyke at ANU, for oxygen and carbon isotopic measurements that will provide millennial scale chronology over the Holocene. Special efforts were made to measure the activities of the plutonium isotopes in Timor Sea surface water, as we have previously measured anomalously high sediment activities of ^{241}Am, the daughter of ^{241}Pu. We thought that this Timor Sea site may have collected high fallout from 1952-56 Monte Bello Island bomb tests, and we wish to further test this hypothesis.

We judge the coring operations in soft sediments to be successful, but most of the results from this work will come from laboratory analyses over the next year. We lacked appropriate coring equipment for hardground sediments associated with submarine seeps and deep mounds. For geochemical work, including gas and pore water chemistry, the requirements for a gas and water tight drill corer are difficult to accomplish.

4. Test hypotheses about interactions of seep oil and methane with biota, and how this affects biodiversity in this region.

Max Rees benthic sled camera performed well, being towed by the ship, and as a 1-2 day mooring, in water depths from 90 to 500 m. Still camera and video film were obtained with 10-14 hour duration of images at some sites. Casual inspection of the images on the ship suggested that benthic fish and invertebrate fauna were abundant and diverse at seep sites, but experience with other non-seep mounds and reefs makes us cautious to claim any special biological enrichment effects, until perhaps taxonomists inspect the organisms that we collected at seep sites. Sampling the hardground seafloor at seep sites with heavy grab samplers or coring equipment was not successful. The ship's rock dredge did bring up fragments of biota and rock samples, but this type of sampling is non-quantitative and destructive of biological organisms. There were no obvious unusual anaerobic or chemosynthetic communities on the sediment surface. The tides and currents move a large amount of oxygenated seawater over the Cornea Seep site, and it seems likely that anaerobic vent water is rapidly diluted by normal seawater. Mound tops at water depths below 200 m are exposed to even stronger currents that would move and dilute vent fluids down current rapidly.

Samples were taken of zooplankton and the "vent tubes" for microbiological, stable isotopic, and mineralogical studies that might reveal links to vent fluid and gas fluxes. Most of the expected Archaea and sulfate reducing microbial community probably reside in the surface few meters of the hardground carbonate pavement material, in association with hydrocarbons and gas pressure from kilometres below the seafloor. Our initial observations suggest that microbial activity might be very low at these sites, as little CO_2 was measured in the gas bubbles escaping to the atmosphere from the sea surface. Vent tube samples have also been sent to the NT Museum (Dr Chris Glasby) to identify the epibenthic organisms found on the exterior of the "vent tubes".

Planktonic photosynthetic production, as measured by Dr. McKinnon's oxygen production and consumption measurements, did not appear to be greatly stimulated by methane fluxes through the water column at the Cornea Seep Site, and was not greatly enhanced in comparison to other shallow water non-seep sites. Inner and mid continental shelf sites all along this coast have relatively rich planktonic biodiversity, probably due to rapid mixing of the water column and sediment resuspension, which provides more nutrients to the biological community. Live zooplankton from net hauls were used in experiments to estimate growth rate of copepods by means of a deck incubation method. Ph.D. student Luis Filippe Gusmao obtained triplicate zooplankton tows for RNA/DNA ratio analyses, chitiobiase analyses, and other biochemical methods to estimate zooplankton growth rates.

Ph.D. student Ken Wasmund will return to the University of the Sunshine Coast with water and sediment samples for laboratory microbial culture and biochemical measurements. Laboratory analyses will involve both molecular (culture-independent) and traditional (culture-dependent) methods, with focus on determining the presence and significance of microbes capable of utilizing hydrocarbons. Molecular work will involve the construction of clone libraries of 16S rRNA genes and functional genes (e.g. dissimilatory sulfite reductase for sulfate reducers) to obtain an unbiased view of phylogenetic diversity within selected samples. FISH will be used to quantify specific groups of microbes (e.g. anaerobic methanotrophs, sulfate reducers, sulfide oxidizers etc) at various sites and depths. Denaturing gradient gel electrophoresis (DGGE) of 16S rRNA genes and 16S rRNA transcripts will be used to 'fingerprint' active microbial communities at various sites and depths in order to understand microbial community compositional changes in relation to levels of hydrocarbons. Traditional methods will be used to isolate the 'cultivable' portion of microbial communities, with emphasis on isolating microbes involved in hydrocarbon degradation. Novel microbes will be characterized in further detail using both molecular and biochemical methods.

5 & 6. Test geological predictions of the locations of submarine vents, map and discover trends in locations of submarine seeps on the seafloor

Approximately 5500 km of sub-bottom profile and swath mapping data was collected during this voyage. Around the 'Cornea Seep Site' we found a central indurated mound that did not transmit the sound from the Sub-bottom profiler. This carbonate pavement mound sits about 4 - 5 meters above the surrounding sandy shelf surface and is the source of the largest methane bubble plumes that we found. When we Smith-MacIntyre Grab sampled the seep sites we found a high density of cemented tubes that we believe are the conduits for both the gas and seep fluids. Swath and seismic surveys were made to the north and NW of Cornea, out to Heywood Shoals, and over some "palaeochannels" that contained soft sediment with higher concentrations of UVF detectable hydrocarbons. Seafloor bubble plume sources were also mapped with the 120 kHz sounder, showing a possible NW and NE orientation of lines of seeps. Our strongest seafloor bubble plume sources were very close (but a bit to the SW) to those discovered by Graham Logan & others of Geoscience Australia in March 2004.

The entire Cartier Trough was shallow-seismic profiled and swath mapped to depths greater than approximately 200m. In the Cartier Trough we find a thick Holocene wedge of sediment on the southeast portion of the basin, prograding to the west. This wedge pinches out towards the middle of the basin. Obvious current scouring from 320 m down to deeper than 400 m is prominent in the southwest part of the Cartier Trough. Scouring is accompanied by large sand waves that are on the order of 1-2 meters high with a wavelength of approximately 100 m. The west side of the trough also displays prominent block faulting, driven by apparent compression from the northwest. Faulting is also clear in the sub-bottom profile records across the Northern portion of the Cartier Trough. This soft sediment deformation includes both growth faults as well as thrust features. The highs ("pinnacle mounds") that had been charted in the deeper central and western Cartier Trough were not found, and we think that they do not exist.. However, along the Southern margin of the Trough, we discovered numerous low mounds (at 200-300 m water depth, the mounds rising 40-60 m above the seafloor) adjacent to the mapped Shoals. On Max's mound we dredged up cemented "vent tubes" that appear to be the same as the tubes we found at the Cornea seep site. We assume these low hard mounds (opaque to sub-bottom profiler) have the same origins as the seep related mound we found at Cornea, and lends credence to the theory that the foundations of many of the Sahul Shoals are seep related. Another prominent feature of the sea floor both east the west of the main Sahul Banks are the trenches or 'moats' that surround or parallel hard-grounds, mounds and banks when they are adjacent to soft sediment packages. Along the western edge of Sahul Banks there are large 'debris' fields formed as large blocks, some on the order of 1km long by hundreds of meters wide, are scattered in deep water to the west of the shallow banks. Presumably these blocks break off the banks during storms and/or earthquakes.

Predictions by Geoff O'Brien of the locations of hydrocarbon and methane seeps in the Cornea region were correct, as confirmed by Graham Logan of GA in March 2004 and our study in June 2005. O'Brien used the occurrence of subsurface seismically opaque "chimneys" and air photographic mapping of slicks to indicate the locations of active seeps. Many of his seismic chimneys and surface slicks were also mapped on and adjacent to the Halimeda Mounds that rim the basin of Cartier Trough, between 200 and 300 m water depths. We found "vent tubes" on top of small hardground mounds, the tops of which were at 230-260 m water depth, along with fossilized shallow-water benthic organisms (sand dollars, sea urchins). We did not find strong evidence for present day methane or hydrocarbon seeps at the Cartier Trough mounds (no deep or surface bubble plumes, and only occasionally was CH_4 above background in Niskin water samples. Future work might devise methods to perform broader continental shelf and slope surveys to assess the frequency of seismically opaque hardground mounds and/or seafloor bubble plumes. We would like to devise a method of coring into the carbonate pavement of these mounds, and that would retain the *in situ* gas and pore water composition.

7. Determine the variations and controls on primary production and respiration of water column plankton, zooplankton growth rates…

In contrast to the apparently large fish harvest in the Timor and Arafura Sea, our measurements of algal photosynthetic carbon fixation and respiration did not indicate high rates of net community primary production. Carbon fixation by photosynthetic algae in excess of respiration & decomposition reactions in the euphotic zone was estimated by Dr. A. D. McKinnon, by measurement of 24 hour oxygen production and consumption rates, yielding net primary production (NPP) of 0.16 Moles C m^{-2} day^{-1} for the Cornea Seep Site. A control site on the inner continental shelf that was not associated with gas seeps had even higher NPP of 0.57 Moles C m^{-2} day^{-1}, so there is little evidence that the gas seeps at Cornea provide nutrients for photosynthetic algal growth. NPP in blue water of the northern Cartier Trough and west of the Sahul Shoals was much lower (-0.019 to 0.033 Moles m^{2} day^{-1}). One site in the central northern part of Cartier Trough (Trap Site 1, Station 3) was heterotrophic, where respiration & decomposition processes exceeded photosynthetic carbon fixation by algae. In general, nutrient concentrations (nitrate, phosphate, silicate, as determined by CSIRO chemist David Terhell) were higher on the mid-shelf region (water depths of 80-120 m) than in surface 0-100 m waters of the continental slope deep water of the Cartier Trough and to the west of Sahul Shoals. Nutrient concentrations were greatly enhanced in slope water deeper than 200 m. Previous research by Dr. Richard Brinkman of AIMS has shown that large internal waves and tidal energy probably provide nutrient injection from deep Timor Sea water to the shelf margin. We suspect that there might be episodes of high productivity during upwelling, and then episodes of low productivity and net heterotrophy when these nutrients are exhausted by algal uptake and removal via sedimentation.

Planktonic photosynthetic production, as measured by Dr. McKinnon's oxygen production and consumption measurements, did not appear to be greatly stimulated by methane fluxes through the water column at the Cornea Seep Site, and was not greatly enhanced in comparison to other shallow water non-seep sites. Inner and mid continental shelf sites all along this coast have relatively rich planktonic biodiversity, probably due to rapid mixing of the water column and sediment resuspension, which provides more nutrients to the biological community. Live zooplankton from net hauls were used in experiments to estimate growth rate of copepods by means of a deck incubation method. Ph.D. student Luis Filippe Gusmao obtained triplicate zooplankton tows for RNA/DNA ratio analyses, chitiobiase analyses, and other biochemical methods to estimate zooplankton growth rates.

8. Determine the reasons for the low abundance of coral on the shoal mound tops, and determine the rate of growth and age of coral and limestone on the mound tops.

Duplicate or triplicate coral cores were obtained from 3 sites on the southern margin of the Cartier Trough and on the Sahul Shoals. We used several shifts of divers, including Dive Master Cary McLean, Irena Zagorskis, David McKinnon, and Max Rees. These coral cores will be examined by Dr. Bradley Opdyke of ANU and Dr. Janice Lough of AIMS, to determine the century scale history of annual coral growth. Dr. Opdyke will use geochemical facilities at ANU to determine trace element and stable isotopic proxy parameters for sea surface temperature and salinity, to determine the recent history of ENSO events and water circulation variations in this region. Dr. Lough will study the calcification rate (using the thickness of the annual growth band, aragonite density, and other parameters). We did not find the "white limestone ridges" noticed on previous AIMS voyages to these sites, which might be pre-Holocene coral outcrops. We also could not core the corals at Cootamundra Shoals, as the visibility at that site was low, and the large bommies found were too deep for our coring operations.

Previous visits to these sites on AIMS ships, and observations by scuba divers on this voyage, suggest that large *Porites* sp. bommies are not dominant on the mound tops, and that much of the surface of the mound tops is bare white biogenic carbonate skeletal debris, often dominated by the remains of *Halimeda* spp. Biodiversity surveys by AIMS biologists Heyward, Smith, Cappo, Speare, and Rees in this region, using towed cameras, suggest that greater coral abundance and diversity is found below scuba diving depths, from 50 to 150 m down the sides of these mounds/shoals. Dr. Heyward thinks these 20-50 m mound tops are swept clean by frequent cyclones. Dr. Opdyke thinks many of these shallow mounds on the continental slope have been subjected to increased heat stress from ocean warming in the last century. We have not yet answered the main question, but we now have some samples that might reveal changes in recent history of coral growth rates. In the future, we hope to develop ship-deployed drill coring equipment that will allow measurement of sediment accumulation history on these mound tops.

Voyage Narrative

After departing Darwin at 1045 on 31 May 05, we began work at our first sediment trap site (11° 09' S. and 125° 00' E. at 500 m water depth) at 0800 on 2 June, on the northern margin of the Cartier Trough. The previous night had been spent swath mapping and sub-bottom profiling the central part of Cartier Trough. Our intent was to obtain useful information about the water column and sediments that would be needed to interpret our results from the sediment trap deployment. This included a CTD profile, including % transmission of light, photosynthetically available radiation (PAR), oxygen, fluorescence, and the normal pressure, salinity, and temperature sensors. Samples were taken from the rosette Niskin bottles for dissolved and particulate nutrient elements (and other major/minor elements), methane and hydrocarbons, and samples for measurements of oxygen consumption and production rates (= net community primary production in the euphotic zone). Three 1000 liter tanks and six 200 liter barrels were filled from the ship seawater supply hose for measurements of plutonium and radium isotopes in surface water. A Smith-MacIntyre Grab sample of surface sediment was taken for microbiological culture work and hydrocarbon chemistry. Triplicate zooplankton net tows with a bongo net were obtained for estimation of copepod growth rates. Our benthic camera sled was deployed on the seafloor for 3 hours, to determine the biological diversity of macrobenthos and fish at this site. We had previously obtained sediment cores and water column data from this site from AIMS research voyages in 2002 and 2004. After this work was done, the aft deck was cleared for deployment of two sediment trap arrays on one mooring wire, which was accomplished smoothly in two hours. Upon completion of work at this station, we steamed for our next work station to the west of Sahul Shoals, running the swath mapper and sub-bottom profiler to test our assumptions about sediment cover in this region.

During 3-4 June, we repeated the procedure above at 11° 26.8'S. and 124° 00 E. at 500 m water depth, to the west of Sahul Shoals. After the deployment of two sediment trap arrays on one mooring wire, we obtained two Kasten cores from within a mile of the sediment trap site. One core was for hydrocarbon chemistry, and the second core was for inorganic elemental analyses and radiochemical estimation of sediment accumulation rate. During this sediment trap deployment time, we had good weather, 5-15 kt winds & clear skies, gentle swells, and all of the ship and scientific equipment worked well. When this work was completed, we departed for the Cornea Seep site to the south.

During 5-10 June, we explored the Cornea Seep site region centered around 13° 38' 34.69" S. and 124° 43' 5.75", where we found large bubble plumes coming from the seafloor, through the water column, and into the atmosphere. These bubble plumes were easy to view on the ship 120 and 200 kHz sounders, and were obvious from swath mapping and sub-bottom profile records of "hardgrounds". Full use was made of the acoustic Doppler current profiler, to determine the direction and strength of the tide, because the bubble plumes were most active at low neap tides. After sufficient mapping work to determine the shape and extent of the hardground, we deployed a set of small sediment traps near the largest bubble plume, and put a lot of effort into water column sampling as described above. A special AIMS CTD and Large Niskin cage designed for sitting on the sediment surface was deployed to obtain large volumes (200-400 liters) of sediment surface water for chemical and radiochemical measurements, looking for signals of submarine seep fluids. Helium balloons were attached to the 30 liter Niskin bottle top vents to obtain seep gases not dissolved in water. Our benthic camera sled was deployed several times in towed mode and stationary mode, to inspect the seafloor near the gas vents. Net tows for zooplankton were done, with some copepods being sampled for stable isotopic measurements to relate vent gas carbon to the food chain system. The Smith-MacIntyre Grab sampler gave us samples of gas vent tubes seen on the sled cameras. The AIMS bubble catcher was deployed from the ship's workboat, and was successful at obtaining 10-100 ml samples of bubble gas near the sea surface, and this gas was determined to be mostly methane by shipboard gas chromatography. Samples of the sea surface slick and apparent oil globules were taken from the workboat. We were not successful at capturing any of the red crabs swimming at the sea surface. We were not successful in our attempts to use the AIMS ROV camera system. Attempts to core the hardground seep site with out Kasten Corer failed, but soft sediment in palaeochannels to the north were successful, and these sediments were found to have much higher hydrocarbon concentrations than at the main bubble seep site. During the night and early mornings of this period, the swath mapping and sub-bottom profiler (operated by Andrea Cortese & Bradley Opdyke) were used to create a detailed map of the region, in coordination with the bubble plume maps detected by the 120 and 200 kHz sounders. Bernadette Heaney kindly spent time putting the coordinates of the sediment sources of the bubble plumes (from saved records of the 120 kHz sounder) into a spreadsheet, so that we could generate a map of the locations of weak, medium, and strong bubble plumes.

During this work time at the Cornea Site, we had excellent calm weather, and optimized work time during low tides, to maximize the bubble plume signal. Two mishaps occurred on 6 June, when the workboat was nearly swamped by the bow & stern thrusters, and the ship apparently drifted over the grapple buoy for the sediment traps, cutting the buoy rope line. The hydraulic system for the A Frame got too hot on 7 June, so we diverted our work to activities that did not need aft deck services. The AIMS lightweight ROV utilising a new ballasted cage deployment system was trialled at the Cornea site. All ROV operations were eventually suspended despite efforts to respond to fiber optic data transmission problems and camera tilt mechanism failure."

We greatly appreciated the use of the CSIRO Sonardyne pinger which was attached (by Steve Thomas) to the AIMS benthic camera sled, the big Niskin cage, and the towed bongo nets, to allow GPS and depth control for these devices. After repeated measurements of the methane bubble plume fluxes, we recovered the sediment traps, and departed for our next work station on the southern margin of Cartier Trough around Pee Shoals.

During 11-18 June we were working on the southern rim of Cartier Trough and Sahul Shoals region, alternating between coral coring operations and exploring the new deep (200-300 m) mounds found by the swath mapping and seismic sounding equipment on this ship and the R/V Melville in July 2003. Coral coring at 18-20 m water depth was successful at Pee Shoals, 11° 45.49' S., 124º 49.65' E., where triplicate cores 30-50 cm were obtained, and at "Kathy's Shoals" nearby at 11° 42.5' S. and 125º 01' E. During this time, coral coring was delayed by troubles with the drilling bit, a slow drill drive motor, and slow & overheating scuba tank compressor. During gaps in the coral coring program, the AIMS sled camera was deployed in various modes (towed, moored for 1-2 days) to obtain shallow and deep water views of macrobenthic biodiversity. Our sled camera was twice damaged during tows over the deep hard mounds, but this was repaired by Cary McLean & his welding gear. Samples were routinely taken almost daily for oxygen productivity and zooplankton growth rate measurements. Kasten cores were obtained along a previously established transect from 250 to 500 m depth zones to the north, in the late afternoon, after the diving work was done for the day. We used the ship's rock dredges to recover living & dead benthos and hard rock samples from the moats & tops of the deep mounds (Max's Mound at 11° 38.102' S. and 125º 06.08' E., top at 222 m, and Melville Mound at 11° 37.282'S. and 125º 07.4' E., top rim of mound at 225 m). We were excited to discover vent tubes similar to those found at the Cornea Site ontop of these deep mounds. Coral coring efforts ontop of the larger Sahul Shoals were made difficult by strong currents, but several good cores were obtained. During this time there were several failures of the ship's electrical system, when the Kasten Corer rope winch spool controls were dead, and when the ship radar was out of action. The lab water supply pump failed on 14 June. This did not seriously impede our work, as John Morton's engineers fixed things as quickly as possible. After recovering our last sled camera mooring on 350 m deep hardgrounds near the Sahul Shoals, we steamed west to recover our sediment traps that were deployed at the beginning of this voyage. The Kasten coring railway, core slicing table, and other aft deck gear were taken apart and consolidated to increase deck space for transit storage of sediment traps.

During 19-20 June, the two large AIMS sediment trap moorings were recovered successfully without incident. This is due to the good work of AIMS mooring team Cary McLean and Barry Bennett, Bosun Tony Hearne, winch operators Graham McDougall and Paddy Chamberlain, and Master Arthur Staron's team on the bridge. After obtaining CTD and Niskin water sample profiles, oxygen productivity and zooplankton samples, and near bottom samples with the AIMS big Niskin Cage, the ship was put to final swath mapping and seismic sounding to complete the Cartier Trough map.

We departed for Cootamundra Shoals en route to Darwin on 21 June, with a mid-day station at 11° 22.5' S. and 126° 52.1' E. that was supposed to be a "control station" for the Cornea Site. We found as much UVF hydrocarbon signal in grab sample sediments, and as much methane in Niskin water samples, as we had found on the inner shelf north of the Cornea Site. We also obtained a CTD profile, large volume radium samples, and complete chemical sampling from the rosette Niskins at this location. At Cootamundra Shoals (10° 50' S., 129° 10' E.), the AIMS dive team found that visibility was poor and most large bommies were too deep for coral coring. Bongo Net tows were done in a nearby deep channel, amidst swarms of small fish, and another large volume sample for radium isotopes was done. Most of the science crew were busy packing equipment and samples for the past few days.

We arrived at Stokes Hill Wharf at 0700 on 23 June, and were able to begin unloading our equipment at 0900. Our equipment was off the ship by noon, and most scientific personnel left the ship before 1500 hrs. Our equipment occupied one semi-trailer and one 22 ft container for shipment to AIMS near Townsville. Frozen samples were carried by scientific staff as excess baggage on the aircraft.

Summary

All scientific staff were happy with the results of this voyage, and all objectives were given adequate time and effort at sea. We accomplished more than expected, due to good weather, lack of major break-down time of ship and scientific gear, and good cooperation between the ship crew and the scientific crew. We can also see the need for improvement in some of our equipment for work on large vessels, and we learned how to attack the next round of questions about submarine seeps in the Timor Sea.

Suggestions for improvement of ship facilities were given in the Operational Report.

Personnel List

Scientific Crew

Gregg Brunskill	AIMS	Chief Scientist, Sediment traps, coring, bubble collector
Kathy Burns	AIMS	Hydrocarbons & methane measurements in water & sediment
Irena Zagorskis	AIMS	Water sample processing, trap & core sediment processing, data recording
John Pfitzner	AIMS	Radiochemistry sampling & shipboard measurements, sediment core processing
Cary McLean	AIMS	Moorings of traps, assist in coring, mechanical & electronic repairs
Max Rees	AIMS	ROV, submarine cameras, benthic biota sampling
Ken Wasmund	Uni of Sunshine Coast	benthic biota & microbial sampling & sample processing
Dave McKinnon	AIMS	oxygen consumption & production, zooplankton sampling, chlorophyll calibration
Luiz Felipe Mendes de Gusmao	AIMS	Zooplankton growth rate experiments
Barry Bennett	AIMS	Moorings, aft deck operations
Bradley Opdyke	ANU	Sub-bottom profiler, Holocene climate change signals from sediment cores
Stephen Thomas	CMR	Voyage Manager & Electronics, System Support Technician
Bernadette Heaney	CMR	Computing, System Support Technician
David Terhell	CMR	Hydrochemistry, System Support Technician
Andrea Cortese	GA	Swath processing

Marine Crew

Arthur Staron – Master
Samantha Durnian – First Officer
Robert Ferries – Second Officer
John Morton – Chief Engineer
Dave Jonker – First Engineer
Seamus Gilbert Elder – Electrical Engineer
Andy Goss – Chief Cook
Angela Zutt – Second Cook
Charmayne Aylett – Chief Steward
Tony Hearne – Bosun
Paddy Chamberlain – IR
Graham McDougall – IR
Phil French – IR
Russel Williams – IR

Acknowledgements

Master Arthur Staron and bridge staff are thanked for careful attention to our scientific plans for research. Rob Ferries was especially good at using and coordinating the 120 kHz sounder output with our attempts to find and sample bubble plumes coming from the seafloor. Tony Hearne gave us safe and extra effort handling equipment on the aft deck, and we greatly appreciate the winch wire & A Frame handling skills of Paddy Chamberlain and Graham McDougall. John Morton and his engineers quickly fixed any problems that came up during this voyage. We were all happy to consume the large loads of good food provided by Andy Goss and the galley staff. We thank the deck crew for extra effort during loading and unloading the ship in Darwin.

We all thank Ron Plaschke and Voyage Manager Stephen Thomas for assistance with the science program before, during, and after the voyage. Bernadette Heaney kept the computers working, and provided extra assistance in tabulating the submarine seep locations from the saved records of the 120 kHz sounder. David Terhell provided prompt effort with our CTD and rosette sensor profiling and shipboard nutrient analytical data. We are grateful to Geoscience Australia for the services of Andrea Cortese on the swath mapper.

Gregg J. Brunskill
Chief Scientist
1 August 2005