SS09/2008
Carbon Chemistry of the Great Barrier Reef

Voyage period
start: 24/07/2008
end: 11/08/2008
PORT OF DEPARTURE Cairns, Australia
PORT OF RETURN Gladstone, Australia

RESPONSIBLE LABORATORY
Centre for Australian Weather and Climate Research
PO Box 1538, Hobart TAS 7001 Australia

CHIEF SCIENTIST(S)
Dr Bronte Tilbrook
Centre for Australian Weather and Climate Research, CSIRO-BOM
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OBJECTIVES AND BRIEF NARRATIVE OF VOYAGE

Scientific Objectives
The uptake and storage of carbon dioxide in the ocean is causing a decrease in carbonate saturation states and increasing the acidity of ocean waters. The changes in water carbonate chemistry that will occur in the coming decades are expected to cause a decline in calcification in corals and other organism that produce calcium carbonate skeletons and help form reef structures. Increased stress on the corals due to acidification is likely to be compounded by bleaching events associated with warming of waters, pollution and perhaps increased storm activity. The resilience of the coral reef system to these changes is a major area of concern, particularly for the Great Barrier Reef.

The voyage was designed to provide data needed to study the regional-scale carbonate chemistry of the Great Barrier Reef. This is the first detailed baseline data of the carbonate chemistry through the region during the dry season in late July/early August. These measurements are significant for investigations of the vulnerability of the reef system to ocean acidification. They provide input
to biogeochemical modelling and allow an assessment to be made of how the carbonate chemistry of the region is influenced by the production and calcification on the reef and in the adjacent Coral Sea, the source waters of the GBR.

The voyage also provided an opportunity for researchers from James Cook University and University of Sydney to obtain benthic grab samples and to improve the bathymetry of the region.

The ships EM300 multibeam swath mapper and Topas sub-bottom profiler was used to map the GBR continental shelf and slope. The ship track covered range of depths, from 20 metres on the inner shelf to over 2000 m in the Queensland Trough and provide data to assist in understanding biodiversity-habitat relationships on the GBR shelf and margin, and for updating navigational charts.

In 2007, dense beds of brittle stars (Ophiopsila pantherina) were observed in underwater dune fields at Hydrographers Pass using Autonomous Underwater Vehicle (AUV) imagery. These brittle star beds are likely due to favourable currents and geology, and represent a previously unknown deep habitat of the Great Barrier Reef. The brittle stars appear to feed by extending a ‘wall of arms’ to capture material swept past the site and the may be important for pelagic-benthic coupling in the region. The dune field site was revisited to determine if the same brittle star beds still existed and to collect grab samples to investigate the taxonomy, diet and substrate preferences of the brittle stars. Another component of the voyage was to take opportunistic grab samples from Halimeda mounds in the northern GBR. There are no publications on the biota associated with Halimeda on the GBR, and this initial study will provide insights into whether this might be considered for future targeted research.

**Specific objectives are:**

1) determine the variability in carbonate chemistry and related biogeochemical parameters (macronutrients, oxygen, salinity and temperature) through the Great Barrier Reef region.

2) utilise these data with models to estimate the net calcification rate in the GBR for the voyage period and determine how the carbonate chemistry of the Coral Sea waters that flow onto the reef are modified by local production and calcification.

3) obtain high resolution bathymetry in the GBR region.

4) collect benthic grab samples of brittle stars off Hydrographers Passage and bottom samples of the Halimeda mounds of the Northern GBR.
**Voyage Objectives:**

**Large scale carbonate chemistry of the Great Barrier Reef waters:**

A major aim of the voyage was to characterise the carbonate chemistry through the reef region and compare this to the carbonate chemistry of the offshore source waters in the Coral Sea. Inshore-offshore sections and stations along the length of the GBR lagoon and offshore were used to characterise gradients in carbonate chemistry.

Water samples during the voyage were obtained using Niskin bottle mounted on a CTD rosette and ship’s underway seawater supply. These samples were analysed onboard for total dissolved inorganic carbon, titration alkalinity, macronutrients, oxygen and salinity. Continuous underway measurements of O2/Ar ratio (net community production estimate) and the surface partial pressure of carbon dioxide (air-sea CO2 flux estimate) were also made.

**Bathymetry**

The ships EM300 multibeam swath mapper and Topas sub-bottom profiler were run for the entire duration of the voyage from Cairns to the arrival at Gladstone, with down-time restrictions in accordance with the GBRMPA permit for the survey. The collection of the bathymetry data was coordinated and run by Dr Robin Beaman, James Cook University.

**Benthic samples:**

On the current voyage, brittle star sampling was carried out when the ship transited through Hydrographers Passage. Previous AUV images over the dune field provide targeted locations for sampling the brittle star beds with a Smith-MacIntyre sediment grab device. Similarly, Halimeda mound sampling was carried out in the LADS Passage region after suitable sites were identified using the ships swathmapper and sub-bottom profiler. Underwater video transects over these sites were used to provide additional ground-truthing of the seabed habitats and sample site selection. The grab samples were organised by Dr Robin Beaman in collaboration with Dr Jodie Webster (James Cook University) and Prof. Maria Byrne (Sydney University).

**Results**

**Water column Sampling**

Water column samples were collected and analysed for carbon parameters over most of the GBR, extending from near Cape Weymouth in the North to Lady Musgrave Island in the South (figure 1), a track of over 5400km length. The 8m draft of the ship, complex reef structures, many unsurveyed regions, and strong tidal currents in narrow passages between reefs influenced the ship track and where samples could be collected. The voyage sampling schedule and locations needed to be revised each day in order to complete the sections in narrow passages in daylight hours. Work at night was typically restricted to well charted shipping channels and to waters offshore of the reef. In the pre-voyage plans, the possibility of launching the ship’s workboat to sample closer to reefs was considered. However, this was not done on the voyage because of time limitations.
The data collected represent the first regional scale survey of the carbonate chemistry of most of the GBR complex. The CTD profiles for this dry season voyage showed that the water column on the shelf was well mixed between the surface and bottom. Changes in the water mass properties were apparent both along the GBR lagoon and between the inshore and offshore waters.

As of December 2008, the finalisation of the carbon measurements made on water samples is awaiting the hydrochemistry bottle data. The analysis of duplicate samples and comparison to certified reference material for seawater, indicate the carbon system measurements meet accuracy and precision targets of ± 2 micromol/kg, for both titration alkalinity and total dissolved inorganic carbon.

**Underway data**

The underway instruments operated on the voyage were an equilibrator inlet mass spectrometer (EIMS) used to determine O2/Ar ratios in surface waters and a pCO2 system. These instruments were on the same seawater supply line with the EIMS in the General Purpose laboratory and the pCO2 system in the CTD room. The ship's underway water supply could not be started in port before the voyage because of concerns the harbour waters might contaminate the seawater supply lines. The water flow to the pCO2 system was started soon after the ship departed the port. This outlet is on a part of the seawater supply line that is used every voyage and is well flushed. The water line to the General Purpose laboratory is not used often and flow to the EIMS system was poor. Leaking drains in the laboratory were also a problem during the first few days of the voyage. The flow and drainage were improved after many hours effort and the EIMS system was started. Intermittent problems with power and water supply caused some data loss of EIMS data during the voyage.

Comparisons of oxygen concentrations measured in surface CTD samples and at the sampling point in the underway line for the EIMS showed some oxygen consumption was occurring in the underway line as the seawater flowed through the line. The oxygen consumption was most prevalent in the first week of the voyage and made data for this time unusable. After this time, the differences in dissolved oxygen measured in surface CTD sample bottle and at the EIMS sampling point were generally below the level of precision for the measurements indicating the oxygen consumption had been reduced. The voyage has provided the first EIMS data through the region, although the first week or more of data appear to be compromised by the oxygen consumption and water supply problems.

The pCO2 system worked throughout the voyage and provided good data. The surface underway pCO2 measurements do show an increase between the offshore waters of the Coral Sea and the waters overlying the GBR (Figure 2). The increase is expected due to net calcification in the GBR complex. The pCO2 values, normalised to a sea surface temperature of 23C, are shown in figure 2. The normalisation removes local effects on pCO2 that are caused by warming or cooling of the waters. In the figure, the values in the southern third of the reef are increased somewhat due to the actual surface waters being less than 23C, while waters in the northern half are usually warmer
than 23°C, causing a decrease in the normalised value. Nevertheless, the changes from lower values in waters just offshore compared to those over the reef do show a net calcification effect. A more detailed analysis of these data will require finalised TCO₂ and titration alkalinity data. The salinity data in figure 2 show some evidence of freshening of surface waters close to shore near Bowen and Mackay, and perhaps in the far north of the reef. High salinity values are apparent in the southern part of the GBR lagoon.

**Bathymetry**

The voyage permit from GBRMPA restricted the use of both instruments to the daylight hours, or during night when offshore of the GBR and greater than 500m from the reef edge. During daylight operations the equipment had to be shut down if any whales or dugongs were sighted within 2km of the ship, and restrictions also applied for restarting the equipment. With these restrictions, the voyage mapped about 1600 km along the GBR continental shelf and slope, with depths ranging from 20 m on the inner shelf to over 2000 m in the Queensland Trough. A diverse suite of seabed habitats were surveyed, including muddy inner shelf environments, to vast inter-reefal Halimeda bioherms, numerous palaeo-channels and outer shelf drowned reefs. On the continental slope, multiple submarine canyons were found to incise the margin and were co-located with landslide scarp and debris flows at the base of the canyons into the Queensland Trough. Additionally, detailed images were obtained of extensive drowned reefs found near the Swains Reef complex that substantially increase the known extent of these underwater features (Figure 3).

**Benthic Sampling**

The substrate of a Halimeda bioherm was sampled by Smith-MacIntyre grab and underwater video on the northern GBR shelf on 28 August. The associated invertebrate biota was preserved in ethanol for post-voyage taxonomic analysis and the sediment frozen for post-voyage analysis.

The brittle star sampling off Hydrographers Passage was conducted after dawn on 5 August at slack water to reduce the drift of the ship due to the typically strong tidal stream currents in the region. Four sediment grabs were obtained on the dune field at precisely-targeted sites. All grabs successfully recovered well-sorted medium-grained carbonate sand indicative of this dynamic environment, in addition to many individual O. pantherina brittle stars (Figure 4). The animals were preserved in ethanol for post-voyage isotope analysis and the sediment frozen for standard sedimentological analysis. In addition, an underwater video within a PVC tube was lowered over the site and the video transect provided information of the seabed substrate and habitat conditions of the brittle star beds. Similarly, the substrate of a Halimeda bioherm was sampled by Smith-MacIntyre grab and underwater video on the northern GBR shelf on 28 August. The associated invertebrate biota was preserved in ethanol for post-voyage taxonomic analysis and the sediment frozen for post-voyage analysis.
Voyage Narrative

July 24-25: The ship departed Cairns at 1600hrs local time on the 24th of July, with a 30 knot wind blowing. The ship sailed offshore through Trinity Opening and tests were carried out on underway instrumentation and the CTD. On board the first night were journalists from the ABC, Cosmos Magazine and the Marine National Facility. The ship sailed overnight to a position offshore of a passage between Agincourt reef no. 4 and Escape Reef. At first light a Niskin bottle leak check was carried out at the offshore location (15° 54.25’S 145° 54.9’E) in about 1160m of water. The same station was then used as a starting point for a CTD section that ran onto the shelf and to the coast. Once on the shelf sampling from a workboat launched from the ship was attempted, but 15 knot winds and waves made the work difficult. The workboat was returned to the ship and the section across the shelf continued. At the completion of the section the ship sailed to off Port Douglas to the transfer four journalists for more science crew. The ship began to move north along the Great Barrier Reef shipping channel at night with occasional CTD’s (approx 15-20nm spacing).

July 26-27: The ship arrived north of Cooktown (CTD 15; 15° 20.9’S 145° 20.3’E) in the early morning and started an easterly section to the back of Ribbon Reef no. 5, followed by a series of CTD’s in a north and westerly direction arriving at the shipping channel off Cape Flattery (CTD 26; 14° 58.9’S 145° 25.3’E) in the early evening. In the evening the ship worked north of CTD 26, past Lizard Island, with hourly CTD’s (CTD 30-37) were made about 3nm south of One and a Half Mile Opening to determine if a tidal signal due to inshore-offshore exchange could be detected in the shelf seawater properties on the shelf. The ship sampled out through One and a Half Mile Opening in the early morning before moving back onto the shelf through Two Mile Opening. The ship carried out a number of CTD on the shelf near Lizard Island and in the late afternoon headed off to the entrance to Fairway Channel CTD50 13° 50.7’S 144° 13.5’E), arriving at about 0400hrs on July 28.

July 28-29: The continued North with occasional CTD’s in the LADS Passage. The region contains extensive Hali mea mounds and on August 28 a Smith–MacIntyre grab sample was used to obtain a sample of surface sediment near 12° 54.7’S 143° 46.8’E, close to the location of CTD55. The most northerly part of the voyage was reached at CTD57 (12° 34.8’S 143° 44.8’E). A series of CTD’s at about 4nm spacing were then completed across the shelf, following the Kupuntutu Passage, and finished on the western side of the shipping channel at CTD 61 in the early evening of July 28. At night the ship travelled down the LADS Passage before turning West past the Fairway Channel entrance (CTD 64) at about 0540hrs and moving south of Corbett Reef. The ship turned North along the two way shipping route and reached CTD 70. One of the science crew was ill and it was decided to curtail any work further north and to head back South, towards Cairns for a personnel transfer. The transfer was not urgent, but did result in a few stations being cut to the north to ensure the ship could complete a section (CTD70 to CTD77) across the shelf and exit one of the few available reef openings before heading back towards Cairns.
July 30-31: After completing the section out into the Coral Sea, the ship travelled South offshore of the reef with stations at approximately 25nm spacing. The ship path offshore was largely determined by the need to follow a track where bathymetry is available on charts. The ship arrived off the Grafton Passage entrance on the morning of July 31, with the transfer of the ill science crew member planned for the evening. An offshore to inshore section was completed in the Grafton Passage (CTD 87; 16º 28.5’S 146º 22.9’E to CTD 92; 16º 51’S 146º 03.8’E), finishing at 1520hrs. The transfer was completed with a new science crew member replacing the ill person at about 1830 hrs off Cairns. The voyage continued to CTD 94 (17º 11’S 146º 10’E), located west of the Frankland Islands, the starting point for a series of inshore-offshore sections.

August 1-3: CTD sections from the GBR lagoon to offshore were completed in the Flora Pass, Geranium Passage, Palm Passage and Flinders Passage (CTD 94 to 129).

August 4-6: A series of stations (CTD 130 to 147) were sampled along the GBR lagoon as the ship travelled towards Mackay. This included a short section from near Hook Island to the northern entrance to the Whitsunday Passage (CTD 133 to 137), where large clumps of Trichodesmium were observed on calm surface waters. At noon on August 4 the ship arrived at the site of CTD 147, off Mackay. A section was begun across the lagoon and along Hydrographers Passage. At the offshore entrance in the early morning of August 5, the ship moved about 4 nm east of the section to take four grab samples of brittle stars in a dune field at about 19º 52’S 150º 27’E (figure 2). The brittle star population was identified on a Southern Surveyor voyage in the previous year. After finishing grab sampling, the last station in the section was then completed ending offshore of the GBR at CTD161 at 1400 hrs on August 5. The ship then travelled around the offshore edge of the Swain Reefs, with sample stations at about 20-25nm spacing.

August 7-11: The remaining days of the voyage were used to sample the Capricorn Channel, both along its axis and in cross section from the Swain Reefs to the shallow waters near the coast. A section was completed across the Capricorn Channel from CTD171 on the southeast edges of the Swain Reefs to CTD185, located near Facing Island, off Gladstone. A section was also completed from near Bustard Head, passing south of Lady Musgrave Island, and into the Capricorn Channel (CTD186 to CTD192), with another from Port Clinton across the channel to Heralds Prong Reef (CTD196 to CTD 202). A number of stations were then occupied in the central part of the channel and along the southern edge of the Swain Reefs (CTD203 to CTD210) before surveying in detail a sunken reef identified from the EM300 swathmapper on the eastern edge of the Swain Reef complex (figure 3). The ship docked in Gladstone at 1330hrs on August 11.
Summary

The voyage was successful in providing comprehensive data on the large-scale carbonate chemistry over most of the Great Barrier Reef. These data will be used to investigate how net production and calcification on the reef is influencing the chemical composition of waters that flow into the reef. All major objectives were met, pending the delivery of final hydrochemistry data which will allow the final quality control of carbonate chemistry data.

PRINCIPAL INVESTIGATORS

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B. Richard Matear, Centre for Australian Weather and Climate Research, BOM-CSIRO, PO Box 1538, Hobart TAS 7001
## Summary of measurements and samples taken

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**Voyage track**

GENERAL OCEAN AREA(S): Coral Sea  
SPECIFIC AREAS: mGreat Barrier Reef.
**Personnel list**

### Scientific Participants

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<thead>
<tr>
<th>Name</th>
<th>Affiliation</th>
<th>Role</th>
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<tr>
<td>Bronte Tilbrook</td>
<td>CSIRO</td>
<td>Chief scientist</td>
</tr>
<tr>
<td>Richard Matear</td>
<td>CSIRO</td>
<td>Co-Chief scientist</td>
</tr>
<tr>
<td>Kate Berry</td>
<td>CSIRO</td>
<td>Carbon chemistry</td>
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<tr>
<td>Kristina Paterson</td>
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<tr>
<td>John Akl</td>
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<tr>
<td>‡Matt Chamberlain</td>
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<td>‡Erika Woolsey</td>
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<td>Rob Beaman</td>
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<td>Bob Beattie</td>
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<td>‡Anne Kennedy</td>
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<td>‡Tony Veness</td>
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<td>Lindsay MacDonald</td>
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<td>Dave Terhell</td>
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<td>*Alicia Navidad</td>
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<td>**Mark Rayner</td>
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<td>†Brett Ramsay</td>
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<td>†John Pickrell</td>
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<tr>
<td>†Edwina Hollander</td>
<td>CSIRO</td>
<td>Communications</td>
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† left ship July 25  
‡ joined ship July 25  
* left ship July 31  
** joined ship July 31

### Marine Crew

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<td>Peter Pearson</td>
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<td>Darren Lack</td>
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Acknowledgements

The competence and help of the officers and crew of the RV Southern Surveyor were greatly appreciated and made the voyage a success. The ship master, Peter Pearson, first mate, John Boyes, and second mate, Darren Lack, are very experienced sailors on the reef. Without their knowledge and patience, the coverage managed would have been much reduced and would have impacted the success of the voyage. The engineers led by Chief Engineer, John Morton, were helpful and responsive to all requests. The ship bosun, Graham McDougall, and crew made deck work and sample collection a smooth and professional operation. The cooks and staff in the mess led by Paul Brown provided excellent food. GBRMPA, and in particular Mel Cowlishaw, are thanked for working with us to obtain the permits for the sampling and in explaining the many issues raised to ensure the requirements for research and sampling on the reef were met. The Marine National Facility helped above and beyond normal responsibilities. Fred Stein, director of the Marine National Facility helped with pre-voyage planning and Don MacKenzie and Lisa Woodward did an excellent job of ensuring the voyage achieved maximum outcomes. Ron Plashcke helped with obtaining medical advice when a member of the science crew became ill and this helped minimise a loss of sampling time. The ABC and Cosmos magazine are thanked for sending journalists (Peter McCutcheon, Brett Ramsay and John Pickrell) who were gave excellent coverage to the voyage. The voyage was supported by the Australian Climate Change Science Program funded through the Australian Department of Climate Change.

Bronte Tilbrook

Chief Scientist
Figure 1: Voyage track (yellow line) and as subset of CTD sample locations (red dots) along the Great Barrier Reef region.
Figure 2: Surface pCO$_2$ (left panel), normalised to 23°C sea surface temperature, and sea surface salinity (right panel) measured along the Southern Surveyor voyage track.

Figure 3: Three-dimensional image of a drowned reef near the Swains Reef complex surveyed using the EM300 multibeam swath sonar. Depth (m) are shown by the colour legend. Survey area 20 km x 4 km. Courtesy R. Beaman, JCU.
Figure 4: The underwater dune field at Hydrographers Pass with brittle star grab sample locations shown by black dots. Inset image shows numerous *O. pantherina* brittle stars from a sediment grab. Courtesy R. Beaman, JCU.
CSR/ROSCP PARAMETER CODES

METEOROLOGY
M01 Upper air observations
M02 Incident radiation
M05 Occasional standard measurements
M06 Routine standard measurements
M71 Atmospheric chemistry
M90 Other meteorological measurements

PHYSICAL OCEANOGRAPHY
H71 Surface measurements underway (T,S)
H13 Bathythermograph
H09 Water bottle stations
H10 CTD stations
H11 Subsurface measurements underway (T,S)
H72 Thermistor chain
H16 Transparency (eg transmissometer)
H17 Optics (eg underwater light levels)
H73 Geochemical tracers (eg freons)
D01 Current meters
D71 Current profiler (eg ADCP)
D03 Currents measured from ship drift
D04 GEK
D05 Surface drifters/drifting buoys
D06 Neutrally buoyant floats
D09 Sea level (incl. Bottom pressure & inverted echosounder)
D72 Instrumented wave measurements
D90 Other physical oceanographic measurements

CHEMICAL OCEANOGRAPHY
H21 Oxygen
H74 Carbon dioxide
H33 Other dissolved gases
H22 Phosphate
H23 Total - P
H24 Nitrate
H25 Nitrite
H75 Total - N
H76 Ammonia
H26 Silicate
H27 Alkalinity
H28 PH
H30 Trace elements
H31 Radioactivity
H32 Isotopes
H90 Other chemical oceanographic measurements

MARINE CONTAMINANTS/POLLUTION
P01 Suspended matter
P02 Trace metals
P03 Petroleum residues
P04 Chlorinated hydrocarbons
P05 Other dissolved substances
P12 Bottom deposits
P13 Contaminants in organisms
P90 Other contaminant measurements

MARINE BIOLOGY/FISHERIES
B01 Primary productivity
B02 Phytoplankton pigments (eg chlorophyll, fluorescence)
B71 Particulate organic matter (inc POC, PON)
B06 Dissolved organic matter (inc DOC)
B72 Biochemical measurements (eg lipids, amino acids)
B73 Sediment traps
B08 Phytoplankton
B09 Zooplankton
B03 Seston
B10 Neuston
B11 Nekton
B13 Eggs & larvae
B07 Pelagic bacteria/micro-organisms
B16 Benthic bacteria/micro-organisms
B17 Phytofilm
B18 Zoobenthos
B25 Birds
B26 Mammals & reptiles
B14 Pelagic fish
B19 Demersal fish
B20 Molluscs
B21 Crustaceans
B28 Acoustic reflection on marine organisms
B37 Taggings
B64 Gear research
B65 Exploratory fishing
B90 Other biological/fisheries measurements

MARINE GEOLOGY/GEOPHYSICS
G01 Dredge
G02 Grab
G03 Core - rock
G04 Core - soft bottom
G08 Bottom photography
G71 In-situ seafloor measurement/sampling
G72 Geophysical measurements made at depth
G73 Single-beam echosounding
G74 Multi-beam echosounding
G24 Long/short range side scan sonar
G75 Single channel seismic reflection
G76 Multichannel seismic reflection
G26 Seismic refraction
G27 Gravity measurements
G28 Magnetic measurements
G90 Other geological/geophysical measurements