





A research charter by the Australian National University

# SS02/2009

Hydrothermal plume and structural geology mapping in the Tonga/Fiji region.

## A research charter by the Australian National University

## Voyage period

22/04/2009 to 25/06/2009

Voyage had 2 Legs: Leg 1: 22/04/2009 to 18/05/2009 PORT OF DEPARTURE (Lautoka, Fiji) PORT OF RETURN (Nuku'alofa, Tonga)

Leg 2: 29/05/2009 to 25/06/2009 PORT OF DEPARTURE (Nuku'alofa, Tonga) PORT OF RETURN (Lautoka, Fiji)

#### **RESPONSIBLE LABORATORY**

Professor Richard J. Arculus Research School of Earth Sciences, Australian National University, Canberra, ACT0200 Australia

## **CHIEF SCIENTIST(S)**

Professor Richard Arculus (Chief Scientist) The Australian National University Research School of Earth Sciences Bldg 47 RSES, ANU, Canberra 0200 AUSTRALIA **Phone:** +61 2 6125 3778 **Fax:** +61 2 6125 5544

Mr Gary Massoth (Deputy Principal Investigator) 2100 Lake Washington Boulevard, Renton, WA 98056 United States of America **Phone:** +1 425 204 9171 **Fax:** +1 425 204 9171

Chief Scientist Leg 1: Gary Massoth Chief Scientist Leg 2: Richard Arculus

# **Scientific Objectives**

The fundamental scientific objective of SS02/2009 is to help gain a greater understanding of ocean floor tectonics and magma activity at the boundary of the Australian and Pacific plates in the northeastern Lau Basin. Previous research voyages have indicated this area is tectonically and structurally complex and is very active from a volcanic and hydrothermal aspect. This Voyage will gather more detail about this activity to help generate an improved model of the current activity and historical construction of this unique part of the Earth's crust. The uniqueness of this area relates to the fact that this major plate margin represents the one of the most rapid centre of crustal spreading on the planet, and hence makes a great laboratory for how new crust forms and reacts in such an environment.

## **Voyage Objectives**

The core objective is to use water column chemistry and bathymetric mapping tools in order identify the tectonic and volcanic features that are most likely to host hydrothermal systems. Hydrothermal sites will be specifically targeted with camera tow and dredge operations to identify and collect rock samples that will be analysed later in laboratories. More specifically, the objectives are:

- Integrate multibeam and plume hunting data to generate high confidence prioritized targets for first pass assessment using the camera tow/grabber/ dredge;
- 2. Implement, assess and improve plume hunting techniques to increase confidence in finding the source of the plumes using CTD and water sampling techniques;
- Gather multibeam data in areas where there is no data and integrate into current database;
- 4. Optimize the real-time tow-yo and MAPR data processing to refine target foot print, using  $\Delta$ NTU, Eh, pH, and filtrates to vector into target source with cross tow and casts;
- 5. Optimise the real-time multibeam data processing to refine target foot print using CARIS and CUBE algorithms.

In regard to sampling operations, the equipment priorities that flow from the voyage objectives are:

- 1. CTD sensor data and water collection;
- 2. Swath mapping data;
- 3. Camera data (user supplied and operated);
- 4. Rock dredge samples.

## Results

1. Integrate multibeam and plume hunting data to generate high confidence prioritized targets for first pass assessment using the camera tow/grabber/dredge.

The integration of the multibeam and plume hunting data was quite successful as multiple targets for follow-up were generated. The improved resolution of the EM300-acquired bathymetry, both on this Voyage but for both legs particularly from SS11/2004 (NoToVE) and SS07/2008 (NoLauVE), allowed for greater precision when planning towyo operations, imaging the tectonics (and hence active volcanic loci) of the Lau Basin.

2. Implement, assess and improve plume hunting techniques to increase confidence in finding the source of plumes using CTD and water sampling techniques.

This was certainly successful. The major part of that success came from completing tow-yo operations along the best features with follow up cross-tows as opposed to doing single hydrocasts which could more easily miss a target. The plume hunting equipment used enhanced our strike rate of targets due to greater sensitivity (e.g., nephelometer is demonstrably superior to a transmissometer in this respect). The introduction of 2 types of Eh meters was great along with the backup of Miniaturised Autonomous Plume Recorders (MAPRs) to cross-check results. This improved tow-yo dataset allowed for greater confidence in targeting with the camera tow and dredge. Most of the water sampling implications will be assessed after lab based analysis is completed.

- 3. Gather multibeam data in areas where there is no data and integrate into current database.
- 4. This was also successful because it helped the interpretation of the critical geological features previously unseen in low resolution data.
- 5. Optimize the real-time tow-yo and MAPR data processing to refine target foot print, using ΔNTU, Eh, pH, and filter resides to vector into target source with cross-tow and casts.

This was a really successful breakthrough as the efficiency of data handling and turn around time to produce a useful product was greatly improved. This helped significantly in planning the follow-up camera tow and dredging operations in a timely fashion which impacted on efficient use of ship time where we did not have to wait very long to wait for the next operation. This was particularly powerful when all data was visualised in 3D for target selection.

6. Optimise the real-time multibeam data processing to refine target foot print using CARIS and CUBE.

This was deemed successful because the enhanced processing power allowed for the production of optimised bathymetric maps that showed distinct geological features that were not readily observable with standard processing. This helped significantly in the recovery of sulfides at NEL5.

## Leg 1. Lautoka to Nuku'alofa

## Day 1. Wednesday April 22nd

Departed Lautoka at 0845 hours Fijian time. Tracked SW from Lautoka through the reef passage. Started swath bathymetry upon reaching deeper water (>1000m), tracking around the northern extent of the Fijian Plateau. Started MBES transit on departure from Fiji, 324 km data collected as of 24h00 local time, average vessel speed 9-10 knots. Engaged with setting up survey procedure and data flow and data formats. Data is acquired in the Kongsberg SIS system and transported across to two CARIS workstations for cleaning and processing. Vessel real-time visualization has been set up using Fledermaus Vessel Manager to visualize the vessel progress along bathymetric DTM (currently using SeaSat bathymetric data for Fijian waters). We are currently able to monitor vessel progress and show display the extent of MBES swathe coverage in real-time. We have also successfully run a USBL simulation, which was used to test the real-time mode for when the vessel commences Tow-yo operations. We are also busy testing backscatter data processing capabilities in Fledermaus, and resolving issues with different line projections for planned lines from ArcGIS for import into other software CARIS and Fledermaus, with the aim of making the processes more streamlined. Tony Veness, CSIRO Swathman, is developing Python script for re-exporting actual lines traversed from SIS system back into ArcGIS, to enable reconciliation of proposed work vs. actual work performed. The camera was set up. There are some parts missing but we worked around this issue. The camera is operational. CSIRO in Perth has been notified of the problem. VSAT and networking issues have been resolved. Currently networking through the Southern Surveyor central network drive. The VSAT feed is also patched through this system. The CTD has been set-up and tested. The system appears to be working well and we are confident that we will be ready to deploy as soon as we get to the first line (NEL1). Dredges were inspected and appear to be in good condition.

#### Day 2. Thursday April 23rd

Continuous swath mapping through the 24 hour period. Tracked in a general easterly direction towards Tonga, continued to follow the North Fiji Fracture Zone and just reached the most NW extent of the Peggy Ridge at the end of the day, ~445 line km were covered at ~9.5knots. It was suggested from the swath team that the data has some gaps in it due to travelling at greater than 9 knots and therefore suggested to reduce speed for our main areas in the NE Lau. A site is chosen on the NW Peggy Ridge to do a second pass swath to ascertain if this area is suitable for the calibration of the Sonardyne. They are looking for depths of 700-800m to drop the transponder. It may take several hours to complete the test. The VSAT has been made available to the crew of the Southern Surveyor, on two computers in the recreation room. There has been a good shift in morale amongst the crew. A few incidents of seasickness have been noted. The sick have been asked to take it easy. Set up Fledermaus project for Tongan water with historical MBES DTM (composite) and backscatter data from Thompson 2008 voyage, and proposed tow-yo tracks. Spent considerable time addressing data format issues between various software packages being used in the processing flow. Processing of data in CARIS is going smoothly. Will begin analysis and processing of Backscatter data in Fledermaus and export of DTM data into ArcGIS and address any problems with dataflow process.

#### Day 3. Friday April 24th

We arrived at the location on the NW Peggy Ridge where the water depth is suitable for the Sonardyne calibration. Two swath mapping sweeps over the location clarified that the water depth was less than 1000m. The successful calibration test was completed after 7.5 hours. Swath mapping continued in a general easterly direction towards Tonga following interesting broad bathymetric features, 300 line km of MBES data acquired up to 24h00.. Basic training on the MAPRS, Helium crimper, Tow Camera was carried out today.

#### Day 4. Saturday April 25th

SS towed CTD underwater package NE along line NEL1b for over 5 hours and ~ 9 line km before it was decided that the wire was being pushed by the deep currents up against the A-frame and starting to go under the ship. It was decided to recover the CTD and swath map to the NE end of line NEL1a, redeploy the CTD and tow in the reverse direction, 18 line kms of towpath were accomplished in total. A decision was made to swath map at ~7-8 knots to improve the data quality. One swath was completed to the NE and tow yo recommenced on NEL1a heading SW. 149 line kms of swath data were collected. A toolbox talk was carried out this morning prior to CTD deployment. An ANZAC ceremony was carried out this morning on the back deck.

#### Day 5. Sunday April 26th

Operation	Line Kms completed	Hours completed	New Targets
Multibeam	13	2	-
Tow Yo	46	19	-
Dredge (grabber)	-	3	-
Total	48	24 (incl transits)	-

Tow yo continued down the NEL1a line with little response to indicate any plumes. 3 bottles triggered where a small Eh spike occurred with no corresponding NTU. These bottles will be used as training run for filtering. Recovered package at ~7pm local time to allow for maintenance. Problems with the forward hydrographic winch require that it be re-spooled. The bearings were replaced after the last voyage and the cable was not spooled on correctly. To make the most of this operation we decided to add the 'grabber' to the wire and drop it onto a particularly interesting volcanic feature to see if we could capture a rock sample. This exercise was unsuccessful for two reasons: firstly, the mechanism did not release and therefore no material was collected; secondly, the cable did not spool out enough (i.e., >1800m) to fix the overlap issue. The day finished with a swath across the volcano pair approx 90 degrees to the previous swath. This is to test the idea that multiple passes of EM300 over the same site can enhance the resolution of bathymetric features and also the backscatter definition. Completed Fiji - Tonga swath transect at 07h07. Data was acquired at 9-10 knots, and gridded 40 -50 m ell-size. Data quality is noticeably compromised at these speeds, with noticeable gaps in the data and therefore needs to be interpolated to produce decent images. Started swath line NEL1A at 13h58 and completed 19h47. Data was acquired at 6-7 knots and marked data quality improvement noted in both MBES DTM and Backscatter. MBES was gridded to 25 m cell size and backscatter to 12 m.

#### Day 6. Monday April 27th

Operation	Line Kms completed	Hours completed	New Targets
Multibeam	110	9	-
Tow Yo	-	19	-
Dredge (grabber)	-	3	-
Total	-	24 (incl transits)	-

Tow yo continued down the 80 km long NEL1c line through volcanic and rifted zones without CTD sensor indication of a plume. At the end of the line a series of water samples were collected to do a pH profile of the ocean to use as a training session, to test of the onboard procedures and equipment as well as providing a regional background profile. A swath mapping exercise confirmed that EM300 data can be collected whilst towing at 1.5 knots and that the swath beams do not interfere with the USBL. This was followed by a long swath line to complete the NEL1A-E program. Upon completion of this swath there was a short transit to NEL2a and NEL2b CTD tow lines.

### Day 7. Tuesday April 28th

Operation	Line Kms completed	Hours completed	New Targets
Multibeam	120	6	-
Tow Yo	27	18	-
Total	-	24 (incl transits)	-

Most of the day was spent on tow yo lines NEL2a and NEL2b. Unfortunately these areas produced no water column anomalies. Swath mapping is almost continuous now with each tow yo and transit line mapped. This was followed by a five hour transit to tow line NEL5a. Due to consistent strong ocean currents pulling the tow package in a westerly direction, the Master has suggested we tow from N to S to avoid the wire coming under the ship. Tow line NEL5a commenced at 8pm. The ship barely went 2 km along this line and the wire was hard against the ship and the call was made to pull it up and try and reset to another position along the line and tow in reverse. We recast the CTD at a section 3.5 km down the line headed NE. The objective is to cross the main ridge and a previously known plume site.

#### Day 8. Wednesday April 29th

In transit

## Day 9. Thursday April 30th

Operation	Line Kms completed	Hours completed	New Targets
Multibeam (6-7 knots)	37	5	-
Multibeam (1.5 km tow yo)	35	-	-
Tow Yo	35	13	-
Maintenance- breakdown	-	6	
Total	-	24 (incl transits)	-

The day started with a continuation of the towline NEL5b. The only water column activity was detected near the completion when a significant NTU anomaly was detected with no corresponding Eh response. Water samples were collected and processed for pH and helium. As this plume was high in the water column (~200-400m), no anomalous pH and no Eh anomaly, it was interpreted to have been sourced

from the ridge (possibly the eruptive site) ~2.5 km to the west. Therefore this is not designated as a target site. When the CTD was being recovered at the end of this tow it was noticed that there was something wrong with the cable and hence all operations ceased while the problem was investigated. The details of this issue have been documented in an incident report. A consensus of senior personnel from the vessel and Nautilus was a modification required for the survey to accommodate the need to continue gathering data plus arrive at a site whereby the cable on the forward drum could be unspooled and reset on the drum. In the early afternoon we recommenced operations starting with swath mapping along lines NEL8A and NEL8E which was on transit to the tow line NEL9a which was towed from S to N.

#### Day 10. Friday May 1rst

Operation	Line Kms completed	Hours completed	New Targets
Tow Yo	0	3	-
Maintenance- breakdown	-	21	
Total	-	24 (incl transits)	-

Tow line NEL9a was completed, no water column anomalies detected. The Master decided to transit to Apia, Western Samoa to drop off a sick crew member and to wait for a replacement. During the transit over the Tonga Trench, the forward winch was unspooled and respooled under tension to correct wrap issues. The operation was completed successfully and there is general confidence that it will handle the rest of the tow campaign. A larger snatch block was installed in hope of less wear on the wire splice at ~3,400M wire out. The fleet angle of the forward winch allows better clearance of the A-frame, and is the preferred winch for CTD operations. A procedure has been developed onboard to display tow-yo CTD data in Fledermaus as vertical sections.

#### Day 11. Saturday May 2nd

Day spent in Apia.

#### Day 12. Sunday May 3rd

Operation	Line Kms completed	Hours completed	New Targets
Multibeam (1.5 km tow yo)	16	6.5	-
Transit		14	-
Maintenance/port call	-	3.5	
Total	-	24	

The ship left the Apia dock at 03:30, and transited to NEL9b. The CTD was launched the line NEL 9b was started with no plumes detected.

#### Day 13. Monday May 4th

Operation	Line Kms completed	Hours completed	New Targets
Multibeam (1.5 km tow yo)	40	-	-
Tow Yo	40	21.5	1
Transit	-	2	-
Maintenance/port call	-	0.5	-
Total	40	24	-

CTD tow line NEL9b was completed very early morning with no major plumes detected. Some small high elevation NTU anomalies were detected but were interpreted as coming off the main ridge to the east. Line NEL 9c was then completed with detection of a strong plume signal on top of the ridge at the junction of the previous RV Thompson tow line. Water samples were sampled and 2 bottles filtered for particulates. Dark colored particulates were observed under a binocular microscope. This area is considered a new target for Nautilus Minerals. We then completed CTD tow line NEL10a whilst we plotted and planned a camera tow for the NEL9 area. CTD tow line NEL10a had moderate success with an interesting plume on the crest of the volcanic feature termed East Mata. A low NTU response and high Eh response resembled the plume previously noted at this site by NOAA colleagues in 2008. There was also an anomaly detected on the flanks of East Mata which showed a reasonable NTU response but no Eh. An attempt was made at a camera tow along the ridge at NEL9 but due to a mechanical failure of the coring winch shortly after launch this operation was aborted.

## Day 14. Tuesday May 5th

Operation	Line Kms completed	Hours completed	New Targets
Multibeam (6-7 knots)	3	1	-
Multibeam (1.5 km tow yo)	24	-	-
Tow Yo	24	16.5	3
Dredge	-	2	-
Transit	-	4.5	-
Total	40	24	-

The crew reported that they have fixed the coring winch used for camera tows. A dredge operation occurred in the early hours of the morning following a tool box discussion. A 1.5 hour long operation retrieved rocks dominated by light white-grey pumice and no mafic basalts. There was considerable hydrothermal alteration, deposits of native sulphur and Fe-staining. A strong sulphur smell permeated everything recovered including numerous large live mussels, one large snail and a worm. No sulfide mineralization was observed. Clearly, a low temperature hydrothermal vent field was dredged. Tow line NEL10c along a NE trending ridge failed to produce plume targets. In contrast NEL10b, which tracked N-S over a series of E-W trending elongate volcanic features, produced several sites of intense plume activity. The conduct of this line was delayed due to tow direction considerations, requiring a stop of a northerly tow and return to that position from the north end of the line. The NEL10a E. Mata site was selected for a later cross tow. The lower West Mata plumes were excluded from the Nautilus list due to the subtle nature, no Eh and being in the shadow of an active eruption.

## Day 15. Wednesday May 6th

Operation	Line Kms completed	Hours completed	New Targets
Multibeam (6-7 knots)	39	2.25	-
Multibeam (1.5 km tow yo)	18	-	-
Tow Yo	18	12	-
Dredge	-	2.25	-
Transit	-	7.5	-
Total	11	24	-

Two CTD towlines were competed around the big ("O") caldera, NEL6c & d. Line NEL6d was started but terminated early due to the wire unravelling at the splice termination, similar to what happened to the aft winch wire. After a quick meeting to discuss the options messages were relayed to the beach and agreement was reached on the course of action. It was decided that both wires would be repaired (new shims installed) whilst at sea. This required unspooling into deep water to be able to get to the splice section. We travelled northward about 24 nm to a deep water location and repairs were carried out.

### Day 16. Thursday May 7th

Operation	Line Kms completed	Hours completed	<b>New Targets</b>
Multibeam (6-7 knots)	39	2.25	-
Multibeam (1.5 km tow yo)	18	-	-
Tow Yo	18	12	-
Dredge	-	2.25	-
Transit	-	7.5	-
Total	11	24	-

## Day 17. Friday May 8th

Operation	Line Kms completed	Hours completed	New Targets
Multibeam (6-7 knots)	50	5	-
Multibeam (1.5 km tow yo)	20	-	-
Tow Yo	20	14	-
Transit	-	2	-
Maintenance/port call	-	3	-
Total	11	24	-

Following wire repairs in deep water, we returned to the remaining CTD towlines along the flanks of Nel"O" caldera ,NEL6a & b. Neither line produced a water anomaly below the caldera rim. Line NEL6a was terminated early due to further problems with shims at the splice in the aft CTD wire. While we swath mapped NEL8, the crew wound the aft winch wire above the termination onto an available winch spool, cut the CTD wire inwards of the splice and re-terminated the CTD wire. While the fresh CTD termination 'cured' (12-h required) it was decided to switch back to the forward winch where a wire out restriction of 3000m would be in effect. Swath mapping of NEL8 was terminated early due to time constraints although a low-lying bathymetric ridge (1700 to 550 m depth) was selected for a CTD tow.

#### Day 18. Saturday May 9th

Operation	Line Kms completed	Hours completed	New Targets
Multibeam (1.5 km tow yo)	28*	-	-
Tow Yo	24	14.5	-
Tow Camera	2	5	-
Transit	-	4.5	-
Total	-	24	-

\*NB. swath mapping below ship extends further than end of every tow line

In the early hours of this morning tow line NEL8 was completed with no plume anomalies detected. Following a 3-hour transit to the NEL5 plume site, two new tow lines on the spreading centre were conducted. A cross tow at this site resulted in a repeat Eh response and a broad and complex NTU plume. We next completed line NEL5c, which was moved from the depths of the zone between the NELSC and NELCa up onto the ridge. This line yielded no new anomalies and finished by crossing and confirming the existing anomaly at its northern end. This two was followed up with a camera tow which intersected the most intense anomalies detected in the target area.

#### Day 19. Sunday May 10th

Operation	Line Kms completed	Hours completed	New Targets
Multibeam (6-7 knots)	50	4	-
Multibeam (1.5 km tow yo)	16*	-	-
Tow Yo	15	9	-
Dredge	0.2	3	-
Transit	-	4	-
Maintenance/port call	-	6	-
Total	-	24 +	-

\*NB. swath mapping below ship extends further than end of every tow line

The day started with a S-to-N CTD tow yo along NEL7. Early in the line we encountered an NTU response with no Eh over a distance of at least 3 km recognized to be distal (~4.5km north) remnant of the NEL5 plume. At the ~12 km mark, a small but distinct Eh and NTU anomaly was detected but not sampled. During this period the towcam video was downloaded and viewed. Careful examination revealed white mat and occasional squat lobsters leading up to a chimney field associated with talus and widespread coatings. Another winch problem surfaced this day. NEL7 was terminated early because of the 'knife' on the level-wind was worn to the extent that it allowed the wire started to bunch on the winch drum. At the time we noticed the problem, ~3000m of wire were out requiring that we once again head for deep water to replace the level-wind knife. Completion of the NEL7 line was dropped to accommodate the necessary respooling, after which we transited back to the NEL5 site to dredge the suspected venting site. Although weather conditions hampered the first attempt at dredging, a second attempt was successful. We recovered a substantial quantity of weathered basalt along with bits of sulfide chimney talus. The sulfides were chalcopyrite to sphalerite-rich generally appeared to be weathered. Several samples contained barite and anhydrite and what looked like botryoidal Mn crystals. Fe-staining and Mn coatings were common and several eroded snail shells and squat lobsters were also recovered.

#### Day 20. Monday May 11th

Operation	Line Kms completed	Hours completed	New Targets
Multibeam (1.5 km tow yo)	31*	-	-
Tow Yo	30	19	-
Transit	-	5	-
Total	-	24	-

\*NB. swath mapping below ship extends further than end of every tow line

Today we transited to the most southern extent of the Mangatolo Triple Junction (MTJ) and tow line NEL4 where no plume anomalies were detected. The weather worsened as a large swell developed. A CTD deployment at southern end of the NEL4 line was aborted early in the tow and the tow direction and line approach reversed to accommodate wire drift. Half way through the re-directed tow, it was noticed the USBL signals degraded due to possible battery and/ or rough water. The CTD/USBL package was retrieved, a fresh relay beacon installed, and a faster ping rate selected to compensate for the rougher weather. The NEL4 line was completed and we transited to tow line NEL14b.

#### Day 21. Tuesday May 12th

Operation	Line Kms completed	Hours completed	New Targets
Multibeam (1.5 km tow yo)	41*	-	-
Tow Yo	40	18	-
Transit	-	1.5	-
Maintenance/port call	-	4.5	-
Total	-	24	-

\*NB. swath mapping below ship extends further than end of every tow line

The weather moderated as we arrived at the northern end of line NEL14b. During deployment of the CTD a small kink in the CTD wire occurred resulting in the need to reterminate the wire, this time using a faster setting seal. The first attempt failed at depth resulting in a second re-termination that worked for the duration of the expedition. The NEL14b tow failed to produce a noticeable plume anomaly on the plot displays used to monitor sensor response. A deep profile in helium was collected.

### Day 22. Wednesday May 13th

Operation	Line Kms completed	Hours completed	New Targets
Multibeam (1.5 km tow yo)	38*		-
Tow Yo	38*	18.5	-
Transit		5.5	-
Total	-	24	-

\*NB. swath mapping below ship extends further than end of every tow line

As we neared completion of NEL14b, the wind swung SE forcing a CTD recovery and a redirected tow to finish the line. Closer examination while post-processing the NEL14b tow data revealed two small plume anomalies identified as coincident NTU and Eh signals. Watch standers were encouraged to enhance the viewing scales on real-time monitoring plots. Line NEL14d was conducted next without plume detection. The 85-km-long NEL11a tow line was divided to accommodate the S-to-N tow direction demanded by prevailing sea and wind conditions and mimimize transit time. The northern 35-km tow section was commenced.

## Day 23. Thursday May 14th

A further 23 km of NEL11a, 12 km of NEL11b and a 3km NEL11\_crossTow1 were completed today for a cumulative 38 km of towpath. Multiple plumes near the cross-over point of the 11a and 11b towpaths were detected.

## Day 24. Friday May 15th

Operation	Line Kms completed	Hours completed	New Targets
Multibeam (1.5 km tow yo)	31	-	-
Tow Yo	30	16	1
Tow Camera		1.5	-
Transit		6.5	-
Total	-	24	-

Most of today was spent on the southern section of line NEL11a (referred to here as the South Central Fonualei). A low-level NTU anomaly was detected on the western ridge line. Upon our return to the NEL 11a Central Fonualei plume region, a second cross tow detected spikes in Eh and NTU similar to the previous tows. Our most intense plume signals were used to select a camera towpath. The NEL11a (south central) tow covered 27 line km while the NEL11\_CrossTow2 extended only 2.5km. NEL11\_camera tow1 was launched in the last hour of the day.

## Day 25. Saturday May 16th

Operation	Line Kms completed	Hours completed	New Targets
Multibeam (6-7 knots)	30	3	-
Multibeam (1.5 km tow yo)	31	-	-
Tow Yo	6	3.5	1
Tow Camera		4.45	-
Dredge		3	-
Transit		9.45	-
Total	-	24	1

The ~2-km-long camera tow begun at the end of the previous day passed through the intersection of plume anomalies detected during 3 CTD tows in this region. Upon its completion, CTD tow-yo operations continued along a mid section of line NEL11a until the camera footage was viewed. Unfortunately the had camera failed to start due to a battery issue, which was quickly resolved, and a second attempt made on the same line. Although the camera failed to return any footage, the cage returned a small sample of sulfide rich in bornite with traces of chalcopyrite. Two dredges at different local plume anomaly coordinates failed to recover further sulfides but did return weathered basalt. Following the dredges we transited south to the south end of the NEL12a towline, completing one swath line (NEL11A) at 6.5 knots enroute. We commenced the NEL12a tow S-to-N shortly before midnight. Upon post-processing of the NEL11a southern extent tow data, we resolved another target approximately 5km south of the site central venting area. This site lies on a small ridge line between NEL11a and NEL11b and was identified by significant Eh response on the two lines.

## Day 26. Sunday May 17th

Operation	Line Kms completed	Hours completed	New Targets
Tow Yo	33	15.5	1
Transit		8.5	-
Total	-	24	1

Today at 1530L we ended Leg 1 operations, and began the transit to Nuku'alofa, Tonga. The vast majority of the CTD lines were completed (only 3 lines remained untouched). CTD line NEL12a was completed and produced a final target total of 12. An Eh anomaly was detected on the northern flank of the southernmost significant volcanic construct within the Fonualei basins. An abbreviated cross tow (NEL12\_CrossTow1) confirmed the plume anomaly with a slightly greater intensity suggesting the source may lie west of line NEL12a.

## Day 27. Monday May 18th

In transit to Nuku'alofa.

## Port period Tuesday May 19th to Thursday May 28th

## Leg 2. Nuku'alofa to Lautoka

## Day 1. Friday May 29th

Paperwork problems concerning loading of a container of provisions from Australia onto the ship delayed departure.

## Day 2. Saturday May 30th

Operation	Line Kms completed	Hours completed	New Targets
Multibeam (6-7 knots)	186	9.0	-
Multibeam (1.5 km tow yo)	-	-	-
Tow Yo	-	-	-
Tow Camera	-	-	-
Dredge	-	-	-
Transit	-	11	-
Maintenance/port call	-	13	-
Total	-	24	-

Provisions loaded, we departed Nuku'alofa at 1255 hours Tongan time. The transit route was designed to pass over Volcano 5 and part of Volcano 6, which required minimal deviation from a straight path to ELSC7. Stopped at 1500 for a vessel in distress. Stayed with vessel until pilot from Nuku'alofa arrived to tow him back to port. Resumed transit around 1630. Stopped at around 1720 for a test dip to check flying of the CTD rosette with the new stabilising fin. Resumed transit at 1750. Preparation and integration of all MBES and Fledermaus 3D visualisation software and processing streams have been completed, and multibeam system is performing well.

#### Day 3. Sunday May 31st

Operation	Line Kms completed	Hours completed	New Targets
Multibeam (6-7 knots)	-	-	-
Multibeam and Tow yo (1.5 k	(nots) 17.2	13	-
Multibeam (Transit)	169	7.5	-
Tow Yo	-	-	-
Tow Camera	-	-	-
Dredge	-	-	-
Transit	-	3.5	-
Maintenance/port call	-	-	-
Total	-	24	-

Continued transit to start of ELSC7\_TY\_1 swath mapping along the way. At 07:30 Arrived at south end of ELSC7\_TY\_1. Toolbox talk held before CTD deployment. At 09:30, CTD deployed. Tow line ELSC7\_TY\_1 started from the south end. A helium sample profile was completed in a deep basin about one quarter of the way up the line. Samples were taken every 100m from 2960m to 1600m depth. A (very) small Eh and NTU anomaly was observed on south flank of steep knoll (centre of knoll at 525950E 7468080N). Data will be processed and reviewed. 15:20 Wire was being swept under the stern of the vessel and decision was made to recover the CTD to deck. Decided to try line ELSC7\_TY\_2 starting from the SE end as the wind is more favourable. 16:20 CTD on deck, transit to next location. 16:30 Toolbox talk held with the Day shift – CTD deployment and recovery. 18:20 Launch CTD at eastern end of ELSC7\_TY\_2. 20:35 Completed about 3.2 line kms when wind changed direction to W-SW and again forcing the vessel over the cable. Now head to north end of ELSC7\_TY\_1 and survey towards south. Named this line ELSC7\_TY\_1a. 21:30 CTD on deck, transit to next location. 23:00 Launch CTD at northern end of ELSC7\_TY\_1a.

## Day 4. Monday June 1st

Operation	Line Kms completed	Hours completed	New Targets
Multibeam (6-7 knots)	-	-	-
Multibeam and Tow yo (1.5	knots) 39	21	2
Multibeam (Transit)	-	-	-
Tow Yo	-	-	-
Tow Camera	-	-	-
Dredge	-	-	-
Transit	-	3	-
Maintenance/port call	-	-	-
Total	-	24	-

00:00 Continued towing ELSC7\_TY\_1a. Two anomalies were discovered on this line. The northern one is Eh only at a depth of around 2200m. The second anomaly is on the same mound where the weak Eh anomaly was found yesterday. There is a good Eh anomaly with associated weak  $\Delta$ NTU anomaly at a depth of about 1950m. The southern edge of the anomaly was closed off and then we recovered the CTD. 13:30 CTD on deck. 15:15 CTD deployed on cross tow ELSC7\_TY\_3 which was designed to go over the northern Eh anomaly plus also hit some of the mounds targeted in proposed

line ELSC7\_TY\_2 (which was not completed). This tow was disappointing with a weak (0.002) regional NTU anomaly noticed at about 1900m on most upcasts. No Eh anomaly was observed. Possibly this line was too far north. 20:50 Started having problems with the USBL dropping out consistently when only 1700-2000m behind the ship. As we had completed most of ELSC7\_TY\_3 we decided to recover to deck. 21:45 CTD on deck and transiting to start line ELSC7\_TY\_4 which is designed to track over a major volcanic edifice feature which appears to be the southern extent of the VFR and then cross the main anomaly from this morning. 22:50 CTD launch at ELSC7\_TY\_4. Unless we get a good  $\Delta$ NTU anomaly on this line, we will then push on to area ELSC6.

#### Day 5. Tuesday June 2nd

Operation	Line Kms completed	Hours completed	New Targets
Multibeam (6-7 knots)	-	-	-
Multibeam and Tow yo (1.5	knots) 42.8	20	
Multibeam (Transit)	58	-	-
Transit	-	4	-
Total	-	24	-

00:00 Continued tow line ELSC7\_TY\_4. No plumes were detected which was disappointing. No response when this line crossed over the plumes detected yesterday. Decided to push on to ELSC6. 06:00 CTD on deck and transit to ELSC6. 09:50 CTD deployed at south end of ELSC6\_TY\_1. Got blown a little to the east of the planned line due to the southerly wind. Detected a weak shallow plume – 0.01 peak dNTU at 1450-1500m of water – located on north side of mound at 547600E 7549600N. Plume noted on a couple of adjacent down/up casts. Very shallow in the water column and very weak with no Eh signature. Difficult to pinpoint where source might be. Closed this plume off to the north and on next down cast detected a nicer looking plume at 1800-1850m though still only about 0.01 dNTU and no eH. Plume located close to where the Telve Tow Yo through Twin Peaks finishes. Initial thoughts are that this is the same as the deeper plume seen in the Telve data on the east side of Twin Peaks. These plumes were not considered worth further work. The data and water samples need to be properly analysed. Decision made to push onto ELSC4 next.



Figure 1: Status of CTD tow lines in ELSC - 02/06/2009

#### Day 6. Wednesday June 3rd

Operation	Line Kms completed	Hours completed	New Targets
Multibeam (6-7 knots)	-	-	-
Multibeam and Tow yo (1.5	knots) 42	20	
Multibeam (Transit 10 knot	s) 62	4	-
Total	-	24	-

00:00 Completing the north end of ELSC6\_TY\_1. 02:00 CTD on deck and transit to ELSC4. 06:10CTD off deck at south end of ELSC4\_TY\_1. Small NTU anomalies noted between 1800-2000m deep along a lot of the line which appears to be a regional weak plume. Continued towing this line for the remainder of the day with no plumes noted.

## Day 7. Thursday June 4th

Operation	Line Kms completed	Hours completed	New Targets
Multibeam (6-7 knots)	-	-	-
Multibeam and Tow yo (1.5	knots) 76	21	
Multibeam (Transit 10 knot	s) -	3	-
Total	-	24	-

00:00 Continuing tow line ELSC4\_TY\_1. No plume anomalies detected. 07:45 CTD on deck after full toolbox talk with night shift on CTD and MAPR recovery procedures. Transit to ELSC3. 08:45 Full toolbox talk on bridge on CTD and MAPR deployment. 09:20 CTD off deck for ELSC3\_TY\_1. Small NTU plume (no Eh) discovered on south side of small volcanic cone at 1940-1990m depth. This is about 4-5 km east of last years CELSC\_Plume006 target area which was ROV mapped from the Norsky. No plume source was discovered last year. An EW cross tow covering both CELSC\_ Plume006 and the new plume is being considered. Another small NTU (no Eh) plume was discovered on the south side of the next group of volcanic cones at a similar depth. 17:20 Persistent USBL failures led to decision to recover CTD to deck and swap beacons. 18:35 CTD on deck after full toolbox talk on bridge with day shift on CTD recovery and deployment procedures. 20:00 CTD off deck to continue surveying ELSC3\_TY\_1. This second launch on this line is called ELSC3\_TY\_2. No plumes detected by 24:00.

#### Day 8. Friday June 5th

Operation	Line Kms completed	Hours completed	New Targets
Multibeam (6-7 knots)	-	-	-
Multibeam and Tow yo (1.5	knots) 50	19.5	
Multibeam (Transit 10 knot	s) -	4.5	-
Total	-	24	-

00:00 Continuing tow line ELSC3\_TY\_2. No plume anomalies detected. Line finished and crew instructed to recover CTD. 18:50 CTD on deck after full toolbox talk with day shift on CTD and MAPR recovery procedures. Transit to cross tow ELSC3\_TY\_3. 23:30 CTD off deck at west end of ELSC3\_TY\_3 after another full toolbox with day shift on CTD and MAPR launch procedures. 24:00 CTD still on descent. Plans are in place to transit to WL2 after ELSC3\_TY\_3 is completed to swath map down the proposed tow line WL2\_TY\_2 and then transit the WL4 to start the WL CTD tows.

#### Day 9. Saturday June 6th

Operation	Line Kms completed	Hours completed	New Targets
Multibeam (6-7 knots)	75	6	-
Multibeam and Tow yo (1.5	knots) 14.6	11	
Multibeam (Transit 10 knot	s) -	7	-
Total	-	24	-

00:00 Cross tow ELSC3\_TY\_3 discovered an NTU and Eh plume about 1.4km to the east of the Norsky CELSC\_Plume006 ROV track. Plume depth is 1850-2050m with max  $\Delta$ NTU about 0.05 and an Eh kick of 20-25 mV. A separate weaker NTU only plume was found east of the volcanic cone at the eastern end of the tow. This corresponds to the plume found at the south end of tow ELSC3\_TY\_1.

06:50 CTD on deck after toolbox. Plans drafted for another cross tow to traverse NS through the larger plume and try and pinpoint the source. 09:00 CTD off deck after toolbox at south end of ELSC3\_TY\_4. Same NTU and Eh plume mapped out well at a depth of 1850-2000m. Max  $\Delta$ NTU is about 0.08 and Eh kick of about 10 mV. A second deeper plume was also seen at 2190m depth with a  $\Delta$ NTU of about 0.015. Data review suggests source is possibly the western flank of ridge just to the SE. This is the only feature that appears to be at the right level. The top of the ridge is at 2140m depth. The eastern plume near the south end of ELSC3\_TY\_1 could either be coming from the nearby volcanic cone or possibly a NS ridge to the north, although the ridge is a bit deep. 13:20 CTD on deck after toolbox. Transiting to WL2. 16:05 Start swath mapping down proposed tow line at WL2. 22:20 Finish swath line and transit to WL4\_TY\_1. Note that WL4\_TY\_1 has been shortened to fit in with timing for planned fire drill and man overboard muster tomorrow at 13:00.

#### Day 10. Sunday June 7th

Operation	Line Kms completed	Hours completed	New Targets
Multibeam and Tow yo (1.5	knots) 27	16.5	
Multibeam (Transit 10 knot	s) -	5	-
Maintenance/port call/Drills	6 -	2.5	-
Total	-	24	-

02:30 CTD off deck at WL4\_TY\_1 after full toolbox on CTD launch. No plumes were discovered on this tow. 11:30 CTD on deck after toolbox. CTD recovered before line completed so everyone is available for muster and drills. Ship starts transiting to WL2 after we decided not to complete the remainder of WL4. 13:00 Emergency muster and drills. 13:40 Ship stops for engine maintenance. 15:25 Back underway towards WL2. 16:20 CTD off deck at south end of WL2\_TY\_1 after toolbox. Bathy from RV Southern Surveyor EM300 swath shows much better definition (unsurprisingly but gratifyingly) than the existing EM120 data. Weak NTU plume at 700-800m seen near start of line. Possible source volcanic cone to west. Also weak NTU plume seen at base of 300m fault scarp at 1400-1450m which is probably related to material falling down the cliff.

## Day 11. Monday June 8th

Operation L	ine Kms completed	Hours completed	New Targets
Multibeam and Tow yo (1.5 ki	nots) 40	17	
Multibeam (Transit 10 knots)	-	7	-
Total	-	24	-

Continued CTD tow line WL2\_TY\_1. No plumes found on this line. 17:10 CTD on deck. Decided not to tow WL1 and transit straight to ELSC1. Transit will be about 8 hours.

## Day 12. Tuesday June 9th

Operation	Line Kms completed	Hours completed	New Targets
Multibeam (6-7 knots)	25	2	-
Multibeam and Tow yo (1.5	knots) 36	20.5	4
Multibeam (Transit 10 knots	s) -	1.5	-
Total	-	24	-

01:35 CTD off deck at south end of ELSC1\_TY\_1 after XBT profile completed. This tow along the ELSC discovered multiple plumes some just NTU and some both NTU and Eh. There are too many plumes to detail here, but the strongest plume with 0.18 NTU and associated Eh response was chosen for a cross tow. There is a distinct NW-SW structure crossing the spreading centre at this point and the cross tow is designed to run along that structure. Unfortunately due to a tenement boundary the cross tow could not be extended too far to the east. Current plans are to have the cross tow ELSC1\_TY\_2 completed by about first light tomorrow so that a camera tow can be run by Shannon during daylight hours. 20:00 CTD on deck after completion of ELSC1\_TY\_1. Then travelled down a swath line designed to widen our coverage of the western ridge flanks on the way down to the planned cross tow. 22:55 CTD off deck for cross tow. Plumes noted in first downcast on tenement boundary.



Status of CTD Tow Lines in ELSC and West Lau - 09/06/09 24:00

Figure 2: Status of CTD tow lines in ELSC and West Lau 09/06/2009

## Day 13. Wednesday June 10th

Operation	Line Kms completed	Hours completed	New Targets
Multibeam (6-7 knots)	30	3	-
Multibeam and Tow yo (1.5	knots) 27	16	-
Multibeam (Transit 10 knot	s) -	5	-
Total	-	24	-

Continued towing cross tow ELSC1\_TY\_2. Strong NTU plume was observed when crossing the first tow line and then continuing to the west. No Eh was observed though. Due to the prevailing winds, the ship got blown about 600m to the north of the intended track so missed the main part of the target anomaly, hence the lack of Eh response on the cross line. Some weak NTU responses were also seen at the NW end of this tow. 07:00 CTD on deck. Started swath mapping back to the main plume area to complete a better located cross tow. 10:00 CTD off deck for cross tow ELSC1\_TY\_3. A series of NTU plumes were seen on this line at different depths and with different strengths. A definite deeper NTU and Eh plume was recorded near the target plume, and looks to be associated with a series of small mounds in a circular pattern seen in the new EM300 bathymetry (see figure below). Decided that this target was now well enough defined so no camera tow was completed. 15:00 CTD on deck. Started transit to CL9. While on transit the coring winch was tested using a clump weight. 19:55 CTD off deck at south end of CL9

## Day 14. Thursday June 11th

Operation	Line Km	s completed	Hours completed	New Targets
Multibeam and Tow yo (1.5	knots)	52	24	-
Total		-	24	-

All day today CTD towing on line CL9\_TY\_1. No plumes were found on this entire line. A helium sampling profile will be completed at the north end of this tow.

#### Day 15. Friday June 12th

Operation	Line Kn	ns completed	Hours completed	New Targets
Multibeam and Tow yo (1.5	knots)	40	21.25	-
Multibeam (Transit 10 knot	s)	-	2.75	-
Total		-	24	-

Continued towing CL9\_TY\_1 with no plumes encountered. A helium sampling profile was completed during retrieval up to 1600m depth. 05:00 CTD on deck (after 33 hour tow) and transiting to west end of CL5\_TY\_1. 07:45CTD off deck. Line was straightened due to wind direction. A helium sampling profile was completed at the start of this line. No plumes were encountered. CTD recovery started at 24:00. Transit to CL8 will start in the early hours of tomorrow.

## Day 16. Saturday June 13th

Operation L	ine Kms completed	Hours completed	New Targets
Multibeam and Tow yo (1.5 ki	nots) 25	15.5	-
Multibeam (Transit 10 knots)	-	8.5	-
Tow Yo	-	-	-
Total	-	24	-

00:40 CTD on deck after CL5\_TY\_1. Helium samples processed. Start transit to CL8. 05:10 CTD off deck at south end of CL8\_TY\_1 after toolbox talk on bridge and XBT profile. No plumes were detected on this line. 20:05 CTD on deck after toolbox on bridge. Start transit to CL7.

## Day 17. Sunday June 14th

Operation	Line Kms completed	Hours completed	New Targets
Multibeam (6-7 knots)	105	9.25	-
Multibeam and Tow yo (1.5	knots) 24	14.75	-
Total	-	24	-

00:00 On site for launch at CL7\_TY\_1. Full toolbox held on bridge. 00:15 CTD off deck. No plumes were detected on this line. The line was shortened so that it covered only areas of outcrop as indicated on MSR backscatter images. 09:15 CTD on deck. On way to CL6\_TY\_1 we swathed mapped up the southern end of the Central Lau SC which has not been swathed mapped in detail previously. 14:40 CTD off deck at southern end of CL6\_TY\_1 after full toolbox talk on bridge. No plumes were encountered over the first 5 hours apart from a very (very) weak NTU signature within 100m of the sea floor. This appeared on almost every downcast. 19:25 Due to a sudden wind shift to westerlies the bridge decided we had to recover the CTD to deck as the ship was being blown over the cable. A front is currently passing over us and the winds are very variable making it difficult to tow. 20:17 CTD on deck. Decided to complete some small lines of swath mapping to keep us close to the point where we stopped towing, until the front passes and the winds settle. 24:00 Swath mapping completed and back on site to pick up tow CL6\_TY\_2 where CL6\_TY\_1 was terminated.

## Day 18. Monday June 15th

Operation	Line Kms completed	Hours completed	<b>New Targets</b>
Multibeam (6-7 knots)	30	4.5	-
Multibeam and Tow yo (1.5 k	nots) 19	13.5	-
Multibeam (Transit 10 knots)	-	-	-
Tow Camera	1.5	4 operation	
2 preparation	-		
Total	-	24	-

00:00 On site to start tow CL6\_TY\_2 where CL6\_TY\_1 was terminated last night. This two detected several NTU plumes with no Eh response with the best not far from the reported sulfide site from the 1990 Keldysh voyage. At about 07:00 a 0.1 NTU and strong Eh anomaly was detected at around 2150m depth. This location is about 3km south of the plume detected in a vertical cast on last year's SS voyage. Decided to recover the CTD to deck and complete a cross tow to tie down this plume. 09:10 CTD on deck and commence infill swath lines on way down to cross tow to allow time for data and sample processing. 12:20 CTD off deck for cross tow CL6\_TY\_3. The plume was again found on this line with an NTU of about 0.1 and strong sharp Eh response down to 2.95. The Eh anomaly occurred on one down cast only and sits on a distinct NNE ridge segment within an overlapper zone of the CLSC (See pictures below). A further NTU and weak Eh plume was noted on the eastern end of this tow along a SE trending ridge/structure. 15:40 Start recovery of CTD to deck with a camera tow along the NNE ridge segment planned. 16:33 CTD on surface and personnel on wet deck report visible damage to the lower frame ring of the CTD. 16:43 CTD recovered safely to deck. 17:45 Toolbox on bridge to cover camera system launch and recovery. 19:10 Camera off aft deck for CL6\_CT\_1. 22:30 Camera back on deck after tow. Commence swathing until daylight for CTD repairs and dredge preparation.

## Day 19. Tuesday June 16th

Operation	Line Kms completed	Hours completed	New Targets
Multibeam (6-7 knots)	134	8.25	-
Multibeam and Tow yo (1.5	knots) 2	2.25	-
Dredge	-	5.5	-
Transit	-	4.5	-
Maintenance/port call	-	3.5	-
Total	-	24	-

00:00 Continuing swath mapping over an area for a planned Tow Yo on a NE trending spur off the CLSC.

Review of the footage from last night's camera tow showed outcropping pillow basalts with minimal sediment cover. For a lot of the tow the camera was too far off bottom to collect visuals of the sea floor. A review of the track also showed significant deviation from the planned track (over 100m in some places). So while no chimneys or anomalous biomarkers were seen it was decided to dredge the strongest Eh responses from the CTD data. 08:15 End of swath mapping and vessel at all stop while replacement CTD frame is moved to the wet lab and fitted with equipment and sensors from the damaged frame. (New CTD ready and tested by about 16:00). 11:50 Start transit to start point for dredge operations over the Eh plume discovered on tow lines CL6\_TY\_2 & 3. Toolbox held on bridge. 13:30 Dredge off deck for CL6\_D\_1. 16:55 Dredge back on deck. Recovered samples consisted entirely of fresh black volcanic glass. 18:15 Dredge off deck 500m south for dredge CL6\_D\_2. 21:00 Dredge back on deck and again recovered samples consisted of entirely fresh black volcanic glass. Decided to return to CTD tow-yo. 21:45 CTD off deck with new bright yellow rosette for tow line CL6\_TY\_4 which is continuation of the long tow along the CLSC. A small NTU plume (0.02) with significant Eh response was seen on the first downcast at 2100m-2170m depth (100m-30m off seafloor). This response continued on subsequent down casts and is getting stronger as we head north (NTU up to 0.06).

#### Day 20. Wednesday June 17th

Operation	Line Kms completed	Hours completed	New Targets
Multibeam (6-7 knots)	20	2.5	-
Multibeam and Tow yo (1.5	knots) 49	21.5	4
Total	-	24	-

00:00 Continuing tow line CL6\_TY\_4 up the CLSC. This was a extremely successful tow with at least 4 new plume targets identified. At the south end of the tow is a moderate NTU anomaly with no Eh (CL\_3). Plume looks to be drifting to the north and it is not far from the anomalous CTD cast from voyage SS200807.

Next (CL\_4) is a series of very strong Eh kicks with only a weak NTU response over a strike length of about 8 km. Third (CL\_5) is the best target with a coincident strong NTU (0.1+) and strong Eh plume which started abruptly on one upcast and continued to the north. Filtering of samples from peak of plume showed particulates on the filter paper. Possible source is some small mounds on top of the ridge. Cross tow is planned. There was then one extremely sharp Eh spike (down to 1.0) which we are not sure whether is real or not. After this point the Eh data appeared to be changing with depth, however there were still real data spikes overprinting this variation. Will get Sean to check the Eh data from the MAPR mounted on the rosette to compare the data. Fourth definite plume (CL\_6) was at the northern end of the line with again coincident NTU and Eh responses. A cross tow is also planned here. 19:50 CTD on deck at end of tow. Commenced small line of swath mapping to the east to cover some small ridges parallel to the north extent of the CLSC while samples and data were processed. 22:30 CTD off deck again at cross tow CL6\_TY\_5 over plume CL\_5.

#### Day 21. Thursday June 18th

Operation	Line Kms completed	Hours completed	New Targets
Multibeam (6-7 knots)	50	7.5	-
Multibeam and Tow yo (1.5	knots) 8	8.75	-
Tow Camera	-	5.5	-
Dredge	-	2.25	-
Total	-	24	-

00:00 Continuing cross tow CL6\_TY\_5 over plume target CL\_5 with again an NTU and Eh response noted. Appear to be getting deeper towards the west which may indicate the source is closer. 03:00 CTD on deck. Moving to east to complete swath lines to map out secondary ridges to the east of the north end of CLSC. Could be failed ridges at the start of spreading. Analysis of the Eh from the rosette mounted MAPR for the end of the long tow line yesterday after the massive Eh kick on the Nakamura sensor suggests that the Nakamura sensor was not working properly after that kick. Advice from NOAA colleagues is something organic likely caused the large Eh kick; only other time they have seen a large Eh with no nephels is above a CO2-venting site in the Marianas. The sensor was changed prior to the next tow. 08:25 CTD off deck again at second cross tow CL6\_TY\_6 over plume target CL\_6. NTU responses of up to 0.03 were seen but with little Eh response. 12:45 CTD on deck and decision made to camera tow across plume target CL\_5. 13:55 Camera off deck for CL6\_CT\_2. 17:10 Camera back on deck and footage downloaded for review. Initial indications are of sediment draped pillow basalts. Unfortunately due to the steep terrain of the central rift maintaining visual contact of the seafloor through this main area of interest was not possible. Video will be logged in more detail overnight. Decided to dredge the central rift and up one wall where a terrace feature is observed in the bathymetry. 18:10 Dredge off deck. 20:15 Dredge back on deck with good haul of rocks (primarily basalt) but unfortunately no sulfides. 21:30 Completed small swath line to fill in a hole in the coverage to the east of the CLSC and then started transit over to CL2\_TY\_1. 22:40 CTD off deck at south end of CL2\_TY\_1.

#### Day 22. Friday June 19th

Operation	Line Km	s completed	Hours completed	New Targets
Multibeam and Tow yo (1.5	knots)	37	24	-
Total		-	24	-

00:00 Continuing CTD tow line CL2\_TY\_1 along a parallel ridge to the CLSC. Two excellent plumes were found on this tow. Both are coincident strong NTU and Eh responses. The first (CL\_7) is on the south flank of an elongated mound where there is a distinct flattening of slope. The second plume (CL\_8) occurs about 10km to the north. Cross tows were planned to further define these plumes. 16:40 CTD on deck at the end of tow CL2\_TY\_1 and started transit down to cross tow on plume CL\_8. 18:25 CTD off deck for CL2\_TY\_2 over plume CL\_8. This tow defined two separate sources for the plume relating to two knolls on either side of the ridge axis. In both cases the highest NTU and Eh responses occurred on down casts on top of these knolls. 21:45 CTD on deck and moving to next cross tow. 22:55 CTD off deck at cross tow CL2\_TY\_3 over plume CL\_7. Note the two cross tows don't appear on the tow status figure below as they are covered by the plume stars.

#### Day 23. Saturday June 20th

Operation	Line Kms completed	Hours completed	New Targets
Multibeam (6-7 knots)	38	7	-
Multibeam and Tow yo (1.5	knots) 7	4.5	-
Dredge	-	12.5	-
Total	-	24	-

00:00 Continuing cross tow CL2\_TY\_3 over plume target CL\_7. The NTU response on this cross tow appeared a little weaker and higher in the water column than on the main tow. The Nakamura Eh sensor on the CTD was playing up again so it proved worthwhile having the MAPR on the rosette as a backup. The MAPR Eh response is also higher in the water column than the main tow, with the strongest response just to the west. 03:20 CTD on deck. Commenced swath mapping to the east of the north end of the CLSC to fill in some swath gaps while waiting for crew to be available for dredging operations in daylight. 08:00 Start of four dredge operations at CL2 after full toolbox on bridge. Two dredges were completed on plume target CL\_8 and another two on target CL\_7. At CL\_7 two knolls on either side of the main ridge were tested. At CL 8 a flatter area of bathy on the west side of the ridge near the Eh anomaly, and also across the main ridge under the main NTU anomaly were targeted. No sulfides were recovered in any of the four dredges. Full descriptive logging of the dredge samples will be completed overnight. 20:20 End of dredging operations and start transit to tow line CL6\_TY\_7 which is testing a small NS ridge system just to the east of the north end of the CLSC. Swath mapping completed on transit to fill in some holes. 22:50 CTD off deck for tow CL6\_TY\_7. Dropped into a very sharp NTU plume (0.04) with no Eh on the first down cast at 2100m depth.

### Day 24. Sunday June 21st

Operation	Line Kms completed	Hours completed	New Targets
Multibeam (6-7 knots)	15	2	-
Multibeam and Tow yo (1.5	knots) 31	22	3
Total	-	24	-

00:00 Continuing tow line CL6\_TY\_7. A good NTU plume was discovered on this line at the south end. This shows that these small ridges to the east of the north end of the CLSC are active. Cross tow CL6\_TY\_8 was completed across a prominent knoll but in hindsight smaller knolls to the north could be the plume source. No Eh anomaly occurred on these lines. 10:30 CTD on deck after cross tow. Moving to CL1.

12:45 CTD off deck at south end of tow line CL1\_TY\_1.Two plume signatures were discovered on this line. The first is a moderate NTU plume with a very weak Eh response corresponding to where the target NS ridge crosses an older EW ridge. This plume is at 2150m depth. Further north into a basin, a very sharp and stratified NTU plume was seen higher in the water column at around 2000m. The source area for this plume is not clear as it is 300m+ off the seafloor and the nearest shallower terrain is over 3km away. This plume was closed off to the north. No cross tows were completed so that we could complete as many tows over new terrain as possible before leaving. 22:00 CTD on deck and transiting to CL1\_TY\_2. Completed small swath line on the way to extend good bathy coverage from SS voyage last year.



Figure 3: Status of CTD Tow lines in Central Lau and Peggy Ridge – 21/06/09

#### Day 25. Monday June 22nd

Operation	Line Kms completed	Hours completed	New Targets
Multibeam (6-7 knots)	181	20.5	-
Multibeam and Tow yo (1.5	knots) 6	3.5	-
Multibeam (Transit 10 knots	3) -	1	-
Total	-	24	-

01:00 CTD off deck at south end of CL1\_TY\_2. No plumes recorded on the part of the line that was completed (about first third of line done). 03:30 Gale force winds and high seas cause termination of CTD operations. 04:20 CTD on deck. Commence swathing until weather calms down. Swath data being collected between Peggy Ridge and the CLSC where there are gaps in last year's SS voyage bathy coverage. 24:00 Weather still untenable for CTD operations with 30+ knot wind gusts and large swell.

## Day 26. Tuesday June 23rd

Operation	Line Kms completed	Hours completed	New Targets
Multibeam (6-7 knots)	124	11.5	-
Multibeam and Tow yo (1.5	knots) 3	3.5	-
Multibeam (Transit 10 knots	5) -	9	-
Total	-	24	-

00:00 Continuing swath mapping due to weather, ensuring we stayed east of 177°W. 11:30 Decided to break away from swath mapping and head for PR2\_TY\_2 (northernmost of the tow-yo lines on figure for 21-06-2009) and complete as much of the line as possible. 13:05 CTD off deck after toolbox on bridge. The tow was along a NS ridge splaying off the main Peggy Ridge. The 3km of this line that was surveyed showed a weak and sharp NTU only plume close to the sea floor (60-100m). The plume measured only about 0.01  $\Delta$ NTU but appeared to be consistently associated with mounds along the ridge we were following. This opens up many NS ridges coming off the Peggy Ridge as possible targets. 16:30 CTD on deck and commenced transit to Lautoka.

#### Day 27. Wednesday June 24th

Day spent cleaning, packing, report writing, data assembly and computer back-ups.

#### Day 28. Thursday June 25th

Arrived Lautoka 0930hours. Delayed berthing until 1800 hours due to congestion at wharf.

## **Summary**

For the First Leg, Chief Scientist Gary Massoth summed up his overall impressions as: The major objectives for plume exploration were fully achieved: all high-priority tow lines were surveyed for plumes and all critical swath lines were surveyed. Several historically known vent sites were confirmed to still be actively venting and their positions on the seafloor narrowed for further exploration. In addition several new vent sites were discovered in the NE Lau region as well as on the Fonualei Spreading Center. For the Second Leg, for my overall impressions, I quote an email (23-06-2009) to me while in transit from the last Site to Lautoka, from Jonathan Lowe (Exploration Manager, Nautilus Minerals): "From Nautilus' perspective, you have certainly moved the game forward in Tonga, exceeding all of our targets for the voyage".



## Summary of measurements and samples taken

ltem No.	PI	NO	UNITS	DATA TYPE	DESCRIPTION
1	2		1219 line km	H10	towed undulating CTD profiler, nephelometer, Eh, selective pH, and selected samples for He isotope analysis
2	1		4603 line km	G74	multibeam swath map
3	1	12	100 kg	G01	dredged volcanic rock and volcanogenic massive sulfide samples
4	1	1	1 kg	G02	grabbed sediment

#### **CURATION REPORT**

Item No.	Description
1	Marine National Facility, Nautilus Minerals
2	Marine National Facility, Nautilus Minerals
3	Australian National University (Research School of Earth Sciences, Building 47)

4 Australian National University (Research School of Earth Sciences, Building 47)



GENERAL OCEAN AREA(S): Lau Basin

## SPECIFIC AREAS:

Leg 1, a region bounded by: (top left) 15°S 175° 30'W, (bottom right) 18°S 173° 30'W Leg 2, a region bounded by: (top left) 17°S 177°W, (bottom right) 23°S 175° 30'W

# **PERSONNEL LIST** LEG 1 Scientific Participants

Name	Affiliation	Role
Gary J. Massoth	ANU/Nautilus Minerals/	
	Mass-Ex3 Consulting (USA)	Chief Scientist
Lisa Baptista	Nautilus Minerals	Cruise Manager
Shaun Bloomer	Marine Data Consultants (S. Africa)	Surveyor
Anna Bradney	ANU	Water Sampling Lead/CTD
Peter Crowhurst	Nautilus Minerals	Technical Director/CTD Lead
Susan John	Nautilus Minerals (PNG	CTD Lead
Rebecca Norman	ANU	Water Sampling Lead/CTD
lan Stevenson	Nautilus Minerals	Geophysics
Clayton Summers	Marine Data Consultants (S. Africa)	Multibeam
Sisi Vaioleti	Nautilus Minerals (Tonga)	Water Sampling/CTD
Gilbert Kalalo	International SOS (Philippines)	Doctor
Drew Mills	CSIRO	Voyage Manager/
		Electronics Support
Bob Beattie	CSIRO	Computing Support
Tony Veness	CSIRO	Swath Support

## **Official Observer**

Mohammed Saiyaz

Scientific Officer, Mineral Resources Department, Fiji

## **Marine Crew**

Name	Role
lan Taylor	Master
John Barr	lst mate
Rob Ferries	2nd Mate
Roger Thomas	Chief Engineer
Mike Sinclair	Ist Engineer
Dave Pauley	2nd Engineer
John Howard	Bosun
Graham McDougall	IR
Aaron Moore	IR
Matt Barrett	IR
Dave Persson	IR (to 01/05/2009)
Sean Lawrence	IR (from 03/05/2009)
Di Brasher	Chief Steward
Paul Brown	Chief Cook
John Leonard	2nd Cook

## **PERSONNEL LIST**

# LEG 2

# **Scientific Participants**

Name	Affiliation	Role	
Richard Arculus	ANU	Chief Scientist	
Lisa Baptista	Nautilus Minerals	Cruise Manager	
Rob Angus	Nautilus Minerals	CTD Lead	
Jonathan Hargraves	MDC	Surveyor	
Shannon Johns	CSIRO E&M	CTD Lead	
Kledy Koloa	Nautilus Minerals	Geophysics/Geology	
Merinda Nash	ANU	Water Sampling/CTD	
Sean Plunkett	Nautilus Minerals	Geophysics	
Alison Swadling	Nautilus Minerals	Water Sampling Lead/CTD	
Hemaloto Tupou	Nautilus Minerals	Tongan Employee	
Tarun Whan	ANU	Water Sampling/CTD	
Gilbert Kalalo	International SOS (Philippines)	Doctor	
Lindsay Pender	CSIRO MNF		
Voyage Manager/Co	mputing Support		
Karl Forcey	CSIRO MNF	Electronics Support	
Bernadette Heaney	CSIRO MNF	Swath Support	

## **Marine Crew**

Name	Role
Les Morrow	Master
Michael Tuck	lst mate
John Boyes	2nd Mate
Upendra Kapugeekiyana	Chief Engineer
Dave Jonker	Ist Engineer
Seamus Elder	2nd Engineer
Tony Hearne	Bosun
Kel Lewis	IR
Steve Salter	IR
Paul O'Neill	IR
George Jarvis	IR
Steve Salter	IR /Engine Room
Ashleigh Pollock	Chief Steward
Andy Goss	Chief Cook
Luke Riley	2nd Cook

## ACKNOWLEDGEMENTS

Prior to SS02/2009, the persistence and wisdom of Fred Stein (MNF) and Michael Avent (RSES, ANU) and their respective legal advisors were crucial in ensuring the whole enterprise took place.

# Richard J. Arculus

Chief Scientist

# Appendix 1 – Dredge Report

# Leg 1

Station notes	Date (UTC) on bottom off bottom	Latitude on bottom off bottom	Longitude on bottom off bottom	Sample number: description	Sample
NEL10_Dredge1	2009-05-06	15°1.395'S 15°1.331'S	173°47.016'W 173°47.138'W	<ol> <li>Dark grey vesicular aphanitic lava. Coarsely vesicular interior (3-4mm) becoming finer towards crust (&lt;1mm). Vesicles show flow textures. Surface is glassy with ropey texture and Fe staining.</li> <li>Vesicular aphanitic lava with stripey pillow margin. Coarsely vesicular interior (3-4mm) becoming finer towards crust (&lt;1mm).</li> <li>Variably vesicular olivine (e.g. conchoidal fracture, oily lustre) pyhric lava with stripey pillow margin. Coarsely vesicular interior (3-5mm) becoming finer towards crust (&lt;1mm). Fe and Mn staining.</li> <li>Variably vesicular olivine pyhric lava. Patchy Fe and Mn staining.</li> <li>Dark vesicular lava with minor amount of microphenocrysts. Small patches of glass. Mn coating and Fe staining.</li> <li>Lighter grey sparsely vesicular (&lt;1mm) lava. Oval enclave. Minor quantaties of microphenocrysts.</li> <li>Variably vesicular olivine?-plag? phyric lava. More phyric rich relative to other dredge samples. Fe and Mn coating.</li> <li>Dark grey variabley vesicular lava with microphencrysts (of?). Tabular segmented crust. Coarsely vesicular interior (5-6mm) becoming finer towards crust (&lt;1mm). Glassy flow-like texture towards interior. Flow textures in vesicles apparant.</li> </ol>	
NEL9_Dredge 1	2009-05-05	15 4.828'S 15 1.392'S	173 47.136'W 173 47.019'W	<ol> <li>White, coarsely vesiculated (&lt;50%) sulphur bearing pumice. Three common minerals, a dark mineral (olivine?) green, vitreous, almost greasy lustre, &lt;5mm (&lt;1%wt); a colourless, vitreous mineral, (quartz?) &lt;5mm (&lt;1%wt), Native Sulphur associated with vesicles (&lt;10%wt). Elongated vesicles (&lt;1mm to &gt;1 cm size) regularly arranged, sub-parallel, "woody" texture. Approx 10cm length</li> <li>(includes two samples) White, coarsely vesicular, sulphur-rich pumice with MnOx/FeOx staining. Native Sulphur associated with vesicles (&lt;30% pumice surface covered with S). MnOx/FeOx staining on opp face to Sulphur precip. &lt;1% crystallised (same minerals as 1.) Live Mussels still attached to oxide-stained surface.</li> <li>White, coarsely vesicular, pumice similar to 2. Smoothed edges, erosion of vesiculated structure. Native Sulphur associated with vesicles (~25% surface covered ) Fe/ Mn oxide staining present on opp side to S precip. &lt;1% crystals, same minerals as 1.</li> </ol>	

				<ol> <li>White, coarsely vesiculated, Mn/Fe oxide-stained pumice. No sulphur precipitation. Less ordered and regular vesiculation than 1. vesicles ~30%. &lt;1% crystallisation, same minerals as 1.</li> <li>As for 3. No Fe/Mnoxide staining present</li> <li>As for 4. Very heavily stained with Fe/Mn oxide (&gt;80% surface covered). Well rounded surfaces. Erosion of vesicular structure.</li> <li>Assorted small (&lt;2mm to&gt;2cm), pumaceous samples from dredge pipe. Variably Fe/Mn oxide stained, some hosting native S, some with well rounded surfaces.</li> </ol>	
NEL5_Dredge1	2009-05-10	15 18.319'S 15 18.409'S	174 14.112'W 174 14.136'W	<ul> <li>Brassy, fine-grained, moderately porous, chalcopyrite-sphalerite chimney. Minor barite and MnOx occur together in veinlets and cavities. Slightly weathered with Mn/Fe-oxide staining. Pods of chalcopyrite and sphalerite localised about conduits. Chalcopyrite (25% wt), Sphalerite (12% wt), Barite (5% wt), MnOx (&lt;5% wt)</li> <li>Brownish-grey, moderately porous, fine grained sphalerite-chalcopyrite-chimney . Minor botroidal MnOx, euhedral barite occur together in cavities. Mineral zonation along conduits: barite and MnOx in association, chalcopyrite, well-formed sphalerite. Sphalerite (25% wt), Chalcopyrite (10% wt), Barite (10% wt), MnOx (5% wt)</li> <li>Brownish fine-grained, moderately porous sphalerite chimney. Some samples have Mn/Fe-oxide crust. Samples are soft and highly altered to clay in parts. Occassional veinlets with well-formed sphalerite crystals (&lt;1mm). Very fine-grained, disseminated pyrite. Sphalerite (40% wt, Pyrite&lt;1% wt)</li> </ul>	#22521
NEL11a_CameraTow2	2009-05-15	16 38.598'S 16 39.644'S	174 31.121'W 174 31.703'W	Brownish-dark grey, moderately porous, fine-grained bornite-chalcopyrite chimney. Minor fine-grained disseminated pyrite, euhedral barite in cavities. Very soft and crumbles easily. Some samples have Fe/Mn-oxide crust. Pieces of chimlets <10cm are included. Bornite (~40%wt), Chalcopyrite (~10%wt), Pyrite (<10%wt), Barite (<1%wt)	#22522
NEL11_Dredge 1	2009-05-15	16 39.374'S 16 39.476'S	174 31.581'W 174 31.568'W	1.Grey fine-grained, aphanitic volcanic.	#22523
NEL11_Dredge 2	2009-05-15	16 38.779'S 16 38.920'S	174 31.242'W 174 31.153'W	2. Dark-grey coarsely vesicular aphanitic lava. (Basalt?) Vesicles 1-5cm rounded, becoming finer towards crust.	#22524

# Appendix 2 – Dredge Report

# Leg 2

Station notes	Date (UTC) on bottom off bottom	Latitude on bottom off bottom	Longitude on bottom off bottom	Sample number: description
CL6_D_1	2009-06-16	18°31.763'S 18°31.771'S	176°24.420'W 176°24.166'W	<ol> <li>(2-samples) Large (&gt;25 cm- largest dimentions) dark grey aphanitic pillow lava (some sediment in cracks). Surface is glassy (&lt;5 mm) with Fe staining. Extensive Mn coating. Very small vesicles under crust (&lt;1 mm). Low temperature sea water alteration</li> <li>Moderately sized (approximately 25 cm-largest dimention) dark grey aphanitic fragmented pillow lava. Crust is glassy with low temperature sea water alteration and Fe staining under crust. Extencive Mn coating. Very small vesicules under crust (&lt;1 mm).</li> <li>(5 samples) Smaller (&lt;15 cm-largest dimention) lighter grey, aphanitic pillow lava fragment. Extensive Mn coating and Fe staining. Very small patches to no glassy rind.</li> <li>Thin wafers (pillow rinds) to thick chunks of black glass fragments from dredge pipe. A very few examples have Fe and/or Mn staining. Most exhibit microphenocrysts (plag) and some show ropey texture on surface. Very small vesicles present in thinner samples.</li> </ol>
CL6_D_2	2009-06-16	18°31.999'S 18°32.076'S	176°24.639'W 176°24.329'W	<ol> <li>Thin wafers (pillow rinds) to thick chunks of black glass fragments (lava tubes) from dredge pipe. Some examples show ropey texture on surface and some have Fe staining. Most exhibit microphenocrysts (plag). Very small vesicles present in thinner samples.</li> <li>(2 samples) very dark grey aphanitic lava encrusted in flow banded (?) and ropey textured glass (&gt;5 mm). Vesiculated (&lt;2 mm) interior. No Mn or Fe staining present</li> <li>Mn coated glassy top of lava tube (2 cm thick). Small dropplets of glass present on lower surface and sparsely on upper surface. Vesiculated interior parallel to flow surface (&lt;1 mm thick)</li> <li>Almost entirely glass encrusted (&gt;2 cm) lava flow tube. Large cylinderical cavity (3 cm across) with 'pimples' that passes through sample.</li> <li>Fragmented flow surface on bottom of aphanitic lava flow encrusted with glass on upper surfaces. Large vessicles and enclaves (&gt;2 cm) present throughout sample.</li> <li>Small (&lt;15 cm-largest dimention) grey aphanitic pillow lava fragment. Fe staining under glassy rind present. Very small vesicles (&lt;1 mm) in lava segment.</li> <li>Very small (&lt; 2 cm largest dimention) Mn encrusted pummice and small lava fragments.</li> <li>(many samples) Fragmented glass encrusted (some as wafers others as ropey textures) aphanitic dark grey lava with large vesicle and cylinderical cavities some of which are smooth whilst others are coarse on the inside of the cavities (10-30mm).</li> </ol>
CL6_D_3	2009-06-17 Ge Summary	18°11.334'S 18°11.490'S - \$\$02/2009	176°16.502'W 176°16.461'W	<ol> <li>Many samples (&gt;15) of poorly phanitic dark grey pillow basalt fragments mostly of moderate size (&lt;15 cm across) although some are only 3-10 cm across. Phenocrysts consist of plag- ol-(minor cpx) all &lt; 3 mm. Mn coatings, Fe staining and low temperature seawater alteration present on the majority of surfaces. Glassly (some envaginated) outer surfaces with phenocrysts of plag present. Devitrofication evident on some of the rinds (?). Vessicles pevade pillows and some of the glassy rinds (&lt;2 mm).</li> </ol>

				<ol> <li>(two large samples, &lt; 20 cm across) Glass encrusted (as wafers in some sections, others invaginated) phanitic dark grey basaltic pillow lava with vesicles (&lt;2 mm) and large cylinderical cavities some of which are coarse on the inside (10-50 mm across). Small phenocrysts of plag-ol-(minor cpx?) present (most much &lt; 3 mm).</li> <li>Thin wafers (pillow rinds) to thicker chunks of black glass fragments from dredge pipe. Most examples have Fe and/or Mn staining. All exhibit small phenocrysts of plagioclase (&lt; 3 mm) and some show ropey texture on surface (from envagination). Very small vesicles present (&lt;1.5mm) in most samples.</li> </ol>
CL2_D_1	2009-06-19	18° 2.808'S 18° 2.880'S	176°20.324'W 176°20.106'W	<ol> <li>(6-samples) Large (&gt;20 cm- largest dimensions) dark grey aphanitic pillow lava. Surface is glassy (&lt;10 mm) with Fe staining. Some unquenched surfaces show Mn coating. Unvesiculated and microphenocrysts of plag-ol (minor) present. Large cylinderical vessicle cavities some of which are coarse on the inside (10-50 mm across) present in the centre of pillows.</li> <li>bucket was collected of volcanic glass fragments (5-10 mm thickness), minor plagioclase phenocrysts present.</li> </ol>
CL2_D_2	2009-06-19	18° 3.098'S 18° 3.138'S	176°19.566'W 176°19.424'W	1. 8 (8-34 cm sized) pieces of pillow basalt with a large bucket of fragmented glassy rinds. Pillow basalt: fractured pillow fragments and whole pillow buds/lobate flow fragments, abundant plagioclase phenocrysts (< 1 mm), minor vesicles in outer rinds (1-2 mm), some glassy rinds (2-3 mm), more extensive Fe-oxidation of outer surfaces and within fractures, pervasive low-temperature seawater alteration, outer surfaces show evidence for extensive quench fragmentation. Volcanic glass: woody pumice texture on outer flow surfaces, thickness ranges from 1-2 cm, aphyric glass/obsidian.
CL2_D_3	2009-06-19	18°8.139'S 18°8.204'S	176°22.258'W 176°22.023W	1. ~ 30 (6-30 cm sized) pieces of pillow basalt with a large bucket full of fragmented glassy rinds. Pillow basalt: pillow buds and fractured pillow fragments, some 10-50 cm vugs in the interiors of larger pillows, 1-5 mm glassy rinds on flow tops, quench fragmentation, minor vesicles in rinds 3-5 mm round, aphanitic, Fe-oxidation on fracture surfaces and outlining flow features, light grey low temerature seawater alteration on some surfaces. Volcanic glass: 1-2 mm plagioclase phenocrysts in some glass fragments, up to 9 mm in thickness.
CL2_D_4	2009-06-19	18°8.182'S 18°8.384'S	176°22.085'W 176°21.900'W	1. 3 (8-19 cm sized) pieces of pillow basalt with a small bucket of fragmented glassy rinds. Pillow basalt: fractured pillowed flow fragments and pillow buds, 2-4 mm vesicles on interior of one pillow fragment, rest of pillow buds have < 1 mm vesicles, aphanitic, quench fragmentation on outer surfaces, Fe-oxidation on interior and fracture surfaces and outlining flow features, light grey low-temperature seawater alteration on fracture surfaces of larger pillow fragment. Volcanic glass: aphanitic, up to 5 mm in thickness.

## **CSR/ROSCOP 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) Particulate organic matter (inc POC, PON) B71 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 Phytobenthos Zoobenthos B18 B25 Birds B26 Mammals & reptiles Pelagic fish B14 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