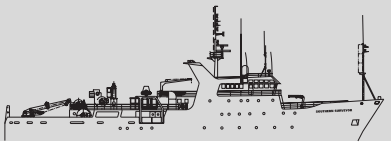

MARINE
NATIONAL FACILITY

2004 program

RV Southern Surveyor

voyageplan

# SS11/2004

NOTOVE-2004 (Northern Tonga Vents Expedition)
Submarine hydrothermal plume activity and petrology of the northern Tofua Arc, Tonga.

**Itinerary**

Depart Nuku'alofa 1000 hrs, Wednesday 27 October, 2004
Arrive Brisbane 1000hrs, Tuesday 23 November, 2004

**Principal Investigator**

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CSIRO
MARINE RESEARCH

## Scientific Objectives

1. It is proposed to extend the same successful plume-location/characterisation approach used on the SS02/2003 voyage in the southern Tofua arc, northwards along the strike of the arc to its northern termination. With increasing rates of plate convergence in this direction, the obvious hypothesis to test is whether an increase in mass flux manifest by the intensity (frequency of centres and scale of plumes) of hydrothermal plume activity exists.

2. The second major objective is to recover fresh glassy rock samples for detailed chemical analysis, particularly of volatile elements and compounds, and stable isotopic characteristics. This effort will complement the samples recovered during the SS02/2003 voyage, which are now being analysed. Our overall primary objective with these (glassy) rock samples is to quantify the volatile fluxes in supra-subduction zone settings, and attempt to distinguish the components involved (mantle wedge, subducted crust, overriding arc lithosphere).

3. Recovery of massive sulfides which will be analysed for their geochemical signatures including isotopes to characterize the chemical conditions of ore formation.

## Specific objectives are:

1. To perform the first detailed, high-resolution, swathmap bathymetric surveys of individual submarine volcanoes of the northern Tofua Arc between 20o 50'S and 15o 20'S, using the Kongsberg EM300 system;

2. To perform the first detailed, high-resolution swathmap bathymetric survey of the Fonualei Rifts, a nascent backarc basin immediately adjacent and northwest of Fonualei;

3. Dredge igneous rock targets identified on these submarine volcanoes, and the floor of the Fonualei Rifts, in order to recover fresh glassy rock samples for detailed age studies and chemical analysis, particularly of volatile elements and compounds, radiogenic and stable isotopic characteristics.

4. Dredge hydrothermal sulfide-rich and altered rock samples for studies of base and precious metal mineralisation;

5. To explore with the transmissometer/nephelometer-equipped CTD rosette for hydrothermal plume activity in these volcanoes and rifts, and to recover water samples for immediate analysis on board and subsequent shore-based laboratory analysis.

**Table 1. Coordinates (centres of survey areas) of Specific Targets**

| Area | | Latitude | Longitude |
|---|---|---|---|
| A | | 20° 50′S | 175° 32′W |
| B | Hunga Ha'apai | 20° 35′S | 175° 22′W |
| | Fonua Fo'ou | 20° 20′S | 175° 22′W |
| C | | 20° 08′S | 175° 09′W |
| D | | 19° 27′S | 174° 55′W |
| E | Metis Shoal | 19° 12′S | 174° 50′W |
| | Home Reef | 19° 00′S | 174° 47′W |
| F | | 18° 30′S | 174° 20′W |
| G | Fonualei | 18° 02′S | 174° 20′W |
| H | | 17° 52′S | 174° 15′W |
| I | | 17° 35′S | 174° 10′W |
| | Fonualei Rifts centred at | 17° 35′S | 174° 30′W |
| J | | 17° 10′S | 173° 50′W |
| K | | 16° 40′S | 173° 40′W |
| L | | 16° 20′S | 173° 55′W |
| M | Tafahi | 16° 51′S | 173° 43′W |
| N | Curacoa | 15° 35′S | 173° 40′W |
| O | | 15° 20′S | 174° 00′W |

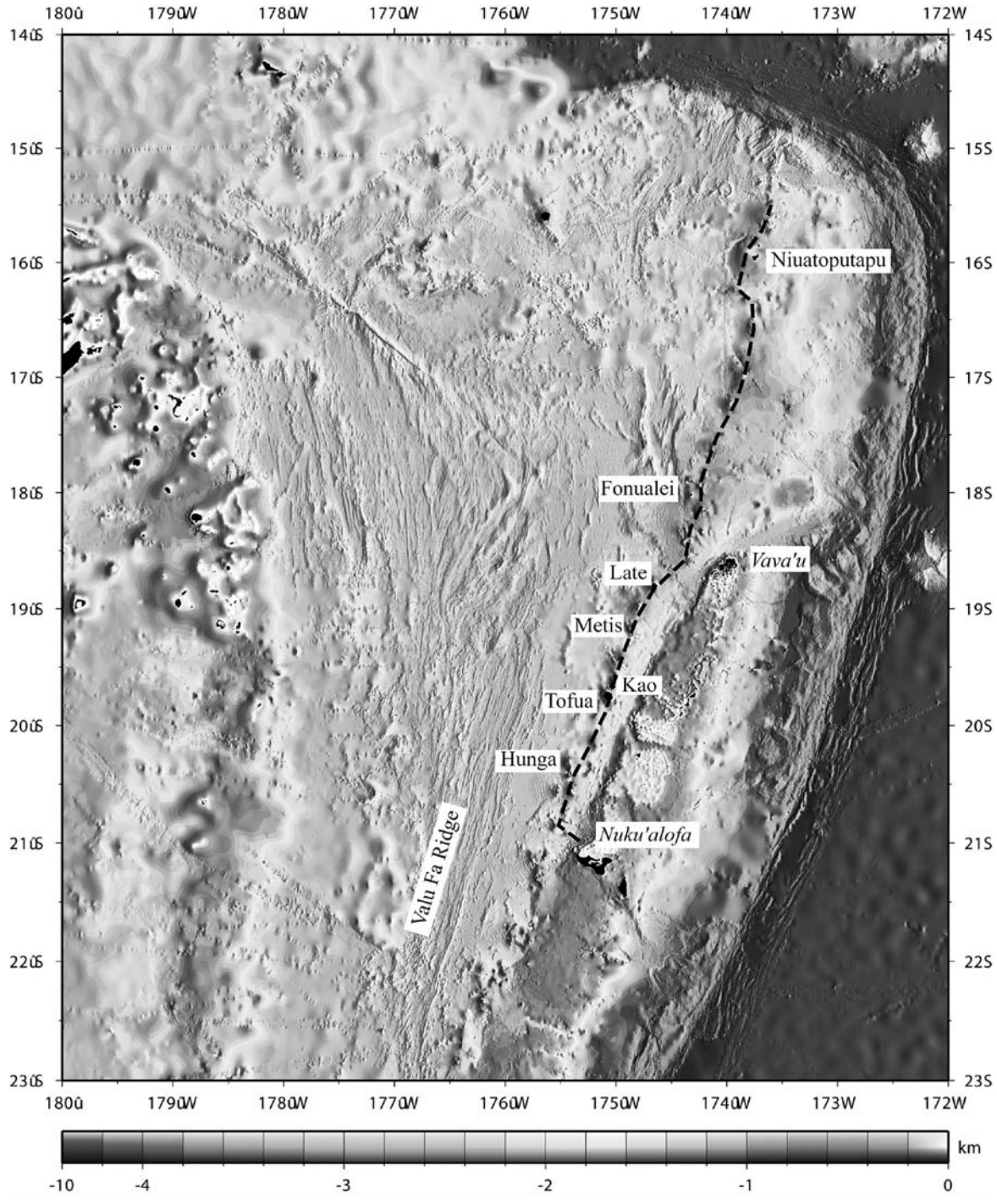


**Figure 1.** Proposed voyage track - starting port is Nuku'alofa (Tonga). Islands are named. The Ship's track will pass over seamounts that are likely to be submarine volcanoes based on the experience of the SO167 and SS02/2003 voyages. Coordinates of specific targets are listed in Table 1.

## Voyage Objectives

With the use of the Australian Marine National Facility research vessels (RV Franklin and RV *Southern Surveyor*), the volcanic and hydrothermal products of submarine activity in a number of the island arcs and backarcs of the southwestern Pacific have been recovered in the past few years - voyages to the Manus backarc basin, the Tabar-Lihir-Tanga-Feni chain (PNG), New Georgia Group and inappropriately-named "Melanesian Arc Gap" (Solomon Islands), the arc-backarc troughs of the New Hebrides, and the Lau-Tonga System. CSIRO Exploration & Mining, supported by the resource exploration industry, have been specifically pursuing ship-borne studies of actively-forming, hydrothermally-generated submarine ore deposits in arc-backarc systems of the southwestern Pacific. These relatively shallow (<2500m) marine environments, are clearly more appropriate as analogues of ancient base and precious metal, "volcanogenic hydrothermal massive sulfide" deposits than those typical of the major mid-ocean ridges. For example, an important group of economically valuable ore deposits (particularly the so-called "porphyry Cu-Au" and Pb-Zn-rich "Kuroko" types) are unequivocally associated with island arc-backarc settings. The concentration processes for the base and precious metals in these ore deposits are believed to be inextricably linked with the production and evolution of arc-backarc magmas (Ishibashi & Urabe, 1995).

More globally, over the past 20 years, there has been a major effort to understand the processes involved with seafloor hydrothermal systems. Following the spectacular discoveries in the late 1970's of carbonate-sulfate-sulfide chimneys spewing sulfide-laden fluids at temperatures ≤410ºC at the major mid-ocean ridge systems, similar vents have been discovered in many of the backarc basins of the world (e.g., Ryukyu; Izu-Bonin-Mariana; Manus; and Lau). The remarkable concentrations of base chalcophile and precious metals in these backarc systems are close analogues to volcanogenic hydrothermal ore deposits that form the prime recoverable resources of some of the world's largest mines. In addition to the societal relevance of basic research into these systems, there is also intense interest in the processes of elemental transfer from rock to fluid, the influence of magmatic fluids, the extent of seawater involvement and ionic exchange between seawater and rock, and the possibility of determining the flux of elements, possibly some recycled via subduction zone processes, from the Earth's interior to the exospheric (hydrosphere-atmosphere-biosphere) systems.

In fact, the submarine portions of many western Pacific island arcs comprise the bulk of the active volcanism in these settings, and constitute significant sources of hydrothermal inputs into the oceans (de Ronde et al., 2001; Massoth et al., 2003a). For arcs that have now been surveyed in detail [Kermadec (840 km), Tofua (425), Solomons (125), Tabar-Lihir-Tanga-Feni (225) and Marianas (1290)], we know there is a major volcanic structure per ~ 27 km of arc strike and on average, 30% of these are hydrothermally active. Most volcanoes along intraoceanic arcs are simple cones, but there are also a number of calderas which, in the case of the southern Tofua Arc, are dominated by felsic (rhyolitic), explosively-erupted rock types. Depths to vent sites range from ~50 to 2000 m and thus hydrothermal emissions are being injected into mid- to shallow-parts of the oceans. The vast majority of vents occur at, or very near, the summits of the cones with subordinate, deeper flank vent sites. Vent sites within caldera volcanoes are mainly located adjacent to the caldera walls.

Venting along the Kermadec arc is characterized by hydrothermal plumes that are chemically heterogeneous when compared to MOR sites, i.e., they range from being highly enriched in dissolved ionic species (e.g., Fe) and $^{3}He$, $CO_2$ and sulfur gases, to $^{3}He$-rich but with very low concentrations of ionic species (Massoth et al., 2003b). Evidence for a magmatic component in arc vent systems derives from the nature and concentrations of various gas species and Fe. The venting of hydrothermal systems at relatively shallow depths and with high gas contents assists volatile phase separation that should promote the formation of massive sulfide (Cu-Zn ± Pb ± Au) deposits.

At the southern end of the Lau backarc basin, the Valu Fa Ridge of the Eastern Lau Spreading Centre (ELSC) hosts some of the most active hydrothermal systems on the planet (von Stackelburg and von Rad, 1990; Fouquet et al., 1991; Herzig et al., 1998; SS02/2003 Voyage report [www.marine.csiro.au/nationalfacility/voyagedocs/2003/0203s.htm]; Massoth et al., 2003b). The ELSC is propagating southwards into pre-existing Lau backarc Basin crust, and the spreading axis gradually approaches (to about 40 km) the axis of the island arc. The Tofua arc itself is highly active with numerous submarine eruptions reported in the last 50 years. Thus within a relatively confined region geographically, highly active arc and backarc systems are in close proximity. Petrologically, the Tofua arc magmas are one of a small group of arcs (on a global basis) that are derived from an ultra-depleted mantle (supra-subducted slab) wedge source, and range from basalt to rhyolite in composition, thus forming one of the global end-members of arc magmatism (Kamenetsky et al., 1997; Ewart et al., 1998).

The SS02/2003 voyage completed for the first time in any arc-backarc system, a geographically continuous and systematic study of the hydrothermal plume activity, using vertical hydrocasts (including CTD-optical profiling) and "tow-yos" to map plume sizes, distributions, and chemical signatures, coupled with rock dredging of the southern portion of the ELSC ("Valu Fa Ridge" – Fig. 1) and adjacent (southern) Tofua arc between 21 and 25°S. It is now proposed to extend this research northwards during SS11/2004 voyage along the Tofua Arc to its termination at ~ 15°S (Fig. 1). Along strike, the rate of plate convergence between the Tofua Arc and Pacific Plate increases from about 160 mm/year at 21°S (latitude of Nuku'alofa, and the northernmost point reached on SS02/2003), to the fastest rate known on Earth of 240 mm/year at 16°S (Niuatoputapu) (Bevis et al., 1995). Greater rates of plate convergence should lead to increased rates of arc magma production and volatile fluxes through the subduction zone system. Immediately adjacent to the northern Tofua Arc between latitudes of 17° and 18° S, a nascent backarc rift (Fonualei Rifts) is developing, similar to the Valu Fa Ridge further south. A complication in the case of the Tofua Arc in terms of magma and fluid sources is the possible advection into the mantle wedge overlying the downgoing Pacific Plate of "Samoan Plume-type" mantle (Regelous et al., 1997; Ewart et al., 1998).

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Von Stackelberg, U. & von Rad, U. 1990. Geological evolution and hydrothermal activity in the Lau and North Fiji Basins (Sonne Voyage SO-35) - a synthesis, *Geol. Jb.*, 92, 629-660.

## Voyage Track

From Nuku'alofa, we will sail about 25 nautical miles northwest to a submarine volcano (Area A) at 20º 50'S, 175º 32'W) which will be the location for the first multibeam swath map, vertical hydrocast(s) and dredge operations. This volcano is the next structure northwards along the Tofua Arc from the last volcano studied during SS02/03, and was reported to be breaking surface during eruptions in 1999.

From Area A, we will proceed generally NNW along the Tofua Arc and the targets listed in Table 1. Our mode of operation will be to obtain a detailed swathmap, followed by dredging of promising young volcanic rock and hydrothermal emission sites. Our last planned target is a large circular structure (O) to the west of the main axis of the Tofua Arc; from there we will sail to Brisbane.

## Time Estimates

| Action | Time (hours) | (days) |
|---|---|---|
| from Nuku'alofa to Area A | 3 | 0.125 |
| swath mapping @ 8 knots, 1360 nm | 170 | 7.08 |
| CTD Casts (30 at 10 samples each = 300 samples) | 60 | 2.5 |
| Rock sampling | 160 | 6.67 |
| from O to Brisbane | 192 | 8.0 |
| transits between sites | 36 | 1.5 |
| contingency | 27 | 1.125 |
| **Total** | **(648 hours)** | **27.0** |

Based on experience, the following times (hours) are estimated for operations other than swath mapping, including positioning and set-up:

| Operation | 1000m | 2000m | 3000m |
|---|---|---|---|
| CTD single dip | 2.0 | 3.0 | 3.5 |
| Dredge | 3.0 | 3.5 | 4.0 |

### *Southern Surveyor* Equipment

In addition to the swathmapper, we are assuming that the type of equipment in place for our last RV *Southern Surveyor* voyage (SS06/2004) can be made available for the SS11/2004 voyage, comprising:

- all winches, deck crane, deck machinery
- all laboratories
- GPS, scientific sounder (narrow and broad beam receivers)
- CTD-transmissometer, 11 * 10 litre Niskins
- Smith-McIntyre grab(s)
- computers, trackplot (or equivalent) software
- fridges and freezers, clean air cabinet
- ADCP
- Benthos altimeter
- 2 National Facility dredges

### User Equipment

From Canberra (ANU & GA):

- sample buckets
- stationery/sampling supplies
- rock saw
- weak links for dredges

From CSIRO (North Ryde):
equipment for rock dredging:

- 2 Lister-type dredges

equipment for water sampling and on-board analysis:

- Filtration racks, 3 ea. with two positions (0.65 cu. m)
- Clean air flow hood (0.54 cu. m)
- Sample boxes for trace metals,18 ea. (1.50 cu. m)
- Computer/monitor/printer/VCR for CTD (0.25 cu. m)
- Tool chests, 4 ea. (0.66 cu. m)
- Ice chests, 3 ea. (0.60 cu. m)
- Shipping trunks for onboard flow injection analysis ($H_2S$ and Mn)
- pH determinations. (0.60 cu. m)
- Sulfide sampling storage totes and support equipment. (0.30 cu. m)
- Dry nitrogen cylinders, G-size, 3 ea. (0.30 cu. m)

To be delivered to RV *Southern Surveyor* at Brisbane prior to departure of SS10/2004, and off-loaded at Brisbane on return of SS11/2004 (ship's crane required).

## Special Requests

1. Prior checking and calibration of wire-out and tension measurement;
2. Functioning transmissometer

## Personnel List

Professor Richard J. Arculus – ANU-Earth & Marine Sciences, petrology/tectonics

Dr. T. J. Worthington – Christian-Albrechts-Universität zu Kiel, petrology

Mr Chris Dale – Univ. of Durham (UK), petrology-isotopes

Ms Sam Burgess – ANU - RSES, petrology-isotopes

Ms Lauren Cooper – Boston University, petrology/melt inclusions

Mr. Kurt Worden – Geoscience Australia, petrology/tectonics

Ms Nicole Keller – ANU-RSES, petrology/volatiles

Ms Samantha Hammond – Open University (UK), petrology/Li isotopes

Ms Mitzy Pepper – ANU-Earth & Marine Sciences, petrology/zoology

Ms Niccole Mikkelson – ANU-Earth & Marine Sciences, petrology

Cameron Buchanan – Geoscience Australia, swath

Bob Beattie – CSIRO Marine Research, Voyage manager/ Computing

Jeff Cordell – CSIRO Marine Research, Electronics Support

Rennie Vaimo'unga – Ministry of Lands, Survey and Natural Resources. Nuku'alofa, Tonga Observer

This voyage plan is in accordance with the directions of the National Facility Steering Committee for the Research Vessel *Southern Surveyor*.

**Professor Richard Arculus**
*Chief Scientist*