Report

Exploring the ocean floor in northeast Zealandia:
The 2015 VESPA voyage

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This is an account of the 2015 VESPA voyage of discovery exploring a submarine sector of northeast Zealandia. It took place on board the French research vessel R/V *L'Atalante*.

VESPA is an acronym for 'Volcanic Evolution of South Pacific Arcs', a research project conceived and led by co-chiefs Martin Patriat (IFREMER = Institut français de recherche pour l'exploitation de la mer, Brest, France) and Nick Mortimer (GNS Science, Dunedin, New Zealand). This voyage was the culmination of 10 years' planning by Martin, Nick, and Julien Collot (SGNC = Service Géologique de Nouvelle-Calédonie, Nouméa, New Caledonia). Unfortunately Julien Collot was not able to participate in the voyage because of the impending birth of his second child.

L'Atalante departed from Nouméa, New Caledonia, on 22 May and returned to Nouméa on 18 June. We were at sea for 25 days and travelled 7700 km (averaging about 13 km/hour), exploring northern parts of (1) the Norfolk Ridge to the immediate south of New Caledonia and north of Norfolk Island; (2) the southern end of the Loyalty Ridge, which lies to the east and south of New Caledonia; (3) the northern end of the Three Kings Ridge, which extends north of New Zealand and lies to the southeast of the Loyalty Ridge; and (4) the Cook Fracture Zone.

The Cook Fracture Zone is one of the most conspicuous tectonic features on sea-floor maps of the southwest Pacific Ocean. It is a transform fault oriented NW–SE and it offsets the once-contiguous Loyalty Ridge and Three Kings Ridge by about 300 km.

Transform faults are akin to stretch marks or tears, and they are characteristic of oceanic crust which forms so much of the Earth's sea-floor. They are a three-dimensional spatial necessity and serve to accommodate change in shape of the sea-floor as it spreads and grows on a global scale. There are many transform faults, and most of the larger ones have been named. Well to the south of the Cook Fracture Zone and more or less parallel to it, is the Vening-Meinesz Fracture Zone. These two transform faults have worked in concert and have been instrumental in the stretching history of Zealandia and the geomorphological evolution of some of the distinctive sea-floor topography and geometry between New Zealand and New Caledonia.

R/V *L'Atalante* at berth in Noumea on 19 May 2015, prior to our voyage.

The principal objective of the VESPA voyage was to sample volcanic rock formations exposed on the deep sea floor in water depths of 1000–5000 m using a dredge: 34 dredge sites were scheduled. Accordingly, a major preoccupation for the co-chiefs and the science team was dredge site selection. This was a complex decision-making process based primarily on interpretation of bathymetric and seismic data acquired during the voyage. To some extent, decisions were also governed by data acquired on previous voyages of exploration.

Why sample volcanic rocks? Two reasons: (1) to try and confirm the interpretation that the Loyalty and Three Kings Ridges are offset segments of a once-continuous volcanic arc of Eocene age; and (2) to try and ascertain polarity of subduction for this arc – was the subduction oriented from east to west or from west to east? To answer this, geochemistry is required. Accordingly, there were geochemists on board, including Patricia Durance (GNS Science), who brought along a brand new portable XRF (X-ray fluorescence) instrument.

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Dr Campbell is the author, with Gerard Hutching, of *In Search of Ancient New Zealand* (Penguin 2007 2011) and the editor, with Geoff Hicks, of *Awesome Forces: The Natural Hazards that Threaten New Zealand* (Te Papa Press 1998 2012). Last year, he and Nick Mortimer co-authored *Zealandia: our continent revealed* (Penguin 2014).

Hamish is a past president of the New Zealand Association of Scientists.

As subduction proceeds, down-going oceanic crust is subducted in an orderly manner ever deeper beneath adjacent crust (either continental or oceanic). As the 'slab' of oceanic crust descends, crustal melting occurs, and this manifests itself as volcanism at the Earth's surface. A volcanic arc forms. Hence the 'Pacific Ring of Fire'. Geochemists have determined that there is a tell-tale chemical pattern that reflects the spatial and temporal evolution of melting as this dynamic process proceeds. The ratios of several minor elements, including yttrium, niobium and strontium, have been shown to be especially useful in 'finger-printing' and tracking this process. So, chemical analysis of volcanic rocks across an arc will establish the 'polarity' of subduction i.e. the direction of descent of the down-going slab. For decades, earth scientists have wrangled over the subduction polarity of the Loyalty and Three Kings Ridges. This information is critical to our understanding of how Zealandia has evolved. The VESPA voyage is going to sort this simple matter out once and for all.

As luck would have it, the Cook Fracture Zone has effectively created two natural cross-sections through the volcanic arc of interest: the southern end of the Loyalty Ridge and the northern end of the Three Kings Ridge. So, geochemical transects across these entities should be mirror images of each other. Hence the reason we were gunning for volcanic rocks exposed on the sea floor on either side of the Cook fracture Zone.

Secondary objectives of the voyage included: (1) acquisition of more than 1000 km of seismic reflection data, enabling visualisation of the subsurface geological structure below the sea floor, (2) sea floor bathymetry using sophisticated multi-beam sonar technology, and (3) magnetic data relating to the sea floor magnetic record (polarity and intensity), especially along the north and south sides of the Cook Fracture Zone.

The seismic data enabled us to determine where hard ridge-forming 'basement' rock formations are exposed on the sea floor as opposed to soft 'cover' sediments that have accumulated since the ridge was formed. And the bathymetric data enabled us to visualise sea floor topography. From a dredging perspective, the best approach is to dredge up a slope and into the prevailing wind direction.

By the way, the dredge comprises a one-metre-wide circular steel band with 'teeth' to help grab into the substrate, and a coarse chain-metal 'bag' made up of steel rings that are 5 cm in diameter. The dredge resembles a crown (as in King Neptune..) with a yoke to attach the cable above it and the bag below it.

I was invited to participate in this voyage as a geologist and palaeontologist. I was delighted to be asked and happily accepted. Why a palaeontologist? To try and constrain the age of volcanic rocks using associated fossil-bearing sedimentary rocks.

Initially there were 52 of us on board the *L'Atalante*, 35 officers and crew, and 17 in the science team. However, during the voyage one of the crew (Philippe Le Doze) was returned to Goro (southeast New Caledonia) because of the death of his mother in France. This excursion to Goro took more than 30 hours but was easily accommodated within our three days of built-in contingency planning.

Most of the officers and crew were from Brest in Brittany, France, home port of the *L'Atalante*, home of IFREMER, the ship's owner, and Genavir, the ship's operating agency. *L'Atalante* was captained by Commander Jean-René Glehen. He was supported by a highly skilled team of officers, engineers, mechanics, electricians, IT experts, and able-bodied seamen (matelots). Most importantly, there were two French chefs! Of the officers and crew, three were women and the youngest at just 22, had three years of experience working on a dredge at the mouth of the Loire.

The science team comprised 17 scientists, technicians, students and marine mammal observers from at least seven research institutes and universities in France, New Caledonia, New Zealand, and England.*

For most, crew and science team alike, life on board revolved around 4-, 8- or 12-hour shifts of duty. This was especially demanding for those who suffered from sea-sickness, and/or 'la Grippe'. Fortunately I was not afflicted. At any one time there were always people sleeping or trying to sleep. A ship has to be run non-stop 24 hours per day, and along with it, the science programme. For VESPA, this included acquisition of seismic data, bathymetric data, magnetic data, and dredging, as well as whale spotting.

Dredge operations governed the science programme for us geologists: getting from A to B, deploying the dredge at 1 m/s, engaging the sea floor, dragging the dredge across the sea floor for some time (up to 30 minutes) at 1 kt/h, then bringing the dredge aboard at 1 m/s, investigating the contents, deliberating over what to retain and what to throw back over-board, then proceeding on from B to C.

We would then spend some hours processing all the rock samples in the laboratory, making good use of the sinks (for washing), rock saw (for cutting), oven (for drying), portable XRF for on-board chemical analysis, binocular microscope and cameras. Sub-sample selection for various purposes and agencies, numbering, recording, bagging, and stowing all had to be done before the next dredge haul came aboard.

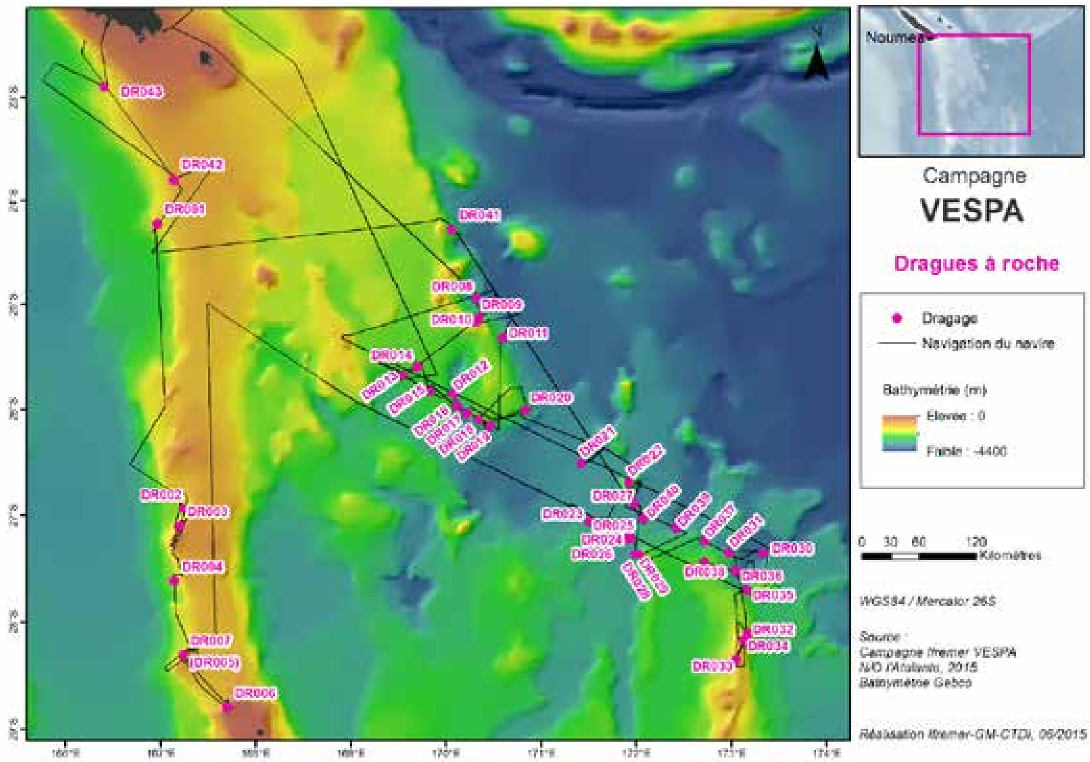
All this had to be done in harmony with prevailing weather and sea conditions, and in such a way that the dredge was recovered intact. On one occasion it became snagged, the cable broke and the dredge was lost. We began with four dredges at our disposal, but thanks to very dextrous skills on the bridge where cable-tension was carefully monitored and the ship's progress adjusted accordingly, no more were lost. For all that, the dredge became stuck on numerous occasions and in several instances it took several hours to extricate it.

The ship had 8000 m of cable on board but rarely did we need to deploy more than 5000 m. Imagine an 85 m-long ship dragging a 2 m-long dredge at the end of a 5000 m length of cable. That was us on 43 occasions. Long-lining par excellence!

Note that no location instruments were deployed on the dredge itself or the cable, simply because of the cost impli-

*** IFREMER, France**: Martin Patriat (geophysics), Mathilde Pitel-Roudaut (geophysics technician), Charline Guerin (geophysics technician). **University of Brest, France**: Claire Bassoullet (geochemistry), Arnaud Agranier (geochemistry). **SGNC, New Caledonia:** Samuel Etienne (geophysics), Caroline Juan (geophysics), Mathieu Mengin (geology technician), Fanny Soetaert (geophysics intern). **GNS Science, New Zealand:** Nick Mortimer (geology), Patricia Durance (geochemistry), Hamish Campbell (geology). **Students:** Clément Roussel (IFREMER/SGNC/VUW, New Zealand: geophysics), Nina Jordan (University of Leicester, England: geology), Méderic Aman (University of Strasbourg, France: geology). **MMOs (Marine Mammal Observers):** Laura Ceyrac (from Réunion), Thomas Auger (from New Caledonia).

A summary map (colour coded for bathymetry), in French, showing location of the 43 dredge sites, and the track of the R/V *L'Atalante.*



cations. Instruments are expensive and dredges are subject to significant rough and tumble on the ocean floor. So, location of the dredge was therefore imprecise. All measurable physical parameters were very carefully monitored. We did carry out deep-water tests observing dredge behaviour while deploying location instruments. This was very useful and provided us with confidence in our understanding of the likely error in location of the dredge on the sea floor when we used it.

We exceeded our original target dredge number by 9 and recovered rock in 36 dredges. We estimate that we landed more than 8 tonnes of rock and retained about 10%, split between IFREMER, SGNC, GNS Science, and the University of Brest. A total 'bag' sample selection of 163 kg was air-freighted from Nouméa to GNS Science in New Zealand (Avalon, Lower Hutt).

Time can pass slowly on a ship, paced by the daily rituals of sun-rise, breakfast, lunch, sun-set and dinner, and for the addicted (alas, most of the ship's company…) a relentless chain procession of cigarettes and coffee. A key factor in consumption was price: a carton of cigarettes on *L'Atalante* cost only €10 whereas in France it costs €70. By the way, the ship was essentially alcohol 'dry', with wine served only with Sunday lunch.

I must say that I enjoyed this voyage immensely. It was my first ocean-going experience on a research vessel. I have travelled to and from the Chatham Islands on two occasions with the Royal New Zealand Navy, on the *Inverell* in early 1976, and the *Resolution* in 2005, but only in a transport capacity. My first previous significant experiences on ocean-going vessels were as a child. My father (John Douglas Campbell; 1927–2001) was a lecturer in the Geology Department at Otago University, Dunedin, and in 1961 he was granted sabbatical leave in Cambridge, England, with the aid of a Nuffield Scholarship. We travelled as a family of six (four children) on board the *Rangitiki* from Wellington to Southampton (June to July 1962) via Pitcairn, the Panama Canal, Jamaica, Miami and Bermuda. Ten months later, we returned on board the *Himalaya* from London to Auckland (May to June 1963) via Gibraltar, the Suez Canal, Aden, Bombay, Penang, Singapore, Perth, Adelaide, Melbourne and Sydney. Being the oldest child and 9 to 10 years old, I have strong memories of these two amazing six-week-long voyages. I was old enough to remember. And I have been fascinated and involved in oceanic exploration ever since, but primarily through on-land geology and the medium of marine sedimentary rocks. Deep marine sediments can be observed as sedimentary rock formations exposed in many places in New Zealand.

I calculated a distance of 50 m between my bunk and the rock laboratory on the *L'Atalante*, and half way between and down a gangway was the galley (dining room) on B Deck. The food was absolutely outstanding with the main meal being lunch each day, comprising five courses of the finest French cuisine. Salads and cheeses accompanied every meal. I rolled off that ship…. Bring on the next voyage! But here are a few further observations.

Ships are incredibly noisy places: engine throbbing, motors, air conditioning, propeller shudder, crashing seas, wind, doors, alarms, pumps, machine tools, vacuum cleaners, voices, plumbing sounds, the laundry. My cabin (10C.. port for'ard on C deck) was right next to the laundry…and just above 'le sondeur' which exploded into life every five seconds and sounded like a highly amplified giant sparrow. Amazingly my brain got used to it and blanked it out. Now I struggle to even recall that sound. Its specific purpose was to generate frequencies that would provide seismic data relating to just the top few tens of metres of sediment on the sea floor.

The SW Pacific Ocean south of New Caledonia and north of Norfolk Island is remarkably empty, with negligible flotsam and jetsam. I observed small fragments of drifting seaweed only once. On this occasion I was peering down from a very awkward position at the very front of the ship at the very cutting edge of the bow, and several of us noticed a population of small flies dancing in the air up to a metre above the water line. How tenacious and opportunistic life is and what a place to live! I wondered what sort of flies they might be and what they were living on but failed to collect any. I presume that the sharp edge of a ship's bow can 'catch' floating seaweed so to speak, and along with it a small ecosystem of kelp flies.

We saw three container ships in 25 days at sea, and no aircraft. I was very interested to learn that all registered vessels of a certain size are legally required to carry transponders. Our radar could interrogate the transponder of a remote vessel and determine its name, heading, departure point, destination, freight, and other details. Amazing! On our last day, we were followed into port by a strange looking two-masted yacht which proved to be *Rainbow Warrior II*.

We did see whales (hump-backs, sperm whales, orca, dolphins, rorquals) on more than 12 occasions and, following agreed protocols, the ship was required to cease seismic data acquisition (using two percussive compressed air 'guns') two or three times because of proximity to whales. We saw sea birds every day but not in great numbers. They included albatross, shearwaters, petrels, frigate birds, boobys, tropic birds….and we found a stowaway on board: a single welcome swallow, presumably from Nouméa. We saw many flying fish, and one magnificent specimen accidentally landed on C Deck in a storm.

The large flying fish that accidentally landed on board.

I was surprised by the general absence of life in our dredge hauls: almost nothing! Mind you, the dredge bag was coarse with its mesh of 5 cm steel rings. But there was also a remarkable absence of shelly encrusting organisms on the rocks we dredged. One dredge sample (DR-07) did prove momentous, for me at least. We found three small live brachiopods attached to black manganese-encrusted volcaniclastic breccia which I was able to identify as *Amphithyris*. I described a new species of this genus (*A. richardsonae*) from Fiordland with Charles Fleming in 1981. We named this species after Joyce Richardson who worked for some years on brachiopods at the NZOI (New Zealand Oceanographic Institute, precursor to NIWA). A revision of the genus *Amphithyris* was published just last year (Nauendorf, Wörheide & Lüter 2014: *Zootaxa 3847 (2)*: 221–240). All biological material that VESPA collected was preserved in alcohol and submitted to IRD (Institut de Recherche pour le Développement) in Nouméa, including these very rare brachiopods.

Early in the VESPA voyage, Claire Bassoullet (our most experienced science voyager) asked for a steel pipe to be attached to the bottom of the dredge bag so that as it dragged the sea floor it would fill up with a sample of modern sea floor sediments. This duly happened. Of the 43 dredges, pipe samples were recovered from 37. We processed the contents on board the ship using a nest of five sieves: 1 mm, 500 µm 250 µm 125 µm, and <125 µm. These separates were then dried in an oven at temperatures no greater than 60°C. They were then examined under the binocular microscope and bagged in plastic bags and/or plastic bottles.

These 'pipe' samples are of interest because they constitute a record of what is accumulating on the sea floor today in terms of both biogenic and clastic (sand, silt, clay) components, at or within the locale of each dredge site. Some samples are rich in mineral, pumice and volcanic glass content relating to volcanic eruptions. Others are rich in rock fragments that may relate to the geology of the dredge site. Given that VESPA established remarkably accurate and/or precise spatial data with respect to the actual dredge sites, these samples are very well-located on the sea floor.

Of particular interest to biologists is the biogenic content of the pipe samples. This includes planktic forams in the main, representative of modern plankton productivity within the water mass. Benthic forams were also recovered, including a spectrum of agglutinating forms (tubiform and rhizoform), and various worm tubes. Then there are the shells or shelly elements of molluscs (micro-molluscs, pelagic molluscs), barnacles, brachiopods, bryozoans, echinoderms and corals, along with sponge spicules, fish otoliths, and shark teeth. No bone was observed.

Small bottles of sea floor mud and/or ooze samples were collected from 25 dredges. These are now lodged with GNS Science in Avalon, Lower Hutt. A duplicate set is with SGNC in Nouméa. An 'ooze' is a geological term for a sediment that is dominated by skeletal remains of single-celled organisms. In the deep marine environment, oozes are dominated by forams, coccoliths, and radiolarians.

What next? A draft report on the VESPA voyage was completed prior to disembarkation. This was a remarkable achievement and it has now been finished and submitted. Samples have only just arrived in the various institutions involved, but laboratory work has already commenced.

In October this year (2015) *L'Atalante* will complete a five-week voyage, TECTA (Tectonic Events of the Cenozoic in the Tasman Area), exploring the Norfolk Basin and its origins. This voyage will involve seismic data acquisition only; no dredging. However, several of the VESPA dredge sites were deliberately located on scheduled TECTA seismic profiles. These samples will be critical for geological interpretation of the TECTA seismic data.

It is anticipated that a scientific meeting will be held in New Zealand in 2016 for all those involved in the 2015 VESPA and TECTA voyages, and this will be the opportunity to collectively discuss all scientific results and prepare publications.

These two voyages exemplify one way in which the New Zealand earth science community, and GNS Science in particular, is able to embrace the challenge of exploring the geology of the greater part of submarine northern Zealandia. It can only be done by close collaboration, in this case with French, New Caledonian, and Australian research interests, maximising the use of available and appropriate marine assets (ships, equipment and expertise) that are essential for marine exploration.

The €45,000 per day cost of the use of R/V *L'Atalante* was generously funded entirely by the French Ministry for Higher Education and Research (Ministère de l'Enseignement supérieur et de la Recherche, MESR) for which all concerned on the VESPA voyage will be eternally grateful. Our scientific knowledge of northern Zealandia owes much to the enlightened largesse of the French government and the taxpayers of France.