Deciphering Ontong Java Atoll, Nukumanu Atoll, and Kroenke Canyon, Western Equatorial Pacific

Final Project Report for RV Falkor FK141015 15 October – 3 November 2014

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Executive Summary

Kroenke Canyon on the Ontong Java Plateau (OJP) extends for approximately 500 km between its hypothesized origin at Ontong Java and Nukumanu atolls and its mouth at the transition between the Plateau and the Nauru Basin. For FK141015, RV *Falkor* departed Pohnpei, Federated States of Micronesia, on 15 October 2014, and arrived in Guam, USA, on 3 November 2014. During the voyage we acquired primarily EM302 multibeam data along 6,288 line-km over the 13 days in the survey area, augmented by EM710 multibeam data in shallower water. Overall, the EM302 ensonified 23,439 km^2 of seafloor in the survey area, in water depths ranging from 87 m to 4,444 m (Figure ES1). XBT data (12 casts) were acquired routinely, and the CTD was tested, returning useful data from one cast.

Of similar scale and relief to the Grand Canyon (Arizona, USA), and with multiple tributaries, Kroenke Canyon incises pelagic sediment, sedimentary rock, and igneous rock of OJP. We mapped the thalweg of Kroenke Canyon from approximately 150 km northeast of the atolls to its mouth at the transition between the OJP and the Nauru Basin (Figure ES1). Due to the loss of HROV *Nereus* several months prior to FK141015, seafloor sampling that had been planned for the voyage was not possible, and the Knudsen CHIRP 3260 sub-bottom profiling system did not yield any sub-bottom data that had planned to be acquired. Due to shipyard delays, the number of ship-days available for FK141015 was reduced from the original 30 to 20, and correspondingly the number of ship-days available for science in the survey area was reduced from the original 23 to 13.

Ultimate project goals for FK141015 include: 1) understanding and modeling how submarine canyons and atolls form and evolve on oceanic plateaus, isolated from terrestrial influences and subject to sea level fluctuations; 2) testing potential genetic relationships between a) the atolls and Kroenke Canyon, and b) the atolls and OJP; and 3) contributing to assessing tsunami risk on low-lying atolls. Intended impacts are to advance knowledge of canyon and submarine landslide development globally, to better understand emplacement and post-emplacement volcanism of LIPs, and to improve tsunami risk assessment.

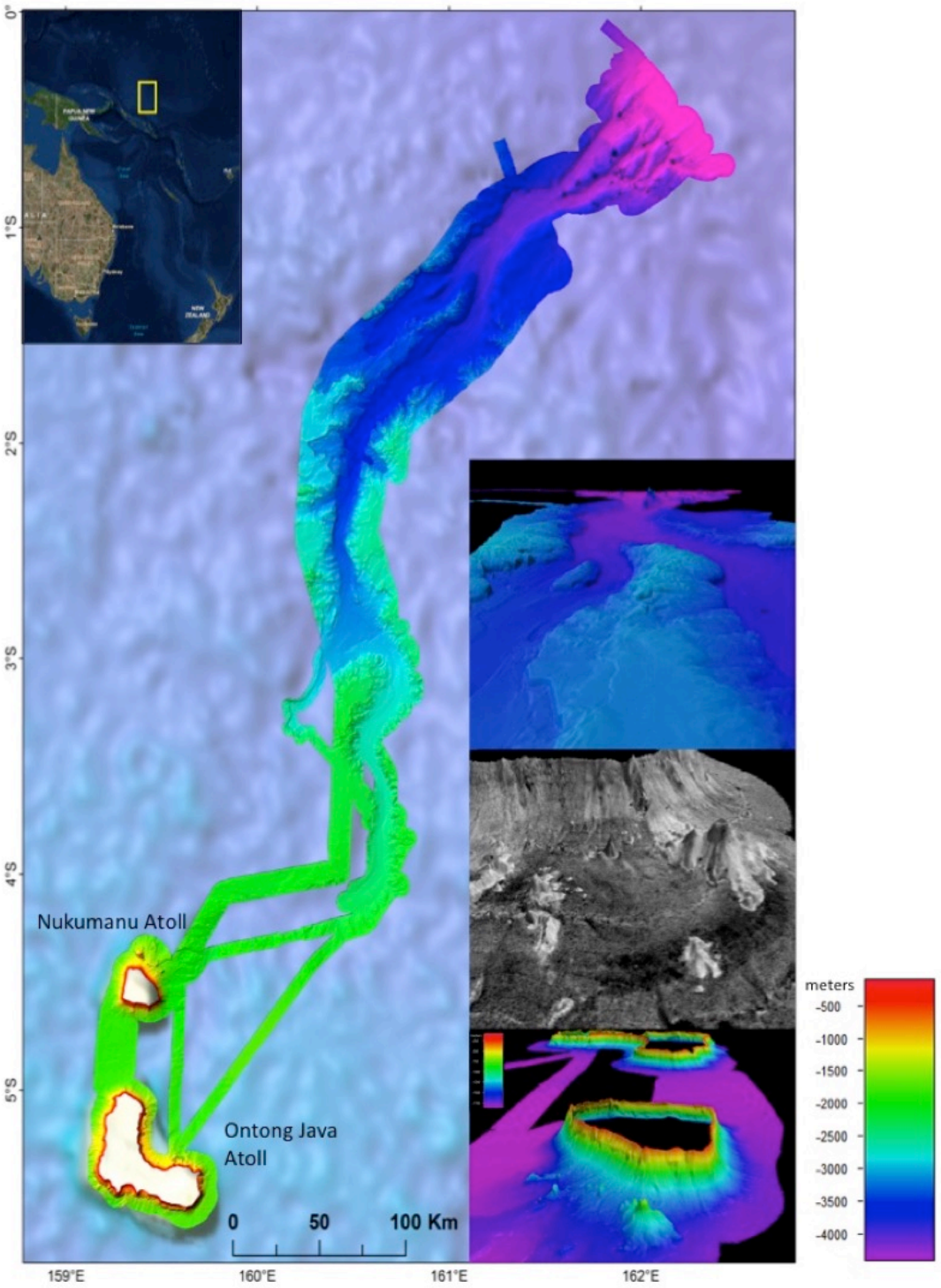

Figure ES1. Multibeam bathymetry of the Ontong Java Plateau, western equatorial Pacific Ocean, acquired during FK141015 superimposed on predicted bathymetry (after Sandwell and Smith, 1997, 2009; and Becker et al., 2009). Main map: Kroenke Canyon extends for ~500 km north-northeast of Ontong Java and Nukumanu atolls, which surmount the shallowest portions of the High Plateau. See inset in upper left for regional location. Upper right: perspective bathymetry view from ~1.5°S looking down the thalweg of Kroenke Canyon towards the northeast. Middle right: perspective backscatter view from ~4°S looking at seamounts north of Nukumanu Atoll towards the south. Lower right: perspective bathymetry view from ~4°S looking at Nukumanu (foreground) and Ontong Java (background) atolls towards the south.

Introduction

The enigmatic Ontong Java Plateau (OJP) in the western equatorial Pacific (Figure 1), the Earth's most voluminous large igneous province (LIP), encompasses an area of ~1.86 x 10^6 km^2, slightly smaller than Greenland (Coffin and Eldholm, 1994). The maximum crustal thickness of the OJP exceeds 30 km (Gladczenko et al., 1997; Miura et al., 2004) and perhaps attains 38 km on the feature's crest (Richardson et al., 2000). Pillow and massive basalts cored by the Deep Sea Drilling Project (DSDP) and Ocean Drilling Program (ODP) from the OJP lie beneath a sedimentary section hundreds of meters thick, and a 3-4 km thick basalt section on Malaita in the Solomon Islands is obducted OJP crust (Petterson et al., 1997). Dating of these basalts suggests that much of the uppermost OJP was emplaced during the Cretaceous, ca. 122 Ma ago, with subsequent minor volcanism at ~90 Ma and more recently (eg, Tejada et al., 1997; Fitton et al., 2004). At least part of the plateau appears to have been constructed on ~160 Ma oceanic crust (Ishikawa et al., 2005).

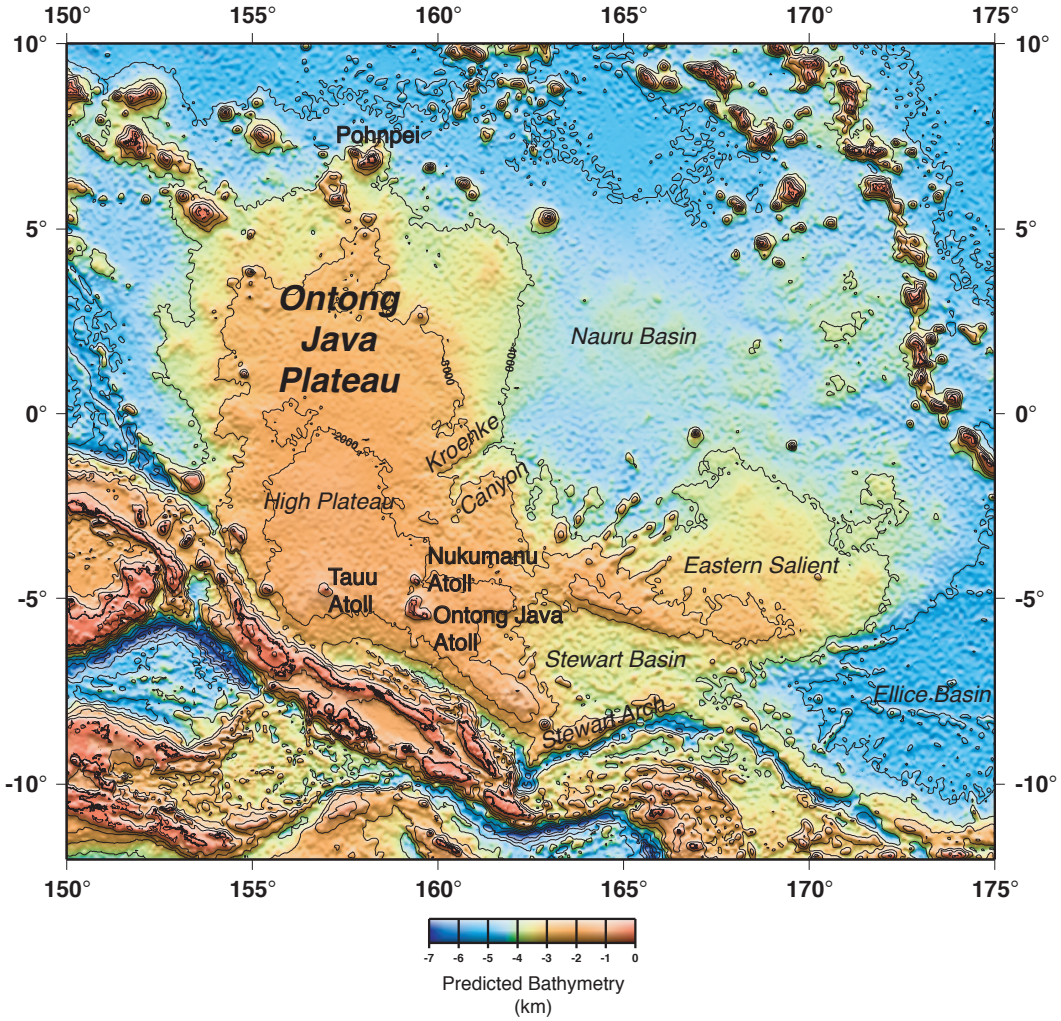

Figure 1. Bathymetry of the Ontong Java Plateau, western equatorial Pacific Ocean. Ontong Java and Nukumanu atolls surmount the shallowest portions of the High Plateau. Contour interval: 1000 m. After Sandwell and Smith, 1997, 2009; and Becker et al., 2009.

During FK141015 we investigated three prominent, yet unmapped and poorly known features on the OJP: Ontong Java Atoll, Nukumanu Atoll, and Kroenke Canyon. Ontong Java Atoll, the largest atoll in the Pacific, covers 1400 km^2, but only 12 km^2 of this area is land, distributed among 122 islands. The atoll has a maximum elevation of 13 meters, and the islands are home to ~1800 inhabitants. It belongs to the Solomon Islands. Nukumanu Atoll has a maximum elevation of two meters, encompasses 22 islands with a total area of 4.6 km^2, is home to ~730 inhabitants, and belongs to Papua New Guinea. Kroenke Canyon, with relief apparently exceeding 1000 m, may extend >500 km from these two atolls into the neighboring abyssal Nauru Basin. No igneous rock crops out on the coralline atolls, and no dredged igneous rock samples were available for the atolls or canyon. Modern multibeam bathymetric data were not available around the atolls, and were limited to a few random crossings of Kroenke Canyon.

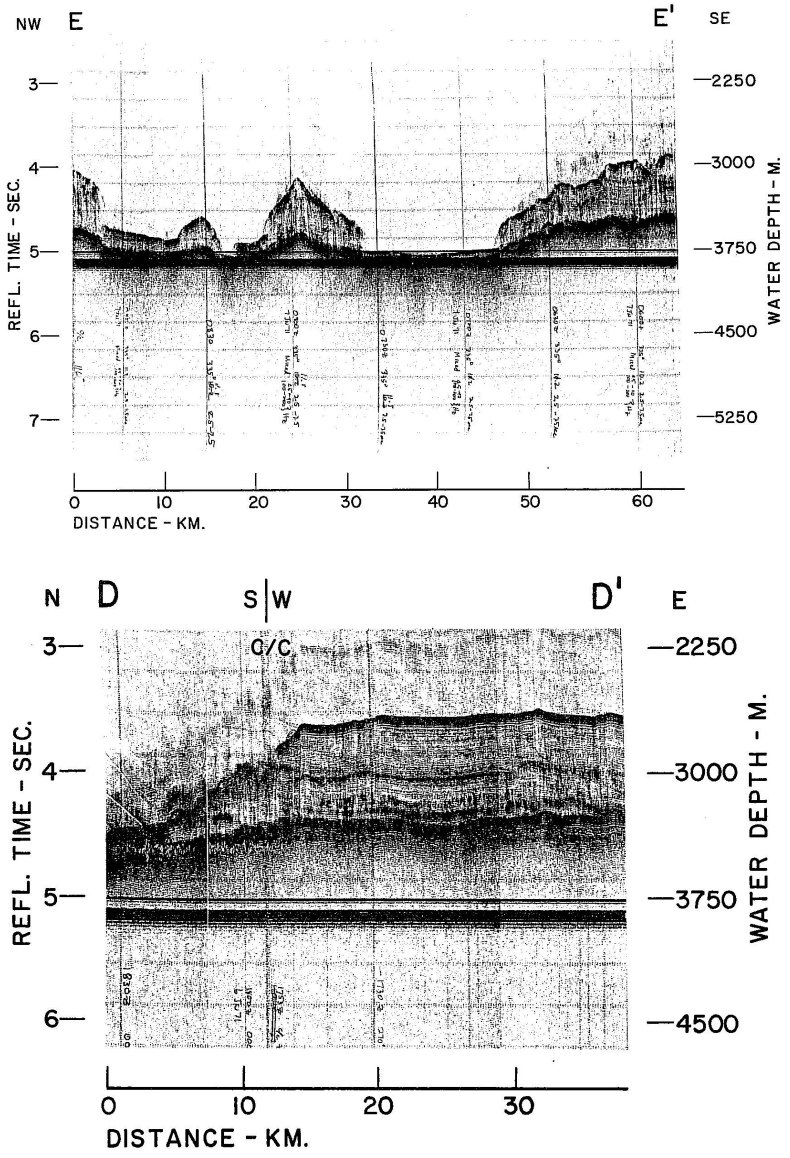

Figure 2. Seismic reflection profiles across Kroenke Canyon near the boundary between the OJP and Nauru Basin (Kroenke, 1972) (see Figure 1 for approximate location). The canyon appears to have eroded 1000 m or more of sediment. These are the only known marine geophysical data delineating Kroenke Canyon.

Research Hypotheses/Questions

Atolls

We hypothesized that the two large atolls, Ontong Java and Nukumanu, are significantly younger than the ca. 122 Ma OJP. The basis for this hypothesis is the stratigraphic interpretation that Tauu Atoll, to the west of the large atolls (Figure 1), is significantly younger than OJP (Inoue et al., in preparation), and the proposed track of OJP over the Wallis hotspot (Kroenke et al., 2004), which would attribute the large atolls to Tertiary Wallis hotspot magmatism. However, it is possible that the large atolls are similar in age to OJP, thereby offering a petrological and geochemical window into OJP's origin. FK141015 multibeam bathymetry and backscatter data from around the atolls has revealed the submarine morphology of the atolls' foundations, and has indicated the presence of outcropping igneous rock on the seafloor. Such outcrops offer opportunities for future dredging and/or ROV/AUV/submersible sampling. The petrology, geochemistry, and geochronology of igneous rock samples will reveal whether or not igneous rocks forming the atolls' foundations are resemble or differ from igneous basement of the main OJP.

We hypothesized that given the approximate L-shape of Ontong Java Atoll, it may have experienced flank collapse or other mass wasting from its northeastern quadrant (Figure 3, left). However, the limited FK141015 multibeam bathymetry around Ontong Java Atoll have not yet revealed whether its current shape reflects mass wasting or its original configuration (cfr. Figure 3, right).

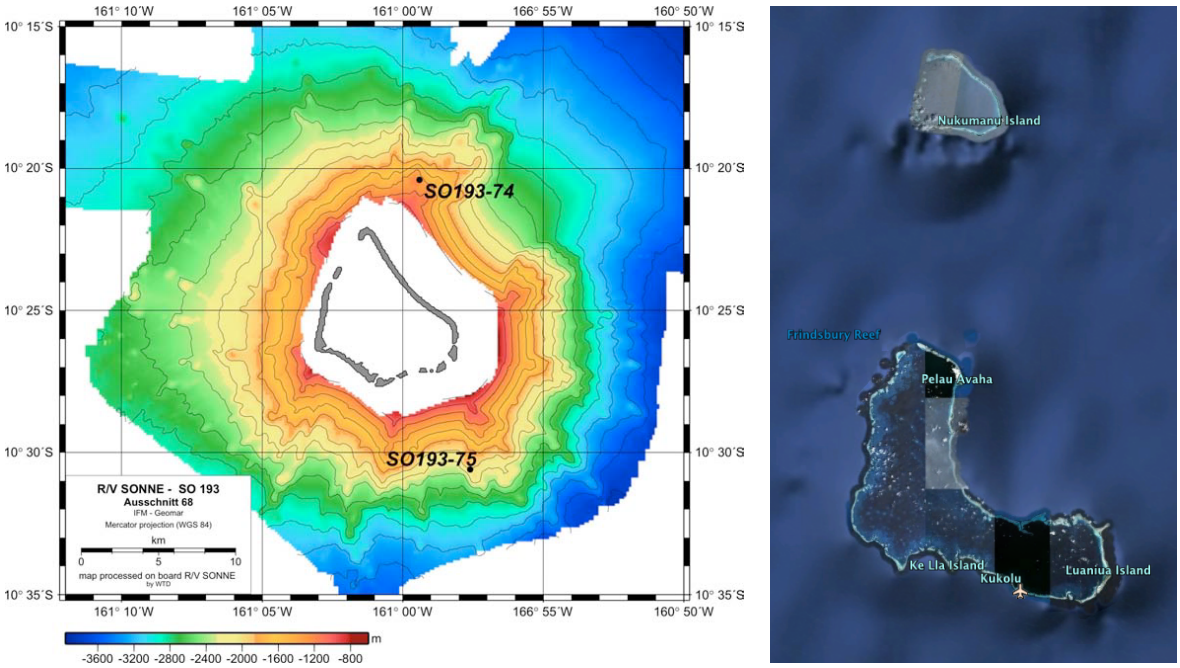

Figure 3. Left: Bathymetric map of the submarine base of Manihiki atoll on the Manihiki Plateau west of the Ontong Java Plateau. Note the collapsed northeast flank of the atoll, interrupting the general circular shape of the atoll and its submarine foundation (Werner and Hauff, 2007). Right: Images of Ontong Java Atoll (lower) and Nukumanu Atoll (upper) (Google Earth); see Figure 1 for regional location. The northeastern quadrant of Ontong Java Atoll may have experienced mass wasting.

The new FK141015 data are enabling assessment of tsunami risk for the atolls by providing the bathymetric data necessary for modeling of tsunami runup. Portions of the atoll bounded by shallow bathymetry seaward are inherently safer than those with abrupt transitions to deep water, as more shoreward-propagating wave energy is dissipated through bottom friction and turbulence in shallow water than in deep water. Knowledge of the seafloor morphology and shallow stratigraphy around the atolls is also laying the groundwork for assessing the effects of sea level fluctuations on atoll development, specifically by providing the data necessary to identify future coring and drilling sites where records of such changes are preserved.

Our research into Ontong Java and Nukumanu atolls is thus important for both pure scientific reasons and societal relevance. The FK141015 data are shedding light on temporal, and potentially genetic relationships between the atolls and the OJP, on atoll development, and on tsunami hazard. They are also providing information required for future marine geophysical (especially seismic), dredging, coring, and drilling investigations.

Kroenke Canyon

We hypothesize that the head of Kroenke Canyon is situated in the vicinity of Ontong Java and Nukumanu atolls, which would suggest that erosion of the atolls' ancestral subaerial volcanic islands supplied material for turbidity currents that formed the canyon. From the FK141015 multibeam data, we are able to trace the thalweg of Kroenke Canyon to within 150 km of the atolls. However, it is possible that the major tributary of Kroenke Canyon originates elsewhere on OJP, although all available evidence to date, except some accretionary lapilli, indicate that OJP was never above sea level. Additional multibeam data will be required to test this hypothesis.

Major submarine canyons with no obvious terrestrial source region constitute a new area of investigation. A recent global compilation of large submarine canyons (Harris and Whiteway, 2011) shows few such features on oceanic plateaus (Figures 4, 5). However, this study could be biased because most submarine canyon research has focused on siliciclastic systems with terrestrial sources. Despite their importance in Earth surface systems, major canyons on carbonate shelves/slopes and plateaus without obvious terrestrial sources have remained uninvestigated until FK141015. In siliclastic systems, the length of a submarine canyon is believed to be proportional to sediment volume. Kroenke Canyon, however, is exceptionally long, but lacks an obvious terrestrial source region. Major questions involve why the canyon is so long without a significant terrestrial source region, the origin of turbidity currents presumably responsible for formation of the canyon, the role of sea level fluctuations in the evolution of the canyon, potential consequences of sea level rise on the canyon, and the extent of any associated submarine fan in the Nauru Basin. Additional multibeam data will be required to investigate the presence or absence of such a submarine fan.

Investigating Kroenke Canyon is important because it will help explain a fundamental, yet unexplained phenomenon in Earth surface processes, namely how a major canyon can form in isolation from a terrestrial source region. The FK141015 data are helping to illuminate how Kroenke Canyon developed, but additional data are needed to test whether or not the atolls and the canyon are genetically linked, and on past and potential future effects of sea level fluctuations. As the lower reaches of the canyon offer a window into deeper portions of the OJP

sediment section and possibly into OJP igneous basement rock, the new data are providing information necessary for future deep sediment and potentially igneous basement sampling via dredging, coring, drilling, and ROV/AUV/submersible sampling.

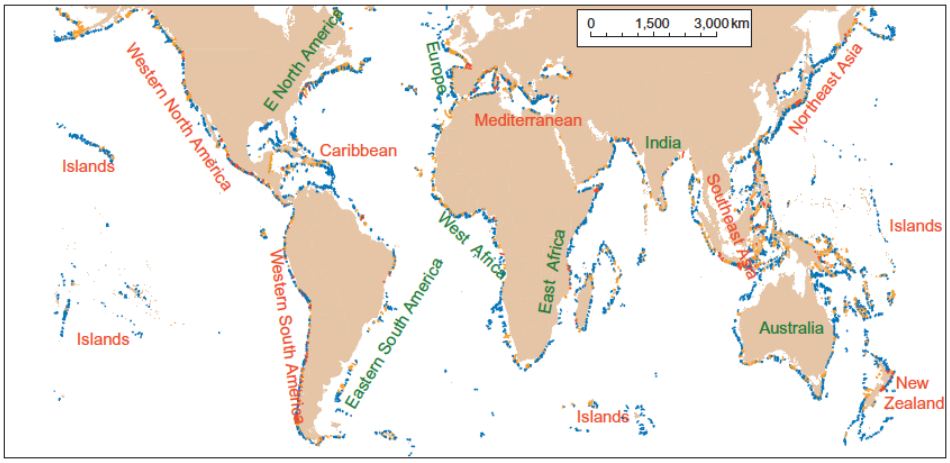

Figure 4. Global distribution of large submarine canyons (Harris and Whiteway, 2011). Active continental margins are labeled in red; passive margins in green. Note the paucity of large, shelf-incising canyons identified on submarine plateaus not contiguous with major landmasses. Key to canyon types: red, incising shelf and connecting to rivers; yellow, incising the shelf; blue, confined to the slope.

		Active margins	Passive margins
	Canyon occurrence (number)	3,605	2,244
	Type 1 occurrence (number)	119	34
Mean values	Slope (degrees)	6.0	3.8
	Spacing (km)	25.2	43.0
	Length (km)	37.1	53.7
	Cumulative length (km)	133,000	121,000
	Depth range (m)	1,998	1,984
	Dendricity (km)	58.7	106
	Sediment thickness (m)	944	2,624

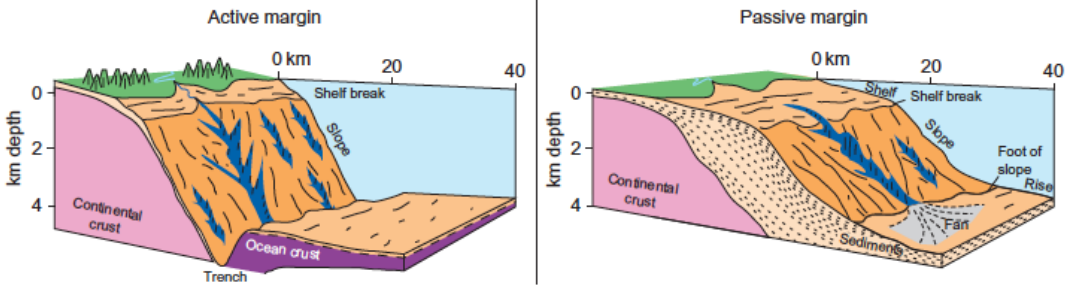

Figure 5. Geomorphic aspects contrasting submarine canyons incising active and passive continental margins (Harris and Whiteway, 2011). OJP is analogous to a passive margin, but without a contiguous continent. See Figure 4 for global distribution of canyons along active and passive continental margins.

Strategy and Methodology

Atoll and submarine canyon formation and evolution on oceanic plateaus constitute new areas of research, and therefore represent prime targets for unique and novel exploration and discovery. The primary goals of FK141015 are: to test potential genetic relationships between a) the atolls and the OJP, and b) the atolls and Kroenke Canyon; to understand and model how atolls and

canyons form and evolve on oceanic plateaus, isolated from terrestrial influences and subject to sea level fluctuations; and to contribute to understanding tsunami risk on low-lying atolls.

FK141015 acquired the first comprehensive multibeam bathymetric and backscatter data from Ontong Java Atoll, Nukumanu Atoll, and most of Kroenke Canyon, thereby creating a lasting legacy in ocean exploration and discovery. These new data from these unexplored features enables us to address the goals by elucidating the morphology and reflectivity of the seafloor around the atolls, including their volcanic foundations, and along Kroenke Canyon. Our results will contribute to overall understanding of erosional processes affecting oceanic island (eg, Morgan et al., 2000; Hills et al., 2002; Moore and Clague, 2002; Mitchell et al., 2002, 2003; Smith et al., 2002; Mitchell, 2003; Morgan et al., 2003; Masson et al., 2002, 2008; Mitchell and Lofi, 2008) and submarine canyons (eg, Mitchell, 2004, 2008; Harris and Whiteway, 2011). Furthermore, the bathymetric and backscatter maps that we generate will provide essential information required for future marine geophysical (especially seismic) and geological sampling (dredging, coring, drilling, ROV/AUV/submersible) work.

Intrinsic Scientific Value

The major scientific outcomes of our work should include:

1. The first-ever bathymetric maps of atolls on OJP, Ontong Java and Nukumanu atolls.
2. One or more models of atoll formation on oceanic plateaus.
3. The first-ever bathymetric map of a submarine canyon on an oceanic plateau, Kroenke Canyon.
4. One or more models of submarine canyon formation on oceanic plateaus.

Impact
Scientific audiences are interested by both the novelty and significance of studies of atolls and a submarine canyon situated on a submarine plateau, an environment where such features have not been studied previously. Awareness of atolls and submarine canyons is being raised in general audiences, especially in the context of rising sea level threatening indigenous cultures, tsunami risk, and massive undersea erosion.

Relationship of Outcomes to the Interests of SOI, the Wider Scientific Community, and Humanity
Our work is contributing to creating a lasting legacy in ocean exploration and discovery by investigating atolls and a submarine canyon for the first time on any oceanic plateau, thereby fostering a deeper understanding of our marine environment. Our international, multidisciplinary research team brings together some of the world's leading experts on oceanic plateaus, and we are committed to open sharing of information about the oceans. As a result of our work, the wider scientific community will have the data base necessary to justify, support, and conduct future dredge and ROV/AUV/submersible sampling expeditions as well as future marine geophysical cruises. Humanity is benefitting from access to new information that will assist Pacific island states and territories in addressing tsunami risk and mitigation as well as the challenges of rising sea level.

Collaborations

Our shipboard and shore-based research team is international, bringing together scientists and students from Australia, Israel, the United Kingdom, and the USA. We are a mix of early career, mid-career, and senior scientists, and jointly mentored PhD, MSc, and Honours students are involved in the project. An Expression of Interest to complete mapping of Kroenke Canyon and the atolls, and to obtain geological samples, has been submitted to SOI in collaboration with German scientists.

Project Deliverables

Four main data types were acquired during FK141015: EM302 and EM710 multibeam data, and XBT (12 casts) and CTD (one test cast) water column data (Table 1). It is our understanding that Lamont-Doherty Earth Observatory of Columbia University has been contracted by SOI to deliver final processed bathymetry and backscatter data. SOI has the complete XBT (Table 2) and CTD data set for FK141015.

Table 1. FK141015 data summary.

Instrument/System	Deliverable	Responsible Organisation
EM302	Processed multibeam data	Lamont-Doherty Earth Observatory
EM710	Processed multibeam data	Lamont-Doherty Earth Observatory
XBT	Expendable bathythermograph data	Schmidt Ocean Institute
CTD	Conductivity/Temperature/Depth	Schmidt Ocean Institute

Table 2. XBT locations.

Cast	Date	Time	Latitude	Longitude
1	15-Oct-14	01:38	6 40.877N	158 35.262E
2	16-Oct-14	16:27	0 47.551S	161 20.407E
3	18-Oct-14	03:43	4 56.672S	159 35.160E
4	19-Oct-14	05:29	3 58.450S	160 20.367E
5	20-Oct-14	09:32	0 54.787S	161 19.624E
6	23-Oct-14	03:30	5 04.793S	159 27.404E
7	23-Oct-14	03:37	5 06.189S	159 27.020E
8	23-Oct-14	03:41	5 07.031S	159 26.767E
9	25-Oct-14	01:43	1 41.352S	160 33.104E
10	26-Oct-14	23:49	2 29.825S	160 38.507E
11	31-Oct-14	23:29	8 07.001N	153 36.562E
12	2-Nov-14	10:23	12 27.307N	146 12.290E

Publications

The project has yielded high-quality data-rich outputs that will be presented at scientific workshops and conferences, and published in top-ranked international scientific journals. Three months post-cruise, two University of Tasmania students are working on the FK141015 data as part of an Honours thesis (Nicholas Adams) and a Masters thesis (Amelia Travers). Completion

of the two theses is anticipated in mid-2015, at which point manuscripts will be prepared for submission and review by end-2015, with publication possible in 2016. We intend to prepare one or more abstracts for submission for presentation at the American Geophysical Union December 2015 meeting in San Francisco. The presentations and publications will address the morphology, origin, and evolution of Ontong Java and Nukumanu Atolls, and Kroenke Canyon. Wide dissemination of research outcomes will be assisted by the diverse and international composition of the research team. Each institution represented and individual members of the research team have excellent records of presenting and publishing geoscientific research of high impact. As noted above, another important outcome of this project is providing fundamental bathymetric mapping data to future research expeditions.

Outreach

SOI (Mark Heckman, Carlie Wiener, Mark Shrope) and Institute for Marine and Antarctic Studies (Craig Macaulay) professionals worked together to engage the general public and media in the project. Chief Scientist Mike Coffin, student Amelia Travers, and Mark Heckman combined to produce daily blogs during the voyage that are available on the SOI website. Multiple scientific party members and ship's crew participated in Carlie Wiener's radio show *All Things Marine* conducted during the voyage, and Mike Coffin, Amelia Travers, and Mark Heckman video linked from RV *Falkor* with two high school classes at University of Hawaii at Manoa's University Laboratory School. Pre- and post-cruise media releases from the Institute for Marine and Antarctic Studies generated local and national radio and newspaper interviews.

Education

An important component of this project is involvement of five undergraduate (Adams) and graduate (Ketter, Neale, Reyes, Travers) students, who represent the next generation of scientists. We help to sustain the future of geoscience by integrating Honours, MSc, and PhD student projects into our research. The hands-on experience of being involved in a research cruise, which enables students to take some ownership of the way data is collected and interpreted, is key in successful research training. During FK141015, we ran a shipboard seminar series utilizing the expertise of the entire research team. The concepts and results of this project will be used in undergraduate and graduate teaching at all of the partner institutions and beyond. Student feedback indicates that they are excited and enthused by working on new data and current research problems. The integration of teaching and research increases student interest in the Earth sciences, an area of critical skills shortage across the globe.

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Appendix I: Letter to RV *Falkor* Captain from Shipboard Scientific Party

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IMAS INSTITUTE FOR MARINE AND ANTARCTIC STUDIES

UNIVERSITY of TASMANIA AUSTRALIA

3 November 2014

Captain Philipp Günther
Research Vessel *Falkor*

Dear Captain Günther

The entire FK141015 scientific party wishes to thank and commend you, C/O Thiago Da Silva, C/E Allan Watt, Purser Adriana Zamudio, Chefs Carlos Waihrich & Arkadiusz Ochocki, Cruise Coordinator/Lead Marine Technician Colleen Peters, Marine Technician Paul 'Jimbo' Duncan, and the rest of your able officers and crew for your vital contributions to the successful outcome of FK141015. You and your crew have been wonderfully cooperative, conscientious, capable, good-humoured, diligent, perceptive, and professional. It has been an extraordinary pleasure to work aboard this superb vessel, especially with such enthusiastic and welcoming shipmates imbued with a positive, 'can-do' attitude.

We look forward to future opportunities to sail aboard *Falkor*.

Yours sincerely

Prof Millard 'Mike' F Coffin
Executive Director, IMAS

Nicholas Adams
University of Tasmania

Mark Heckman
University of Hawaii

Tomer Ketter
University of New Hampshire

Jennifer Neale
University of Southampton

Andres 'AJ' Reyes
University of Guam

Amelia Travers
University of Tasmania

cc: Eric King, SOI Director of Marine Operations
Dr Victor Zykov, SOI Director of Research

Appendix II: RV *Falkor* FK141015 Crew List

Surname	Name	Position	Male/Female	Nationality
Adams	Nicholas	Scientist	M	Australia
Alcala	Hazel	Stewardess	F	Philippines
Bachniak	Sergiusz	Cadet	M	Poland
Benitez	Archel	Deckhand	M	Philippines
Coffin	Millard	Chief Scientist	M	USA
Da Silva	Thiago	Chief Officer	M	Brazil
Duncan	Paul	Marine Tech	M	UK
Gerasimov	Todor	ETO	M	Bulgaria
Günther	Philipp	Captain	M	Germany
Hay	Douglas	2nd Engineer	M	UK
Heckman	Mark	Scientist	M	USA
Hurdwell	Oliver	2nd Officer	M	UK
Ketter	Tomer	Scientist	M	Israel
Neale	Jennifer	Scientist	F	UK
Ochocki	Arkadiusz	Chef	M	Poland
Oliphant	Joshua	3rd Engineer	M	Canada
Pabustan	Edwin	Fitter	M	Philippines
Peters	Colleen	Lead Marine Tech	F	USA
Reyes	Andres	Scientist	M	USA
Sarzuelo	Dante	Fitter	M	Philippines
Suits	Erik	3rd Officer	M	Estonia
Tabaque	Ramon	3rd Engineer	M	Philippines
Travers	Amelia	Scientist	F	Australia
Utley	Michael	Bosun	M	UK
Virrey	Mary Ann	Stewardess	F	Philippines
Virrey	Wendel	Deckhand	M	Philippines
Waihrich	Carlos	Chef	M	Brazil
Watt	Allan	Chief Engineer	M	UK
Zamudio	Adriana	Purser	F	Colombia