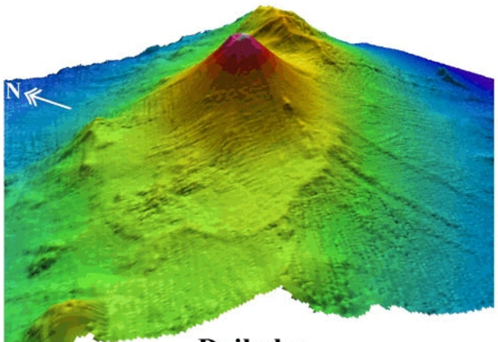
Submarine Ring of Fire 2003 - Mariana Arc

R/V Thomas G. Thompson Cruise TN153

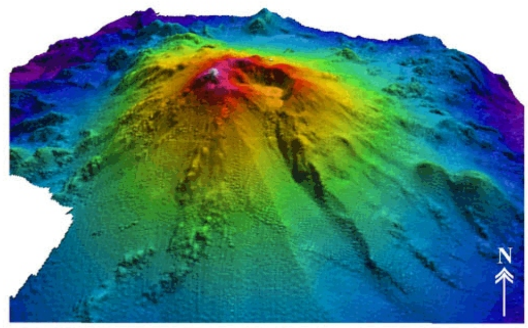
February 9 - March 5, 2003

Guam - Guam

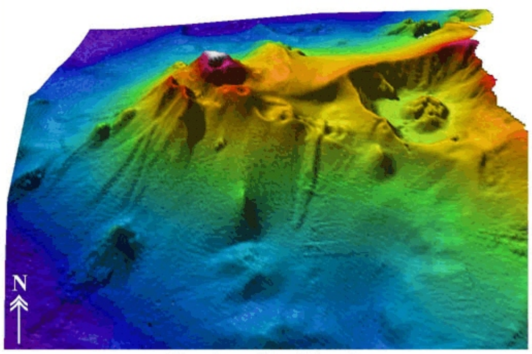
The Study of Hydrothermal Venting



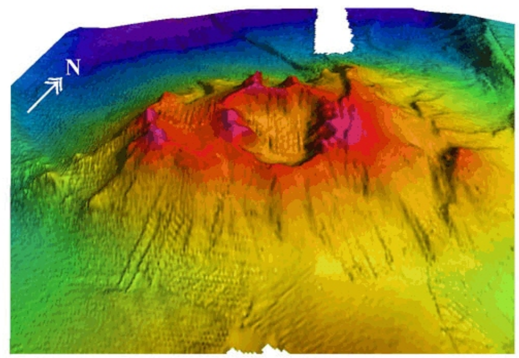
Daikoku
323 - 2779 meters



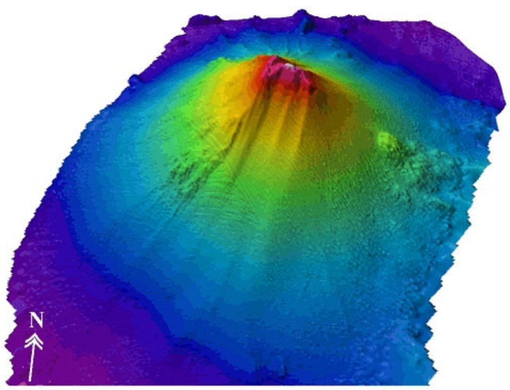
Kaguga 2
323 - 2779 meters



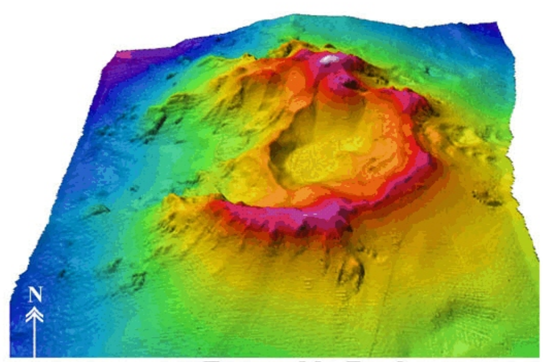
Zealandia Bank
143 - 1769 meters



Northwest Uracas
66 - 2700 meters



Northwest Rota 1
527 - 3142 meters



Esmeralda Bank
54 - 1400 meters

EXPLORE

Submarine Ring of Fire 2003 – Mariana Arc
R/V T. G. Thompson Cruise TN-153
February 9 - March 5, 2003 Guam to Guam

<u>**Co-Chief Scientists**</u>
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Cover: 3-dimensional image of submarine volcanoes mapped during 2003 Submarine Ring of Fire Expedition. Images constructed from 35-meter grids of EM300 multibeam data, which were brought into the Fledermaus program and vertically exaggerated 2 times. Hydrothermal plumes were found over the summits of all of these volcanoes. Locations of these volcanoes are on Figures 2-5 at the back of the report.

1.0 RING OF FIRE 2003 CRUISE SUMMARY

Background

There are ~20,000 km of volcanic arcs in the western Pacific region alone, of which only ~13% have been systematically surveyed, including the work accomplished on the Submarine Ring of Fire Expedition this field season. Submarine hydrothermal venting along these arcs therefore remains largely undetected and unexplored. The first compilation of hydrothermalism within these tectonic settings identified only seven submarine arc volcanoes with active hydrothermal activity in the Pacific (*Ishibashi and Urabe*, 1995). More recent work along a 260-km section of the Kermadec arc (*de Ronde et al*., 2001) found 7 of 13 submarine volcanoes studied to be hydrothermally active. Projection of this frequency of vent sites to volcanic arcs around the world suggests that hundreds of submarine arc volcanoes may inject globally significant fluxes of heat and chemicals into the oceans (*de Ronde et al*., in press).

There are at least four fundamental reasons to explore the geological and hydrothermal features of volcanic arcs: 1) Through water/rock reaction, the variety of magma and rock composition in volcanic arcs generates a wider range of hydrothermal fluid chemistry than found at typical mid-ocean ridge (MOR) sites. 2) The shallow water depth of many submarine volcanoes places the hydrothermal effluents high in the water column, increasing the likelihood that submarine volcanic processes will affect surface ocean processes such as primary productivity, and allows hydrothermal tracer studies in the upper ocean. 3) The geologic environments at arc volcanoes are similar to those known to be conducive to large ore deposits. 4) The wide range of habitat conditions on volcanic arcs may nurture unique and diverse microbial and faunal communities.

Hydrothermal discharge along volcanic arcs differs fundamentally from that along spreading centers because of the complex source history of the fluids arising from subduction zones. The more fractionated magmas that construct these arcs give rise to a wider range of volcanic rock compositions than the mostly basalt-dominated MOR rocks. Consequently, arc magmas have higher water content than MOR magmas and can contribute to the metals and gases transported by hydrothermal fluids (e.g., *de Ronde et al.,* 2001). Consequently, arc vent fluids will have a unique breadth of chemical composition through water/rock reactions and the addition of magmatic fluids (e.g., *Stüben et al*., 1992; *McMurtry et al.,* 1993). Of particular interest, this variability includes vent fields considered the best modern analogues of volcanogenic massive sulfide deposits currently exploited on land, particularly the gold-rich variety (*Rona*, 1988; *Ishibashi and Urabe*, 1995).

Vent sites associated with discrete arc volcanoes occur over a depth range from >2000 meters up to the sea surface. The shallow summits of many submarine arc volcanoes provide access to the upper ocean for hydrothermal and volcanic effluents. This has implications for tracer studies of mid-depth geostrophic flow and for the natural "iron-fertilization" of near-surface waters of the western Pacific (e.g., *Wells et al*., 1999; *Coale et al*., 1996). Both volcanic eruptions and volcanic hydrothermal systems produce abundant quantities of biologically-available iron, and the hot fluids rise and entrain great volumes of ambient deep ocean seawater rich in essential nutrients such as nitrate and phosphate. The result is that eruptions of these volcanoes and their subsequent hydrothermal activity likely lead to increased oceanic productivity in the regions near these volcanoes.

Volcanic arc terrains related to subduction zones are known from the geologic record to contain some of Earth's most intensely mineralized areas - and thus provide a significant proportion of our mineral wealth (*Barrie and Hannington,* 1999). The most valuable ore deposit types associated with subduction zones and active volcanic arcs are massive sulfide deposits, porphyry copper deposits and epithermal precious metal deposits.

Geologic Setting and Previous Work

The western subducting edge of the Pacific plate, one half of the Pacific submarine ring of fire, hosts more volcanic arcs than any other convergent plate boundary on Earth. Among the most volcanically active—and the only submarine volcanic arc in waters under U.S. jurisdiction—is the Mariana Arc. Including the Volcano Arc immediately to the north, the Mariana Arc region features more than 50 submarine volcanic edifices in addition to 11 major subaerial volcanoes dotted along more than 1000 km (Figs. 1 and 2). The combined Territory of Guam and the Commonwealth of the Northern Mariana Islands U.S. Exclusive Economic Zone (EEZ) encompasses most of the arc; from its southern terminus near 13ºN to near its intersection with the Volcano Arc near 23º N. Volcanic activity in the Mariana Arc and the Volcano and Izu-Bonin Arcs to the north is frequent and widespread. The Smithsonian Global Volcanism Program lists 11 subaerial and 10 submarine volcanoes with recorded activity along the Mariana Arc. Most of the activity from submarine volcanoes comes from the shallowest peaks, where eruptions and hydrothermal activity can produce observable changes in the surface waters. More than half the volcano summits are at depths >300 m, however, where hydrothermal or volcanic activity occurs unseen and unexplored.

Exploratory mapping and sampling of the Mariana Arc have been ongoing since the 1960s. Geophysical surveys (seismic reflection and refraction, gravity, and magnetics) dredging, sidescan sonar, conventional single beam bathymetric profiling, manned submersible dives, and deep-sea drilling investigated different portions of the Mariana Arc [see *Fryer*, (1995) and *Fryer,* (1996) for a review of many of these studies].

Navy multibeam SASS data collected in this region in 1985 provided initial locations for 39 submarine arc volcanoes and *Bloomer et al*. (1989) used these data to identify four volcanic provinces: The Southern Seamount Province (SSP) [Figs. 1-3], the Central Island Province (CIP) [Figs. 1,3,4), the Northern Seamount Province (NSP) [Figs. 1,2,5], and the Volcano Arc (VA) [Fig. 1]. The first three make up the Mariana Arc proper (Fig. 2). The SSP extends from 13º to 16ºN and includes more than 15 known submarine volcanoes (based on latest maps), with depths ranging from ~40 - 1200 m. Possible submarine eruptions have occurred on Ruby Volcano and Esmeralda Bank (Figs. 2 and 3) [*Norris and Hart*, (1970); *Stuben et al*., (1992)]. The CIP is the oldest part of the arc, with an age of ~5 my. Extending from 16º to 20º40'N, this province is dominated by mostly large active subaerial volcanoes but there are also 13 submarine volcanoes (Figs. 2 and 4). Several of these islands have had historical eruptions (Pagan, Asuncion, Farallon de Pajaros) and Anatahan, the southernmost of the islands (Figs. 2 and 3), began an eruption on May 11, 2003, just 2 months after our expedition ended. There were no previous reports of historical eruptions on Anatahan. The NSP extends from 20º40' to 24ºN and includes more than 20 submarine volcanoes with depths ranging from ~100-1500 m (Figs 2 and 5). There are reports of possible submarine eruptions in the vicinity of Kasuga 1, Fukujin, and Nikko (Figs. 2 and 5). The VA, north of 24ºN, is in the Japanese EEZ. Intermittent but intense T-phase activity was centered here at ~26ºN during the period from 1998 to 2000. There are at least seven submarine volcanoes in this area (~100-1500 m depths), two of which have had known volcanic activity.

Active hydrothermal sites have been sampled on three volcanoes in the Mariana Arc. *Stüben et al*. (1992) collected sediments and water samples from Esmeralda Bank, a shallow breached caldera (depth ~300 m) at the southern end of the arc. High concentrations of CH_4, CO_2, and H_2S were interpreted as evidence of a recent eruption and ongoing magmatic degassing. To the north, *McMurtry et al*. (1993) collected one sample of low-temperature fluids at both Kasuga 2 and Kasuga 3 near 21º30'N. The Kasuga 2 sample showed evidence of addition of volcanic CO_2 and SO_2 to a seawater-derived hydrothermal fluid. Thus the scant but tantalizing evidence presently available supports the view that Mariana Arc fluids are likely to be gas rich compared to normal MOR fluids, an environment conducive to microbiological growth and ore deposition. *Ishibashi and Urabe* (1995) also reported on a hydrothermal site on a seamount in the southernmost back-arc basin.

Observations from passing ships and from airplanes, together with acoustic-detection of eruption sounds trapped in the SOFAR channel (T-phases), also points to submarine volcanic activity in the Mariana Arc. Pioneering work in the 1960s, using hydrophones installed for tracking ballistic missiles over the

Pacific, detected submarine eruptions near Saipan and southwest of Farallon de Pajaros Island (*Norris and Johnson*, 1969; *Norris and Hart*, 1970). Over the past 10 years the Navy's SOSUS Pacific arrays (*Fox et al.*, 1994/1995) have intermittently recorded seismicity from 12º to 18ºN and 139º to 144ºE, the area along the Mariana Arc in U.S. territorial waters north of Saipan and Guam. Since 1995, however, activity has significantly increased from this region, including more than 500 locatable earthquakes ©. *Fox and R. Dziak*, unpublished data). The signals are diagnostic of shallow-crust, shallow-water seismicity (impulsive, short duration). However, since the Mariana Arc lies outside of optimum SOSUS coverage, the earthquakes cannot be specifically located on individual volcanoes.

In the late 1990s the Mariana Arc was designated as a special study site for the NSF MARGINS Program. A series of recent expeditions by U.S. and Japanese scientists has considerably expanded the high-resolution data sets available for the back-arc basin and the southern part of the arc. In 2001 the *R/V Melville* (PIs – S. Bloomer, R. Stern and P. Fryer) conducted a series of surveys using the Hawaii Mapping Research Group's MR1 sidescan sonar (also used on the 2003 expedition) that covered the SSP and the eastern portion of the back-arc spreading center from about 12º to 15ºN (Figs. 1-3). Some additional multibeam data were collected on a follow-up expedition (2001) in conjunction with a dredging campaign (S. Bloomer, personal communication).

The 2003 Submarine Ring of Fire Expedition

Our expedition was funded by the NOAA Office of Ocean Exploration and the NOAA VENTS Program (the latter as part of our ongoing investigation of oceanic impacts of hydrothermal venting). This program was originally scheduled for the beginning of 2004, but an unexpected deficit in the February - March 2003 *T.G. Thompson* schedule that appeared in December 2003 accelerated the planned timetable. A period of concerted scientific and logistical planning culminated in a 25-day cruise extending from February 9 to March 5, 2003, including work in the territorial waters of Japan between 24 and 27 February (UTC). The primary goals of the expedition included: (1) acoustically imaging all of the major submarine volcanoes of the volcanic arc from Guam (~12ºN) to the juncture of the Mariana and Volcano Arcs at about 23ºN using the MR1 towed sidescan sonar (for more on this system see: http://www.soest.hawaii.edu/HMRG/MR1/index.html) and the *T.G. Thompson's* high resolution EM300 multibeam system (Figs. 2-5, Fig. 7), (2) conducting a reconnaissance survey of the water column overlaying each submarine volcano using a CTD/rosette system to map and sample hydrothermal plumes (e.g. Fig. 6), and (3) deploying an array of five moored autonomous hydrophones (for more on the hydrophones see: http://www.pmel.noaa.gov/vents/acoustics/haru_system.html) in the back-arc basin (Fig. 2) to monitor acoustic signals emanating from the Mariana Arc.

Our systematic exploration of this little-explored but scientifically significant ocean area was extraordinarily successful. We mapped more than 18,000 km^2 with the MR1 sidescan sonar and almost 28,000 km^2 with the EM300 multibeam system. More than 50 individual volcanoes were surveyed at least partially with the EM300 system. MR1 sidescan data were collected over the full length of the volcanic arc (linking up with the previously surveyed area to the south). During the course of the cruise we conducted 70 CTD stations over 55 submarine volcanoes, collecting 3055 samples for twelve different types of chemical analyses. Five hydrophone moorings deployed at intervals along the arc will record data for the next seven months. Our surveys covered more than 10 degrees of latitude from the southernmost Mariana Arc at 12ºN to its intersection with the next arc to the north (Izu-Bonin) at 23ºN. The Japanese government graciously permitted our work along the Izu-Bonin Arc within the Japanese EEZ.

As a result of the extensive acoustic mapping done during the cruise, we increased the total number of located submarine volcanoes in the Mariana Arc from the earlier estimate of 39 (*Bloomer et al.*, 1989) to at least 56 (not counting many small volcanic constructs with relief of a few hundred meters or less) (Figs. 2-5). Volcano spatial density is greatest in the SSP (5.8/100 km of arc), sparsest in the CIP (2.8/100 km), and intermediate in the

NSP (4.4/100 km). Evidence for active hydrothermal venting was observed at 11 submarine volcanoes (Figs. 2-5) and an additional site on the southern back-arc spreading center, though detailed analyses of collected samples could increase this total. The frequency of active submarine volcanoes in each province is similar at ~20%. Our results confirmed historical hydrothermal activity at Kasuga 2 (but not Kasuga 3) (*McMurtry et al.*, 1993), and Esmeralda Bank (*Stüben et al.*, 1992). We also confirmed hydrothermal activity on Nikko (Fig. 5), where historical volcanic activity had been inferred from observations of discolored surface water and/or seismic signals. No shipboard evidence for hydrothermal activity (but further chemical analyses are pending) was found at Fukujin (Fig. 5), Makhahnas, and Ahyi (Fig. 4), three other volcanoes with similar circumstantial historical volcanic evidence.

Additional Information and Contacts

Additional images, maps and other results from the cruise are available at Ocean Exploration website at: http://www.oceanexplorer.noaa.gov/explorations/03fire/

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2.0 CRUISE PARTICIPANTS

2.1 Scientific Party and Affiliations

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Ko-ichi Nakamura	Marine Chemistry, National Institute of Advanced Industrial Science and Technology, Japan
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Geoff Lebon	Marine Chemistry and Data Analysis, University of Washington, JISAO
Ron Greene	Helium Sampling and Data Analysis, Oregon State University, CIMRS
Matt Fowler	Hydroacoustics, Oregon State University, CIMRS
Stacy Maenner	Marine Chemistry, NOAA Pacific Marine Environmental Laboratory, Seattle, Washington
Kelly Kaiser	Chemist, formerly of DePaul University
Shannon Ristau	Geologist, NOAA Corps
Andrew Graham	Chemist, University of Washington
Fernando Martinez	Marine Geophysicist/HMRG group, University of Hawaii
Paul Johnson	Marine Geologist/HMRG party chief, University of Hawaii
Steven Tottori	Engineer/HMRG group, University of Hawaii
Jennifer Engels	Marine Geology/Geophysics Graduate Student, University of Hawaii

2.2 *R/V Thomas G. Thompson* Crew

Philip A. Smith	Master
John A. Parsons	1st Mate
Thomas G. Drake	2nd Mate
Eric Haroldson	3rd Mate
Brian Clampitt	AB
Frank L. Spetla Jr.	AB
Jacob H. Greenberg	AB
Michael Durnan	AB
Robert Harmeling	AB
Marcella Braniff	AB
Matthew J. Skelly	AB
Charles E. Ormiston	Chief Engineer
Bryan B. Blondeau	1st Engineer
Richard D. Leonard	2nd Engineer
Steven Layn	3rd Engineer
Stuart A. Meacham	Oiler
David A. Bartell	Oiler
Nathan Gardner	Oiler
Peter Rudy	Wiper
Frank D. McBriar	Chief Steward
Michael D. Maupin	2nd Cook
Hasheem Bell	Steward Assistant

3.0 CRUISE LOG

TN153 Cruise Log - Mariana Arc Submarine Ring of Fire 2003

Date	JD	Time (GMT)	Event - Comments	Event	Cast	Lat N (deg)	Lat N (min)	Long E (deg)	Long E (min)
8-Feb	39	20:40	Departed Apra Harbor Guam. Local time 06:40, February 9, 2003 (GMT 10 hours behind local time).						
9-Feb	40	03:08	Start EM300 line along Southern Back-arc Spreading Center.						
		08:25	End EM300 survey of Southern Back-arc Spreading Center.						
9-Feb	40	09:00	Start along-axis CTD tow-yo on Southern Back-arc Spreading Center.	T03A-01	001	12	40.8225	143	22.3249
10-Feb	41	15:30	End along-axis tow-yo on Southern Back-arc Spreading Center.			13	15.0914	143	43.6509
			Active hydrothermal system present on Southern Back-arc Spreading Center.						
		15:45	Start EM300 line heading south along east side spreading axis.						
		18:30	End EM300 line back along east side spreading axis.						
		19:00	Start across-axis CTD tow-yo at Southern Back-arc Spreading Center.	T03A-02	002	12	55.8000	143	38.8700
		23:45	End across-axis tow-yo. (approximate time)			12	59.0400	143	34.6500
11-Feb	42	01:24	Start logging EM300 in area of first MR1 calibration.						
		02:15	MR1 deployed for calibration and testing.						
		05:00	MR1 back on board.						
		06:45	Start CTD tow-yo at Seamount X Volcano.	T03A-03	003	13	14.1479	144	0.6385
		09:21	End tow-yo at Seamount X.			13	15.9617	144	2.0337
			Active hydrothermal system present on Seamount X Volcano.						
		12:25	Hydrophone # 1 deployed. Depth 3834 m. [12:25 - 15:10]	Hyd-1		13	37.8300	144	4.0500
		15:10	EM300 transit to Tracey Volcano. [15:10 - 18:10]						
		19:14	Start CTD tow-yo at Tracey Volcano.	T03A-04	004	13	38.0000	144	25.5200
		21:37	End tow-yo at Tracey.			13	38.0180	144	23.1700
		21:45	EM300 transit to Northwest Guam Volcano. [21:45 - 00:14]						
12-Feb	43	01:25	Start CTD tow-yo at Northwest Guam Volcano.	T03A-05	005	14	0.9270	144	39.3420
		03:45	End tow-yo at Northwest Guam.			14	1.5800	144	36.9100
		03:45	EM300 transit to West Rota Volcano. [03:45 - 06:33]						
		06:48	CTD vertical cast at West Rota - shallow, southeast peak. [06:48 - 07:10]	V03A-01	006	14	17.0071	144	52.9994
		08:01	CTD vertical cast at West Rota - southeast of the caldera. [08:01 - 09:06]	V03A-02	007	14	18.1201	144	50.5030
		10:08	CTD vertical cast at West Rota - northwest end of the caldera. [10:08 - 11:14]	V03A-03	008	14	20.2684	144	49.4035
		11:22	Transit to Northwest Rota Volcano group. [11:22-13:28]						
		13:49	Start CTD tow-yo at Northwest Rota-1, the western-most volcano in the Rota group.	T03A-06	009	14	35.1556	144	45.8434
		16:00	End tow-yo at Northwest Rota-1.			14	36.7423	144	46.4965
			Active hydrothermal system present on Northwest Rota-1.						
		16:29	Start EM300 survey of Northwest Rota-1.						
		18:24	End EM300 survey of Northwest Rota-1.						
		18:25	Transit to Northwest Rota-2 Volcano. [18:25 - 19:20]						
		19:30	CTD vertical cast on Northwest Rota-2. [19:30 - 22:00]	V03A-04	010	14	37.0960	144	53.3860
		22:00	EM300 transit to Northwest Rota-3. [22:00 - 22:30]						
		23:02	CTD vertical cast on Northwest Rota-3 Volcano. [23:02 - 00:08]	V03A-05	011	14	35.7000	144	59.5400
13-Feb	44	00:08	EM300 transit to Northwest Rota-4. [00:08 - 01:40]						
		01:40	CTD vertical cast on Northwest Rota-4 Volcano. [01:40 - 02:15]	V03A-06	012	14	44.0900	145	4.7000

Date	JD	Time (GMT)	Event - Comments	Event	Cast	Lat N (deg)	Lat N (min)	Long E (deg)	Long E (min)
		02:30	EM300 transit to Esmeralda Bank. [02:30 - 03:41]						
		03:50	Start EM300 survey of Esmeralda Bank.						
		08:52	End EM300 survey of Esmeralda Bank.						
		09:00	CTD vertical casts 07and 08 at Esmeralda Bank. [09:00 - 12:08]						
			CTD vertical cast at Esmeralda Bank caldera.	V03A-07	013	14	57.5991	145	14.6877
			CTD vertical cast on small cone at north rim of Esmeralda Bank caldera.	V03A-08	014	14	58.2491	145	14.9770
			Active hydrothermal system present on Esmeralda Bank Volcano.						
		12:08	Start EM300 survey of North Esmeralda Volcano.						
		13:08	End EM300 survey of North Esmeralda.						
		13:09	CTD vertical casts 09 and 10 at North Esmeralda Volcano. [13:09 - 14:10]						
			CTD vertical cast just south of summit of North Esmeralda Volcano.	V03A-09	015	15	1.4872	145	13.5021
			CTD vertical cast just north of summit of North Esmeralda Volcano.	V03A-10	016	15	3.2942	145	14.5332
		14:10	Start EM300 survey over North Esmeralda Volcano.						
		14:28	End EM300 survey over North Esmeralda.						
		14:29	EM300 transit to West Tinian Volcano. [14:29 - 15:50]						
		15:50	CTD vertical cast south of the summit of West Tinian Volcano. [15:50 - 16:33]	V03A-11	017	15	3.9009	145	25.0026
		16:33	EM300 survey over the top of West Tinian Volcano. One narrow survey line because the volcano is only ~50 meters deep at the summit. [16:33 - 17:00]						
		17:00	CTD vertical cast on the summit of West Tinian. [17:00 - 17:27]	V03A-12	018	15	4.9017	145	25.1019
		17:27	EM300 transit to West Saipan Volcano. [17:27 - 18:54]						
		19:11	Start CTD tow-yo of West Saipan Volcano.	T03A-07	019	15	16.6000	145	27.0880
		20:33	End tow-yo of West Saipan.			15	17.9500	145	27.1100
		20:33	Em300 transit to Ruby Volcano. [20:33 - 22:36]						
		22:36	Start EM300 survey of Ruby Volcano.						
14-Feb	45	01:31	End EM300 survey of Ruby.						
		01:32	Start CTD tow-yo of Ruby Volcano.	T03A-08	020	15	34.9114	145	34.3942
		03:00	End CTD tow-yo of Ruby. (approximate time)			15	36.9600	145	34.5800
		03:15	CTD vertical cast on North Ruby Volcano. (approximate time)	V03A-13	021	15	39.5000	145	35.2000
		04:16	EM300 transit to begin MR1 sidescan survey Box A - the southern survey area. [04:16 - 06:11]						
		06:11	Start calibration lines for MR1 sonar survey.						
		14:02	End calibration lines for MR1 sonar survey.						
		14:02	Start MR1 Box A (16-18N) - Line 1 (south to north, EM300 lines 71 - 76).	Start MR1-A		15	48.9	145	35
15-Feb	46	06:36	End MR1 Box A - Line 1.			18	0	145	35
		06:50	Start MR1 Box A - Line 2 (north to south, EM300 lines 77 - 81).			18	0	145	39
		21:11:00	End MR1 Box A- Line 2.			16	1	145	40
		22:06	Start MR1 Box A - Line 3 (south to north, EM300 lines 82 - 87).			16	1	145	45
16-Feb	47	12:20:00	End MR1 Box A - Line 3.			18	0	145	45
		13:12	Start MR1 Box A - Line 4 (north to south, EM300 lines 88 - 95).			18	0	145	50
		21:52	POSMV errors cause navigational problems [21:52 - 23:14]. Ship had to circle to reset system.						
Feb 17	48	04:57	End MR1 Box A - Line 4. This ends the MR1 sidescan / EM300 survey of Box A from 16 to 18 degrees North.	End MR1-A		16	0	145	50

Date	JD	Time (GMT)	Event - Comments	Event	Cast	Lat N (deg)	Lat N (min)	Long E (deg)	Long E (min)
		04:58	Recovered the MR1 system. [04:58 - 07:00]						
		07:00	EM300 transit to East Diamante Volcano and setup for CTD. [07:00 - 07:18]						
		07:18	Start CTD tow-yo at East Diamante Volcano.	T03A-09	022	15	54.2300	145	37.8800
		10:36	End CTD tow-yo at East Diamante.			15	56.7689	145	41.0556
		10:36	Start EM300 survey of East Diamante Volcano.						
		13:14	End EM300 survey of East Diamante.						
			Active hydrothermal system present on East Diamante Volcano.						
		13:14	CTD vertical cast at Middle Diamante Volcano. [13:14 - 15:01]	V03A-14	023	15	56.7289	145	31.8098
		15:01	EM300 transit to West Diamante Volcano. [15:01 - 16:43]						
		16:43	Start CTD tow-yo on West Diamante Volcano.	T03A-10	024	15	56.5517	145	24.2745
		18:42	End CTD tow-yo on West Diamante.			15	57.7500	145	25.4280
		18:43	EM300 transit to Northeast Anatahan Volcano. [18:43 - 22:26]						
		22:26	CTD vertical cast at Northeast Anatahan Volcano. [22:26 - 23:32]	V03A-15	025	16	25.7100	145	46.8800
		23:32	EM300 transit to South Sarigan Volcano. [23:32 - 00:47]						
18-Feb	49	00:48	CTD vertical cast at South Sarigan. [00:48 - 01:45]	V03A-16	026	16	35.0600	145	46.8000
		01:45	EM300 transit and survey from South Sarigan to West Sarigan Volcanoes. [01:45 - 03:38]						
		03:39	Getting into position and setting up for CTD. [03:39 - 04:08]						
		04:09	CTD vertical cast at West Sarigan Volcano. [04:09 - 04:48]	V03A-17	027	16	44.1100	145	37.3600
		04:49	Start EM300 transit to and survey of Zealandia Bank.						
		08:49	End EM300 survey of Zealandia Bank.						
		08:50	Three CTD vertical casts at Zealandia Bank (18 - 20). [08:50 - 12:06]						
			CTD vertical cast in Zealandia Bank Caldera, north of the central cone.	V03A-18	028	16	53.2031	145	49.3881
			CTD vertical cast in Zealandia Bank Caldera southwest of the central cone.	V03A-19	029	16	52.7080	145	49.1848
			CTD vertical cast at Zealandia Bank in the saddle between the caldera with the cone and the west peak.	V03A-20	030	16	52.2029	145	48.3663
		12:07	EM300 fill-in/transit over Zealandia to position of more CTDs. [12:07 - 12:30]						
		12:31	CTD vertical cast on western peak of Zealandia Bank. [12:31 - 13:07]	V03A-21	031	16	52.6721	145	47.0306
			Possible active hydrothermal system on Zealandia Bank.						
		13:07	Start EM300 transit and survey west of Zealandia Bank over West Zealandia Volcano then on to North (New) Zealandia.						
		14:46	End EM300 survey of West and North (New) Zealandia Volcanoes.						
		14:46	Start CTD tow-yo of North Zealandia Volcano.	T03A-11	032	16	58.3200	145	42.7170
		16:37	End CTD tow-yo of North Zealandia.			16	59.6076	145	43.2174
		16:37	EM300 transit to deploy Hydrophone # 2. [16:37 - 19:00]						
		19:00	Hydrophone # 2 deployed (position for anchor drop point). [19:00 - 20:35]	Hyd-2		17	0.1440	145	25.1350
		20:35	EM300 transit to West Guguan-3. [20:35 - 22:48]						
		22:49	Set up for CTD tow-yo. [22:49 - 23:09]						
		23:10	Start CTD tow-yo at West Guguan-3 Volcano.	T03A-12	033	17	19.8810	145	19.3870
19-Feb	50	01:00	End CTD tow-yo at West Guguan-3.			17	21.4400	145	19.3700
		01:00	EM300 transit to tow-yo site at West Guguan-2 Volcano. [01:00-02:25]						
		02:26	Set up for CTD at West Guguan-2. [02:26 - 02:39]						
		02:39	Start CTD tow-yo at West Guguan-2, from the southwest to the northeast.	T03A-13	034	17	15.5000	145	33.6900

Date	JD	Time (GMT)	Event - Comments	Event	Cast	Lat N (deg)	Lat N (min)	Long E (deg)	Long E (min)
		04:14	End CTD tow-yo at West Guguan-2.			17	16.5560	145	35.4670
		04:18	EM300 transit to West Guguan-1 Volcano. [04:18 - 05:11]						
		05:11	Start CTD tow-yo at West Guguan-1 Volcano.	T03A-14	035	17	16.4100	145	42.9200
		07:33	End CTD tow-yo at West Guguan-1.			17	17.2200	145	45.0300
		07:34	EM300 transit to deep area west of Alamagan for a vertical cast, which will be used as a background reference. [07:34 - 10:09]						
		10:10	CTD deep-water vertical cast for background samples. [10:10 - 12:42]	V03A-22	036	17	38.0489	145	36.2274
		12:43	EM300 transit to beginning of MR1 Box B survey. [12:43 - 13:37]						
		13:37	MR1 deployed for survey Box B (18-20N). [13:37 - 15:10]						
		15:10	Start MR1 Survey Box B - Line 1 (south to north, EM300 lines 162 -168).	Start MR1-B		17	50	145	25
20-Feb	51	08:34:00	End MR1 Survey Box B - Line 1.			20	0	145	0
		09:38	Start MR1 Survey Box B - Line 2 (north to south, EM300 lines 169 -177).			20	0	145	9
21-Feb	52	02:26	End MR1 Survey Box B - Line 2.	End MR1-B		17	50	145	30
		02:36	Positioning and recovery of MR1. [02:36 - 04:25]						
		05:07	EM300 transit to Daon Volcano, which is southeast of Pagan Island. [05:07 - 06:12]						
		06:13	Start CTD tow-yo on Daon Volcano.	T03A-15	037	17	57.2873	145	29.0003
		08:31	End CTD tow-yo on Daon.			17	58.3458	145	28.9830
		08:32-16:57	EM300 transit north to Poyo Volcano and survey over the top. [08:32 - 17:42]						
		17:43	Start CTD tow-yo at Poyo Volcano.	T03A-16	038	19	12.3806	145	31.4861
		19:50	End CTD tow-yo at Poyo.			19	14.0000	145	32.3920
		19:56	EM300 transit to Cheref Volcano. [19:56 - 21:48]						
		21:48	Start CTD tow-yo at Cheref Volcano.	T03A-17	039	19	25.9500	145	27.9900
		23:39	End CTD tow-yo at Cheref.			19	23.9200	145	26.6900
		23:39	EM300 transit to Maug Caldera. [23:39 - 03.29]						
22-Feb	53	03:29	At Maug Caldera for CTD and EM300 surveys, moved from the west to the east side of the central cone. [03:29 - 05:42]						
			CTD vertical cast on west side of cone in the caldera.	V03A-23	040	20	1.3400	145	12.9700
			Active hydrothermal system probably present in Maug caldera. Further data analysis is needed.						
		05:42	EM300 transit to deployment site for MR1. [05:42 - 06:14]						
		06:15	Deployed MR1 sonar fish. [06:15 -08:10]						
		08:11	Heading to start of MR1 sonar survey C (20-23degN). [08:11 - 09:50]						
		09:51	Start MR1 survey Box C - Line 1 (southeast to northwest heading ~323 degrees, EM300 lines 205 - 215).	Start MR1-C		19	56	145	1
23-Feb	54	06:40:00	End MR1 survey Box C - Line 1.			22	11.4	143	25.4
		07:22	Start MR1 survey Box C - Line 2 (northwest to southeast heading ~138 degrees, EM300 lines 216 - 223).			22	11	143	22
24-Feb	55	00:34	End MR1 survey Box C - Line2.			20	13.4	144	59.2
		01:14	Start MR1 survey Box C - Line 3 (southeast to northwest heading ~323 degrees, EM300 lines 224 - 239).			20	10	144	55
25-Feb	56	07:01	End MR1 survey Box C - Line 3.			23	15	142	15
			Note: MR1 survey Box C Line 3 went farther northwest than the previous two lines (23 deg 5' N) into the Japanese EEZ.						

Date	JD	Time (GMT)	Event - Comments	Event	Cast	Lat N (deg)	Lat N (min)	Long E (deg)	Long E (min)
		07:01	Start short MR1 survey line from the northeast to the southwest, over Northwest Nikko Volcano (EM300 lines 240 - 242). Box C - Line 3b.			23	15	142	15
		08:50	End short MR1 survey line from the northeast to the southwest, over Northwest Nikko Volcano (EM300 lines 240 - 242). Box C - Line 3b.	End MR1-C		23	9	142	2
		08:51	Recovered MR1 sonar. [08:51 - 10:00]						
		10:01	Start EM300 survey over Northwest Nikko Volcano from west to east.						
		11:50	End EM300 survey over Northwest Nikko Volcano.						
		12:09	Start CTD tow-yo on Northwest Nikko Volcano.	T03A-18	041	23	8.1296	142	6.7693
		15:28	End CTD tow-yo on Northwest Nikko.			23	10.3884	142	7.6280
		15:28	EM300 transit to Nikko Volcano. [15:28 - 16:27]						
		16:27	Start EM300 survey of Nikko Volcano.						
		18:15	End EM300 survey of Nikko..						
		18:26	Start CTD tow-yo at Nikko Volcano (southwest cone).	T03A-19	042	23	4.4040	142	19.1900
		19:25	End CTD tow-yo at Nikko (southwest cone).			23	5.2200	142	19.9500
		19:25	EM300 transit to northeast side of Nikko caldera. [19:25 - 21:21]						
		21:21	Start CTD tow-yo at Nikko Volcano (northeast cone).	T03A-20	043	23	6.3700	142	21.7900
		22:02	End CTD tow-yo at Nikko (northeast cone).			23	7.2500	142	21.8900
			Active hydrothermal system present at Nikko Volcano.						
		22:09	EM300 transit to Northwest Syoyo Volcano. [22:09 - 00:29].						
26-Feb	57	00:50	Start CTD tow-yo at Northwest Syoyo Volcano.	T03A-21	044	22	41.2750	142	27.5860
		02:32	End CTD tow-yo at Northwest Syoyo.			22	42.8200	142	28.3000
		03:10	EM300 transit to North Syoyo Volcano. [03:10 - 05:08]						
		05:16	Start CTD tow-yo at North Syoyo Volcano.	T03A-22	045	22	44.8690	142	43.7330
		07:21	End CTD tow-yo at North Syoyo.			22	47.5773	142	44.9855
		07:22	EM300 transit to West Syoyo Volcano. [07:22 - 09:32]						
		09:45	Start CTD tow-yo of West Syoyo Volcano, over main peak - west of the caldera.	T03A-23	046	22	29.2995	142	31.2926
		12:33	End CTD tow-yo of West Syoyo.			22	32.8770	142	32.1267
		13:34	CTD vertical cast of West Syoyo, in the caldera. [13:34 - 15:22]	V03A-24	047	22	30.5004	142	32.4010
		15:30	EM300 transit to Southwest Syoyo. [15:30 - 17:26]						
		17:26	Start CTD tow-yo over Southwest Syoyo Volcano.	T03A-24	048	22	22.2170	142	45.4688
		19:50	End CTD tow-yo over Southwest Syoyo.			22	24.8860	142	44.9090
		19:50	EM300 transit to Syoyo Volcano. [19:50 - 22:33]						
		22:33	Start EM300 survey over Syoyo Volcano.						
27-Feb	58	00:32	End EM300 survey at Syoyo.						
		01:00	Start CTD tow-yo at Syoyo Volcano.	T03A-25	049	22	27.8040	142	58.3820
		01:20	End CTD tow-yo at Syoyo.			22	28.2800	142	58.4800
		01:28	Start EM300 transit to and survey of Fukuyama Volcano.						
		04:04	End EM300 survey of Fukuyama Volcano.						
		04:30	CTD vertical cast on North Fukuyama cone. [04:30 - 05:30]	V03A-25	050	22	22.5900	143	7.1400
		05:51	CTD vertical cast on South Fukuyama cone. [05:51 - 07:01]	V03A-26	051	22	21.2041	143	5.6489
		07:01	Transit to small volcano named Northern Back-arc Volcano. [07:01 - 09:34]						
		9:35	CTD vertical cast at Northern Back-arc Volcano. [09:35 - 11:34]	V03A-27	052	21	54.8498	143	6.3480
		11:35	EM300 transit to and survey of Fukujin Volcano. [11:35 - 14:01]						
		14:10	Three CTD vertical casts at Fukujin Volcano (casts 28 - 30). [14:10 - 19:08]						

Date	JD	Time (GMT)	Event - Comments	Event	Cast	Lat N (deg)	Lat N (min)	Long E (deg)	Long E (min)
			CTD vertical cast at Fukujin Volcano, north of the shoal area.	V03A-28	053	21	58.9979	143	28.0030
			CTD vertical cast at Fukujin Volcano, southeast of the shoal area.	V03A-29	054	21	52.9012	143	28.7503
			CTD vertical cast at Fukujin Volcano, west of the shoal area.	V03A-30	055	21	55.7900	143	24.9000
		19:08	EM300 transit to and survey of Kasuga-1 Volcano. [19:08 - 23:00]						
		23:09	Start CTD tow-yo of Kasuga-1 Volcano.	T03A-26	056	21	46.0130	143	42.3750
28-Feb	59	00:09	End CTD tow-yo of Kasuga-1.			21	47.4000	143	42.3500
		00:22	EM300 transit to Kasuga-2 Volcano. [00:22 - 02:33]						
		02:33	Start CTD tow-yo at Kasuga-2 Volcano.	T03A-27	057	21	36.3000	143	38.7740
		04:08	End CTD tow-yo at Kasuga-2.			21	36.7800	143	37.6800
		04:08	Start EM300 survey at Kasuga-2 to complete coverage.						
		05:40	End EM300 survey at Kasuga-2.						
			Active hydrothermal system present at Kasuga-2.						
		05:41	EM300 transit to and survey of Kasuga-3 Volcano. [05:41 - 08:12]						
		08:12	Start CTD tow-yo of Kasuga-3 Volcano.	T03A-28	058	21	23.8900	143	37.7500
		09:10	End CTD tow-yo of Kasuga-3.			21	24.0463	143	38.6532
		09:27	EM300 transit to and survey over Southwest Daikoku Volcano. [09:27 - 12:23]						
		12:49	Start CTD tow-yo of Southwest Daikoku Volcano.	T03A-29	059	21	7.0957	143	56.0081
		14:39	End CTD tow-yo of Southwest Daikoku.			21	8.3563	143	55.2891
		14:42	EM300 transit to Northwest Eifuku Volcano. [14:42 - 16:50]						
		17:20	Start CTD tow-yo of Northwest Eifuku Volcano.	T03A-30	060	21	29.0455	144	2.8934
			End CTD tow-yo of Northwest Eifuku.			21	29.6500	144	1.0800
			Active hydrothermal system present at Northwest Eifuku.						
		18:04	EM300 transit to Eifuku Volcano. [18:04 - 20:15]						
		21:00	Start CTD tow-yo of Eifuku Volcano.	T03A-31	061	21	24.3900	144	8.3900
		21:52	End CTD tow-yo of Eifuku.			21	25.3400	144	8.8800
		21:53	EM300 transit to Daikoku Volcano. [21:53 - 22:56]						
		23:34	Start CTD tow-yo over Daikoku Volcano.	T03A-32	062	21	18.8100	144	11.2700
1-Mar	60	00:31	End CTD tow-yo over Daikoku.			21	20.0500	144	11.8400
			Active hydrothermal system present at Daikoku.						
		01:27	EM300 transit to South Daikoku Volcano. [01:27 - 06:26]						
		06:26	CTD vertical cast at South Daikoku Volcano. [06:26 - 07:24]	V03A-31	063	21	1.3630	144	31.5190
		08:04	EM300 transit to Chamorro Volcano. [08:04 - 10:09]						
		10:51	Start CTD tow-yo at Chamorro Volcano.	T03A-33	064	21	47.9960	144	42.4570
		12:08	End CTD tow-yo at Chamorro.			21	49.2452	144	41.3550
		12:31	EM300 transit to Northwest Uracas Volcano. [12:31 - 15:02]						
		15:29	CTD vertical cast at Northwest Uracas Volcano. [15:29 - 17:06]	V03A-32	065	20	34.8970	144	50.3993
			Active hydrothermal system present at Northwest Uracas.						
		15:06	EM300 transit to Makhahnas Volcano. [15:06 - 20:00]						
		20:29	Start CTD tow-yo at Makhahnas Volcano.	T03A-34	066	20	27.4000	144	50.4900
		21:27	End CTD tow-yo at Makhahnas.			20	28.8300	144	50.7300
		21:37	Start EM300 survey of Ahyi Volcano.						
2-Mar	61	01:32	End EM300 survey of Ahyi.						
			Four CTD vertical casts around the summit of Ahyi Volcano (33 - 36). [02:00 - 05:20]						
			Ahyi (1st CTD - south of shallow area).	V03A-33	067	20	25.7000	145	1.8200

Date	JD	Time (GMT)	Event - Comments	Event	Cast	Lat N (deg)	Lat N (min)	Long E (deg)	Long E (min)
			Ahyi (2nd CTD - east of shallow area).	V03A-34	068	20	26.6400	145	2.6900
			Ahyi (3rd CTD - north of shallow area).	V03A-35	069	20	27.0500	145	2.0500
			Ahyi (4th CTD - west of shallow area).	V03A-36	070	20	26.5100	145	1.3000
		05:20	Start EM300 survey to fill gap on Ahyi Volcano.						
		05:40	End EM300 survey to fill gap on Ahyi.						
		05:41	Deployed MR1 sonar. [05:41 - 06:49]						
		06:50	EM300 transit to beginning of MR1 Line. [06:50 - 08:31]						
		08:31	Start MR1 survey Box C - Line 4 (south to north, eastern line, heading ~318, EM300 lines 345 - 348).	Start MR1-C Line 4		20	18.0000	145	10.0000
		17:11	End MR1 survey Box C - Line 4.	End MR1-C Line 4		21	15.0000	144	25.0000
		17:12	Recovered MR1 sonar, then EM300 lines to fill in some of the gaps between previous MR1 lines in Box C. [17:12 - 23:31]						
		23:31	EM300 transit to Hydrophone #3 deployment site. [23:31 - 01:58]						
3-Mar	62	01:58	Hydrophone # 3 deployment (position for anchor drop point). [01:58-03:48]	Hyd-3		20	0.0300	144	30.2300
		03:48	EM300 transit to Hydrophone # 4 deployment site. [03:48-12:12]						
		15:07:00	Hydrophone # 4 deployment (position for anchor drop point). [12:12-15:07]	Hyd-4		18	16.8400	143	45.7200
		15:08:00	EM300 transit to Hydrophone #5 deployment site. [15:08 - 05:09]						
4-Mar	63	06:40:00	Hydrophone # 5 deployment (position for anchor drop point). [05:09 - 07:00]	Hyd-5		15	44.8020	143	44.9770
		07:00	EM300 transit to West Rota Volcano. [07:00 - 16:05]						
		16:05	Start EM300 survey of West Rota Volcano.						
		19:17	End EM300 survey of West Rota.						
5-Mar	64	02:00	Arrive in Guam (local time noon, 5 March, 2003).						

4.0 TABLES

4.1 Cruise Statistics

Data Type		
MR1 Sidescan Sonar Coverage	9600 nm^2	17,225 km^2
EM300 Bathymetry Coverage	15,775 nm^2	29,213 km^2
CTD casts	70 total	
CTD samples	3055 total	

4.2 CTD Sample Type, Number, Description

Sample Type	# of Samples	CTD Sample Description
pH	621	A measure of acidity of a solution. Changes in pH are caused by volcanic gasses like carbon dioxide and sulfur dioxide.
^{3}He	569	The helium isotope is a hydrothermal tracer signal, which is introduced into the ocean by seafloor volcanic activity.
CH_4	412	Methane is another common hydrothermal tracer. Methane is also a food source and a by-product for/of microbes in hydrothermal environments.
CH_4 ISO	111	Methane isotopes help pin point the source of the methane to determine if it is formed by microbes, rocks and water, or was an original volcanic gas.
BIO	16	Microbiological samples.
CO_2	94	Carbon dioxide is the most abundant volcanic gas in submarine volcanoes. It dissolves in water to form carbonic acid which lowers the pH of the water.
H_2S	128	Hydrogen sulfide is mostly formed when the sulfur in seawater reacts with hot rocks, however the original magma contains some hydrogen sulfide also.
Sal	219	Salinity (dissolved salts in seawater).
TDM	547	Total dissolved metals - the total amount of metals (dissolved plus particulate) in the sample. Acid is added to the sample which causes particulate metals to dissolve before analysis.
DM	133	Dissolved metals - the amount of dissolved metals. The sample is first passed through a filter to remove the particulate metals before analysis.
XRF	186	X-ray fluorescence determines the chemical makeup of particles found in the water column above an active volcano.
SEM	19	Scanning electron microscopy allows one to look at the particles to identify their characteristic sizes, morphology (shape) and chemistry.

4.3 Location of Surveyed Mariana Arc Submarine Volcanoes

Volcanoes (south to north)	summit depth (m)	Long-E (decdeg)	Lat-N (decdeg)	Long-E (deg)	Long-E (min)	Lat-N (deg)	Lat-N (min)
Seamount X	1230	144.0167	13.2500	144	1.0020	13	15.0000
Tracey	738	144.4107	13.6333	144	24.6420	13	37.9980
NW Guam	1170	144.6375	14.0167	144	38.2500	14	1.0020
W Rota	309	144.8333	14.3250	144	49.9980	14	19.5000

Volcanoes (south to north)	**summit depth (m)**	**Long-E (decdeg)**	**Lat-N (decdeg)**	**Long-E (deg)**	**Long-E (min)**	**Lat-N (deg)**	**Lat-N (min)**
NW Rota 1	527	144.7750	14.6000	144	46.5000	14	36.0000
NW Rota 2	1786	144.8917	14.6192	144	53.5020	14	37.1520
NW Rota 3	1201	144.9958	14.5958	144	59.7480	14	35.7480
NW Rota 4	945	145.0783	14.7333	145	4.6980	14	43.9980
Esmeralda Bank	54	145.2458	14.9583	145	14.7480	14	57.4980
N Esmeralda	155	145.2417	15.0383	145	14.5020	15	2.2980
W Tinian	35	145.4167	15.0833	145	25.0020	15	4.9980
W Saipan	293	145.4500	15.3000	145	27.0000	15	18.0000
Ruby	180	145.5733	15.6042	145	34.3980	15	36.2520
N Ruby	726	145.5883	15.6583	145	35.2980	15	39.4980
E Diamante	127	145.6583	15.9167	145	39.4980	15	55.0020
Middle Diamante	1149	145.5333	15.9500	145	31.9980	15	57.0000
W Diamante	367	145.4133	15.9542	145	24.7980	15	57.2520
NE Anatahan	459	145.7833	16.4250	145	46.9980	16	25.5000
S Sarigan	316	145.7750	16.5875	145	46.5000	16	35.2500
W Sarigan	212	145.6200	16.7417	145	37.2000	16	44.5020
Zealandia Bank	144	145.8000	16.8833	145	48.0000	16	52.9980
W Zealandia	619	145.7208	16.8875	145	43.2480	16	53.2500
N Zealandia	307	145.7167	16.9800	145	43.0020	16	58.8000
W Guguan 1	906	145.7292	17.2792	145	43.7520	17	16.7520
W Guguan 2	803	145.5750	17.2650	145	34.5000	17	15.9000
W Guguan 3	1678	145.3250	17.3400	145	19.5000	17	20.4000
Daon	774	145.4833	17.9625	145	28.9980	17	57.7500
Poyo	1327	145.5167	19.2233	145	31.0020	19	13.3980
Cheref	< 109	145.4667	19.4083	145	28.0020	19	24.4980
Supply Reef	?	145.1000	20.1300	145	6.0000	20	7.8000
Maug	54	145.2217	20.0208	145	13.3020	20	1.2480
Ahyi	64	145.0292	20.4375	145	1.7520	20	26.2500
Makhahnas	416	144.8417	20.4667	144	50.5020	20	28.0020
NW Uracas	703	144.8400	20.5833	144	50.4000	20	34.9980
Chamorro	804	144.7042	20.8100	144	42.2520	20	48.6000
S Daikoku (1)	< 301	144.5250	21.0225	144	31.5000	21	1.3500
SW Daikoku	936	143.9292	21.1267	143	55.7520	21	7.6020
S Daikoku 2	1880	144.4167	21.2083	144	25.0000	21	12.5000
Daikoku	323	144.1942	21.3242	144	11.6520	21	19.4520
Eifuku	284	144.1450	21.4150	144	8.7000	21	24.9000
NW Eifuku	1551	144.0433	21.4875	144	2.5980	21	29.2500
Kasuga 3	1120	143.6333	21.4000	143	37.9980	21	24.0000
Kasuga 2	297	143.6417	21.6100	143	38.5020	21	36.6000
Kasuga 1	583	143.7083	21.7767	143	42.4980	21	46.6020
Fukujin	??	143.4583	21.9417	143	27.4980	21	56.5020

Volcanoes (south to north)	summit depth (m)	Long-E (decdeg)	Lat-N (decdeg)	Long-E (deg)	Long-E (min)	Lat-N (deg)	Lat-N (min)
N Backarc	2418	143.1067	21.9117	143	6.4020	21	54.7020
S Fukuyama	1422	143.0958	22.3550	143	5.7480	22	21.3000
N Fukuyama	1356	143.1192	22.3775	143	7.1520	22	22.6500
SW Syoyo	1424	142.7617	22.3867	142	45.7020	22	23.2020
Syoyo	481	142.9833	22.4750	142	58.9980	22	28.5000
W Syoyo	1735	142.5333	22.5083	142	31.9980	22	30.4980
NW Syoyo	1255	142.4667	22.6950	142	28.0020	22	41.7000
N Syoyo	516	142.7250	22.7792	142	43.5000	22	46.7520
Ichiyo	1511	142.5333	22.9375	142	31.9980	22	56.2500
Nikko	392	142.3255	23.0784	142	19.5300	23	4.7040
NE Nikko	533	142.3632	23.1114	142	21.7920	23	6.6840
NW Nikko	1122	142.1200	23.1542	142	7.2000	23	9.2520

4.4 Location of Hydrophones Deployed (Anchor Drop Positions)

Hydrophone	Long-E (decdeg)	Lat-N (decdeg)	Long-E (deg)	Long-E (min)	Lat-N (deg)	Lat-N (min)
hyd-1	144.067500	13.630500	144	4.0500	13	37.8300
hyd-2	145.418917	17.002400	145	25.1350	17	0.1440
hyd-3	144.503833	20.000500	144	30.2300	20	0.0300
hyd-4	143.762000	18.280667	143	45.7200	18	16.8400
hyd-5	143.749617	15.746700	143	44.9770	15	44.8020

4.5 CTD Vertical Cast Numbers and Locations

Cast	Station Name	Volcano	Lat-N (deg)	Lat-N (min)	Long-E (deg)	Long-E (min)
1	T03A-01(start)	Back-arc Spreading Center	13	40.8225	143	22.3249
	T03A-01(3nd)		13	15.0914	143	43.6509
2	T03A-02(start)	Back-arc Spreading Center	12	55.8000	143	38.8700
	T03A-02(end)		12	59.0400	143	34.6500
3	T03A-03(start)	Seamount X	13	14.1479	144	0.6385
	T03A-03(end)		13	15.9617	144	2.0337
4	T03A-04(start)	Tracey	13	38.0000	144	25.5200
	T03A-04(end)		13	38.0180	144	23.1700
5	T03A-05(start)	NW Guam	14	0.9270	144	39.3420
	T03A-05(end)		14	1.5800	144	36.9100
6	V03A-01	W Rota	14	17.0071	144	52.9994
7	V03A-02	W Rota	14	18.1201	144	50.5030
8	V03A-03	W Rota	14	20.2684	144	49.4034

Cast	Station Name	Volcano	Lat-N (deg)	Lat-N (min)	Long-E (deg)	Long-E (min)
9	T03A-06(start)	NW Rota 1	14	35.1556	144	45.8434
	T03A-06(end)		14	36.7423	144	46.4965
10	V03A-04	NW Rota 2	14	37.0960	144	53.3860
11	V03A-05	NW Rota 3	14	35.7000	144	59.5400
12	V03A-06	NW Rota 4	14	44.0900	145	4.7000
13	V03A-07	Esmeralda Bank	14	57.5991	145	14.6877
14	V03A-08	Esmeralda Bank	14	58.2491	145	14.9770
15	V03A-09	N Esmeralda	15	1.4872	145	13.5021
16	V03A-10	N Esmeralda	15	3.2942	145	14.5332
17	V03A-11	NW Tinian	15	3.9009	145	25.0026
18	V03A-12	NW Tinian	15	4.9017	145	25.1019
19	T03A-07(start)	W Saipan	15	16.6000	145	27.0880
	T03A-07(end)		15	18.3050	145	27.0650
20	T03A-08(start)	Ruby	15	34.9114	145	34.3942
	T03A-08(end)		15	36.9600	145	34.5800
21	V03A-13	N Ruby	15	39.5000	145	35.2000
22	T03A-09(start)	E Diamante	15	54.2300	145	37.8800
	T03A-09(end)		15	56.7689	145	41.0556
23	V03A-14	Middle Diamante	15	56.7289	145	31.8098
24	T03A-10(start)	W Diamante	15	56.5517	145	24.2745
	T03A-10(end)		15	57.7500	145	25.4280
25	V03A-15	NE Anatahan	16	25.7100	145	46.8800
26	V03A-16	S Sarigan	16	35.1200	145	46.6500
27	V03A-17	W Sarigan	16	44.1100	145	37.3580
28	V03A-18	Zealandia Bank	16	53.2031	145	49.3881
29	V03A-19	Zealandia Bank	16	52.7080	145	49.1848
30	V03A-20	Zealandia Bank	16	52.2029	145	48.3663
31	V03A-21	Zealandia Bank	16	52.6721	145	47.0306
32	T03A-11(start)	N Zealandia	16	58.3200	145	42.7170
	T03A-11(end)		16	59.6076	145	43.2174
33	T03A-12(start)	W Guguan 3	17	19.8810	145	19.3870
	T03A-12(end)		17	21.4400	145	19.3700
34	T03A-13(start)	W Guguan 2	17	15.5000	145	33.6900
	T03A-13(end)		17	16.5560	145	35.4670
35	T03A-14(start)	W Guguan 1	17	16.4100	145	42.9200
	T03A-14(end)		17	17.2200	145	45.0300
36	V03A-22	deep cast (background)	17	38.0489	145	36.2274
37	T03A-15(start)	Daon	17	57.2873	145	29.0003

Cast	Station Name	Volcano	Lat-N (deg)	Lat-N (min)	Long-E (deg)	Long-E (min)
	T03A-15(end)		17	58.3458	145	28.9830
38	T03A-16(start)	Poyo	19	12.3806	145	31.4861
	T03A-16(end)		19	14.0000	145	32.3920
39	T03A-17(start)	Cheref	19	25.9500	145	27.9900
	T03A-17(end)		19	23.9200	145	26.6900
40	V03A-23	Maug	20	1.3400	145	12.9700
41	T03A-18(start)	NW Nikko	23	8.1296	142	6.7693
	T03A-18(end)		23	10.3884	142	7.6280
42	T03A-19(start)	Nikko	23	4.4040	142	19.1898
	T03A-19(end)		23	5.2200	142	19.9500
43	T03A-20(start)	NE Nikko	23	6.3700	142	21.7900
	T03A-20(end)		23	7.2500	142	21.8900
44	T03A-21(start)	NW Syoyo	22	41.2750	142	27.5860
	T03A-21(end)		22	42.8200	142	28.3000
45	T03A-22(start)	N Syoyo	22	44.8690	142	43.7330
	T03A-22(end)		22	47.5773	142	44.9855
46	T03A-23(start)	W Syoyo	22	29.2995	142	31.2926
	T03A-23(end)		22	32.8770	142	32.1267
47	V03A-24	W Syoyo	22	30.5004	142	32.4010
48	T03A-24(start)	SW Syoyo	22	22.2170	142	45.4688
	T03A-24(end)		22	24.8860	142	44.9090
49	T03A-25(start)	Syoyo	22	27.8040	142	58.3820
	T03A-25(end)		22	28.2800	142	58.4800
50	V03A-25	N Fukuyama	22	22.5900	143	7.1400
51	V03A-26	S Fukuyama	22	21.2041	143	5.6489
52	V03A-27	N Back-arc	21	54.8498	143	6.3480
53	V03A-28	Fukujin	21	58.9979	143	28.0030
54	V03A-29	Fukujin	21	52.9012	143	28.7503
55	V03A-30	Fukujin	21	55.7900	143	24.9000
56	T03A-26(start)	Kasuga 1	21	46.0120	143	42.3760
	T03A-26(end)		21	47.4200	143	42.3500
57	T03A-27(start)	Kasuga 2	21	36.3000	143	38.7740
	T03A-27(end)		21	36.7800	143	37.6800
58	T03A-28(start)	Kasuga 3	21	23.8900	143	37.7500
	T03A-28(end)		21	24.0463	143	38.6532
59	T03A-29(start)	SW Daikoku	21	7.0957	143	56.0081
	T03A-29(end)		21	8.3563	143	55.2891
60	T03A-30(start)	NW Eifuku	21	29.0455	144	2.8934

Cast	Station Name	Volcano	Lat-N (deg)	Lat-N (min)	Long-E (deg)	Long-E (min)
	T03A-30(end)		21	29.6500	144	1.0800
61	T03A-31(start)	Eifuku	21	24.3900	144	8.3900
	T03A-31(end)		21	25.3400	144	8.8800
62	T03A-32(start)	Daikoku	21	18.8100	144	11.2700
	T03A-32(end)		21	20.0500	144	11.8400
63	V03A-31	S Daikoku	21	1.3630	144	31.5190
64	T03A-33(start)	Chamorro	20	47.9960	144	42.4570
	T03A-33(end)		20	49.2452	144	41.3550
65	V03A-32	NW Uracas	20	34.8970	144	50.3993
66	T03A-34(start)	Makhahnas	20	27.4000	144	50.4900
	T03A-34(end)		20	28.8300	144	50.7300
67	V03A-33	Ahyi	20	25.7000	145	1.8200
68	V03A-34	Ahyi	20	26.6400	145	2.6900
69	V03A-35	Ahyi	20	27.0500	145	2.0500
70	V03A-36	Ahyi	20	26.5100	145	1.3000

5.0 FIGURES

Figure Captions

Figure 1. Satellite derived bathymetry from *Sandwell and Smith* (1997) of the Mariana Arc region, indicating islands and approximate positions of submarine volcanoes. 500 meter contour interval. Black dashed lines identify four volcanic provinces: Southern Seamount Province (SSP), Central Island Province (CIP), Northern Seamount Province (NSP), and Volcano Arc (VA).

Figure 2. Summary map showing data collected and hydrothermal sites on the Submarine Ring of Fire 2003 Expedition at the Mariana Arc. The volcanoes were mapped in whole or partly with the EM300 and MR1 sonar systems. The overlying water column was sampled with the CTD, indicated by the black circles on the tracklines. The location of the axis of the back-arc spreading center was provided by Fernando Martinez (*Martinez and Taylor*, in press). Nomenclature for Tracey and Seamount X from *Fryer et al.* (1998). SW Syoyo, W Syoyo and NW Syoyo referred to previously as, respectively, Seamounts C, B and A by *Baker et al.* (1996). Changes were proposed here because of repetition of these names in the southern Mariana back-arc (see *Fryer et al.* 1998).

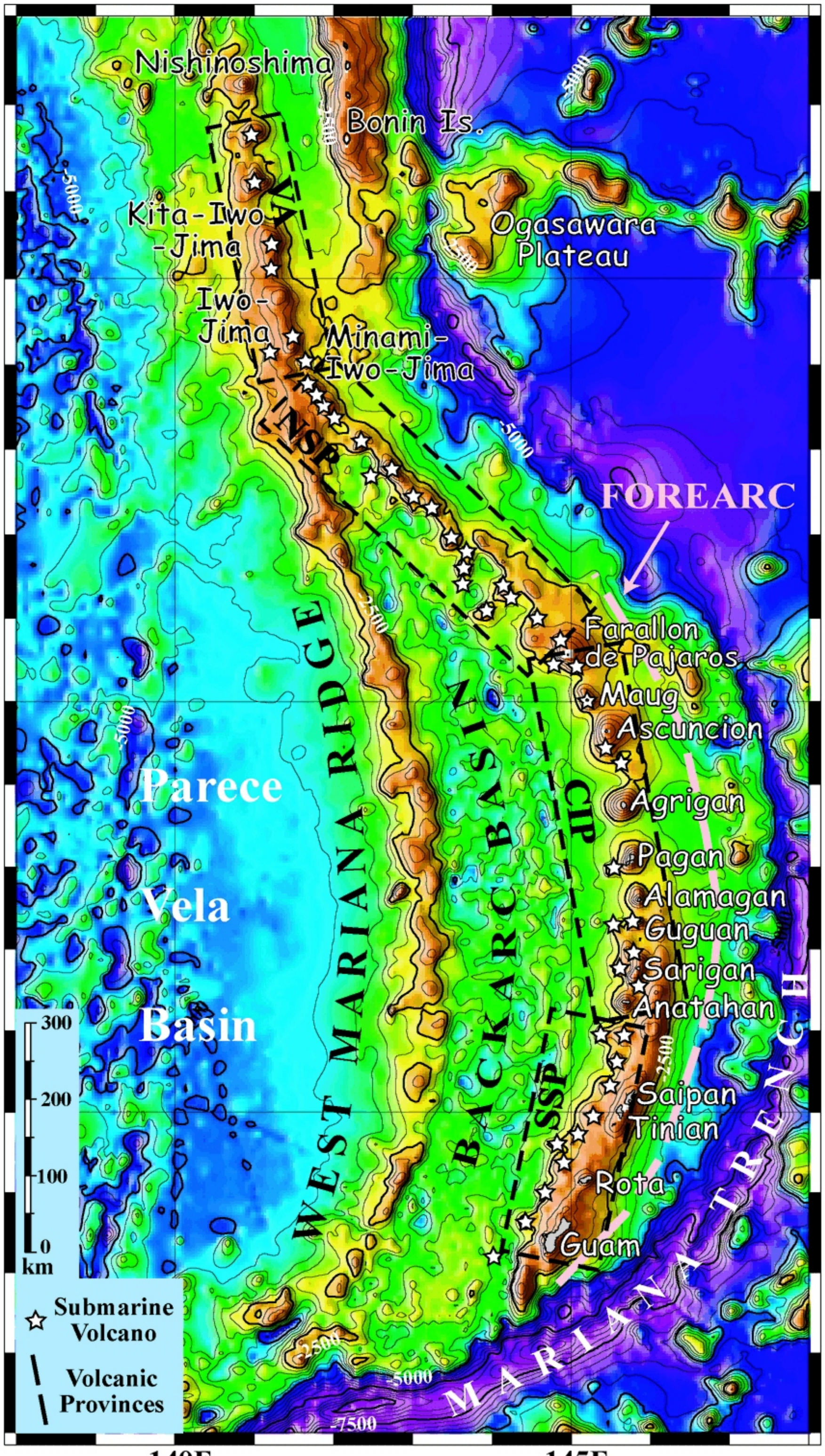
Figure 3. Southern back-arc and southern seamount province of the Mariana Arc explored on the 2003 Submarine Ring of Fire Exploration. Nomenclature for Tracey and Seamount X from *Fryer et al.* (1998).

Figure 4. Central island province of the Mariana Arc explored on the 2003 Submarine Ring of Fire Exploration.

Figure 5. Northern seamount province of the Mariana Arc explored on the 2003 Submarine Ring of Fire Exploration. SW Syoyo, W Syoyo and NW Syoyo referred to previously as, respectively, Seamounts C, B and A by *Baker et al.* (1996). Changes were proposed here because of repetition of these names in the southern Mariana back-arc (see *Fryer et al.* 1998).

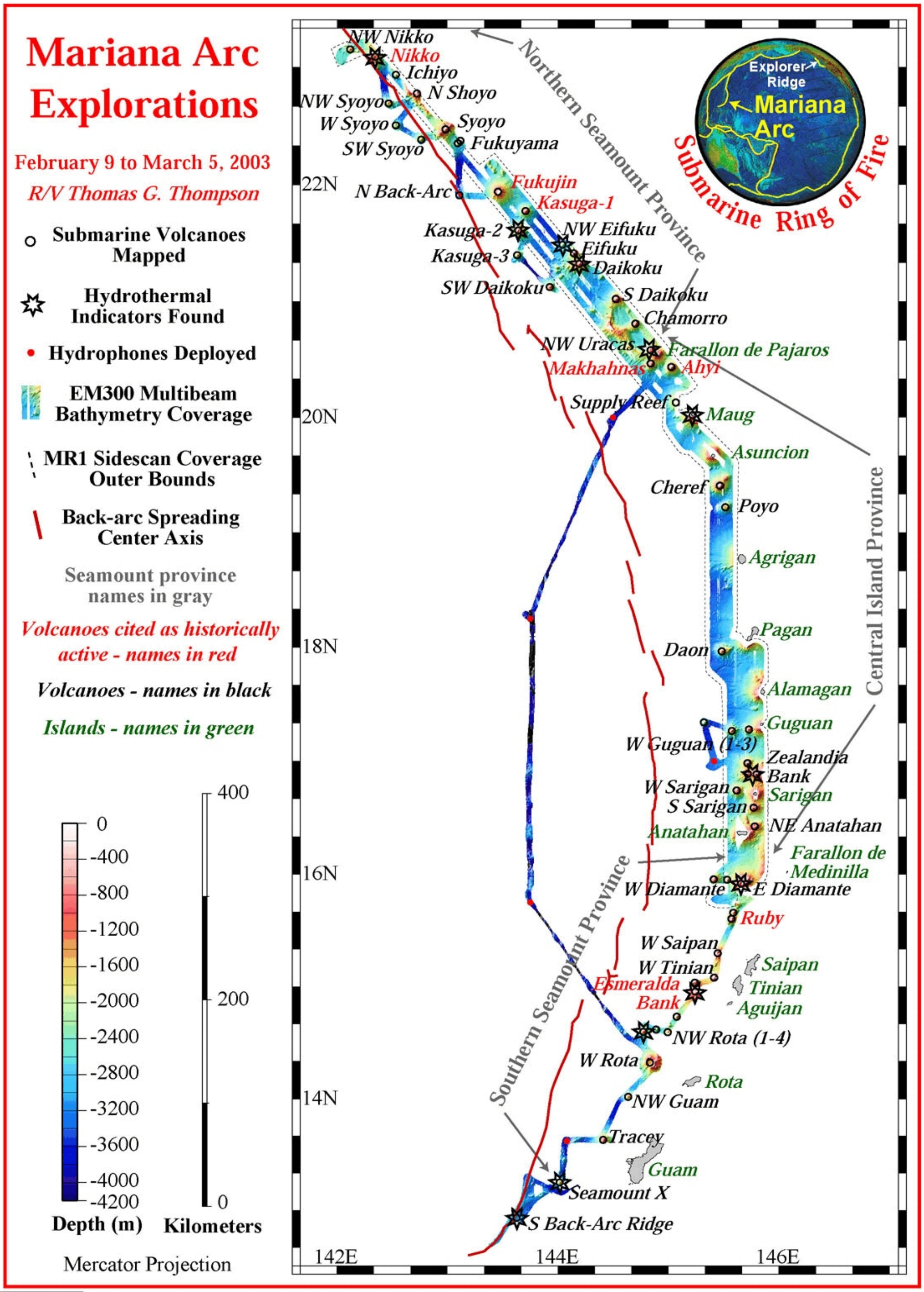
Figure 6. Examples of hydrothermal plumes discovered during the expedition. The location of hydrothermal vent fields can be estimated by mapping the distribution of particle plumes, measured in nephelometry turbidity units (NTU). The most intense plumes are depicted as yellow, red and brown colors. The black dots trace the track of the CTD as it is towed through the water column. Both images are 17 times vertically exaggerated. Images created by Sharon Walker.
Top: Tow-yo T03A-02, an across-axis tow of the southern Mariana back-arc ridge. The most intense plumes were observed over the most inflated portion of the ridge. **Bottom:** Tow-yo T03A-09 at East Diamante submarine volcano revealed intense plumes near the summit. The plume at East Diamante was approximately 10 times more intense than the plume observed over the back-arc spreading center.

Figure 7. **Top:** EM300 bathymetry in the area of Farallon de Pajaros Island (formerly Uracas). The data are gridded at a 50 meter cell size. **Bottom:** MR1 sidescan sonar in the area of Farallon de Pajaros Island (formerly Uracas). The data are gridded at a 16 meter cell size. Darker tones represent higher backscatter areas.



Nishinoshima
Bonin Is.
Kita-Iwo
-Jima
Iwo-
Jima
Minami-
Iwo-Jima
Ogasawara
Plateau
NSP
FOREARC
Farallon
de Pajaros
Maug
Ascuncion
Agrigan
Pagan
Alamagan
Guguan
Sarigan
Anatahan
Saipan
Tinian
Rota
Guam
CIP
SSP
WEST MARIANA RIDGE
BACKARC BASIN
Parece
Vela
Basin
MARIANA TRENCH
-5000
-2500
-7500
300
200
100
0
km
Submarine Volcano
Volcanic Provinces
25N
20N
15N
140E
145E

Figure 1



Mariana Arc Explorations
February 9 to March 5, 2003
R/V Thomas G. Thompson
Submarine Volcanoes Mapped
Hydrothermal Indicators Found
Hydrophones Deployed
EM300 Multibeam Bathymetry Coverage
MR1 Sidescan Coverage Outer Bounds
Back-arc Spreading Center Axis
Seamount province names in gray
Volcanoes cited as historically active - names in red
Volcanoes - names in black
Islands - names in green
Depth (m)
Kilometers
Mercator Projection
Explorer Ridge
Mariana Arc
Submarine Ring of Fire
Northern Seamount Province
Central Island Province
Southern Seamount Province
NW Nikko
Nikko
Ichiyo
N Shoyo
NW Syoyo
W Syoyo
Syoyo
SW Syoyo
Fukuyama
N Back-Arc
Fukujin
Kasuga-1
Kasuga-2
Kasuga-3
NW Eifuku
Eifuku
Daikoku
SW Daikoku
S Daikoku
Chamorro
NW Uracas
Farallon de Pajaros
Makhahnas
Ahyi
Supply Reef
Maug
Asuncion
Cheref
Poyo
Agrigan
Pagan
Daon
Alamagan
Guguan
W Guguan (1-3)
Zealandia Bank
W Sarigan
Sarigan
S Sarigan
Anatahan
NE Anatahan
Farallon de Medinilla
W Diamante
E Diamante
Ruby
W Saipan
Saipan
W Tinian
Tinian
Esmeralda Bank
Aguijan
NW Rota (1-4)
W Rota
Rota
NW Guam
Tracey
Guam
Seamount X
S Back-Arc Ridge
22N
20N
18N
16N
14N
142E
144E
146E

Figure 2

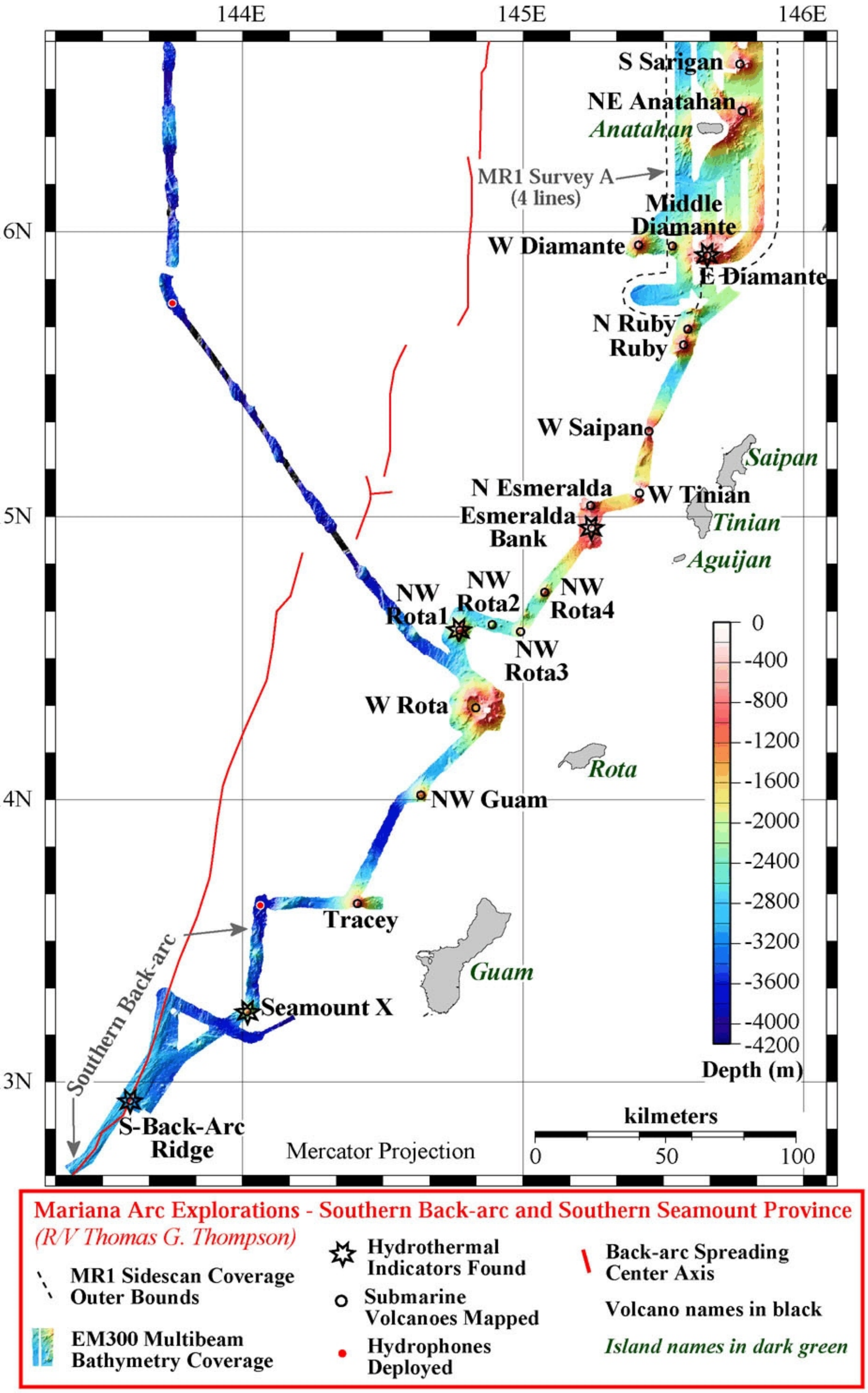

144E
145E
146E
16N
15N
14N
13N
S Sarigan
NE Anatahan
Anatahan
MR1 Survey A
(4 lines)
Middle
Diamante
W Diamante
E Diamante
N Ruby
Ruby
W Saipan
Saipan
N Esmeralda
W Tinian
Esmeralda
Bank
Tinian
Aguijan
NW
Rota1
NW
Rota2
NW
Rota4
NW
Rota3
W Rota
Rota
NW Guam
Tracey
Guam
Southern Back-arc
Seamount X
S-Back-Arc
Ridge
Mercator Projection
kilmeters
0
50
100
0
-400
-800
-1200
-1600
-2000
-2400
-2800
-3200
-3600
-4000
-4200
Depth (m)
Mariana Arc Explorations - Southern Back-arc and Southern Seamount Province
(R/V Thomas G. Thompson)
MR1 Sidescan Coverage
Outer Bounds
EM300 Multibeam
Bathymetry Coverage
Hydrothermal
Indicators Found
Submarine
Volcanoes Mapped
Hydrophones
Deployed
Back-arc Spreading
Center Axis
Volcano names in black
Island names in dark green

Figure 3

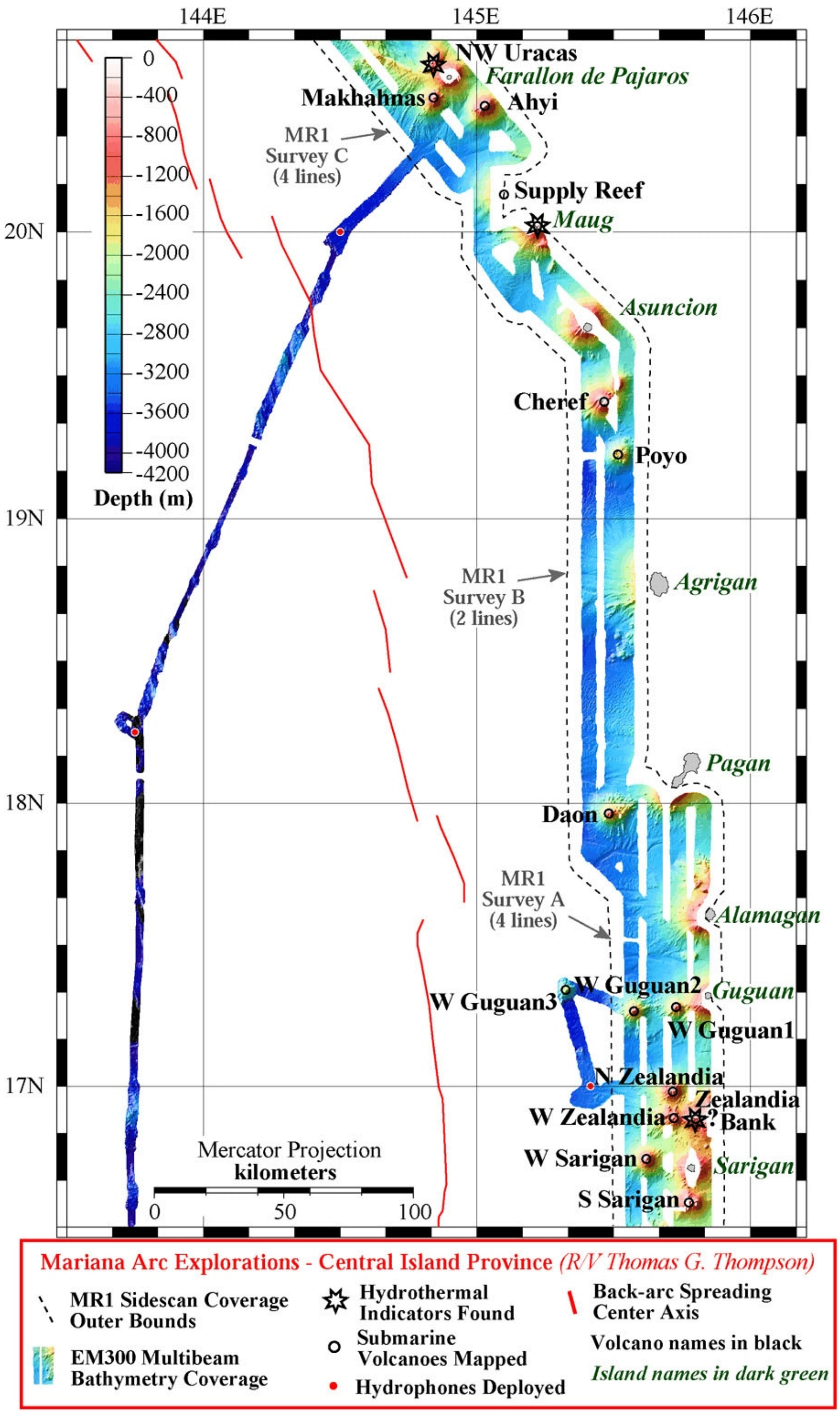

144E
145E
146E
20N
19N
18N
17N
0
-400
-800
-1200
-1600
-2000
-2400
-2800
-3200
-3600
-4000
-4200
Depth (m)
NW Uracas
Farallon de Pajaros
Makhahnas
Ahyi
MR1
Survey C
(4 lines)
Supply Reef
Maug
Asuncion
Cheref
Poyo
MR1
Survey B
(2 lines)
Agrigan
Pagan
Daon
MR1
Survey A
(4 lines)
Alamagan
W Guguan3
W Guguan2
Guguan
W Guguan1
N Zealandia
Zealandia
Bank
W Zealandia
W Sarigan
Sarigan
S Sarigan
Mercator Projection
kilometers
0
50
100
Mariana Arc Explorations - Central Island Province (R/V Thomas G. Thompson)
MR1 Sidescan Coverage
Outer Bounds
EM300 Multibeam
Bathymetry Coverage
Hydrothermal
Indicators Found
Submarine
Volcanoes Mapped
Hydrophones Deployed
Back-arc Spreading
Center Axis
Volcano names in black
Island names in dark green

Figure 4

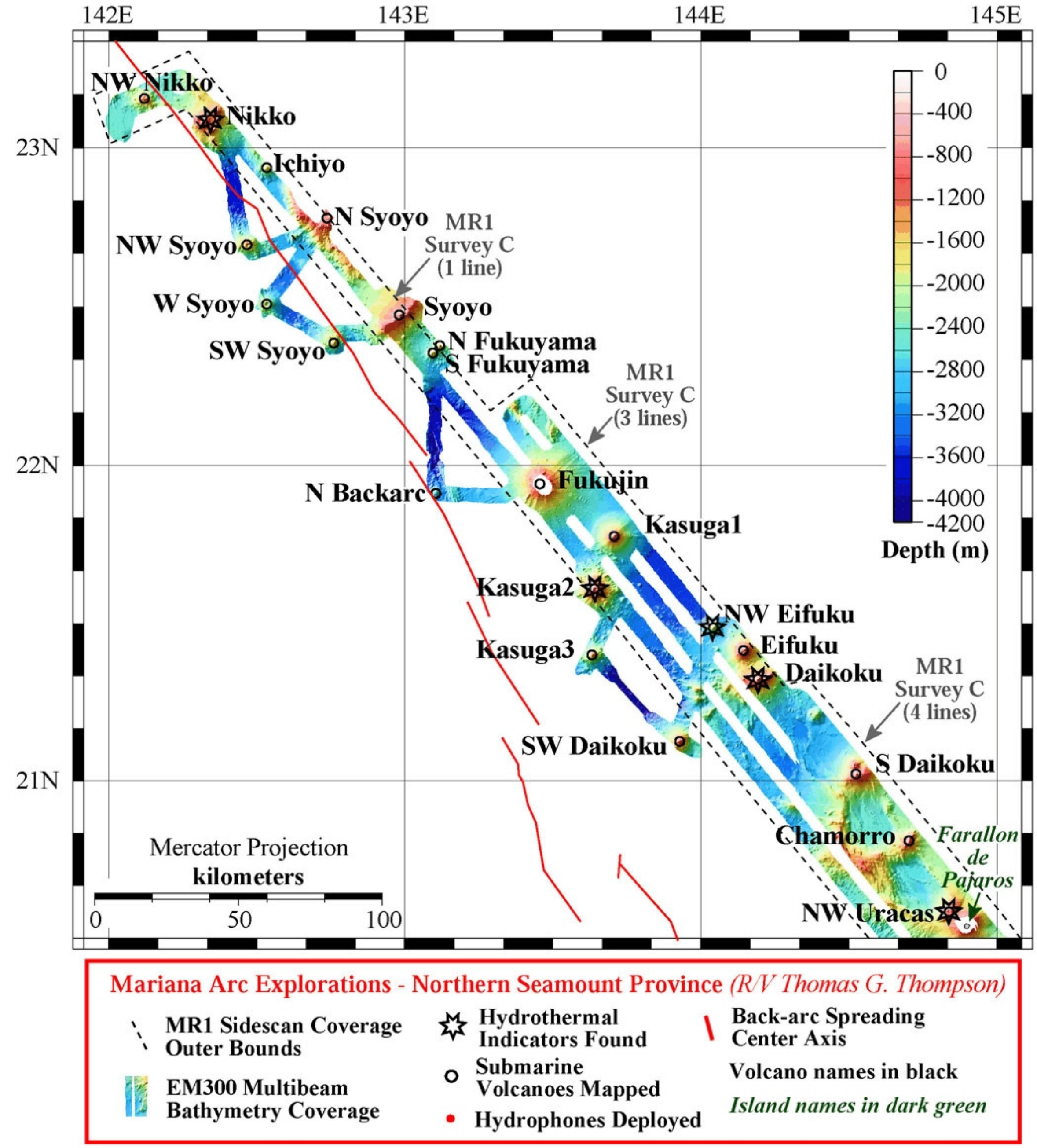

142E
143E
144E
145E
23N
22N
21N
NW Nikko
Nikko
Ichiyo
N Syoyo
NW Syoyo
W Syoyo
SW Syoyo
Syoyo
N Fukuyama
S Fukuyama
MR1 Survey C (1 line)
MR1 Survey C (3 lines)
MR1 Survey C (4 lines)
Fukujin
N Backarc
Kasuga1
Kasuga2
Kasuga3
NW Eifuku
Eifuku
Daikoku
SW Daikoku
S Daikoku
Chamorro
NW Uracas
Farallon de Pajaros
0
-400
-800
-1200
-1600
-2000
-2400
-2800
-3200
-3600
-4000
-4200
Depth (m)
Mercator Projection
kilometers
0
50
100
Mariana Arc Explorations - Northern Seamount Province (R/V Thomas G. Thompson)
MR1 Sidescan Coverage Outer Bounds
EM300 Multibeam Bathymetry Coverage
Hydrothermal Indicators Found
Submarine Volcanoes Mapped
Hydrophones Deployed
Back-arc Spreading Center Axis
Volcano names in black
Island names in dark green

Figure 5

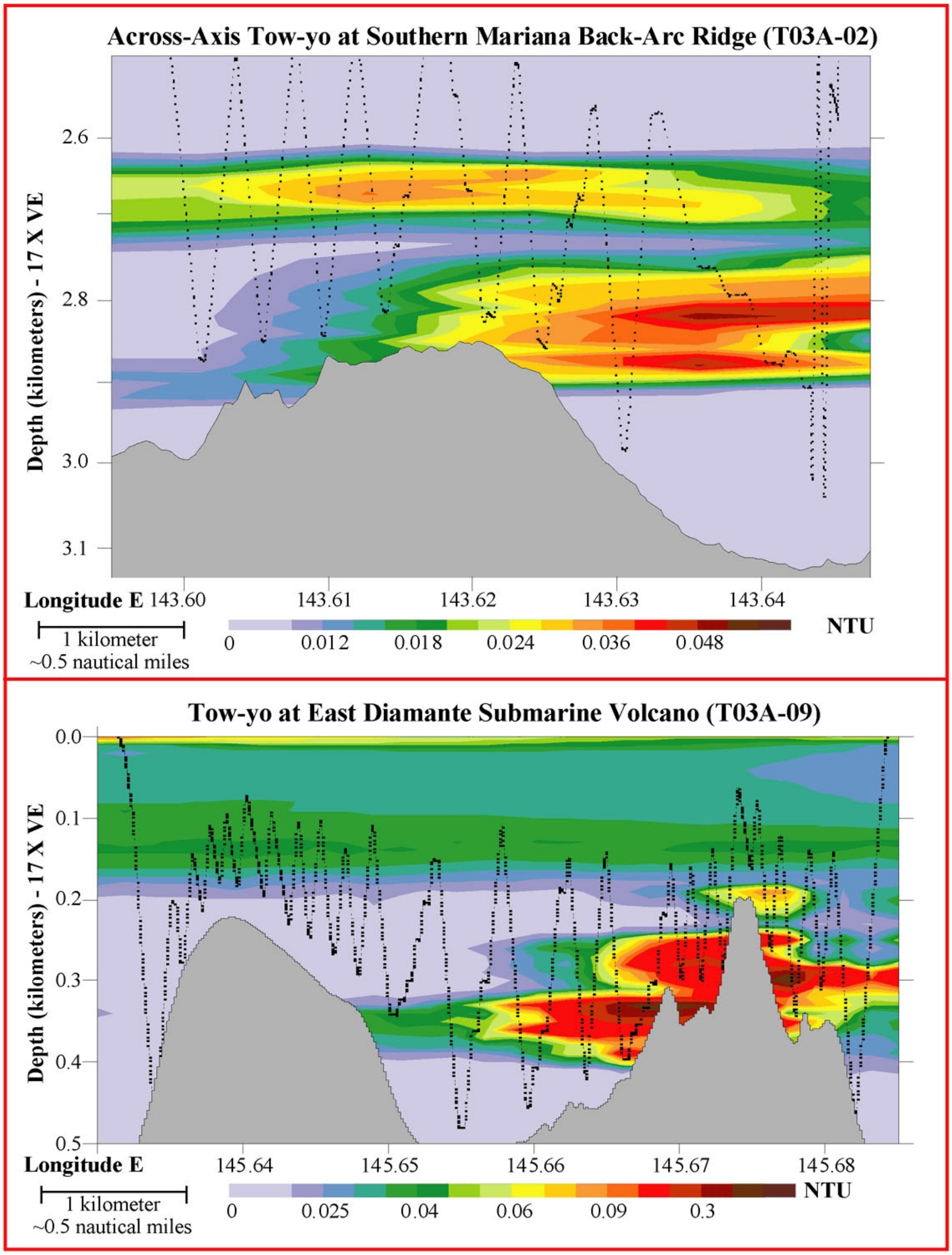
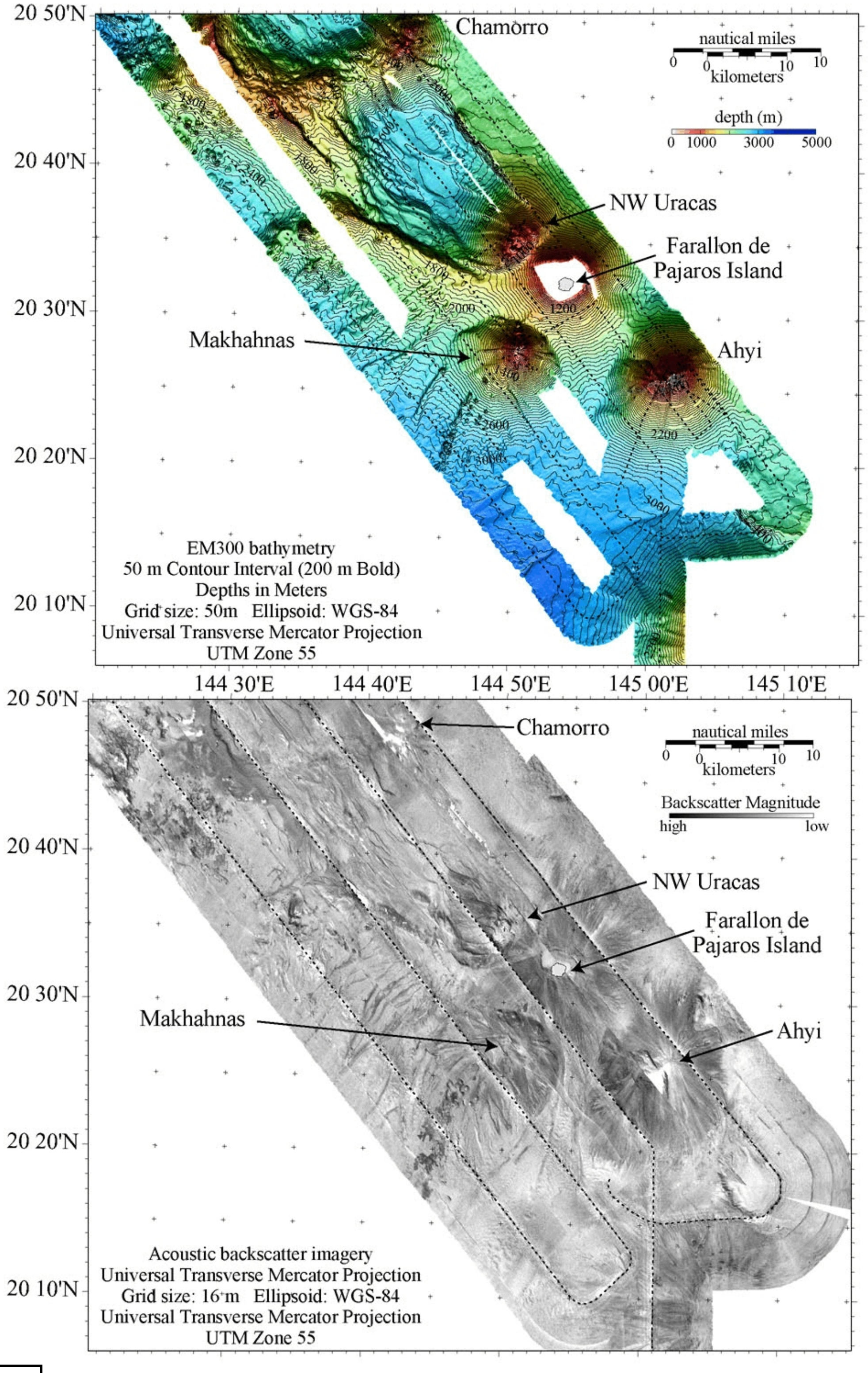

Across-Axis Tow-yo at Southern Mariana Back-Arc Ridge (T03A-02)
Depth (kilometers) - 17 X VE
2.6
2.8
3.0
3.1
Longitude E 143.60
143.61
143.62
143.63
143.64
1 kilometer
~0.5 nautical miles
0
0.012
0.018
0.024
0.036
0.048
NTU
Tow-yo at East Diamante Submarine Volcano (T03A-09)
Depth (kilometers) - 17 X VE
0.0
0.1
0.2
0.3
0.4
0.5
Longitude E
145.64
145.65
145.66
145.67
145.68
1 kilometer
~0.5 nautical miles
0
0.025
0.04
0.06
0.09
0.3
NTU

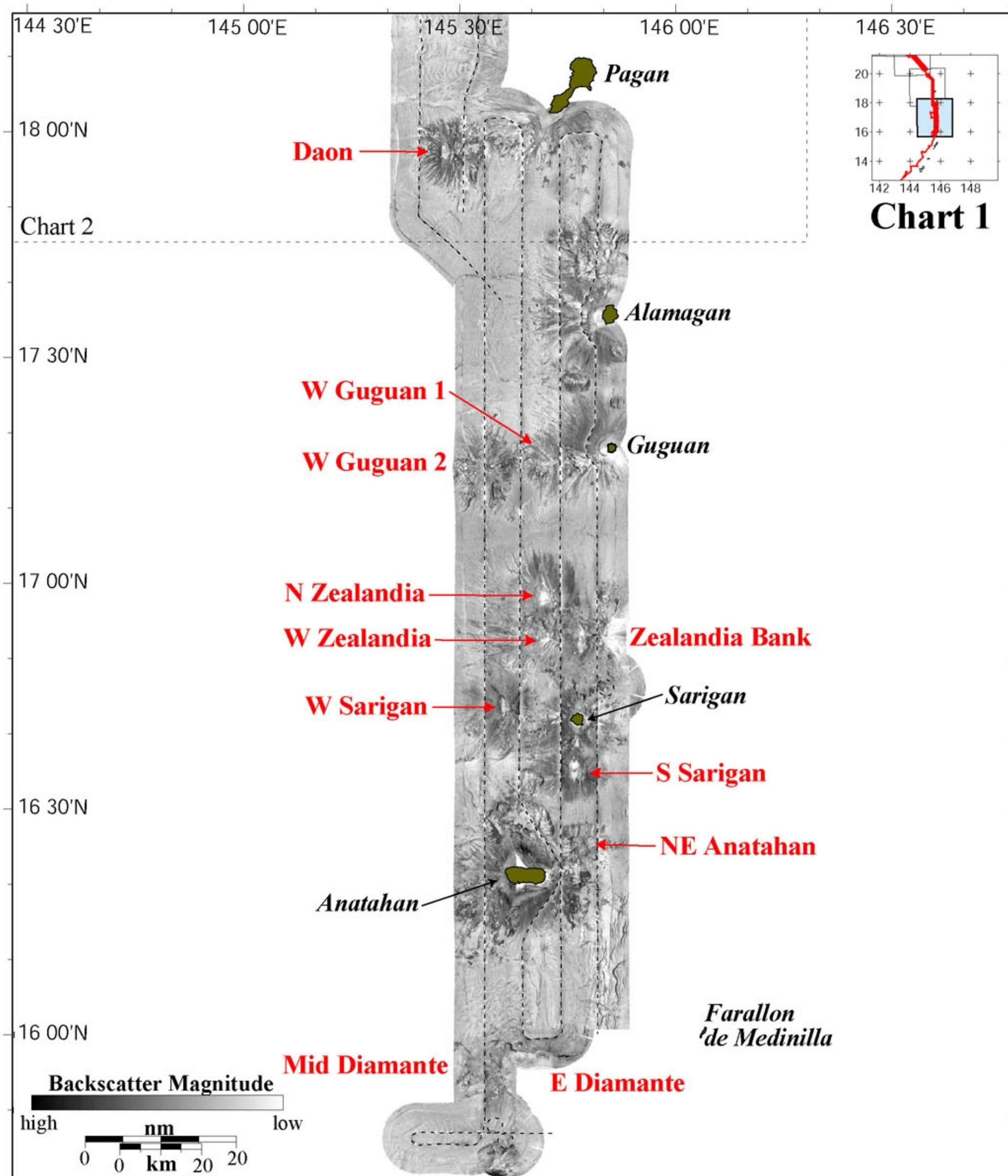
Figure 6



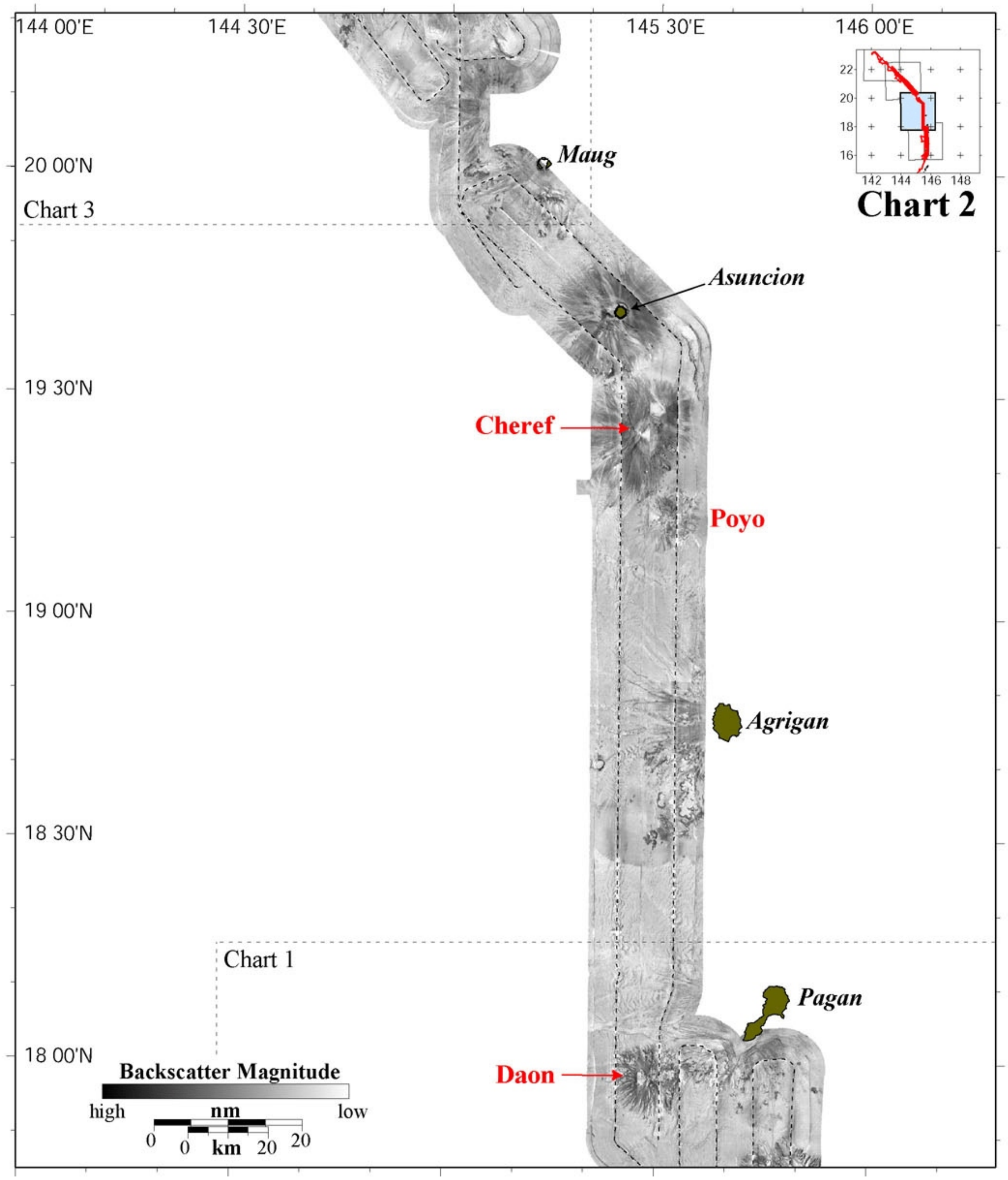
Chamorro
nautical miles
kilometers
depth (m)
0 1000 3000 5000
NW Uracas
Farallon de Pajaros Island
Makhahnas
Ahyi
EM300 bathymetry
50 m Contour Interval (200 m Bold)
Depths in Meters
Grid size: 50m Ellipsoid: WGS-84
Universal Transverse Mercator Projection
UTM Zone 55
20 50'N
20 40'N
20 30'N
20 20'N
20 10'N
144 30'E
144 40'E
144 50'E
145 00'E
145 10'E
Backscatter Magnitude
high
low
Acoustic backscatter imagery
Universal Transverse Mercator Projection
Grid size: 16 m Ellipsoid: WGS-84
Universal Transverse Mercator Projection
UTM Zone 55

Figure 7

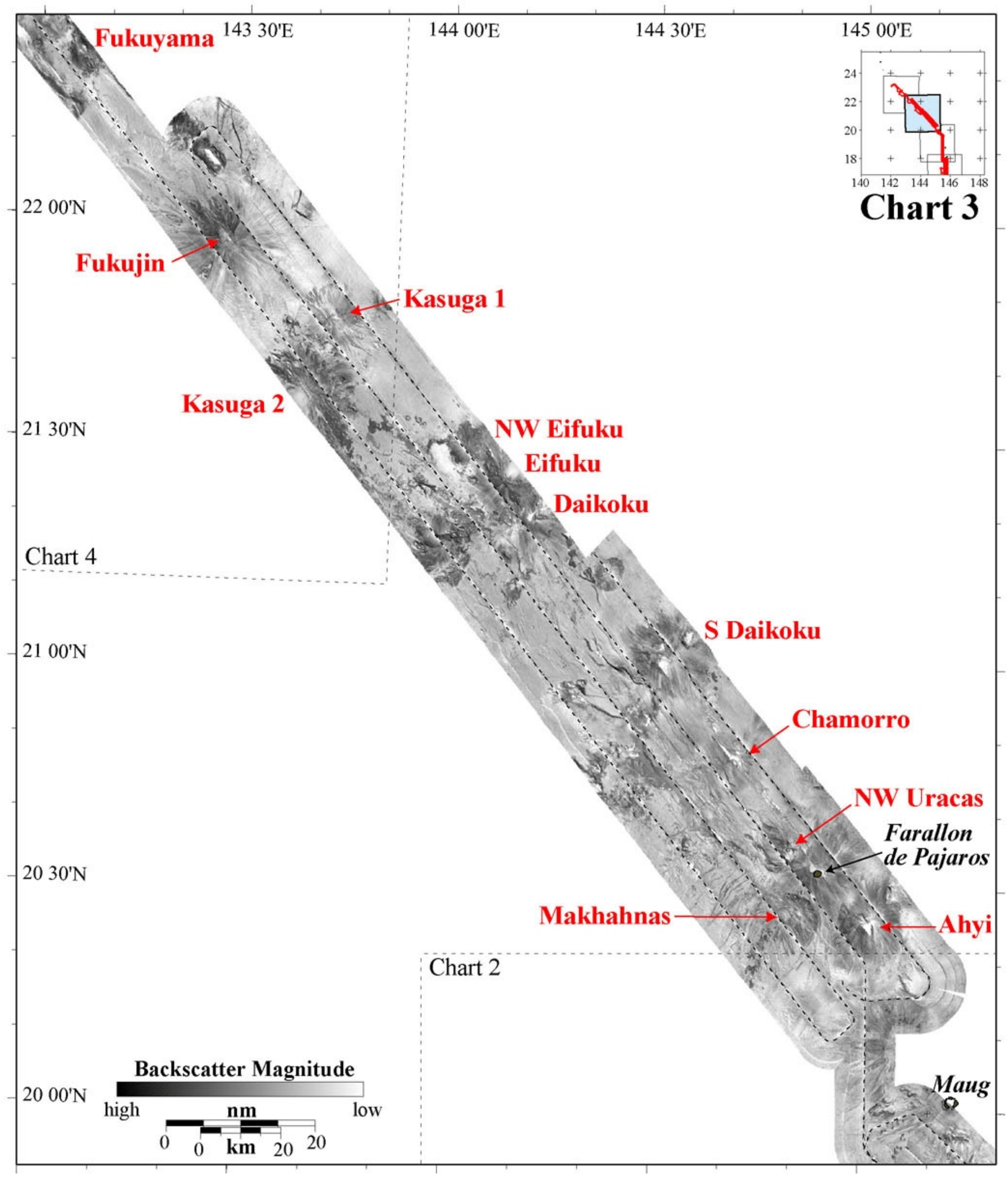
APPENDIX: MR1 Sidescan Sonar Charts 1 - 4 (South to North)



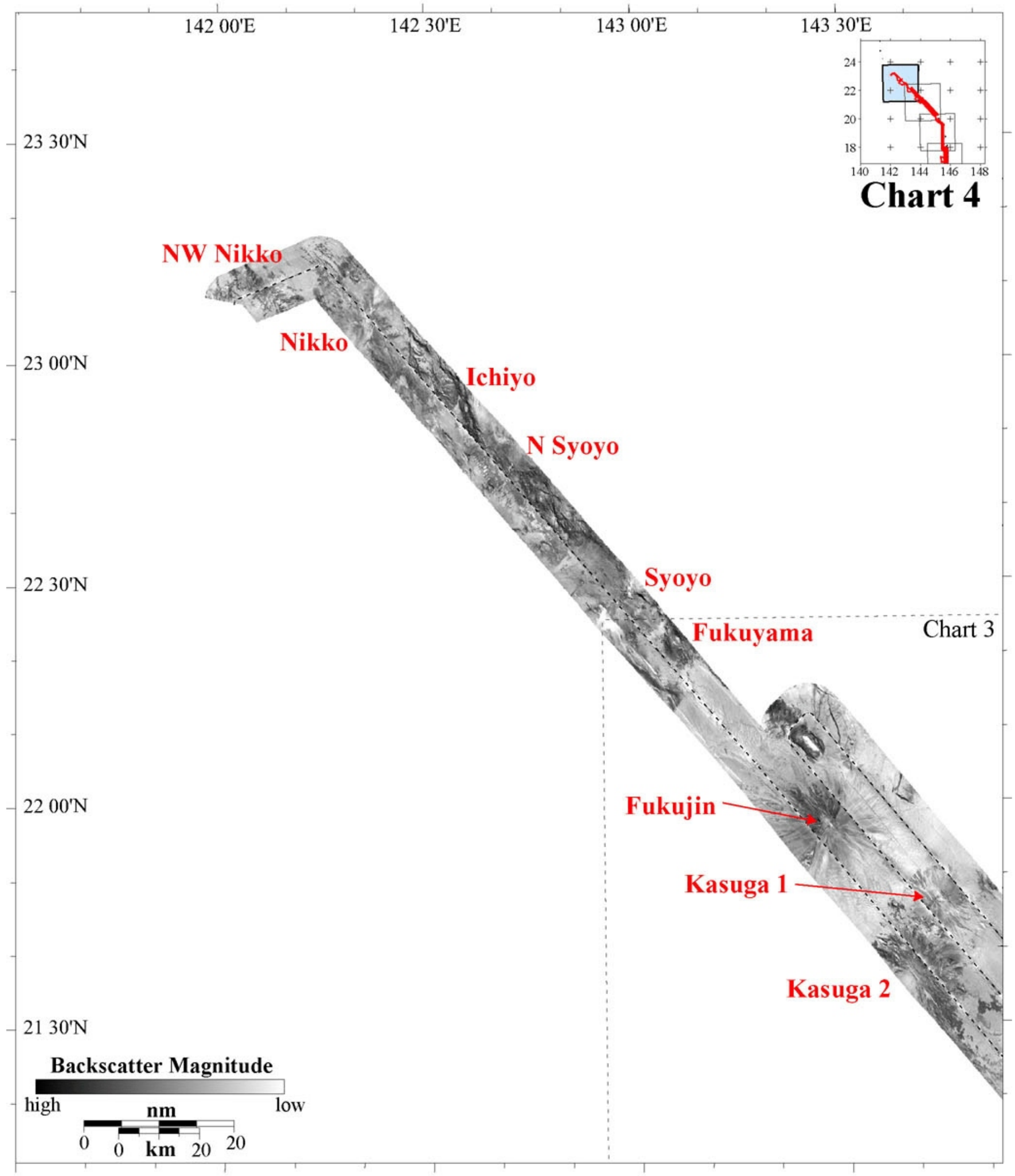
MR1 Acoustic Backscatter Imagery, UTM Projection Zone 55.
Grid size: 50 meters (Full data resolution is 16 meters).
Darker tones represent higher backscatter areas.
Map modified from original created by Paul Johnson, Hawaii Mapping Research Group.



MR1 Acoustic Backscatter Imagery, UTM Projection Zone 55.
Grid size: 50 meters (Full data resolution is 16 meters).
Darker tones represent higher backscatter areas.
Map modified from original created by Paul Johnson, Hawaii Mapping Research Group.



MR1 Acoustic Backscatter Imagery, UTM Projection Zone 55.
Grid size: 50 meters (Full data resolution is 16 meters).
Darker tones represent higher backscatter areas.
Map modified from original created by Paul Johnson, Hawaii Mapping Research Group.



MR1 Acoustic Backscatter Imagery, UTM Projection Zone 54.
Grid size: 50 meters (Full data resolution is 16 meters).
Darker tones represent higher backscatter areas.
Map modified from original created by Paul Johnson, Hawaii Mapping Research Group.