Catastrophic volcanic activity at Rumble III volcano based on EM300 bathymetry and direct seafloor imaging

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Non-Technical Summary

The Kermadec-Tonga Arc, located between New Zealand and Fiji, hosts numerous submarine volcanoes generated by the collision of the Pacific and Australian plates. Rumble III volcano, located along the arc 300 km northeast of the Bay of Plenty, New Zealand, is known to be hydrothermally active as documented by a plume rising from the summit area; however, little research has been conducted at this volcano. This study, conducted on March 9-11, 2009 aboard the *R/V Thomas G. Thompson* during a University of Washington student research cruise, investigates the geology of Rumble III volcano and its volcanic activity. High-resolution submarine bathymetry and imagery collected with a deep towed camera system show striking differences compared to prior investigations. The summit has collapsed and is now 100 m deeper than last recorded in 2007, the adjacent 800 m wide caldera has almost completely filled in, and much of the side of the volcano has fallen away. Volcanic deposits that include lava flows and ash were documented throughout the images from the deep towed camera taken from two runs conducted at and surrounding the summit of the volcano. In concert, these observations indicate a recent catastrophic volcanic eruption has occurred at Rumble III volcano in the past two years and highlight the dynamic nature of volcanoes in the Kermadec Arc.

Abstract

Located in the Southern Kermadec Arc, Rumble III volcano is one of the shallowest volcanoes rising to a water depth of 310 m. Except for preliminary investigations concerning hydrothermal activity through plume detection, little research has been conducted at this site. This study, conducted on March 9-11, 2009 during a University of Washington student research cruise, investigates the geology and volcanic activity of Rumble III volcano. Using the EM300 multibeam sonar on the *R/V Thomas G. Thompson* in concert with direct seafloor imaging from a TowCam system, it was discovered that the bathymetry has drastically changed since the last mapping of the volcano completed in 2007. The conical summit has collapsed by nearly 100 m, the nearby 800 m crater has been almost completely filled in with ash, and much of the side of the volcano has slid away. Volcanic deposits that include lava boulders, hackley flow, pillow lavas, and talus were documented along the walls of the summit. Thick deposits of ash covered most of these flows indicating fallout through the water column: the collapsed summit area was also covered in a deep layer of ash. These data indicate that a large catastrophic volcanic eruption has occurred in the past two years. Sixty percent of the volcanism on the planet occurs within the oceans, yet little is known about the dynamics of these systems, in contrast to continental environments. The catastrophic volcanic activity of Rumble III volcano highlights the dynamic nature of volcanoes in the Kermadec Arc.

The Kermadec-Tonga Arc extends 2,500 km between New Zealand and Fiji making it the longest arc on the planet. It has been the focus of submarine volcanic research since discovery of volcanic activity in the 1960s (de Ronde et al. 2007; Figure 1).

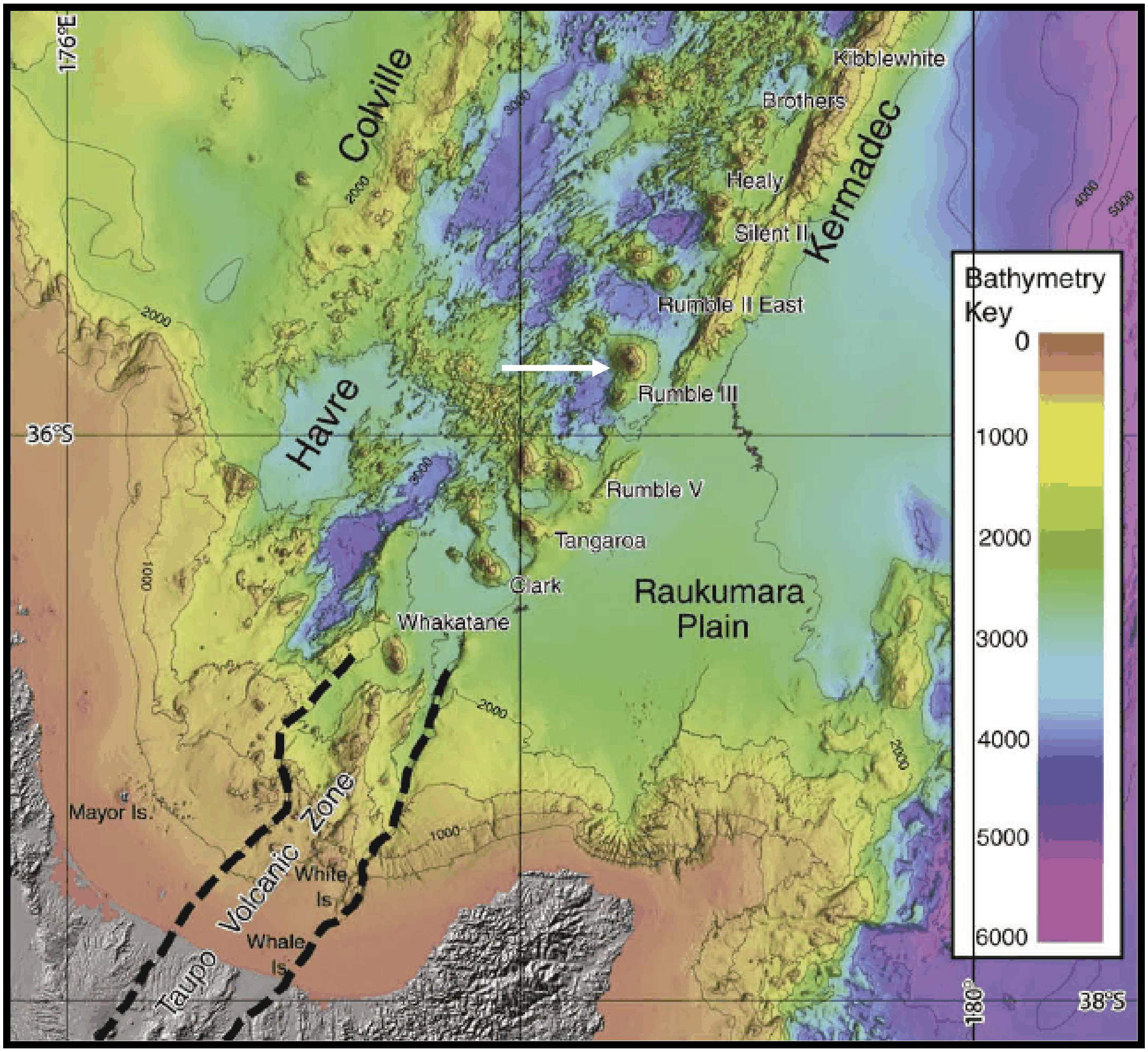


Figure 1: Map of the Kermadec-Tonga Arc modified from Wysoczanski et al. 2009. Rumble III is depicted by the white arrow.

Submarine volcanoes line the arc, formed as a result of the Pacific-Australian plate convergence. Many of the volcanoes, including Rumble III, host hydrothermal sites (Smith and Price 2006). Located between its neighboring seamounts, Rumble II East and Rumble IV, Rumble III volcano lies at 35°44.377′ S, 178°29.839′. Rumble III is an active stratovolcano and one of the shallowest in the Kermadec Arc system. It has a basal diameter of 26 km and in 2007 rose from a water depth of 3000 m to 220 m (Massoth et al. 2003; Wright et al. 2002).

Hydrothermal activity in the Kermadec Arc is unique from other hydrothermal systems found around the world's oceans. The vents exhibit a wide range of chemical diversity at seven out of thirteen of the volcanoes so far investigated (Massoth et al. 2003). Hydrogen Sulfide (H_2S) values within a plume in this region have been recorded as high as 18,700 nM (Massoth et al. 2003). Typical iron concentrations are between 23-76 nM, but in certain volcanoes along the arc, such as Macauley, values reach up to 2,600 nM (de Ronde et al. 2007). In addition, a wide range of rock diversity has been documented along the arc with compositions ranging from dacite to basalts (Wright et al. 2002). Several volcanoes, including Rumble III, host hydrothermal plumes that show extreme enrichments in magmatic volatiles. Due to the shallow depth of Rumble III, volitiles are especially concentrated in the plume and greatly enrich the overlying water in magmatic volatiles and dissolved ionic species, such as iron (II) and manganese (II) ions (Massoth et al. 2003). Prior to this study, Rumble III had not been well studied (beyond detecting that there was active venting).

This study investigates the recent geological evolution of Rumble III. Based on past studies conducted both in this region and other areas that host hydrothermal systems, faults and fissures have been noted as prominent geological features that focus hydrothermal flow (Glickson et al. 2007). This phenomenon was observed at the Mothra Hydrothermal Field at the Endeavour Segment located on Juan de Fuca Ridge. At Endeavor, flow is focused via faults and fissures similar to what is found at other volcanoes, such as Brothers, along the Kermadec Arc (Glickson et al. 2007). For example, Brothers Volcano, located north of Rumble III hosts three active hydrothermal sites. In 2005, these sites were mapped, imaged with a submersible, and key features such as faults, landslides, and lava flows were imaged, indicating that Brothers is indeed hydrothermally and volcanically active (de Ronde et al. 2005).

Prior to the University of Washington study, only a single plume investigation had been conducted above Rumble III that detected hydrothermal activity. A bathymetric survey using an EM120 multibeam system was conducted, along with a few ground truth swaths of camera runs that documented lava flows and volcanic deposits (Massoth et al. 2003; Wright et al. 2002). During this 2009 study, an EM300 multibeam sonar survey in concert with a deep-towed camera system was used to generate the first detailed bathymetric map (30 m grid size) of the volcano and to provide direct seafloor imaging. These data show that dramatic changes have occurred at Rumble III volcano over a 2-year period and highlight the dynamic nature of volcanoes in the Kermadec Arc.

Materials and Methods

This study took place on March 9-11, 2009 aboard the *R/V Thomas G. Thompson* at Rumble III volcano. After completing a sound velocity profile using an expendable bathythermograph (XBT), a series of 18 survey lines were completed using the EM300 hull-mounted multibeam system at a ship speed of between 7-10 knots. Sixteen track lines oriented northeast to southwest were completed with the addition of half an additional line at the northern most portion of the volcano, leading to a swath bisecting all the others down the center of the survey grid (Appendix 1; Figure 2). This provided full coverage of the seamount with a grid size of 30 m and an overlap in swath coverage of 30% or higher. Due to weather and wind conditions, the lines were completed over a period of three days and later merged to create the final bathymetry maps.

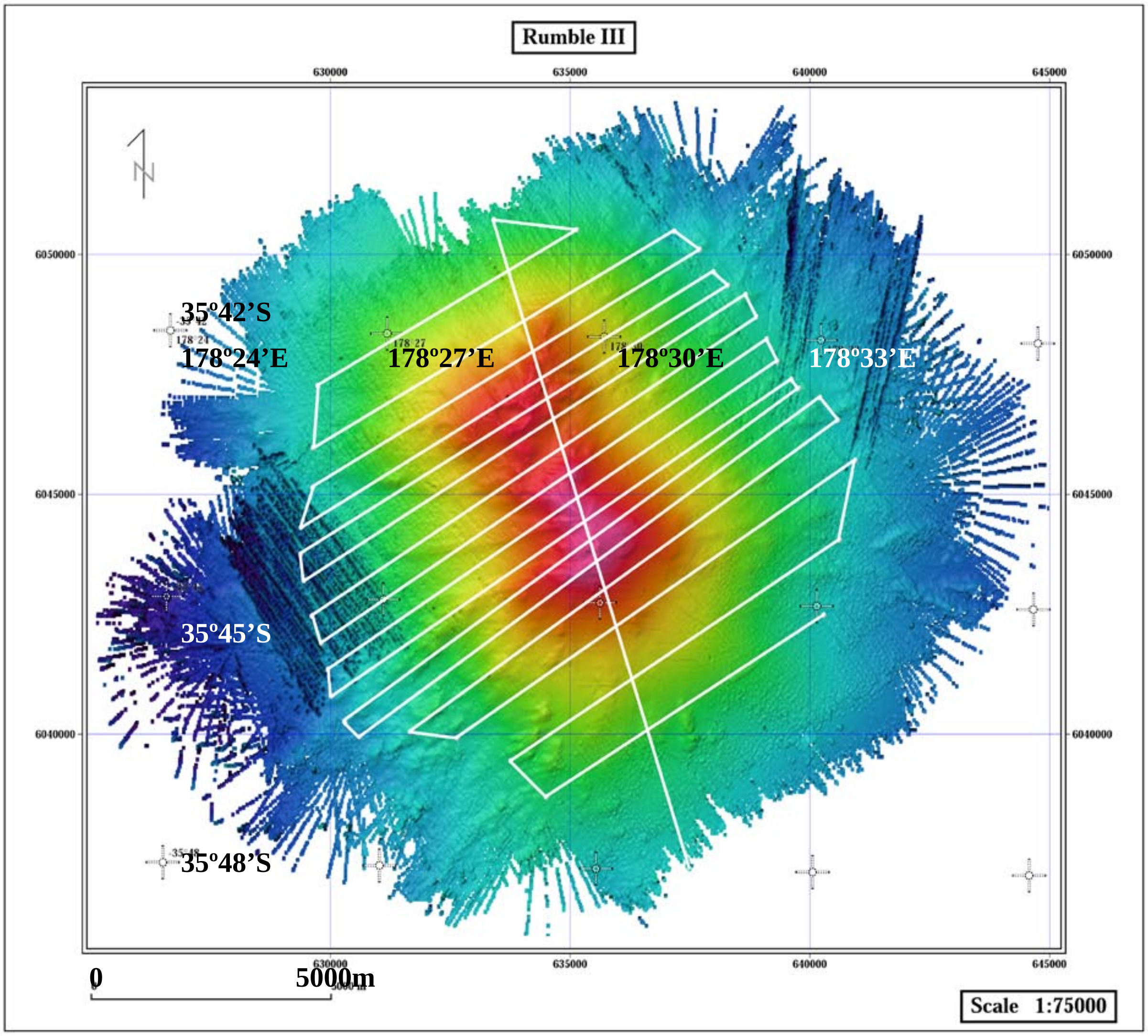


Figure 2: Map of Rumble III volcano showing EM300 survey track lines. The X-Y grid is a UTM grid and the crosshairs indicate latitudes and longitudes.

The EM300 multibeam system data were processed using Computer Aided Resource Information System (CARIS) software. CARIS was used to validate, prepare, compile, and store all of the bathymetric data for Rumble III volcano operating in a ping-to-chart format (http://www.caris.com). Upon uploading into Caris, the track lines were merged together and made into a smoothed base surface map. The lighting direction and angle were adjusted to accentuate the bathymetric profile of the seamount.

Following processing in CARIS, the data were brought into Fledermaus software utilized to generate three-dimensional visualizations and a fly-through movie of Rumble III volcano. This software was also used to combine the CARIS images from the three different days of mapping into one integrated data set for visualization (http://ww.ivs3d.com/products/fledermaus/; Bradwell et al. 2008).

A towed camera system, "TowCam," was used to obtain real-time images of the seafloor at Rumble III (Figure 3). The TowCam was equipped with a high-resolution (3.3 mega pixel) digital camera and had the ability to take water samples (http://www.whoi.edu/instruments/viewInstrument.do?id=9929). The locations of the two TowCam runs were based upon the results obtained from the plume surveys and prior knowledge of the vents likely locations. Conductivity-temperature-depth-optical (CTDO) tow-yo data collected by Marie Salmi and Anna Belcher provided guides for camera tow locations. Spikes in redox potential (Eh) helped guide the location of camera tows because they are indicators of hydrothermal activity. The TowCam track lines for the surveys were planned, plotted, and completed with the camera flown typically 3-4 meters off the bottom with the ship traveling between 0.25-0.5 knots (Figure 4). A picture was taken once every 9 seconds. The camera is equipped with two green lasers that are 41 cm apart to provide a scale for image analysis.

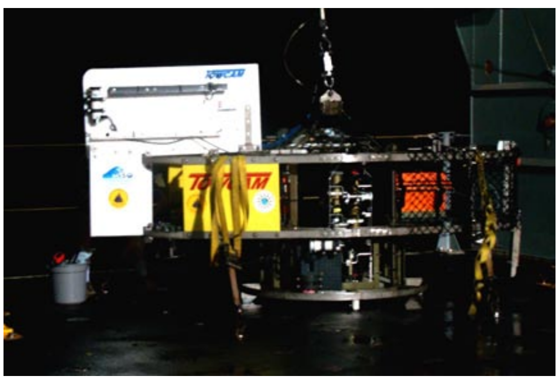


Figure 3: TowCam on the back of the R/V Thomas G. Thompson.

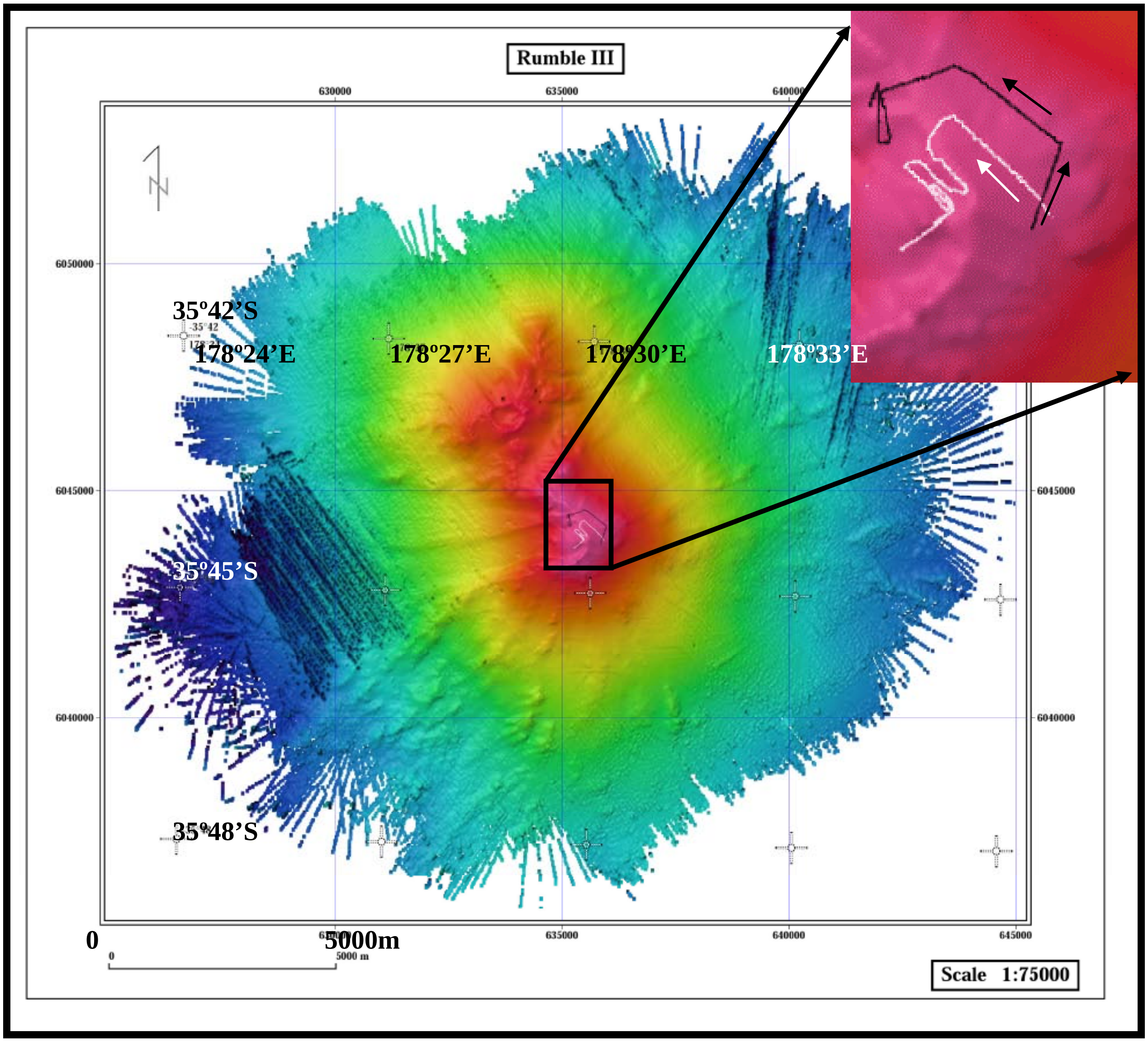


Figure 4: Map of Rumble III volcano showing TowCam survey track lines. TowCam run 8 is in white and TowCam run 9 is in black. Arrows are included to indicate the heading of each survey. The X-Y grid is a UTM grid and the crosshairs indicate latitudes and longitudes.

The EM300 bathymetric data and TowCam data were coregistered by being combined into a strip map for each camera run. TowCam runs were analyzed frame-by-frame using a substrate categorization system and the presence of biology was noted. Specific geologic units were identified based on unique characteristics, and relative coverage was denoted by 0-5

(0=0%, 1=1-25%, 2=26-50%, 3=51-75%, 4=76-99%, 5=100%) (Appendix 2). The different types of units (substrates) were assigned a symbol. Using Excel, the geologic units for each camera run were annotated along each camera tow line. Finally, the EM300 bathymetric data were displayed using the COVE (Common Observatory Visualization Environment) visualization program allowing it to be displayed alongside the already existing bathymetry in the Kermadec Arc region (http:/www.cs.Washington.edu/homes/keithg/oceans.html; Figure 5).

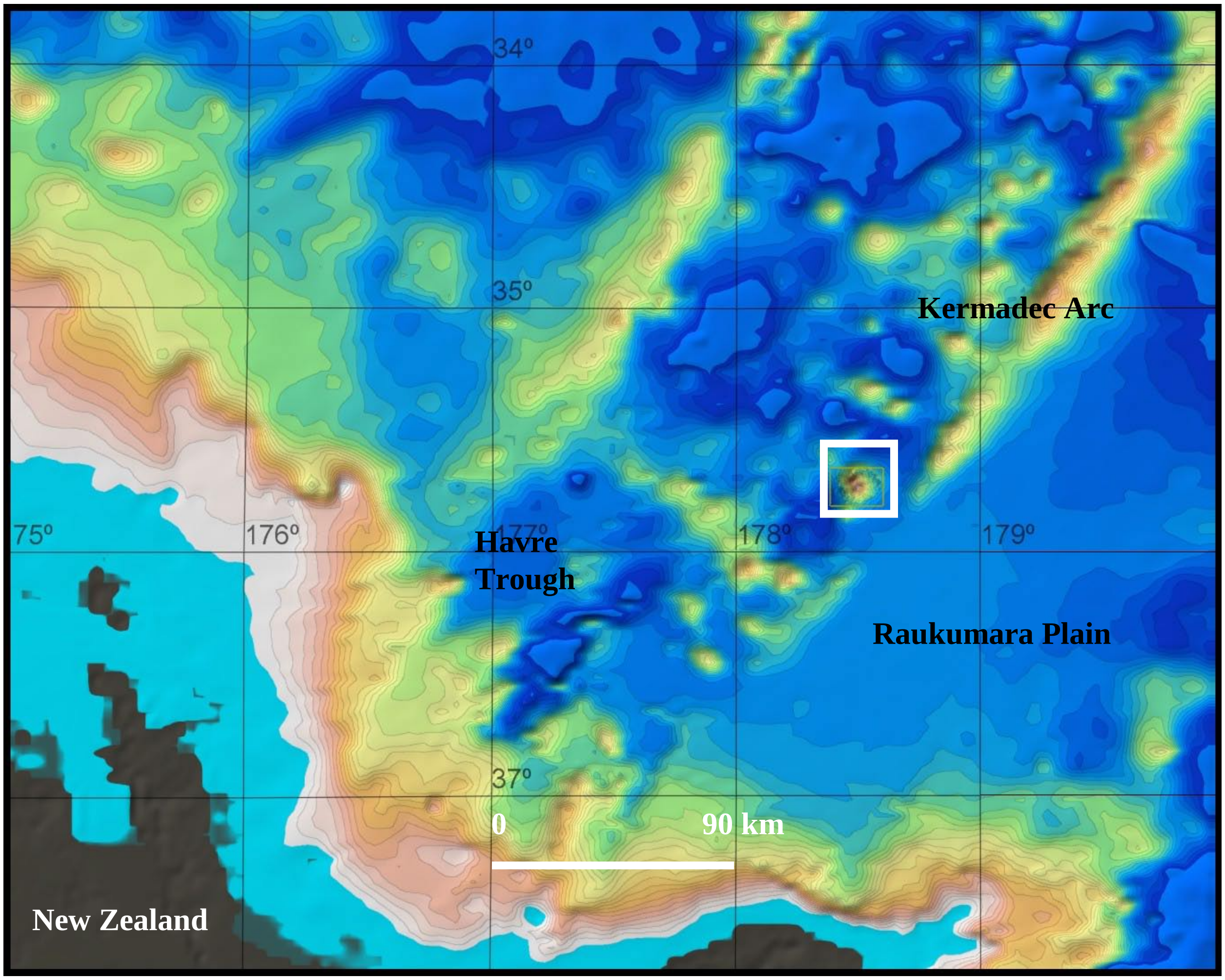


Figure 5: Map of the Kermadec Arc created in COVE. Rumble III volcano is outlined in white.

Results

The bathymetry of Rumble III, based on EM300 mapping, shows that the volcano is 11 km across and 6 km wide (Figure 6). The 30 m grid shows the main summit rising to a water depth of 310 m (Figure 7a). An extensive scarp, 1 km wide, can be seen starting just west of the main summit extending down the entire slope of side of the volcano and widening to the east to over 2 km (Figure 6). Ridges border this scarp area on both sides and also run down the center. Ridges also line the summit extending from the northwest to southwest side. To the north lies the caldera at 800 m in width and 100 m deep from rim to floor (Figure 7b).

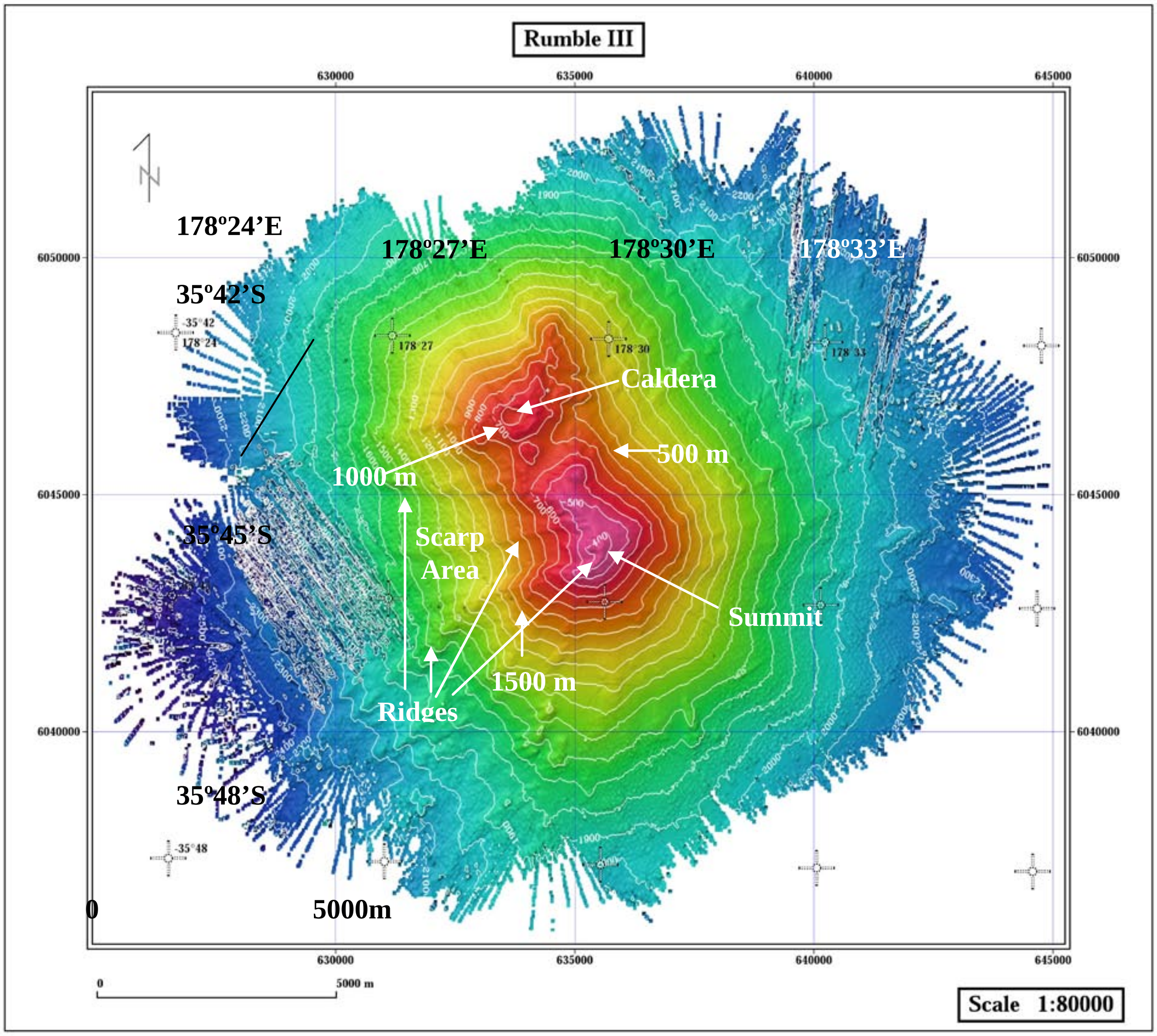
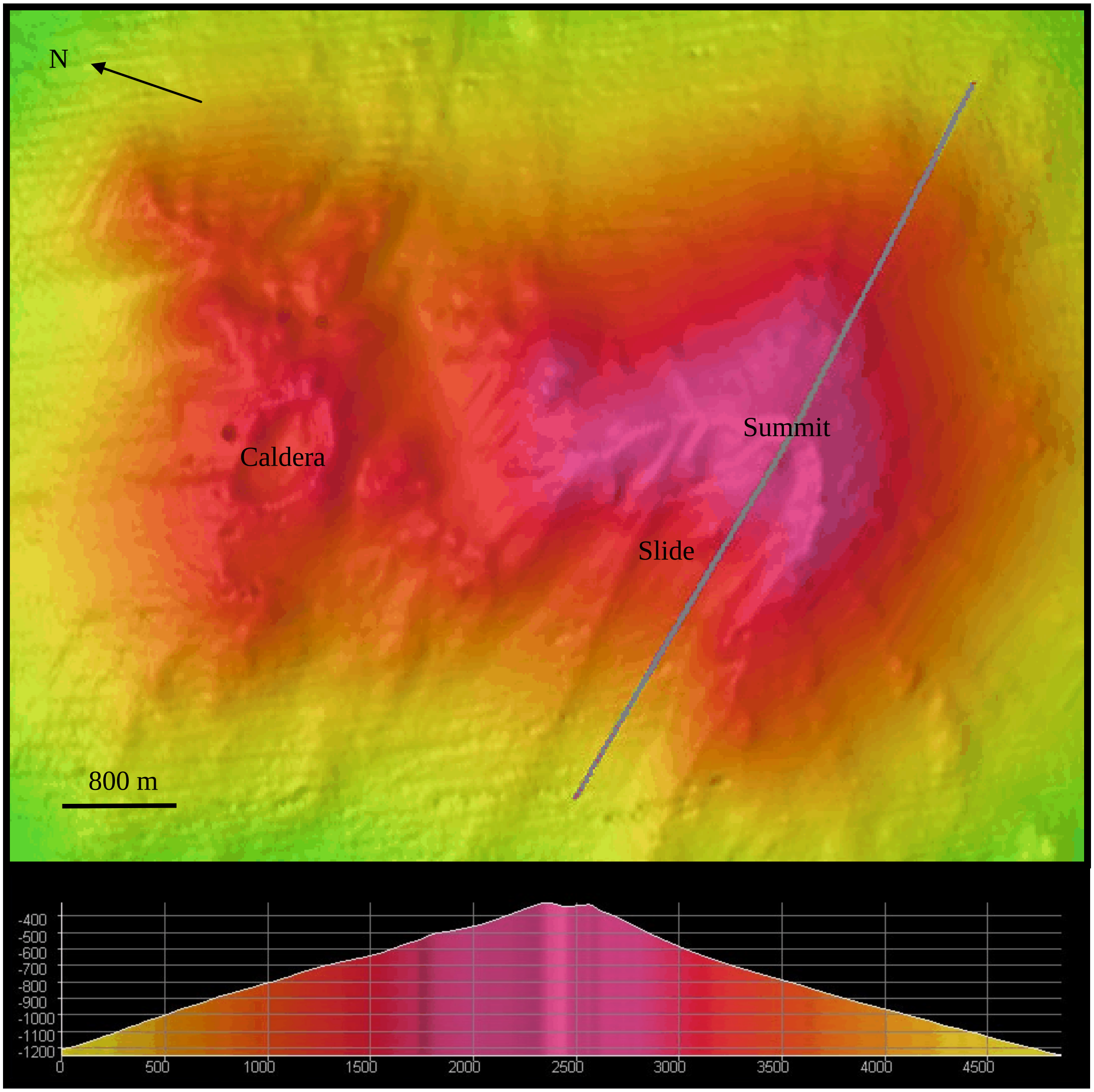


Figure 6: Bathymetric map of Rumble III volcano created in Fledermaus with 100 m contours. The X-Y grid is a UTM grid and the crosshairs indicate latitudes and longitudes.

7a.


N
Summit
Caldera
Slide
800 m
-400
-500
-600
-700
-800
-900
-1000
-1100
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0
500
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7b.

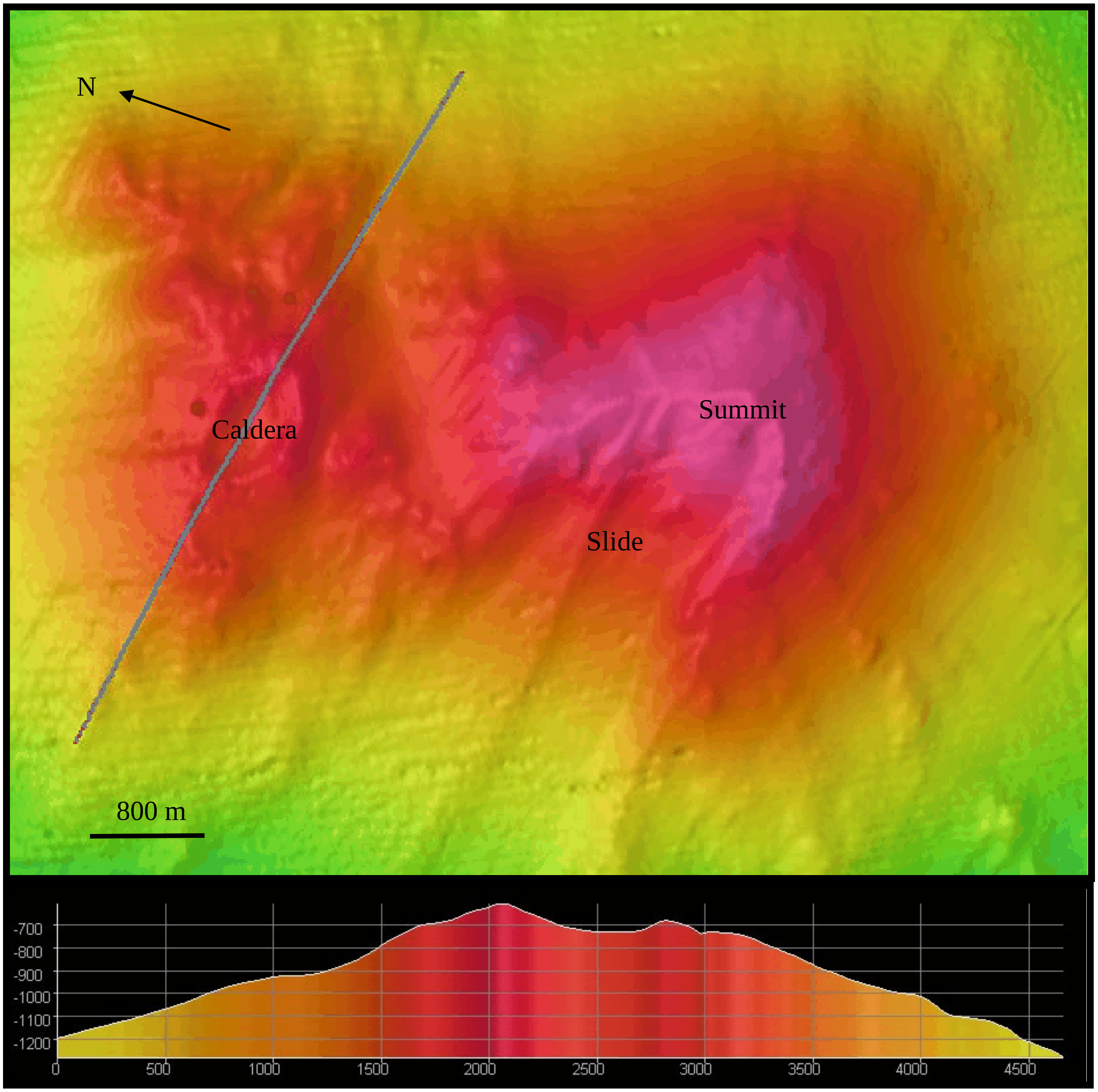

Figure 7: A. Profile of summit made in Fledermaus. B. Profile of caldera made in Fledermaus.

A comparison of the 2007 and 2009 bathymetry shows that the bathymetric profile of the seamount has completely changed (Figure 8). The old map, created using the EM120 system, shows Rumble III volcano having an obvious conical summit as well as a nearby crater. As seen on the new map, the summit has dropped from 220 m to 310 m and is no longer conical in shape.

The scarp area has grown near the summit starting farther upslope. In addition, the bottom of the caldera has been filled now having a depth from rim to floor of 100 m.

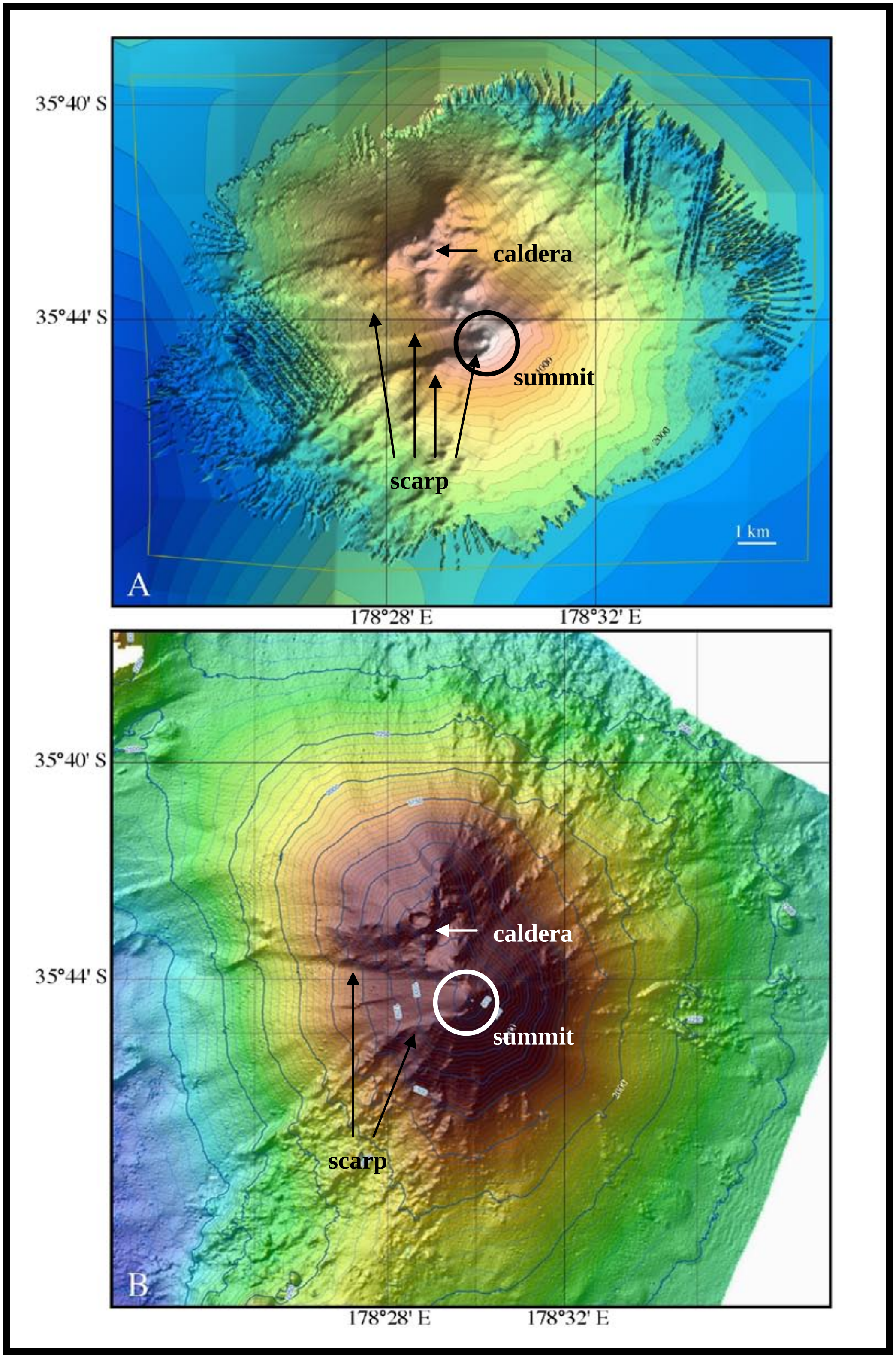

Figure 8: New (top) and previous (bottom) bathymetric map of Rumble III volcano. The newer

image was created using COVE. The older map of Rumble III volcano was made in 2007 using the EM120 multibeam system. Modified map from: http://www.volcano.si.edu/world/volcano.cfm?vnum=0401-13-volpage=photos&photo=120042.

Based on analyses of the tow-cam images, twelve different geological substrates, or units, were identified (Figure 9). Ash, typically dark gray/black, was especially common throughout both camera tows. It draped over flows and rocks and occurred as thick deposits with well developed rippled layers (Figure 10). Gray/dark brown talus was also common. Typically, talus either occurred in covering steep slopes or scattered on flat surfaces (Figure 10). The size of the talus blocks ranged from pebbles to large boulders of a foot or more in diameter. Pillow lavas were documented in both tows, as well, occurring in areas commonly accompanied by hydrothermal deposits or talus. The pillows ranged from one to a couple of feet in diameter and were typically dark brown in color. Sediment, ranging from brown to light brown in color, was documented in both tows, but often only in small amounts atop ripples. Hackley flows were only documented at one point in camera tow 9 along a sloped face. They were characterized by light gray protruding rocks. Hydrothermal deposits were seen at several points along camera tow 8, characterized by white/cloudy material that did not follow ripple patterns. Only once in camera tow 9 were hydrothermal deposits seen. At the end of camera tow 8, a hydrothermal plume was encountered (Figure 11). The water turned blurry and milky white for the extent of the camera tow until the camera was pulled up and back onboard. Finally, vertical rock walls, or scarps, were encountered in both tows near the edge of the summit leading down to the slide area (Figure 9). Due to their sheer vertical nature, they likely mark vertical faults at the ridge of the summit.

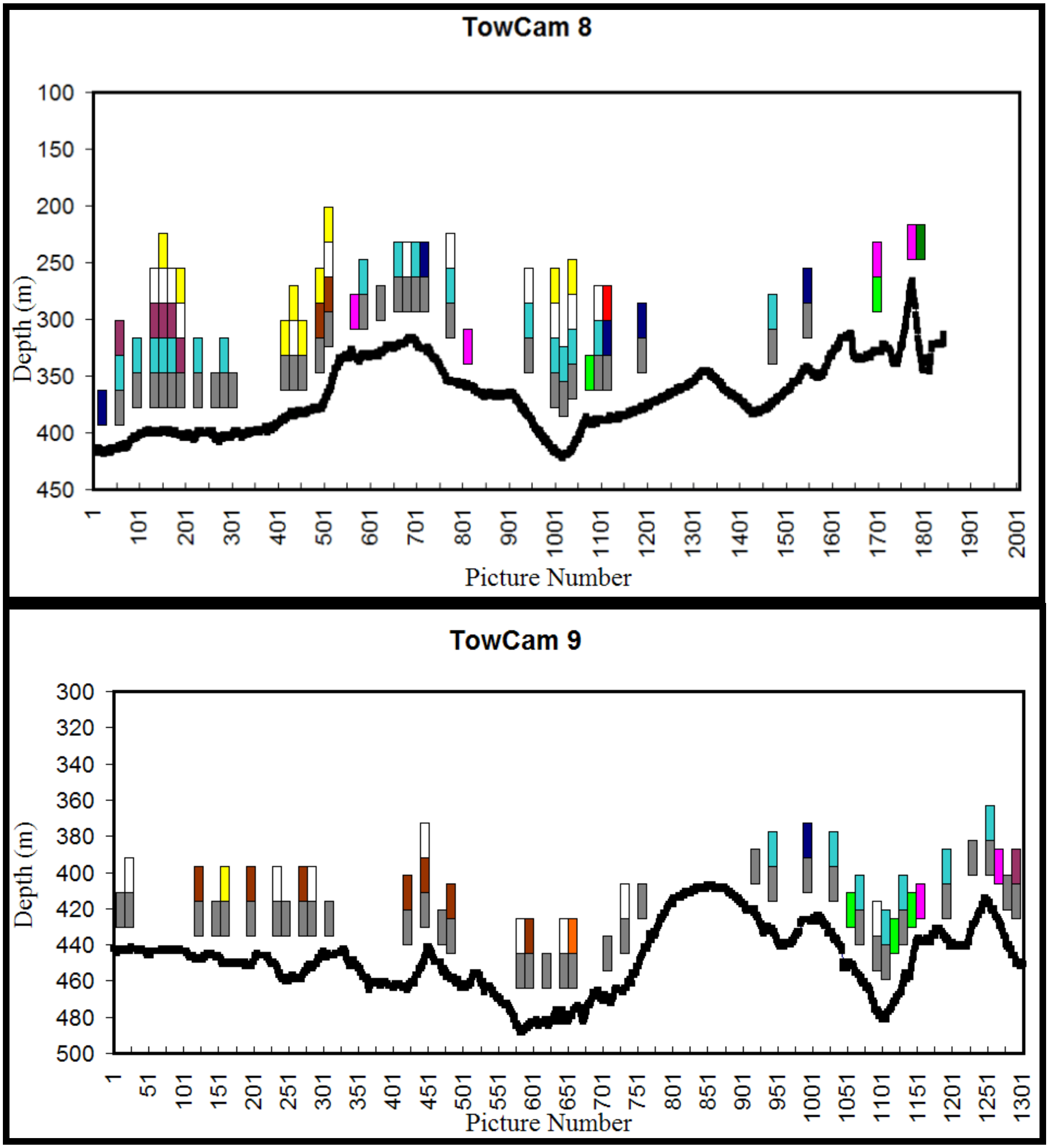

Figure 9: Strip map of geological substrate from TowCam 8 and 9 made in Excel. Each location of a color box (or boxes) indicates the substrate at that point and onward (to the right) until the next color box (or boxes) occurs. Black indicates the depth. Ash=gray, talus=white, pillows=brown, sediment=dark blue, <25% sediment=light blue, hackley flow=orange, ash on rock=pink, scattered rocks=purple, hydrothermal deposits=yellow, plume=dark green, scattered talus=red, rock wall/vertical fault=light green.

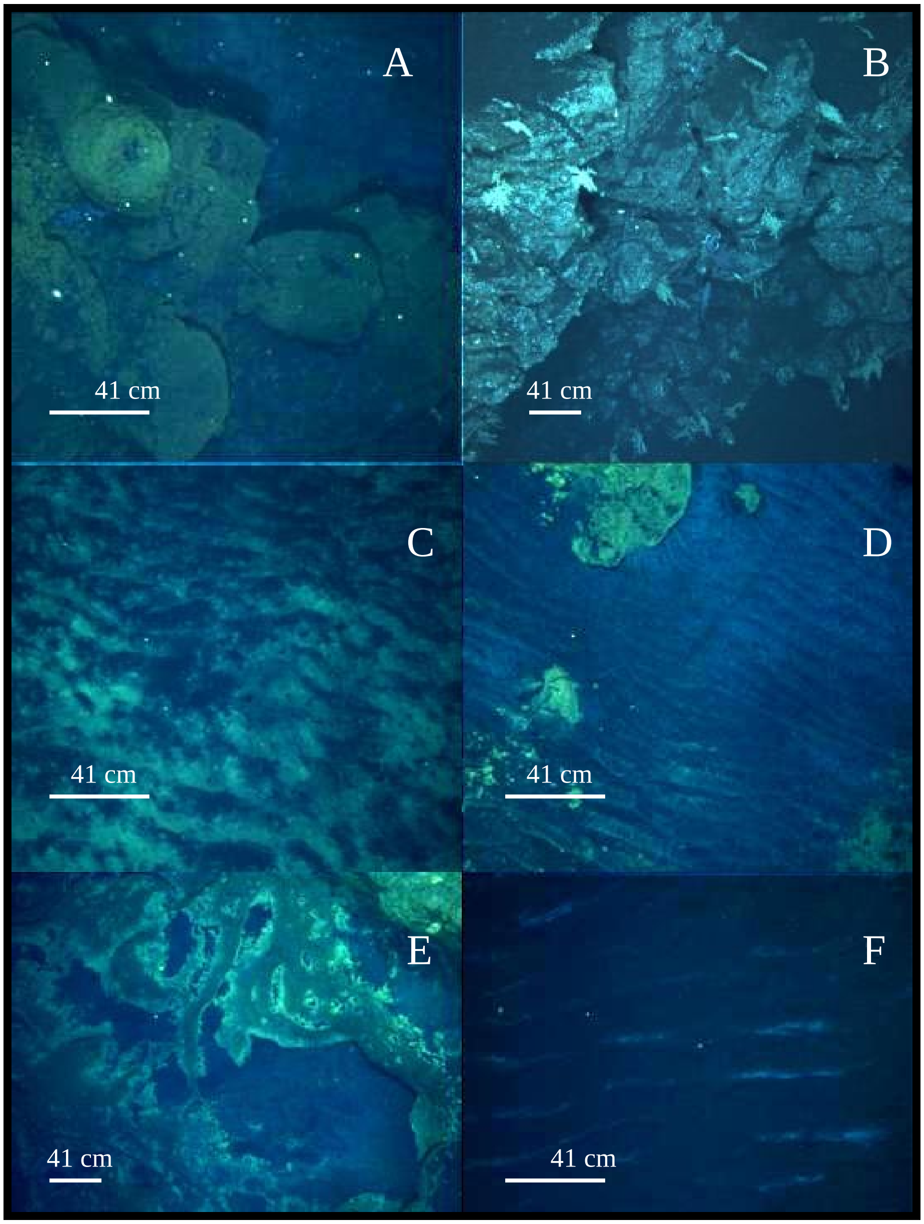

Figure 10: Geology of Rumble III. A) Displays truncated pillows, B) Hackley flow with ash and coral, C) Hydrothermal deposits with ash, D) Rippled ash with rocks, E) Ash on volcanic rock, F) Layers of ash on top of an old sulfur flow/lava lake.

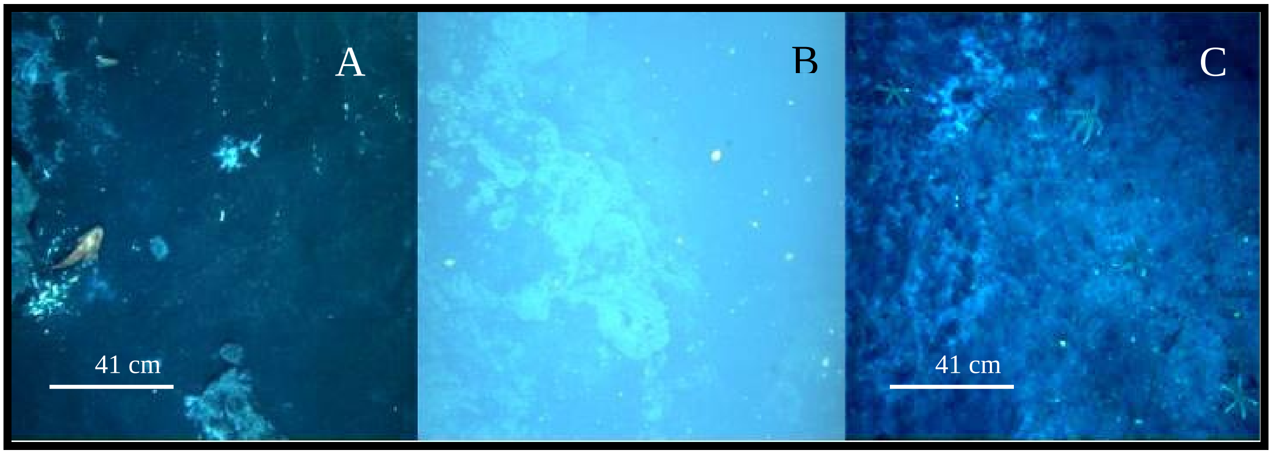

Figure 11: Biology and venting at Rumble III. A) Fish, mussels, and coral fragments, B) Entering a plume near the top of the summit, C) Five starfish and a fish.

In addition to geology, biology was also noted along the TowCam runs (Figure 11). Towards the beginning of the camera tow 8, evidence of mussels was found near the summit which may indicate diffuse venting. Fish, starfish, coral, and shells (gastropods) were documented on both camera tows but were not the main focus on this study.

Discussion

Since the last study of Rumble III volcano in 2007, a catastrophic volcanic event has occurred: both the bathymetric data and TowCam images provide strong evidence of a recent large eruption. These data show that the volcano summit is now at a water depth of 310 m, nearly 100 m deeper than it was in 2007, and much of the nearby 800 m wide crater has been filled in and is now at a water depth of 775 m below the surface (Figure 6). The crater has significantly been filled with volcanic ash that forms extensive deposits. In addition, much of the side of the volcano has also slid away making it much less round in shape. Scarps beginning at the east tip of the summit extend branching to the west; they bound an extensive slide area. This area begins near the summit spanning a width of 1 km and widening to over 2 km down-slope near the base of the volcano. In concert, these observations provide evidence for a recent major eruption that resulted in the collapse of the summit cone, sliding of substrate down the west slope, and filling of the crater.

This drastic bathymetric change holds a striking resemblance to the topographic change that occurred after the 1980 Mount Saint Helens eruption in Washington State, United States of America. Mount Saint Helens, prior to the eruption, resembled Rumble III seamount being relatively round and having a conical top. After the catastrophic eruption in 1980, the topography of the mountain was transformed (Figure 12; Major and Mark 2006). The top was completely blown and the side collapsed. The similarity in topographic change suggests that a catastrophic eruption of similar nature occurred at Rumble III volcano supporting the theory that a catastrophic volcanic event has indeed occurred within the last two years.

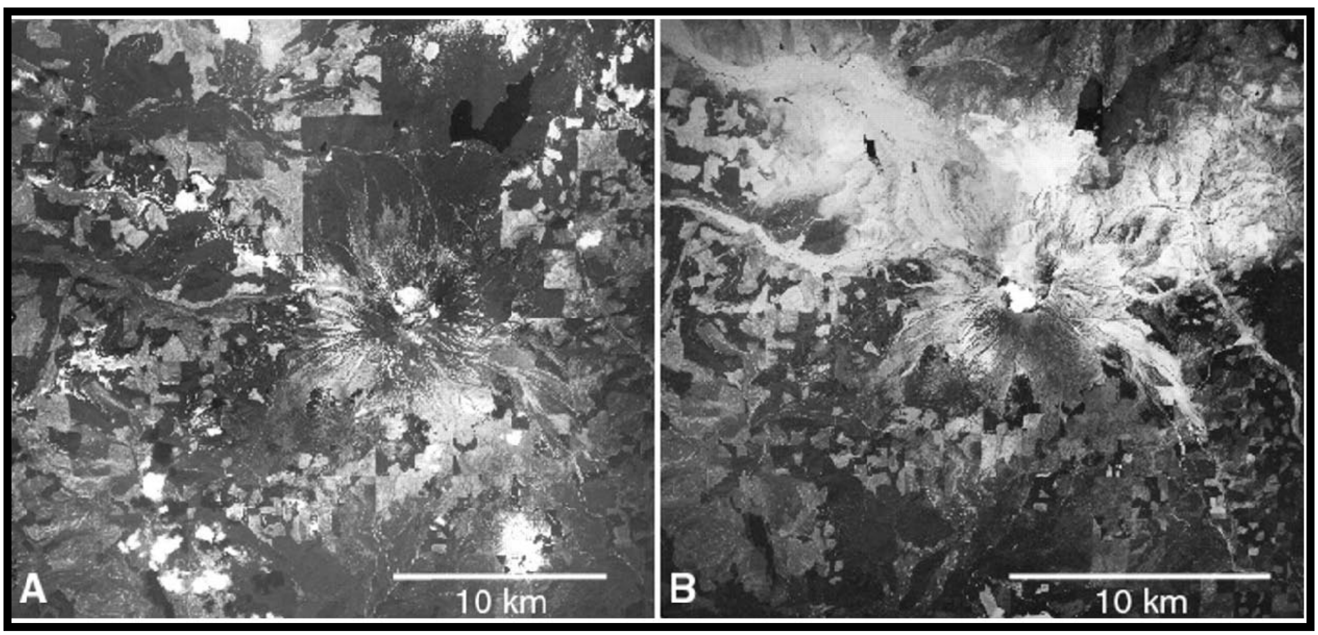

Figure 12: Aerial photos of Mount Saint Helens before (A) and after (B) the 1980 eruption showing the change in topography (Major and Mark 2006).

White Island, located just off the coast of New Zealand in the Bay of Plenty, has commonly experienced explosive eruptions and perhaps serves as a good example of processes also active at Rumble III (Figure 13). White Island is approximately 2 by 1.5 km and rises 321 m above sea level (Nishi et al. 1996). The geology of White Island is very similar to that of Rumble III, hosting a volcanic-hydrothermal system beneath the volcano. White Island has experienced a series of well-documented eruptions over the last fifty years that lead to the collapsing and reforming of three craters and shaping of the two cones (Nishi et al. 1996). This pattern of cause and effect of eruptions resulting in the formation and collapse of craters and reshaping of cones is likely what is happening beneath the surface of the ocean at Rumble III volcano. Similar to White Island, the recent eruption at Rumble III likely resulted in the collapse of the summit, a major landslide down-slope to the west of the summit, and shallowing of the caldera due to infilling by ash.

Figure 13: Image of White Island, Bay of Plenty, New Zealand from http://www.minoanatlantis.com/pix/

White_Island_Marine_Volcano.jpg.

The rift patterns along the Kermadec Arc also suggest that volcanism is common throughout the extent of the arc (Wysoczanski, R. J., E. Todd, I. C. Wright, M. I. Leybourne, J. M. Hergt, C. Adam and K. Mackay, in press). In particular, rifts similar to those on Rumble III are documented near the volcano (Figure 14). Immediately southwest of Rumble III, rifts run adjacent to the volcanic front. The orientation of these ridges is interpreted to be a product of volcanism that occurs with rifting (Wysoczanski, R. J., E. Todd, I. C. Wright, M. I. Leybourne, J. M. Hergt, C. Adam and K. Mackay, in press).

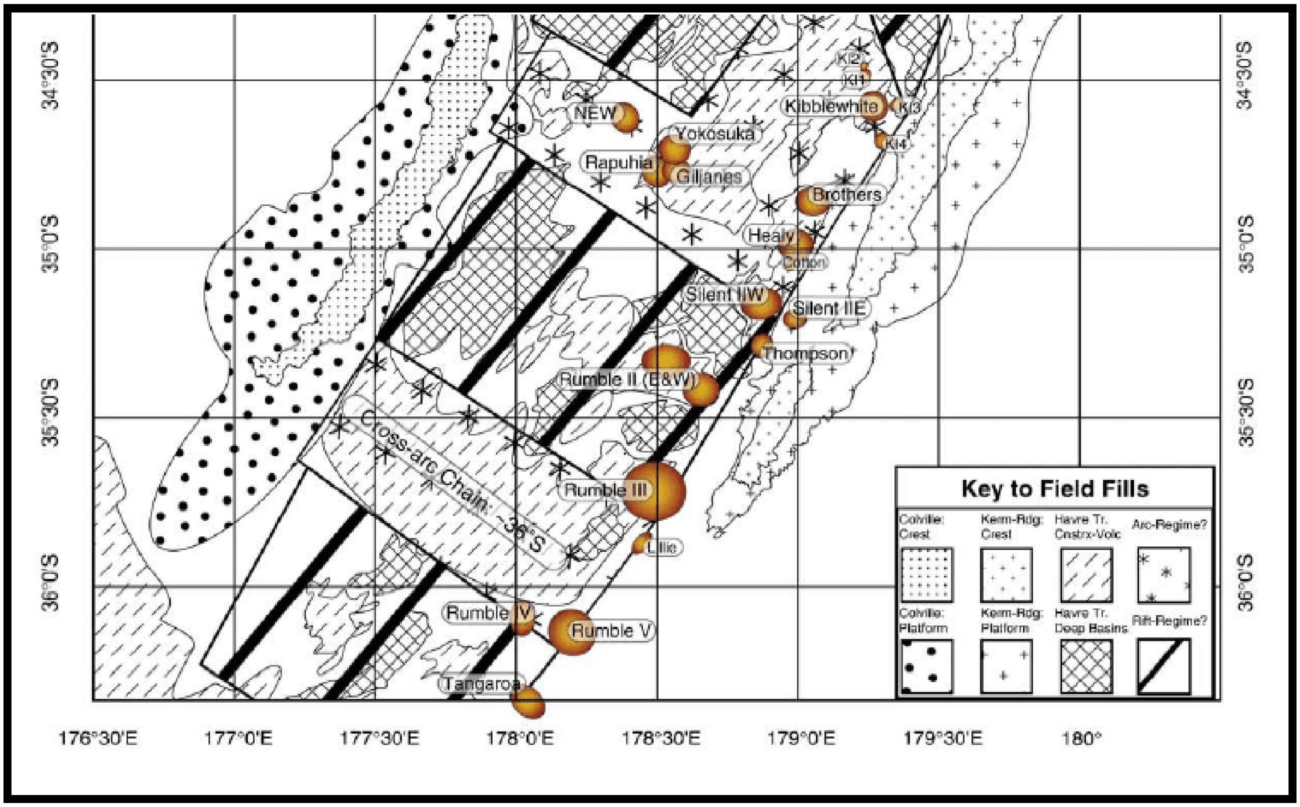

Figure 14: Adapted from a map by Wysoczanski, R. J., E. Todd, I. C. Wright, M. I. Leybourne, J. M. Hergt, C. Adam and K. Mackay, in press. Conceptual diagram of the structural fabric of the southern Havre Trough, defining areas of 'arc regime' and 'rift regime' based on structural orientation and topography.

Findings from the TowCam images also show that a recent catastrophic volcanic event has occurred. Evidence of volcanic flow deposits was documented in both camera tows (Figure 9). Lava boulders, hackley flow, truncated lobate or pillows, as well as talus were seen commonly throughout both tows. In concert, these observations strongly indicate recent explosive volcanic activity. The extensive ash deposits and the observation of significant drapings of ash atop lava flows and debris strongly supports the conclusion that a catastrophic event in the form of a large volcanic eruption has occurred (Figure 10). Ash is clearly documented covering sediment, rocks, and flows throughout both camera tows (Figure 9). Suspension fallout of ash can only occur from an explosive eruption (Fisher 1984).

For further study, access to the use of an ROV (remotely operated underwater vehicle) such as Jason would be advantageous (http://www.whoi.edu/page.do?pid=8423). A robotic vehicle tethered to the ship with a fiber cable would allow increased control and knowledge about the position of the vehicle, high-resolution bathymetry mapping using the multibeam system included on the ROV, and real-time high definition imagery from multiple cameras with a wider view angle. Samples could also be gathered using the ROV’s two mechanical arms to document the age and chemistry of the rock samples to provide insight into the nature of the eruption and when it occurred.

Conclusions

- Since the last study of Rumble III volcano in 2007, catastrophic volcanic activity has occurred.
- The bathymetric profile of the seamount has completely changed since it was last mapped in 2007. The summit of Rumble III has collapsed and is now nearly 100 m deeper at 310

m and much of the 800 m wide crater was filled by ash. It is 775 m below sea level, 100 m deep from the rim to the floor. In addition, much of the west side of the volcano has slid down-slope.

- Volcanic flow deposits were documented in both camera tows. Lava boulders, hackley flow, truncated lobate or pillows, as well as talus were common. All of these geologic substrates indicate volcanic activity.
- The massive abundance of ash, in particular draped across substrates in many areas, provides compelling evidence for a large catastrophic volcanic eruption since 2007.
- These data show that dramatic changes have occurred at Rumble III over a two-year period and highlight the dynamic nature of volcanoes in the Kermadec Arc.

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References

Bradwell, T., M. Stoker and M. Krabbendam. 2008. Megagrooves and streamlined bedrock in NW Scotland: The role of ice streams in landscape evolution. Geomorphology. **97**: 135-156.

De Ronde, C. E. J., M. D. Hannington, P. Stoffers, I. C. Wright, R. G. Ditchburn, A. G. Reyes, E. T. Baker, G. J. Massoth, J. E. Lupton, S. L. Walker, R. R. Greene, C. W. R. Soong, J.

Ishibashi, G. T. Lebon, C. J. Bray and J. A. Resing. 2005. Evolution of a submarine magmatic-hydrothermal system: Brothers Volcano, southern Kermadec Arc, New Zealand. Econ. Geol. **100**: 1097-1133.

De Ronde, C. E. J., E. T. Baker, G. J. Massoth, J. E. Lupton, I. C. Wright, R. J. Sparks, S. C. Bannister, M. E. Reyners, S. L. Walker, R. R. Greene, J. Ishibashi, K. Faure, J. A. Resing and G. T. Lebon. 2007. Submarine hydrothermal activity along the mid-Kermadec Arc, New Zealand: large-scale effects on venting. Geochem. Geophys. Geosyst. **8**, Q07007, doi: 10.1029/2006GC001495.

Fisher, R. V. 1984. Submarine volcaniclastic rocks. Geological Society of London Special Publications. **16**: 5-27.

Glickson, D. A., D. S. Kelley and J. R. Delaney. 2007. Geology and hydrothermal evolution of the Mothra Hydrothermal Field, Endeavour Segment, Juan de Fuca Ridge. Geochem. Geophys. Geosyst. **8**, Q06010, doi: 10.1029/2007/GC001588.

Major, J. J. and L. E. Mark. 2006. Peak flow responses to landscape disturbances caused by the cataclysmic 1980 eruption of Mount St. Helens, Washington. Geological Society of America Bulletin. **118**: 938-958.

Massoth, G. J., C. E. J. De Ronde, E. T. Baker, J. E. Lupton, R. J. Arculus and R. W. Embley. 2003. Fluids from arcs: a submarine magmatic-hydrothermal perspective. Proceedings of the State of the Arc Conference (SOTA) (2003).

Nishi, Y., S. Sherburn, B. J. Scott and M. Sugihara. 1996. High-frequency earthquakes at White Island volcano, New Zealand: insights into the shallow structure of a volcano-hydrothermal system. J. Volcanol. Geotherm. Res. **72**: 183-197.

Smith, I. E. M. and R. C. Price. 2006. The Tonga-Kermandec Arc and Havre-Lau back-arc system: Their role in the development of tectonic and magmatic models for the western Pacific. J. Volcanol. Geotherm. Res. **156**: 315-331.

Wright, I. C. 1996. Volcaniclastic processes on modern submarine arc stratovolcanoes: sidescan and photographic evidence from the Rumble IV and V volcanoes, southern Kermadec Arc (SW Pacific). Mar. Geol. **136**: 21-39.

Wright, I. C., P. Stoffers, M. Hannington, C. E. J. De Ronde, P. Herzig, I. E. M. Smith, and P. R. L. Browne. 2002. Towed-cam investigations of shallow intermediate water-depth submarine stratovolcanoes of the southern Kermadec Arc, New Zealand. Mar. Geol. **185**: 207-218.

Wright, I. C., T. J. Worthington and J. A. Gamble. 2005. New multibeam mapping and geochemistry of the 30°-35° S sector, and overview, of southern Kermadec Arc volcanism. J. Volcanol. Geotherm. Res. **149**: 263-296.

Appendicies

Waypoints						
Track Line	Waypoint	Lat. Start	Long. Start	Waypoint	Lat. End	Long. End
1	1	35°45.1′ S	178°33.1′E	2	35°47.2′ S	178°29.3′E
2	3	35°46.8′ S	178°28.8′E	4	35°44.25′ S	178°33.3′E
3	5	35°43.35′ S	178°33.5′E	6	35°46.55′ S	178°28.05′E
4	7	35°46.49′ S	178°27.4′E	8	35°42.9′ S	178°33.25′E
5	9	35°42.65′ S	178°33.0′E	10	35°46.55′ S	178°26.7′E
6	11	35°46.4′ S	178°26.5′E	12	35°42.55′ S	178°32.7′E
7	13	35°42.45′ S	178°32.6′E	14	35°46.1′ S	178°26.3′E
8	15	35°45.8′ S	178°26.25′E	16	35°42.25′ S	178°32.4′E
9	17	35°42.0′ S	178°32.25′E	18	35°45.5′ S	178°26.15′E
10	19	35°45.2′ S	178°26.015′E	20	35°41.75′ S	178°32.1′E
11	21	35°41.5′ S	178°31.95′E	22	35°44.8′ S	178°25.9′E
12	23	35°44.5′ S	178°25.85′E	24	35°'41.4 S	178°31.7′E
13	25	35°41.25′ S	178°31.5′E	26	35°44.2′ S	178°25.85′E
14	27	35°43.75′ S	178°26.0′E	28	35°41.0′ S	178°31.3′E
15	29	35°40.8′ S	178°30.30.95′E	30	35°43.3′S	178°26.0′E
16	31	35°42.6′ S	178°26.05′E	32	35°40.8′ S	178°29.6′E
17	33	35°40.7′ S	178°28.45′E	34	Not Completed	

Appendix 1: Table of Waypoints for the 17 track lines including latitudes and longitudes.

TowCam Image Analysis									
		% Coverage: 0=0-0%, 1=1-25%, 2=26-50%, 3=51-75%, 4=76-99%, 5=100-100%							
Time (GMT)	X (Lat)	Y (Long)	Z (Depth m)	Image #	Talus	Truncated Lobate (Pillow)	Massive Flow	Sediment	Rock
TOWCAM RUN 8 part a									
13:41:45	-35.7378	178.5012	406.9	195	0	0	0	0	1
13:41:55	-35.7378	178.5012	405.68	196	0	0	0	0	1
13:42:05	-35.7378	178.5012	405.68	197	0	0	0	0	0
13:42:15	-35.7378	178.5012	406.9	198	0	0	0	0	0
13:42:25	-35.7378	178.5012	405.68	199	0	0	0	0	1
13:42:35	-35.7378	178.5012	405.68	200	0	0	0	0	1
13:42:45	-35.7377	178.5012	404.47	201	0	0	0	0	1
13:42:55	-35.7377	178.5011	403.25	202	0	0	0	0	1
13:43:05	-35.7377	178.5011	405.68	203	0	0	0	0	1
13:43:15	-35.7377	178.5011	405.68	204	0	0	0	0	0
13:43:25	-35.7377	178.5011	403.25	205	0	0	0	0	0

Ash	Hydrothermal Deposits (Sulfer)	Biology (Yes/No/ Maybe)	Ripples	Faulting (Vertical Cliff)	Water Column Particulates (in plume)	Flocculant (white dots settled on bottom)	Nothing Shots (water column etc.)	Comments
4	0	Yes				x		Coral and Shells
4	0	Yes				x		Shells
5	0	Yes				x		Coral-not much
5	0	Yes				x		Coral
4	0	Yes				x		Fish, Coral
4	0	Yes				x		Fish
4	0	Yes				x		Coral
4	0	Yes				x		Coral
4	0	Yes				x		Coral
5	0	No	x			x		
5	0	Yes	x			x		Coral

Appendix 2: Example of TowCam Analysis Spreadsheet. Top table leads into bottom- all one long horizontal table in excel.