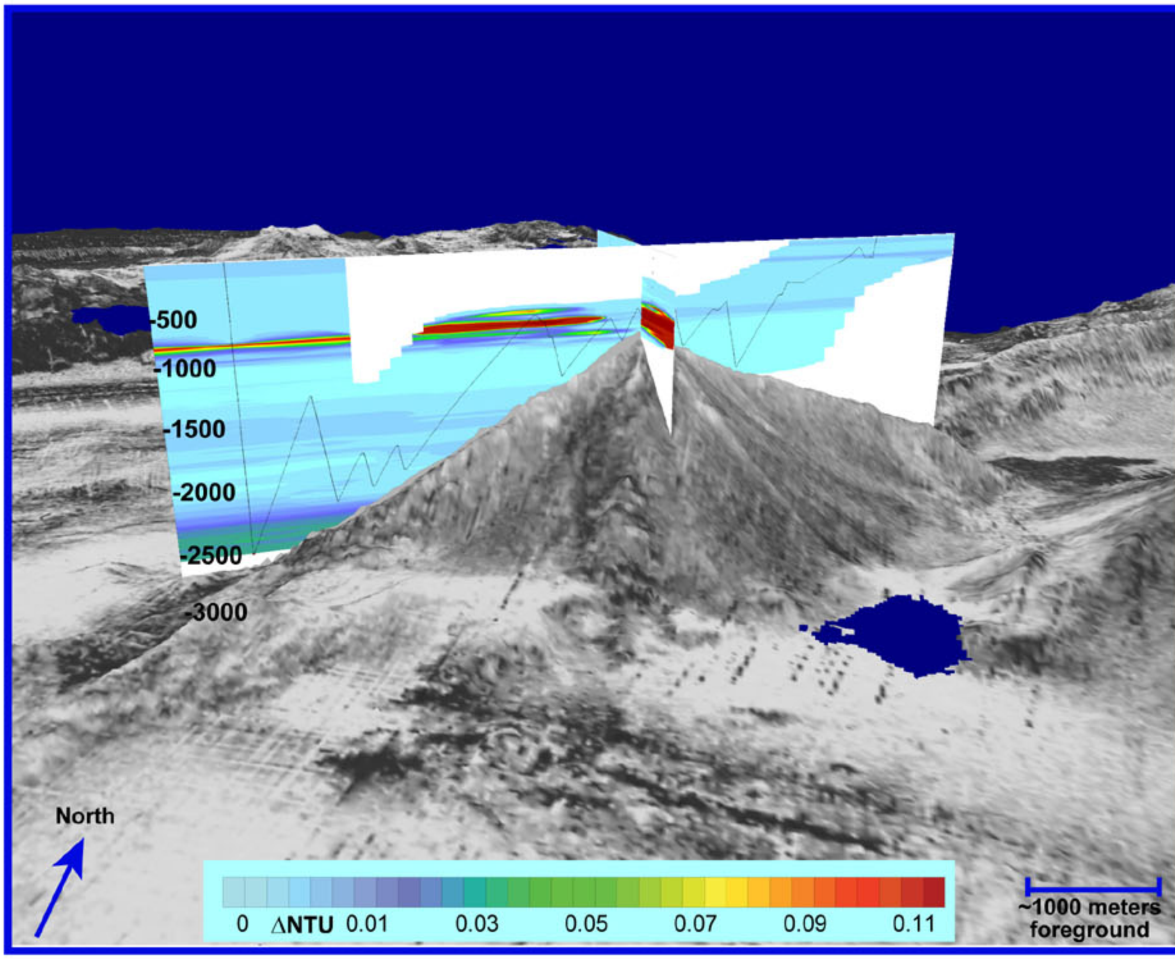
Northeast Lau Basin
R/V *Thompson* Expedition TN227
November 13 - 28, 2008
Apia to Apia, Western Samoa



West Mata Volcano, Northeast Lau Basin
CTD tows T08C-16 and T08C-17

CTD tow-yo fence diagram (2D) of tows 16 and 17 inserted into 3D object created by draping EM300 acoustic backscatter data over EM300 bathymetry. Darker backscatter shades represent higher reflectivity seafloor. Optical backscatter (shown here in dimensionless units of Nephelometric Turbidity Units above background, or ΔNTU) shows the distribution of particle plumes. West Mata depth ranges from 1185 m at the summit to ~2900 m at its western base. 30 m grid-cell size. 1.5 times vertical exaggeration. Dark blue areas are bathymetric data gaps or water column above the seafloor.

Report compiled by Susan G. Merle
(Oregon State University / NOAA Vents Program)

Cover image created by Susan Merle and Sharon Walker

This report is for internal use only. None of the figures, text or tables can be used without permission of the principal investigator(s) of the data sets:

Bathymetry and backscatter data: Bob Embley (robert.w.embley@noaa.gov)
CTD chemistry data: John Lupton (john.e.lupton@noaa.gov)
Ed Baker (edward.baker@noaa.gov)
Joe Resing (joseph.resing@noaa.gov)
Marv Lilley (lilley@u.washington.edu)

Table of Contents

Figure Captions

Cover. CTD tow-yo fence diagram (2D) of tows 16 and 17 inserted into 3D object created by draping EM300 acoustic backscatter data over EM300 bathymetry. Darker backscatter shades represent higher reflectivity seafloor. Optical backscatter (shown here in dimensionless units of Nephelometric Turbidity Units above background, or DNTU) shows the distribution of particle plumes. West Mata depth ranges from 1185 m at the summit to ~2900 m at its western base. 30 m grid-cell size. 1.5 times vertical exaggeration. Dark blue areas are bathymetric data gaps or water column above the seafloor. *Cover image created by Susan Merle and Sharon Walker*.

Figure 1. R/V Thompson expedition TN227 area of operations. Major tectonic features are labeled. Inset shows the Lau basin, surrounding islands and the expedition area.

Figure 2. NE Lau CTD and EM300 mapping operations during the TN227 expedition. All vertical casts and tows are labeled. EM300 bathymetry collected during the cruise (bright colors) is overlaid on a combination grid of multiple lower-resolution bathymetry data sets and satellite altimetry data (muted shades).

Figure 3. Northeast Lau Spreading Center (NELSC) CTD vertical casts and tows. CTD data indicates this is a possible eruptive site. Maka and Tafu volcanic edifices are shown. CTD data are overlaid on EM300 bathymetry collected during the TN227 expedition. Bathymetry grid-cell size is 30 meters. 100 meter contour interval.

Figure 4. West Mata Volcano CTD vertical casts and tows. CTD data indicates this is a possible eruptive site. Those data are overlaid on EM300 bathymetry collected during the TN227 expedition. Bathymetry grid-cell size is 30 meters. 100 meter contour interval.

Figure 5. Bathymetry of the Northern Lau Basin region, with seafloor fabric shaded from the east and islands filled in black. Systematic survey data from the MMAJ9507 and MW9603 cruises define the central part of the basin south of 17°S. Tectonic features labeled by Fernando Martinez (UH). Map modified for this report from: Zellmer, K.E., B. Taylor, A three-plate kinematic model for Lau Basin opening, *Geochem. Geophys. Geosyst.*, 2, 2000GC000106, 2001.

Figure 6. EM300 bathymetry collected during the TN227 cruise (bright colors) is overlaid on a combination grid of multiple lower-resolution bathymetry data sets and satellite altimetry data (muted shades). 40 meter grid-cell size. 500 meter contours.

Figure 7. EM300 acoustic backscatter data collected during the TN227 cruise is outlined in yellow. Darker tones represent higher backscatter areas. 40 meter grid-cell size. Backscatter data is overlaid on a lower-resolution bathymetric hillshade file (light gray).

Figures 8, 9, 10, 14, 15, 16, 17. CTD tows mapped the distribution of hydrothermal plumes over multiple segments of the MTJ, NELSC, West Mata and Volcanoes "O" and "P". Optical backscatter (shown here in dimensionless units of Nephelometric Turbidity Units above background, or dNTU, for select CTD tows) shows the distribution of particle plumes. Anomalies of oxidation-reduction potential (ORP) indicate "younger" or "fresher" plume fluids, an indication of where the CTD tows passed closest to seafloor sources. The path of the CTD is shown by the black saw-tooth line; bottle trips are black diamonds labeled with Niskin bottle numbers.

Figure 11. Cross-sections of hydrothermal temperature anomaly (dT), light scattering (dNTU), and oxidation reduction potential (ORP, or "Eh") anomaly (dE/dt) along the track of CTD tow-yo T08C09, in the vicinity of the presumed eruption on the NELSC. dE/dt is the time derivative of the raw ORP value, which emphasizes hydrothermal anomalies (negative values indicate greater anomalies). In each panel the white sawtooth shows the CTD path. Contour intervals for each panel are noted in the lower right. The dT maximum at ~15.39°S presumably marks the eruption site. The offset of dNTU and dE/dt maxima from the dT maximum suggests that the discharge fluids were low in particles and reduced chemical species relative to shallower plumes.

Figure 12. Cross-sections of hydrothermal temperature anomaly (dT), light scattering (dNTU), and oxidation reduction potential anomaly (dE/dt) along the track of CTD tow-yo T08C010 in the vicinity of the presumed eruption on the NELSC, about 18 hrs after T08C09 (Figure 11). Note the absence of a strong dNTU signal over the eruption site.

Figure 13. Cross-sections of hydrothermal temperature anomaly (dT), light scattering (dNTU), and oxidation reduction potential anomaly (dE/dt) along the track of CTD tow-yo T08C018 in the vicinity of the presumed eruption on the NELSC, about 7 days after T08C09 (Figure 11). All anomalies have significantly decreased since T08C09

1.0 Northeast Lau R/V *Thompson* TN227 Expedition Summary

John Lupton, Chief Scientist

Details. Cruise dates Nov. 13-28, Apia to Apia, Western Samoa. 16 operational days at sea.

Overview. The main objective of the expedition was to search for hydrothermal activity in the NE Lau region by conducting water-column plume surveys. In addition to the water column work, we also conducted bathymetric mapping of the seafloor using the shipboard EM300 multibeam system, concentrating on areas where high resolution maps did not exist. The primary targets were the NE Lau Spreading Center (NELSC), the Mangatolo Triple Junction (MTJ), also called the Kings Triple Junction, and the large caldera named Volcano O (Figure 1).

Summary of field work. During the 16 days of the expedition, we completed 28 vertical hydrocasts and 19 tows and mapped ~8300 km^2 of seafloor with the shipboard multibeam system (Figure 2). During the tows the CTD/rosette package was winched up and down while the ship moved forward at about 1 knot, resulting in a saw-tooth survey pattern in the water column (see figures 8 - 17). We began our field work in the western part of our target area with surveys over the MTJ. After surveying all three arms of the triple junction with tows and casts, we moved eastward and began water-column surveys of the NELSC and two associated volcanic edifices named Maka and Tafu (Figure 3). Our initial survey of the NELSC found a complex suite of water-column plumes at several levels up to 700 m above the seafloor. Water samples from these plumes contained volcanic glass shards and extremely high hydrogen concentrations. Taken together, these findings point to a seafloor eruption occurring on the NELSC either during or shortly before our survey. At West Mata volcano about 70 km northeast of the NELSC, we also detected unusual plumes over the volcano summit highly enriched in suspended particles, helium, hydrogen, and CO_2 (Figure 4). The particles consisted mainly of sulfur and Fe-oxyhydroxides. Multibeam surveys conducted with the shipboard EM300 system showed extensive areas of high backscatter on the flanks of the volcano. The high backscatter and the plume characteristics point to ongoing and long-lived eruptive activity at West Mata. In addition to this possible eruptive activity on the NELSC and on West Mata, we also found several sites of hydrothermal activity in the region, including Volcano O, Maka, and West Mata and Volcano P (Figure 1).

Background and previous studies. The region combines arc, backarc, and a trench/backarc intersection all in one small area, which makes this a unique region that had never been explored in any detail for volcanic and hydrothermal activity. In addition, a very large oceanic plume of volcanic helium is present to the east of this region, suggesting that somewhere within the NE Lau Basin there exists a large and extensive volcanic source [*Lupton et al*., 2003]. Previous to the expedition, a considerable amount of data had been gathered in this region by piggybacking on other cruises. As shown in figure 5, the tectonics of this region are quite interesting. The Lau Basin hosts the back-arc spreading center of the Tonga-Kermadec subduction system. It has a fairly simple geometry south of latitude 19°S, but north of about 18°S the back-arc extension of the Central Lau Spreading Center (CLSC) splits into three different spreading zones: the Fonualei Rift and Spreading Center and Mangatolo Triple Junction (FRSC and MTJ), the Northwest Lau Spreading Center (NWLSC), and the Futuna Spreading Center (FSC). These extensional zones are truncated on the south by the Peggy Ridge (PR) and the Lau Extensional Transition Zone (LETZ), which make up an extensive transform (strike-slip) fault system. The highest spreading rate occurs in the northeastern part of this system, and our expedition (TN227) revealed that several active hydrothermal systems exist in this region (see field work above).

References:

Lupton, J.E., D.G. Pyle, W. J. Jenkins, R. Greene, and L. Evans, Evidence for an extensive hydrothermal plume in the Tonga-Fiji region of the south Pacific, *Geochem. Geophys. Geosyst., 5*, Q01003, doi:10.1029/2003GC000607, 2003.

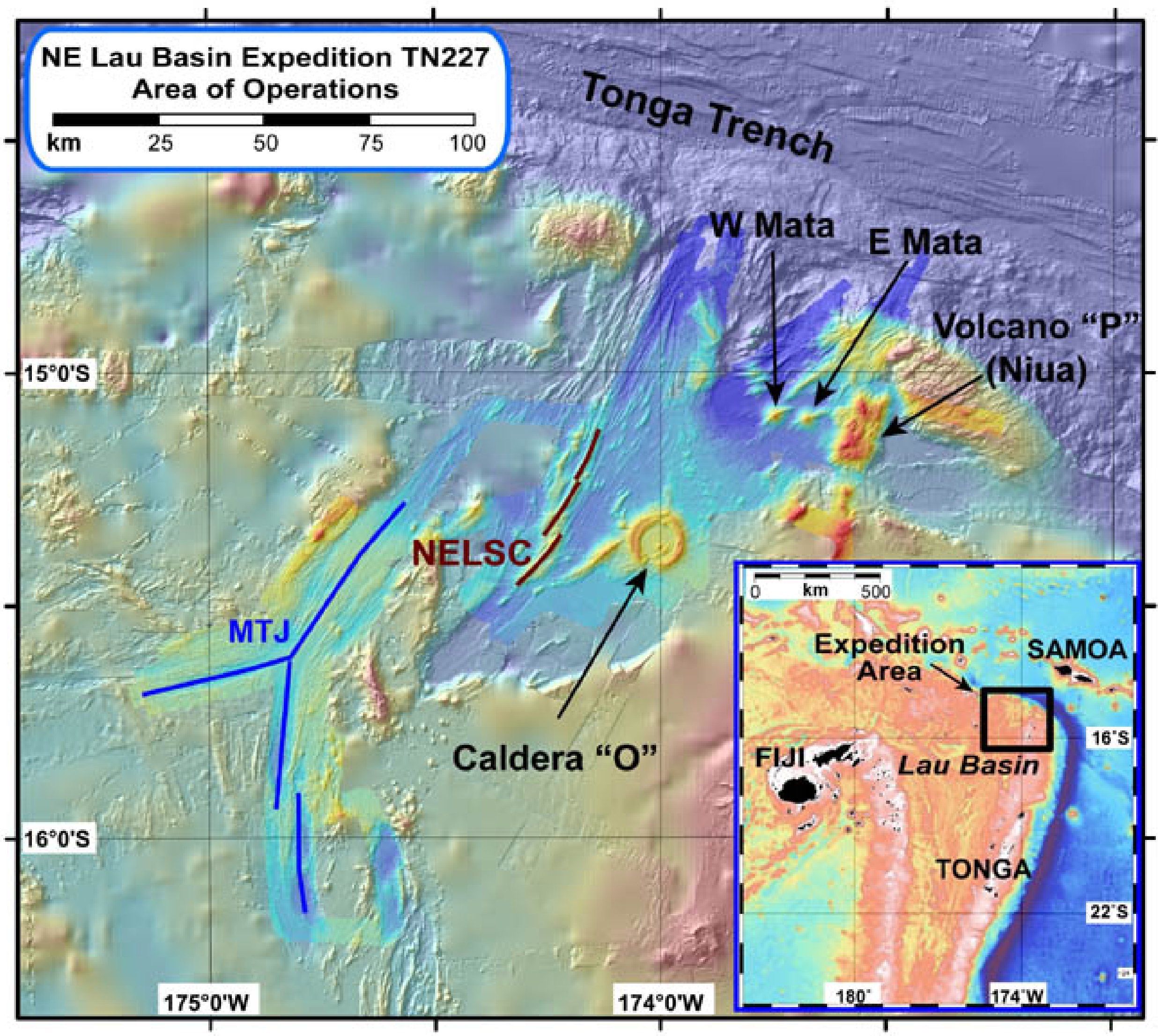
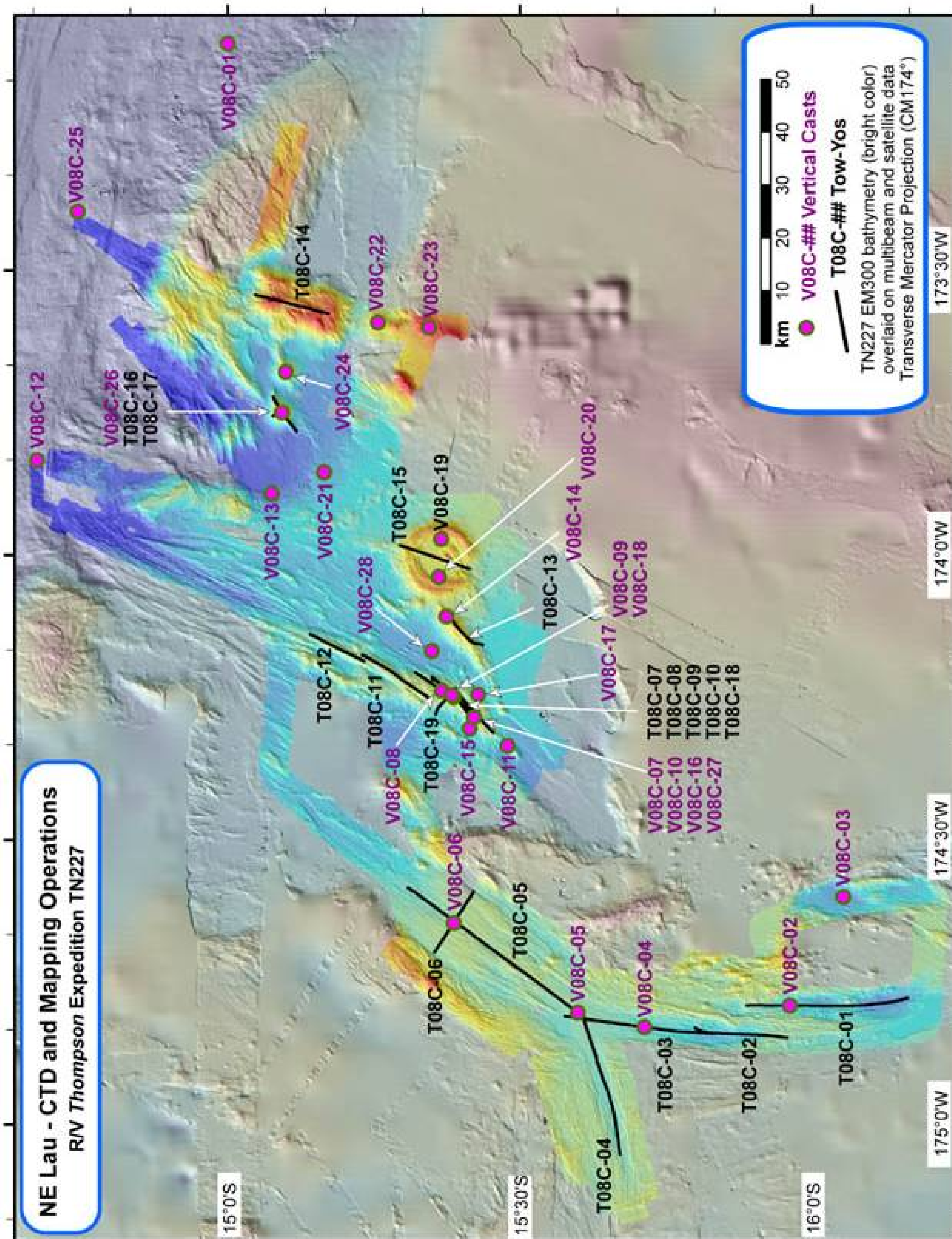
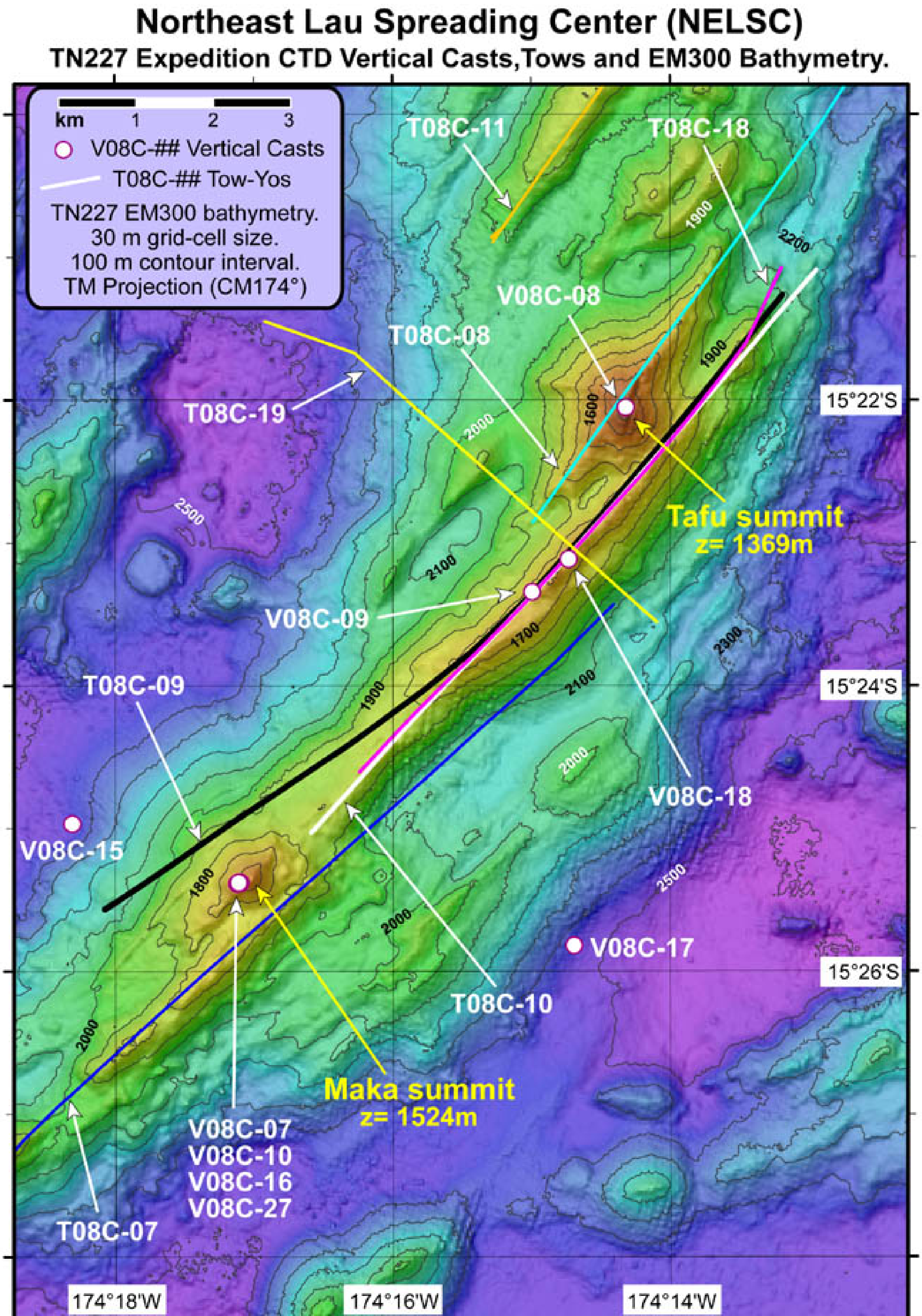


Figure 1



NE Lau - CTD and Mapping Operations
R/V *Thompson* Expedition TN227
km 0 10 20 30 40 50
V08C-## Vertical Casts
T08C-## Tow-Yos
TN227 EM300 bathymetry (bright color) overlaid on multibeam and satellite data Transverse Mercator Projection (CM174°)
15°0'S
15°30'S
16°0'S
175°0'W
174°30'W
174°0'W
173°30'W
V08C-01
V08C-02
V08C-03
V08C-04
V08C-05
V08C-06
V08C-08
V08C-11
V08C-12
V08C-13
V08C-14
V08C-15
V08C-17
V08C-19
V08C-20
V08C-21
V08C-22
V08C-23
V08C-24
V08C-25
V08C-26
V08C-28
V08C-07 V08C-10 V08C-16 V08C-27
V08C-09 V08C-18
T08C-01
T08C-02
T08C-03
T08C-04
T08C-05
T08C-06
T08C-11
T08C-12
T08C-13
T08C-14
T08C-15
T08C-16
T08C-17
T08C-19
T08C-07 T08C-08 T08C-09 T08C-10 T08C-18

Figure 2



Northeast Lau Spreading Center (NELSC)
TN227 Expedition CTD Vertical Casts, Tows and EM300 Bathymetry.
km 1 2 3
V08C-## Vertical Casts
T08C-## Tow-Yos
TN227 EM300 bathymetry.
30 m grid-cell size.
100 m contour interval.
TM Projection (CM174°)
T08C-11
T08C-18
T08C-08
V08C-08
T08C-19
Tafu summit
z= 1369m
V08C-09
T08C-09
V08C-18
V08C-15
T08C-10
V08C-17
Maka summit
z= 1524m
V08C-07
V08C-10
V08C-16
V08C-27
T08C-07
15°22'S
15°24'S
15°26'S
174°18'W
174°16'W
174°14'W

Figure 3

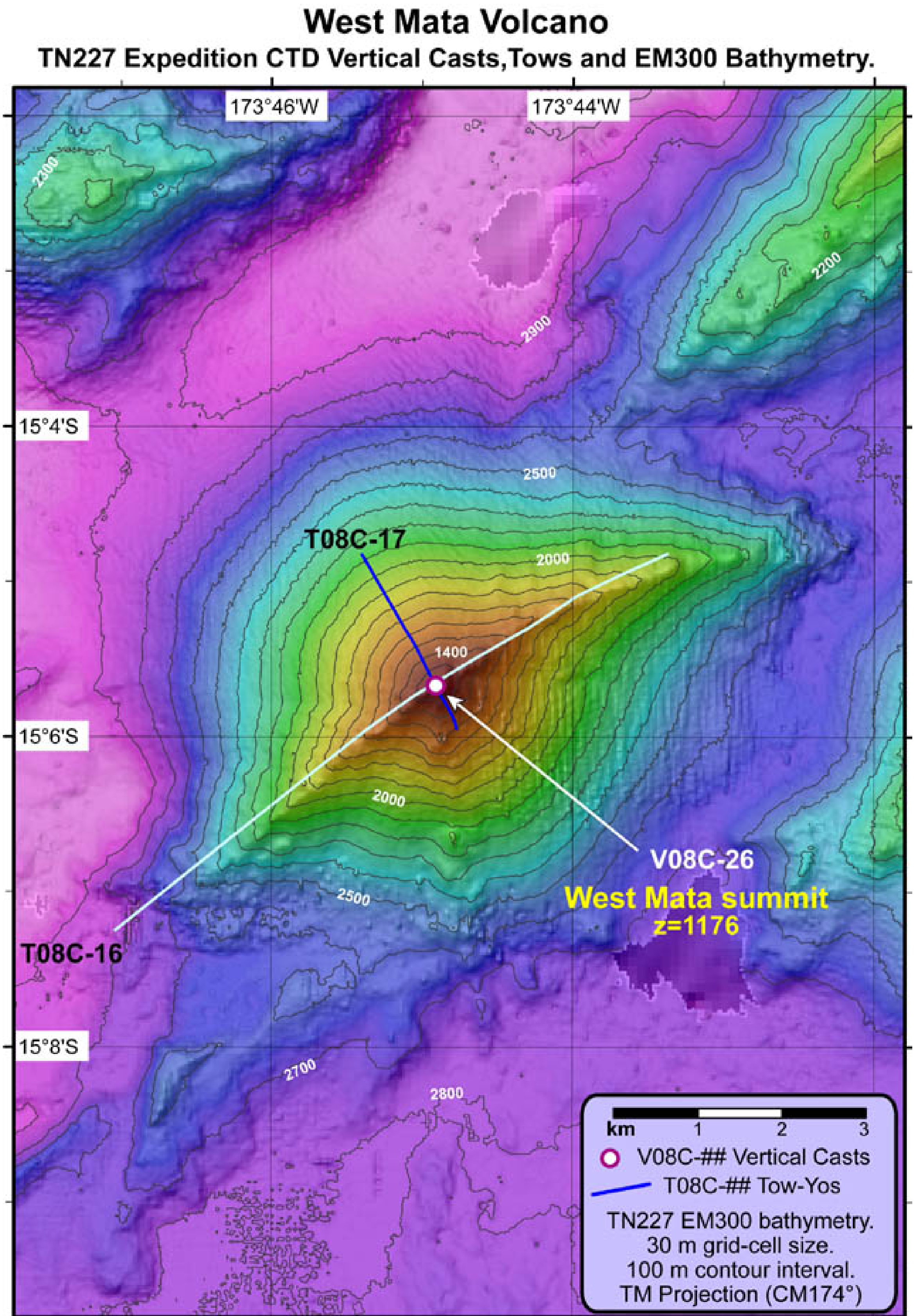

West Mata Volcano
TN227 Expedition CTD Vertical Casts,Tows and EM300 Bathymetry.
173°46'W
173°44'W
15°4'S
15°6'S
15°8'S
2300
2200
2900
2500
2000
1400
2700
2800
T08C-17
T08C-16
V08C-26
West Mata summit
z=1176
km
1
2
3
V08C-## Vertical Casts
T08C-## Tow-Yos
TN227 EM300 bathymetry.
30 m grid-cell size.
100 m contour interval.
TM Projection (CM174°)

Figure 4

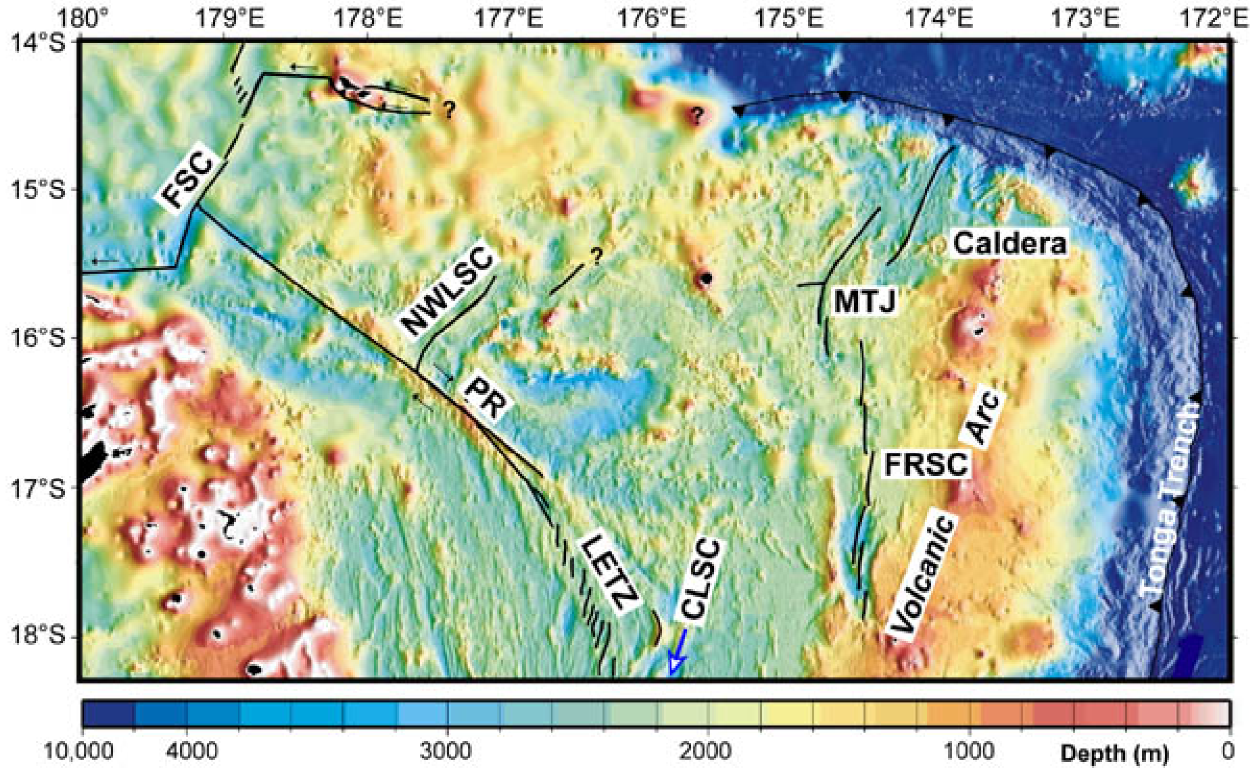


Figure 5

Bathymetry of the Northern Lau Basin region, with seafloor fabric shaded from the east and islands filled in black. Systematic survey data from the MMAJ9507 and MW9603 cruises define the central part of the basin south of 17°S. Tectonic features labelled by Fernando Martinez (UH). Map modified for this report from: Zellmer, K.E., B. Taylor, A three-plate kinematic model for Lau Basin opening, Geochem. Geophys. Geosyst., 2, 2000GC000106, 2001.

2.0 NE Lau TN227 Scientific Party and Affiliations

Chief Scientist: John.E. Lupton (john.e.lupton@noaa.gov)
NOAA Pacific Marine Environmental Laboratory, Newport OR

Name	Affiliation	Interest, Task on cruise
Lupton, John	NOAA/PMEL	Chief Sci., CTD ops, dissolved gases
Baker, Edward	NOAA/PMEL	CTD ops, physical oceanography
Embley, Robert	NOAA/PMEL	Volcanology, marine geology
Resing, Joe	JISAO/UW/PMEL	CTD ops, plume chemistry
Lilley, Marv	U of W	Dissolved gases
Merle, Susan	CIMRS/OSU/PMEL	Mapping, data management
Walker, Sharon	NOAA/PMEL	CTD ops, plume mapping
Greene, Ronald	CIMRS/OSU/PMEL	CTD ops, helium isotopes
Hemery, Gwen	GNS New Zealand	CTD ops
Dyriw, Nick	ANU, Australia	CTD ops, Graduate student
Upchurch, Lucia	U Texas at Austin	CTD ops, plume chemistry
Baumberger, Tamara	ETH Zurich	Dissolved gases, Graduate student
Crowhurst, Peter	Nautilus Minerals	Observer, geologist
Puzic, Jelena	Tech Cominco	Observer, geologist

3.0 TN227 Cruise Operations Log

Northeast Lau R/V *Thompson* TN227 - Nov. 13-28, Apia to Apia, Western Samoa

Date (Local)	Time (Local)	Date (UTC)	Time (UTC)	Event	Latitude	Longitude
GMT is 11 hours ahead of local Samoan time						
Vertical Casts highlighted in yellow					Tows highlighted in green	
13-Nov	0900	13-Nov	2000	Depart Apia harbor, Western Samoa.	-13.833333	-171.833333
13-Nov	1500	14-Nov	0200	CTD dunk test at deep station in the Tonga-Tofua trench. Check out the CTD package. Test successful		
13-Nov	2000	14-Nov	0655	V08C-01 start. Trench area. repeat of V04A-04 - helium cast	-14.999658	-173.100483
13-Nov	2300	14-Nov	1000	V08C-01 end.		
13-Nov	2305	14-Nov	1005	Proceeding to survey point A.		
13-Nov	2315	14-Nov	1015	Launched XBT (sound velocity profile) for EM300 data.		
13-Nov	2330	14-Nov	1030	Start EM300 survey. Will survey all the way to MTJ. Logging EM300 and 3.5 kHz subbottom data. Water deep here (~5000 m) so EM300 data not very good		
14-Nov	0030	14-Nov	1125	At survey point A. Turning to new course (282°). Z=1600m Data looking good.		
14-Nov	1610	15-Nov	0310	End of EM300 and 3.5 kHz surveys. Stop logging.		
14-Nov	1700	15-Nov	0400	T08C-01(start). Southernmost segment of MTJSC.	-16.162150	-174.783283
15-Nov	0640	15-Nov	1735	T08C-01(end)	-15.885633	-174.795633
15-Nov	0715	15-Nov	1815	Start EM300 and 3.5 kHz surveys (line 19). Z=2330 m.		
15-Nov	0935	15-Nov	2035	Stop logging EM300 and 3.5 kHz.		
15-Nov	0945	15-Nov	2052	V08C-02 start. Sample plume seen during T08C-01.	-15.963000	-174.795833
15-Nov	1145	15-Nov	2245	V08C-02 end.		
15-Nov	1153	15-Nov	2253	Start EM300 logging (line 24)		
15-Nov	1245	15-Nov	2345	Start 3.5 kHz logging.		
15-Nov	1355	16-Nov	0055	Stop logging EM300 and 3.5 kHz.		
15-Nov	1405	16-Nov	0108	V08C-03 start. N end of Fonualei Rift.	-16.055667	-174.604000
15-Nov	1605	16-Nov	0305	V08C-03 end.		
15-Nov	1610	16-Nov	0310	Start EM300 logging (line 27)		
15-Nov	1645	16-Nov	0345	Start 3.5 kHz logging.		
15-Nov	2015	16-Nov	0715	Stop logging EM300 and 3.5 kHz.		

Date (Local)	Time (Local)	Date (UTC)	Time (UTC)	Event	Latitude	Longitude
15-Nov	2025	16-Nov	0725	T08C-02 start. Northern segment of southern MTJSC - part 1 - S->N tow ended due to weather	-15.956405	-174.852063
16-Nov	0610	16-Nov	1640	T08C-02 end.	-15.795100	-174.832783
16-Nov	0625	16-Nov	1725	Start EM300 logging. On transit to next tow.		
16-Nov	0735	16-Nov	1835	Stop logging EM300.		
16-Nov	0750	16-Nov	1850	T08C-03 start. Northern segment of southern MTJSC - part 2 - changed course to tow N->S	-15.577450	-174.813767
16-Nov	1910	17-Nov	0610	T08C-03 end.	-15.838268	-174.845845
16-Nov	1940	17-Nov	0640	Start EM300 logging (line 34).		
16-Nov	2000	17-Nov	0700	Change XBT to T5_00002.EDT.asvp.		
16-Nov	2226	17-Nov	0926	Stop logging EM300.		
16-Nov	2250	17-Nov	0950	V08C-04 start. Area of slight plume seen during T08C-03	-15.713567	-174.833510
17-Nov	0045	17-Nov	1145	V08C-04 end.		
17-Nov	0050	17-Nov	1150	Start EM300 logging (line 40). Survey western arm of triple junction (MTJSC). 3.5 kHz on also.		
17-Nov	0137	17-Nov	1237	EM300 line 41. Real start of survey. Line 40 was over previous data.		
17-Nov	0535	17-Nov	1635	Stop logging EM300 and 3.5 kHz.		
17-Nov	0610	17-Nov	1710	T08C-04 start. Western arm of MTJSC	-15.609450	-174.818883
17-Nov	1750	18-Nov	0450	T08C-04 end.	-15.670225	-175.058152
17-Nov	1755	18-Nov	0455	Start EM300 logging (line 49). No 3.5 kHz during lines 49 and 50 to check if it is causing EM300 data spikes and dropouts. Conclusion was that the 3.5 kHz subbottom is interfering with the EM300 bathymetry data.		
17-Nov	2055	18-Nov	0755	Stop logging EM300.		
17-Nov	2100	18-Nov	0800	V08C-05 start. Over known sulfide mound on MTJSC. Just north of the triple junction.	-15.599693	-174.807050
17-Nov	2243	18-Nov	0943	V08C-05 end.		
17-Nov	2358	18-Nov	1058	T08C-05 start. N arm (limb) of MTJSC	-15.611387	-174.816870
18-Nov	1656	19-Nov	0356	T08C-05 end.	-15.309192	-174.586023
18-Nov	1710	19-Nov	0410	Start EM300 logging (line 51).		
18-Nov	2125	19-Nov	0825	Stop EM300 logging.		
18-Nov	2157	19-Nov	0857	T08C-06 start. Across-axis tow at anomaly seen during T08C-05 - N.MTJSC	-15.355230	-174.699673

Date (Local)	Time (Local)	Date (UTC)	Time (UTC)	Event	Latitude	Longitude
19-Nov	0602	19-Nov	1702	T08C-06 end.	-15.422358	-174.593125
19-Nov	0615	19-Nov	1715	Start EM300 logging.		
19-Nov	0639	19-Nov	1739	Start 3.5 kHz logging.		
19-Nov	0643	19-Nov	1743	Stop 3.5 kHz logging. (noise issues?)		
19-Nov	0834	19-Nov	1934	Stop EM300 logging.		
19-Nov	0840	19-Nov	1944	V08C-06 start. MTJ - additional profile.	-15.387683	-174.648200
19-Nov	1012	19-Nov	2112	V08C-06 end.		
19-Nov	1033	19-Nov	2133	Start EM300 logging. Line from MTJ to NELSC.		
19-Nov	1104	19-Nov	2204	Start 3.5 kHz logging.		
19-Nov	1308	20-Nov	0008	Begin EM300 survey over NELSC (first pass of 3 during cruise). Lines 67 and 68.		
19-Nov	1314	20-Nov	0014	Stop 3.5 kHz logging to reduce noise seen in EM300 data.		
19-Nov	1430	20-Nov	0130	Stop EM300 logging at south end of NELSC.		
19-Nov	1457	20-Nov	0157	T08C-07 start. Southernmost end of NELSC. Marv Lilley found large hydrogen anomaly on this tow (in area of "eruption").	-15.455433	-174.312983
19-Nov	2022	20-Nov	0722	T08C-07end.	-15.390280	-174.239850
19-Nov	2040	20-Nov	0740	Start EM300 logging. Line 69.		
19-Nov	2308	20-Nov	1008	Stop EM300 logging.		
19-Nov	2328	20-Nov	1028	V08C-07 start. Maka site (southern high on southern segment of NELSC)	-15.423050	-174.285033
20-Nov	0112	20-Nov	1212	V08C-07 end.		
20-Nov	0142	20-Nov	1242	Start EM300 logging. Line 72.		
20-Nov	0148	20-Nov	1248	Start 3.5 kHz logging. Want to see if it is actually interfering with the EM300 data. See data spikes almost immediately.		
20-Nov	0151	20-Nov	1251	Stop 3.5 kHz logging.		
20-Nov	0200	20-Nov	1300	Start 3.5 kHz logging again. Immediately see EM300 data drop outs.		
20-Nov	0207	20-Nov	1307	Stop 3.5 kHz logging for good. It IS interfering with the bathymetry data. No more 3.5 kHz data this cruise.		
20-Nov	0310	20-Nov	1410	Lost GPS from 1410 - 1412.		
20-Nov	0345	20-Nov	1445	Stop EM300 logging.		

Date (Local)	Time (Local)	Date (UTC)	Time (UTC)	Event	Latitude	Longitude
20-Nov	0501	20-Nov	1601	V08C-08 start. Over summit of "Tafu - place of fire" (high at northern end of NELSC)	-15.367633	-174.238600
20-Nov	0643	20-Nov	1743	V08C-08 end.		
20-Nov	0723	20-Nov	1823	T08C-08 start. Tow over Tafu (northern high on NELSC).	-15.380912	-174.249778
20-Nov	1111	20-Nov	2211	T08C-08 end.	-15.323267	-174.207900
20-Nov	1129	20-Nov	2229	Start EM300 logging. To the east of the neovolcanic ridge.		
20-Nov	1352	21-Nov	0052	Stop EM300 logging.		
20-Nov	1409	21-Nov	0109	T08C-09 start. Tow from west of Maka (southern high on NELSC) and tow over ridge to east of Tafu.	-15.425967	-174.300983
20-Nov	1947	21-Nov	0647	T08C-09 end.	-15.354260	-174.219663
20-Nov	1950	21-Nov	0650	Start EM300 logging. Survey between NELSC and the caldera.		
20-Nov	2205	21-Nov	0905	Stop EM300 logging.		
20-Nov	2313	21-Nov	1013	V089C-09 start. At location of buoyant plume sampled during T08C-09	-15.389172	-174.249873
21-Nov	0119	21-Nov	1219	V089C-09 end.		
21-Nov	0158	21-Nov	1258	Start EM300 logging. Line 82		
21-Nov	0301	21-Nov	1401	Stop EM300 logging.		
21-Nov	0325	21-Nov	1425	V08C-10 start. Maka site (southern high on NELSC)	-15.423000	-174.285000
21-Nov	0455	21-Nov	1555	V08C-10 end.		
				Problem with CTD wire termination. Had to be re-terminated.		
21-Nov	0902	21-Nov	2002	T08C-10 start. Neovolcanic ridge between Maka and Tafu (eastern side).	-15.417165	-174.276488
21-Nov	1347	22-Nov	0047	T08C-10 end.	-15.351517	-174.215717
21-Nov	1357	22-Nov	0057	Start EM300 logging. Survey from end of last tow (T08C-10) till start of next cast (V08C-11).		
21-Nov	1557	22-Nov	0255	Stop EM300 logging.		
21-Nov	1613	22-Nov	0313	V08C-11 start. Southern end of NELSC (S of Maka)	-15.481270	-174.335910
21-Nov	1807	22-Nov	0507	V08C-11 end.		
21-Nov	1833	22-Nov	0533	Start EM300 logging. Line 88. This line is a re-survey over NELSC eruptive site. 10 kts.		
21-Nov	1929	22-Nov	0629	Finished re-survey. Changed survey line to 89. Increase speed to 11 kts.		

Date (Local)	Time (Local)	Date (UTC)	Time (UTC)	Event	Latitude	Longitude
21-Nov	2229	22-Nov	0913	Stop EM300 logging.		
21-Nov	2251	22-Nov	0951	T08C-11 start. Central segment of NELSC. To the northwest of previous NELSC tows.	-15.347713	-174.254767
22-Nov	0602	22-Nov	1702	T08C-11end.	-15.232493	-174.177257
22-Nov	0626	22-Nov	1726	Start EM300 logging. Line 94.		
22-Nov	0802	22-Nov	1902	Stop EM300 logging.		
22-Nov	0842	22-Nov	1942	T08C-12 start. Northernmost segment (#2) of NELSC (northwest of previous casts).	-15.235717	-174.187867
22-Nov	1359	23-Nov	0059	T08C-12 end.	-15.144017	-174.140950
22-Nov	1425	23-Nov	0125	EM300 start logging. Line 96. Survey of northern NELSC segments to northern trench.		
22-Nov	1736	23-Nov	0436	EM300 stop logging.		
22-Nov	1744	23-Nov	0444	V08C-12 start. Deep station north of NELSC - in trench	-14.675103	-173.833255
22-Nov	2047	23-Nov	0747	V08C-12 end.		
22-Nov	2100	23-Nov	0800	XBT. New SVP T5_00004.EDF.asvp		
22-Nov	2106	23-Nov	0806	Start EM300 logging. Line 100.		
23-Nov	0023	23-Nov	1123	Stop EM300 logging.		
23-Nov	0033	23-Nov	1133	V08C-13 start. Repeat of V04A-05 in area between caldera and NELSC. (Actual location - north of the caldera and west of W Mata.)	-15.077333	-173.891333
23-Nov	0246	23-Nov	1346	V08C-13 end.		
23-Nov	0256	23-Nov	1356	EM300 start logging.		
23-Nov	0623	23-Nov	1723	EM300 stop logging.		
23-Nov	0647	23-Nov	1747	T08C-13 start. Along ridge between NELSC and caldera (ended tow when ship was blown off course)	-15.438667	-174.158833
23-Nov	1132	23-Nov	2232	T08C-13 end.	-15.385867	-174.110567
23-Nov	1211	23-Nov	2311	V08C-14 start. Vertical cast to finish T08C-13	-15.376333	-174.107333
23-Nov	1308	24-Nov	0008	V08C-14 end.		
23-Nov	1314	24-Nov	0014	EM300 start logging. Line 112. Fill in gap between volcano "O" and SW/NE ridge to west of it.		
23-Nov	1333	24-Nov	0033	EM300 stop logging.		
23-Nov	1507	24-Nov	0207	V08C-15 start. Basin west of Maka.	-15.416167	-174.305167
23-Nov	1658	24-Nov	0358	V08C-15 end.		

Date (Local)	Time (Local)	Date (UTC)	Time (UTC)	Event	Latitude	Longitude
23-Nov	1703	24-Nov	0403	EM300 start logging. Line 113. Second pass over eruptive ridge on NELSC. Different SVP than previous survey.		
23-Nov	1821	24-Nov	0521	EM300 stop logging over Tafu.		
23-Nov	1909	24-Nov	0609	V08C-16 start. Over Maka site (NELSC).	-15.423112	-174.285372
23-Nov	1956	24-Nov	0656	V08C-16 end.		
23-Nov	2147	24-Nov	0847	V08C-17 start. Basin east of Maka.	-15.385300	-174.245500
23-Nov	2346	24-Nov	1046	V08C-17 end.		
24-Nov	0051	24-Nov	1151	V08C-18 start. On NELSC ridge - at eruptive site (based on bathy differences and temp anomalies)		
24-Nov	0214	24-Nov	1314	V08C-18 end.		
24-Nov	0316	24-Nov	1416	EM300 start logging. Line 114. On the way to Volcano "O".		
24-Nov	0526	24-Nov	1626	EM300 stop logging.		
24-Nov	0542	24-Nov	1642	V08C-19 start. East side of caldera "O"	-15.367000	-173.971667
24-Nov	0701	24-Nov	1801	V08C-19 end.		
24-Nov	0719	24-Nov	1819	EM300 start logging. Line 117. Southeast part of caldera.		
24-Nov	0851	24-Nov	1951	EM300 stop logging.		
24-Nov	0859	24-Nov	1959	V08C-20 start. West side of caldera "O"	-15.363500	-174.038667
24-Nov	1019	24-Nov	2119	V08C-20 end.		
24-Nov	1033	24-Nov	2133	EM300 start logging. Line 119. Within caldera and enroute to northern basin.		
24-Nov	1200	24-Nov	2300	EM300 stop logging.		
24-Nov	1224	24-Nov	2324	V08C-21 start. South end of northern basin.	-15.166667	-173.854000
24-Nov	1414	25-Nov	0114	V08C-21 end.		
24-Nov	1432	25-Nov	0132	EM300 start logging. Line 121. The Matas ("eye" in Tongan). Small volcanoes west of Volcano P (also called Niua - "coconut" in Tongan).		
24-Nov	1634	25-Nov	0334	EM300 stop logging.		
24-Nov	1654	25-Nov	0354	T08C-14 start. Volcano P.	-15.174200	-173.577107
24-Nov	2353	25-Nov	1053	T08C-14 end.	-15.049950	-173.544113
25-Nov	0001	25-Nov	1101	EM300 start logging. Line 125. From volcano P to the south.		
25-Nov	0207	25-Nov	1307	EM300 stop logging.		

Date (Local)	Time (Local)	Date (UTC)	Time (UTC)	Event	Latitude	Longitude
25-Nov	0319	25-Nov	1419	V08C-22 start. Volcano (?) directly south of "P".	-15.259037	-173.589475
25-Nov	0406	25-Nov	1506	V08C-22 end.		
25-Nov	0423	25-Nov	1523	EM300 start logging. Line 129. Heading south to next feature.		
25-Nov	0534	25-Nov	1634	EM300 stop logging.		
25-Nov	0551	25-Nov	1651	V08C-23 start. Second volcano (?) south of "P"	-15.345833	-173.598833
25-Nov	0625	25-Nov	1725	V08C-23 end.		
25-Nov	0638	25-Nov	1738	EM300 start logging. Line 131. Heading west toward East Mata.		
25-Nov	0825	25-Nov	1925	EM300 stop logging.		
25-Nov	0838	25-Nov	1938	V08C-24 start. Volcano west of "P" - "Mata-East". Huge Eh anomaly at summit.	-15.100833	-173.677500
25-Nov	0944	25-Nov	2044	V08C-24 end.		
25-Nov	0954	25-Nov	2054	EM300 start logging. Line 133. East Mata to Lupton trench station.		
25-Nov	1220	25-Nov	2320	Depth over 4000 meters. Barely tracking bottom with EM300.		
25-Nov	1233	25-Nov	2333	EM300 stop logging. Depth is ~5750m.		
25-Nov	1242	25-Nov	2342	V08C-25 start. Cast in trench (for helium).	-14.744000	-173.396000
25-Nov	1504	26-Nov	0204	V08C-25 end. Time column is messed up in this CTD file.		
25-Nov	1531	26-Nov	0231	EM300 start logging. Line 136. Trench site to West Mata.		
25-Nov	1758	26-Nov	0458	EM300 stop logging.		
25-Nov	1806	26-Nov	0506	V08C-26 start. At West Mata volcano. Highest H2 ever recorded in a plume (Marv Lilley).	-15.094547	-173.748480
25-Nov	1916	26-Nov	0616	V08C-26 end.		
25-Nov	1933	26-Nov	0633	EM300 start logging. Line 140 (don't use line 139). West Mata to the northwest and then back to Volcano "O".		
25-Nov	2332	26-Nov	1032	EM300 stop logging.		
26-Nov	0013	26-Nov	1113	T08C-15 start. South to north across the caldera "O".	-15.416083	-174.026095
26-Nov	0536	26-Nov	1636	T08C-15 end.	-15.279234	-173.977799
26-Nov	0553	26-Nov	1653	EM300 start logging. Line 146? Caldera "O" to West Mata.		
26-Nov	0748	26-Nov	1848	EM300 stop logging.		

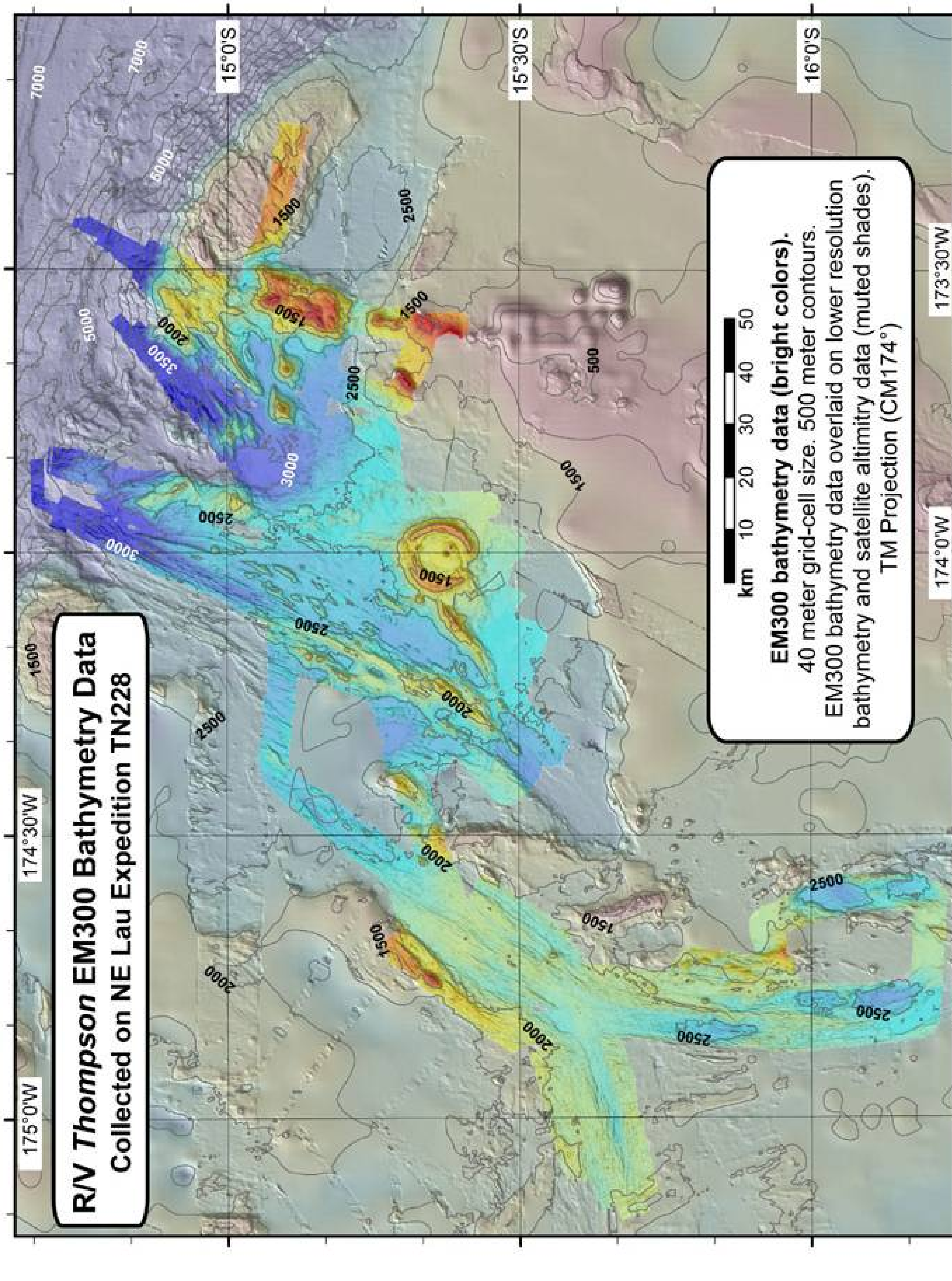
Date (Local)	Time (Local)	Date (UTC)	Time (UTC)	Event	Latitude	Longitude
26-Nov	0759	26-Nov	1859	T08C-16 start. Tow along spine of West Mata (W->E)	-15.120833	-173.784000
26-Nov	1202	26-Nov	2302	T08C-16 end.	-15.080333	-173.722833
26-Nov	1420	27-Nov	0120	EM300 start logging. Line 149. Enroute back to NELSC eruption site.		
26-Nov	2024	27-Nov	0724	EM300 stop logging.		
26-Nov	2039	27-Nov	0739	T08C-18 start. Tow near-bottom tow along ridge at eruption site N of Maka (S of Tafu)	-15.410160	-174.270705
27-Nov	0202	27-Nov	1302	T08C-18 end.	-15.351215	-174.219918
27-Nov	0315	27-Nov	1415	T08C-19 start. Across-axis tow at eruption site N of Maka S of Tafu.	-15.392613	-174.234920
27-Nov	0711	27-Nov	1811	T08C-19 end.	-15.357500	-174.282000
27-Nov	0822	27-Nov	1922	V08C-27 start. At Maka - Southern NELSC.	-15.423000	-174.285167
27-Nov	1013	27-Nov	2113	V08C-27 end.		
27-Nov	1130	27-Nov	2230	V08C-28 start. Eastern basin (E of NELSC).	-15.351500	-174.169000
27-Nov	1406	28-Nov	0106	V08C-28 end.		
27-Nov	1424	28-Nov	0124	EM300 start logging. Line 156. Last survey - on transit back to Samoa. Survey north to fill gaps and survey rift zone near trench.		
27-Nov	2206	28-Nov	0906	EM300 stop logging. Depth is 4735 at end of survey. Switched to extra deep mode - very narrow swath.		
28-Nov	0900	28-Nov	2000	Arrive at Apia harbor. End of Cruise.	-13.833333	-171.833333

4.0 R/V Thompson TN227 EM300 Bathymetric Surveys

Susan Merle and Bob Embley

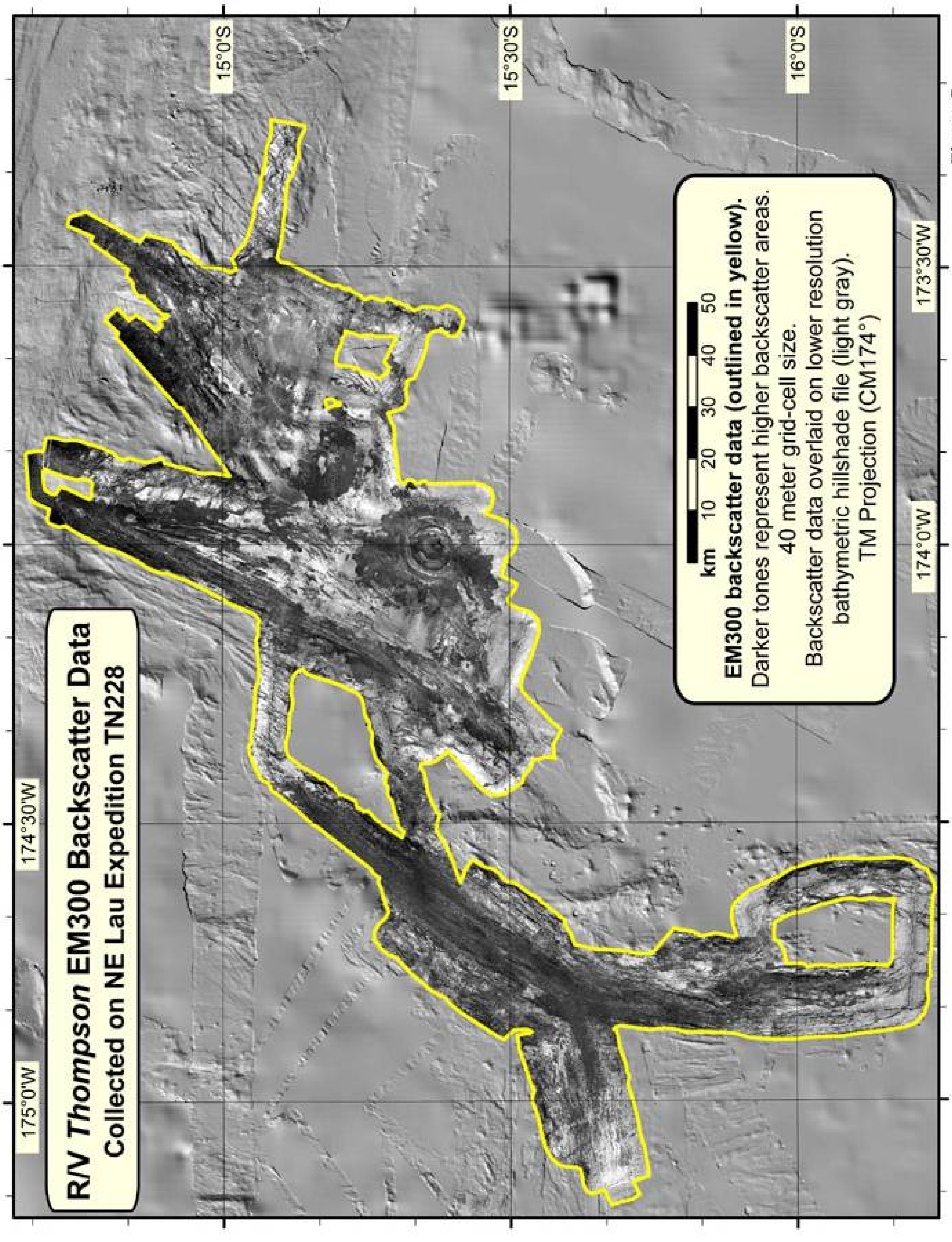
The R.V *Thompson's* hull-mounted EM300 (30 kilohertz frequency) multibeam system can acquire up to 135 beams per ping with a maximum 150° swath when the angles are set at 75° per side. During the expedition the angles were generally set at 65° to cut down on bad data at the swath edge and compensate for weather etc. Survey speeds were 10 to 11 knots.

The surveys concentrated on areas where high resolution maps did not exist. Most mapping was performed in the break between CTD casts and tows and during transits from one area to another. The main areas of operation during the cruise were mapped including the MTJ, NELSC, the Mata volcanoes, and volcanoes O and P. Over 8300 km^2 of seafloor were mapped. EM300 bathymetric and acoustic backscatter data grids have been created at 25 meter resolution for the entire area.



R/V *Thompson* EM300 Bathymetry Data
Collected on NE Lau Expedition TN228
EM300 bathymetry data (bright colors).
40 meter grid-cell size. 500 meter contours.
EM300 bathymetry data overlaid on lower resolution bathymetry and satellite altimitry data (muted shades).
TM Projection (CM174°)
km 10 20 30 40 50
175°0'W
174°30'W
174°0'W
173°30'W
15°0'S
15°30'S
16°0'S

Figure 6



R/V *Thompson* EM300 Backscatter Data
Collected on NE Lau Expedition TN228
175°0'W
174°30'W
174°0'W
173°30'W
15°0'S
15°30'S
16°0'S
km 0 10 20 30 40 50
EM300 backscatter data (outlined in yellow).
Darker tones represent higher backscatter areas.
40 meter grid-cell size.
Backscatter data overlaid on lower resolution
bathymetric hillshade file (light gray).
TM Projection (CM174°)

Figure 7

5.0 CTD Shipboard Program

Ed Baker

The primary objective of the shipboard water column sampling program was to search for hydrothermal discharge in the vicinity of the Mangatolou Triple Junction, along the Northeastern Lau Spreading Center, and at several discrete volcanoes associated with the nearby Tafua volcanic arc. These features are all part of the northern Lau Basin, where the proximity of spreading centers and a volcanic arc suggests that magma sources to power hydrothermal venting would be abundant. Exploration for hydrothermal sources was done by sampling the water column for hydrographic and chemical traces of vent discharge. The instrument used to collect the water-column data was the Vents SeaBird 911plus CTDO (conductivity-depth (pressure)-temperature-optical) profiling system. Sampling bottles were closed on command from the ship, usually when a scientist monitoring the sensors saw strong evidence of a plume. The CTDO carried sensors that measured light backscattering and oxidation-reduction potential (PI: E. Baker), which are highly sensitive to hydrothermal precipitates and reduced chemical species, respectively.

Once the CTDO was recovered, seawater was sampled for analyses of pH (PI: J. Resing), helium isotopes (PI: J. Lupton), H_2, (PI: M. Lilley) CH_4 (PI: M. Lilley), CO_2 (PI: J. Resing), dissolved and particulate metals (PI: J. Resing), microscopic analysis (PI: J. Resing), and microbiology (PI: TBD). Over 3200 individual samples for various analyses were collected. These samples came from 19 CTDO tows and 28 casts.

Only slight evidence of hydrothermal activity was found in the Mangatolou Triple Junction area. Along the NELSC vigorous venting was located at the summit of Maka volcano, which sits astride the ridge. Strong evidence of an ongoing eruption near 15.39°S on the ridge was also inferred from high-rising plumes (~1000 m), high H_2 concentrations, and abundant glass shards in the plumes. The eruptive activity had ceased by the end of the cruise. Several of the discrete volcanoes were also active, especially West Mata. The plume over the summit of West Mata was ~175 m thick, with extremely high concentrations of various chemical species indicative of erupting magma (e.g., H_2).

Sample type	***Abbreviation***	***# of samples***	***Responsible PI***
Helium isotope analysis	*3He*	*705*	*John Lupton, NOAA PMEL, Newport OR*
Methane and hydrogen	*CH4, H2*	*710*	*Marv Lilley, UW, Seattle WA*
pH (acidity)	*pH*	*740*	*Joseph Resing, NOAA PMEL Seattle WA / UW*
Total carbon dioxide	TCO_2	*152*	*Joseph Resing*
Total dissolvable trace metals	*TDMe*	*573*	*Joseph Resing*
Dissolved trace metals	*DMe*	*164*	*Joseph Resing*
Particulate bulk chemistry	*XRF*	*166*	*Joseph Resing*
Particle morpholy and type	*SEM*	*45*	*Joseph Resing*
Microbiology (frozen)	*Micro*	*8*	*TBD*

5.1 CTD Cast Table

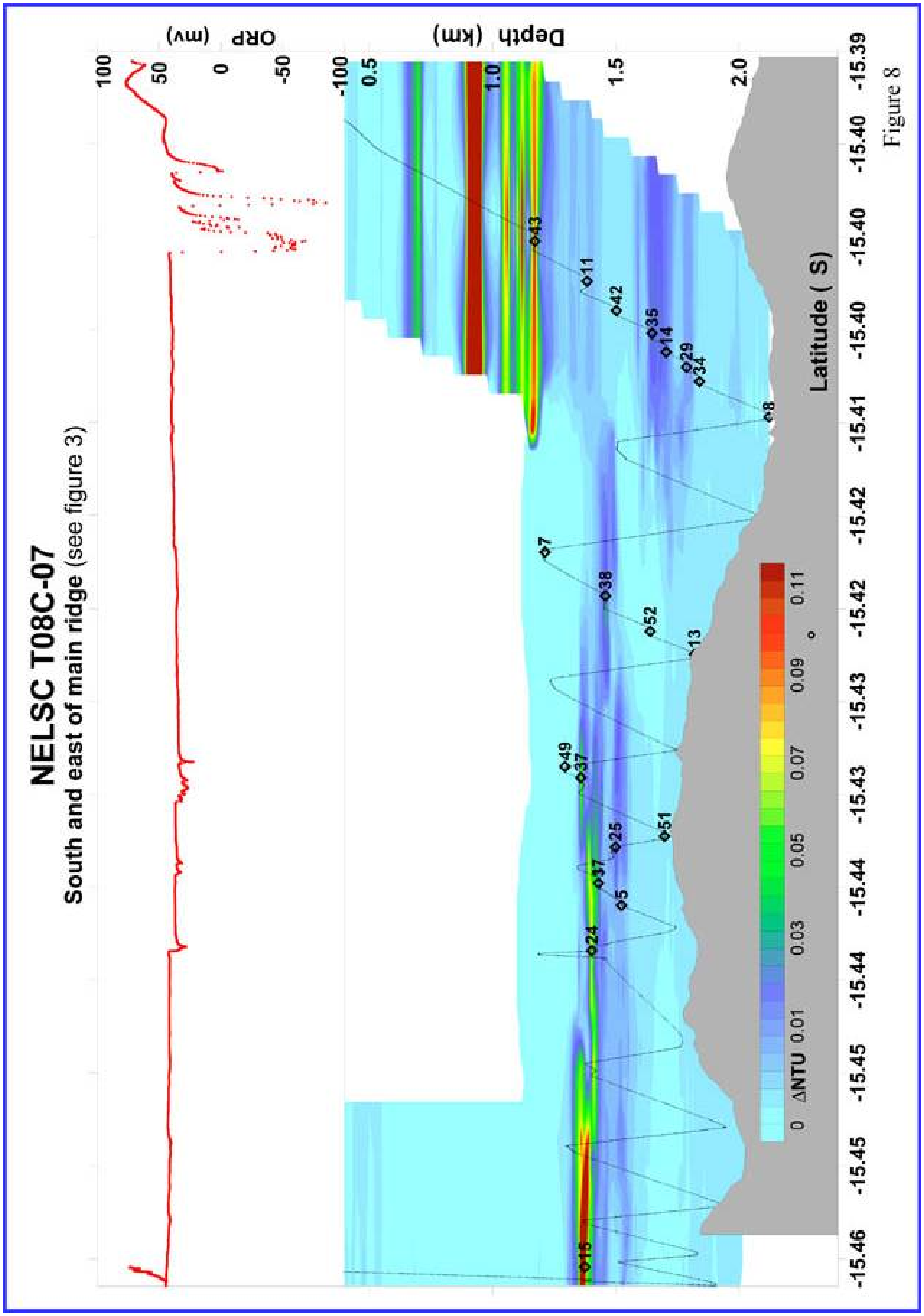
Sharon Walker

Cast	StaName	Comments	Latitude	Longitude
1	V08C-01	repeat of V04A-04 - helium cast	-14.999658	-173.100483
	T08C-01(start)		-16.162150	-174.783283
2	T08C-01(end)	southernmost segment of MTJSC	-15.885633	-174.795633
3	V08C-02	to sample plume seen during T08C-01	-15.963000	-174.795833
4	V08C-03	N end of Fonualei Rift	-16.055667	-174.604000
	T08C-02(start)		-15.956405	-174.852063
5	T08C-02(end)	northern segment of southern MTJSC - part 1 - S->N tow ended due to weather	-15.795100	-174.832783
	T08C-03(start)		-15.577450	-174.813767
6	T08C-03(end)	northern segment of southern MTJSC - part 2 - changed course to tow N->S	-15.838268	-174.845845
7	V08C-04	vertical at area of slight plume seen during T08C-03	-15.713567	-174.833510
	T08C-04(start)		-15.609450	-174.818883
8	T08C-04(end)	west limb of MTJSC	-15.670225	-175.058152
9	V08C-05	over known sulfide mound on N. MTJSC	-15.599693	-174.807050
	T08C-05(start)		-15.611387	-174.816870
10	T08C-05(end)	N limb of MTJSC	-15.309192	-174.586023
	T08C-06(start)		-15.355230	-174.699673
11	T08C-06(end)	across-axis tow at anomaly seen during T08C-05 - N.MTJSC	-15.422358	-174.593125
12	V08C-06	MTJ - additional profile	-15.387683	-174.648200
	T08C-07(start)		-15.455433	-174.312983
13	T08C-07(end)	southern end NELSC	-15.390280	-174.239850
14	V08C-07	Maka site	-15.423050	-174.285033
15	V08C-08	over summit of "Tafu"	-15.367633	-174.238600
	T08C-08(start)		-15.380912	-174.249778
16	T08C-08(end)	tow over "Tafu"	-15.323267	-174.207900
	T08C-09(start)		-15.425967	-174.300983
17	T08C-09(end)	start W of Maka and tow over ridge to E of Tafu	-15.354260	-174.219663
18	V08C-09	at location of bouyant plume sampled during T08C-09	-15.389172	-174.249873
19	V08C-10	Maka site	-15.423000	-174.285000
	T08C-10(start)		-15.417165	-174.276488
20	T08C-10(end)	E side of ridge between Maka and Tafu	-15.351517	-174.215717
21	V08C-11	S end of southern segment of NELSC (S of Maka)	-15.481270	-174.335910
	T08C-11(start)		-15.347713	-174.254767
22	T08C-11(end)	N segment of NELSC	-15.232493	-174.177257
	T08C-12(start)		-15.235717	-174.187867
23	T08C-12(end)	N segment #2 of NELSC	-15.144017	-174.140950
24	V08C-12	deep station N of NELSC - in trench	-14.675103	-173.833255
25	V08C-13	repeat of V04A-05 in area between caldera and NELSC	-15.077333	-173.891333
	T08C-13(start)	along ridge between NELSC and caldera (ended tow when ship was blown off course)	-15.438667	-174.158833
26	T08C-13(end)		-15.385867	-174.110567
27	V08C-14	vertical cast to finish T08C-13	-15.376333	-174.107333
28	V08C-15	basin W of Maka	-15.416167	-174.305167
29	V08C-16	Maka	-15.423112	-174.285372
30	V08C-17	basin E of Maka	-15.430367	-174.244848
31	V08C-18	on ridge - at eruptive site (based on bathy differences and temp anomalies)	-15.385300	-174.245500

Cast	StaName	Comments	Latitude	Longitude
32	V08C-19	E side of caldera "O"	-15.367000	-173.971667
33	V08C-20	W side of caldera "O"	-15.363500	-174.038667
34	V08C-21	S end of northern basin	-15.166667	-173.854000
	T08C-14(start)		-15.174200	-173.577107
35	T08C-14(end)	"Volcano" P (Niua)	-15.049950	-173.544113
36	V08C-22	volcano south of "P"	-15.259037	-173.589475
37	V08C-23	second volcano south of "P"	-15.345833	-173.598833
38	V08C-24	volcano west of "P" - "Mata-East"	-15.100833	-173.677500
39	V08C-25	cast in trench (for helium)	-14.744000	-173.396000
40	V08C-26	2nd volcano west of "P" - "Mata-West"	-15.094547	-173.748480
	T08C-15(start)		-15.416083	-174.026095
41	T08C-15(end)	caldera "O" tow	-15.279234	-173.977799
	T08C-16(start)		-15.120833	-173.784000
42	T08C-17(end)	tow along spine of Mata (W->E)	-15.080333	-173.722833
	T08C-17(start)		-15.099167	-173.746167
43	T08C-17(end)	tow across Mata (S->N)	-15.080167	-173.756833
	T08C-18(start)		-15.410160	-174.270705
44	T08C-18(end)	near-bottom tow along ridge at eruption site N of Maka	-15.351215	-174.219918
	T08C-19(start)		-15.392613	-174.234920
45	T08C-19(end)	across-axis tow at eruption site N of Maka	-15.357500	-174.282000
46	V08C-27	Maka	-15.423000	-174.285167
47	V08C-28	eastern basin	-15.351500	-174.169000

5.2 CTD Plots

Sharon Walker and Ed Baker created the following CTD tow-yo plots. Figure captions are at the beginning of this report. CTD plots follow.



NELSC T08C-07
South and east of main ridge (see figure 3)
ORP (mv)
Depth (km)
Latitude (S)
ΔNTU

Figure 8

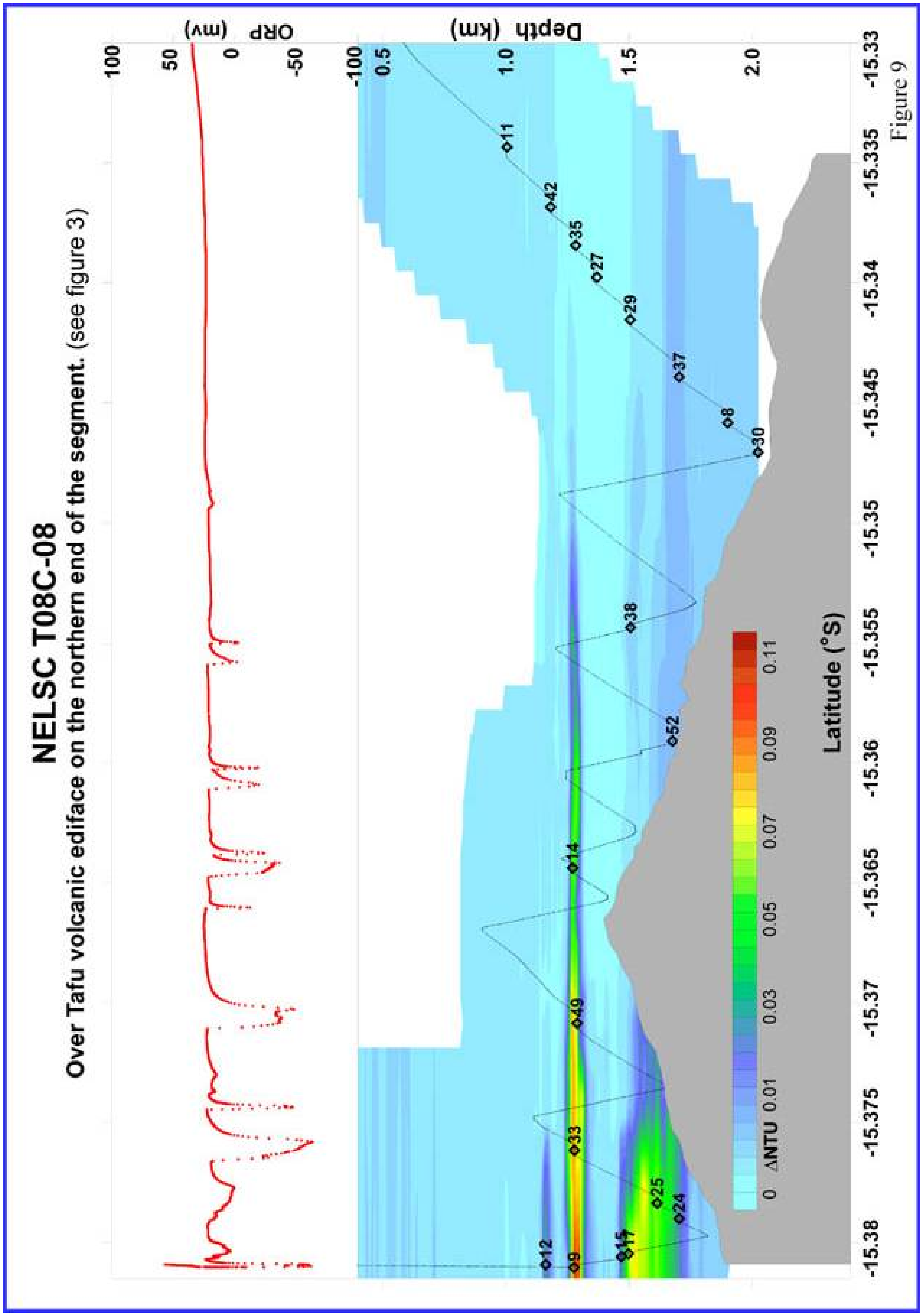

NELSC T08C-08
Over Tafu volcanic ediface on the northern end of the segment. (see figure 3)
ORP (mv)
100
50
0
-50
-100
Depth (km)
0.5
1.0
1.5
2.0
Latitude (°S)
-15.38
-15.375
-15.37
-15.365
-15.36
-15.355
-15.35
-15.345
-15.34
-15.335
-15.33
ΔNTU
0
0.01
0.03
0.05
0.07
0.09
0.11
12
9
15
17
24
25
33
49
14
52
38
30
8
37
29
27
35
42
11

Figure 9

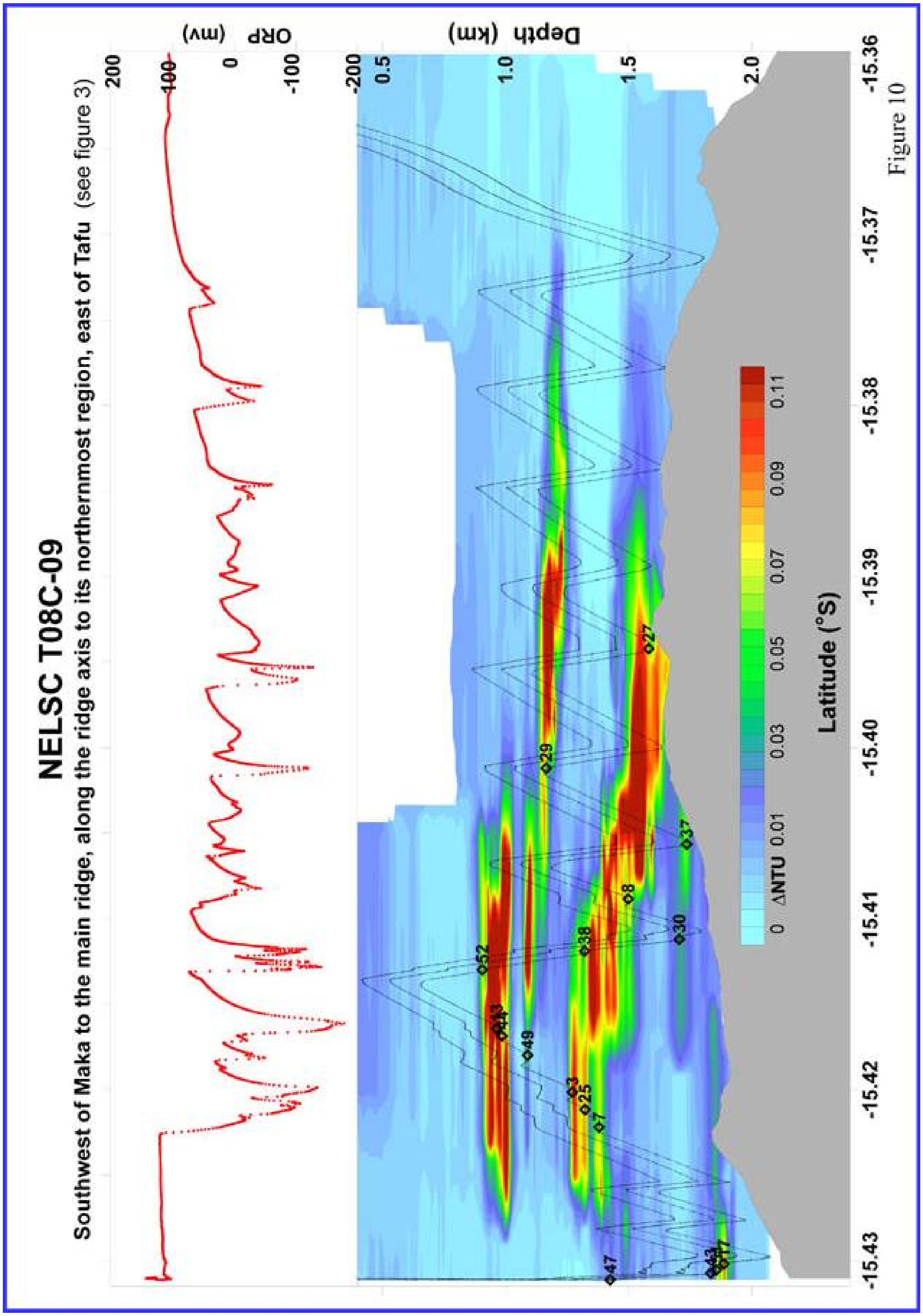
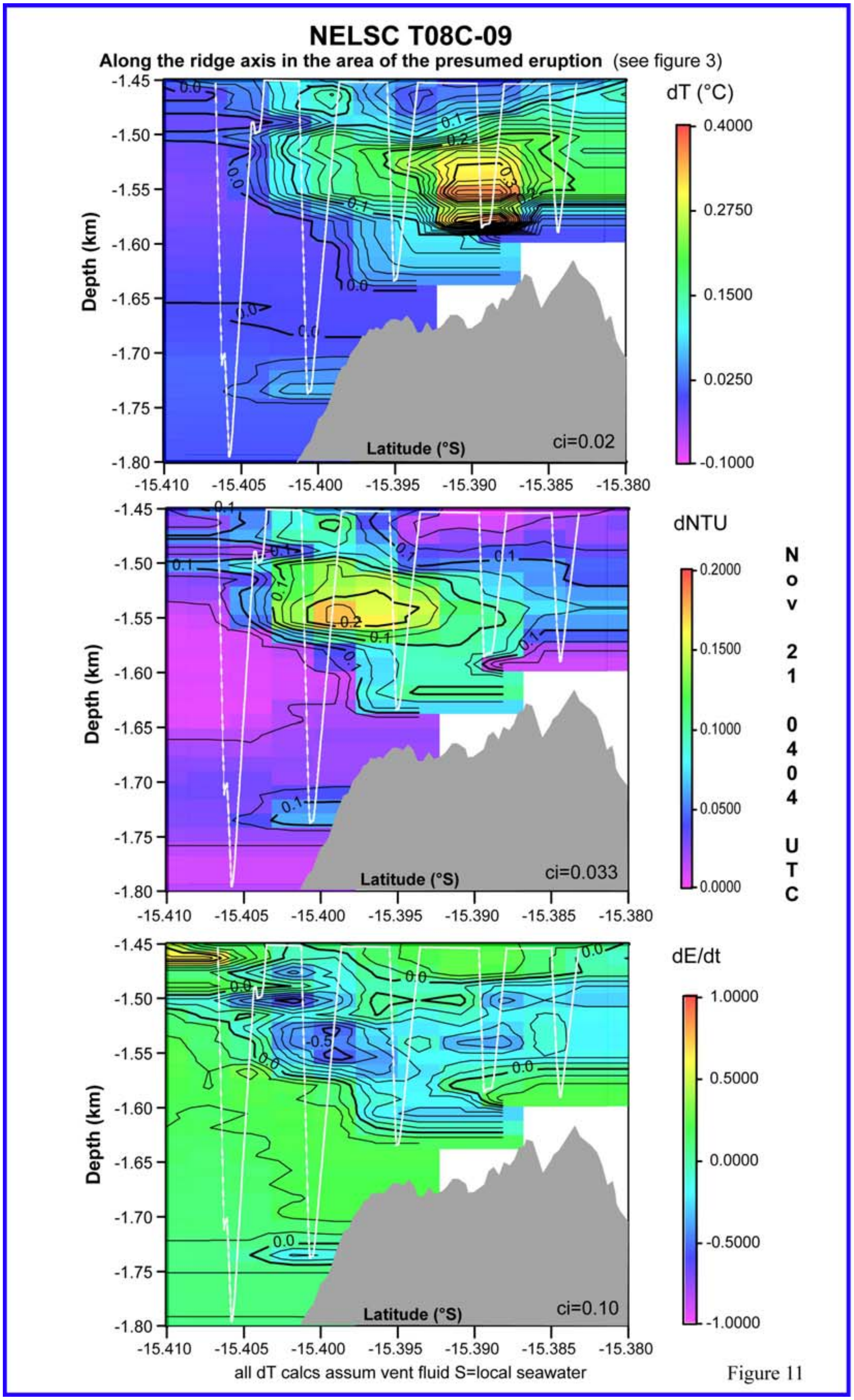
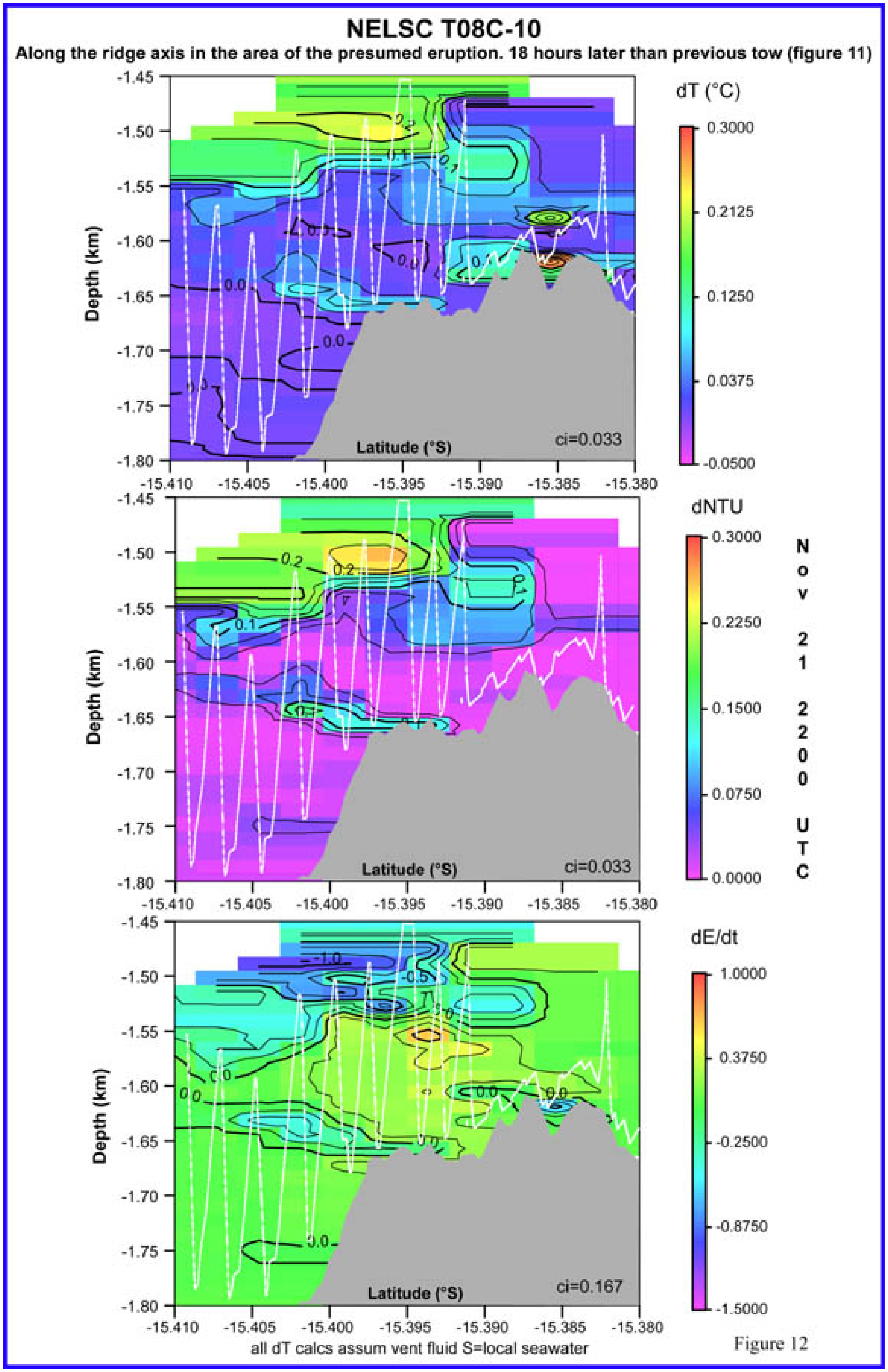

NELSC T08C-09
Southwest of Maka to the main ridge, along the ridge axis to its northernmost region, east of Tafu (see figure 3)
ORP (mv)
Depth (km)
Latitude (°S)
ΔNTU
0
0.01
0.03
0.05
0.07
0.09
0.11
-15.43
-15.42
-15.41
-15.40
-15.39
-15.38
-15.37
-15.36

Figure 10



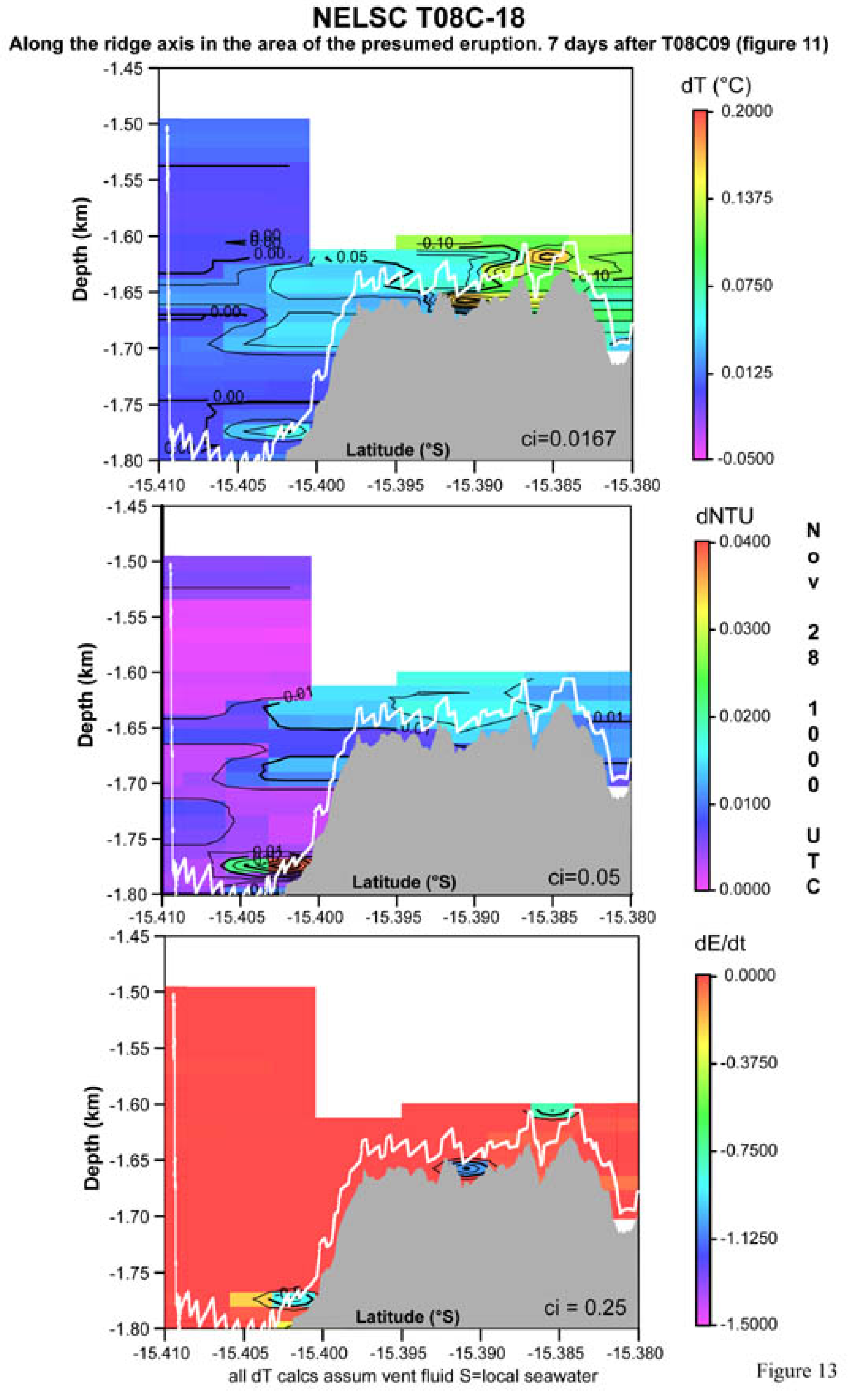
NELSC T08C-09
Along the ridge axis in the area of the presumed eruption (see figure 3)
dT (°C)
0.4000
0.2750
0.1500
0.0250
-0.1000
ci=0.02
Latitude (°S)
Depth (km)
dNTU
0.2000
0.1500
0.1000
0.0500
0.0000
ci=0.033
Nov 21 0404 UTC
dE/dt
1.0000
0.5000
0.0000
-0.5000
-1.0000
ci=0.10
-15.410 -15.405 -15.400 -15.395 -15.390 -15.385 -15.380
-1.45 -1.50 -1.55 -1.60 -1.65 -1.70 -1.75 -1.80
all dT calcs assum vent fluid S=local seawater

Figure 11



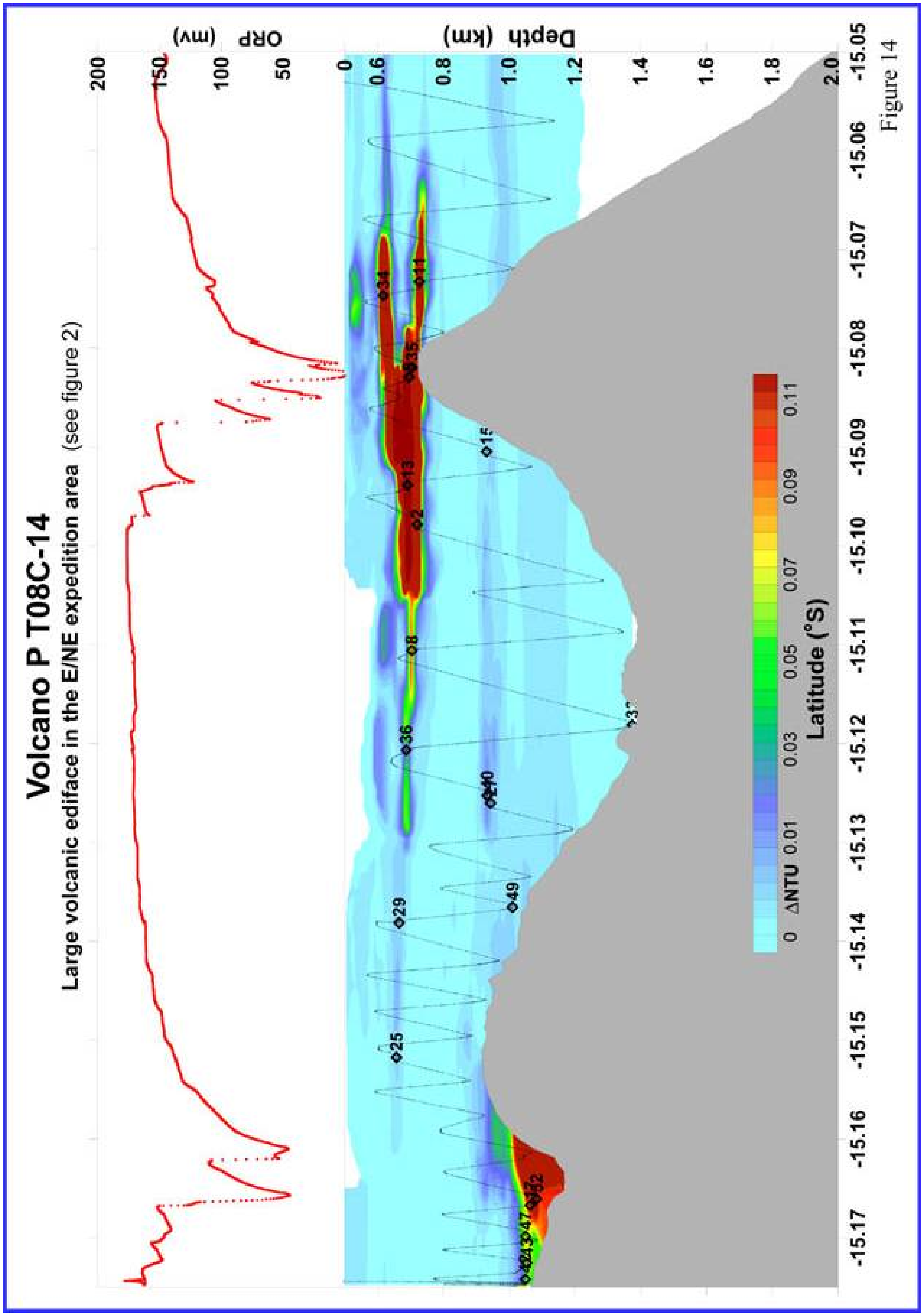
NELSC T08C-10
Along the ridge axis in the area of the presumed eruption. 18 hours later than previous tow (figure 11)
dT (°C)
dNTU
dE/dt
Depth (km)
Latitude (°S)
ci=0.033
ci=0.033
ci=0.167
Nov 21 2200 UTC
all dT calcs assum vent fluid S=local seawater

Figure 12



NELSC T08C-18
Along the ridge axis in the area of the presumed eruption. 7 days after T08C09 (figure 11)
dT (°C)
dNTU
dE/dt
Depth (km)
Latitude (°S)
ci=0.0167
ci=0.05
ci = 0.25
Nov 28 1000 UTC
all dT calcs assum vent fluid S=local seawater

Figure 13



Volcano P T08C-14
Large volcanic ediface in the E/NE expedition area (see figure 2)
ORP (mv)
200
150
100
50
Depth (km)
0
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
ΔNTU 0 0.01 0.03 0.05 0.07 0.09 0.11
Latitude (°S)
-15.17
-15.16
-15.15
-15.14
-15.13
-15.12
-15.11
-15.10
-15.09
-15.08
-15.07
-15.06
-15.05

Figure 14

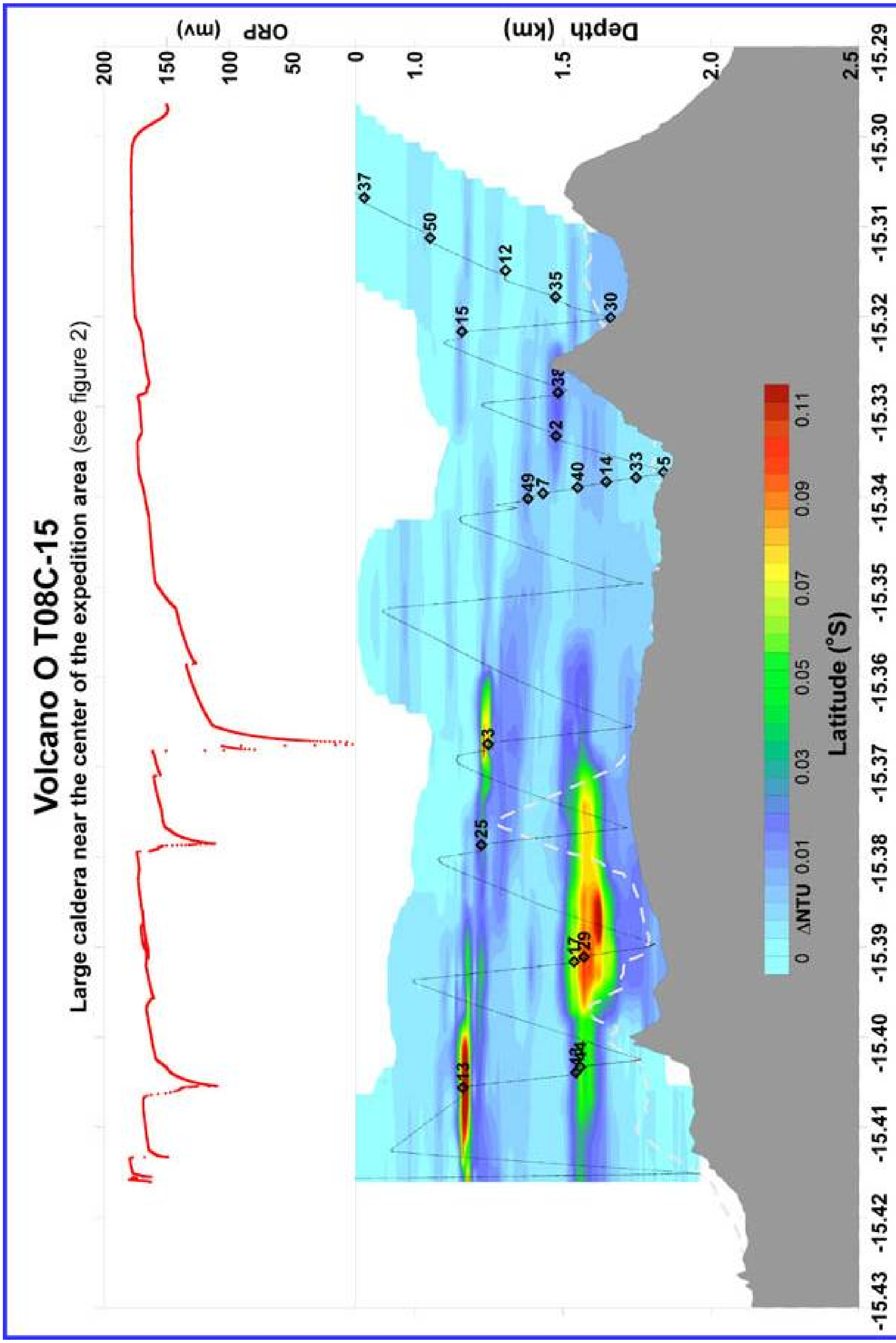

Volcano O T08C-15
Large caldera near the center of the expedition area (see figure 2)
ORP (mv)
200
150
100
50
0
Depth (km)
1.0
1.5
2.0
2.5
Latitude (°S)
-15.43
-15.42
-15.41
-15.40
-15.39
-15.38
-15.37
-15.36
-15.35
-15.34
-15.33
-15.32
-15.31
-15.30
-15.29
ΔNTU
0
0.01
0.03
0.05
0.07
0.09
0.11

Figure 15

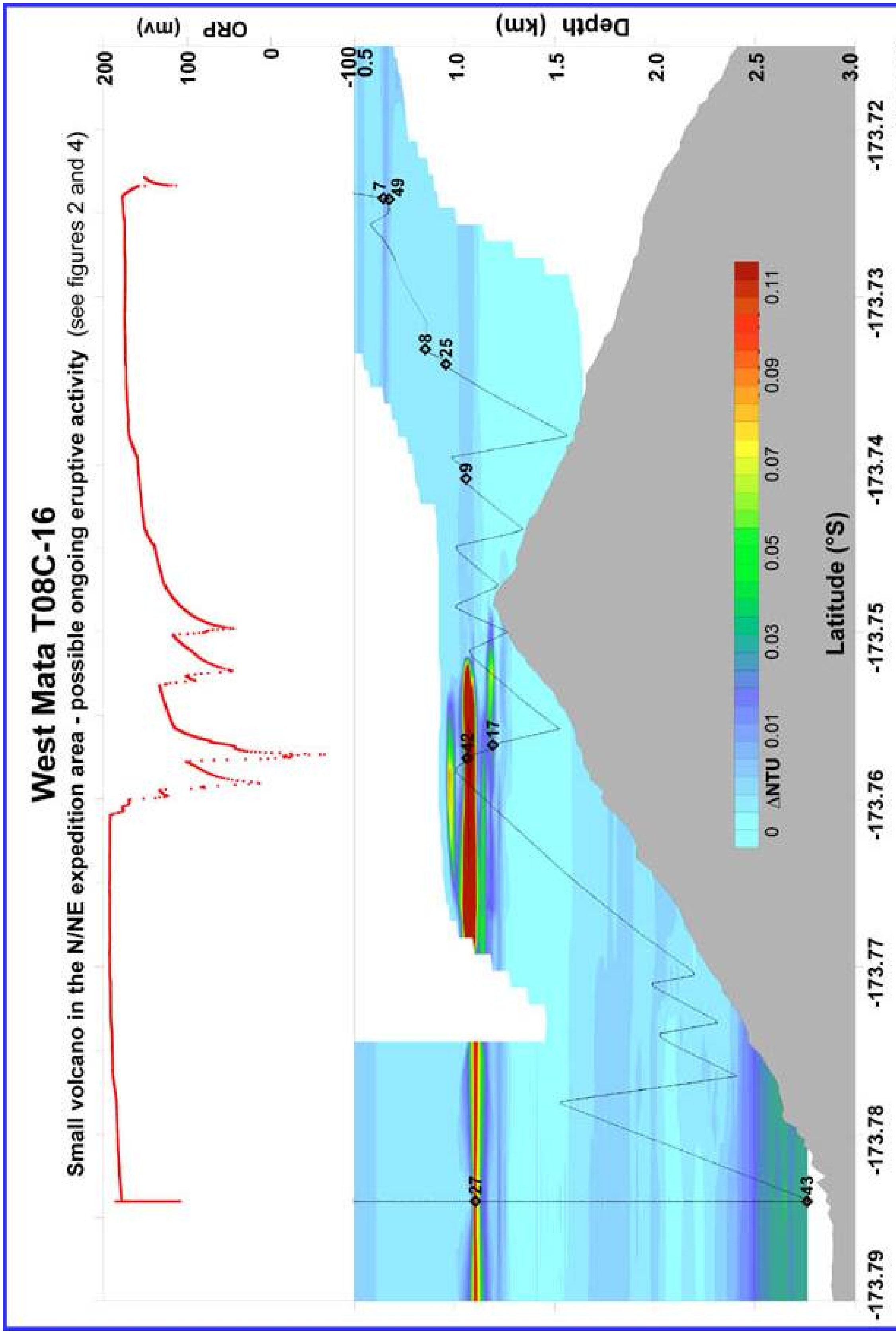

West Mata T08C-16
Small volcano in the N/NE expedition area - possible ongoing eruptive activity (see figures 2 and 4)
ORP (mv)
200
100
0
-100
Depth (km)
0.5
1.0
1.5
2.0
2.5
3.0
Latitude (°S)
-173.79
-173.78
-173.77
-173.76
-173.75
-173.74
-173.73
-173.72
ΔNTU
0
0.01
0.03
0.05
0.07
0.09
0.11
27
43
12
17
9
8
25
7
49

Figure 16

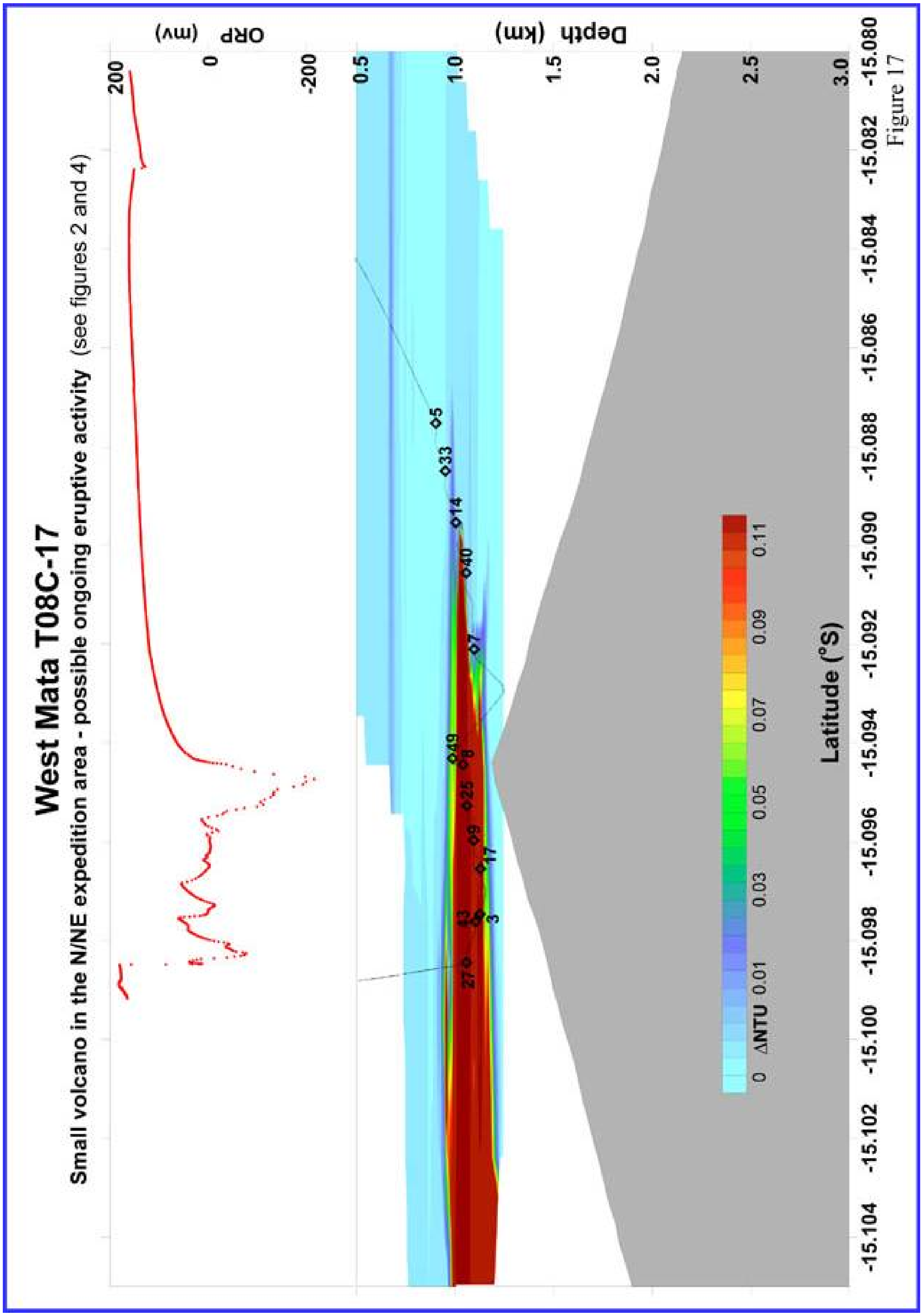

West Mata T08C-17
Small volcano in the N/NE expedition area - possible ongoing eruptive activity (see figures 2 and 4)
ORP (mv)
200
0
-200
Depth (km)
0.5
1.0
1.5
2.0
2.5
3.0
ΔNTU
0
0.01
0.03
0.05
0.07
0.09
0.11
Latitude (°S)
-15.104
-15.102
-15.100
-15.098
-15.096
-15.094
-15.092
-15.090
-15.088
-15.086
-15.084
-15.082
-15.080

Figure 17