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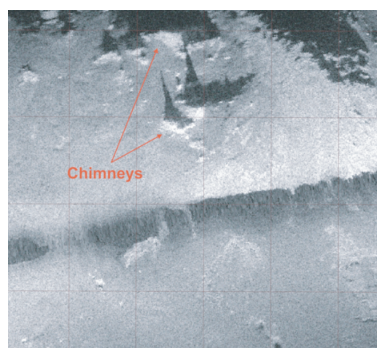
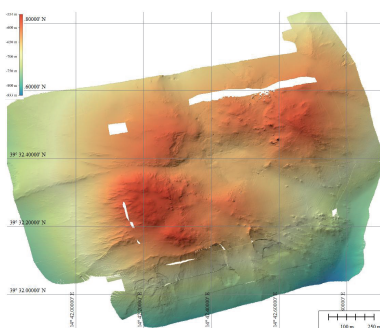
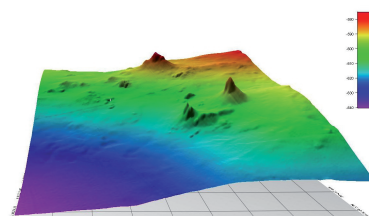
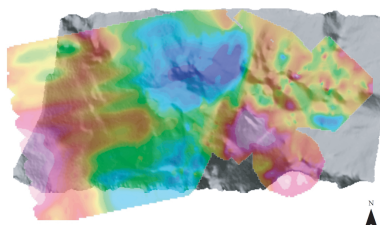
RV POSEIDON Fahrtbericht / Cruise Report POS 442

"AUVinTYS"

High-resolution geological investigations of hydrothermal sites in the Tyrrhenian Sea using the AUV "Abyss"

31.10. – 09.11.12

Messina - Messina



Berichte aus dem GEOMAR
Helmholtz-Zentrum für Ozeanforschung Kiel

Nr. 16 (N. Ser.)

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RV POSEIDON

Fahrtbericht / Cruise Report

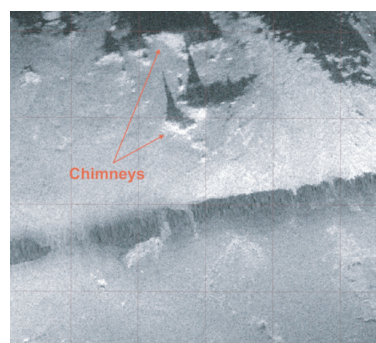
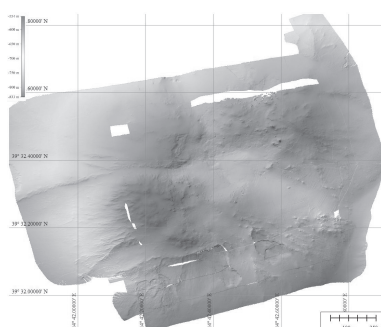
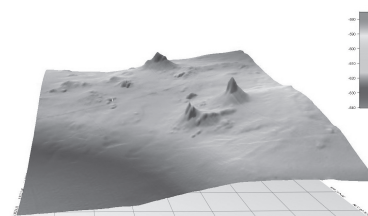
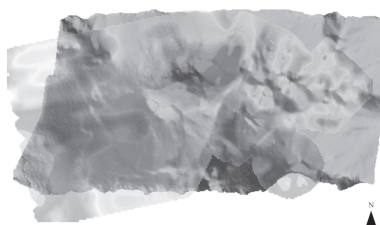
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1=GEOMAR, Helmholtz Centre for Ocean Research Kiel; 2=Istituto Nazionale di Geofisica and Vulcanologia, Portovenere.

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Theo Griesse	first mate
Hero Nannen	second mate
Hans-Otto Stange	first engineer
Günther Hagedorn	second engineer
Matthias Jensen	electrician
Ralf Meiling	motor man
Wilfried Kluge	cook
Bernd Gerischewski	steward
Joachim Mischker	boson
Bernd Rauh	ships mechanic
Frank Schrage	ships mechanic
Roland Heyne	ships mechanic
Sven Erber	ships mechanic
Ronald Kuhn	seaman

2 Introduction & scientific objectives

S. Petersen

During cruise P442 we investigated the local geological setting of a known hydrothermal deposit (Palinuro Volcanic Complex) in the Tyrrhenian Sea in high-resolution using the capabilities of the autonomous underwater vehicle (AUV) "ABYSS" from GEOMAR. This is the third try to get the AUV into the Tyrrhenian Sea as this scientific program was shifted from a previous Poseidon cruise (P412) in the spring 2011 to a RV Meteor cruise in 2012 because of the participation of the AUV "ABYSS" in the search for the lost Air France flight AF447. Participation of "ABYSS" in the Meteor

cruise in early 2012 failed for logistical reasons as the AUV containers were stopped in New Zealand due to their dangerous goods content (Li-batteries) and therefore didn't make it back in time to Europe.

The investigation of submarine hydrothermal systems in the Tyrrhenian Sea (Fig. 1) is aimed at a better understanding of the formation of metal deposits in island arcs where the shallow water depth (usually < 1000 m) and the influence of the subducting plate result in enrichments of gases, precious metals as well as abundant toxic elements (such as As, Hg, Pb, Sb. and Tl) at the seafloor. These enrichments make such sites interesting not only from an economic geology point of view, but also because of the geogene input of toxic metals into the environment. The use of GEOMARs autonomous underwater vehicle (AUV) "ABYSS" allows to answer questions related to the lateral and vertical extent of the partially sediment-covered mineralization as well as to the structural control of the venting and its associated faunal communities (Thiel et al., 2012). High-resolution bathymetric, sidescan sonar, as well as photographic surveys have been performed during this cruise. Additionally chemical sensors (CTD, Eh, turbidity) investigated the water column for signs of hydrothermal activity in areas not previously investigated. During the cruise a subbottom-profiler on the AUV as well as a magnetometer were tested for their potential to search for sediment-covered hydrothermal mineralization. The search for buried sulfide deposits is one of the greatest problems in massive sulfide exploration and hinders a full understanding of the resource potential of seafloor massive sulfides (Hannington et al., 2011). The results of this cruise will therefore have implications for future exploration programs.

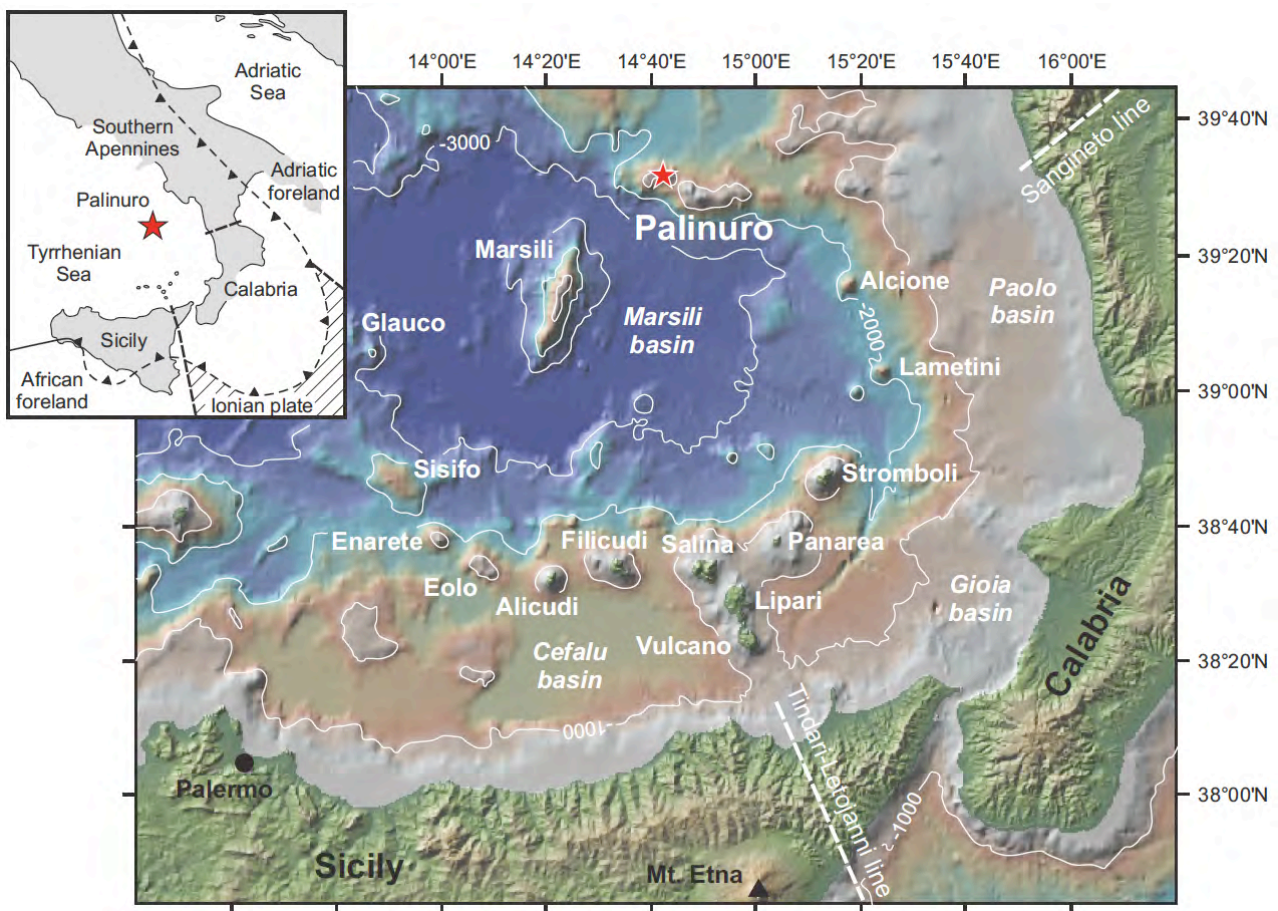


Fig. 1: Location of the Palinuro Volcanic Complex in the Tyrrhenian Sea.

3 Cruise Narrative

S. Petersen

October 29th 2012, Monday

Four scientists from Germany arrive in Messina in order to set up the AUV on board Poseidon. The truck from Germany carrying the two AUV container arrives in the evening.

October 30th 2012, Tuesday

This day is used for unloading the launch and recovery system (LARS) and fixing it on the aft deck of Poseidon. The AUV van is loaded and connected to the vessel.

October 31st 2012, Wednesday

The remaining scientists from Germany, Canada, Australia, and Italy arrive at the vessel. RV Poseidon is leaving port at 18:00 and heading for the Palinuro volcanic complex. Weather is windy (up to 8Bft) and rainy as we pass the strait of Messina.

November 01st 2012, Thursday

Arriving in the working area at 08:00 but wind and waves are too high to deploy the AUV. Since weather forecast sees improvement towards the evening, we wait. At 16:00 scientific work starts with the deployment and calibration of transponders (station 468) near the western summit of Palinuro volcanic complex, where known massive sulfide occurrences exist.

November 02nd 2012, Friday

In the morning the AUV is launched for its first mission (station 469; AUV dive #115), a multibeam survey using the Reson Seabat 7125 with a 200kHz setting and the magnetometer. The mission is flown at an altitude of 100m above bottom. The AUV is working fine during the entire day.

November 03rd 2012, Saturday

Mission ends shortly before 01:00 LT when the AUV surfaces. The instrument is later recovered in daylight for charging the batteries. The second dive is planned with two consecutive missions over the summit crater hosting the mineralization. The first part of the mission is a multibeam survey using the 400 kHz setting and flying closer to the bottom (40m altitude) followed by a sidescan sonar survey (210 kHz, range 400m) following the same track. The AUV is launched at 19:49 LT and the mission (station 470; AUV dive #116) started shortly thereafter. Early in the mission a reset of the vehicle ends the station. Remainder of the day is used for identifying the problem.

November 04th 2012, Sunday

The next station (station 471) is a repetition of that from the previous day with the 400 kHz multibeam. The vehicle is launched at 10:14 LT and the mission (AUV dive #117) started shortly thereafter. The vehicle performed well and was recovered at 15:39. The next dive (station 472; AUV dive #118) was launched at 20:03 LT and repeated the sidescan sonar mission from the previous day. The mission lasted until the next morning.

November 05th 2012, Monday

The AUV was recovered in the morning and reconfigured during the day for the next mission. Poseidon performed a multibeam survey (station 473) during the day of the shallowest part of the Palinuro volcanic complex. Increasing wind and swell in the

afternoon and evening did not allow for deployment of the AUV. Waiting on weather until the next morning.

November 06th 2012, Tuesday

The AUV was deployed in subbottom profiling configuration at 07:28 LT (station 474; AUV dive #119). The trimming was incorrect at the beginning and the AUV had to be recovered. The relaunch started at 08:10 LT. Mission was slightly short to a vehicle reset. Vehicle was recovered 13:29. Subbottom data was collected but no magnetic data. The evening was spent with changing from the SBP configuration to the photo configuration.

November 07th 2012, Wednesday

The next mission (station 475; AUV dive #120) was deployed at 08:12 LT in order to take photographic images from various areas on the summit. The mission went fine, however, photos were only taken during the first part of the survey, while magnetic data was collected during the entire mission. After changing back to the multibeam configuration during the afternoon, the AUV was deployed a last time in the evening (19:50 LT, station 476; AUV dive #121) collecting 400 kHz echosounding data adjacent to the previous dive areas. During the dive an oil leak was progressively becoming more severe, so that the dive had to be terminated after midnight.

November 08th 2012, Thursday

The AUV was left at the surface until it could be recovered at daybreak. Shortly thereafter the transponders were released (stations 477 and 478) and RV Poseidon started the journey back to Messina with a short stop next to Stromboli.

November 09th 2012, Friday

Poseidon reached the pilot station at 08:45 LT and docked in Messina at 09:11 LT.

4 Results

4.1 AUV operations

M. Rothenbeck, M. Deutschmann, L. Triebe, S. Petersen, S. Plunkett

The AUV "ABYSS" performed 7 missions in the course of the cruise with a total mission time of 46.5 hours and a total distance covered of 248 km. Four dives were devoted to multibeam mapping using the 200 kHz and 400 kHz option. Single dives were devoted to a) a sidescan sonar mission, b) a subbottom profiler survey in order to possibly detect the contact between buried massive sulfides and the overlying softer sediments, and c) one dive taking still photos at a low altitude to the seafloor in a very dense line pattern. Magnetic data (Applied Physics APL1540 3-axis fluxgate) was collected during all missions, however, dive #119 did not write data to the disk. A calibration of the magnetic data was performed prior to some dives (Fig. 2). Conductivity, temperature, pressure, turbidity and redox-potential (Eh) were also collected on all dives.

The following missions were flown by ABYSS:

<u>Dive</u>	<u>Date</u>	<u>Mission time</u>	<u>Distance</u>	<u>Data collected</u>
115	02.11.2012	14 h 52 m	81.2 km	200kHz MB+magnetics; 100m altitude; no MB data collected, mag data is fine
116	03.11.2012	00 h 56 m	-	400kHz MB+magnetics aborted early in the mission
117	04.11.2012	05 h 43 m	32.8 km	400kHz MB+magnetics; 40m altitude; data is good
118	04.11.2012	09 h 14 m	51.5 km	120kHz SSS+magnetics; data is good
119	06.11.2012	04 h 25 m	23.9 km	subbottom profiler+magnetics; SBP data is good; no magnetic data
120	07.11.2012	05 h 07 m	27.0 km	Foto survey+magnetics; photos only for some boxes; magnetic data is good
121	07.11.2012	06 h 08 m	31.8 km	400kHz MB+magnetics; 40m altitude; mission aborted due to oil leak; data collected that far is good
		total: 46 h 25 m	248.2 km	

Mission 115 (multibeam; 469AUV)

Date: Nov 02nd, 2012 Launch: 09:08 UTC Recovery: 05:35 UTC
 On bottom: 09:58 UTC Mission time: 14 h 52 m Distance travelled: 81.2 km

ABYSS investigated the crater on the eastern side of the western summit at Palinuro using the Reson Seabat 7125 with a 200kHz setting. The mission is flown at an altitude of 100m above bottom with a line spacing of 150m (Fig. 3). The magnetometer data is also collected on a separate data logger. Prior to starting the echosounding the magnetomer was calibrated on a preselected path in a depth of 100m. The AUV's CTD data does not show anomalies in salinity or bottom temperature, however, a small anomaly is detectable in the redox-potential sensor at the southern rim of the crater (see Fig. 4). Also, turbidity shows the same plume as the Eh sensor, as well as a wider, weak plume over the Eastern half of the dive.

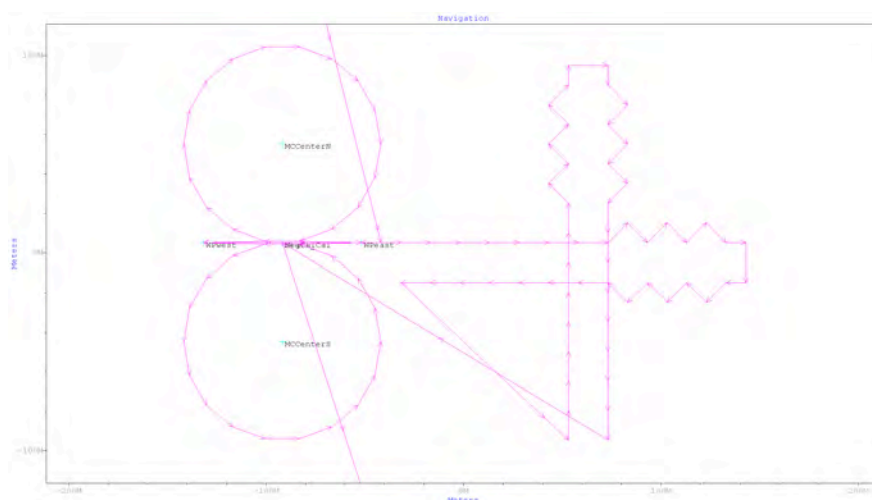


Fig. 2: Tracklines for the calibration of the magnetic sensor. The calibration is flown in a water depth of 100m prior to each dive where the configuration was changed. The vessel is at least 500m away to prevent interference.

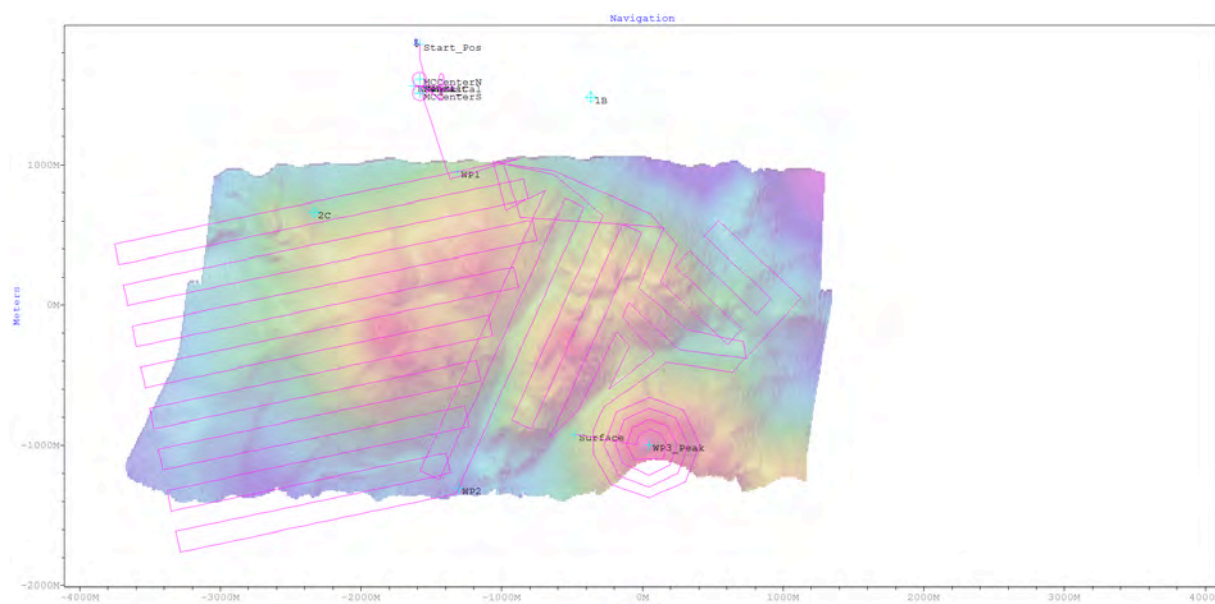


Fig. 3: Mission setup for multibeam dive 115 (469AUV) over the crater hosting seafloor mineralization. Underlying bathymetry (10 m grid size) is from Meteor cruise M86/4.

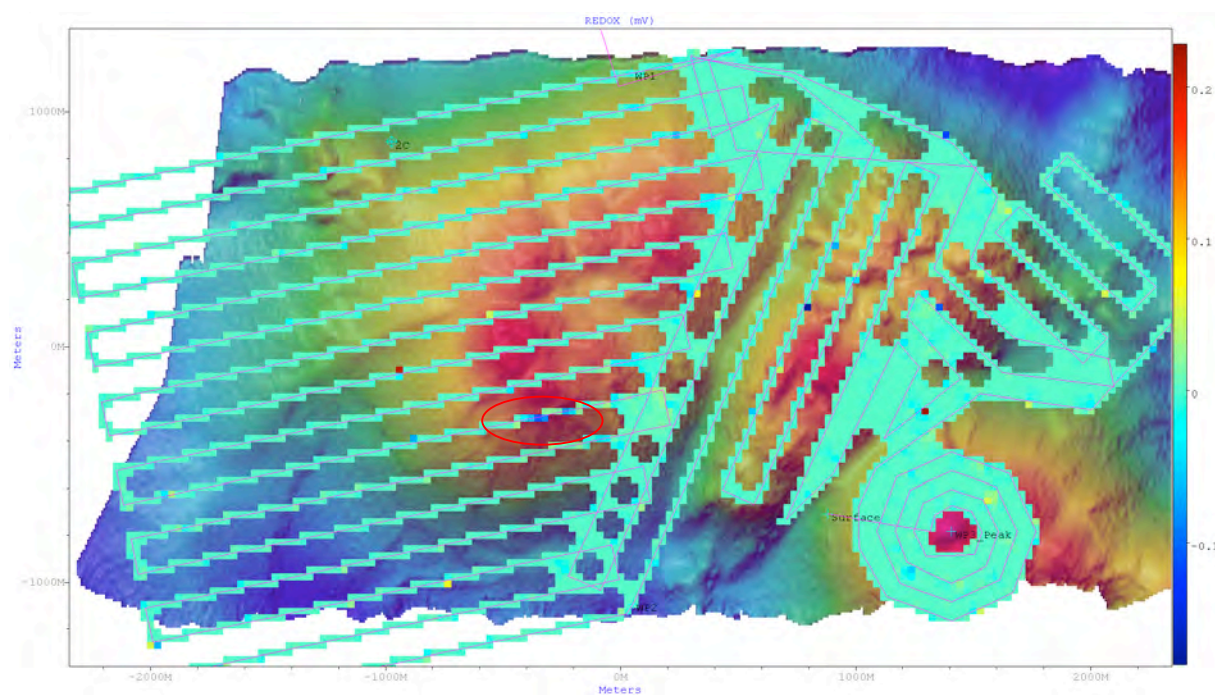


Fig. 4: Delta-Eh along the track of dive #115. Note the Eh low at the southern rim.

Mission 116 (aborted; 470AUV)

Date: Nov 03rd, 2012

Launch: 18:48 UTC

Recovery: 20:35 UTC

On bottom: 19:43 UTC

Mission time: 0 h 56 m

Distance travelled: -

Abyss was supposed to investigate the mineralized area by multibeam mapping 400kHz followed by a sidescan sonar mission. After the calibration of the magnetic sensor and descent to the seafloor, the mission was aborted very early due to a reset of the vehicle. Ascent weight was dropped and vehicle surfaced at 20:15. Reson Seabat 7125 was not logging during the mission!

Mission 117 (multibeam; 471AUV)

Date: Nov 04th, 2012

Launch: 09:13 UTC

Recovery: 15:39 UTC

On bottom: 10:02 UTC

Mission time: 05 h 43 m

Distance travelled: 32.8 km

The mission was using the 400 kHz multibeam sensor to map the topography while flying at an altitude of 40m (Fig. 5). Mission went smoothly and data was recovered showing numerous sulfide chimneys and mounds in the eastern part of the crater whereas the area of sulfides drilled in 2007 does not show evidence for chimney formation. Turbidity showed similar but less widespread response on southern rim when compared to previous dive highlighting the ephemeral nature of venting (Fig. 6).

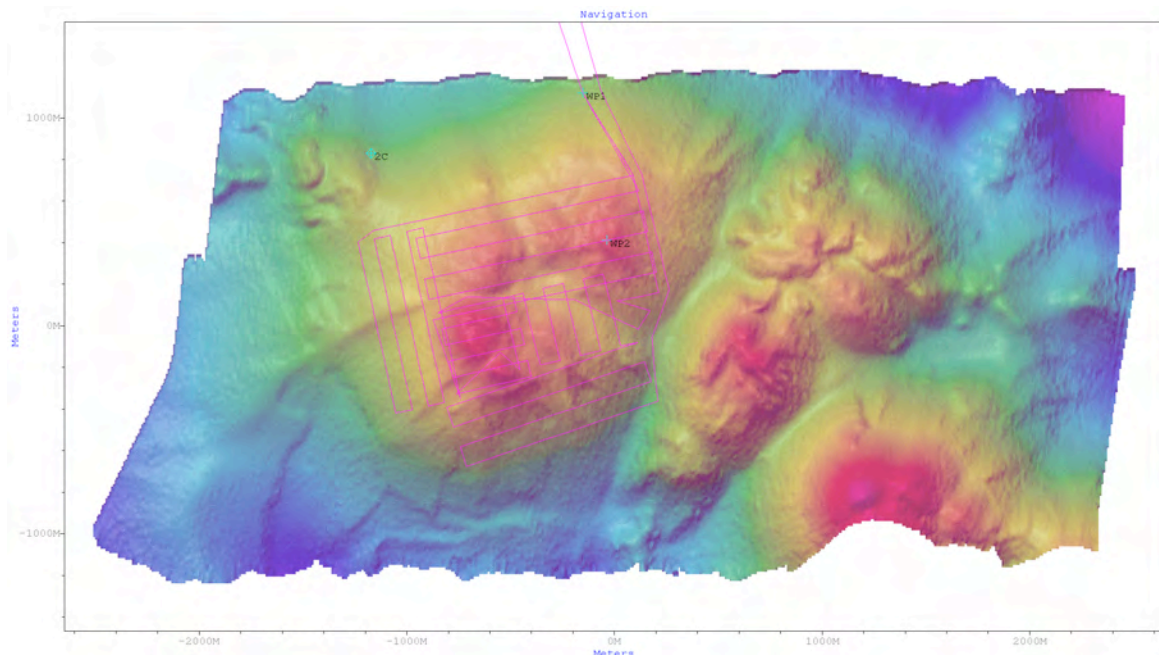


Fig. 5: Mission setup for multibeam dive #117 (471AUV) over the crater hosting seafloor mineralization. Underlying bathymetry (10 m grid size) is from Meteor cruise M86/4.

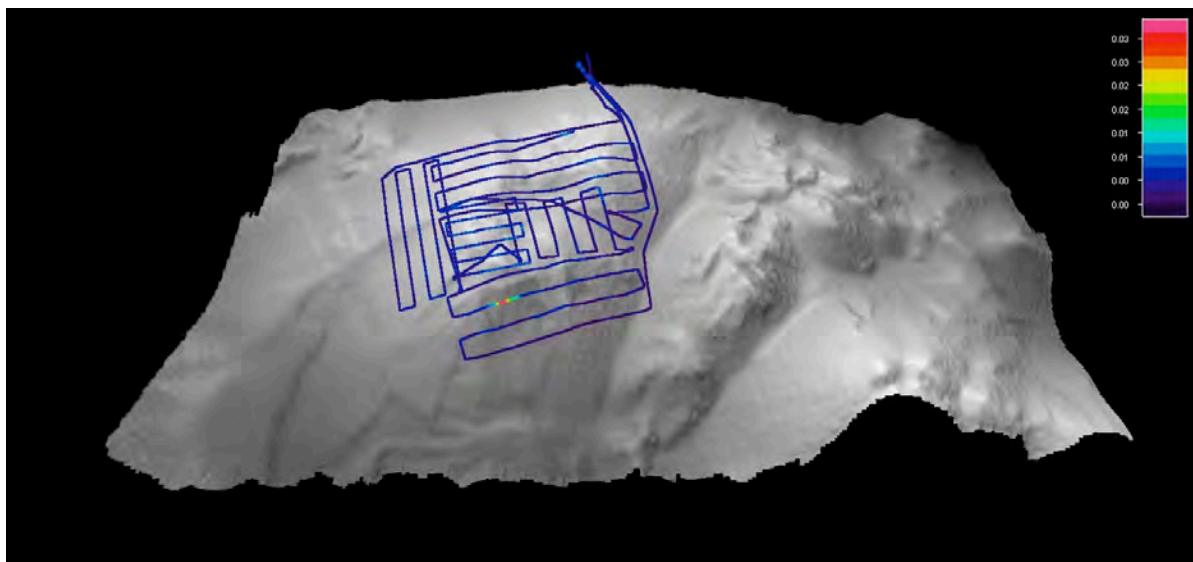


Fig. 6: Turbidity along the track of dive #117. Note the anomaly at the southern rim. Underlying bathymetry is from Meteor cruise M86/4.

Mission 118 (Sidescan; 472AUV)

Date: Nov 04th, 2012

Launch: 19:00 UTC

Recovery: 06:03 UTC

On bottom: 19:58 UTC

Mission time: 09 h 14 m

Distance travelled: 51.5 km

Sidescan sonar survey over the summit (Fig. 7). This mission repeats the previous tracks, but is extended to the west. The mission is cut short by low battery status and the final 1.5 lines are missing, however, the area of main interest is completely covered. The redox potential sensor shows a signal near the 2007 drill targets (Fig. 8), while the turbidity signal shows again a small anomaly along the southern rim (Fig. 9). There is evidence for additional sulfide chimneys just north of the bathymetric survey.

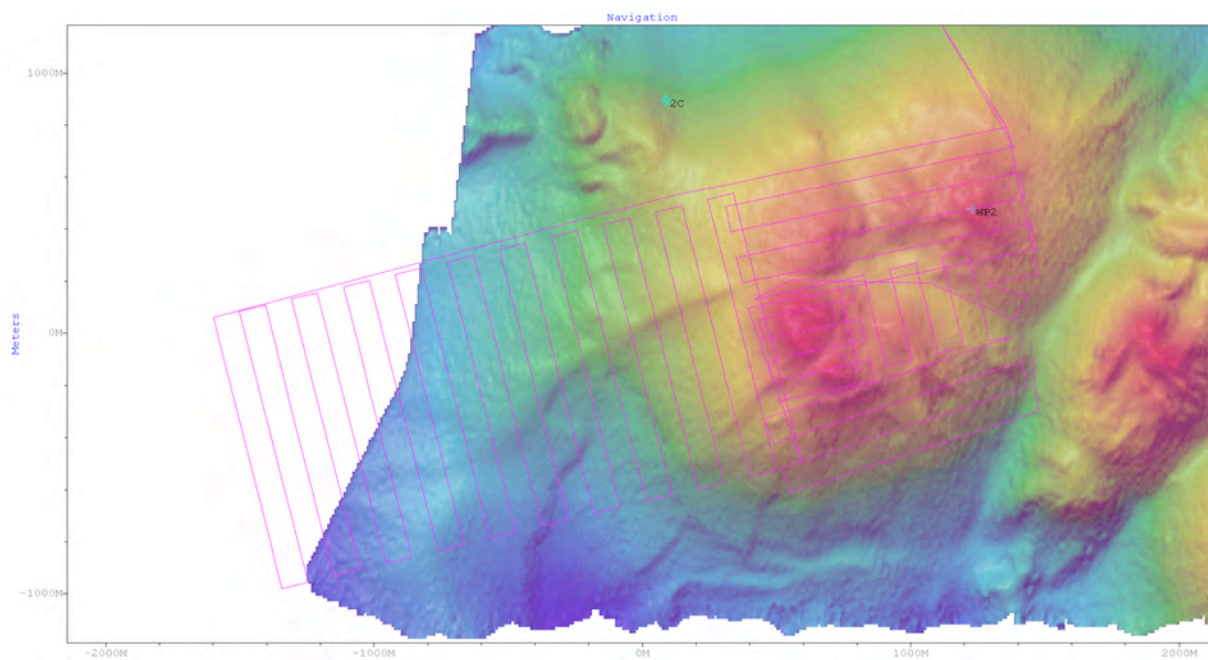


Fig. 7: Mission setup for sidescan dive 118 (472AUV) over the crater hosting seafloor mineralization. Underlying bathymetry (10 m grid size) is from Meteor cruise M86/4.

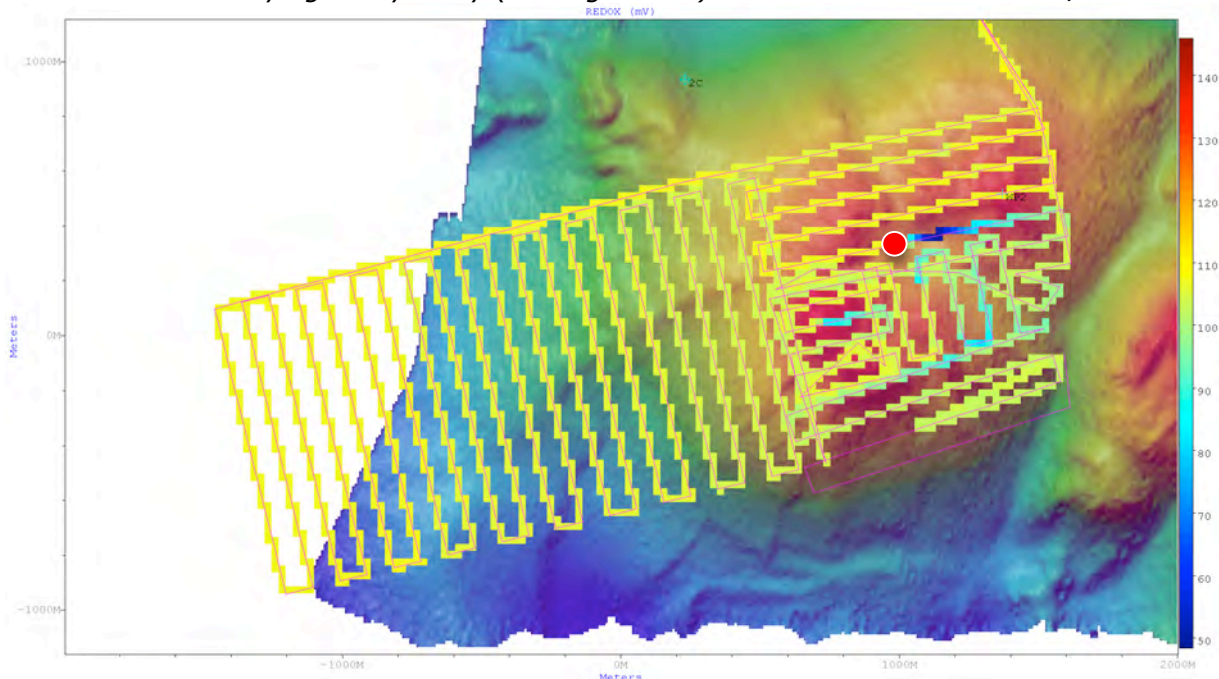


Fig. 8: Redox-potential along the track of dive #118. Note the Eh low in the crater just east of the area of sulfide drilling in 2007 (red dot). Few Eh hits are also present in the southern part of the summit.

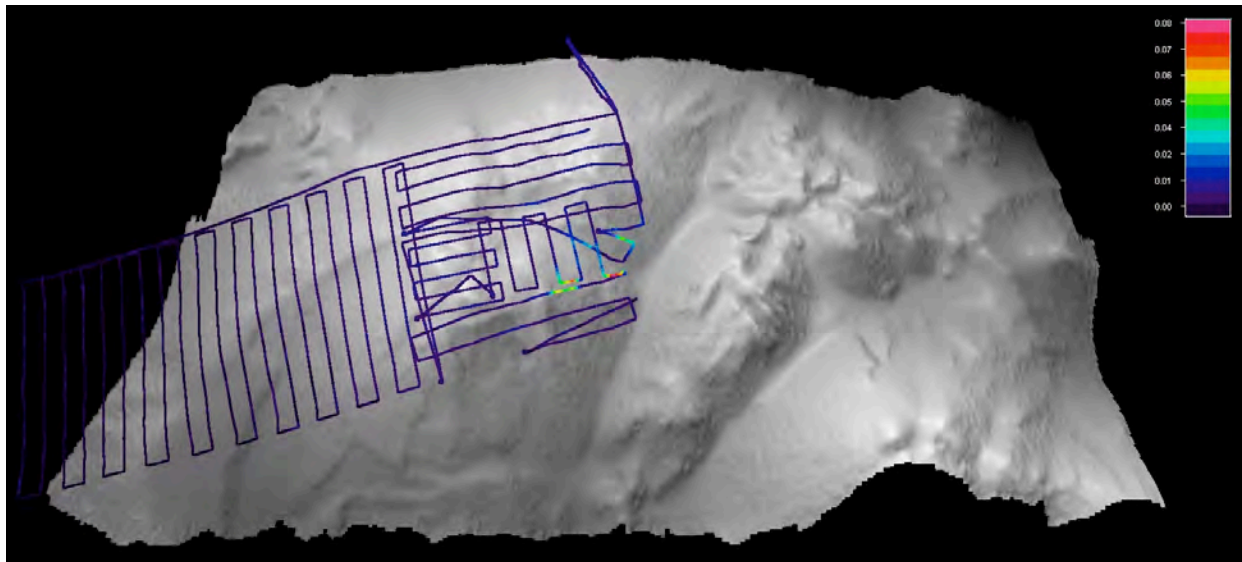


Fig. 9: Turbidity along the track of dive #118. Note the weak anomalies at the southern rim. Underlying bathymetry is from Meteor cruise M86/4.

Mission 119 (SBP; 474AUV)

Date: Nov 06th, 2012 Launch: 07:09 UTC Recovery: 12:29 UTC
On bottom: 08:09 UTC Mission time: 04 h 25 m Distance travelled: 23.9 km

Subbottom profiler survey (4-24 kHz) over the summit (Fig. 10). Line spacing of 10m with 4-16 and 10 ms. Mission flown at 580m and 550m height depending on topography. Mission aborted at 11:38 due to system reset resulting in a bottom time of 3 hours and 29 minutes. Most of the dive targets were visited. The AUV was recovered at 12:29. Subbottom data is fine, however, no magnetic data was recorded.

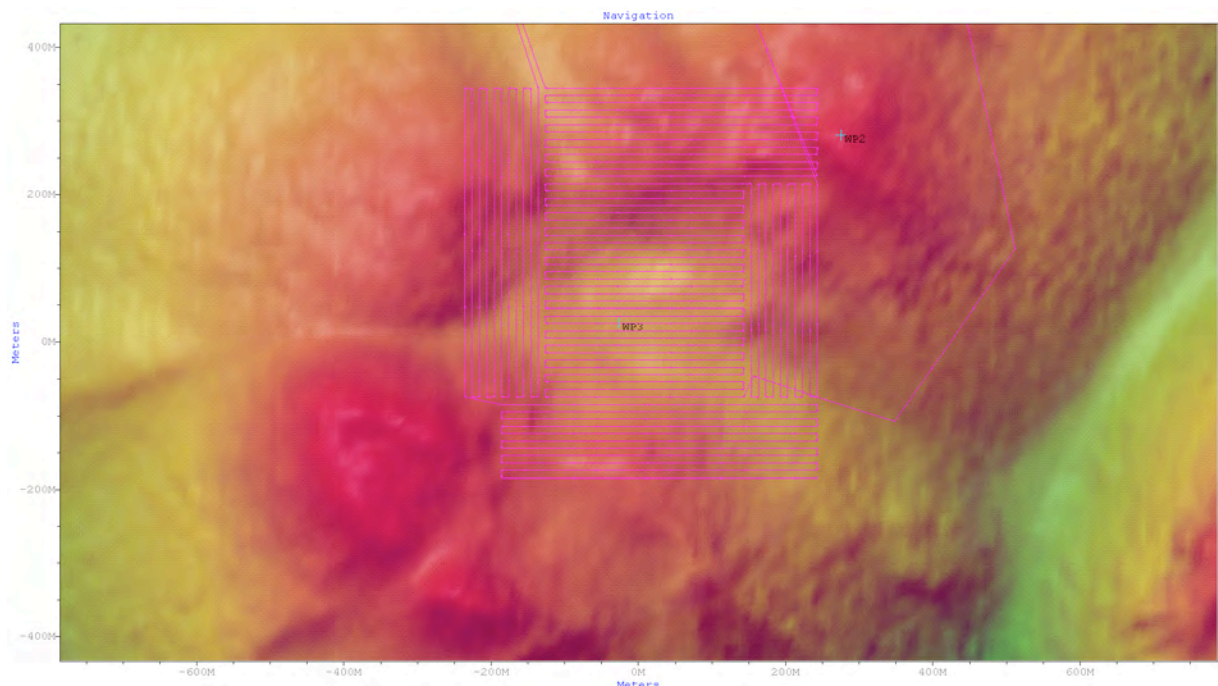


Fig. 10: Mission setup for the subbottom dive #119 (474AUV) over the crater hosting seafloor mineralization. Underlying bathymetry (10 m grid size) is from Meteor cruise M86/4.

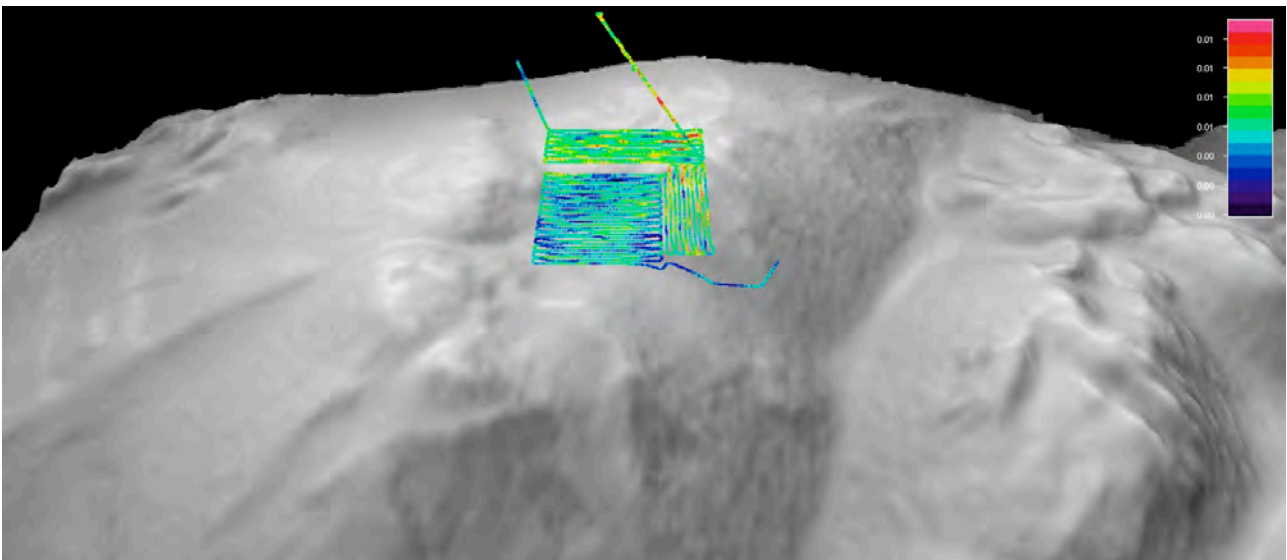


Fig. 11: Turbidity along the track of dive #119 showing no clear anomalies over the crater summit. Underlying bathymetry is from Meteor cruise M86/4.

Mission 120 (ESC; 475AUV)

Date: Nov 07th, 2012 Launch: 07:11 UTC Recovery: 12:38 UTC
 On bottom: 08:07 UTC Mission time: 05 h 07 m Distance travelled: 27.0 km

Mission for photographing selected areas of the summit is launched at 08:11 LT. The surveys are run with a 5m line spacing and at an altitude of 10m (Fig. 12). Small areas around the large chimneys (height >10m) have been overflowed at an altitude of 20m to be able to photograph them. Magnetic data is fine for the entire mission. Turbidity data shows anomalies in south and, even more subdued, near eastern rim, and at one point where the AUV probably struck the seafloor in the NE area producing a strong turbidity response on a single line only, that is non-existent on neighboring lines (Fig. 13).

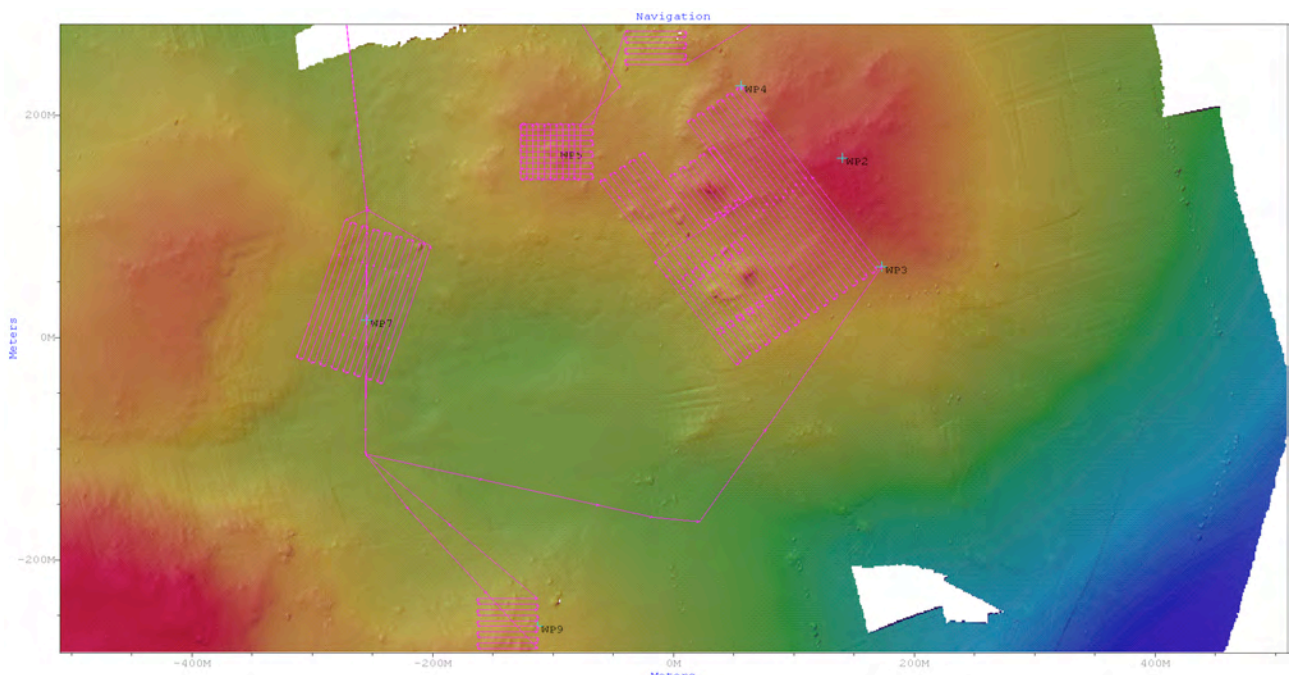


Fig. 12: Mission setup for the camera dive #120 (475AUV) over the crater hosting seafloor mineralization. Underlying bathymetry is from dive 119 (this cruise). Camera runs cover the area of drilling (westernmost survey) as well as the area with the newly found chimneys to the east.

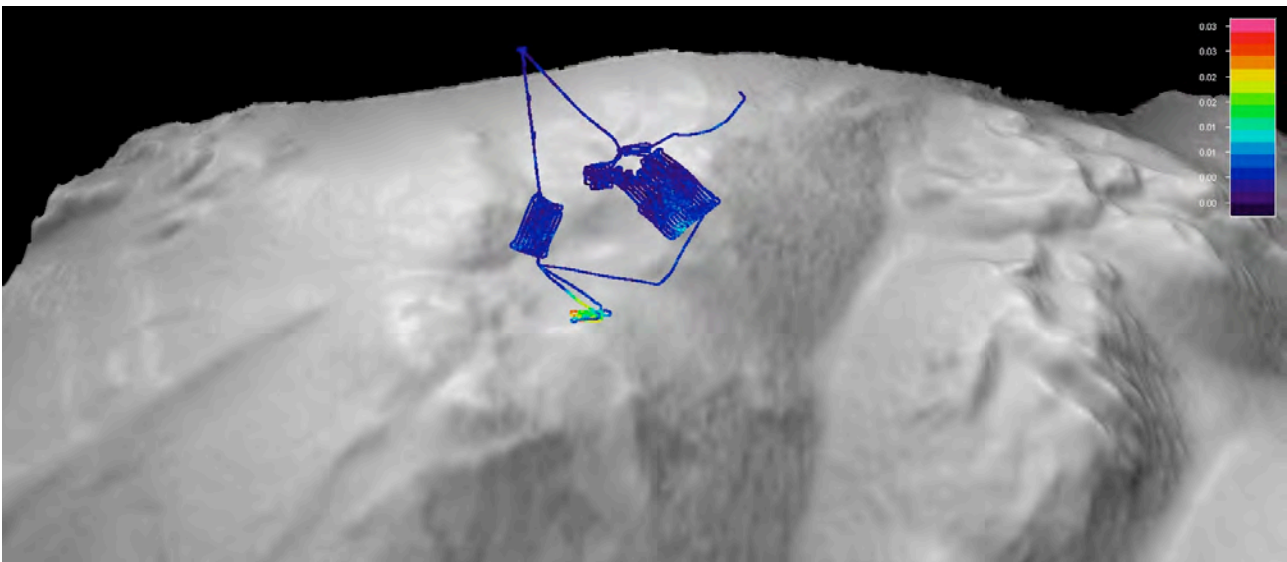


Fig. 13: Turbidity along the track of dive #120. Note the weak anomalies at the southern rim. Underlying bathymetry is from Meteor cruise M86/4..

Mission 121 (multibeam; 476AUV)

Date: Nov 07th, 2012 Launch: 18:49 UTC Recovery: 05:50 UTC
On bottom: 19:29 UTC Mission time: 06 h 08 m Distance travelled: 31.8 km

Multibeam mission intended to add bathymetric data to the existing map from dive #117 (Fig. 14). Soon after beginning of the mission oil status is showing decreasing values. At 23:43 we interrupt the mission and redirect the vehicle in order to map one line covering the chimneys previously seen in the sidescan data. Mission is canceled early due to the leakage - not reaching those chimneys. Water column sensors do not show anomalies (Fig. 15).

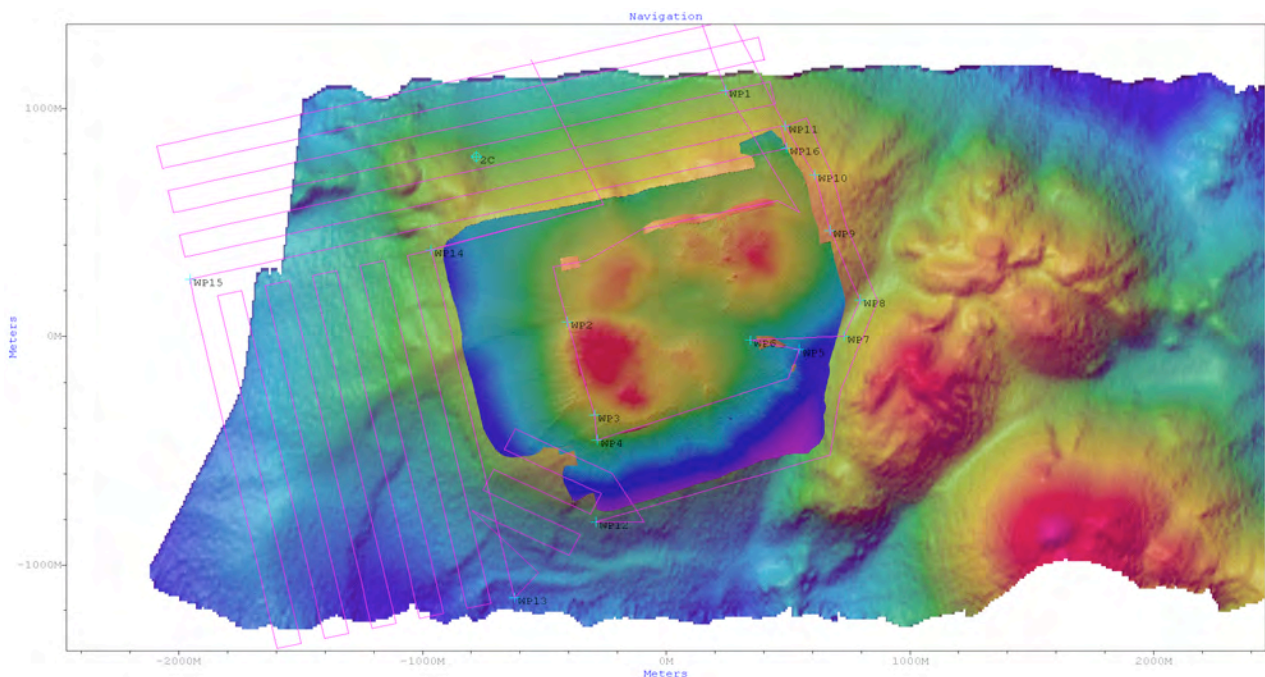


Fig. 14: Mission setup for the multibeam dive #121 (476AUV) along the western and northern flanks of the crater hosting seafloor mineralization. Underlying bathymetry (10 m grid size) is from Meteor cruise M86/4. Map on top shows extent of bathymetric data from dive #117.

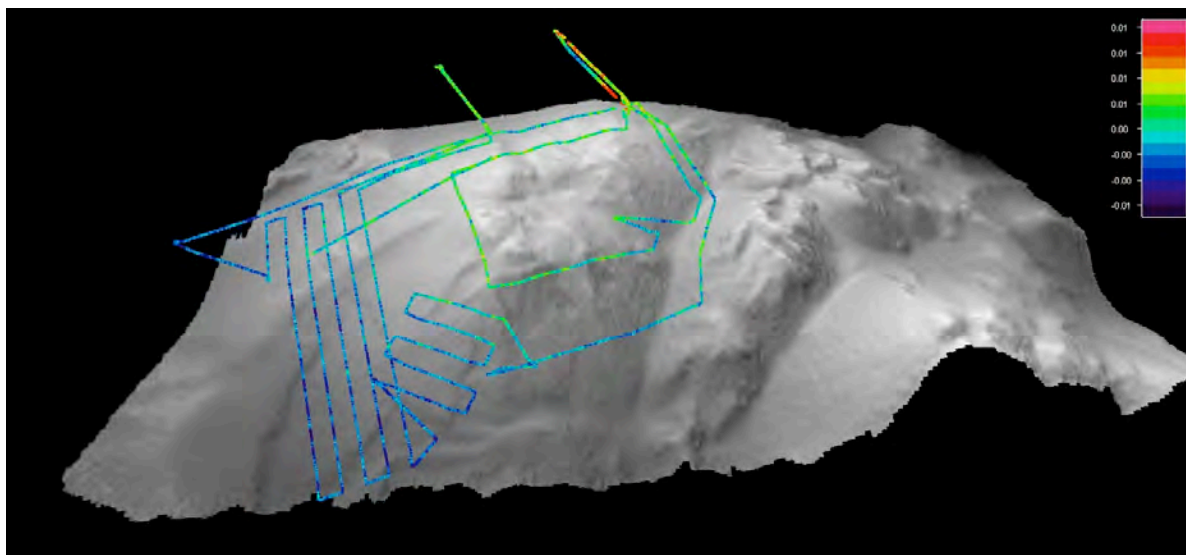


Fig. 15: Turbidity along the track of dive #121. No clear anomaly in the southern and western parts of the flank, but a weak signal upon approaching the summit in the NE. Underlying bathymetry is from Meteor cruise M86/4..

4.2 Multibeam Mapping with the AUV

N. Augustin, I. Yeo

The AUV mounted RESON Seabat 7125 multibeam system (200/400 kHz) was used during three AUV dives at P442 (Abyss dives #116, 117 and #121). Dive #116 (at 200kHz) did not succeed. For dives #117 and #121 we operated the system at 400 kHz with 512 equi-angular beams. Besides the mandatory data such as sonar settings, beam geometry data and bathymetric data we also recorded backscatter imagery data and snippets, which are needed for processing the backscatter data (because of their amplitude information). A single transmission from the projector unit illuminates a 128° swath on the sea floor. The seabed return signal is received by the receiver unit, digitized, and stored as *.S7K files, a proprietary RESON format, on a hard drive. The amount of data increases by approximately 10 MB per minute during a high frequency survey. This rate depends of course on the ping rate. The multibeam surveys are operated in altitude mode (40 m), meaning the vehicle is following the topography as closely as possible. The ping rate was set to automatic mode and varies with the altitude. In general, the dive missions were planned using a line spacing of 150 m with an overlap of approximately 20%. A new file is created for every 256 MByte of data collected. The bathymetric data collected with the AUV have been quality checked, preliminary processed and gridded with RESONs PDS2000 and QPS Fledermaus Professional (DMagic, 3DEditor Modules; Fig. 16) with a spatial acoustic resolution up to 60 cm; Fig. 17).

The evaluation of bathymetric data from dive Abyss #121 revealed a weak navigation and strong non-linear positioning offsets of the mapped areas compared to the data of dive Abyss #117 as well as the side scan sonar operation Abyss #118. Therefore, a navigational post-processing will be done after the cruise.

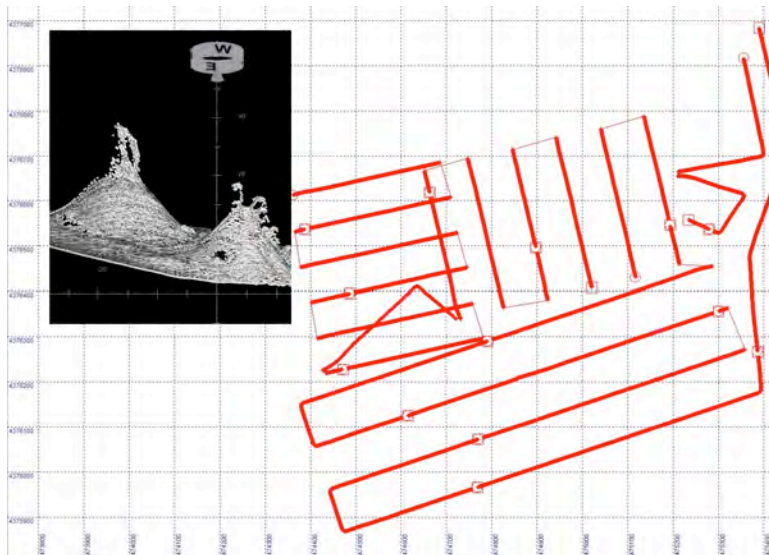


Fig. 16: Combined screenshots of PDS2000 from editing windows. The red lines represent partially edited course information of the southern part of dive Abyss #117. The inset shows the point-cloud of soundings of two mound structures with steep chimneys on top. The left structure is about 20 m high.

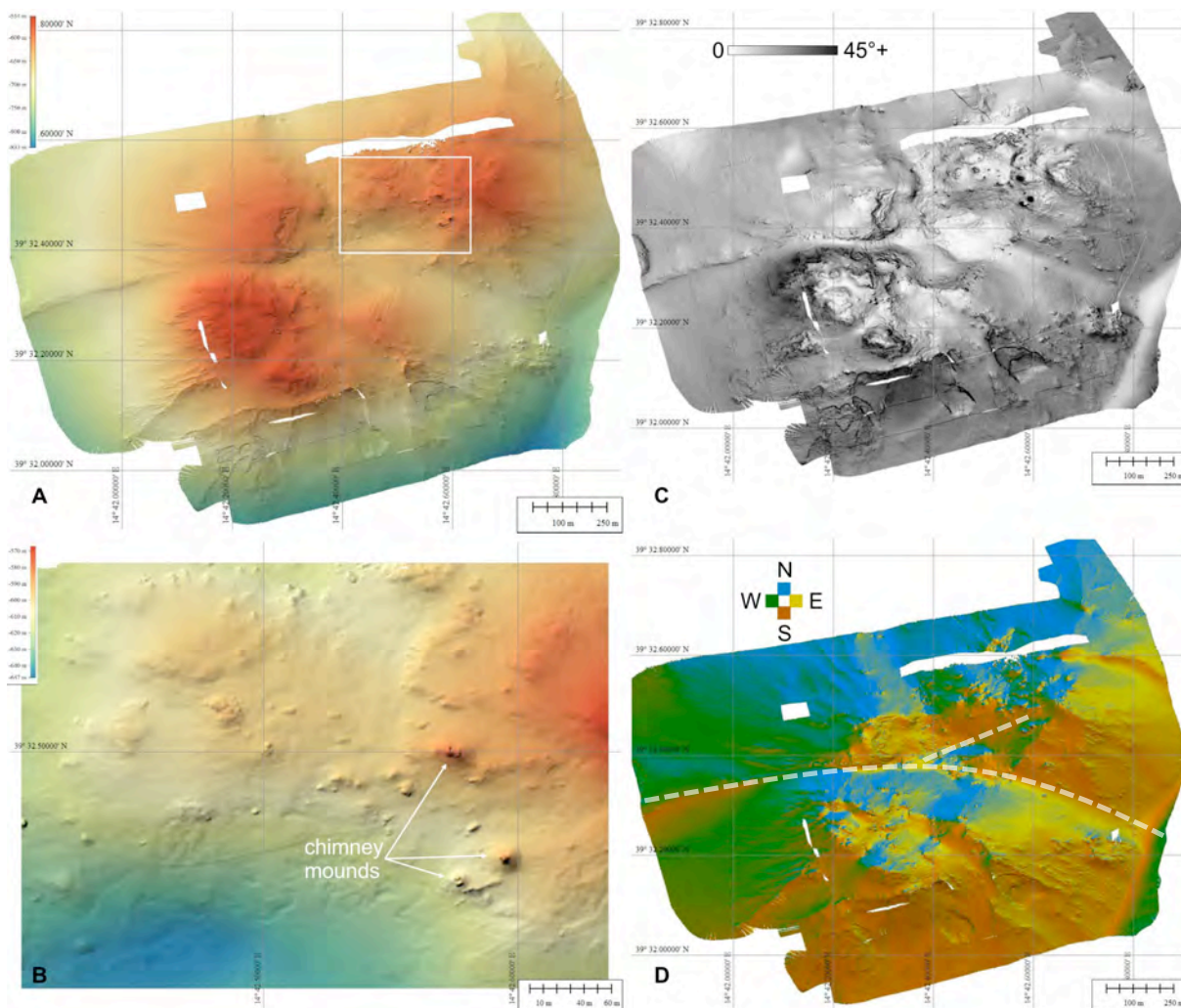


Fig. 17: AUV dive Abyss #117 multi beam data of the central area of interest. (A) Color-coded and shaded digital elevation model (DEM) with a spatial acoustic resolution of 60 cm. The white box indicates the area of (B) Crop of the DEM shown above. White arrows mark large, up to 20 m high chimney mounds at the western flank of the eastern hill. The bump area west of these mounds is most probably made of smaller hydrothermal edifices. (C) Slope shaded DEM shows the overall smooth hills of the target area. Somewhat higher roughness and therefore more distinct slope changes are visible in the area of the chimney field at the eastern high.

4.3 AUV Sub-Bottom Profiler

N. Augustin, I. Yeo

For dive ABYSS #119 the AUV was equipped with an Edgetech 2200-MP full spectrum chirp sub-bottom profiler to collect information about sub-surface massive sulfide distribution in the vicinity of the 2007 drill sites as well as the newly discovered chimney field. The Edgetech 2200-MP system offers three frequency range options: 1-6 kHz, 2-16 kHz, and 4-24 kHz. During mission #119 the system was set to 4-24 kHz and the vehicle operated in altitude mode at two distinct depths (550m and 580 m depending on topography) with a line spacing of 10m. The collected data has been roughly processed in SonarWiz and displayed in Fledermaus (Fig. 18). A detailed processing and evaluation of the sub-bottom profiler data is needed after the cruise at GEOMAR, Kiel.

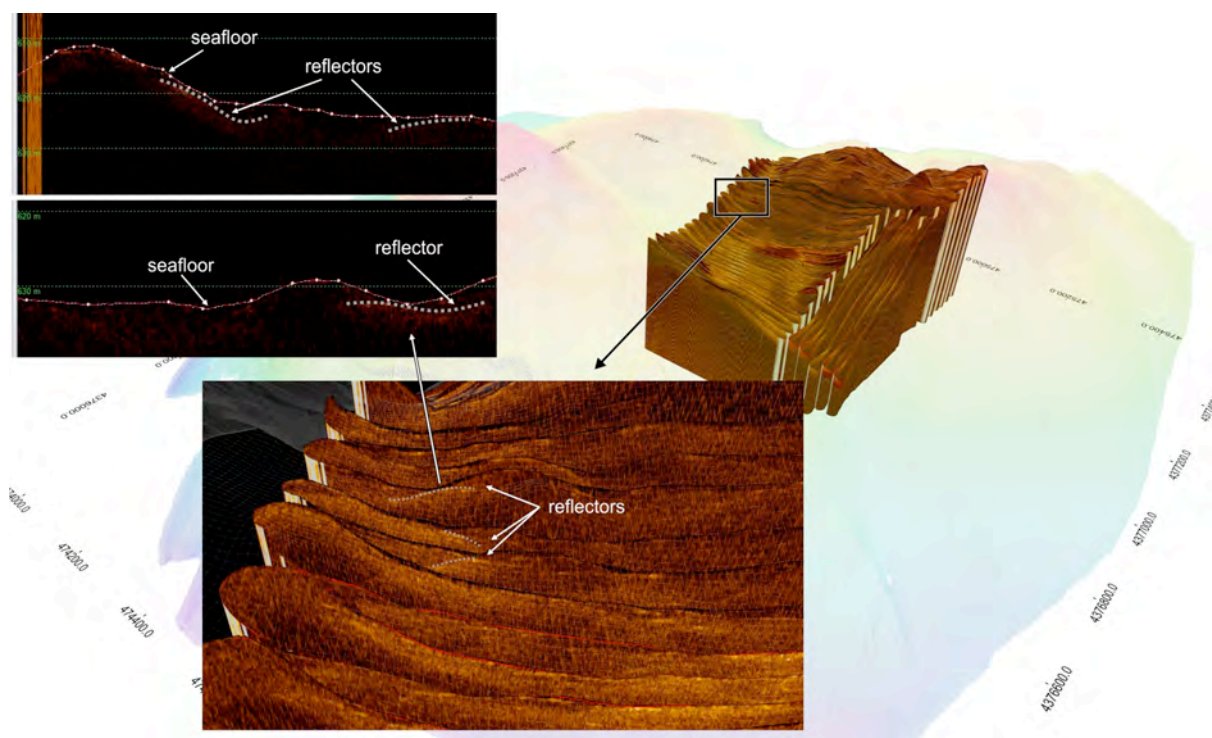


Fig. 18: Preliminary results of AUV dive Abyss #119 sub-bottom profiler mission. The main view shows the overall mission and the position of track lines in the bathymetry of dive Abyss #117 (Fledermaus screen-grab). The insets show details from the 2007 drill site area. Bottom: roughly processed, water column substracted profiles. Top: 8.5 kHz Hanning-filtered profiles (SonarWiz). Both pictures already show reflectors (marked by dashed lines), which possibly reflect the contact between sediments and hard rock in the shallow sub-seafloor, e.g. volcanics or massive sulfides.

4.4 Sidescan sonar imaging

I. Klaucke, I. Yeo, N. Augustin

The sidescan sonar survey of the Palinuro seamount (AUV dive #118) was carried out using the 120 kHz sensor for 400 metres of range. Such a range requires an ideal altitude of the AUV of 40 metres above the seafloor, but relief in the survey area prevented the survey to be composed of long, parallel tracks (see section 4.2).

Spacing between survey lines was only 100 metres resulting in multiple overlap and complete coverage. Mosaicking of the processed data, however, was seriously hampered by this survey layout. On the other hand individual sidescan sonar lines show great detail.

Two different software packages were available for processing of the raw sonar images: Caraibes and SonarWiz. While SonarWiz can directly import the raw data that are registered in the EdgeTech JSF-format, Caraibes requires the raw data to be first converted into the XTF-format and then imported into Caraibes (Fig. 19). For the importation the sampling rate of 25.1 kHz has to be known. Both packages allowed processing the data to a final pixel size of 0.75 metres.

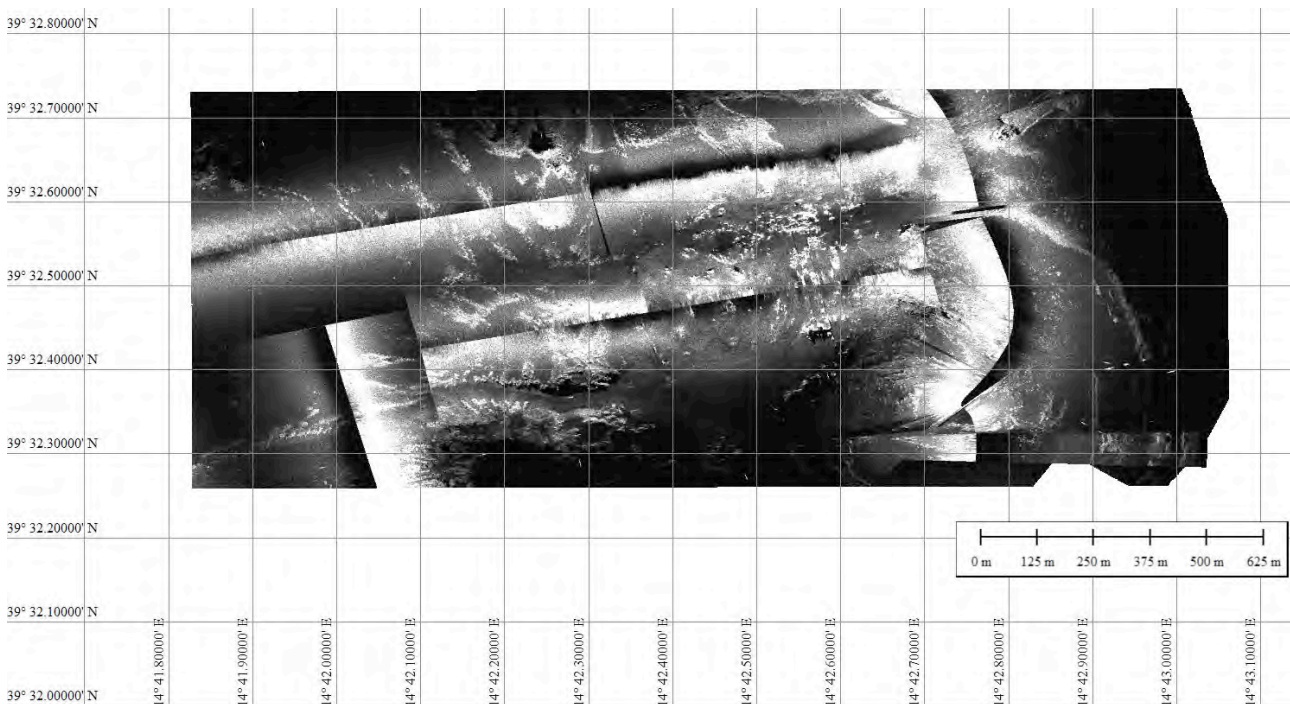


Fig. 19: Part of sidescan mosaic processed with Sonarwiz showing several hydrothermal chimneys around 39°32.5'N and 14°42.5'E.

The sidescan sonar data show mainly uniform low backscatter intensities in the western part of the survey while the eastern part shows irregular high backscatter patches that can be both combined with shadows and without shadows. The high backscatter patches are generally less than a few tens of metres in diameter. At the northern margin of the survey larger structures in excess of one hundred metres are visible. They form an intricate and often circular pattern of high and low backscatter intensities. The eastern margin of the uniform backscatter area shows increasing evidence for small high backscatter patches that are only a few metres across. The density of these patches increases eastward and ultimately gives way to larger high backscatter structures. The combination of tools used during the cruise and combining the information with data from previous cruises allows the following geological interpretation of the observed backscatter patterns.

The area of uniform low backscatter intensity corresponds to those parts of the volcano that are completely covered with sediments. Moving eastward more and more volcanic structures still peak through the sediments. First only isolated large blocks are visible then entire structures can be discerned. Whether this phenomenon is due to preferential accumulation of sediments in the western depression and higher relief

in the East than in the West or reworking of sediments by bottom currents cannot be determined with the current dataset. There are, however, no clear indications for strong currents, such as sediments waves or ripples. The sedimented area is surrounded by high relief areas that show clear indications for layered volcanic deposits (Fig. 20). Finally, the high backscatter patches with long shadows are interpreted as chimneys resulting from hydrothermal deposits (Fig. 20 and 21).

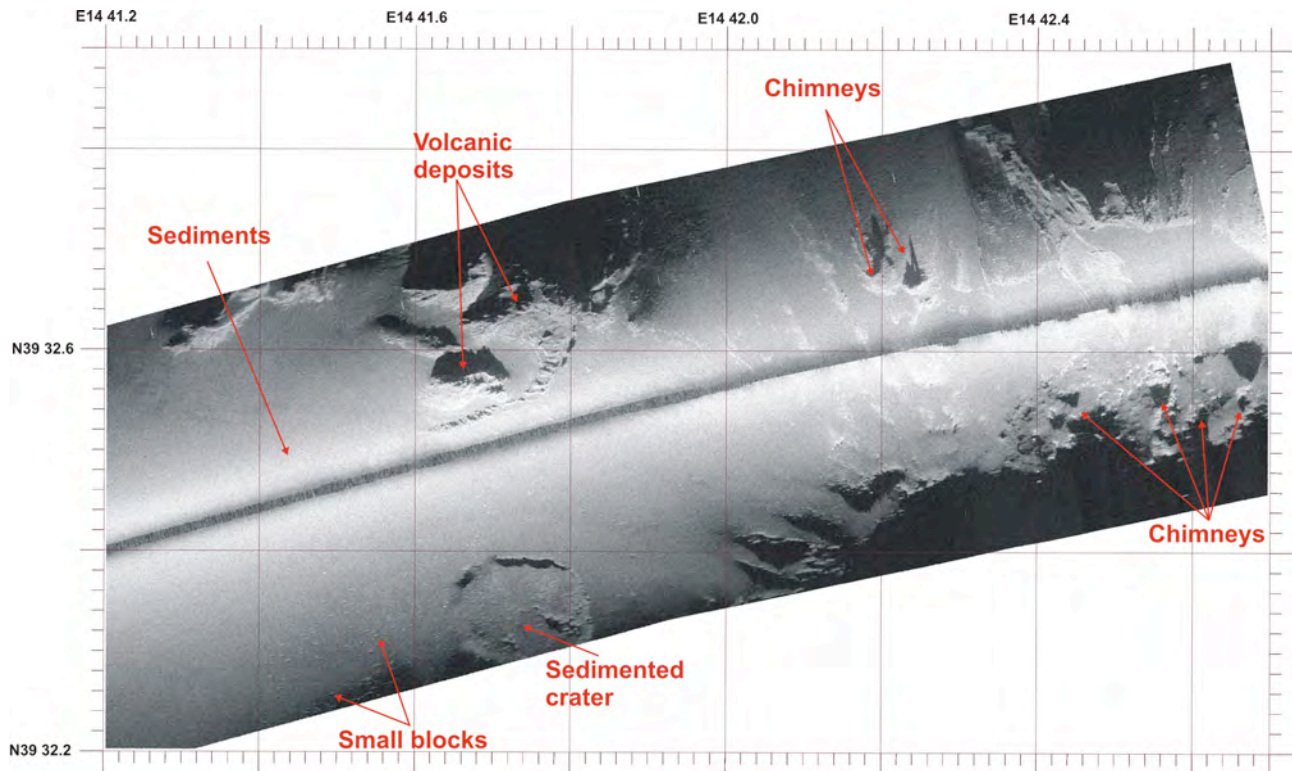


Fig. 20: Sidescan sonar profile processed with Caraibes showing the main elements of the study area: sediments, volcanic structures and chimneys.

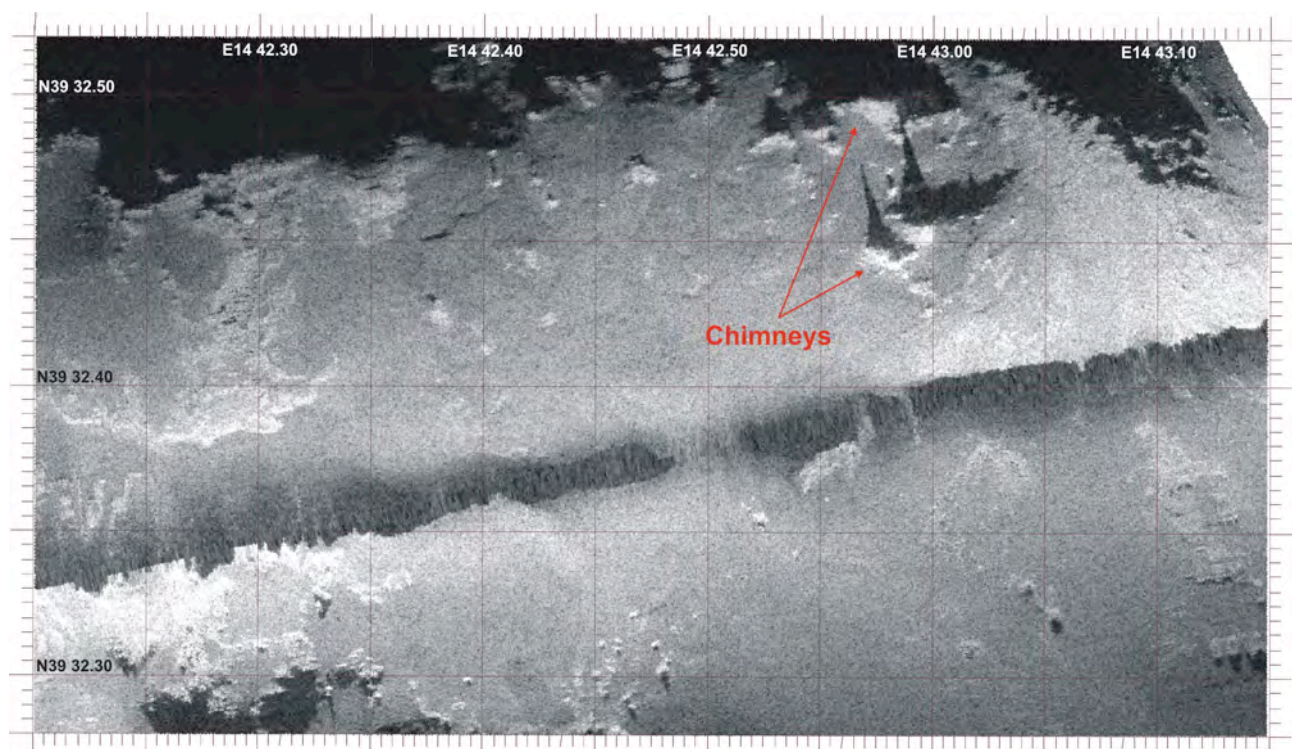


Fig. 21: Detail of sidescan sonar profile processed with Caraibes showing the most prominent hydrothermal chimneys (see Fig. 17).

4.5 Magnetic data acquisition

L. Cocci, S. Plunkett, and N. Augustin

Magnetic data was collected by the AUV on dives #115, #117, #118, #120 and #121. The AUV is equipped with an Applied Physics Systems flux gate magnetometer, writing to a stand-alone data logger, relying on the AUV for power. The magnetometer and data logger are placed within a titanium pressure housings on a titanium outrigger frame mounted at the lower front of the AUV, to maximize the distance between the magnetometer and the magnetic sources within the AUV.

At the beginning of each dive, the AUV performs a set of calibration manoeuvres, involving a pair of 360-degree rotations on the plane, and a set of three upwards and downwards pitches, and three port and starboard yaws on each of the principle headings. These manoeuvres are carried out at 50m depth, with the vessel laterally separated from the AUV by at least 500m, as far from the magnetic sources of the seafloor geology and vessel so that the calibrations are made in an area of relatively constant magnetic field. From this, the three dimensional variation of the magnetic field of the AUV at the magnetometer (which is a product of magnetic sources on the AUV and the earth's magnetic field) is modelled mathematically (with respect to pitch and heading, roll is a minimal factor as the AUV generally maintains a very stable roll attitude) and applied as a correction to the observed magnetic field, to leave only the magnetic field due to seafloor magnetisation variation.

The magnetic field of the AUV at the magnetometer varies throughout a range of $\approx 800\text{nT}$, while the magnetic field 100m above Palinuro has a range of around 1200nT , making the compensation of magnetic data very important, and some small residual errors between lines are still evident in some areas of the surveys. Note that diurnal variation has not been corrected for, but its effects (long period drift in the earth's magnetic field) are not evident in any of the seafloor magnetic data collected.

Dive #115 was surveyed at a nominal altitude of 100m, with a line spacing of 150m, in several different line directions. As a result, high frequency anomalies of linear features did not translate well to the final grid, but the correlation of the intersections of the survey lines with these high frequency anomalies reveal that they are mostly related to faults oriented in a generally North to South direction, correlating well with faults observed in the bathymetric data (Fig. 22). The intensity of the magnetic field reveals a high degree of demagnetisation has taken place, creating a large low magnetic anomaly centred on the crater type area between the western peaks, and on the seamounts directly east of this. A greater intensity of this demagnetisation is also likely to be responsible for the clear local magnetic field anomalies of the faults, which form conduits for hydrothermal fluid flow. Interestingly, there are several areas of higher magnetic field located on the flanks of the larger peaks (often in correlation with additional volcanic features in the bathymetry, especially obvious on the northwest of the main seamount) peripheral to the survey area, along with some of the small ridges in the northeast. These can be interpreted as relatively unaltered volcanic regions, due either lower permeability, no intersection with faults channelling the altering hydrothermal fluids, or potentially younger features that have not been altered as yet.

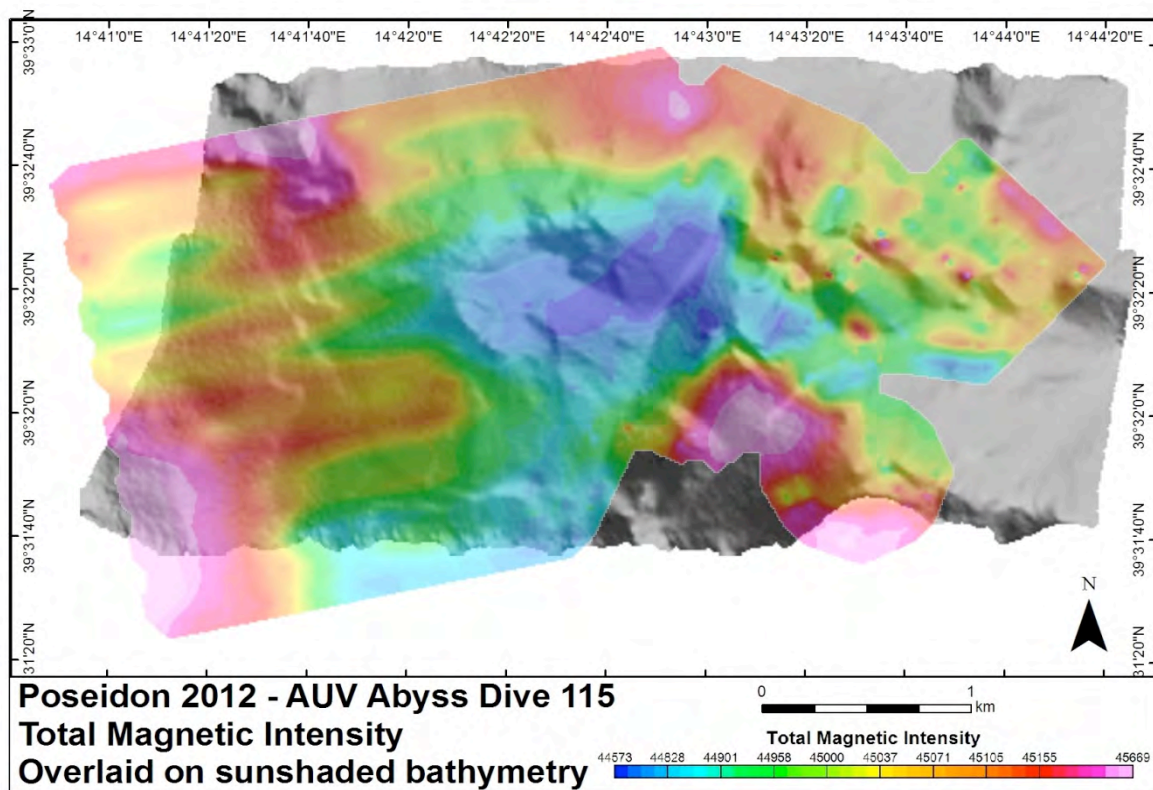


Fig. 22: Total magnetic intensity collected on AUV dive #115, at 100m altitude with 150m line spacing at West Palinuro.

Dives #117 and #118 were surveyed at a nominal altitude of 40m, a line spacing of 100m, and a variety of line directions. The same features as above were observed, with some extension further to the west. Acoustic surveys on these dives identified widespread chimney areas, with potential mounds, and it was hoped that the near seafloor magnetic data would identify demagnetised magnetic low anomalies corresponding to the sulphide occurrences. However, the magnetic field is dominated by the large scale anomalies related to alteration of the host volcanic, making it difficult to identify smaller (both laterally and in intensity) anomalies that may be related to seafloor sulphide deposits (Figs. 23 and 24). The line spacing of 100m also makes it difficult to correlate smaller anomalies between adjacent survey lines, with the exception of faults, which can be identified by their consistent strike across several lines.

The magnetic data collected on dive #121 is an extension to the multibeam survey of dive #115. This area is almost completely covered by magnetic surveys of dives #117 and #118. The data has been processed, but in doing so, some large navigation errors were identified. So, before interpretation (and combination with the magnetic data from dives #117 and #118) can be carried out, the magnetic data will need to be merged with the corrected navigation obtained during processing of the concurrent multibeam data.

A high resolution 5m line spacing, 8m nominal flying height camera survey was carried out by the AUV on dive #120. The magnetic data collected from this dive is shown in figure 20 below. This data reveals subtle short wavelength variation in the magnetic field, not clearly visible in wider spaced surveys. Local magnetic field lows represent the effects of hydrothermal alteration in the near surface, and correspond well with the expected faults, as well with some of the observed (in acoustic data) chimney locations, and presumably coincident sulphide deposits.

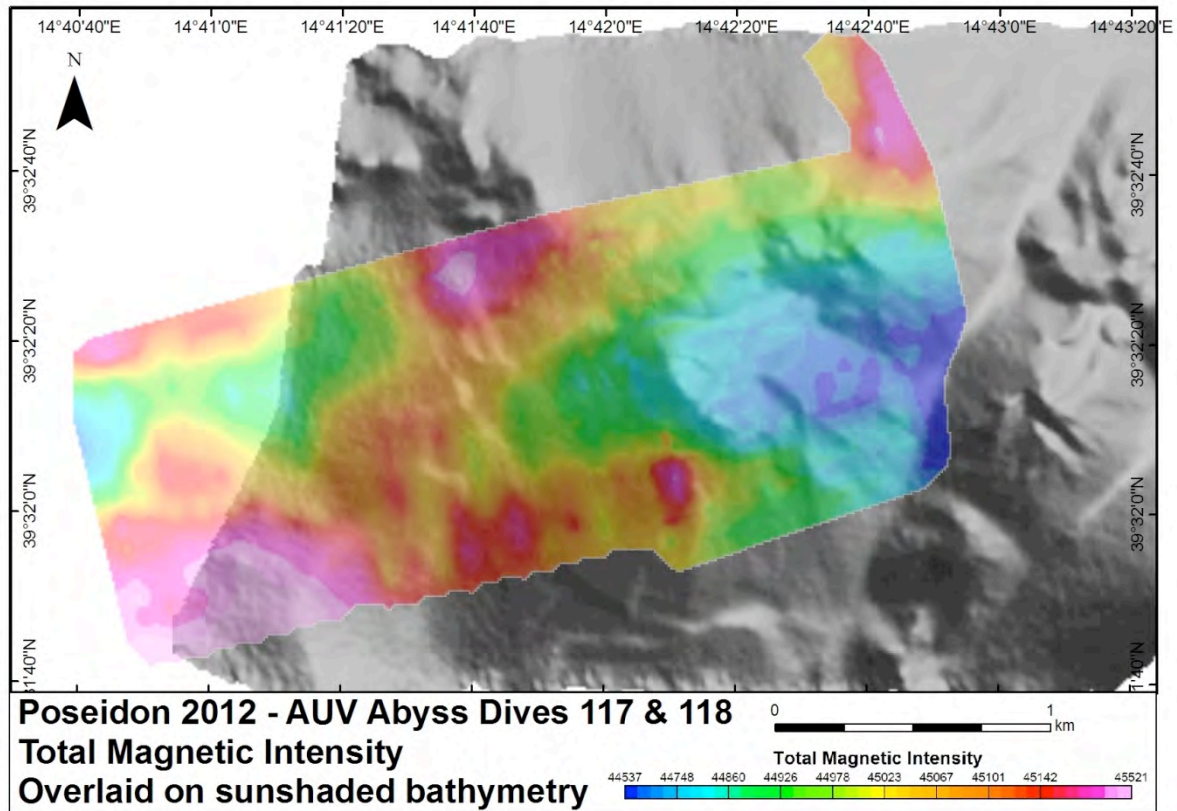


Fig. 23: Total Magnetic Intensity collected on dives #117 & #118, at 40m altitude with 100m maximum line spacing at West Palinuro.

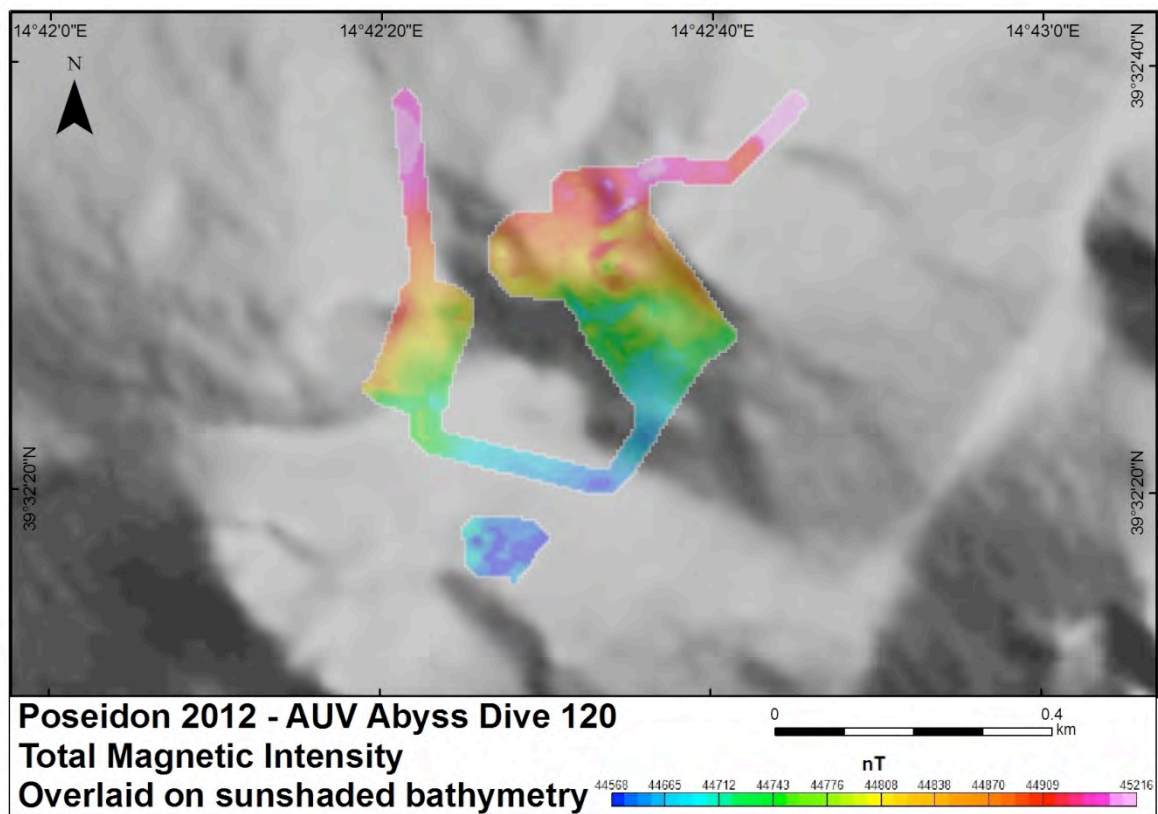


Fig. 24: Total Magnetic Intensity collected on dive #120, at ~8m altitude with 5m maximum line spacing over selected camera investigation sites on West Palinuro.

Performing reduce to pole transformation on this dataset does not move the anomaly locations appreciably, as the small sources are modelled as being right at seafloor already. However it does accentuate the residual compensation errors, so the total magnetic intensity is presented below, being a more easily interpretable dataset (with respect to differentiation of geological anomalies vs artefacts).

This dive does need some further processing. The roll calibration, which has been bypassed for the wider survey spacing is more critical here, due to the almost constant turning of the AUV between and while aligning with the short survey lines. The methodology of this will be similar to that of the pitch calibration, but will have to be carried out post cruise, due to lack of time on board. Figure 25 shows the remaining roll effect in the data. It also shows how important the compensation is, as the magnetic field of the AUV is much stronger than the subtle variations in the magnetic field here (which are a result of the seafloor geology).

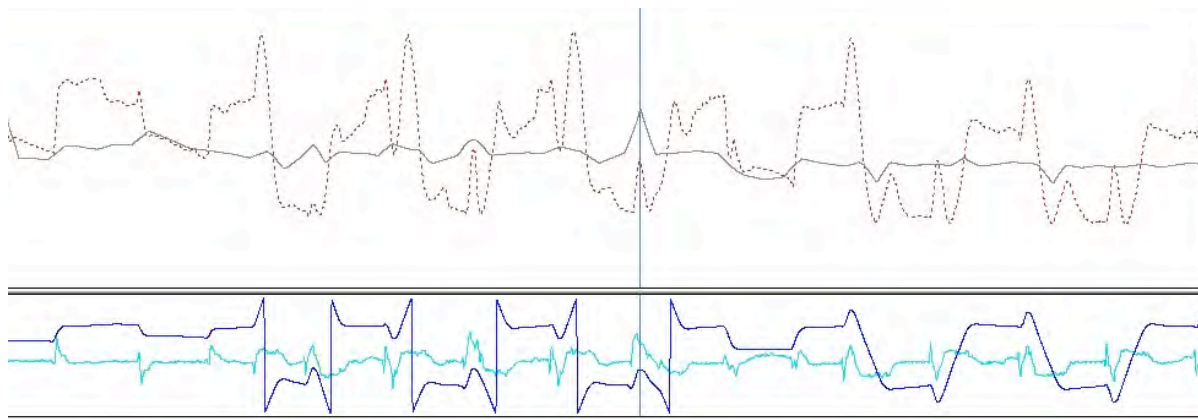


Fig. 25: Profile of a selected section of dive 120. The dashed red profile up top shows the raw uncorrected magnetic field, with the compensated version in black. The lower panel shows heading in dark blue, and roll in light blue. It is evident that many of the short wavelength spikes remaining in the compensated magnetic data correspond with the roll of the AUV. The roll of the AUV in this profile is centred on 0°, up to a maximum of slightly over $\pm 3^\circ$.

A full coverage survey of the sea surface magnetic field of the entire Palinuro volcanic complex was collected in 2008 (Figs. 26 and 27). The magnetic anomaly distribution shows a clear differentiation of the magnetic properties of the eastern and western sectors, which is very likely to be a direct result of variation in magnetisation (magnetic susceptibility) between the different sectors of the 70 km long volcanic complex. Smaller scale variations in the magnetic field are generally a result of localised magnetisation changes in the seafloor lithology, but may also be partially attributed to “topographic” effect caused by variation in the distance between the recording magnetometer and the seafloor (due to depth differences across the survey area). That is, at deeper depths, magnetic anomalies will have reduced intensity, and greater wavelength, and vice versa for shallower areas.

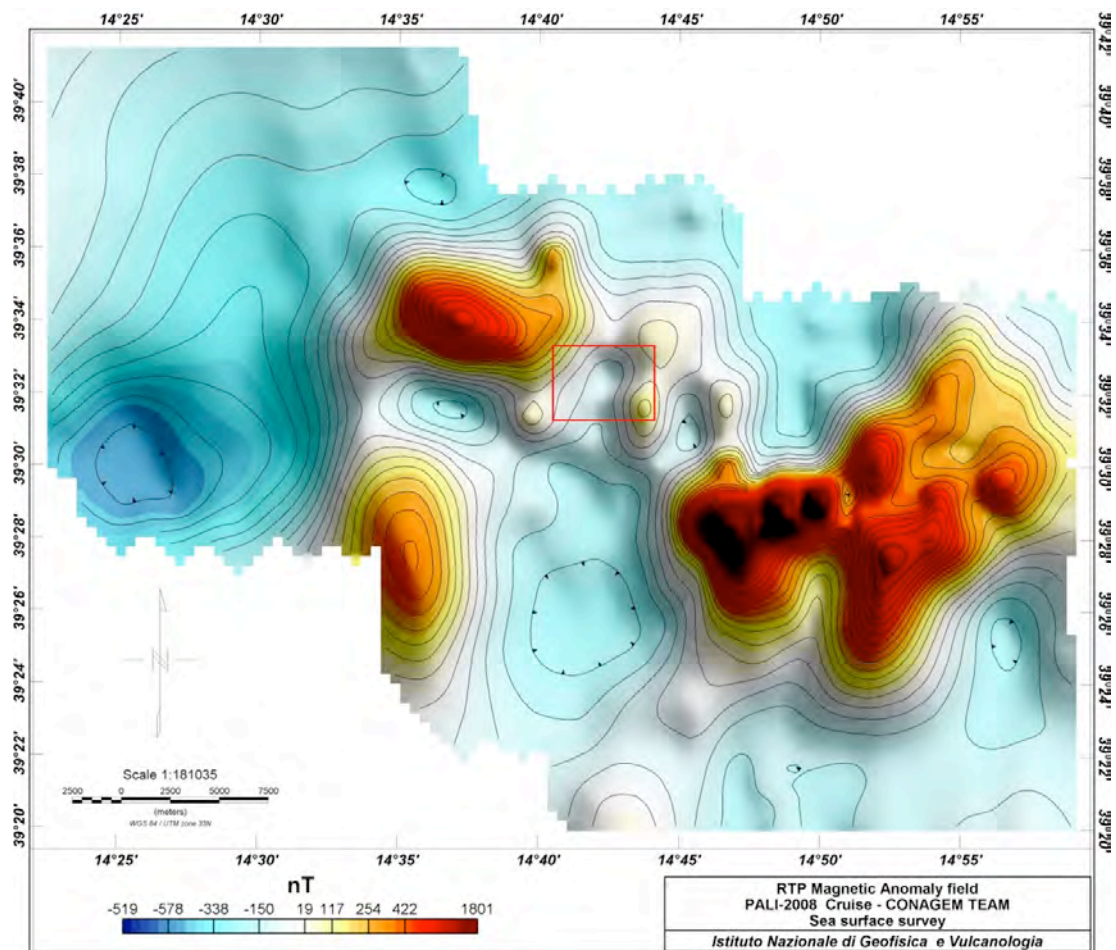


Fig. 26: Reduced to the Pole magnetic anomaly field collected during the PALI2008 cruise by INGV team in collaboration with the Italian Navy. The red box identifies the area investigated by the #117 and #118 AUV dives.

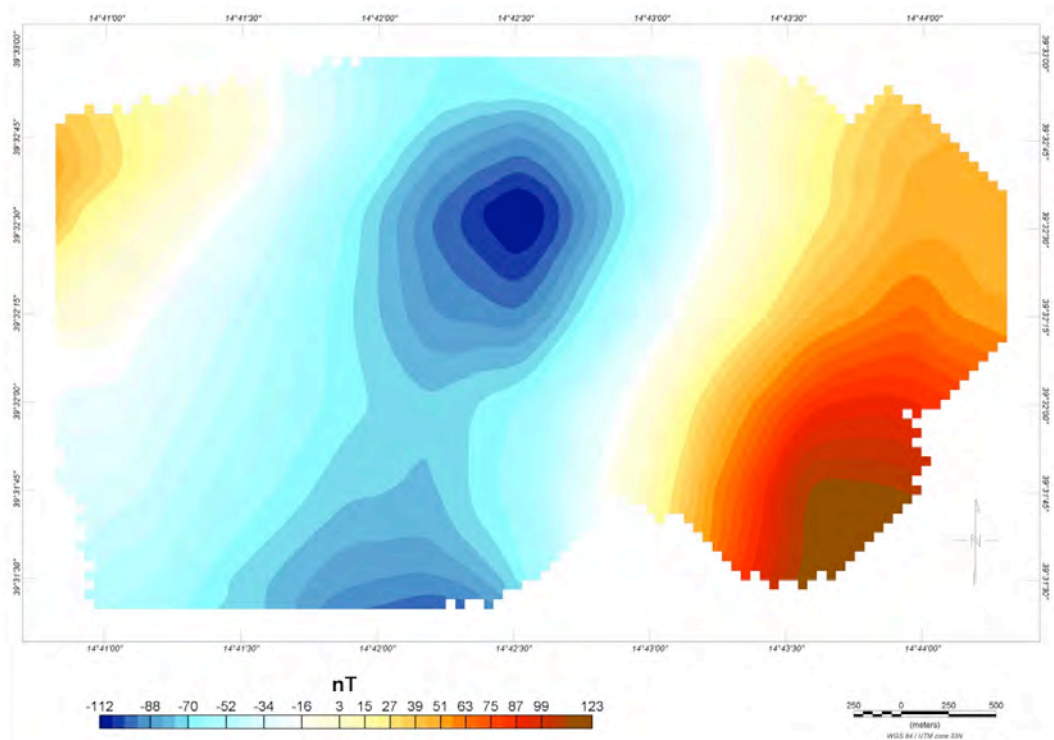


Fig. 27: Subset of the RTP sea surface magnetic anomaly as shown in figure 21 zoomed to the AUV survey areas.

This effect is most apparent in areas of steep bathymetric gradient such as the central-eastern sector of Palinuro. The western zone of the volcanic structure is characterised by a large magnetic low likely due to near zero magnetisation of the seafloor rock here. This pattern agrees with the presence of hydrothermal alteration and potential massive sulphides such as described by (Petersen et al., 2014). The low resolution of the sea-surface magnetic data does not permit fine scale interpretation of the local variation in the magnetic susceptibility of the seafloor. As pictured, over the AUV survey areas the sea surface rtp magnetic anomaly is dominated by a large low containing no small-scale information as to the local seafloor geology. Magnetic data acquired during these AUV surveys reveal unprecedented details of the seafloor magnetisation highlighting a complicated pattern mostly attributed to hydrothermal alteration. The new near bottom datasets show a magnetic low localised at the centre of the morphological depression with a geometry complicated by hydrothermal alteration related the main fault system and several sulphide chimney areas.

A strong correlation between mineralisation observed in acoustic datasets collected during this cruise, and the magnetic anomaly is evident in the reduced to the pole magnetic anomaly map shown in figure 28. The magnetic low also extends north down the flank of the volcanic peak, indicating potential hydrothermal alteration and mineralisation aligned along the north-south fault system in this area. At the eastern edge of this main magnetic low is a more intense anomaly clearly aligned along a NNE-SSW fault zone between the adjacent volcanic peaks. As expected, a simple inversion of this signal to seafloor magnetic susceptibility highlights near zero (within ± 0.01 SI) magnetisation of the seafloor coincident with this magnetic low anomaly.

The magnetic field of this area seems to be constrained by two main factors: the large area of low or near-zero hydrothermally demagnetised volcanic rocks and sulphide deposits and the intersection of fault systems that defines, at the large scale, the hydrothermally altered and potentially mineralised area.

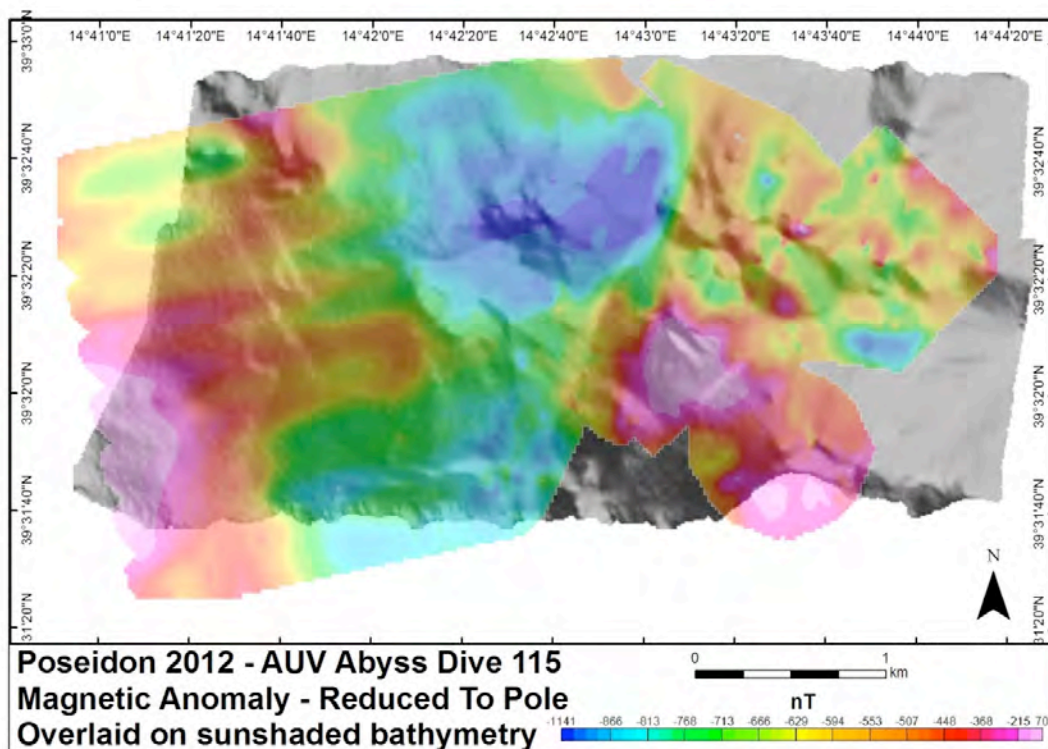


Fig. 28: RTP near bottom magnetic anomaly (dive #115) collected by the AUV, draped on bathymetry.

4.6 Photo survey

S. Petersen

A single dive was devoted to photography using the AUV's electronic still camera module (station 475AUV; dive #120; Fig. 29) flying at a very low altitude (ca. 5 m). The dive targeted at specific areas incorporating the area of drilled massive sulfides (drilled during M72/3 in 2007), areas that show evidence of chimney formation during previous AUV dives, namely in the eastern part of the crater. Due to the rough terrain and the inability of the AUV to follow the bathymetry in a smooth and gentle way, many photographs turned out to be out of focus. Therefore mosaicing, a proposed outcome from this survey, was not possible. The subsurvey over the largest chimneys was flown at an altitude of 20 m, however, the hard disk stopped recording before reaching this target.

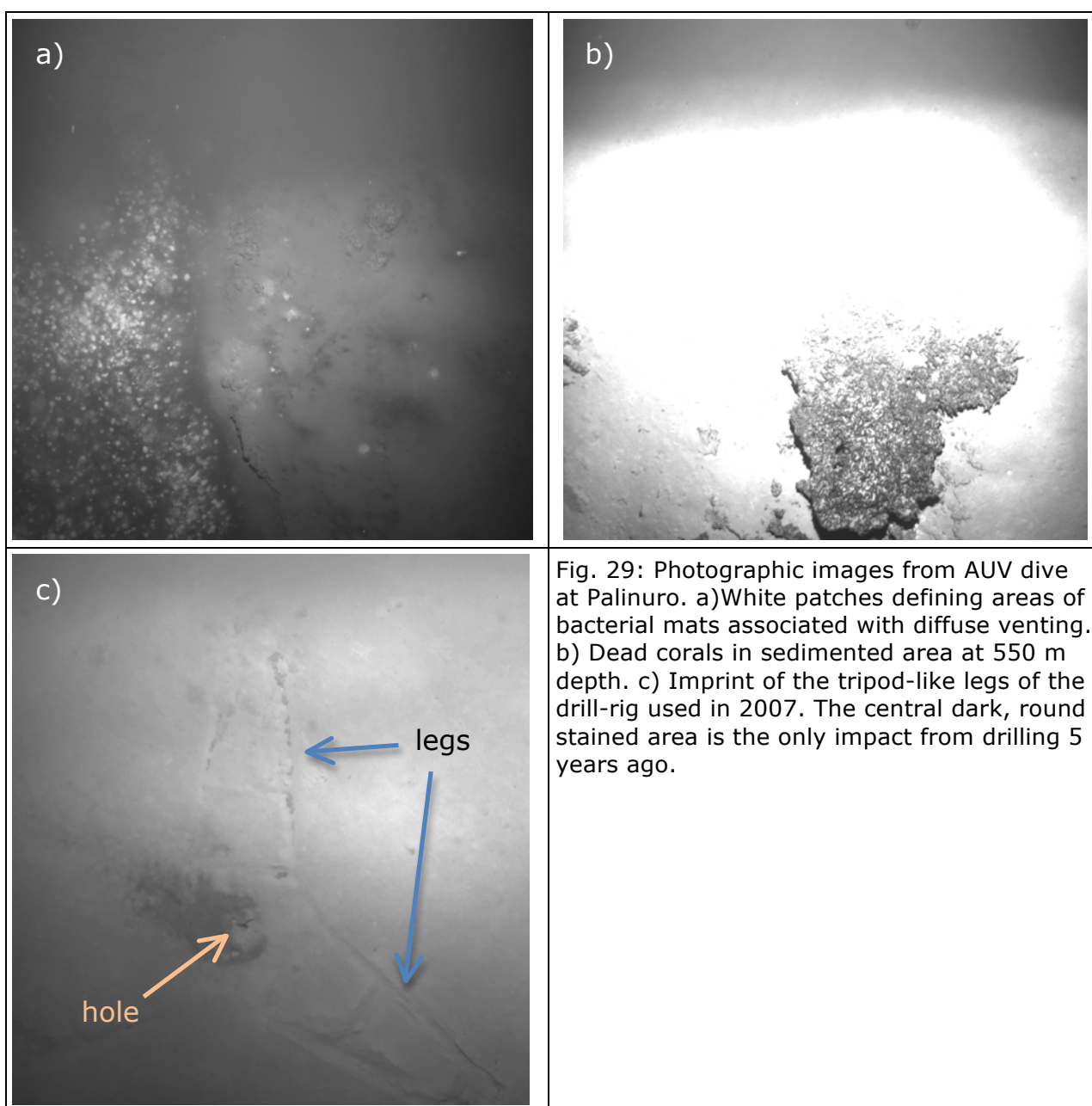


Fig. 29: Photographic images from AUV dive at Palinuro. a) White patches defining areas of bacterial mats associated with diffuse venting. b) Dead corals in sedimented area at 550 m depth. c) Imprint of the tripod-like legs of the drill-rig used in 2007. The central dark, round stained area is the only impact from drilling 5 years ago.

5 Station list

S. Petersen

Station	Gear		Date	Time	Position Lat.	Position Long.	Depth
POS442/468	AUV-TR	-	01.11.12	16:10	39° 33.10' N	14° 43.20' E	-
POS442/468	AUV-TR	-	01.11.12	16:27	39° 32.74' N	14° 41.83' E	784
POS442/469	AUV	start	02.11.12	09:08	39° 33.39' N	14° 42.38' E	1126
POS442/469	AUV	end	03.11.12	05:36	39° 31.64' N	14° 44.98' E	1034
POS442/470	AUV	start	03.11.12	18:49	39° 33.54' N	14° 42.38' E	1213
POS442/470	AUV	end	03.11.12	20:33	39° 32.45' N	14° 41.95' E	667
POS442/471	AUV	start	04.11.12	09:14	39° 33.56' N	14° 42.38' E	1180
POS442/471	AUV	end	04.11.12	15:40	39° 33.58' N	14° 42.34' E	1219
POS442/472	AUV	start	04.11.12	19:03	39° 33.55' N	14° 42.39' E	1213
POS442/472	AUV	end	05.11.12	06:00	39° 32.64' N	14° 43.10' E	750
POS442/473	MB	start	05.11.12	09:50	39° 29.66' N	14° 48.78' E	341
POS442/473	MB	end	05.11.12	15:11	39° 29.64' N	14° 49.23' E	212
POS442/474-1	AUV	start	06.11.12	06:28	39° 33.57' N	14° 42.36' E	1232
POS442/474-1	AUV	end	06.11.12	06:29	39° 33.57' N	14° 42.34' E	1198
POS442/474-2	AUV	start	06.11.12	07:10	39° 33.54' N	14° 42.43' E	1195
POS442/474-2	AUV	end	06.11.12	12:29	39° 32.86' N	14° 42.50' E	1187
POS442/475	AUV	start	07.11.12	07:12	39° 33.54' N	14° 42.42' E	-
POS442/475	AUV	end	07.11.12	12:39	39° 32.52' N	14° 42.54' E	-
POS442/476	AUV	start	07.11.12	18:50	39° 33.55' N	14° 42.40' E	-
POS442/476	AUV	end	08.11.12	05:50	39° 32.68' N	14° 41.57' E	-
POS442/477	AUV-TR	-	08.11.12	07:38	39° 32.77' N	14° 41.89' E	-
POS442/478	AUV-TR	-	08.11.12	08:08	39° 33.22' N	14° 43.22' E	-

6 Data and Sample Storage

All data from the AUV is stored at a dedicated server at GEOMAR (responsible: Mr. Marcel Rothernbeck) and will be made public after publication of the results. The bathymetric data is also stored on dedicated servers at GEOMAR (responsible: Dr. N. Augustin; email: naugustin@geomar.de) and will be made available to the appropriate Italian authorities and INGV at the end of 2015.

7 Acknowledgements

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