Metal fluxes and Resource Potential at the Slow-spreading TAG Midocean Ridge Segment (26°N, MAR) – Blue Mining@Sea

Bridgetown (Barbados) – Ponta Delgada (Portugal)
25.05.-28.06.2016
RV METEOR Fahrtbericht / Cruise Report M127
Extended Version

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1 Summary

Cruise M127 is an integral part of the EU-FP7 project “Blue Mining: Breakthrough Solutions for the Sustainable Deep Sea Mining Value Chain” and is addressing research questions regarding the nature and resource potential of marine minerals, especially seafloor massive sulfides (SMS) along mid-ocean ridges. The cruise left from Bridgetown (Barbados) in the evening of May 25th and reached the working area at 26°N on the Mid-Atlantic Ridge on May 30th (Fig. 1.1). One of the main tasks during the cruise was mapping of the TAG segment (26°N) in various resolutions. This included ship-based multibeam mapping over the entire length of the ridge segment as well as high-resolution mapping using an autonomous underwater vehicle (AUV) flying close to the seafloor (40-100 m altitude).

The ship-based multibeam mapped along 710 nautical miles of profile lines covering approximately 7,000 km² in the working area. Another 1,800 nautical miles of lines were mapped on the transit from Barbados to the working area and from there back to the Azores. The AUV was used on 19 missions, usually with survey times close to the seafloor of between 10 and 12 hours. Most dives provided maps with a resolution of 2 m and collected a number of other parameters with its sensors at the same time. Two dives were devoted to mapping points of interest in 50 cm resolution.

Seismic work, as the 2nd important part of the cruise, included refraction and reflection seismics with airgun shots and multichannel seismic streamer records being compiled along 49 profiles on 8 survey runs (230 nautical miles in total length). Additionally, 22 ocean bottom seismometers (OBS) and 9 ocean bottom hydrophones (OBH) deployments were undertaken. The seismic work was hampered by problems with the compressor, for which the oil could not be cold enough at the beginning. This was later solved with the help of the ships crew. Deep-towed streamer work could also not be performed because of continued problems with the streamer that could not be resolved on board. A series of 6 ocean bottom electro-magnetic stations (OBEM) were deployed as preparation for the up-coming RRS James Cook cruise, which is also part of the Blue Mining project.

A modular towed instrument platform (HYBIS) was used to deploy 10 of the (OBS) to the seafloor with high precision. Since this platform has built-in cameras and can be equipped with a sampling module we used this instrument later in the cruise to further visually inspect the seafloor and select locations for sampling.

The final instrument being used was a short (3m) gravity corer for sediment sampling. In the course of the cruise 35 stations were attempted of which 22 stations successfully retrieved sediment for some of which ship-board analyses showed very high concentrations of copper. Rock fragments were recovered in 9 stations indicating the volcanic nature of those sampling stations. At the end of the cruise all Ocean Bottom Seismometers (OBS) were recovered. Only the six OBEM were intentionally left behind.

Station work in the working area ended on 20:30 LT on June 23rd when the 5 day transit to Ponta Delgada was started. During the transits from and to the working area 3 ARGO floats were deployed and the ship-based multibeam and the 75-kHz ADCP collected data in international waters. The cruise ended 09:00 LT of June 28th with docking in Ponta Delgada.

Overall on 1/3 of the cruise was used for the transit and 2/3 for stations work and transits within the working area (Fig. 1.2). Most of station time was devoted to geophysical work including seismic profiling and the deployment and recovery of the instruments.
Fig. 1.1: Map of the cruise track from Bridgetown (Barbados) to Ponta Delgada (Azores, Portugal). Insert shows cruise track in the working area with ship-based bathymetry (red lines) and seismic profiles (other colors). Other station work is limited to the very center of this map.

Fig. 1.2: Cruise time-use statistics. A) About 2/3 of the ship time was spent in the working area with the remaining 1/3 spend on the long transits to and from the working area. B) Seismic profiling (27%) and ship-based multibeam mapping account for most of the station time being used. This is followed by the deployment/recovery of OBS and OBH (17%; combining deployments in free-fall mode and by HYBIS), gravity coring, and geological dives using HYBIS. Deployments of the OBEM via cable as well as the deployment and recovery of the AUV used minimal ship-time. The AUV used 20.5 h of ship-time while mapping the seafloor for 161 h.
## Participants

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FFCUL          Fundação da Faculdade de Ciências da Universidade de Lisboa (Portugal)
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Memorial       Memorial University of Newfoundland, St. Johns (Canada)
DWD            Deutscher Wetterdienst, Seeschiffahrtsberatung, Hamburg (Germany)
3  Research program

(S. Petersen)

Cruise M127 is an integral part of the EU-FP7 project “Blue Mining: Breakthrough Solutions for the Sustainable Deep Sea Mining Value Chain” that is, among others, addressing research questions regarding the nature and resource potential of marine minerals, especially seafloor massive sulfides (SMS) along mid-ocean ridges. These deposits are often seen as a possible future contribution to a secure metal supply for global human needs. Resource estimates, however, are lacking several of the fundamental answers that need to be addressed. There are currently several orders of magnitude between resources estimates based on observations at the seafloor and those based on calculated metal fluxes. In order to provide realistic resource estimates, we need to understand how much of the metal that is released by high-temperature fluid convection over a given length of a ridge axis and over a specific geological time frame is actually deposited as massive sulfides. Additionally, exploration is currently only targeting active deposits. It is assumed that 10 times more inactive massive sulfides are occurring within the neovolcanic zone, but until recently the technology to identify those deposits was lacking thereby underestimating the global resource potential. Within the framework of the Blue Mining project some of these technical limitations are addressed and this provides us with the tools to address, for the first time, the full metal potential and fluxes of a slow-spreading mid-ocean ridge.

Slow-spreading mid-ocean ridges, such as the Mid-Atlantic Ridge are known to host accumulations of large submarine massive sulfide (SMS) deposits. The TAG Hydrothermal field at 26°N on the Mid-Atlantic Ridge, for instance, is characterized by a large active black smoker complex and by several similar-sized inactive (eSMS) sites, despite the fact that only small areas of this ridge segment were ever investigated in detail. This area was therefore chosen as the working area for the seagoing activities within “Blue Mining”. In the time between submitting the Blue Mining proposal to the EU in 2013 and the Meteor M127 cruise in 2016, the French Research Institute for Exploitation of the Sea (IFREMER), has obtained an exploration license for seafloor massive sulfides from the International Seabed Authority in 2014.

During our cruise, detailed high-resolution AUV-based mapping on a segment scale combined with 2D seismic observations and the investigation of surface sediments will help to answer the following scientific questions:

1) What is the accumulation rate of sulfide formation at a slow-spreading ridge and how does it change over time?
2) Is there more sulfide present in inactive deposits compared to active deposits?
3) What are the regional and local spatial controls of these large hydrothermal fields?
4) What is the 3-dimensional structure of inactive sulfide deposits?
5) How far out (back in time) can we trace hydrothermal activity using geophysical and geochemical instrumentation (AUV-based surveys plus sediment geochemistry)?

The rationale behind these questions is the following:
Q1) What is the accumulation rate of sulfide formation at a slow-spreading ridge and how does it change over time?

We do not know how much of the metal that is released by high-temperature fluid convection over a given length of a ridge axis and over a specific geological time frame is actually deposited as massive sulfides. There are simply no systematic surveys for massive sulfide abundance on a ridge segment scale and back in time (away from the ridge axis). Even the amount of sulfide along the neovolcanic zone is likely highly underestimated. In a recent survey within known vent sites at the Endeavour Segment, AUV-based high-resolution bathymetry was used to identify extinct sulfide chimneys and mounds. There, in only eight 18-hour dives the number of chimneys and mounds present was quadrupled (Jamieson et al., 2014). This is especially noteworthy since this vent site has seen well over one hundred submersible and ROV dives over the past 30 years and is considered to be the best studied submarine hydrothermal field on Earth. The total sulfide tonnage estimated from the high-resolution data at this vent field is now 1.2 Mt, a four-fold increase compared to the previous estimate of 0.3 Mt largely based on active structures. Thus, the global inventory of submarine hydrothermal deposits may be similarly biased towards active systems, and the $3 \times 10^9$ t Cu+Zn global estimate by Hannington et al (2011) should be considered a minimum, even for the neovolcanic zones.

Q2) Is there more sulfide present in inactive deposits compared to active deposits? and
Q3) What are the regional and local spatial controls of these hydrothermal fields?

If there is indeed more sulfide present in inactive deposits, how do we explore for such inactive occurrences in a fast and cost-efficient way? The hypothesis is, that large eSMS deposits can be found in a strip of a few tens of kilometers away from mid-ocean ridges at only a few meters below a sediment or lava carapace. The potential to find sulfide deposits that far from the ridge axis opens up a vast area of the seafloor for future exploration. However, without a distal signature, e.g. a geochemical or geophysical anomaly that is detectable over hundreds of meters or even kilometers away from deposit, and with only poorly constrained geophysical properties, inactive deposits are difficult to locate or evaluate. Without a better understanding of their size, structure, and distribution, the resource potential of eSMS remains uncertain. Knowledge about the regional and local spatial controls of sulfide deposition are currently still lacking. This is largely a reflection of the lack of high-resolution investigations away from the spreading centers. However, large inactive deposits have been discovered in the past few years, especially at slow-spreading ridges. These include the Krasnov, Semyenov, and Petersburg sites (Cherkashov et al., 2010; Shilov et al., 2012) that are estimated to contain up to 14 million tonnes of sulfides in the case of Semyenov and Krasnov (Cherkashov et al., 2010). As stated above, these systems cannot be found with traditional exploration technologies that are looking for geochemical or geophysical tracers in the water column. Russian scientists used time-consuming towed geophysical and electrochemical sensor-package operations for their discoveries up to 12 km away from the ridge axis (Petersburg deposit; Shilov et al., 2012). Their systematic surveys use a so-called self-potential sensor package that is towed close to the seafloor. In order to be able to cover larger areas of the seafloor, the Russian research vessel spends about 6 months at sea every
year on exploration. Techniques to identify such deposits time and cost efficiently on a regional scale are still lacking. We currently also lack the ability to identify buried deposits (beneath a few meters of sediments or lava) thereby further underestimating the resource potential of explored areas. This limitation results in a narrow exploration corridor as we can only venture off-axis, when we can detect deposits under cover. Sediments may provide such a far-field halo around inactive deposits at a scale comparable to that of plume mapping. Although sediment geochemistry has been a standard tool in marine geology for over a century, there have been few modern advances to adapt this technique to the search for marine minerals. This contrasts with the search for ore deposits on land, where exploration geochemistry has achieved a high degree of sophistication, including the application of ultra-sensitive tracers such as mobile metal ions and pore-fluid gases. Depth profiles of metals in the sediments can potentially be used to estimate the age of a source (and how far away it might be, based on spreading rates), but few sensitive mineralogical, geochemical or isotopic vectors have been tested that could be traced back to metal sources more than 1-2 km distant or at depth below the sampled core. Gravity coring and ship-based analytics (e.g. portable XRF, PIMA, portable XRD) in combination with structural interpretation of AUV-based high-resolution self-potential, magnetics, and bathymetry data may open up a new frontier in exploration technology and were tested during this cruise. Geophysical and geochemical vectors to ore may then help answering scientific questions on metal accumulation rates over time and metal fluxes.

Q4) What is the 3-dimensional structure of sulfide deposits?

SMS deposits are three-dimensional bodies and therefore any resource estimate must build on depth information. Tonnage calculations reported for most known seafloor deposits, however, are only based on interpretation of visual surface information of the outcrop thickness and lateral extension as well as on distribution of Fe-staining at the surface. In many cases, these estimates are considered to overestimate their size and tonnage (Hannington et al., 2011). For example, the tonnage estimates for Krasnov and Semyenov are entirely based on visual surface observation in combination with chemical composition of surface samples. Finding these deposits is not enough. Resource estimates need reliable subsurface information. Drilling is currently the only technology that provides depth information of SMS deposits and has only been performed for few deposits. Since drilling is very expensive, there is a pressing need to develop or modify existing technologies to gain subsurface information. Geophysical tools such as seismic and marine electromagnetics (EM) could provide this information. Due to the rough morphology reflection seismic data collected at the sea surface will be heavily disturbed by side echoes and diffraction events, which can partly be suppressed with modern seismic processing techniques (e.g. Peirce et al., 2007). Refracted seismic events from Ocean Bottom Seismometers (OBS) can be used to further improve reflection seismic images (e.g. Planert et al., 2010). These techniques have so far mainly been applied to crustal scale investigations and were, in the framework of this cruise, tested for investigating shallow eSMS deposits.

Q5) How far out (back in time) can we trace hydrothermal activity using geophysical and geochemical instrumentation (AUV-based surveys plus sediment geochemistry)?
As stated above, exploration for inactive sulfide occurrences is mainly limited to the immediate surrounding of active vents sites. One of the aims of cruise M127 is to test, if AUV-based mapping technologies or sediment sampling at the surface are able to detect mineralization under cover. In the case of the TAG segment, the detection of indications for mineralization under the sediment cover along the eastern rift valley wall, where slumps are expected to occur that cover the younger volcanic rocks was tested. Time depending, we wanted to extend the map as far east, and away from the ridge axis, as possible. Ground truthing of these targets, however, was beyond the scope of this project, as this would rely on drilling operations.

Specific technology topics of interest within “Blue Mining” that were addressed during cruise M127 were:

1) Test of AUV-based self-potential sensor package for use in exploration of inactive sulfide occurrences (eSMS).
2) Produce regional, high-resolution topographic maps to aid a geochemical study of surface sediments (cover rocks) to identify concealed sulfide mineralization.
3) Produce high-resolution topographic maps of eSMS to aid the drilling program for RRS James Cook cruise JC138, scheduled for July/August 2016.
4) Provide high-resolution geophysical sections across type examples of eSMS.

4 Narrative of the cruise
(S. Petersen)

Preparations for the seismic work and the setup of the AUV during the port call in Bridgetown resulted in the presence of several members of the scientific crew well before the official boarding. Leaving the ROV Quest on board for M128 provided additional constraints on the logistics since five containers with material came from Kiel, and were met by two containers with seismic gear that came from RV Sonne via New Zealand. Preparations were interrupted on May 23rd by an official banquet on the vessel organized by the German consulate/embassy and the ship’s crew. Guests from the island were introduced to the ship and the scientific instruments were presented. The science party was complete on the evening of Wednesday May 25th when RV Meteor left port at 21:00 LT after a search for stowaways. The luggage of 3 scientists and 8 crewmembers never made it to Bridgetown. The transit time was used to set up the labs of the various working groups, to prepare the AUV, HyBis and the mobile winch (Werner-Winde), and for scientific talks describing the goals of the various working groups. Since leaving the Exclusive Economic Zone of Barbados on 20:00 LT on May 26th (May 27th 00:00 UTC) the 75 kHz ADCP and the Kongsberg EM122 multibeam echosounding system collect transit data that will be made publically available directly after the cruise.

In the afternoon of May 29th, the transit was interrupted in order to deploy an ARGO float for the MOCCA project. Two more floats follow at the end of the cruise as we approach Ponta Delgada. The stop was used to obtain a sound velocity profile (#557XBT), for a short test deployment of HyBis (#558HYBIS) and the AUV (#559AUV), both showing the need for additional maintenance, and a test of all releasers to be used for OBS/OBH/OBEM deployments.
The ARGO float was deployed as the final station of this stop before continuing the transit. After repairing HyBis, a second short break of the transit at noon on May 30th allowed a further test of this instrument as well as of the releasers that didn’t perform the day before. A few hours later, station work in the working area (TAG segment at 26°N on the Mid-Atlantic Ridge) started just before midnight on May 30th with acquiring a new sound velocity profile.

The early morning hours of May 31st saw a multibeam survey that mapped the central part of the segment before testing and adjusting the AUV buoyancy and trim (08:00 – 11:20 LT). The afternoon was used to deploy the first of six Ocean Bottom Electro-Magnetic stations that will be recording variations in the electromagnetic field in passive mode for the duration of this cruise. They stayed on the seafloor, however, and were used for passive and active controlled-source EM works before and during the following RRS JAMES COOK cruise in July/August 2016. In order to provide more accurate positions of these stations they are deployed on the cable and aided with subpositioning using POSIDONIA. At 18:30 LT the AUV was deployed for its first real mission. The night was used to enhance the coverage of the existing bathymetric map of the area.

June 01st was used to deploy four more OBEM stations with two short breaks related to the recovery of the AUV in the late morning and its redeployment in the afternoon. One OBEM station did not release and had to be deployed a second time. The OBEM stations are located on a WNW-ESE profile line spanning a distance of 3 km across two known inactive sulfide mounds in the Alvin Zone, the Shinkai Mound and the Southern Mound.

A first gravity corer was placed in the northern part of the working area on June 2nd to obtain background sediment, followed by a short multibeam survey. Two OBS instruments were placed near the active TAG mound. A seismic profile line was started using the surface streamer, but had to be cancelled after six hours due to a failure of the air compressor. The two OBS instruments were released and recovered. In the evening the AUV was launched.

During night-time of June 03rd two gravity corers were deployed in the faulted terrain in the west, both returning empty. These stations were followed by a short multibeam survey to detect water column signals associated with active venting. Three OBS instruments were deployed on the flanks and the top of Shinkai Mound using the cable to aid deployment with POSIDONIA subpositioning. Between these stations the AUV was recovered at 11:25 LT.

The early morning hours of June 4th were devoted to gravity coring on a profile line towards the active TAG mound. Station was placed close to a previous location and returned empty again, while station returned volcanic glass. Later, a series of 6 OBS instruments was deployed in free-fall mode. Two further OBS instruments were deployed at the flanks of Shinkai Mound via the cable to finalize the network.
over this extinct sulfide deposit (#596HYBIS, #597HYBIS). From 19:40 LT to 22:00 LT the AUV AYBSS was occupying the vessel as it was send on a calibration mission for the magnetometer at shallow water depth (#599AUV; AYBSS dive 227) and was supposed to be reprogrammed for the next mission at the sea surface via WIFI connection (AYBSS dive 228). The connection was lost, however, and the AUV had to be recovered, was reprogrammed in the LARS and then redeployed for AYBSS dive 229 all under the same station number. During the night two gravity corer stations were performed in small basins near the western side of the working area (#600GC, #601GC).

These two stations were followed on Sunday June 05th by a series of 6 OBS and OBH deployments (in free-fall mode) covering the periphery of the seismic network (stations #602OBS to #607OBH). Later that day, a set of three OBS instruments was deployed on the top and the flanks of Southern Mound, a second large inactive sulfide occurrence in the Alvin Zone (#608HYBIS, #609HYBIS, #611HYBIS). In between the HYBIS stations the AUV AYBSS was recovered at 11:42 LT and then later deployed again at 18:00 LT for its next mission (#610AUV; AYBSS dive 230). Just before midnight the last 3 free-falling OBS stations were deployed (#612OBS, #613OBS, #614OBS).

The early morning hours of Monday June 06th started with 3 gravity coring stations (#615GC, #616GC and #617GC) in the eastern part of the working area that collected short (< 2m) sections of hydrothermally influenced sediments. Around 09:10 LT the AUV Abyss was recovered after finishing its 5th mission of the cruise (#610AUV; AYBSS dive 230). During the day, HYBIS was used to deploy the two remaining OBS on the Southern Mound (stations #618HYBIS and 619HYBIS). The day was finished with yet another AUV launch (#620AUV; AYBSS dive 231).

A long multibeam profile was conducted during the night covering parts of the western rift flank and the northern continuation of the ridge segment (#621MB). In the morning of June 07th the AUV was recovered at 08:09 LT (#620AUV) while rain showers and winds up to 7 Bft from a small weather front passed the vessel. These conditions improved slightly for the following deployment of the deep-tow streamer and airguns that started at 09:50 LT (#622MCS). Seismic profiling continued during the day, however, problems with the electronics and an overturning air gun required pulling in both, the airgun and the deep-tow streamer, and replacing them with the surface streamer and a second airgun.

Seismic profiling using the surface streamer continued through most of June 8th and was only briefly interrupted for the deployment of the AUV in the late evening (21:05 LT; #623AUV; AYBSS dive 232). Seismic profiling continued during the night (#624MCS) and finished on Thursday June 9th at 10:59 LT. The Meteor moved then to the recovery position for the AUV, which was taken aboard on 12:30 LT (#623AUV; AYBSS dive 232). Since the problems with the deep-towed streamer were not resolved, the surface streamer was redeployed for additional profile lines over the inactive sulfide mounds and the proposed detachment fault hosting the deposits (#625MCS). The streamer was recovered just before midnight (LT).
A series of three gravity corers was deployed on June 10th recovering 120 cm of variably hydrothermally influenced sediment from the Shimmering Mound area in the northern part of the Alvin Zone (#626GC) and 300 cm of Fe-oxhydroxides and sulfides from a distinct basin structure (called “Central Area”; #627GC). The third station was placed in the vicinity of Shinkai Mound and returned empty (#628GC). Beginning at 07:55 (LT) a series of five OBH instruments (#629OBH to #633OBH) were released and recovered. One instrument did not release. A short multibeam profile (#634MB) was followed by the launch of the AUV at 20:43 LT (#635AUV; ABYSS dive 233). The mission was aborted shortly after its start due to a mission timeout when the AUV dropped its weight and resurfaced. The mission was restarted as ABYSS dive 234 at 21:35 LT.

The night to June 11th saw the deployment of three gravity corer stations, all of which had low recoveries (#636GC to #638GC). The morning was used to redeploy four OBH instruments. The instruments were positioned along a 4 km long profile over a proposed detachment fault in the northeastern part of the working area (#639OBH to #642OBH). The AUV was recovered at 13:02 LT. A 22-hours long multibeam station extended the existing bathymetry to the next segments in the north and south (#643MB).

Two gravity corer stations were deployed in the afternoon of June 12th. The first corer (#644GC) was deployed in the “Central Area” and recovered 269 cm of strongly layered hydrothermal sediment. Station #645GC recovered 131 cm of pelagic sediment from a basin west of the MIR Zone with a small interval of hydrothermally influenced material at shallow depth. Seismic profiling (#646MCS) started at 20:57 LT and continued until the early afternoon of June 13th. The remainder of that day was used for two gravity corer stations (#647GC in the Central Area and #649GC east of the MIR Zone) interrupted by the deployment of the AUV (#648AUV; ABYSS dive 235) at 20:11 LT.

The night hours of June 14th were used to extend the bathymetric map (#650MB). During the day HYBIS was used twice to investigate the nature of targets identified in the AUV-based bathymetric data either by their relief or by their geophysical response to the AUV sensor package (magnetics, SP, temperature, Eh). Station #651HYBIS confirmed the hydrothermal nature of mound 27, while station #652HYBIS showed that mound 29 is also a structure formed by hydrothermal processes. The AUV was recovered between the two HYBIS stations. At 19:49 LT seismic work continued with a surface streamer survey during station #653MCS that lasted until the next afternoon. The evening of June 15th was used to recover 11 OBS stations (#654OBS to #664OBS). The AUV was deployed for its next mission on 22:12 LT surveying the southern part of the working area (#665AUV; ABYSS dive 236).

The early morning hours of June 16th saw the deployment of 2 gravity corers (#666GC and #667GC) followed by the recovery of another set of OBS instruments (#668OBS to #676OBS). One station did not return and will hopefully be recovered after the time release on June 21st. Following these recoveries, the AUV was picked up at 11:55 LT after successfully completing its 10th mission (#665AUV; ABYSS dive 236). A mound in the northern part of the working area, near Shimmering Mound, was then proven to be hydrothermal in nature by visual inspection and
sampling during station #677HYBIS in the afternoon. In the evening, 2 OBH instruments were recovered (#678OBH and #679OBH), followed by a short ship-based multibeam profile at slow speed over the inactive sulfide mounds to get high-resolution backscatter data (#680MB).

Three gravity corer stations marked the beginning of June 17th targeting the Shimmering Mound area (#681GC, 300 cm of mixed pelagic and light-brown hydrothermal sediment; #682GC, 281 cm of intercalated pelagic as well as green, red and orange hydrothermal layers) and a basin west of the active TAG mound (#683GC, 15 cm of carbonate ooze). The first of two HyBis stations began at 08:42 LT and investigated a mound in the central, faulted area (#684HYBIS). This mound (mound 01) consists of pillow basalt. A second dive confirmed the hydrothermal nature of yet another target, this time mound #09, called “Rona Mound” in remembrance of the late Peter Rona, who worked in the TAG hydrothermal field for many years (#685HYBIS). At 19:26 LT the AUV was launched for its next mission to extend the bathymetric map further to the east (#686AUV; ABYSS dive 237). The night and morning hours were used for mapping the segment end in the south (#687MB).

June 18th started with the recovery of the AUV at 11:09 LT, followed by the launch of HyBis to investigate the area characterized by a strong magnetic low in the AUV-data for the presence of past hydrothermal activity. Several mounds were investigated that proved to be volcanic in origin until mound 11 was reached, where hydrothermal Fe-Mn-oxyhydroxides were observed and sampled at its summit (#688HYBIS). In the evening the AUV was launched for a mission targeting the northeastern part of the working area including the upper parts of a detachment fault (#689AUV; ABYSS dive 238). Gravity coring started at 18:46 LT and continued throughout the night with 4 stations sampling the foot of the slope north of Shimmering Mound (#690GC, 80 cm of carbonate ooze), a basin in the eastern part of the working area (#691GC, 66 cm of carbonate ooze), the MIR Zone (#692GC, 79 cm of carbonate ooze interlayered with hydrothermal sediment), and the summit of mound 11 (#693GC, 71 cm of Fe-Mn-oxyhydroxide gravel).

On June 19th, the AUV was recovered and this station was followed by the final geological HYBIS station targeting a mound showing a prominent magnetic low north of Shimmering Mound (mound 19), however, visual inspection and sampling showed the presence of angular and slightly altered greenstone-like rocks in this area (#694HYBIS). The last remaining of the originally 6 OBEM stations was deployed in the afternoon (15:34 LT; #695OBEM) in order to passively measure the electromagnetic field until the RRS JAMES COOK returns mid-July. Following this, the AUV was deployed for a 400 kHz mission to map the Mir Zone with 50 cm resolution (#696AUV; ABYSS dive 239). Starting at 21:40 LT, seismic profiling was performed over the eastern valley wall and continued until 22:56 LT of June 20th (stations #697MCS and #698MCS). The profiles needed to be interrupted shortly in order to recover the AUV around noon.

Shortly after midnight on June 21st, the AUV was launched for its next mission (#699AUV; ABYSS dive 240) mapping the southeastern corner of the working area. A series of 4 gravity corer stations started at 03:00 LT and targeted the sediment covering the toe of the detachment fault (#700GC, empty), a small basin in the east (#701GC recovering only few pieces of volcanic
pebbles), the northwestern flank of Southern Mound (#702GC, 092 cm of hydrothermally influenced sediment), and a small basin south of mound 27 (#703GC, 300 cm of layered carbonate ooze overlying hydrothermal sediment). Gravity coring finished at 12:49 LT and was followed by the recovery of the 2 OBH instruments that could not be released previously. The set time release worked and both instruments were recovered by 19:39 LT (#704OBH and #705OBH). At 20:02 LT the AUV was launched for its 15th and final mission mapping the southwestern corner of the working area next to the ridge axis (#706AUV; ABYSS dive 241).

During the night and morning hours of June 22nd a multibeam station mapped the northern end of the segment as well as the eastern flank (#707MB). The 2 AUV LBL transponders were on deck by 12:19 LT (#708AUV-T and #709AUV-T). The afternoon was used to take a background sediment sample far away from the ridge axis. The first station (#710GC) returned empty, however, after repeating this station the corer recovered 300 cm of shell-rich sediment (#711GC). The time before leaving the working area was used to finish the last profil line to the north (#712MB), before starting the Transit to Ponta Delgada, which began at 20:30 LT on June 23rd. The transit was interrupted on June 25th and June 26th for the deployment of the two remaining ARGO floats (#713ARGOS and #714ARGOS). Data collection for the Kongsberg EM122 and the 75kHz ADCP stopped just before entering the Portuguese EEZ at 20:00 LT on June 26th.

Cruise M127 ended in the morning of June 28th with meeting the pilot at 08:00 LT and entering the port of Ponta Delgada. Scientific equipment was sent back to Kiel or was set aside for the RRS JAMES COOK arriving a week later.