RV Poseidon
Report of
Cruise POS515
18.06.2017 – 13.07.2017
Dubrovnik, Croatia to Catania, Italy
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Dated: 25.07.2017
Cruise Report
RV Poseidon
Cruise No.: POS515
Areas of Research: Calabrian Arc, Mediterranean Sea
Port Calls: Dubrovnik, Croatia & Catania, Italy
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Number of Scientists: 10
Projects: CALVADOS - CALabrian arc mud VolcAnoes: Deep Origin and internal Structure
Cruise Report

This cruise report consists of 73 pages including cover:

1. Scientific crew ........................................................................................................................ 3
2. Research programme and objectives ..................................................................................... 4
3. Narrative of cruise with technical details ............................................................................. 10
4. Scientific Results
   4.1 Venere mud volcano.................................................................................................. 22
   4.2 Poseidon mud volcano............................................................................................... 37
   4.3 Sartori mud volcano................................................................................................... 45
   4.4 Cetus mud volcano .................................................................................................... 50
5. Scientific equipment............................................................................................................. 52
   5.1 Ocean bottom seismometers ...................................................................................... 52
   5.2 P-Cable 3D imaging system ...................................................................................... 54
   5.4 Seismic source ........................................................................................................... 56
6. Acknowledgements .............................................................................................................. 57
7. Appendices ........................................................................................................................... 58
   A General map of expedition cruise-track .......................................................................... 58
   B Station list ........................................................................................................................ 59
   Table B.1: OBS deployment at Venere mud volcano. ..................................................... 59
   Table B.2: OBS deployment at Poseidon mud volcano .................................................... 60
   Figure B.1: Sound speed measured at OBS stations V01 ................................................ 601
   Table B.3: Log of seismic data acquisition at Venere mud volcano ................................ 62
   Table B.4: 2D Seismic lines at Poseidon and Sartori mud volcano ................................. 66
   Table B.5: 3D Survey lines across Sartotri mud volcano ................................................. 67
   Table B.6: 2D Survey lines across Cetus mud volcano.................................................... 70
8. References ............................................................................................................................ 71
1. Scientific crew

<table>
<thead>
<tr>
<th>Name</th>
<th>Function</th>
<th>Institute</th>
</tr>
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<tbody>
<tr>
<td>Bialas, Jörg</td>
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</tbody>
</table>

**Total 10**

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*Figure 1* Scientists on board the research vessel POSEIDON during the project CALVADOS: from left to right: Sina Muff, Anne Krabbenhöft, Jan Rindfleisch, Jörg Bialas, Nikolas-Ulrich Stange, Oliviero Candoni (kneeling), Michael Riedel, Michel Kühn, Valentin Bähre, and Florian Beeck.
2. Research programme

Mud volcanoes have been found in various geological settings on passive and active margins but are mostly known from collision zones on Earth. Mud volcanoes are well known to occur on land, where at least 1,000 such structures have been counted. The amount of submarine mud volcanoes is believed to be much larger, and recent improvements in seafloor mapping led to the discovery of many mud volcanoes in all oceans. Specifically in the Eastern Mediterranean Sea more than 500 mud volcanoes are known from several regions like the Mediterranean Ridge, the Anaximander Mountains and Florence Rise, the Nile deep-sea fan area, and the Calabrian arc (Mascle et al., 2014). Within the framework of several European projects, scientists from Italy and other countries collected over the last 10 years numerous multibeam and echo sounder data from the inner and outer Calabrian arc (e.g. Gutscher et al., 2017). By combining multibeam bathymetry and backscatter imagery, integrated with sub-bottom profiles and locally proven from geological sampling, a total of 54 mud volcanoes have been identified in a sector of 35,600 km² within the Calabrian Arc (Ceramicola et al., 2014). Sampling has been performed from few mud volcanoes: the Madonna dello Ionio and Pythagoras mud volcano (Praeg et al. 2009), and more recently at Venere and Poseidon mud volcano during expeditions M112 (Bohrmann et al., 2015) and POS-499 (Bohrmann et al., 2016). The role of the two MVs within the accretionary wedge of the Ionian Sea is rather unclear, although the presence of MVs is well known to be related to the collision zone. In this part the eastern Mediterranean Sea contains the convergent plate boundary where the African plate is being subducted beneath Europe, along which accretionary complexes extend over 1500 km from Calabria to Cyprus (Figure 2).

Figure 2. Geological setting of the eastern Mediterranean (from Rabaute and Chamot-Rooke 2007), showing the Calabrian accretionary prism against the Mediterranean Ridge. White arrows indicate motion of the Aegean backstop with respect to Africa.
The Calabrian Accretionary Prism (CAP) lies at the SE tip of the arcuate Apennine-Maghrebide subduction system, a product of rapid roll-back of a NW dipping oceanic slab over the last ca. 30 Ma (Neogene) to open back-arc basins in the western Mediterranean Sea (Malinverno and Ryan, 1986).

Since ca. 10 Ma (late Miocene), slab retreat has driven the pulsed opening of back-arc basins in the Tyrrenian Sea during migration of the accretionary system up to 380 km towards the Ionian domain (Faccenna et al., 2004). Consumption of the slab, and its fragmentation during episodes of tearing beneath bordering continental margins, has narrowed the subduction zone to a tongue of Ionian lithosphere confined between the Maltese and Apulian escarpments (Figure 2), descending NW into the mantle beneath the Aeolian volcanic arc (Faccenna et al., 2004). Roll-back of the subducting slab has slowed or ceased following a regional plate tectonic reorganization at ca. 0.8-0.5 Ma (Goes et al. 2004). Over the same time period, Calabria has undergone a rapid km-scale uplift (Zecchin et al., 2012), argued to be a response to mantle circulation around a slab window beneath the southern Apennines (Faccenna et al., 2011).

Above the subduction zone, the Calabrian accretionary prism is 300 km wide and extends almost 300 km from elevations of up to 1928 m in Calabria, to a frontal thrust in water depths of ca. 4000 m that intersects that of the Mediterranean Ridge (Figure 2; Chamot-Rooke et al., 2005). In the Ionian Sea, Rossi and Sartori (1981) showed the seaward-thinning accretionary prism, referred to as the ‘External Calabrian Arc’, to contain three main morpho-structural zones (Figure 3), recognized in all subsequent work and corresponding to fore-arc basins and pre- and post-Messinian wedges (Praeg et al., 2009; Polonia et al., 2011). The inner fore-arc basins, up to 80 km wide, are underlain by strata up to 2 km thick that is inferred to include thin (<500 m) Messinian evaporites (Minelli and Faccenna, 2010). The pre-Messinian wedge to seaward, up to 100 km wide, is an area of irregular relief that corresponds to thrusts and back-thrusts; it is divided by the up to 750 m high Calabrian Escarpment into an inner plateau and an outer area of higher gradient and relief (Ceramicola et al., 2014). The post-Messinian wedge is up to 100 km wide and includes two main lobes (Figure 3), the western with a décollement at the base of Messinian evaporites and the eastern cutting down into older strata (Polonia et al., 2011). Seismic reflection and refraction data across the outer wedge and its foreland indicate the down-going slab to comprise oceanic or highly-extended crust overlain by up to 4 km of pre-Messinian sedimentary strata, in turn overlain by thick Messinian evaporites (Polonia et al. 2011).
Figure 3. Main morpho-tectonic zones of the Calabrian accretionary prism (Ceramicola et al. 2014). The inner parts of the fore-arc basins have been raised by on-going uplift of Calabria. The pre-Messinian prism to seaward is divided into inner and outer parts by the Calabrian Escarpment, up to 200 km long and 750 m high. The post-Messinian prism incorporates thick evaporites, also present in the outer Mediterranean Ridge [AE: Apulian Escarpment, CE: Calabrian Escarpment, ME: Malta Escarpment].

Seismic reflection profiles across the pre-Messinian wedge and fore-arc basins show that many seabed thrust structures record post-Messinian tectonic movements, expressed as offsets of the reflector marking the base of the Plio-Quaternary succession, the largest example being the Calabrian Escarpment (Polonia et al., 2011). With reference to critical wedge theory, the tectonic movements are argued to record a response to the rapid frontal incorporation of Messinian evaporites, resulting in a reduction in taper that was corrected by out-of-sequence thrusting (OOSTs) and sedimentary underplating throughout the Plio-Quaternary advance of the prism (Minelli and Faccenna, 2010). Within the fore-arc basins, seabed thrusts and normal faults could also reflect on-going gravity-driven sliding above thin evaporites (Minelli and Faccenna, 2010). It has subsequently been suggested that the Calabrian Escarpment and other large OOSTs to seaward could have acted as pathways for post-Messinian fluid flow and mud volcanism, although no structurally-controlled pathways were identified (Polonia et al., 2011). Fluid migration within the prism has also been invoked in reference to seismically-imaged diapiric structures within the Plio-Quaternary succession of the fore-arc basins, originally suggested to be of halokinetic origin (Rossi and Sartori, 1981), but recently argued to be shale diapirs recording upward fluid migration from Messinian or older successions (Ceramicola et al. 2014).

Mud volcanoes are abundant within the eastern Mediterranean accretionary systems, and were first identified in the eastern Ionian Sea from cores of mud breccia from a structure on the western Mediterranean Ridge (Cita et al. 1978). The Mediterranean Ridge and its eastern extensions have since become one of the most intensively studied MV populations on Earth, through seabed studies that have identified hundreds of mud volcanoes (Mascle et al. 2014),
and scientific drilling of two examples that has provided evidence of extrusive activity over at least the last 1.2 Ma (Robertson et al. 1996).

In contrast, until recently, little was known about mud volcanism at the Calabrian accretionary prism. In 1981, two cores containing ‘pebbly mudstones’ were recovered from a seismically unstratified body on the inner prism (subsequently identified as Sartori MV), but mud diapirism as proposed by Cita et al. (1981) was rejected in favour of tectonic chaoticisation along thrusts (Rossi and Sartori 1981; Morlotti et al. 1982). The presence of MVs on the Calabrian accretionary prism was tentatively suggested from a few high backscatter patches observed on partial GLORIA sidescan coverage (Fusi and Kenyon 1996). However, MVs were not proven until 2005, during a campaign of the R/V OGS Explora that acquired the first regional multibeam coverage of Italian waters SE of Calabria, along with cores of mud breccia from two distinctive morphological features (Ceramicola et al. 2006), referred to as the Madonna dello Ionio mud volcanoes in the Spartivento fore-arc basin, and Pythagoras mud volcano on the pre-Messinian wedge to seaward (Praeg et al. 2009). Targeted seismic investigations of these two sites showed both to be the tops of buried extrusive edifices that interfere with Plio-Quaternary sediments (Figure 4) above a regional unconformity (Praeg et al. 2009), inferred to be of mid-Pliocene age (3-3.5 Ma) by correlation to tectono-stratigraphic records exposed onshore in the Crotone fore-arc basin (Zecchin et al. 2012). These findings supported a model in which mud breccia extrusion was triggered by a tectonic reorganization of the accretionary prism ca. 3 Ma ago and has remained episodically active since, making these among the longest-lived mud volcanoes on record (Praeg et al. 2009; cf. Somoza et al. 2012). Recently, integration of multibeam bathymetry with backscatter data across the Calabrian accretionary prism has revealed at least 54 mud volcanoes across the fore-arc basins and pre-Messinian prism.

Figure 4. Seismic image across the Madonna dello Ionio mud volcano and interpretation of stratigraphic units showing interfingering (“Christmas-Tree”) of mud sequences of low acoustic impedance and well stratified units of hemipelagic sediments with high acoustic impedance (from Praeg et al., 2009).
With few possible exceptions most of the mud volcanoes are restricted to the inner plateau of the Calabrian prism, landward of the Calabrian Escarpment (Figure 5). The majority have high backscatter signatures that, based on hemipelagic sedimentation rates and assumed sonar penetration, imply extrusion of mud breccias within the last 56 ka, i.e. during the last glacial-interglacial cycle, consistent with the depths of cored mud breccias at the Madonna dello Ionio, Pythagoras and Sartori mud volcano (Ceramicola et al. 2014). The Madonna dello Ionio and Pythagoras mud volcano were further investigated during two HERMES campaigns equipped with ROVs, which found geological and biological evidence of ongoing mud and/or gas seepage (Praeg et al. 2012).

![Figure 5. NW-SE bathymetric profile 250 km long across the central part of the Calabrian accretionary prism, schematically summarizing the distribution of mud volcanoes in relation to the main morpho-tectonic zones (from Ceramicola et al. 2014).](image)

The main objectives of our studies are on mud volcanoes and the interactions of geological, physical, and chemical processes shaping these structures. By observing ongoing changes and reconstructing past evolution we will improve estimates of gaseous and dissolved methane emissions over time, as well as better understand the role of mud volcanoes as geohazards. The investigations conducted during this project are based on high-resolution 3D seismic imaging of active MVs in different tectonic zones of the CAP as well as OBS imaging and regional 2D lines to tie the new data to the established stratigraphic framework spanning the past ~6 million years (e.g. Praeg et al., 2009). From these data, we aim to identify changes in mud volcano activity since the late Miocene, as well as to image the deep-rooted feeder system of the mud volcanoes. Our new work builds on findings of R/V Meteor cruise M112 conducted during November/December 2014 as well as new findings made during the Poseidon cruise POS-499.

### 2.1 Mud volcano evolution

We want to investigate the temporal progression of individual mud flows at different mud volcanoes to constrain a model for the mud volcano genesis. The mud volcanoes
detected on the CAP are characterized by high backscatter areas, which are interpreted to indicate extruded mud breccias. At several mud volcanoes, it is even possible to distinguish the mud flows by outlining areas with different backscatter intensities. This information allows a first interpretation on the succession of the mud flows by assuming that the backscatter intensity is highest when not buried by hemipelagic sediments but decreases with increasing sediment coverage. By acquiring high-resolution 3D seismic data across the mud volcanoes, it will be possible to extend the seafloor maps downwards (and thus backwards in time) and map previous periods of mud volcano activity. The seismic signature of extruded mud bodies (low acoustic impedance, chaotic reflectivity) is distinctly different from that of regular hemipelagic sediments (layered sequences of higher impedance reflectivity). The complex nature of inter-fingering of mud bodies and hemipelagic sediments (referred to as “Christmas-Tree” signature) is best imaged using 3D seismic data; and only 3D seismic data allow a volumetric assessment of the mud extruded. Using regional 2D lines we will be able to tie the newly acquired 3D data into the existing regional stratigraphic framework defined by Praeg et al. (2009).

2.2 Mud volcano morphologies

Surface expressions of mud volcanoes are highly variable and depend primarily on the fluid content of the extruded mud. Muds with low porosities form mud domes or ridges, more cohesive muds with intermediate fluid content can build large structures with high elevations, whereas high-porosity muds create mud pies on the seafloor. On the CAP various types of mud volcano morphologies could be recognized and the more detailed we can image these structures the more information about the mud flow characteristics can be drawn. Imaging especially the morphologies e.g. of individual flows or the edifices gives new insights into mud volcano processes, which are only possible by high-resolution mapping. The 3D seismic data acquired with the P-cable system will allow us to develop maps of buried (past) mud flows and by using seismic advanced attributes (such as amplitude-draped coherency) we will be able to define internal properties of these older flows allowing identifications of potential changes in the extruded mud-properties over time or their changes post-extrusion, such as consolidation and porosity reduction.

2.3 Deep roots of the mud volcanoes

By selecting different mud volcanoes across the CAP, we are able to characterize different tectonic regimes and their internal structures controlling the location and evolution
of these mud volcanoes. Venere mud volcano is located at the southern rim of the fore-arc basin, but Poseidon mud volcano is within the inner pre-Messinian prism. OBS and regional 2D seismic lines will be used to image the deeper structure of the mud volcanoes. Integration with existing seismic lines previously acquired (including those from cruise M111, Kopp et al., 2015) will provide further structural control on MV location and evolution.

3. Narrative of cruise with technical details

All times and dates listed in this section are local time (UTC + 2).

June 16, 2017, Friday
Arrival and loading of compressor container onboard research Vessel POSEIDON.
Arrival of scientific crew (Beeck, Rindfleisch) in Dubrovnik, Croatia

June 18, 2017, Sunday
Arrival of scientific crew (Riedel, Bialas, Krabbenhöft, Muff, Bähre, Kühn, Stange) in Dubrovnik, Croatia. All personal embark on vessel.

June 19, 2017, Monday
Scientific equipment arrived and was loaded onboard.
Departure Dubrovnik at 16:00 and transit to first study site at Venere mud volcano.
Scientific crew begins installing all scientific gear in laboratories and on deck.
15:30 Safety briefing for all scientific crew

June 20, 2017, Tuesday
Continue transit to first study site at Venere mud volcano. All day continue to install scientific gear. Preparation for OBS deployment included building anchors, programming releasers and pressure cases with recorders, testing radio antennae and flash lights.
10:20 Safety drill for all crew and scientists

June 21, 2017, Wednesday
08:00  Arrival at first OBS drop position at Venere mud volcano. We start with a test of all 13 releasers. The releasers were mounted onto the frame of the CTD unit and lowered using the CTD winch wire to 1500 m water depth. We also run the CTD to measure seawater properties in order to calculate sound speed for the ocean column. These velocities are later useful for OBS re-localization as well as for navigational purposes (e.g. determining distance of receivers from airgun based on observed travel times of the direct wave) and migration of the reflection data.

08:30  CTD frame lowered to 1500m

09:15  All releasers responded and were disabled

09:50  CTD frame back on deck

10:30  OBS V01 deployed

10:49  OBS V02 deployed

11:05  OBS V03 deployed

11:20  OBS V04 deployed

11:32  OBS V05 deployed

11:45  OBS V06 deployed

12:04  OBS V07 deployed

12:24  OBS V08 deployed

12:43  OBS V09 deployed

12:56  OBS V10 deployed

13:08  OBS V11 deployed

13:19  OBS V12 deployed

During Afternoon, we continue to prepare the Trawl-Doors of the P-Cable system; which are stored attached to the outside of the stern during non-P-cable data acquisition.

We decided to be surveying in 2D mode due to limited time available preparing the entire 3D system. A set of 12 lines from the main P-Cable survey were selected, crossing the OBS grid. These lines are a test for our acquisition software, GPS navigation routines, as well as airgun and compressor operations.

17:00  Streamer with 4 active sections (blue oil-filled streamers) and airgun deployed

18:20  Compressor on full service load with gun pressure at 165 bar

However, we encounter issues with the trigger box and the GI gun is misfiring, in part due to the wrong trigger;
To overcome the trigger problem, the geometrics computer provides an internal trigger and the computer is synced with the GPS so that navigation can be accurately defined;

We further encountered serious problems with all lithium batteries used with the streamer birds. The batteries are all non-functional.
The two birds attached to the streamer do not respond: one bird has a motor-problem and is fixed to a depth of 8 m. The other bird is at 0.5 m depth and its position can also not be changed.

19:45 We decide to pull in streamer and remove the birds.
19:55 Streamer re-deployed without birds
20:00 Compressor ground-cable needs to be repaired. Stopping compressor and halt airgun firing.
20:08 Compressor functional again.
20:11 Speed of vessel to 4kn and start survey lines

June 22, 2017, Thursday
01:30 Geometrics computer malfunctions; restart of recording software
08:00 Finishing lines before starting P-cable preparations
08:30 Pulling in gear and prepare P-Cable
  High leakage problems (> 300)
  We also detected problems with GPS on airgun-float: most likely it took on water from high humidity, i.e. no seawater), but unit is fried and non-functional for the remainder of the entire cruise.
17:15 Cross-cable on deck for testing
  We require a string of Serial-numbers (SN) of each “T-box” and we are awaiting this list from Gero Wetzel, who was asked to help from shore (table received at 20:00)
  No operations overnight: ship keeps station.

June 23, 2017, Friday
08:00 Continue testing P-Cable system.
14:00 Decision to test system in water
15:20 Start deploying P-Cable
15:43 First three streamer sections deployed (current at 1.3 amp; leakage at 43).
Test shows that streamer section #3 can no longer be seen: pull back on deck
Streamer #4 attached but leakage > 1000
System is brought back on deck and we see that T-box #4 took in seawater due
to a screw not fully tightened. The box (original SN-6119) replaced by new
box with SN-6117.
18:15 10 sections deployed and check, but box #6 not detected
18:22 Using 2nd Geometrics box, but same problems: decide to abandon 3D
deployment and go for 2D streamer instead;
19:30 All P-cable gear on deck
Prepared 2D streamer with 3 sections (solid state)
Overnight we though to run long refraction lines
20:00 Encounter issues with GI gun: injector not firing
22:40 GI gun repaired and back in water
22:56 GI gun hydrophone already broken and generator not firing
All gear back in and no further activity over night; require creating new airgun
strings, which need to dry and harden over 10 hours

June 24, 2017, Saturday
08:00 begin preparing for P-Cable deployment
The system is put into the water one streamer at a time and testing the unit
immediately; progress slow, but testing seems successful to see immediate
issues on all parts; we switched box #6, which appears to be broken;
16:30 Testing of all P-Cable sections in water, but communication failed and cross-
cable is seen only until box #9
16.45 New airgun strings are not ready yet and no additional options exist, so we
decide to halt all operations and keep ship stationary again.

June 25, 2017, Sunday
08:00 Begin of preparations for new P-cable deployment
14 boxes, 16 streamers; box 1 and box 14 have solid state with 2 sections each.
13:45 P-cable completely deployed; setting 2nd trawl-door
14:10 We no longer receive GPS signal from starboard trawl-door
14:15 Recording unit started
Record length: 4.5 s
Delay 0ms
Sample rate 0.5 ms
128 channels in total (16×8)
14:25 Airgun deployed and firing, 170 bar
14:30 Lost box 14 with streamer 15 and 16; only 112 channels recorded
15:45 Leakage is increasing from ~80 at beginning of survey to now ~120
16:20 Leakage at 290 and increasing fast
16:27 Leakage > 500: abort survey!
   No recovery of system possible any more (overtime regulations)
   We instead run 3 refraction lines (NW-SE orientation) with P-cable deployed;
   for these long offsets lines, we reduce airgun firing rate to 10 seconds

June 26, 2017, Monday
06:00 Recover all gear and start testing
   While recovering backboard trawl-door and P-cable, the starboard trawl-door
   moves across the data cable! We recover all streamers to prevent any damage
   to system.

   With all gear on deck, we require more time for repair the P-cable system and
   re-deploy than initially thought, with high uncertainties if it will be functional;
   potential weather issues forecasted for the middle of the week and battery-
   limitations on OBS force us to go for a 2D survey across Venere.
   This way, we will be able to acquire a useable pseudo-3D reflection grid as
   well as a full coverage for 3D OBS mirror imaging;
   We remove cross-cable from drum and lay it out on backboard working deck
   for testing. All blue streamers are connected for a 2D streamer and together
   with stretch-section and deck cable, the 2D streamer is put onto the drum for
   ease of deployment and recovery.

11:30 2D streamer and airgun deployed; start surveying using the same 84 parallel
       survey lines originally intended for P-Cable acquisition.

   Survey parameters: 0.5 ms sample rate; 4.5 seconds record length
   No deep-water delay; injector fires 55 ms after generator
Streamer is 150 m long (active section) and made up from 12 blue-colored oil-filled streamers; 96 channels in total
25 m stretch and 25 m extra deck-cable; airgun is 20m behind vessel
Two channels are dead:
   #49 (1st channel in section 5) and #65 (channel 5 in section 6)
After line #2, the navigation-depth sounder switched back on at bridge
15:30 – 16:30 Discussion about state of compressor container

June 27, 2017, Tuesday

04:00 Working/Supply compressor from ship turned off; we lost ~120 shots; survey gap is right across central portion of Venere mud volcano (Murphy!). We re-fill this gap later during the survey.
08:00 Finished 12 survey lines
17:30 Finished 18 survey lines
Gun pressure varies between 165 bar and 175 bar.
21:00 – 22:30
Changing order of survey lines; original sequence was optimized for P-cable system; with a 2D streamer, we can make tighter turns; thus, a new sequence of lines was designed by J. Bialas and M. Riedel; this may provide additional time for completing yet missing refraction lines or any additional gaps that may happen in the survey;
Also, we plan to recover all OBS on Sunday, July 2nd, and move to the next survey region at Poseidon mud volcano, starting re-deployment on Monday, July 3rd, followed by 1 day of refraction survey lines. In this plan, the P-cable will hopefully be deployed by Tuesday, July 4th.

June 28, 2017, Wednesday

08:00 Sequence of new lines with tighter turns seems to be working
All gear functions well
P-cable cross-cable on backboard deck was tested: we encountered a problem in the lead-in cable to box #13; since this lead-in cable is no longer functional, we are unable to use these 2 solid-state streamers.
The smaller (shorter) cross-cable now is consisting of 13 boxes. We replace 10m long section-cables with 15 m long segments to increase overall spread.
New survey will be defined, once time-line is more predictable.

**June 29, 2017, Thursday**

All day: continue acquiring 2D lines

**June 30, 2017, Friday**

All day: continue acquiring 2D lines

**July 1, 2017, Saturday**

10:30  End of acquiring parallel lines across Venere mud volcano

11:36  Start 2D refraction survey; airgun at 10 second firing interval

**July 2, 2017, Sunday**

06:00  End of survey at Venere mud volcano

   Recover streamer and airgun

   During the night, wind was high with up to 18 m/s, high seas developed;

06:45  Start OBS recovery sequence

   We start at OBS V03, then move along the long-edge of the OBS grid due to strong winds and surface currents.

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<tr>
<td>V12</td>
<td>12:05</td>
<td>12:27</td>
<td>12:31</td>
</tr>
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High winds and swell prevent additional acquisition of data between Venere and Poseidon mud volcano. We finish the transit and wait on station at Poseidon mud volcano until Monday morning.
July 3, 2017, Monday

Weather is steady with slightly lower wind and swell, allowing us to deploy the OBS.

05:58  OBS P01 deployed
06:13  OBS P02 deployed
06:27  OBS P03 deployed
06:39  OBS P04 deployed
06:51  OBS P05 deployed
07:05  OBS P06 deployed
07:20  OBS P07 deployed
07:52  OBS P08 deployed
08:08  OBS P09 deployed
08:27  OBS P10 deployed
08:42  OBS P11 deployed
08:54  OBS P12 deployed

Weather is still steady and has improved for 2D seismic data acquisition.

09:20  Deploy 2D streamer
09:40  Deploy Airgun

Data acquisition across the two refraction lines at 10 second shot interval and 8 seconds recording time. Sample rate: 0.5 seconds.

After the 2 refraction lines, we acquire a few lines towards and across Sartori mud volcano, lying about 10km further SW.

Winds increase continuously and forecast predicts wind force 7 – 8 over night. We therefore stop data acquisition and recover all gear.

19:30  All gear on deck

Waiting on weather until Tuesday

Preliminary data quality assessment shows low internal reflectivity beneath and around Poseidon mud volcano. In contrast, the lines acquired at Sartori show distinct mud-flow layers onlapping on surrounding sedimentary layers. Below the central portion of Sartori, deeper reflections are identified.
We therefore decided to try the next P-Cable acquisition at Sartori and if possible acquire 2D lines across the Poseidon mud volcano chain.

**July 4, 2017, Tuesday**

08:00  Winds and seas still high; no new data acquisition until late in afternoon  
16:00  Start deploy streamer and airgun  
16:45  Start data acquisition with lines in region of Poseidon mud volcano chain

**July 5, 2017, Wednesday**

06:00  End 2D survey  
06:30  Start recover OBS

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06:30  Start reconfiguring the P-Cable system

14:00  Deploy P-Cable system  
15:15  Port-side trawl-door deployed  
15:45  Start surveying; make turn to Sartori  
       Survey P7000: 7 seconds shot interval, 6.5 seconds recording  
18:40  All communication to P-Cable lost  
       Bringing in starboard trawl-door first: upon close inspection we recognized a problem with the strength-member of the cross-cable: at T-box #1, the strength-member was cut and all weight of towing the system (including trawl-doors) was on the data-cable. This has caused failure of the communication, despite that we were still able to measure current and had no leakage problem.
We brought in the first two T-boxes, exchange cables, strength-members and removed streamer #1 (two solid state sections). The active length of the cross-cable is now 60m, with the paravanes towed at a cross-distance of 120 m. The cause of the issue was a broken shackle, most likely due to ware and tare.

21:00 All gear back out, and all is functional.
Start profile of Sartori 3D cube at 22:05

*July 6, 2017, Thursday*

08:00 no further problems recognized during the night:
We acquired 9 lines in ~14 hours, averaging 1.5 hour per line and turn. This is within the predicted frame of total survey time of 5 days for 81 lines.

*July 7, 2017, Friday*

3D P-cable survey continues without interruption

*July 8, 2017, Saturday*

3D P-cable survey continues without interruption

*July 9, 2017, Sunday*

17:15 Geometrics software stopped updating the window-display of several channels, and we lost connection to a few of the streamers. Reboot of the PC running the system created additional communication problems. We then switched off the power unit, rebooted and finally regained full access to the P-Cable.
18:00 Compressor off, as air filter top has blown off. We temporarily fixed the filter, which will suffice until the end of our expedition. A complete repair will be done back at Sauer&Sohn in Kiel.
18:36 All streamers connected and recognized and data acquisition back to normal.

*July 10, 2017, Monday*

08:00 Survey continues without interruptions.
09:30 We started to define fill-in profiles to increase coverage of the 3D cube.
Our current fold map as of this morning is shown below in Figure 6.
Figure 6. Preliminary fold map of the Sartori 3D P-Cable cube as of July 10, 2017.

July 11, 2017, Tuesday

08:00 Further evaluation of fold-map and in-fill procedures
16:00 End of 3D survey
17:00 All gear on deck
17:05 Start steaming to next study site: CETUS mud volcano
20:30 Start deploy airgun and streamer, made of 4 oil-filled sections
21:00 Start shooting profiles
   Airgun on deck, leakage problems
   Airgun Re-deployed

July 12, 2017, Wednesday

06:00 End of profiles; recover all gear
   Trawl-doors recovered and secured on deck
   Dismounting and packing up
07:30 Start steaming towards Geodesy Stations
20:00 Arrival at geodesy stations
23:00 All completed at geodesy stations
July 13, 2017, Thursday
  10:00  In Port of Catania
  12:00  Start offloading all gear
  15:00  Trucks won’t arrive until Friday morning due to delays at ferry terminal;
         A security firm is hired to dispose guards protecting gear sitting on pier over
         night;

July 14, 2017, Friday
  09:00  Start of truck loading, Compressor-container removal, and custom procedures
  14:00  All gear loaded onto trucks, paperwork for customs completed;
         Remaining scientists disembark vessel;
4. Scientific Results

4.1 Venere mud volcano

Venere is a double-cone mud volcano situated within a larger canyon system (Figure 7). Regional bathymetry from M112 (Bohrmann et al., 2015) and high-resolution AUV bathymetry (Bohrmann et al., 2016) define the distinct morphology. Short-distance mud flows are seen, mostly on the SW flank of the cones. Several gas flares were previously mapped (Bohrmann et al., 2016), but we did not collect any new multibeam water-column data to verify the occurrences. Ring-faults are seen at the seafloor defining a circular caldera of the entire mud volcano feature. Seafloor backscatter shows high seafloor reflectivity around the two cones, whereas the surrounding area is characterized by low to medium backscatter strength (Figure 8).

We acquired data on 12 OBS and along 84 parallel 2D lines (Figure 9). For refraction velocity analyses, an additional set of 7 lines were acquired with longer offsets to the OBS (Figure 10).

Using the 84 parallel lines, a pseudo 3D analysis can be performed. On board, we did analysis time-slices through the 3D volume for first quality data analyses (Figure 11, 12).

A cross-line acquired in perpendicular direction to the main 84 parallel lines highlights the still present static offsets between individual lines (Figure 13). A post-expedition processing will remove these static shifts by using the multibeam data as absolute depth-datum.

A first check on the OBS recording data showed high-quality OBS records on all channels (Figure 14). Refracted arrivals were identified on most OBS.
Figure 7. Image showing morphology of the Venere mud volcano from regional and high-resolution AUV bathymetry. Location of gas flares are shown with red symbols (from Bohrmann et al., 2016). OBS deployed during POS515 are shown with black dots. Regional data are from cruise M112 (Bohrmann et al., 2015) and AUV data are from cruise P499 (Bohrmann et al., 2016).
Figure 8. Morphology of the Venere mud volcano using backscatter. Recent mud flows emanating from the two cones show high backscatter, whereas the surrounding regions show mostly low seafloor backscatter values. Regional data are from cruise M112 (Bohmann et al., 2015) and AUV data are from cruise P499 (Bohmann et al., 2016).
Figure 9. Map of 2D seismic data acquired across Venere mud volcano with bathymetry grid as background. Five examples of survey lines acquired across the OBS grid for refraction velocity analyses are highlighted with thick grey lines.
Figure 10a. Seismic Line 1097, shot in SW-NE direction across Venere mud volcano. OBS positions crossed are shown by black triangles.

Figure 10b. Seismic Line 1099, shot in SE-NW direction across Venere mud volcano. Note the prominent down-dipping reflections beneath the centre of the mud volcano, small-offset faulting within the sediment sequence below the regional unconformity (at ~2.4 s two-way time), and deep higher reflectivity acoustic basement.
Figure 10c. Seismic Line 1100, shot in SW-NE direction across Venere mud volcano. Beneath the central portion of the mud volcano, seismic blanking is caused by the mud-breccia ascending from greater depth, forming the seafloor cone-like expressions.

Figure 10d. Seismic Line 1101, shot in SE-NW direction across Venere mud volcano.
Figure 10e. Seismic Line 1102, shot in SW-NE direction across Venere mud volcano.
Figure 11. Line 1027 from the set of 84 parallel lines across the double cone structure of Venere mud volcano. Indicated are the three depths of time slices shown below.
Figure 12a. Time slice of reflection amplitude at 2.2 seconds two way travel time using all 84 parallel lines. A circular shaped feature marks the extent of the Venere mud volcano composed of mud breccias and mud flows and is sharply truncated relative to the surrounding layered sediments.
Figure 12b. Time slice of reflection amplitude at 2.24 seconds two way travel time using all 84 parallel lines.
Figure 12c. Time slice of reflection amplitude at 2.2 seconds two way travel time using all 84 parallel lines. A donut-shaped structure of the Venere mud volcano is evident. The low-amplitude circular zone is made from mud-breccia. An inner ring of higher reflection amplitude is made from individual sheeted mud flows. This ring is sharply truncated relative to the surrounding sedimentary layers.
Figure 13. Zoom of reflection line 1100 (show perpendicular to the 84 parallel lines) with the continuously picked seafloor shown as solid blue line. Seafloor picks from the crossing lines are shown as blue circles. The seafloor travel-time picks of the 84 survey lines do vary relative to the crossing line in a non-systematic way. This residual static problem will be adjusted post-cruise using the multibeam bathymetry data as absolute datum. This will also increase the sharpness and accuracy of the time slices seen above.
Figure 14a. OBS Record for Station OBS V05 (hydrophone data) showing late refracted arrivals (starting at 3 seconds).
Figure 14b. OBS Record for Station OBS V08 (hydrophone data) showing refracted arrivals (starting at ~2.8 seconds) with an apparent low velocity.
Figure 14c. OBS Record for Station OBS V09 (hydrophone data) showing late refracted arrivals (starting at 3 seconds) with faster velocities than seen on OBS V08 and V05.
4.2 Poseidon mud volcano

This region is characterized by a chain of several mud volcanoes, all showing flat-topped morphology (Figure 15) with high backscatter (Figure 16), in contrast to Venere (cone-type volcano). Here we acquired first 2D seismic data for refraction velocity analyses and a set of regional 2D lines (Figure 17). The 2D data shot after OBS deployment showed very low reflectivity (Figure 18, 19) and only shallow depth penetration of the airgun signals. We therefore abbreviated the survey here and focused on Sartori, which had shown a better seismic sub-surface structure. The OBS, however, did record high quality data with many refracted arrivals (Figure 20).

Figure 15. Map of OBS (black triangles) deployed across the Poseidon mud volcano chain. Also shown is the seafloor bathymetry from regional (M112, Bohrmann et al., 2015) and high resolution AUV mapping (P499, Bohrmann et al., 2016).
Figure 16. Map of seafloor backscatter across the Poseidon mud volcano chain. Regional data are from cruise M112 (Bohmann et al., 2015) and high resolution AUV data are from cruise P499 (Bohmann et al., 2016).
Figure 17. Map of combined bathymetry and backscatter data with OBS position and location of all seismic profiles acquired across the Poseidon mud volcano chain. Two examples of the long-offset refractions lines are highlighted with grey color and shown below.
Figure 18. Image of line P4001 across NW-SE line of OBS at Poseidon mud volcano. Note the absence of deep reflectivity as well as distinct zonation or reflection events around the mud volcano. Locations of OBS are indicated by black triangles.
Figure 19. Image of line P4003 across SW-NE line of OBS at Poseidon mud volcano chain. Note the absence of deep reflectivity as well as distinct mud flows or reflection events around the mud volcano itself. Locations of OBS are indicated by black triangles.
Figure 20a. OBS Record for Station OBS P05 (hydrophone data) showing refracted arrivals starting at 3 seconds.
Figure 20b. OBS Record for Station OBS P06 (hydrophone data) showing refracted arrivals starting at 3 seconds.
Figure 20c. OBS Record for Station OBS P12 (hydrophone data) showing refracted arrivals starting at 4 seconds at the farthest offset to the SE.
4.3 Sartori mud volcano

Sartori mud volcano is a flat-top structure with several distinct mud flows emanating from the western edge of the volcano (Figure 21, 22). Although not the initial target for 3D P-Cable surveying, reconnaissance data acquisition (Figure 23) showed well-layered mud flows, deep stratigraphy, as well as a root of the mud volcano (Figure 24), ideal for 3D seismic imaging, which is in stark contrast to the region around the Poseidon mud volcano. We do lack OBS velocity information for time-migration, but the data acquired only a few kilometers north at Poseidon mud volcano can be extrapolated to Sartori mud volcano.

After acquisition of additional 2D sections across Poseidon MV and the recovery of all twelve OBS, we acquired a P-Cable 3D survey of 4.8 km × 5.8 km grid of 82 N-S oriented survey lines at 60 m spacing (Figure 25). After 5 days of continuous data acquisition with 67 parallel lines, we filled several holes in the 3D coverage by surveying an additional 22 lines.

Figure 21. Seafloor bathymetry around Sartori mud volcano. Regional data are from cruise M112 (Bohmann et al., 2015) and high resolution AUV data are from cruise P499 (Bohmann et al., 2016).
Figure 22. Image showing seafloor backscatter around the Sartori mud volcano. Regional data are from cruise M112 (Bohrmann et al., 2015) and high resolution AUV data are from cruise P499 (Bohrmann et al., 2016). Several distinct high-backscatter mud flows that are partially overlapping are seen west and south of the flat-top mud mound. One smaller mud flow appears to have transported mud to the north.
Figure 23. Map of the region around Sartori mud volcano combining backscatter and bathymetry, showing high backscatter regions of mud flows to the west of the almost circular and flat-top mud mound itself. Seismic line 5005 is highlighted by a thick black line and shown below.
Figure 24. Seismic line 5005 across Sartori mud volcano. A thick sequence of stacked mud flows forming onlaps on regular sedimentary layers is seen in the SW portion of the line. Beneath the central portion of the volcano deep reflectivity appears to form a bowl-shape structure.
Figure 25. Final fold map for the Sartori 3D P-cable survey by incorporating all data with navigation strings recorded. Several shots with the GPS string missing will be added post-expedition.
4.4 Cetus mud volcano

Our last target of the expedition is the Cetus mud volcano. It is the furthest South-located feature visited. The E-W elongated structure shows high backscatter rims (Figure 26). Seismic data across the structure show outstanding rim-like structures and a central zone of the mud volcano made from a stack of mud flows (Figure 27, 28).

Figure 26. Location of seismic lines acquired at Cetus mud volcano (two examples shown below are highlighted in thick black lines). The bathymetry and backscatter is combined.
Figure 27. Seismic line 8001 across Cetus mud volcano.

Figure 28. Seismic line 8010 across Cetus mud volcano.
5. Scientific equipment

5.1 Ocean bottom seismometers

A total of 12 Ocean bottom seismometer (OBS) instruments were provided by GEOMAR and were successfully deployed at the Venere and Poseidon mud volcanoes. The GEOMAR Ocean Bottom Seismometer 2002 (OBS-2002) is a design based on experience gained with the GEOMAR Ocean Bottom Hydrophone (Flueh and Bialas, 1996) and the GEOMAR OBS (Bialas and Flueh, 1999). The basic system (Figure 29) is constructed to carry a hydrophone and a seismometer for active-source seismic profiling. However, due to the modular design of the front end of the system carrier it can be adapted to different seismometers and hydrophones or pressure sensors. The sensors are HTI-04_PCA_ULF hydrophones from High Tech Inc. The seismometer is deployed between the anchor and the OBS frame, which allows for optimal coupling to the seafloor. The three-component seismometer K/MT-210 manufactured by KUM GmbH is housed in a titanium pressure tube. Short-period geophones with a 4.5 Hz natural frequency were used during POS515. The recording device is an MBS recorder of SEND GmbH, which is contained in its own pressure tube and mounted next to the flotation opposite of the release transponder (Figure 29). The floatation is made of syntactic foam and is rated, as are all other components of the system, for a water depth of 6000 m.

While deployed to the seafloor the entire system rests horizontally on the anchor frame. The instrument is attached to the anchor with a release transponder. The release transponder is the K/MT562 made by KUM GmbH. Communication with the instrument located on the seafloor for release and range estimation is possible through a transducer hydrophone, which is lowered from the vessel by ~20 m into the water. Over ranges of 4 to 5 miles release and range commands are successful. After releasing its anchor weight (~60 kg), the OBS instrument turns 90° into the vertical position and ascends to the sea surface. This ensures a maximally reduced system height and water current sensibility at the ground (during measurement). Additionally, the sensors are well protected against damage during recovery and the transponder is kept underwater, allowing for continuous acoustic communication between vessel and the OBS, while the instrument floats to and at the surface.
Figure 29. Ocean Bottom seismometer (OBS), recovered at portside of R/V POSEIDON during research expedition POS515; all system components are labeled. Details see text.
5.2 P-Cable 3D imaging system

The P-cable system (Figure 30) allows towing multiple short streamers across a cable for wider swath-imaging and reducing line-spacing for more surveying (compared to towing a single streamer). We have attempted deploying the system numerous times at Venere mud volcano, but failed repeatedly due to a number of technical problems, including current leakage, failure of lead-in cables, and streamer-issues.

At Sartori mud volcano we deployed a P-Cable system made from 12 parallel streamers (oil-filled and solid-state streamers). The sequence of deploying the system is depicted in Figure 31.

Figure 30. Schematic drawing of the P-Cable used at the Sartori mud volcano. Two paravanes (also referred to as trawl-doors) are towed with the core-lines using the two main winches on board R/V POSEIDON. Between the trawl-doors, a cross-cable is towed, to which twelve short 12.5 m long streamer-sections are connected with T-boxes and lead-in cables. Lengths between streamers along the cross-cable, as well as offset of the GI airgun behind stern are also shown. The entire system is towed at a speed of ~3.5 kn, so that the horizontal distance between the paravanes is ~120m, which corresponds to a 60 m effective spread in common mid-point coverage.
Figure 31. Sequence of P-cable deployment: 1. Starboard paravane is released from vessel, 2. Data cable (red drum) is added, 3. Cross-cable with streamers (blue) is added while additional length of wire is given on paravane and data cable, 4. Completely deployed cross cable with all streamers, 5. Release of port-side paravane and final stretching of cross cable.
5.3 2D multichannel streamer

The individual streamer sections can be combined into a single 2D streamer. The individual streamers are combined with their digitizer (“bottle”) to a stretch-section (25 m) and a tow cable (80 m). We add a repeater to the data cable, connecting the streamer to the recording unit inside the laboratory. We have used different types of 2D streamers during CALVADOS. The first 10 lines acquired at Venere mud volcano were made from three solid-state streamer sections. The bulk of the remaining 2D lines are acquired with a 150 m long streamer, made from 12 oil-filled sections (details see Table 1 and geometry in Figure 32).

Figure 32. Geometry for all 2D seismic data collection. Length of streamer varies between surveys, but gun position and GPS position on board remain identical.

5.4 Seismic source

The seismic source used during the project was a single 210 in$^3$ (~3.4 L) GI gun. The injector is fired with a delay of 50 ms after the generator. For the most part of the survey, the gun was towed ~2 m below sea surface. However, for the long refraction lines at Poseidon mud volcano, we added an extra 2 m rope to lower the gun to greater depth. This was done mainly for safety reasons due to higher seas than usually seen during the previous survey lines. This may also help generating deeper frequencies, for further offset detection of the arrivals on the OBS.
6. Acknowledgements

We would like to thank the master Matthias Günther and the ship’s crew of R/V POSEIDON for their relentless support and making our research possible. This cruise was funded through the GEOMAR ship budget and the RD4 “Marine Geodynamic” internal budget. We would like to thank Prof. Dr. Herzig and the management team at GEOMAR for providing the substantial financial support to carry out this expedition. Additional thanks go to our RD4 team assistants Jasmin Mögeltönder and Anne Völsch, as well as Klas Lakschewitz for logistical support.
7. Appendices

A General Map of cruise-track from Dubrovnik to Catania, and location of mud volcanoes visited.
### Table B.1: OBS deployment at Venere with all instrument specifications.

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Table B.2: OBS deployment at Poseidon mud volcano with all instrument specifications.

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Figure B.1: Sound speed defined from CTD data at Venere mud volcano acquired during releaser test.
**Table B.3: Log of seismic data acquisition at Venere mud volcano**

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**3D seismic lines**

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**OBS shooting lines, no streamer**

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**2D seismic lines Survey P1005**

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2D seismic lines P1006
Table B.4: 2D Seismic lines at Poseidon and Sartori mud volcano

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Table B.6: 2D Survey lines across Cetus mud volcano

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8. References


