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REPORT AND PRELIMINARY RESULTS OF R/V POSEIDON CRUISE POS499

CALABRIAN MUD VOLCANOES

CATANIA (ITALY) – CATANIA (ITALY)
04 MAY – 22 MAY, 2016

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BERICHTE AUS DEM MARUM UND DEM FACHBEREICH GEOWISSENSCHAFTEN
DER UNIVERSITÄT BREMEN

R/V POSEIDON
Cruise Report POS499

Calabrian Mud Volcanoes

Catania (Italy) – Catania (Italy)
04 May – 22 May, 2016

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Cruise sponsored by Deutsche Forschungsgemeinschaft (DFG) through
MARUM – Center for Marine Environmental Sciences

The cruise was performed by
MARUM – Center for Marine Environmental Sciences

2016

R/V POSEIDON Cruise Report POS499

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1 Summary

During R/V POSEIDON Cruise POS499 (Fig. 1) we investigated several mud volcanoes from 4 regional areas of the Calabrian Arc. Venere Mud Volcano in the Crotone Fore-Arc Basin is located in the Squillace Canyon and seems to be the most active volcano. Sartori MV, Cetus MV and the Mud Volcano Ridge are part of the inner Pre-Messinian accretionary prism from which Cetus MV and some volcanoes from the Mud Volcano Ridge emitted mud flows which flowed over the steep slope of the Calabrian Escarpment. During 9 dives with MARUM AUV SEAL 5.000 over 100 km^2 micro-bathymetry were mapped over mud volcanos and its surroundings. The high resolution mapping showed many details of mud volcanism and its morphological expressions. The backscatter maps of the 400 kHz AUV multi-beam show distinct difference to the 12 kHz data which have been measured 2 years ago onboard R/V METEOR during M112. Fresh mud flow activities can be seen in the AUV data whereas the M112 integrate larger seabed thicknesses and show much older mud flows deeper in the sediment sequence.

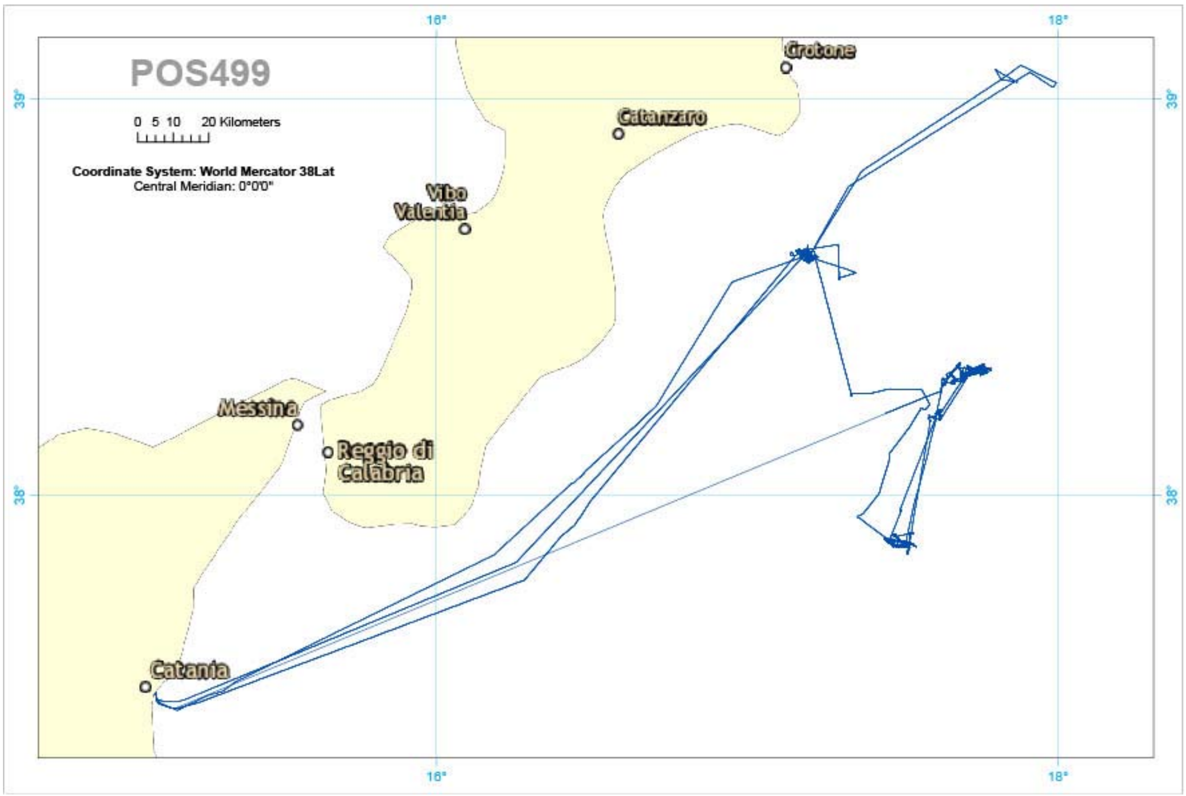


Fig. 1: Cruise track of R/V POSEIDON Cruise POS499 (04 – 22 May 2016, Catania – Catania).

Beside the AUV mapping 25 gravity cores and 29 mini corer stations have been taken to record the depth of the mud flows below hemipelagic sediment cover. Specifically, the mini corer stations record the exact thickness of the overlaying non-volcanic sediments whereas the topmost sediments of the gravity corer have often been disturbed. Based on the thickness of the hemipelagic sequence the minimum age of the mud flow below will be estimated based on the sedimentation rates. Other stratigraphic markers like sapropel and volcanic ash layers have been detected and will help to allow the stratigraphic framework. In addition to the coring stations we measured temperature by self-recording thermistor sensors (MTLs) attached to the core barrel at several locations and used a CTD for hydrographic measurements. Multi-beam echo-sounder (MBES) data with the hull mounted ELAC swath sounder (SB3050) was acquired in the area of Venere Mud Volcano in order to increase the quality of the bathymetric maps. Due to the limited resolution of the MBES, the already existing data recorded during the R/V METEOR Cruise M112 could only be marginally improved.

Fig. 2: R/V POSEIDON approaches the pier in the port of Catania (left). View from the harbour of Catania to the magmatic volcano Etna in the background of the city (right).

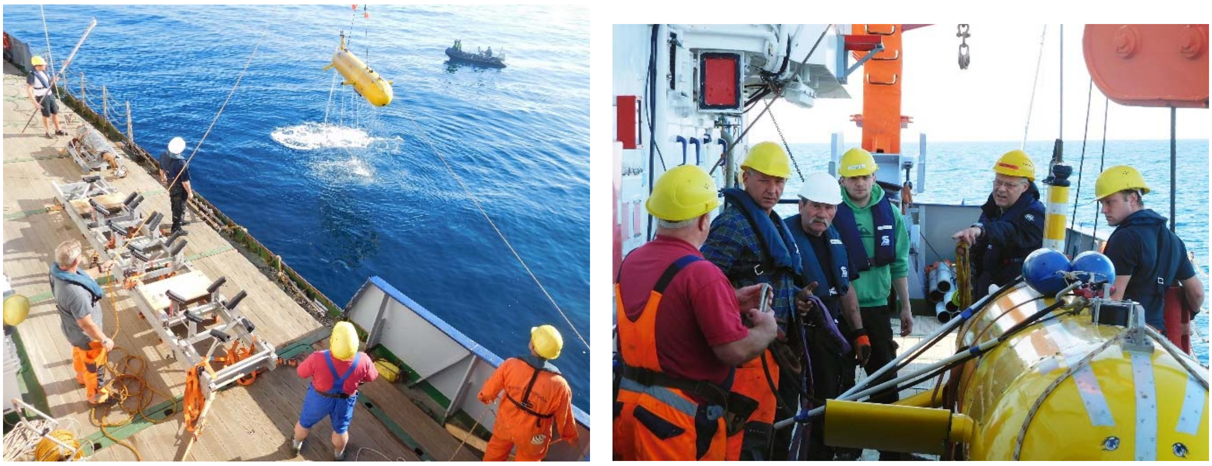


Fig. 3: Recovery of MARUM AUV SEAL 5.000 at the end of the seafloor mission (left). Discussion and arrangements between scientists and crew before the first AUV launching (right).

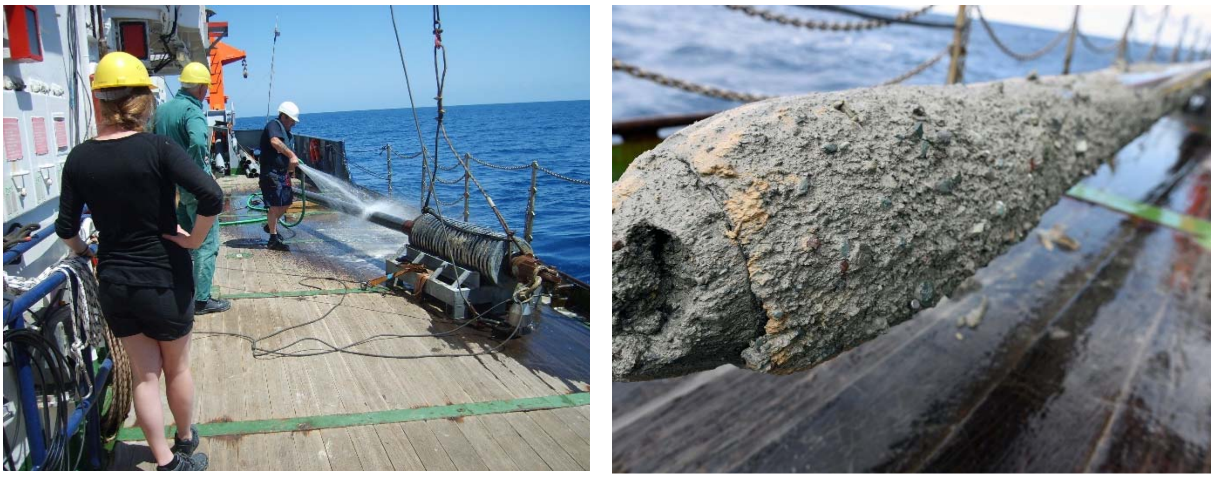


Fig. 4: Gravity corer onboard R/V POSEIDON during POS499 (left). Gravity corer sampled a sticky mud breccia (right).

2 Participants

Table 1: Scientific crew

Name	Discipline	Affiliation
Bohrmann, Gerhard	Chief scientist	FB5, Bremen
Meinecke, Gerrit	AUV SEAL 5.000	MARUM, Bremen
Renken, Jens	AUV SEAL 5.000	MARUM, Bremen
Spiesecke, Ulli	AUV SEAL 5.000	MARUM, Bremen
Von Wahl, Till	AUV SEAL 5.000	MARUM, Bremen
Loher, Markus	Sediments	MARUM, Bremen
Wintersteller, Paul	Hydroacoustics, IT, mapping	FB5, Bremen
Buchheister, Stefanie	Sediments	FB5, Bremen
Bachmann, Katharina	Sediments	FB5, Bremen
Ceramicola, Silvia	Multibeam mapping	OGS, Trieste
Candoni, Oliviero	Multibeam mapping	OGS, Trieste

MARUM Center for Marine and Environmental Sciences, DFG Research Center and Cluster of Excellence, University of Bremen, Postfach 330440, 28334 Bremen, **Germany**

FB5 Department of Geosciences, University of Bremen, Geo Building, Klagenfurter Str. 28359 Bremen, **Germany**

OGS Istituto Nazionale di Oceanografia e di Geofisica Sperimentale – OGS, Borgo Grotta Gigante 42/c, 34010 Sgonico, Trieste**, Italy**

Fig. 5: Scientific crew onboard R/V POSEIDON during POS499.

Table 2: Crew members onboard

Name	Discipline
Günther, Matthias	Master
Wichmann, Gent	Chief Officer
Von Keller, Magnus	2nd Officer
Freund, Hans-Jörg	Chief Engineer
Pieper, Carsten	2nd Engineer
Neitzel, Gerd	Electrician
Engel, Rüdiger	Motorman
Baron, Heiko	Bosun
Heyne, Roland	Seaman
Meiling, Ralf	Seaman
Rauh, Bernd	Seaman
Kuhn, Ronald	AB
Werner, Andre	Seaman
Malchow, Klaus-Peter	Cook
Vogt, Alexander	Steward

Shipping operator: Briese Schiffahrts GmbH & Co KG, Abteilung Forschungsschifffahrt, Hafenstr. 12, 26789 Leer, **Germany**

3 Introduction

3.1 Objectives, Background Research Program

The main objectives of our studies on mud volcanoes in the Calabrian Arc were to study the geological processes of mud volcanism by observing ongoing changes and reconstructing past evolution of mud volcanoes. We wanted to improve the estimates of gaseous and dissolved methane emission with time, and to better understanding the role of mud volcanoes as geohazards. The investigations are based on repeated mapping by AUV, *in-situ* measurements of temperature and chemical parameters, together with acoustic observations and geological sampling. From these data, we aim to identify changes in mud volcano activity and the morphology of mudflow generations over time. The R/V POSEIDON Cruise POS499 builds on findings of R/V METEOR Cruise M112 conducted during November/December 2014. This earlier cruise focussed mainly on the investigation at the Venere Mud Volcano, which has been mapped and studied intensively using AUV and ROV dives. Venere Mud Volcano is located in the shallow part of the inner pre-Messinian accretionary segment and by investigating mud volcano activities of other parts of tectonic segments we hope to enlarge the knowledge of the deeper prism. Based on the M112 data we selected mud volcanoes from the deeper inner pre-Messinian prims, like Cetus MV, Sartori MV and the Mud Volcano Ridge. In detail we planned to follow mainly three aims:

Mud volcano evolution: We wanted to investigate the temporal progression of individual mud flows at different mud volcanoes to finally constraining 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, which could be mapped with sufficient quality and resolution, it is even possible to distinguish the mud flows by outlining areas with different backscatter intensities. This information allows already 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. Ceramicola et al. (2014) suggest determining the maximum age of extrusion by combining the estimated maximum detection depth estimated with the frequency of the echo-sounder together with measured sedimentation rates. Three cores have been analysed in their study resulting sedimentation rates of 4-11 cm/10^3 years on the Calabrian inner prism and 18-26 cm/10^3 years in the fore-arc basin. We planned to apply this method and take additionally sediment cores at mud flows with different backscatter intensities and analyse the overlying hemipelagic cover to prove the first estimation but also allow more precise age information.

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 seafloor structures the more information about the mud flow characteristics can be drawn. Imaging especially the small-scale morphologies e.g. of individual flows or the edifices gives new insights into mud volcano processes, which are only possible by high-resolution mapping.

Mud volcano activity: Mud volcanism is certainly episodic with usually long phases of quiescence and short-lived eruptions, whereas reoccurrence times might vary widely. However, dormant mud volcanoes can show quiescent fluid seepage, which is inferred for the Madonna dello Ionio and

Pythagoras Mud Volcanoes. During M112, the only active fluid seepage was detected at Venere Mud Volcano by water column imaging, which has also shown very recent mud extrusion. Nevertheless, temperature anomalies at Cetus Mud Volcano and elevated methane concentrations in the bottom water at Nikolaus Mud Volcano also point to recent activity, although the last mud expulsion might be several thousand years ago. Systematic water column imaging as well as temperature measurements in the sediments will help to determine the recent activity of the mud volcanoes to be investigated.

3.2 Geological Setting of the Calabrian Arc

Mud volcanoes have been found in various geological settings on passive and active margins, but are mostly known from collision zones on earth like along the southern rim of the Eurasian plate. Mud volcanoes are well known on land like Azerbaijan, where at least 1,000 mud volcanoes have been counted. The amount of submarine mud volcanoes is much larger and recent improvements in seafloor mapping and imagery as well as numerous seismic surveys led to the discovery of many mud volcanoes in all oceans. The number of such mud extrusions in the ocean seems gradually increasing with proceeding marine research activities. 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).

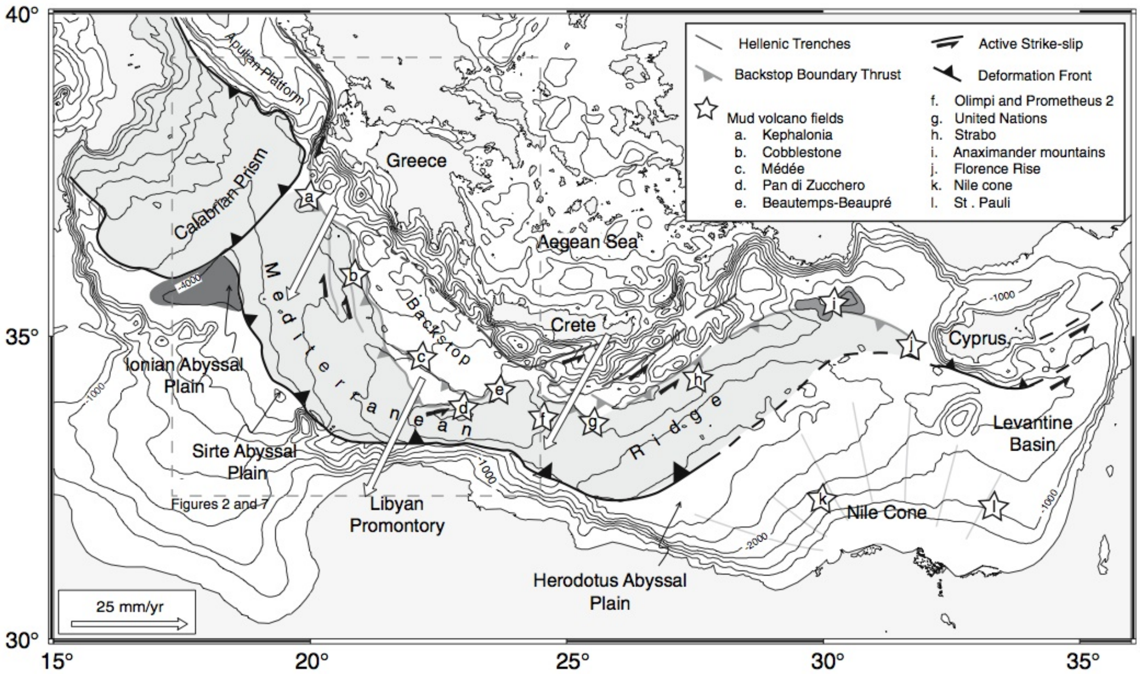


Fig. 6: Geological setting of the eastern Mediterranean (from Rabaute and Chamot-Rooke 2007), showing the Calabrian accretionary prism against the larger accretionary complex of the Mediterranean Ridge. White arrows indicate motion of the Aegean backstop with respect to Africa.

Within the framework of several European projects scientists from Italy and other countries collected over the last 10 years numerous multibeam echosounder data from the inner and outer Calabrian Arc. 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 km^2 within the Calabrian Arc (Ceramicola et al. 2014). Sampling has been performed from only two mud volcanoes: the Madonna dello Ionio and Pythagoras Mud Volcano

(Praeg et al. 2009). The role of the two mud volcanoes within the accretionary wedge of the Ionian Sea is rather unclear, although the presence of mud volcanoes 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 (Fig. 6). The **C**alabrian **A**ccretionary **P**rism (**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).

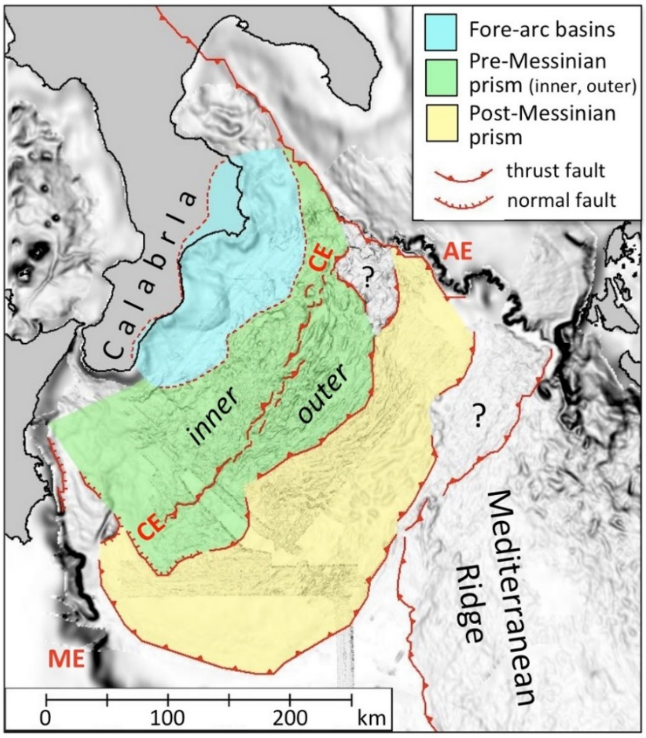


Fig. 7: Main morpho-tectonic zones of the Calabrian accretionary prism (Ceramicola et al. 2014). The inner parts of the fore-arc basins have been raised by on-going uplift of Calabria. The pre-Messinian Prism to seaward is divided into inner and outer parts by the Calabrian Escarpment, up to 200 km long 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.

Since ca. 10 Ma (late Miocene), slab retreat has driven the pulsed opening of back-arc basins in the Tyrrhenian 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 (Fig. 7), 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 CAP 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 (Fig. 8; Chamot-Rooke et al. 2005b). 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 (Fig. 7), 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 (Fig. 8) 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 (Fig. 7), 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).

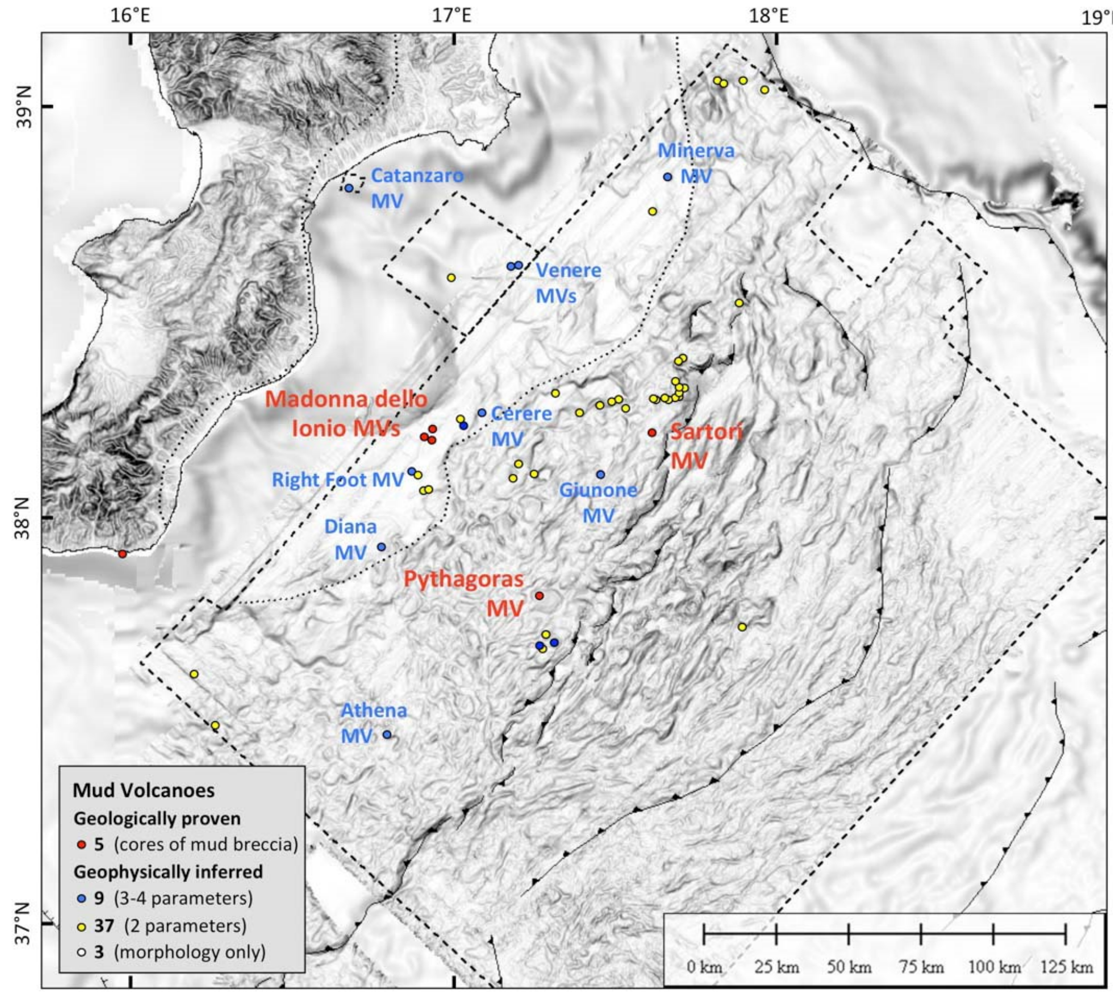


Fig. 8: Shaded relief map of the Calabrian accretionary prism showing locations of mud volcanoes geologically proven by coring and geophysically inferred from up to 4 parameters (morphology, backscatter, sub-bottom acoustic facies and, in the case of Catanzaro MV, a possible hydro-acoustic flare). Dashed lines show extent of multi-beam bathymetric and backscatter data coverage (100 m DEM). After Ceramicola et al. 2014.

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, these 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).

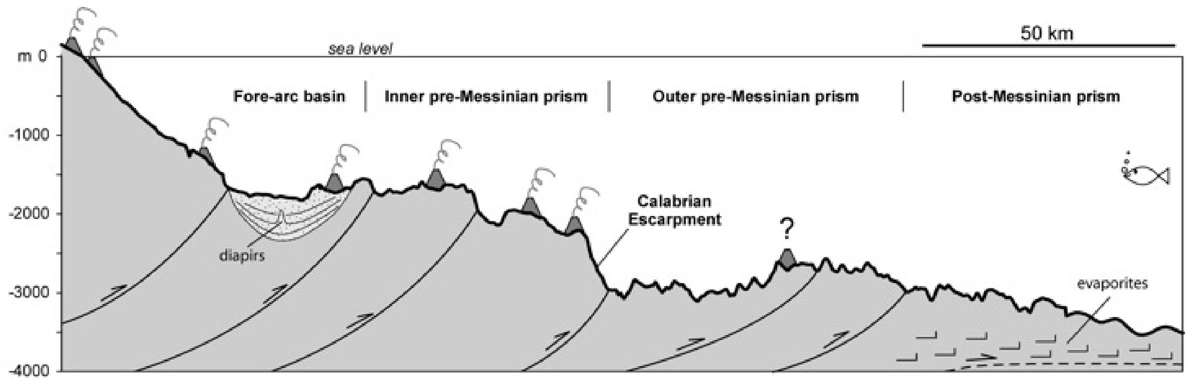


Fig. 9: NW-SE bathymetric profile 250 km long across the central part of the Calabrian accretionary prism, schematically summarizing the distribution of mud volcanoes in relation to the main morpho-tectonic zones (from Ceramicola et al. 2014).

Mud volcanoes (MVs) 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 on 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, Fig. 8), but mud diapirism as proposed by Cita et al. (1981) was rejected in favour of tectonic deformation along thrusts (Rossi and Sartori 1981; Morlotti et al. 1982). The presence of mud volcanoes 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, mud volcanoes 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 MVs in the Spartivento fore-arc basin and Pythagoras MV on the pre-Messinian wedge seawards (Fig. 8; Praeg et al. 2009). Targeted seismic investigations of these two sites showed both to be the tops of buried extrusive edifices that interfinger with Plio-Quaternary sediments 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 (see 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).

More recently, integration of multibeam morpho-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 (Fig. 8). Five of the MVs were proven by coring, while the remainder were identified based on up to four geophysical parameters, the vast majority (40/54) from morphology and/or backscatter based on a 100-m multibeam grid. Nine of the geophysically inferrred MVs were identified with sufficient confidence to be given names (Fig. 8). With one possible exception, all of the MVs are restricted to the inner plateau of the Calabrian prism, landward of the Calabrian Escarpment (Figs. 8 and 9). The majority (50/54 MVs) 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 MVs (Ceramicola et al. 2014). The Madonna dello Ionio and Pythagoras MVs 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).

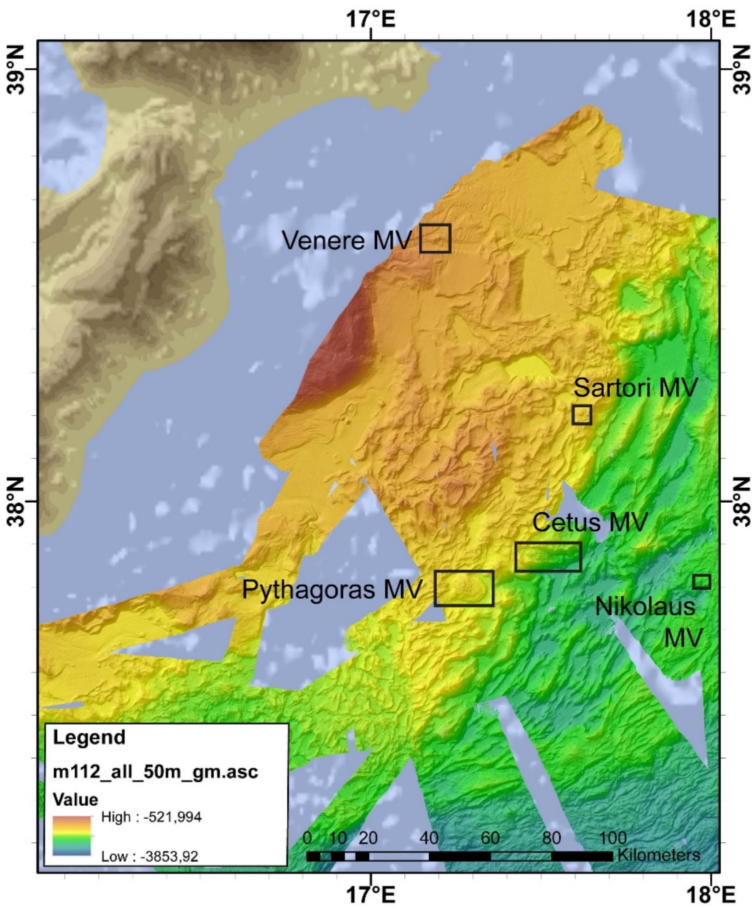


Fig. 10: Swath bathymetry acquired with multibeam EM122 during R/V METEOR Cruise M112 in the northern part of the Calabrian accretionary prism. Locations from mud volcanoes of interest are indicated by boxes. Station work of M112 was performed dominantly at Venere Mud Volcano. Pilot surveys at Sartori, Cetus, Pythagoras and Nikolaus Mud Volcanoes were also performed and will be the targets of this proposal (data are from Bohrmann et al. 2015).

Within the Calabrian arc we performed various investigations on mud volcanoes during R/V METEOR Cruise M112 in 2014 (Fig. 10). M112 was originally planned to take place at the Anaximander Mountains in Turkish waters, however, Turkish research permission could not be realized and an alternate cruise within the Mediterranean Sea guided us with support from Italian colleagues to the Calabrian Arc. From 6 November to 15 December 2014 we surveyed during two legs around 4.400 nautical miles of the Calabrian Arc by EM122 multibeam and Parasound for measuring seafloor bathymetry in more detail and to find gas emission sites in the water column. Gas plumes (flares) were explored by acoustic systems of the ship in order to localize active seepage on the seabed associated to mud volcanism in the area. We have been guided by the 100 m grid bathymetry and 54 locations for mud volcanoes previously found by our Italian colleagues from OGS, Trieste (Ceramicola et al. 2014).

During the cruise we improved the bathymetry to a 30 m grid and a high resolution backscatter map of the same scale which revealed much more details of distinct seafloor features (Bohrmann et al. 2015). Five of the mud volcanoes were disproved and 25 new mud volcanoes have been found, so that the total amount of mud volcanoes in the Calabrian arc is around 70 structures and more. Specifically, around 20 mini-mud volcanoes were mapped in the outer pre-messinian prism seaward of the Calabrian escarpment, which have not been known before the M112 cruise.

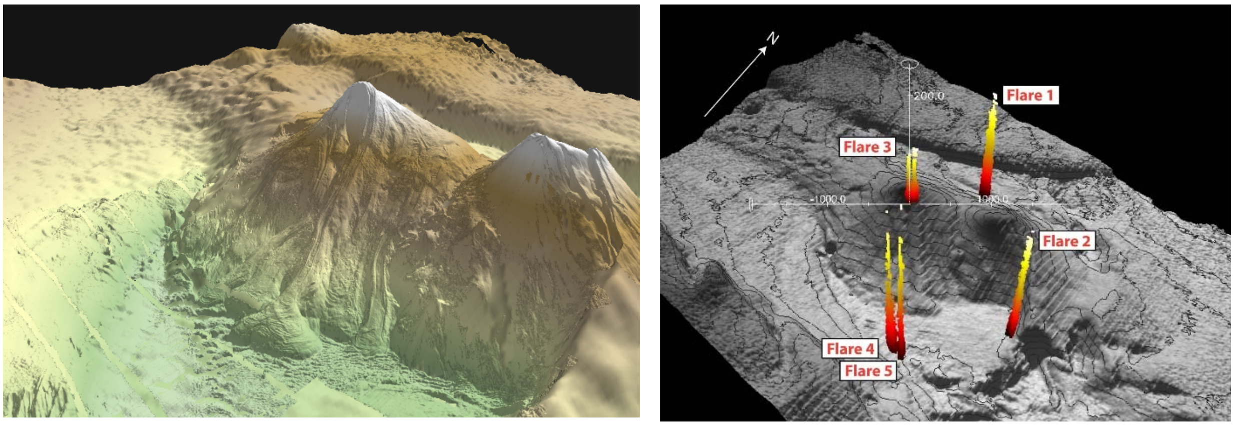


Fig. 11: 3D-view of the AUV-based micro-bathymetry from Venere MV. The left of the two summits is recently active and shows distinct gravity driven mud flows from the summit down to the base of the canyon. Distinct gas bubble sites named Flares 1 -5 are shown on the right side.

We crossed with R/V METEOR all 70 mud volcanoes and found by recording the acoustic data of the water column that only one mud volcano was active by emanating gas bubbles from the seafloor into the water column. Only Venere Mud Volcano was accompanied by 5 distinct gas emission sites called Flares 1-5 (Fig. 11 right image). Those flares are well-associated to seeps at the rim of (Flares 1, 2, 4, and 5) of the mud volcano caldera and Flare 3 to the recent mud outflow area at the western summit of Venere Mud Volcano. Twenty-eight hydro-cast stations document how the expelled methane is distributed in the surrounding water column (Bohrmann et al. 2015). With AUV seal we could map the micro-bathymetry and gravity cores and sampling during ROV dives is showing the rapid flow rates of mud emission at the volcano (Fig. 11). Seven repeated slow speed (3-4 knots) surveys during 3 weeks over five distinct flare locations at Venere MV showed that the relative gas emission intensity vary over days. Four flares exist at the rim of the mud volcano caldera where most probably fractures form pathways for gas migration to the seafloor. At all flare locations active seep manifestations like chemosynthetic fauna, carbonate formations and gas ebullition have been found. Backscatter maps reveal much more seeps at the surroundings of Venere MV. Flare 3 is forming an exception because it is located close to the outflow area of the mud on top of western summit (Fig. 11). The gas expelled with the mud on top of the summit shows a composition which is clearly thermogenic gas in origin, whereas the gas composition at the surrounding seep sites shows a mixture of thermogenic with biogenic gas.

4 Cruise Narrative

(G. Bohrmann)

Research vessel POSEIDON sailed from the "Molo di Mezzogiorno" of the port of Catania at 09:00 local time (LT=UTC+2h) on **Wednesday, 4 May** 2016, to perform its research mission number 499. The target area of this research cruise was the Calabrian Arc in the Mediterranean Sea. Before sailing, R/V POSEIDON had spent three days at dock in Catania while scientists and research tools of cruises POS498 and 499 were exchanged. New research tool on board of POS499 was the autonomous underwater vehicle MARUM AUV-SEAL 5.000. Beside the AUV a mini-corer (MIC) and additional core barrels and core liners were loaded which were transported by a truck from Germany to Catania. The material was stored on deck and in the labs by the vessel's boatswain and seamen. The scientists from Germany, Italy, Switzerland, Austria embarked on the ship on **Tuesday, 03 May** 2016 and used the day for setting up the laboratories.

On **Wednesday, 4 May** 2016 the ship left the port and the pilot station at 10:00 in calm and sunny weather. The track route guided us in northeastern direction along the Calabrian coast to Venere Mud Volcano (Fig. 1). After a first CTD station at 38° latitude to measure a sound velocity profile for calibrating of the multi-beam echo-sounder a multi-beam profile was taken over night until we reached Venere Mud Volcano. On **Thursday, 5 May** 2016 we planned to launch the AUV SEAL 5.000 for micro-bathymetry mapping of the Venere Mud Volcano, however, the sea was too rough and we decided to wait for better weather conditions which had been announced by the weather forecast.

Instead we took a series of seven mini corer samples (MIC-1 – MIC-7; Fig. 13) from different mud flows on the southern flank of Venere Mud Volcano. The mud volcano is eroded along its southern flank by turbidity currents which shape the Squillace Canyon (Fig. 12) during downward flowing of the turbidites. This produced the over-steepening of the volcano's flank and the more recent mud flows from the volcano seem to follow this steep relief. During R/V METEOR cruise M112 in 2014 we mapped those flows in detail and gravity cores showed depending on its age different thicknesses of hemipelagic sediments overlaying the mud flow breccia. By investigating the oldest age of the hemipelagic coverage we are trying to understand the age of the mud flow below. Since the topmost parts in gravity cores are not always undisturbed we had the intention to complete our knowledge of the mud flow age by using a mini corer (MIC) which samples the uppermost part of the seafloor very precise. In fact, by sampling the mud flows with the mini corer we could see small differences in sediment thicknesses on top of the different mud flows. During the night we repeated a flare imaging profile line from cruise M112 two times in order to detect gas emissions at five distinct flare positions named Flare 1-5. Gas emissions have probably been observed at Flares 2, 3 and 4 and show that the mud volcano is still active. Up to now Venere Mud Volcano is the only known mud volcano of the Calabrian Arc which is active by emitting gas into the water column.

On **Friday, 6 May** 2016 we could launch the AUV SEAL during calm sea state and could perform new micro-bathymetric data of the summits of Venere Mud Volcano. A comparison of the raw data did not show a major change in the seafloor features, however, a detailed comparison after processing the data will probably show more. A further flare imaging program was performed during the following night. We recorded the water column anomalies specifically at the active flares from the night before by multiple crossing of the vessel during very low speed between 0.4-0.6 knots. This strategy of profiling revealed much more details of multiple emissions sites at the known seafloor locations.

During **Saturday, 7 May** 2016 we successfully deployed the mini corer at eight locations (MIC-8 – MIC-10) more around the mud volcano (Fig. 13) for sampling the uppermost sediments in high quality. In most cases we recovered mud flow breccia in the deeper cores and hemipelagic sediments on top. At 17:00 we launched AUV SEAL for a mission overnight, which recovered micro-bathymetric data from the southern flank of the volcano until the southern rim of the Squillace Canyon. All of us have been impressed by the high quality of the data and the large scaled scour marks in the canyon. Flute casts are to occur everywhere and are the result of active currents which may be initiated onshore Calabria by rivers that flow over the shelf break and downward into the Squillace Gulf and are focused in the Squillace Canyon.

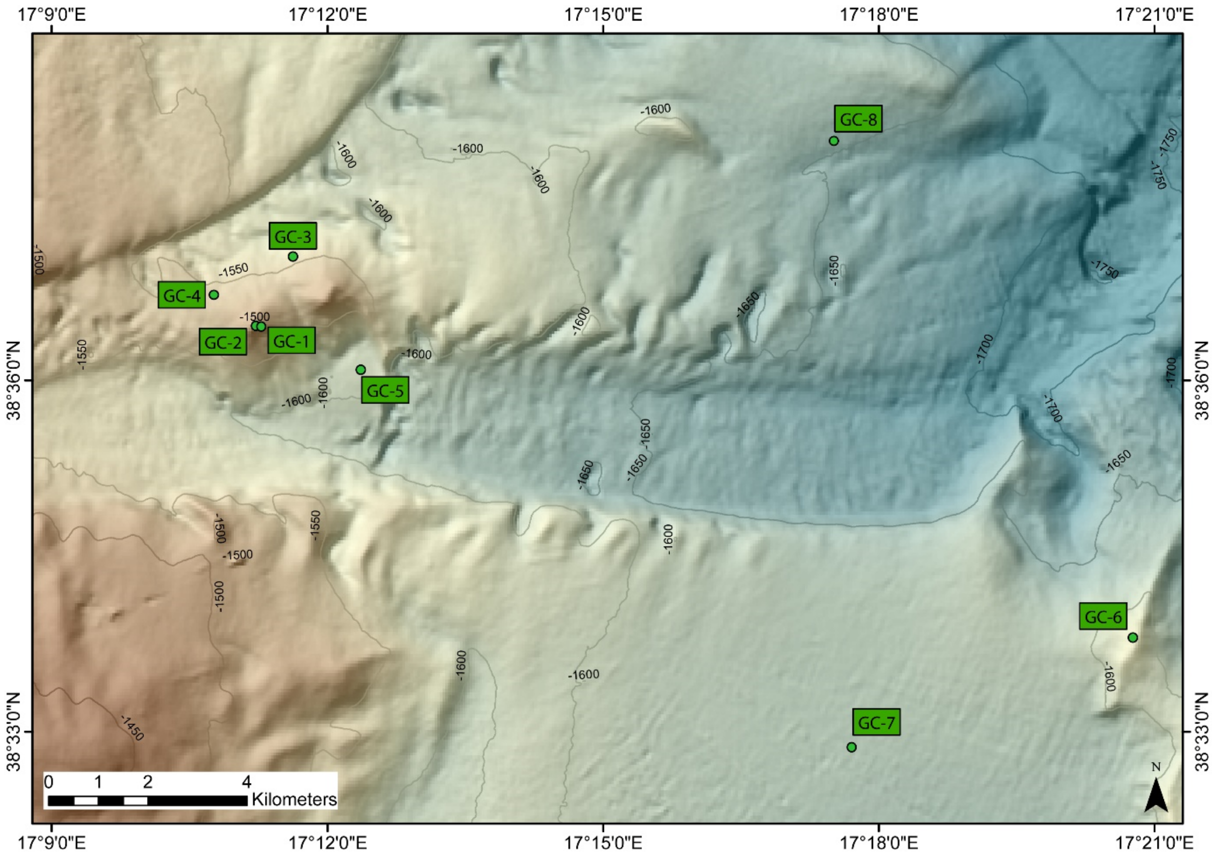


Fig. 12: Squillace Canyon and Venere Mud Volcano with location of gravity cores taken during cruise POS499.

Sunday, 8 May 2016 was the day for gravity coring and we took a series of cores (GC-1 – GC-5) at Venere Mud Volcano (Fig. 12). The first two cores were taken in a plastic bag instead of a liner at the summit where the mud is flowing out. Since this mud is coming from a deep source we sampled gas and pore water to compare the data with results from M112. Two years ago the fluid was depleted in salt content and the methane gas was thermogenic in origin. The quick salinity measurements on board showed again the down-core depletion in salinity. Further gravity cores sampled selected positions in relation to seepage and channel activity (Fig. 12). The plan to launch the AUV at 17:00 was canceled because the vehicle could not be prepared in time for this dive. The reason was the large amount of data from Dive 72, during which we also recorded large files of the water column. The downloading of the data took too many hours and the vehicle needed external power supply which complicated also the recharging of the AUV's batteries. We therefore canceled the dive designated for this night and performed instead a multi-beam profiling survey to the north including a potential mud volcano known from data of our Italian colleagues (Fig. 1).

On **Monday, 9 May** 2016 we started the scientific program onboard R/V POSEIDON with temperature profiles at five sites (Fig. 13) beginning at the outflow area of Venere Mud Volcano and following along the pathway of the mud flow to the east. The temperature logger had been attached to the core barrel and the barrel was closed by a conical cap mounted on the core catcher, to prevent sediment intrusion. Temperatures up to 10°C have been measured in the near surface sediments at the mud outflow area. Further gravity cores have been taken at background stations to compare the normal sedimentation of the area in relation to the mud flow sequences. Planning of those stations showed that it is not easy to find distinct background sites, because the canyon is used by turbidity currents which transport a lot sediment downslope and gravity cores sampled during the R/V METEOR cruise showed widely distributed spill-over sedimentation along the shoulders of the canyon. We therefore took a location for coring 8 nm to the east on a topographic high (GC-6; Fig. 12). We also sampled the plain south of the Canyon and the northern shoulder in order to investigate the local changes in background sedimentation (GC-7; Fig. 12). We had to cancel our plan to start the third AUV-dive to complete the micro-bathymetry of Venere Mud Volcano, because of the failure of the PHINS, the motion sensor system of the vehicle. We ordered immediately a spare part in Germany to be sent to the port of Catania. Instead the AUV dive we again mapped the activity of gas emissions by crossing the well-known flare positions around Venere Mud Volcano using the multi-beam of the ship.

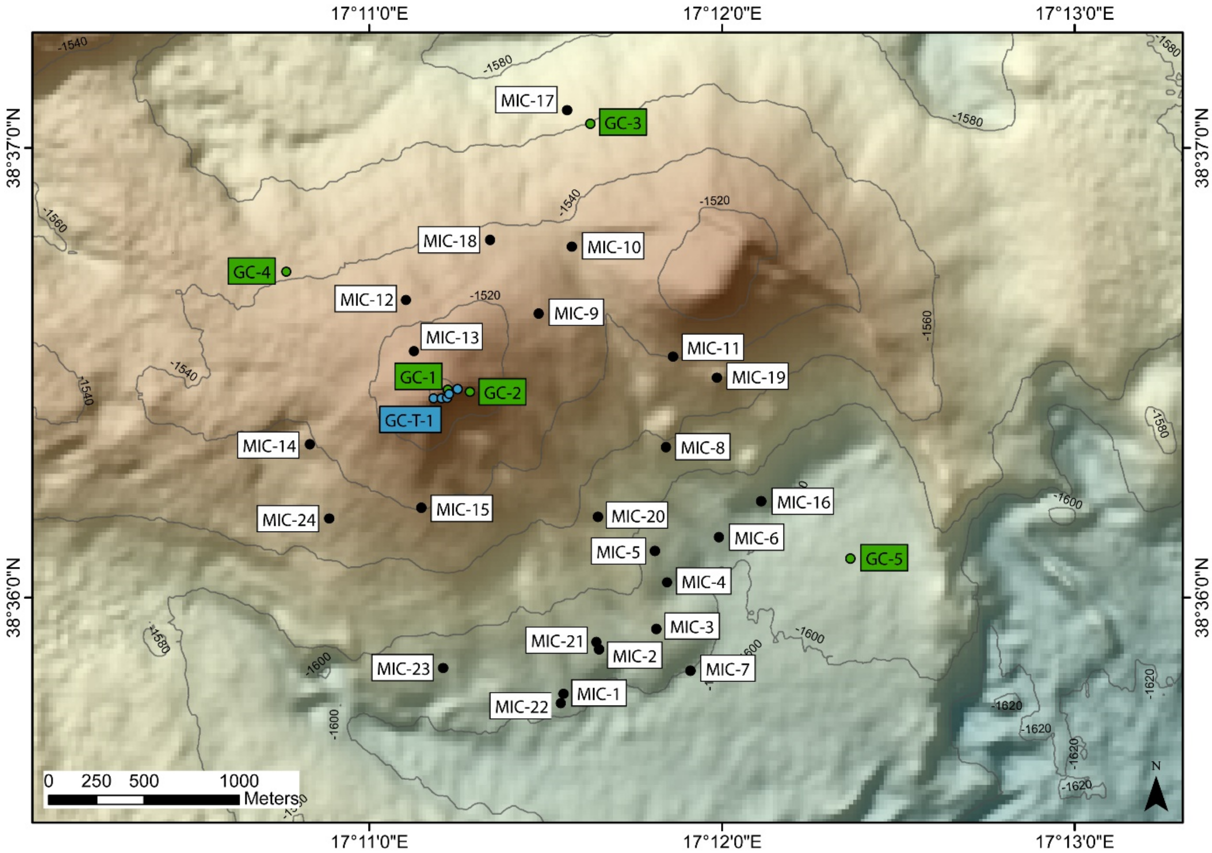


Fig. 13: Locations sampled during Cruise POS499 at Venere Mud Volcano. 24 mini-corer stations sampled the uppermost cms of the seabed to document the youngest sedimentation on top of the mud flow breccia from the mud volcano.

During **Tuesday, 10 May** 2016 we sampled an additional set of mini-corer stations (MIC-17 – MIC-24; Fig. 13) around Venere Mud Volcano to extend our knowledge about the hemiplegic sediments overlaying the mud breccia deposits. Afterwards around 16:30 we started a transit to Catania, where we arrived on **Wednesday, 11 May** 2016 in the morning where R/V POSEIDON moored at the pier "Mole di Levante" in the port of Catania (Fig. 1). A seaman of R/V POSEIDON had to be disembarked because of a medical problem and we waited for a new motion sensor for the AUV, which was sent from MARUM to Catania. In the harbor the AUV crew opened the pressure housing of the AUV and started to prepare the exchange of the motion sensor PHINS. At 17:30 the PHINS was delivered to the ship and could be exchanged in the vehicle. R/V POSEIDON left the port of Catania again at 09:00 on **Thursday 12 May** 2016 and steamed to the area of Venere Mud Volcano where we arrived in the night.

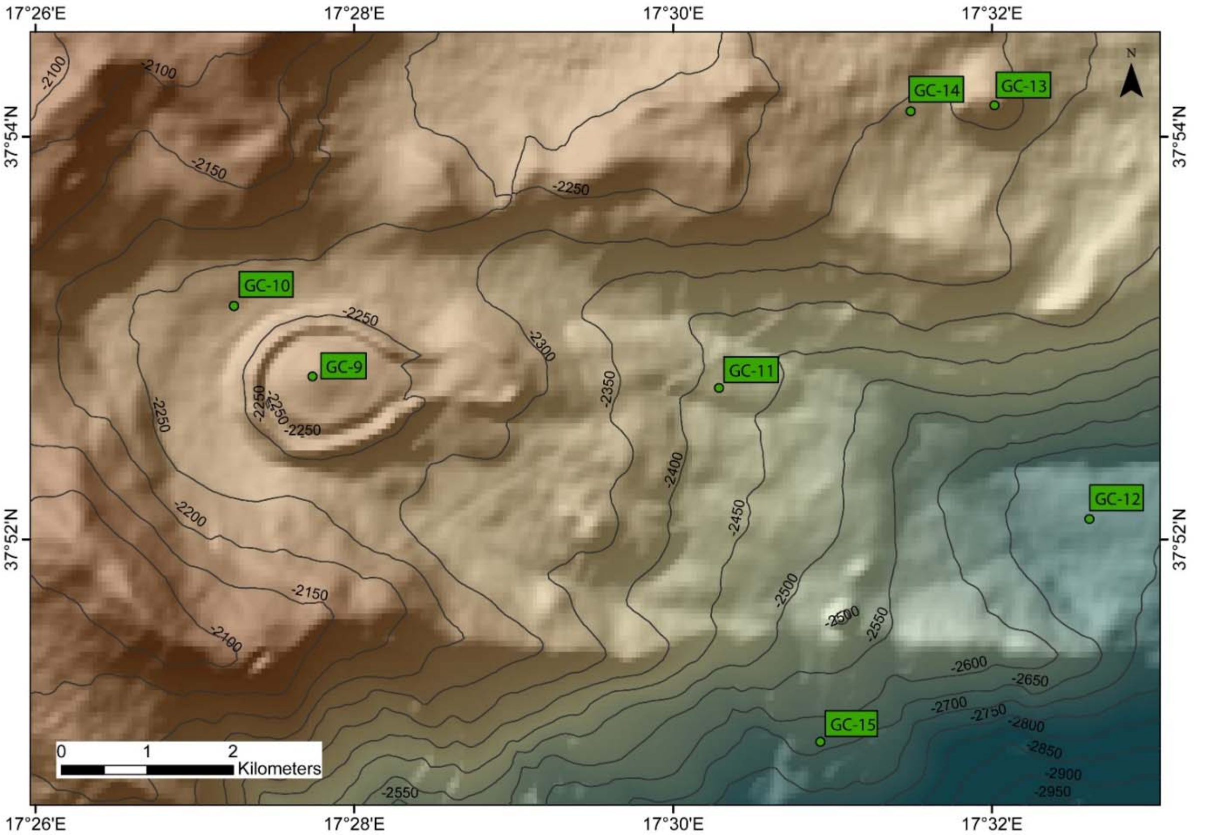


Fig. 14: Cetus Mud Volcano with coring stations during R/V POSEIDON Cruise POS499.

On **Friday 13 May** 2016 we started AUV Dive 73 and mapped the western, northern and eastern parts around the center of the Venere Mud Volcano. This third dive at Venere Mud Volcano of the cruise completed the micro-bathymetry mapping of the volcano and its highly interesting environment in the Squillace Canyon. The recovery of AUV Seal 5.000 happened late evening during rough sea state without technical problems. On the way to Cetus Mud Volcano during the night we mapped several mud volcanoes using the hull-mounted multi-beam ELAC SB3050 of the vessel. We started a gravity core program in the morning of **Saturday 14 May** 2016 in the area of Cetus Mud Volcano (Fig. 14). Cetus MV has a distinct caldera from which the northern part was mapped by AUV SEAL during M112 and a ROV dive showed a slight temperature anomaly which is most probably representing the chimney feeding the mud volcano with fresh mud in the past. A series of mud flows are shown by morphological ridges and different backscatter patterns with flow directions to the East and the mud breccia seems to have flown over the Calabrian Escarpment down to seabed level in deeper water depths. The first gravity in the morning (GC-9, Fig. 14) was taken in the center of the caldera to detect pore water data from the original fresh mud flow in the chimney. Further three cores from outside the caldera sampled the background sedimentation and 2 distinct mud flows (Fig. 14). AUV Dive 74 in the evening was planned to cover the southern part of the caldera and most of the nearby mud flows. Unfortunately, after one line at the bottom the vehicle got unknown problems and decided to come up to the water surface. The examination of the data protocols did not help analyzing the ground-fault of the AUV.

After the vehicle was recovered on **Sunday** morning **15 May** 2016 we continued in taking three gravity cores around Cetus Mud Volcano. Two cores have been taken above a distinct step in the morphology and the last one (GC-15, Fig. 14) sampled a mud flow which flowed over the slope of the Calabrian Escarpment. To our surprise the core penetrated the mud flow and sampled the hemipelagic sediments below and above of the flow unit. The AUV Dive 75 at the evening was performed over Sartori Mud Volcano which shows a well-defined flat-top mud-pie type of volcanic structure with very high backscatter and on its western side mud flows of two different backscatter intensities in the 12 kHz data from EM122 multi-beam data taken during M112 (Fig. 15). The AUV map revealed many details of the mud pie like two circular outflow patches on top and the locations of two mud flows over western rim. Surprisingly the backscatter of the 400 kHz multi-beam on the AUV showed only high intensities at the two distinct outflow channels on the surface of Sartori Mud Volcano.

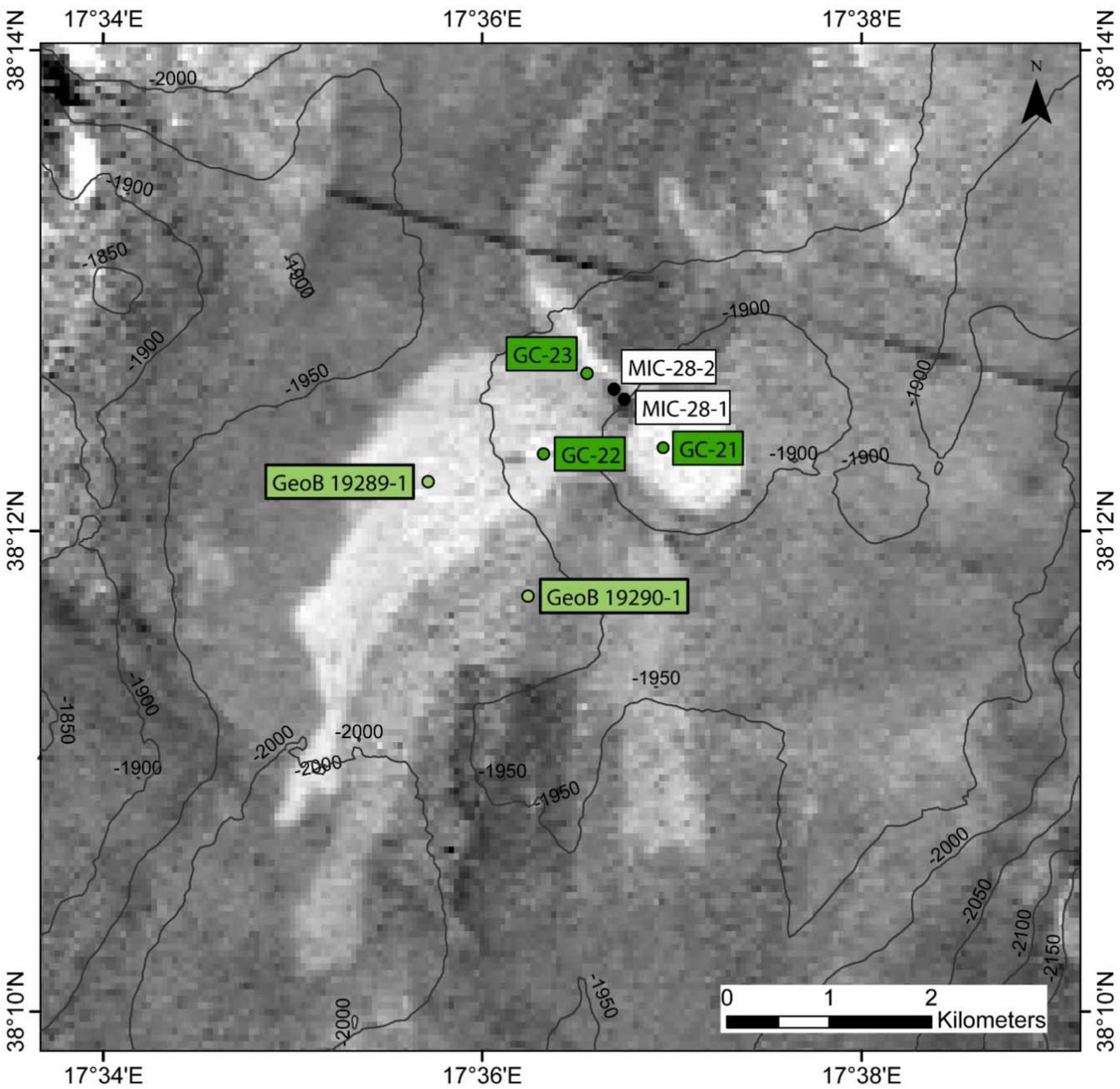


Fig. 15: EM122 backscatter map from Sartori Mud Volcano mapped during R/V METEOR M112 with two GeoB stations from M112 on two different backscatter intensities and the locations of POS499 sampling close and on top of the flat volcano.

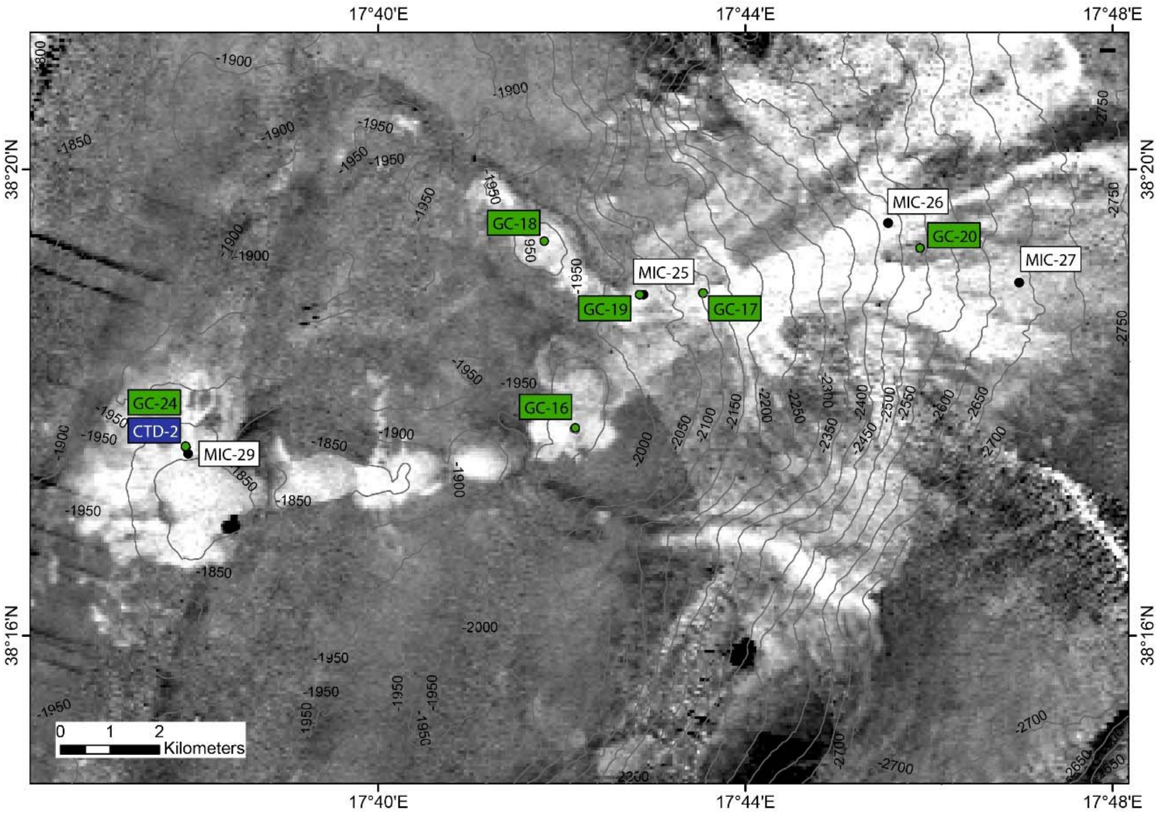


Fig. 16: EM122 backscatter map from Mud Volcano Ridge from R/V METEOR M112 with sample locations of R/V POSEIDON POS499.

On **Monday 16 May** 2016 we steamed to the north and took three gravity cores (GC-16, -17, -18) and MIC-16 at several places at the eastern part of Mud Volcano Ridge (Fig. 16). Mud Volcano Ridge was defined by Ceramicola et al. (2014) because at least ten high-backscatter mounds have been found and form a W-E alignment from which the easternmost mud cone was investigated by us in more detail. We called this mud volcano Poseidon Mud Volcano because Poseidon was not only the God of the Sea in Greek mythology but also our ship is named POSEIDON and celebrated last month its fortieth year since commission. East of Poseidon Mud Volcano the Calabrian Escarpment forms a distinct morphological step in the slope of nearly 700 m and mud from diverse mud volcanoes seems to cover the slope. Mud Volcano Ridge and the slope of the escarpment show high backscatter intensities in the 12 kHz data which was interpreted as an intense mud flow activity at the seabed. The gravity and mini-corer stations taken on Monday (GC-16, -17, 18; MIC-16) and **Tuesday 17 May** 2016 (GC-19, -20; MIC-26, -27) confirmed the mud volcanism is present everywhere. We sampled the mud flows at the slope east of Mud Volcano Ridge with two mini-corer stations (MIC-26 + -27) to determine the hemipelagic deposits overlaying the mud breccia. Gravity corer GC-19 sampled the Poseidon Mud Volcano and GC-20 the slope close to the MIC stations (Fig. 16). As in some other mud volcanoes from the Calabrian Arc the salinity in the core from Poseidon MV decreased from 38 PSU with depth to a level of 10 PSU showing most probably the refreshening effect of pore water by clay dehydration.

On Tuesday night we mapped the micro-bathymetry of seven mounds of the eastern end of MV Ridge during AUV Dive 77 and could prove that all of the cones are mud volcanoes with different backscatter patterns in the 400 kHz data. From four volcanoes with high backscatter patches on top, the mud-pie shaped Poseidon Mud Volcano showed the highest backscatter intensity. In contrast to Poseidon MV which has a flat top, the other three mud volcanoes are more cone shaped volcanoes.

In the morning of **Wednesday 18 May** 2016 we steamed to the south and sampled the Sartori Mud Volcano with gravity corer GC-21 and Mini Corer MIC-28 (Fig. 15). We launched the AUV at the evening ca. 20 nautical miles south at Cetus MV to follow up the former AUV dives there from R/V M112 and POS499. Specifically, the southern part of the caldera and some of the mud flows to the east were mapped by multi-beam echo-sounder. On the way back to the north R/V POSEIDON passed again Sartori Mud Volcano on **Thursday 19 May** 2016, where two gravity cores GC-22 and GC-23 sampled mud flows to the west in close vicinity to the volcano (Fig. 16). Before we planned to launch the AUV again we could take a mini corer station (MIC-29; Fig. 16) at Mud Volcano Ridge in the west. Unfortunately, the weather became too rough with wind speed of Beaufort 6 (Fig. 17) and more and we had to decide to cancel the dive for the night. During the night the sea state calmed and in the morning on **Friday 20 May** 2016 the AUV SEAL 5.000 dived down to the seafloor to perform AUV Dive 79 over Mud Volcano Ridge. Different from the previous dives, when we used the 400 kHz frequency of the multibeam 80 m above the seafloor we used this time the 200 kHz frequency and performed the dive 130 m above the seafloor. There we reached a swath of nearly 400 m and could map 1-2 swaths over the entire Mud Volcano Ridge area and part of the slope to compare those data with the data of the higher frequency from the previous dives. The comparison of the data will be carefully done in the lab in Bremen.

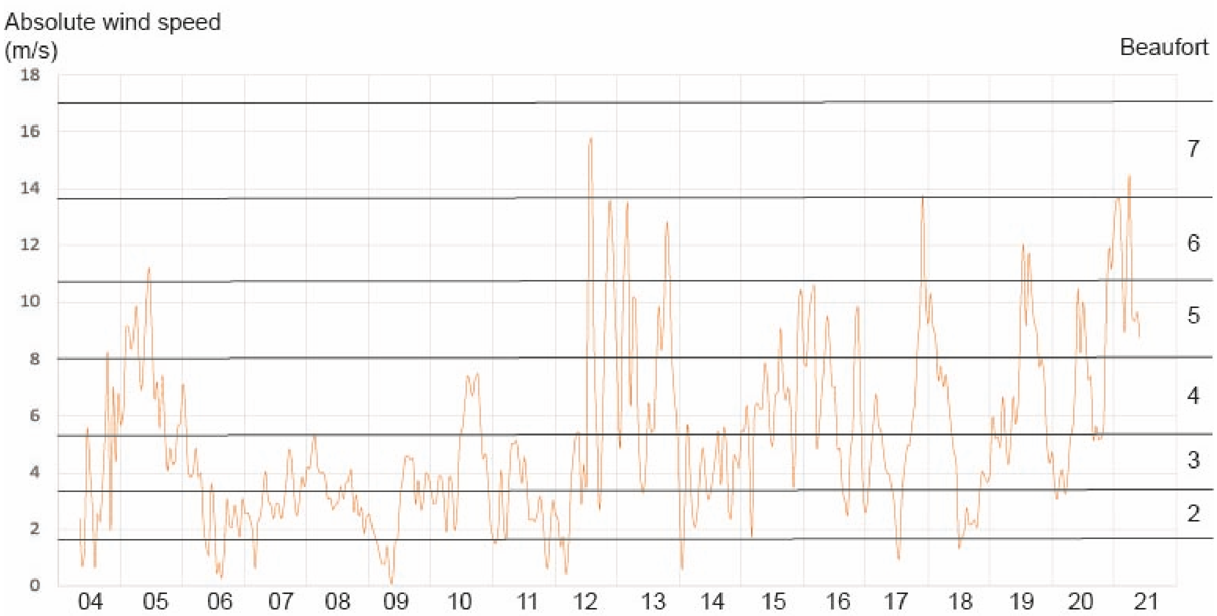


Fig. 17: Wind speed record of R/V POSEIDON during POS499 between May 4 and May 21.

On **Saturday 21 May** 2016 we started at 06:00 with a CTD station to 1.000 m water depth. Attached to the CTD we added our thermistor sensors MTLs in order to have calibration curves with the same hydrographic parameters. After that, we planned a last station on westernmost mud volcano of the Mud Volcano Ridge. Since the sea state was rough, we waited an hour before we deployed the gravity corer. GC-24 recovered a very stiff mud breccia at the base (Fig. 4) overlain by hemipelagic deposits. Since we could never use the heavy winch of the ship, because it broke down, we had to cancel the last gravity corer station on Cetus Mud Volcano. The scientific program was therefore closed at around 10:00 ship time (UTC ca. 08:00) and R/V POSEIDON steamed in direction to Catania where we arrived in the morning of **Sunday 22 May** 2016.

5 Oceanography

(P. Wintersteller, M. Loher)

In order to gather the oceanographic parameters temperature, salinity and derived sound velocity, a Sea & Sun Storage-Probe of the type CTD48M/363 was used. The device was deployed as a single equipment on the rope or 50 m above gravity - or mini-corer devices. This probe is depth-rated down to 2 km water column.

The probe has last been calibrated in 2010. Since the calculation of the depth seems inaccurate and the measurement of temperature and conductivity only starts at a certain pressure of about 5-6 dbar it is recommended to recalibrate the probe.

Fig. 18 shows the positions of the four CTD casts taken in the area of interest. CTD-2 is in the vicinity of Venere MV and is clearly outstanding in comparison to the others.

The graphs (Figs. 19, 20, 21) show the measured down casts of temperature, salinity and the derived sound velocity. The later has been used to correct the acquired multibeam echosounder data.

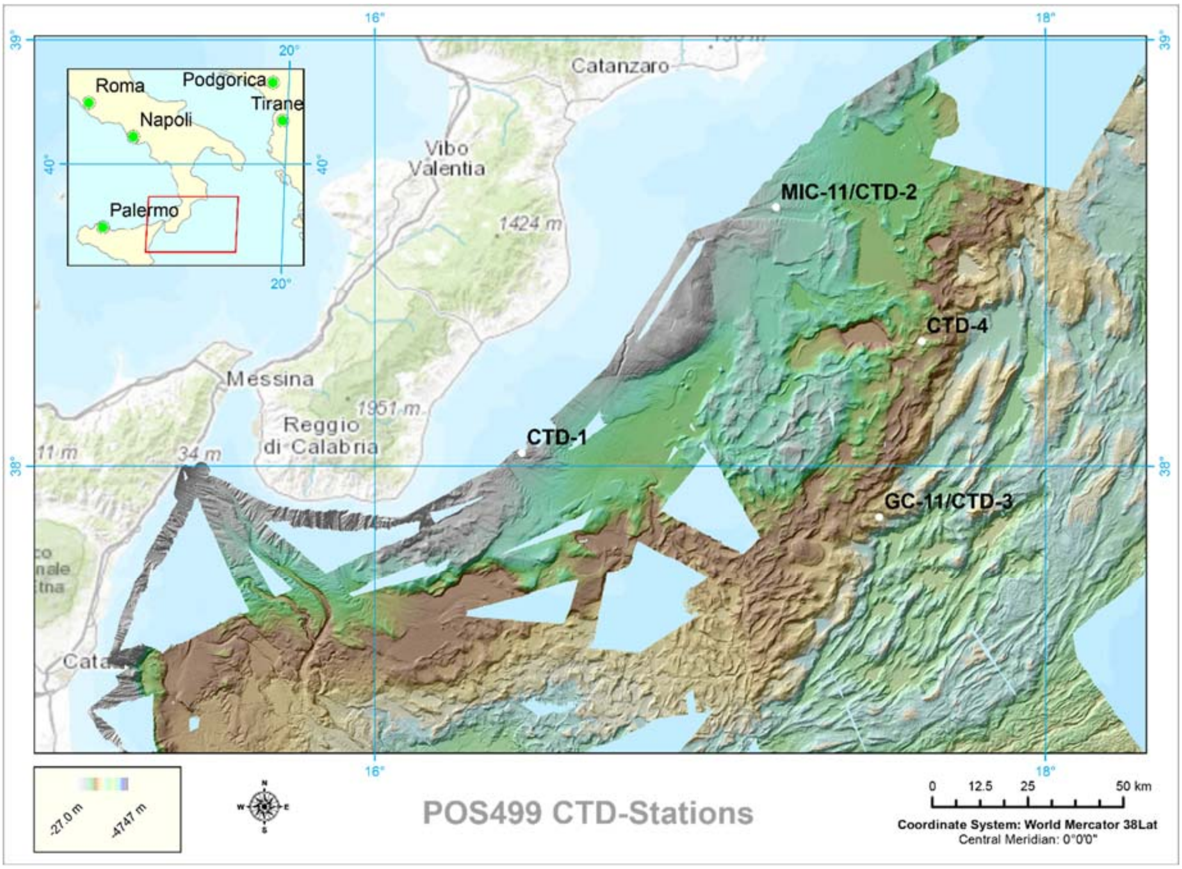


Fig. 18 shows the positions of the CTD stations conducted during POS499.

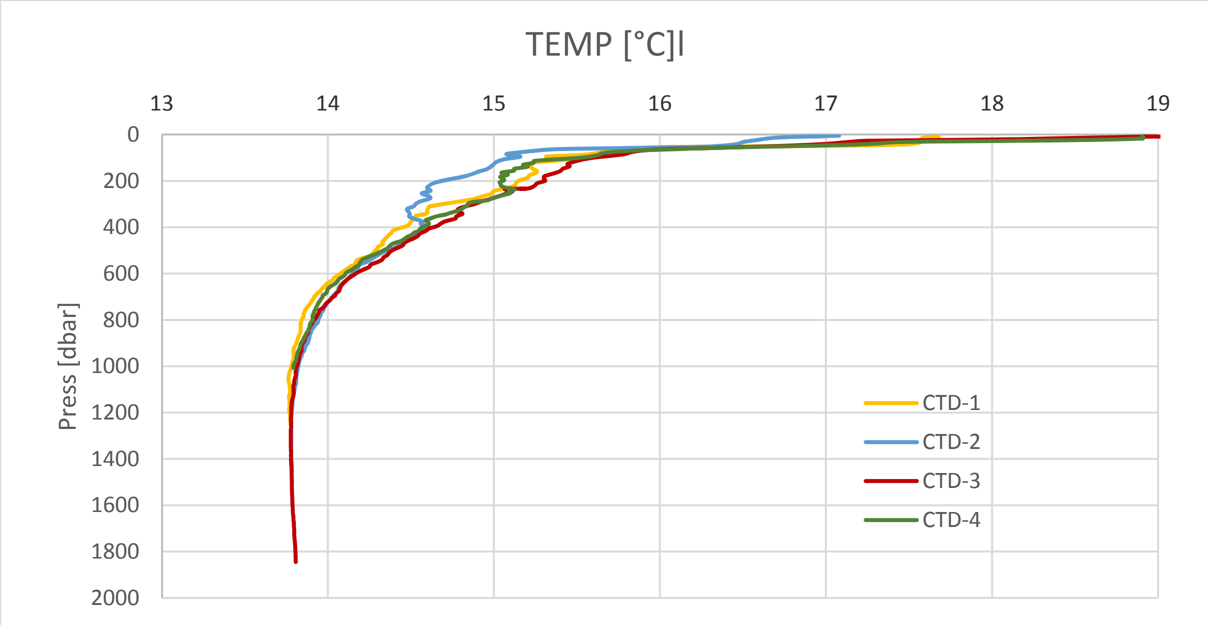


Fig. 19: Temperatures measured.

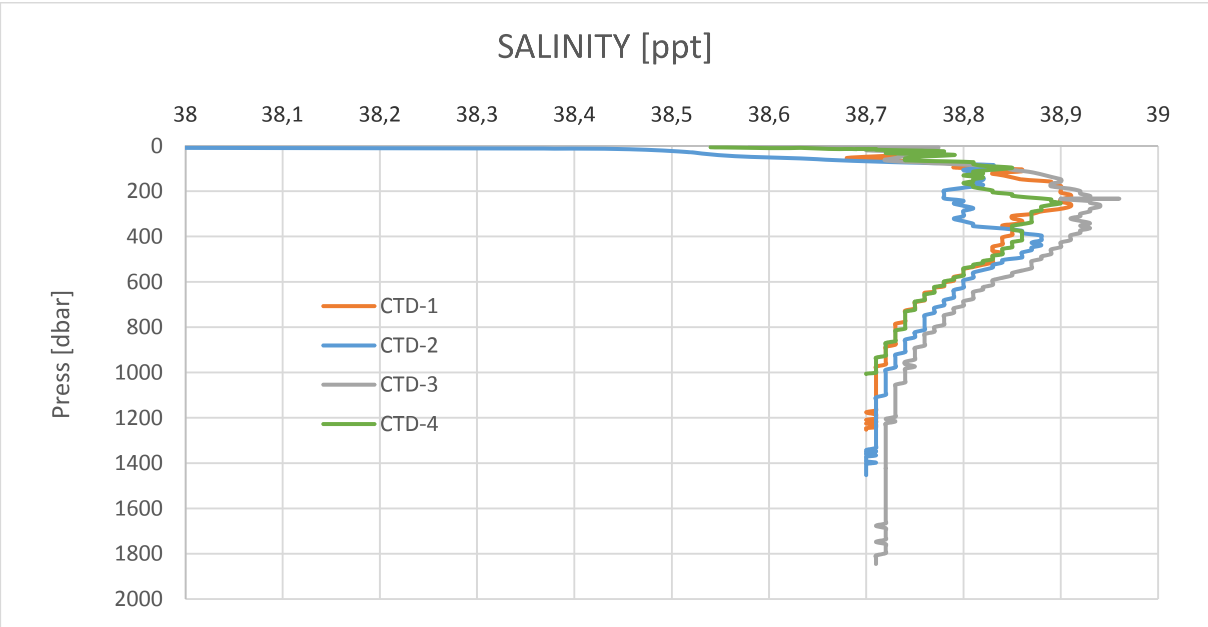


Fig. 20: Salinity as an expression of the measured and strongly correlating conductivity.

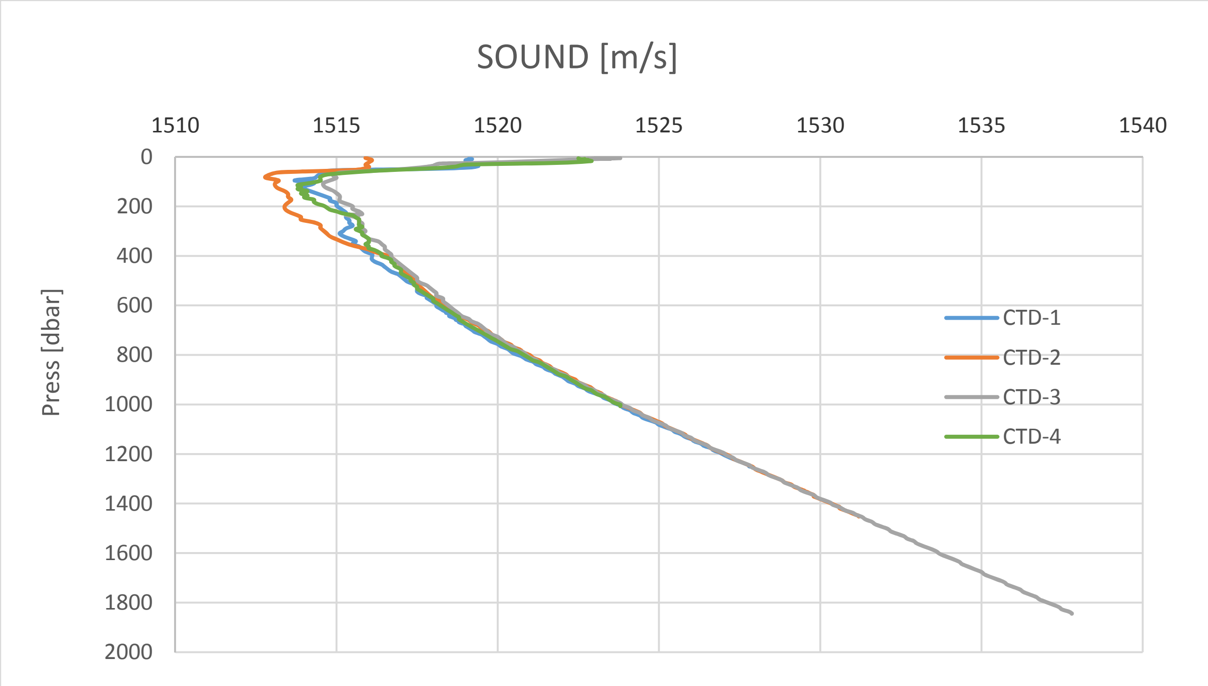


Fig. 21: Sound velocity derived from the CTD data, based on the UNESCO equation (Wong & Zhu 1995).

In every of the shown graphs CTD-2 is outstanding but particular in the temperature vs. salinity plot (Fig. 22). CTD-2 has been taken at the Venere Mud Volcano and seems to be influenced by a different water-mass at depths of about 100-400 m water depth.

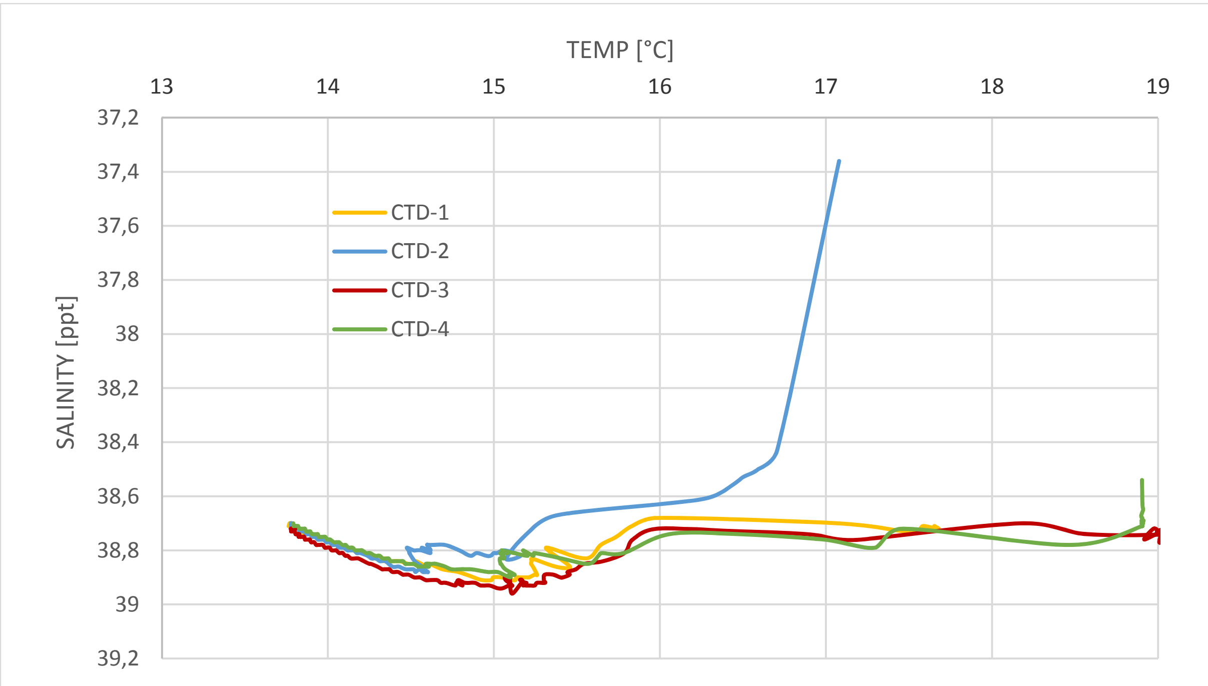


Fig. 22: Temperature vs. salinity plot.

Gačić et al. (2010) showed the Ionian Sea as a potential region of a bimodal oscillating system. This data, as well as the CTD and LADCP data of the former cruise M112 may help to support this approach.

6 Hydroacoustic Mapping

(P. Wintersteller, S. Ceramicola, O. Cardoni, K. Bachmann)

6.1 ELAC Seabeam SB3050

6.1.1 Introduction

AUV based high-resolution bathymetry mapping of potential mud volcano areas has been the aim of this cruise and was successfully conducted on five sites within nine dives (see Chapter 7). During R/V METEOR cruises M112 and M111 this area of the Calabrian Arc has been extensively mapped with state of the art deep sea echo sounder KONGSBERG EM122.

Therefore, vessel mounted mapping has not been a major target on this cruise. Nevertheless, within a total of 230 hours, we mapped 880 km mostly along the north western rim of the current map, shown in color in Fig. 23, over the underlying grey hill-shaded map of M111/112.

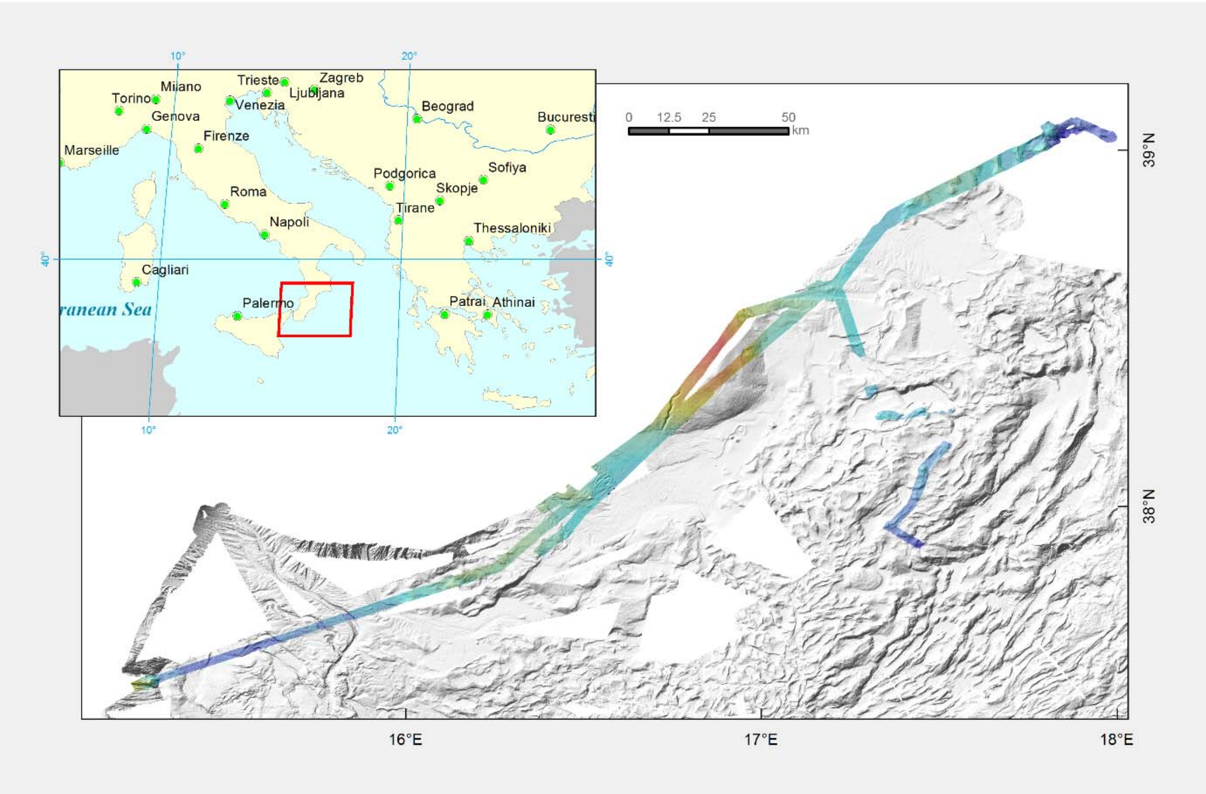


Fig. 23: Overview of the area mapped during POS499.

The data has been recorded with the hull-mounted ELAC SB3050 multibeam echosounder (MBES). It has a beam-width of 1.5°/2° and works at a frequency of about 50 kHz which reduces the swath width crucial below about 1000 m WD, depending on the sediment-type (see Fig. 24 from the ELAC manual). To record appropriate data with respect to this limitations, the swath-width has been set to AUTO mode and was commonly observed at around 80°. This given swath-width refers to a coverage of about 1.6 times the water-depth and reduces the max. number of beams collected per ping to less than 240. Most of the time the multi-ping mode has been used with a receiver reception gain value of 45dB.

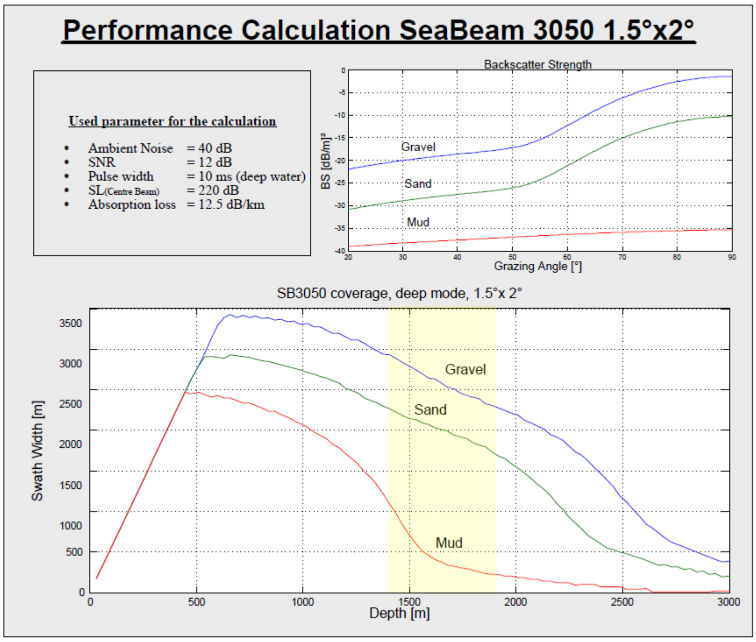


Fig. 24: Performance calculation of the SB3050. The yellow bar shows the depth area where most of the data was recorded. The swath width reached lied between the curve for gravel and sand.

A CODA F180 inertial navigation system (INS) is installed on R/V POSEIDON supplying accurate motion and navigation data to the MBES. Since the system is permanently running no calibration was required. Lever-arms and offsets were saved as *.shipxse "vessel file" within the HydroStar acquisition software. According to the calibration of the MBES by Jens Schneider v. Deimling during cruise POS469 the settings below were used:

Nav. Sensor	*Mot. Sensor*	*Hydrophone*	*Projector*
X=0 *Y=0* *Z=-5.65* *TD=0*	*X=0* *Y=0* *Z=-5.65*	*X=-1.5* *Y=6.36* *Z=4.25* *ROLL=1.45*	*X=-1.41* *Y=5.20* *Z=4.25* *PITCH=-2.40* *YAW=2.00*

While HydroStar records the *.xse as raw format, which was used to be processed to gridded bathymetry, the acquisition software Hypack is utilized in parallel to record *.raw and *.hsx files and to display the recorded data as an online surface.

A negative roll offset of 0.46° was found to the given offsets used in the vessel file and applied to the *.xse data-set during post processing (see the pseudo script Chapter 6.1.2).

6.1.2 Post Processing

The open source software package MBSystem (Caress and Chayes, 1995) was used to post process the data. A pseudo script with commands applied to edit and correct the SB3050 MBES data is displayed below.

```
###############
# Pseudo script to edit and process bathymetry data
#
# creation of a datalist of MB format 94
/bin/ls -1 *xse | awk '{print $1" 94"}' > datalist_xse.mb-1
# creating auxiliary files and a datalist for the processed files
mbdatalist -I datalist_xse.mb-1 -N -V –Z
# applying the rollbias found during this cruise
mbset -I datalist_xse.mb-1 (-PROLLBIASMODE:1) -PROLLBIAS:-0.46
# applying tide based on a model
mbotps -I datalist_xse.mb-1 -F-1 –M –D60
# applying corrections to backscatter as a function of the grazing angle with the seafloor
mbbackangle -F-1 -I datalist_xse.mb-1 -N61/60 -A -Q –V
# manual cleaning with the 3D-editor
mbeditviz –I datalist_xse.mb-1
# release the processing to apply edits and changes to every line and create processed lines
mbprocess -F-1 -I datalist_xse.mb-1
# gridding bathymetry
mbgrid –I datalist_xsep.mb-1 –F1 –A2 –C7 –E40/40m! –O POS499_A2F1C7E40m.grd –V
############
```

6.2 AUV-Mounted KONGSBERG EM2040

6.2.1 Introduction

The EM2040 MBES is a state of the art shallow water MBES, working on three different frequencies: 200, 300, 400 kHz. For AUV surveys 71 to 78 the frequency has been set to 400 kHz, diving in altitude-mode, 80 m above the seafloor, while for Dive 79 the frequency was set to 300 kHz with an altitude of 130 m.

6.2.2 Post Processing

Besides the open source software package MBSystem (Caress and Chayes, 1995), which was used for bathymetric post processing, QPS FLEDERMAUS has been utilized for water column and beam time series ("side scan") data investigations.

Bathymetric processing within the MBSystem workflow starts with attitude correction and a smoothing of the sonar depth which is derived from the PAROSCIENTIFIC pressure sensor (Fig. 25). This cruise has been used for detailed investigation in attitude issues which could finally be solved. The followed manual editing of AUV data is a very time consuming procedure since the resolution and beam density is very high (the produced grids have a cell size of about 1 m). As the navigation of AUV data is lacking of absolute (GPS) correction it has to be corrected relatively, using the mbnavadjust tool of MBSystem. A potential navigation offset could appear due to currents in the water column while the AUV is diving from surface to the given altitude. This correction is the last step and requires a reference e.g. research vessel recorded bathymetry, due to the fact that the USBL (ultrashort base-line underwater acoustic navigation) conducted with an IXBLUE GAPS system did not deliver enough data points.

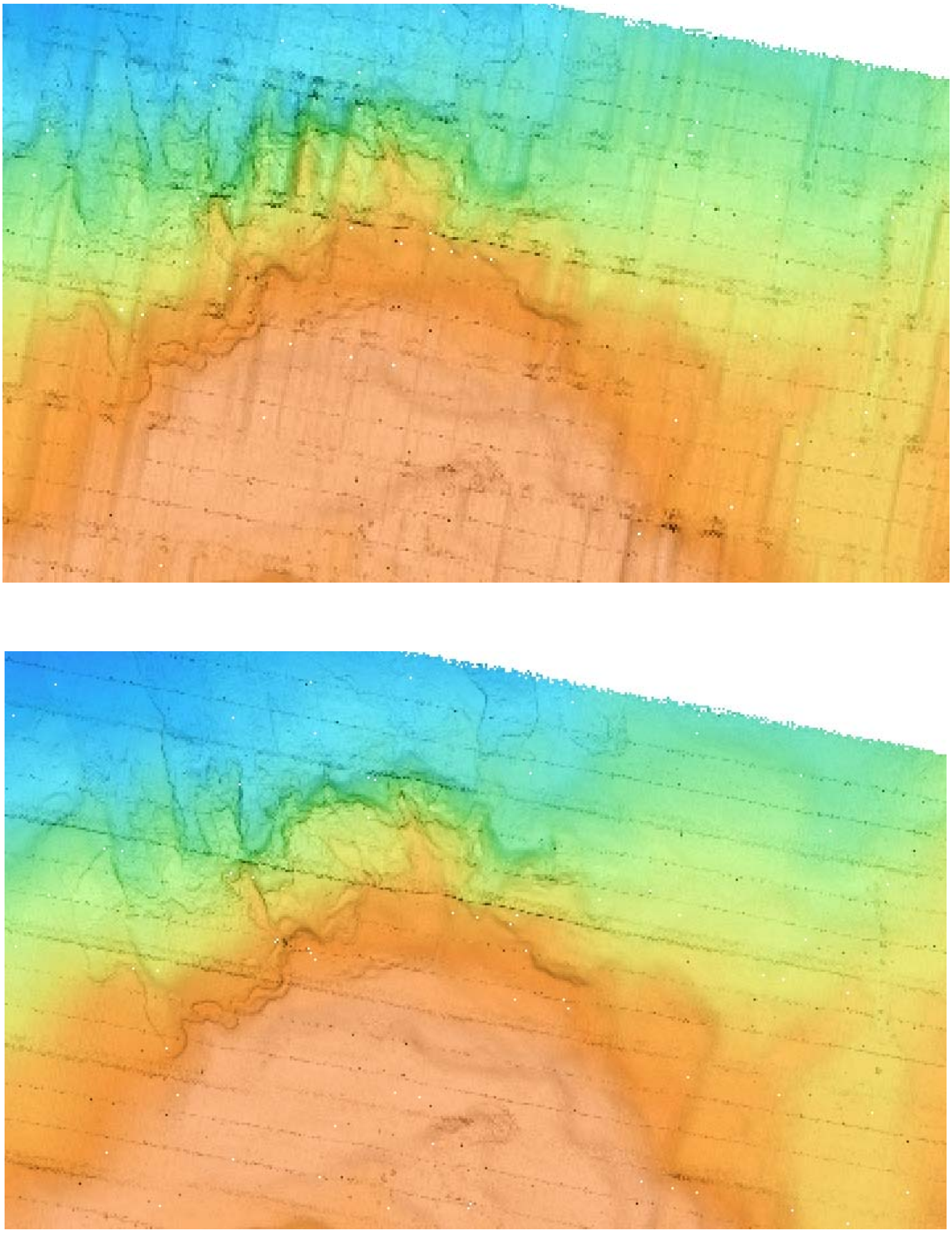


Fig. 25: First step of the bathymetric post-processing, above the raw data, below attitude corrected and smoothed sonar depth.

7 Station Work with the Autonomous Underwater Vehicle (AUV) MARUM SEAL 5000

(G. Meinecke, J. Renken, U. Spiesecke, T. von Wahl)

7.1 Introduction

In the year 2006 the MARUM ordered a deep diving autonomous underwater vehicle (AUV), designed as a modular sensor carrier platform for autonomous underwater applications. The company International Submarine Engineering (I.S.E.) built this AUV in Canada. In June 2007 the AUV "SEAL" was delivered to MARUM and tested afterwards on the French vessel N/O SUROIT (June 2007) and the German R/V POSEIDON (November 2007) in the Mediterranean Sea. Since then, the AUV is in operational mode and was used nine times on field cruises on-board research vessels (R/V SONNE, R/V METEOR, R/V MARIA S. MERIAN, R/V POSEIDON, N/O SUROIT, R/V OR5) and two times in Lake studies (Lake Constance, Lake Neuchatel). Therefore, this R/V POSEIDON cruise POS499 is the 13th field cruise of MARUM SEAL.

7.2 SEAL Vehicle – Basics

The MARUM AUV Seal is No. 5 of the Explorer-AUV series from the company I.S.E. The AUV is nearly 5.75 m long, with 0.73 m diameter and a weight of 1.35 tons. The AUV consists of a modular atmospheric pressure hull, designed from two hull segments and a front and aft dome. Inside the pressure hull, the vehicle control computer (VCC), the payload control computer (PCC), eight lithium batteries and spare room for additional "dry" payload electronics are located. Actually, the inertial navigation system PHINS and the RESON multibeam-processor are located as dry payload here. The tail and the front section, build on GRP-material, are flooded wet bays. In the tail section the motor, beacons for USBL, RF-radio, Flashlight, IRIDIUM antenna and DGPS antenna are located. In the newly constructed aluminium front section the Seabird SBE 49 CTD, the Sercel MATS 200 acoustic modem, the DVL (300kHz), KONGSBERG Pencil beam (675kHz), the recently implemented KONGSBERG EM2040 (200,300, 400kHz), the PAROSCIENTIFIC pressure-sensor and the BENTHOS dual frequency (100/400kHz) side scan sonar are located (optional). The SEAL AUV has a capacity of approx. 15,4 KWh main energy, enabling the AUV for approx. 65 km mission-track lengths. However, mission-track lengths had to be reduced due to the more energy consuming EM2040 MBES compared to former cruises.

For security aspects, several hard- and software mechanisms are installed on the AUV to minimize the risk for malfunction, damage and total loss. More basic features are dealing with fault response tables, up to an emergency drop weight, either released by user or completely independent by AUV time-relays itself.

MARUM put special emphasis on open architecture in hard- and software design of the AUV, in order to be as much as possible modular and flexible regarding the vehicle operations. Therefore, the VCC is based to large extend on industrial electronic components and compact-PCI industrial boards and only very rare proprietary hardware boards have been implemented. The software is completely built on QNX 4.25 – a licensed UNIX derivate, to large extends open for user modifications. The payload PC is built on comparable hardware components, but running either with Windows and/or Linux.

On the support vessel, the counterpart to the VCC is located on the surface control computer (SCC). It is designed as an Intel based standard PC, also running with same QNX OS and a Graphic User Interface (GUI) to control and command the MARUM SEAL AUV. Direct communication with the AUV is established via an Ethernet-LAN, either by hard-wired 100 mb LAN cable plugged to AUV on deck, or by Ethernet-RF-LAN modem - once vehicle is on water. The typical range of RF-communication is around 1 – 2 km distance to vehicle. Within this range the user has all options to operate the AUV in Pilot-Mode, e.g. to maneuver the AUV on water or change vehicle settings. Once the AUV is under water, all communication links were shut down automatically and the AUV has to be in Mission-Mode, means it is working based on specific user-defined missions.

Despite being in mission-mode, it is necessary to communicate with the AUV when it is under water, i.e. asking for actual position, depth and status. To achieve this, on-board the support vessel an acoustic underwater modem with dunking transducer has to be installed (SERCEL MATS modem) communicating with the counterpart on the AUV, on request. Due to limited acoustic bandwidth only rare data sets are available.

7.3 Mission-Mode

The AUV - as dedicated autonomous vehicle - has to be pre-defined operated under water, by demand. As mentioned, only at sea surface a maneuvering by the pilot is possible - once it dives, it will lose communication and therefore must be in a mission-mode. Initialized correctly, fault prevention mechanisms should prevent the AUV for damage/loss in that case.

Simplified, an AUV mission is a set of targets; clearly defined by its longitude, latitude, and a given depth/altitude the vehicle should reach/keep it by a given speed of AUV in a distinct time. The AUV needs to be in a definite 3-dimensional underwater space to know exactly its own position over mission time in order to actively navigating on this. To achieve this basic scenario, the AUV is working at sea surface with best position update possible, e.g. DGPS position. Once it dives, it takes the actual position as starting point of navigation, looks for its own heading and the actual speed and calculating its on-going position change based on the last actual position, e.g. method known as dead reckoning. To achieve highest precision in navigation, a combination of motion reference unit (MRU) and Inertial Navigation System (INS) is installed on the MARUM SEAL AUV – the PHINS inertial unit from IXSEA Company. Briefly, the MRU is "feeling" the acceleration of the vehicle in all three axes (x, y, z). The INS is built on three fibre-optic gyros (x, y, z) and gives a very precise/stable heading, pitch and roll information, based on rotation-changes compared to the axis. Even on long duration missions, the position calculating by the AUV will be very accurate based on that technique.

7.4 Mission Planning

In principle and very briefly it would be accepted by the vehicles VCC to receive a simple list of waypoints as targets for the actual mission (the list has to be in a specific syntax). In order to arrange it more efficient and convenient a graphical planning tool is used for this mission planning. The MIMOSA (© Ifremer) mission-planning tool is a software package specially designed to operate underwater vehicles (AUVs, ROVs, Glider). The main goal of this software is to plan the current mission, observe to AUV once it is underwater and to visualize gathered data from several data sources and vehicles.

MIMOSA is mainly built on two software sources, e.g. an ArcView 9.1 based Graphical Information System (© ESRI ArcGIS) and professional Navigation Charting Software (© Chersoft UK).

In order to plan a mission the user has to work on geo-referenced charts with a given projection (e.g. Mercator); either GIS-maps, raster-charts or S-57 commercial electronic navigational charts (ENCs). These basic charts could be enlarged easily with user specified GIS projects, enhanced with already gathered data, e.g. multibeam data, points of interest. Once installed in MIMOSA, one can create AUV missions by drawing the specific mission by mouse or using implemented set of tools (MIMOSA planning mode). Missions created in that way are completely editable, movable to other geographical locations and exportable to other formats. In order to be interpretable by the MARUM SEAL AUV, the created mission will be translated in the I.S.E. specific syntax; a set of targets, waypoints, depths information and timer will be created and written into an export path. From here the mission file can be uploaded via the SCC (support vessel) into the VCC (AUVs control PC); the AUV has its mission and is capable to dive, based on a valid mission plan.

7.5 Mission Observing/Tracking

The MIMOSA planning tool is also used for supervision, e.g. to monitor the vehicle at sea surface and more interesting under water (MIMOSA observation mode). The MIMOSA software is client based, means one dedicated server is used for planning, while the others are in slave/client mode, picking up actual missions. Therefore, position data strings (UDP broadcast data) from the support ship (i.e. R/V POSEIDON position, heading) are being sent to local network and fed into the MIMOSA software; the same is active for the AUV position data, e.g. DGPS signal once it is on sea surface. During dive the AUV can be tracked automatically via ship-borne ultra short baseline systems (USBL), e.g. IXSEA GAPS or POSIDONIA, using the on-board AUV installed USBL transponder beacon responded signal (delivers position where the vehicle “actually” is).

In addition to this independent position source, vehicles own position (deliver where the vehicle “thinks” it is) can be displayed also. This position is based on transmitted data strings from MATS underwater acoustic modem, only sent from AUV on user request.

To summarize, usually you have displayed in tracking mode:

position of support vessel (lon/lat and heading)
either DGPS of AUV during surface track, or
USBL position (GAPS or POSIDONIA)
and MATS position (underwater acoustic on request)

7.6 Operational Aspects

In general, MARUM SEAL was used at least 12 times on field cruises so far. Thus, several different vessels have been in operation and on each vessel the handling of the AUV is quite a bit different. In principle, the A-frame seems to be the best position to launch and recovery the AUV, because the tendency to hit the ships wall is minimized compared to sideward operation, based on experience. On POS499 the AUV was operated successfully with the main ship crane at portside of vessel.

In principle, the AUV can be operated out of the lab, just with simple PC-console racks. On POS499 cruise, the AUV operations were run out of a 20” operation/workshop van, located on the main deck, aft. The consoles, file-server and printer are installed in the container, workbench, tools and spares as well.

The SERCEL MATS acoustic transducer was installed into the moon pool from R/V POSEIDON. For USBL positioning, the IXBLUE GAPS system was used, installed in the moon-pool as well.

Prior to launch of AUV, the PHINS INS (on-board the AUV) needs to be calibrated (as well as the GAPS system). Therefore, it has to be reset and the support vessel has to be still standing for at least five minutes. After that initial phase (INS coarse align), the vessel needs to run a rectangular course; square-coarse, five minutes @ 3-5 knots each line (INS fine align). At the end of that time-span and course, the PHINS is in so-called “normal mode”, means it has its highest position quality.

7.7 Station Work on POS499

During POS499 we did nine AUV dives. Eight of these dives have been without any technical vehicle problems. For unsolved reasons, one dive was aborted during mission at approx. 2000 m depths, due to a reboot of the main vehicle controller (VCC). For about 18 minutes the AUV has been busy with a VCC process, stopped mission and started to float up. Even after intense data analyzing, it remains unclear why the VCC reboots. As a pity, the VCC also stopped to monitor its health condition inside the log-file – necessary information to analyze the technical issue were missing. After boot-up of AUV, the AUV restarts its mission at the point, were it stopped the mission (prior to reboot). Meanwhile, the AUV was floated up to a shallower water depth, the DVL lost bottom-track and the several build-in fault criteria became active immediately and finally stopped the active mission and pushed the AUV into STOP-MODE.

A second technical issue occurred during pre-dive-check of the AUV, prior to an intended dive. During power-up of the AUV the PHINS inertial system encountered an internal electronic fault. All extended checks pointed to a malfunction in the fibre-optic gyro system of the PHINS V2. We have been unable to solve the problem on board the R/V POSEIDON. Due to the high costs of an INS, no dedicated spare PHINS has been on board – luckily, a comparable newer version of a PHINS (PHINS V3) was in-house at MARUM (Hybrid-ROV PHINS). Colleagues at MARUM managed it to send the spare PHINS V3 from Bremen to Catania from one to the other day. It arrived in the late afternoon and was installed immediately into the already prepared AUV. The AUV team managed it to modify and re-arrange the electrical connections and convert a ZDA-timing signal – finally the new PHINS V3 work well on the AUV. Meanwhile also IXBLUE had analysed internal Log-File Data from the faulty PHINS and stated a “non-repair option a sea” and severe faults on the fibre optic gyro (FOG).

The next dives with the AUV ran well, despite some modification of depth- and heave-data, acquired by the PHINS internal algorithm. Obviously, a change in settings occurred in the new PHINS V3 firmware. After tuning of these settings, the MBES data quality has been absolutely fine.

Dive No. 71 (Fig. 26):
The dive was planned at central Venere MV location. As the first dive on the cruise, the AUV dive was performed at daylight situation. The AUV performed well from the beginning.

The complete mission was planned to 65 km, but terminated in the late afternoon due to end of decks men shifts. Overall mission time has been 6:28 hours at bottom and with 35.5 km track length.

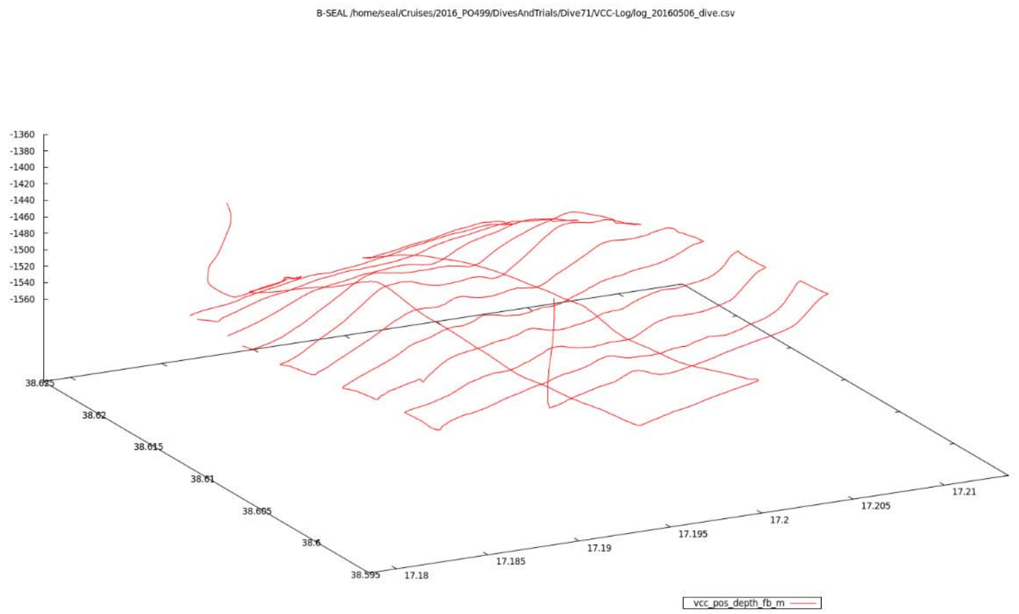


Fig. 26: Dive track of AUV dive no. 71 – (depth of AUV SEAL vs. longitude/latitude).

Dive No. 72 (Fig. 27):

The dive was planned at the deeper SE-part of Venere MV location. At this time, the AUV dive was performed at night operation. The complete mission was planned to nearly 62 km at bottom. Overall mission time has been 11:26 hours at bottom.

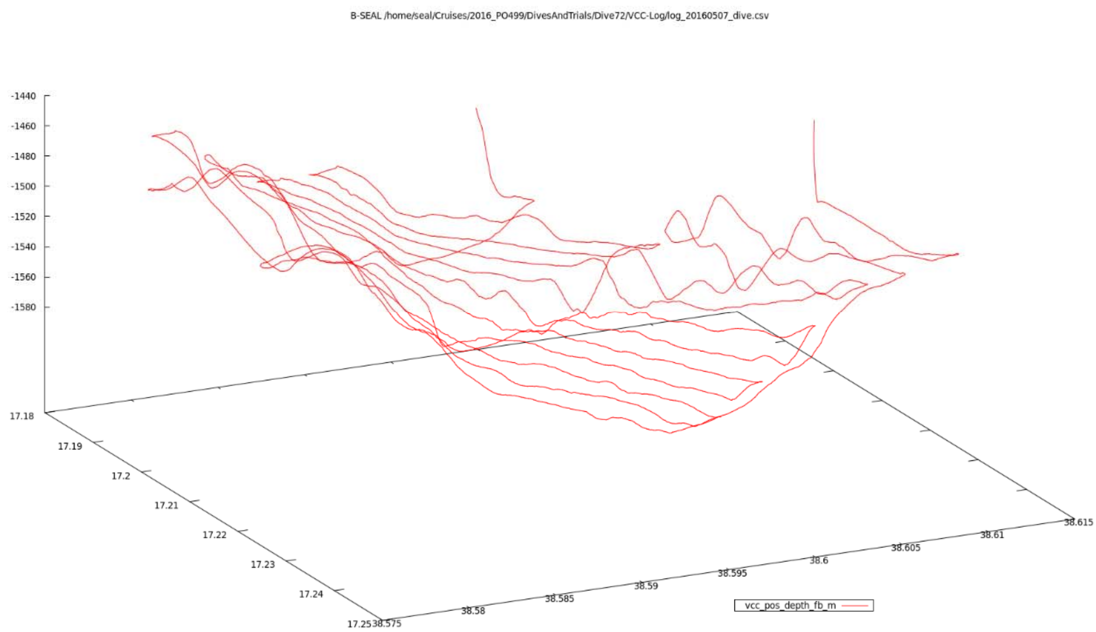


Fig. 27: Dive track of AUV dive no. 72 – (depth of AUV SEAL vs. longitude/latitude).

Dive No. 73 (Fig. 28):

The dive was planned at the NW-part of Venere MV location. As first dive with newly installed PHINS V3, the AUV dive was performed at daylight operation, again. The complete mission was planned to nearly 57 km at bottom, but terminated in the late afternoon due to end of decks men shifts. Overall mission time has been 10:30 hours at bottom.

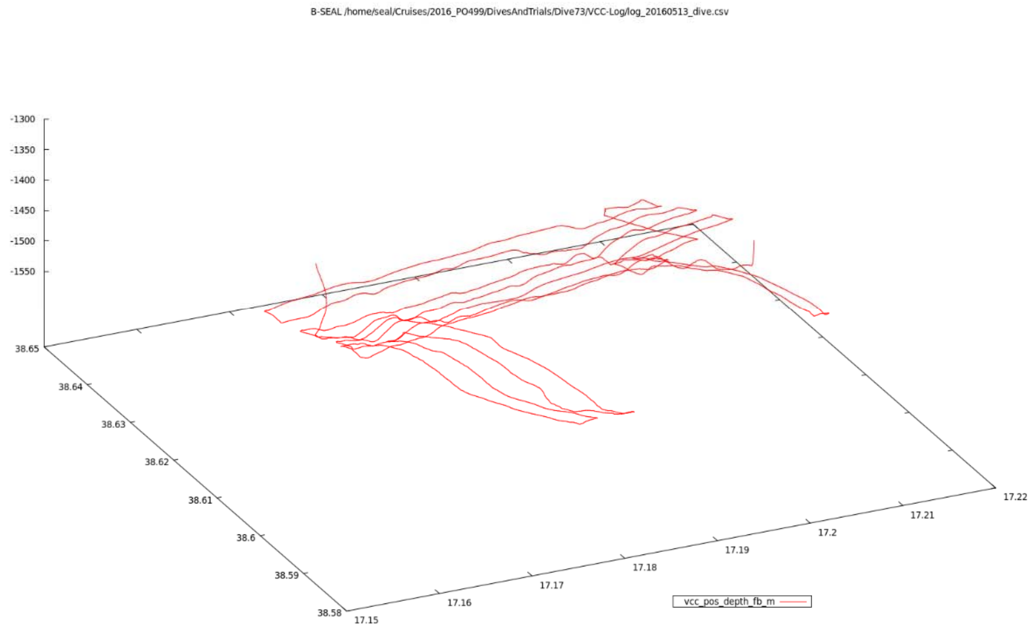


Fig. 28: Dive track of AUV dive no. 73 – (depth of AUV SEAL vs. longitude/latitude).

Dive No. 74 (Fig. 29):

The dive was planned at the Cetus MV location. The mission was planned to maximum duration, due to large extension of Cetus MV. During this dive, the VCC resets during mission and finally aborted the AUV mission on depths. Total mission time at depth has been 2.02 km and 12.2 km respectively.

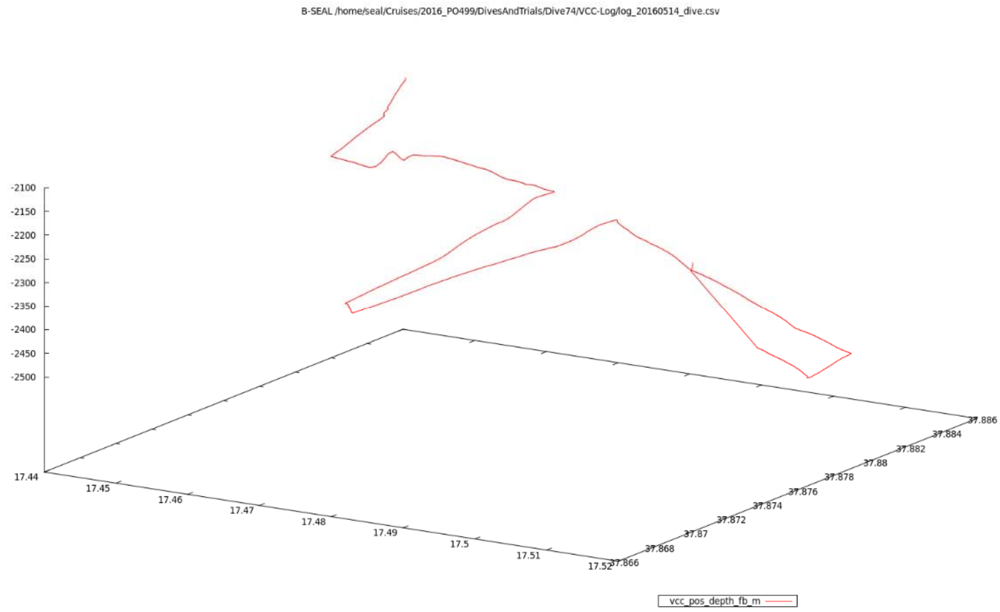


Fig. 29: Dive track of AUV dive no. 74 – (depth of AUV SEAL vs. longitude/latitude).

Dive No. 75 (Fig. 30):

The dive was planned at Sartori MV location. The complete mission was planned to nearly 65 km at bottom. Overall mission time has been nearly 12 hours at bottom.

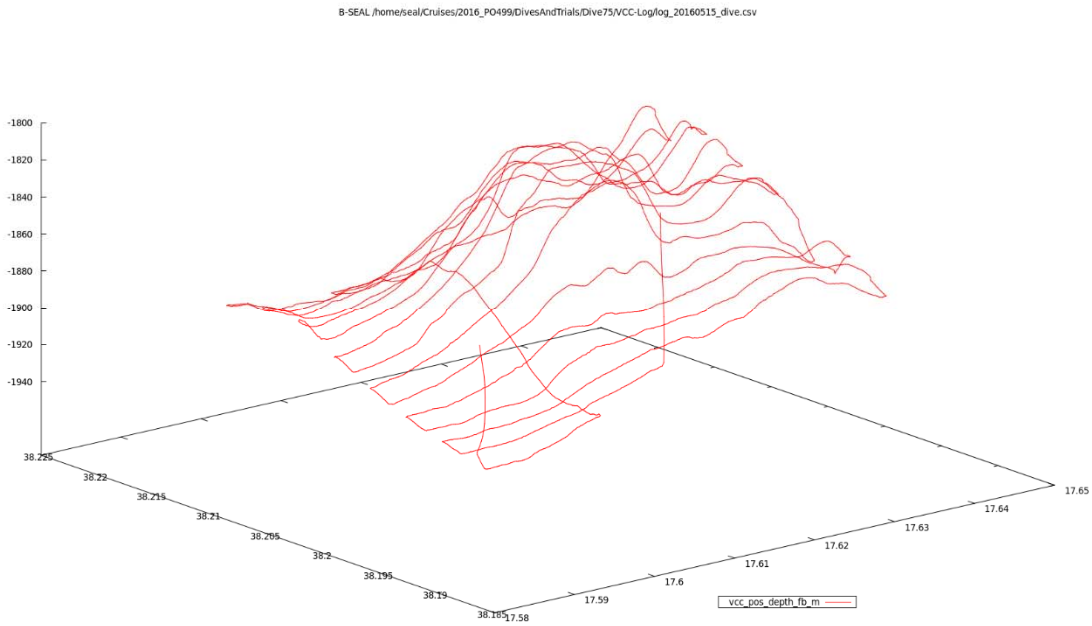


Fig. 30: Dive track of AUV dive no. 75 – (depth of AUV SEAL vs. longitude/latitude).

Dive No. 76 (Fig. 31):

The dive was planned on the deeper part of MV Ridge location. The complete mission was planned to nearly 64 km at bottom. Overall mission time has been again nearly 12 hours at bottom.

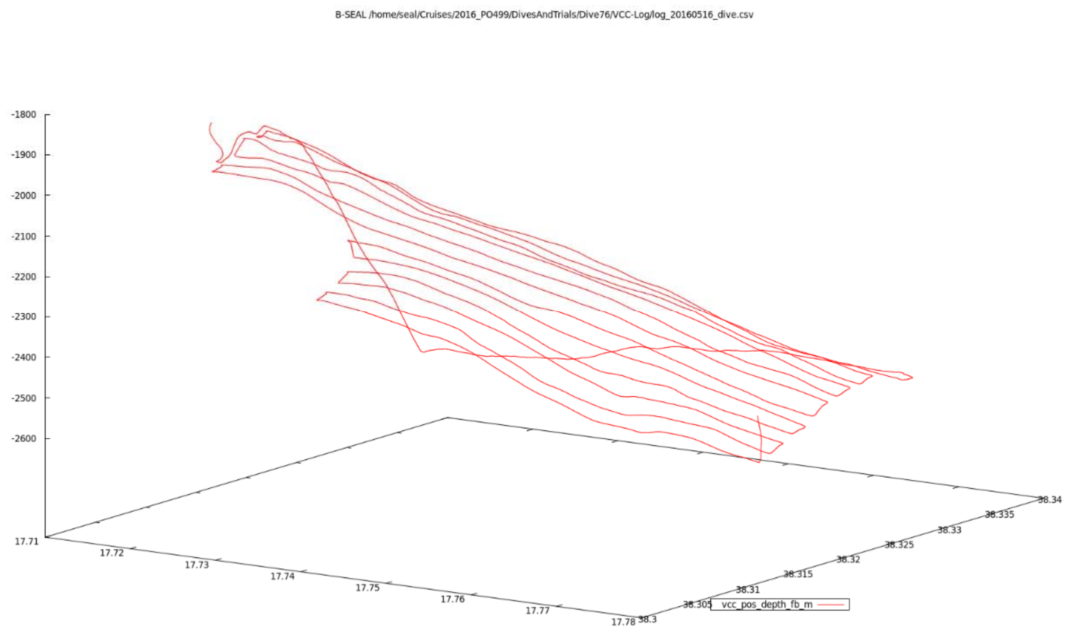


Fig. 31: Dive track of AUV dive no. 76 – (depth of AUV SEAL vs. longitude/latitude).

Dive No. 77 (Fig. 32):
The dive was planned at the central part of MV Ridge location. The complete mission was planned to nearly 63 km at bottom. Overall mission time has been again nearly 11:50 hours at bottom.

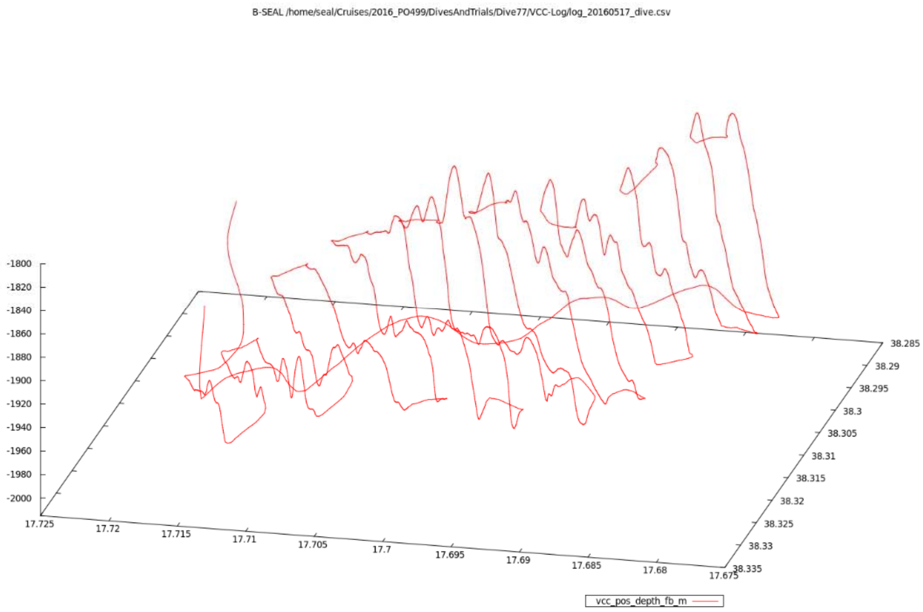


Fig. 32: Dive track of AUV dive no. 77 – (depth of AUV SEAL vs. longitude/latitude).

Dive No. 78 (Fig. 33):
The dive was planned at the Cetus Ridge location – the re-run of the terminated AUV mission dive 74. The complete mission was planned to nearly 64 km at bottom. Overall mission time has been again nearly 12 hours at bottom, terminated according to day men shift start.

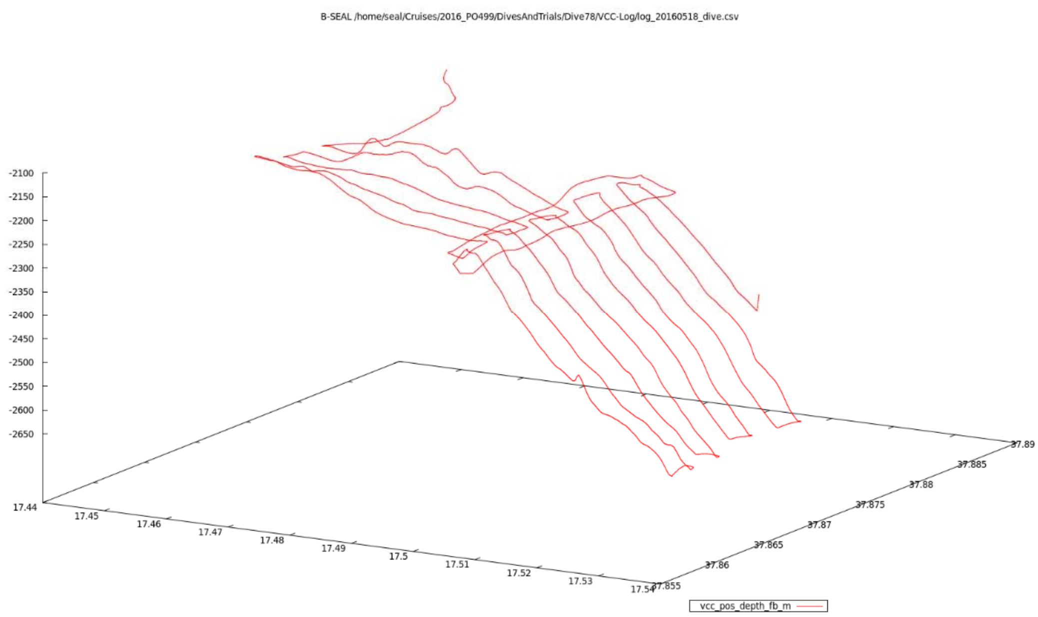


Fig. 33: Dive track of AUV dive no. 78 – (depth of AUV SEAL vs. longitude/latitude).

Dive No. 79 (Fig. 34):

The dive was planned at the MV Ridge location. This mission was created as a re-run of former dive 76 and 77, but covers just the initial parts of the MV structures. During this mission, the EM 2040 has been set to 200 kHz and the AUV was operated at 130 m altitude. The complete mission was planned to 32 km at bottom. Overall mission time has been again nearly six hours at bottom. The dive has been terminated due to upcoming harsher weather conditions.

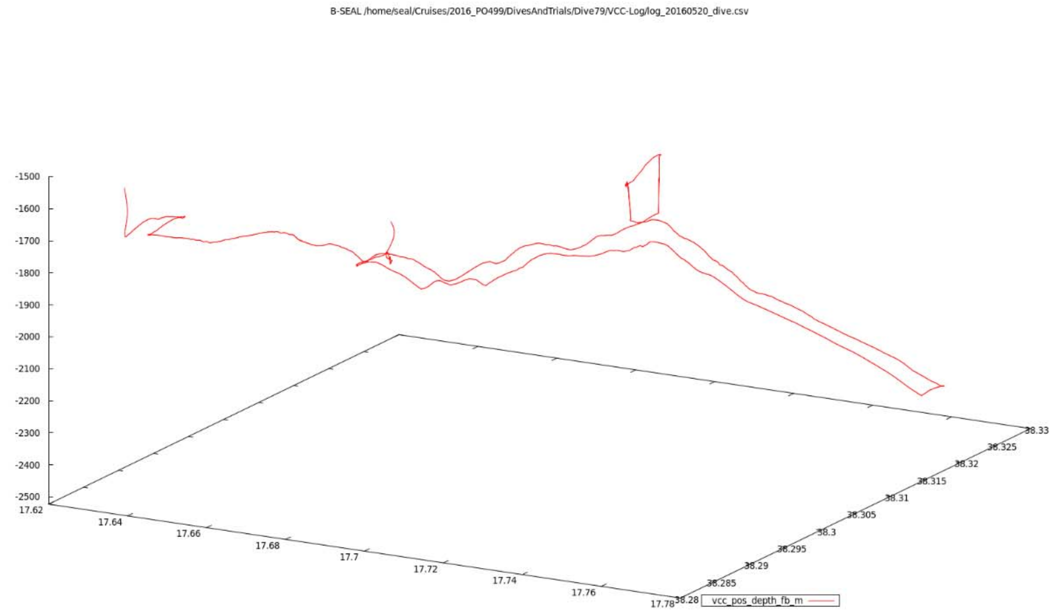


Fig. 34: Dive track of AUV dive no. 79 – (depth of AUV SEAL vs. longitude/latitude).

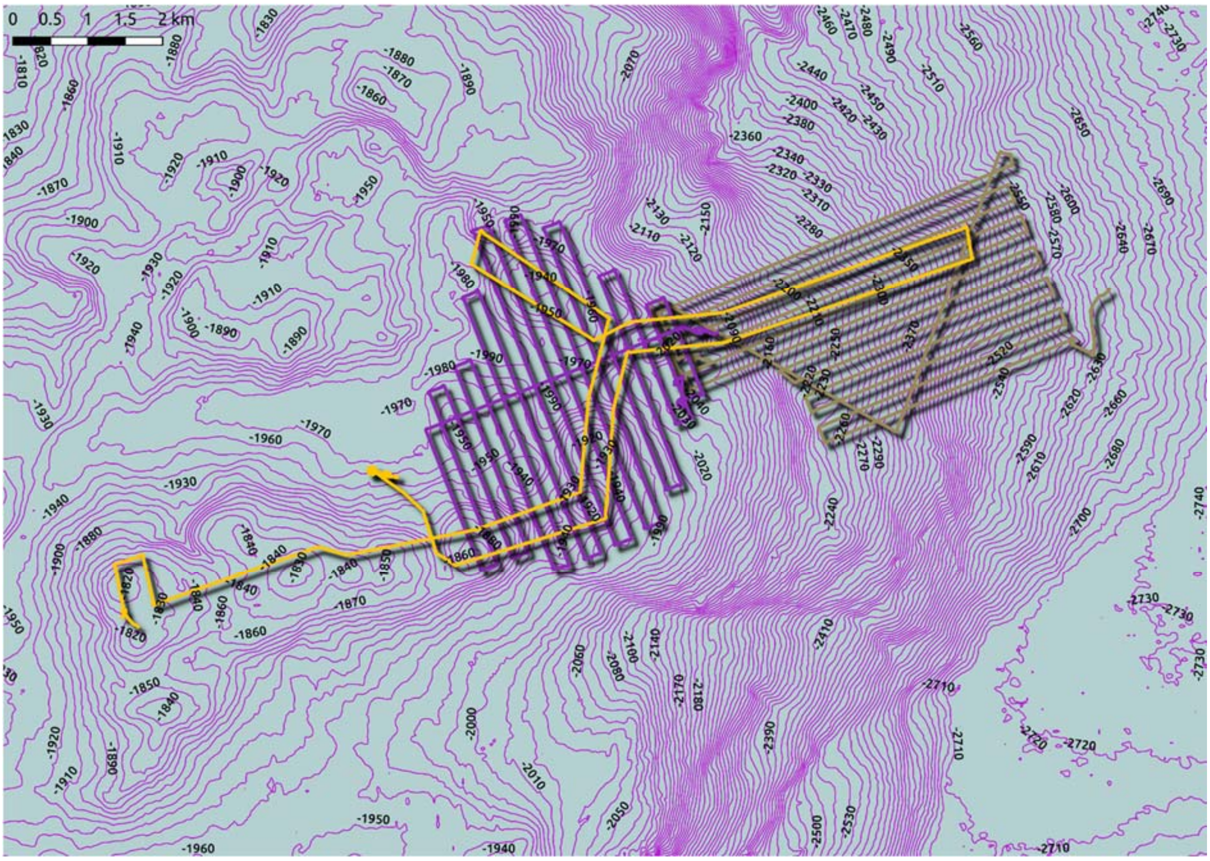


Fig. 35: Compilations of AUV missions at MV ridge location.

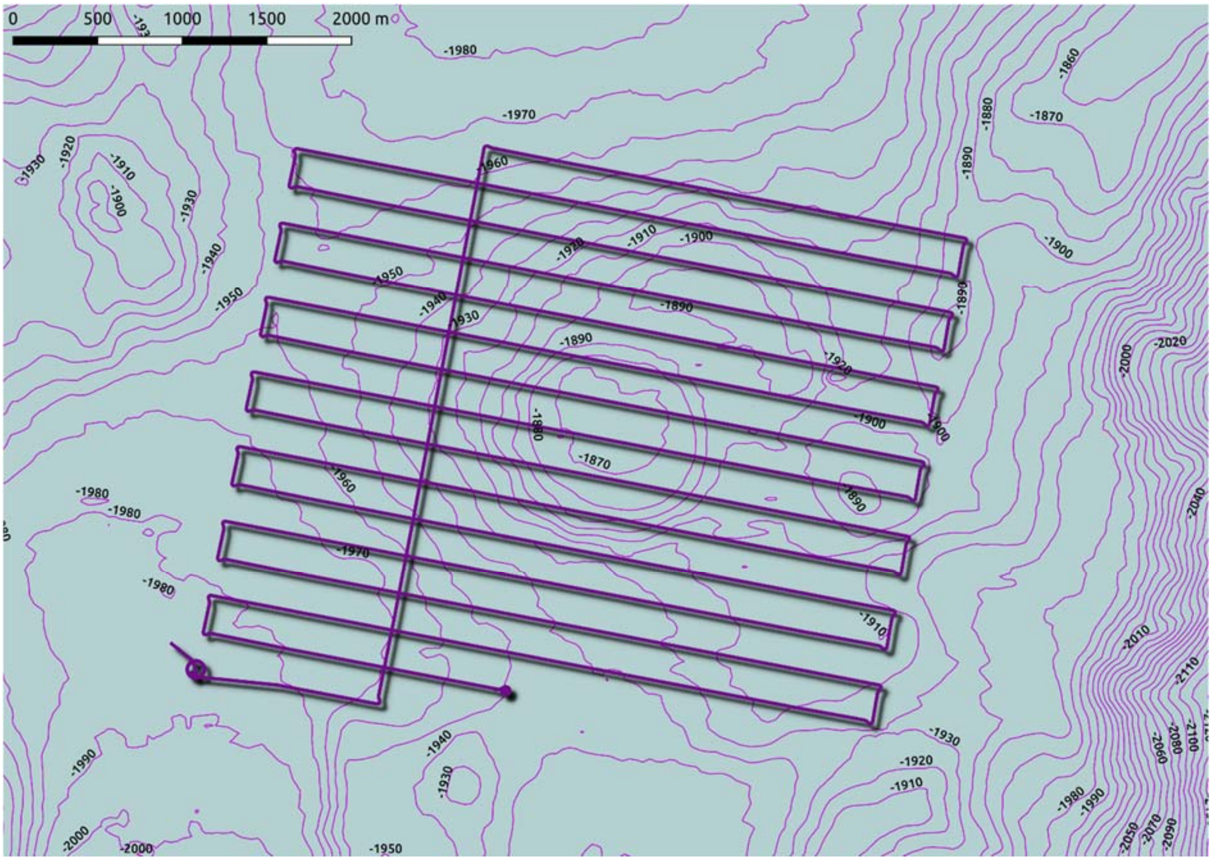


Fig. 36: Compilations of AUV missions at Satori MV location.

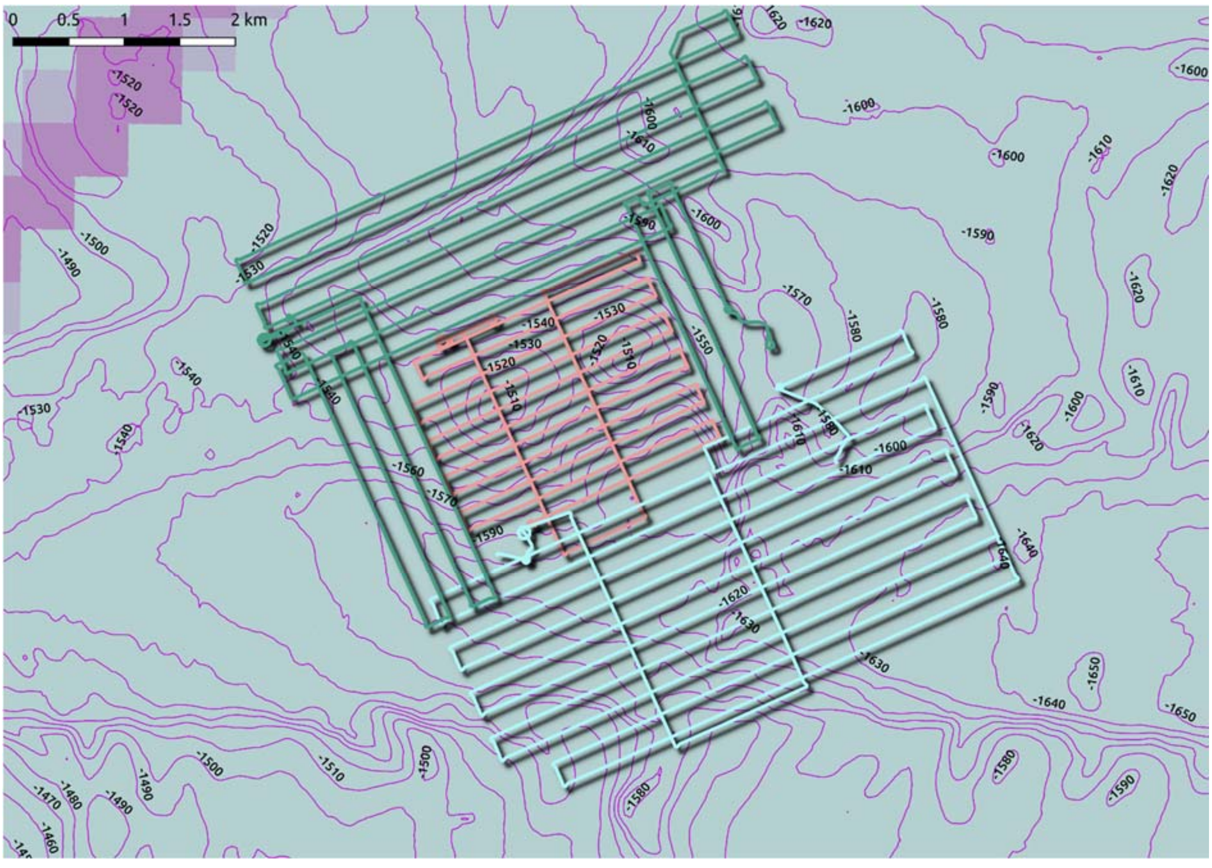


Fig. 37: Compilations of AUV missions at Venere MV location.

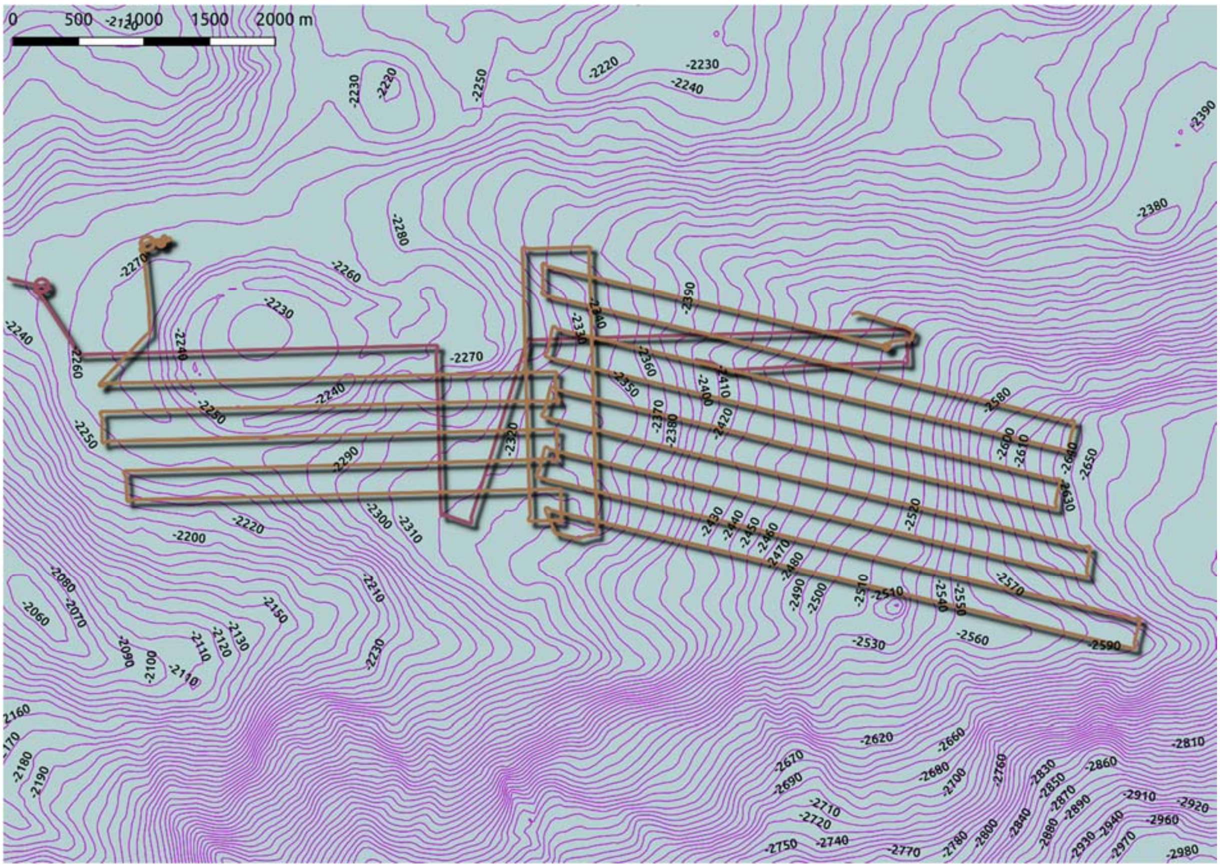


Fig. 38: Compilations of AUV missions at MV ridge location.

8 Sediment Sampling and Description

(M. Loher, S. Ceramicola, S. Buchheister, A.K. Bachmann)

8.1. Introduction

During cruise POS499 a total of 24 gravity cores and 29 mini cores were successfully acquired at several specific areas of the Calabrian Arc (Figs. 12, 13, 14, 15, 16).

A primary scientific aim was the investigation of sedimentological structures resulting from mud volcanism or fluid seepage as well as trying to determine the relative ages of these structures. Gravity cores and mini cores specifically aimed for characteristic morphological features or ambiguous backscatter patterns, in order to test whether these structures indicated any sedimentological evidence of mud volcanism or fluid seepage. Of particular interest was the amount of hemipelagic background sediment overlying different mud breccia deposits of the mudflows. Dating of such material can provide insights into the dynamics, rates and ages of mud extrusion events and related fluid flow (Lykousis et al., 2009). The sedimentation rate of the Calabrian Arc is estimated to range from 4 to 26 cm/kyr (Ceramicola et al., 2014 and sources therein) but specific marker horizons such as sapropels (DeLange, 2008; Mercone et al., 2000) or tephra layers (Keller et al., 1978; Narcisi et al., 1999) may help to decipher the age of potential mud flow deposits further (Lykousis et al., 2009).

Further, mud breccia clasts were collected at different sites and different mud volcanoes with the purpose of investigating the provenance or source material of the mud volcanoes. By analyzing thin sections of the mud breccia clasts a detailed petrological description may be achieved and the potential presence of microfossils could give an indication of the age or stratigraphic framework of the respective clasts.

8.2. Gravity Corer (GC) and Minicorer (MIC)

The GC of the MARUM was deployed with a top weight of ca. 500 kg and either a three or six meter barrel. Further, the barrel could be equipped with a plastic liner (12 cm diameter) for later core storage or with a plastic bag for fast access to the sediments after core retrieval. During Cruise POS499 19 GCs were deployed with the 6 m barrel and plastic liners and five with a plastic bag. Sediment cores in liners were extracted from the barrel and cut in 1 m segments on deck. The cores were then labelled according to MARUM standards and stored as whole rounds or D-tubes after longitudinal split-opening. Core liners were cut with a vibrational saw and the sediment was manually split using a fishing line into work and archive halves. The sediment surface was photographed and a preliminary core description was undertaken on the archive halves (sediment colour following the Munsell colour chart, sedimentary structures, macroscopic estimate of grainsize and composition, fossil remains, etc.).

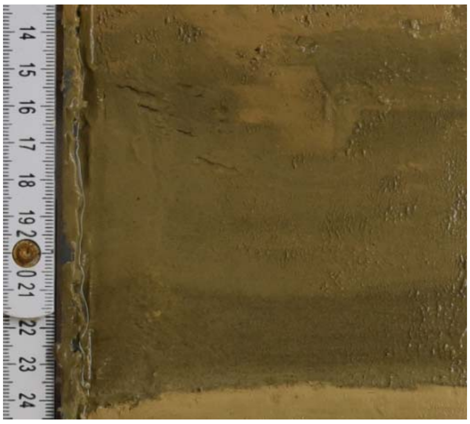
For sampling of surface sediments and in areas where mud breccia deposits might only be covered by a thin layer of hemipelagic drape, a minicorer (MIC) was deployed. The MIC can be equipped by up to four plastic liners of 7 cm diameter (or 6.2 cm diameter for which an additional plastic fixation ring is needed) and 60 cm length. After deployment of the MIC on the seafloor, four corresponding lids for the top and bottom of the liners are triggered to close upon heaving. Due to technical problems with one of the closing arms the MIC was only rigged with three liners. In most cases, the MIC yielded three partially filled liners of sediment sample. Of these, one was immediately frozen at -30°C after the over-standing water had been removed via a tube. A second liner was used for detailed sedimentological description. The amount of overlying, hemipelagic sediment was noted and photographically documented.

8.3. Preliminary Results of Gravity Core Analyses

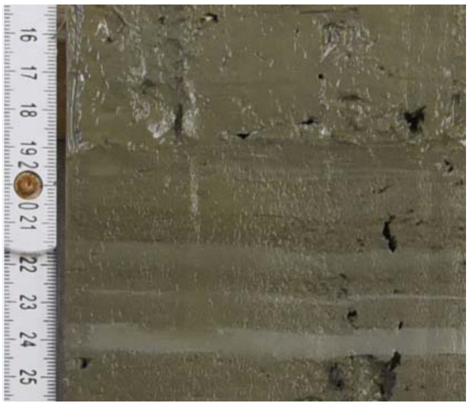
Several of the gravity cores were opened and described on board (s. appendix for description sheets). Generally, all gravity cores obtained in plastic bags were aimed at the fresh mud extrusion sites (potential mud volcano conduits) at different mud volcanoes. These cores did not show hemipelagic sediment overlying the mud breccia and were generally used for pore water analyses (see Chapter 9.2). In contrast, GCs in liners specifically targeted mud flows (as recognized in backscatter data) of different ages. A complex pattern of hemipelagic sediments covering different mud flow deposits was encountered. These sediments are part of the general stratigraphy found within the Calabrian Arc. The following portraits give an overview of sedimentological facies encountered repeatedly in different gravity cores at different mud volcanoes.

Table 3: Overview of sediment facies encountered in gravity cores taken during POS499.

Photographic representation	**Brief description and interpretation**
	A greenish gray matrix composed of sticky clay, silt and sand is host to larger clasts (both hard and friable mud clasts) in the typical mud breccia facies. Where the mud breccia contains a high concentration of methane gas a mousse-like sediment texture could be observed. In deeper core sections and where hemipelagic sediment overlies the mud breccia they often had a massive and compact texture with a chaotic internal structure.
	A frequent facies at the top of most cores was a pale brown clay with little silt showing a moderate reaction with HCl. Pteropod fragments were often abundant and the silt content varied with different settings (e.g. generally higher silt content around the Venere MV).
	The transition from the light brown/yellowish, hemipelagic sediment to the grayer color of the mud breccia is often accompanied by a gradual appearance of fine mud breccia clasts. In addition, the color change may partly result from different oxidation states of the sediments as the patch transition indicates. The top of mud breccia deposits is not always easily defined since bioturbation or reworking may transport mud breccia clasts higher into the otherwise homogeneous looking, marine background sediments.



Numerous dark, grayish brown, silty or fine sandy intervals showed very little or no reaction with HCl and had a peculiar grainy texture. These deposits were interpreted as ash layers (based also on previous investigations on sediment cores from the M112 cruise). A prominent ash layer near the top of several cores could be the Z1 ash layer. Various authors interpret this ash layer differently and attribute ages ranging from 2000 to 3600 years B.P.



Dark greenish or olive gray, organic-rich intervals (abundant and very well preserved pteropod shells), showing a moderate reaction with HCl and a finely laminated internal structure, intercalating with light gray layers. Two slightly different facies of such deposits were encountered and interpreted as sapropelic layers. These specific deposits are known marker horizons throughout the Mediterranean Sea. The upper sapropel is most likely the S1 event.

A typical facies of the hemipelagic sediment found in the Calabrian Arc are very fine and clay rich sediments. The colors range from very light bluish gray to more brownish gray and there is a moderate to strong HCl reaction. Pteropod shells have been found to occur in several intervals as dispersed and often broken fragments.

Dark and sand rich deposits were found as massive deposits showing a clearly graded structure. Quartz, mica, mafic minerals and/or lithic fragments as well as calcitic shell debris were some of the grains which could be identified so far. These deposits were found mainly in cores from the thalweg of the Squillace Canyon (e.g. at the foot of the Venere Mud Volcano).

At the Cetus and Sartori mud volcanoes gravity cores were taken at different mud flows recognized in the backscatter maps. Preliminary core descriptions revealed a complex sedimentological stratigraphy in the vicinity of the Cetus Mud Volcano. Sedimentation rates seem to vary within short distances of each coring site and also the correlation of distinct marker horizons (tephras and sapropels) is not yet clear and will require more detailed post-cruise analyses.

New mud volcanoes were proven in the mud volcano ridge area. The Poseidon Mud Volcano lies at the easterly end of an alignment or chain of mud volcanoes and relatively fresh mud breccia was cored from the central conduit of this structure. Old (buried) mudflows extending over 8 km down the slope of the Calabrian Escarpment were targeted as well.

8.4. Results of Mini Core Analyses

With the mini cores it was possible to target the uppermost sediment sequence up to ca. 25 cm below seafloor. At the Venere Mud Volcano 24 MIC stations were selected based on AUV-derived micro-bathymetry as well as backscatter maps. In numerous sites it was possible to sample not only fresh mud breccia, but also mudflows which were overlain by hemipelagic background sediments. This sedimentary cover consisted of brownish clayey to silty mud with fragments of pteropod shells and other calcitic grains (HCl reaction) and ranged from less than 0.5 cm to over 24 cm. Based on the published sedimentation rate in the forearc basins of the Calabrian Arc (Ceramicola, 2014) of 0.2 mm/yr this indicates that the tested mudflows may range from over 1000 years to recent. Interestingly it was found that not all areas of elevated backscatter could be attributed to the presence of mud breccia but also coarser layers of sand. Specifically this was the case in cores placed in the deepest part of the canyon at the foot of the freshest mudflow originating from the Venere Mud Volcano (Fig. 41).

Fig. 39: Mini core (MIC-18, Venere MV) section showing the transition from hemipelagic background sediment to mud breccia. Large (centimeter-sized) clasts are found even at the top of mudflows. Often there is a gradational transition between the background sediment facies and the mud breccia, possibly due to sediment reworking or bioturbation. Therefore, the occurrence of first rock clasts is not always a sure indication of the top of a mud flow.

Fig. 40: Photo of a mini core (MIC-7, Venere MV) showing the sand interval and overlying silty to sandy drape encountered at the thalweg of the Squillace canyon. Interestingly this core was taken right at the foot of a recent mudflow of Venere. This is suggestive of the fact that the mudflow extending to the canyon floor occurred after the latest major sediment transport in the canyon.

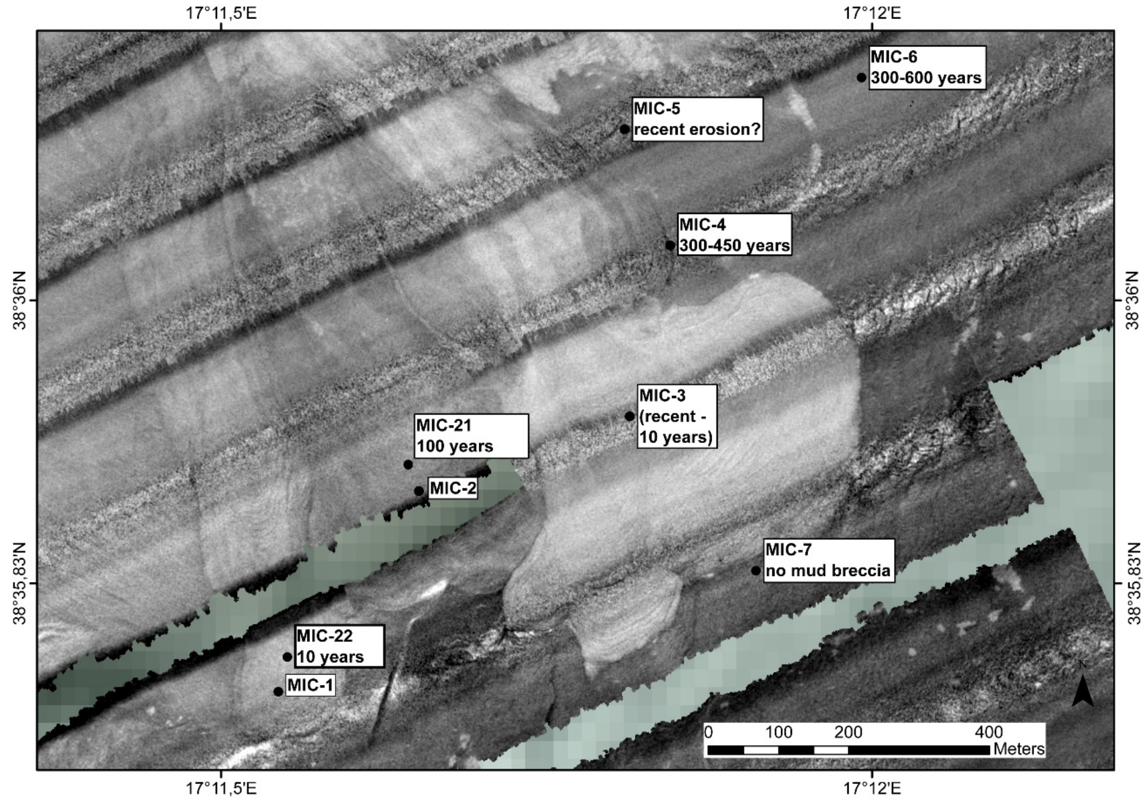


Fig. 41: AUV-derived backscatter map (data from M112, 2014) with locations of MICs on or near mudflows with different backscatter intensities. Preliminary estimates of mud flow ages based on hemipelagic cover of the mud breccia.

At the Sartori Mud Volcano, what appeared to be the most recent mud flows were targeted but not reached with the MIC (29 cm of silty background sediments). At Cetus MV no MICs were attempted but at the Mud Volcano Ridge flows one MIC successfully recovered mud breccia at 20 cm sediment depth in an area of elevated backscatter.

Table 4: List of all MIC stations with basic sedimentological description

GeoB-No.	MIC-No.	Location	Mud breccia at…	Other comments
21303-1	MIC-1	Venere MV	Not opened	Cf. MIC-22
21304-1	MIC-2	Venere MV	Not opened	Cf. MIC-21
21305-1	MIC-3	Venere MV	Not opened	Fresh mud flow
21306-1	MIC-4	Venere MV	6 – 7 cm	
21307-1	MIC-5	Venere MV	3 - 5 cm	Silty overlying sediment
21308-1	MIC-6	Venere MV	8 - 10 cm	Silty overlying sediment
21309-1	MIC-7	Venere MV	None	Sand / turbidite layer
21313-1	MIC-8	Venere MV	3 – 5 cm	Gradual transition to mud breccia
21314-1	MIC-9	Venere MV	8 – 12 cm	Clayey overlying sediment, onset of clasts
21315-1	MIC-10	Venere MV	4 – 8 cm	Silty overlying sediment, then first clast
21316-1	MIC-11	Venere MV	None	Sandy layer at 12 - 23 cm
21317-1	MIC-12	Venere MV	6 – 12 cm	Clay and clasts

21318-1 21319-1	MIC-13 MIC-14	Venere MV Venere MV	6 cm 3 cm	Silty overlying sediment, then small clasts First small clasts
21320-1	MIC-15	Venere MV	10 cm	
21327-1	MIC-16	Venere MV	8 cm	Very clear top of mud breccia
21334-1	MIC-17	Venere MV	None	Wood parts and sandy interval at 16 cm
21335-1	MIC-18	Venere MV	15 cm	Some clasts at 3 cm (reworking?)
21336-1	MIC-19	Venere MV	None	13 – 17 cm layer of coarse sand
21337-1	MIC-20	Venere MV	1 – 1.5 cm	Watery top (anoxic black sediment)
21338-1	MIC-21	Venere MV	1.5 cm	First clasts; silty overlying sediment
21339-1	MIC-22	Venere MV	0.5 – 1 cm	Very soft with small clasts
21340-1	MIC-23	Venere MV	0 cm	Clasts at top
21341-1	MIC-24	Venere MV	2 – 3 cm	First small clasts
21356-1	MIC-25	Poseidon MV	0 cm	Mud breccia from top
21358-1	MIC-26	Mud Volcano Ridge Slope	20 cm	
21359-1	MIC-27	Mud Volcano Ridge Slope	None	20 cm sand layer
21364-1	MIC-28-1	Sartori MV	None	MIC failed
21364-2	MIC-28-2	Sartori MV	None	Mud breccia not reached
21368-1	MIC-29	Mud Volcano Ridge	None	27 cm and no mud breccia

8.5. Mud Breccia Clasts

(S. Ceramicola)

Gravity cores GC-1, GC-2 (Venere MV), GC-9 (Cetus MV), GC-19 (Poseidon) and GC-21 (Sartori MV) were acquired from the top of mud volcanoes edifices. Plastic bags were used instead of liners in order to facilitate rhizon sampling in order to extract pore water from the mud breccia sediment. Once the pore water was collected, the plastic bags were opened, the cores were split, described and photographed (see Appendix Chapter 14.2). All the cores were described to contain mud breccia deposits from top to bottom. Mud breccia found in GC-19 proved Poseidon to be a mud volcano as previously inferred from acoustic methods only. The entire content of the plastic bags was washed away and the clasts washed and photographed. Mud breccia is composed of broken fragments of rocks cemented together by a more or less stiff muddy matrix. Three types of fragments were recognized in the mud breccia from the gravity cores: i) rocky clasts, ii) clasts composed of broken fragments of rocks cemented together by a stiffer muddy matrix (mud clasts), iii) clasts simply made of hard compacted mud, easily breakable and rounded in shape (mud boulder). Only rocky clasts have been collected in plastic bags and sent to Prof. Salvatore Critelli, University of Calabria (Cosenza, Italy). Salvatore's research group will analyze the petrographic characteristics of the clasts and hopefully, important information concerning their composition and provenance will be revealed.

Venere MV:
From a preliminary visual observation of the breccia collected from Venere MV, several mud clasts were observed and a few rocky clasts of big dimensions (about decimeter scale) showing a rather angular shape, no mud boulder were recognized.

Cetus MV:
From a preliminary visual observation of the breccia collected from Cetus MV, several mud boulders of different dimensions (see below) are recognized (not sampled as too fragile). Only few big dimension rocky clasts (10 cm) are present and show a rather angular shape. No mud clasts are observed.

Fig. 42: Clasts collected in GC-9 GeoB21344-1.

Poseidon MV:
GC-19 GeoB21360-1 (445cm)

Sartori MV:
From a preliminary visual observation of the breccia collected from Sartori MV, several mud boulder are identified. Rocky clasts are of smaller dimensions (several centimeters) and show a rather angular shape with flat walls. Few to none mud clasts are observed.

Fig. 43: Clasts collected in GeoB21363-1 (GC-21).

9 Geochemistry

9.1 Methane and Porosity Sampling

(S. Buchheister, M. Loher, A.K. Bachmann)

The main objective of the work on pore water dissolved methane sampling was to determine the amount and isotopic composition of the carbon hydrate as well as to investigate potential connections between the methane concentrations, sulphate content and source of the methane. These parameters will be measured during post-cruise analyses at the institute and aim to provide insights in the activity and diversity of mud volcanoes.

To allow for a precise calculation of the amount of dissolved gas in the pore water, porosity samples needed to be acquired as well. Methane and porosity samples were collected in parallel from several gravity cores, as listed in Table 5 below.

Methane samples were collected with a cut syringe and 3 ml sediment were added to a 20 ml glass crimp vial with 5 ml sodium hydroxide solution (1 M).

To collect the porosity samples a cut 5 ml syringe was used. Approximately 10 ml of sediment were stored in a pre-weighed 20 ml glass vial.

Table 5: Gas samples taken during POS499 (Depth in cm and individual sample number).

GC-1 (GeoB21322-1) Venere MV, top mudflow: Depth [cmbsf] / Sample #					
10 cm / 1	10 cm / 11	30 cm / 2	30 cm / 12	50 cm / 3	50 cm / 14
100 cm / 4	100 cm / 15	150 cm / 5	150 cm / 16	185 cm / 6	185 cm / 17
GC-2 (GeoB21323-1) Venere MV, top mudflow: Depth [cmbsf] / Sample #					
25 cm / 9	25 cm / 19	50 cm / 10	50 cm / 20	75 cm / 21	75 cm / 31
100 cm / 22	100 cm / 32				
GC-3 (GeoB21324-1) Venere MV, near seep 1: Depth [cmbsf] / Sample #					
276 cm / 23	276 cm / 33	176 cm / 24	176 cm / 34	76 cm / 25	76 cm / 35
GC-9 (GeoB21344-1) Cetus MV, central conduit: Depth [cmbsf] / Sample #					
10 cm / 26	10 cm / 36	20 cm / 27	20 cm / 37	30 cm / 28	30 cm / 38
40 cm / 29	40 cm / 39	50 cm / 30	50 cm / 40	75 cm / 41	75 cm / 51
100 cm / 42	100 cm / 52	125 cm / 43	125 cm / 53	140 cm / 44	140 cm / 54
GC-10 (GeoB21345-1) Cetus MV, rim: Depth [cmbsf] / Sample #					
556 cm / 45	556 cm / 55	456 cm / 46	456 cm / 56	356 cm / 47	356 cm / 57
256 cm / 48	256 cm / 58	156 cm / 49	156 cm / 59	56 cm / 50	56 cm / 60
GC-11 (GeoB21346-1) Cetus MV, main flow: Depth [cmbsf] / Sample #					
74 cm / 61	74 cm / 71				

GC-12 (GeoB21347-1) Cetus MV, old flow: Depth [cmbsf] / Sample #					
248 cm / 62	248 cm / 72	148 cm / 63	148 cm / 73	48 cm / 64	48 cm / 74
GC-13 (GeoB21349-1) Cetus MV, MV N of Cetus: Depth [cmbsf] / Sample #					
440 cm / 65	440 cm / 75	340 cm / 66	340 cm / 76	240 cm / 67	240 cm / 77
140 cm / 68	140 cm / 78	40 cm / 69	40 cm / 79		
GC-14 (GeoB21350-1) Cetus MV, mudflow of MV N of Cetus: Depth [cmbsf] / Sample #					
537 cm /70	537 cm / 80	437 cm / 81	437 cm / 91	337 cm / 82	337 cm / 92
237 cm / 83	237 cm / 93	137 cm / 84	137 cm / 94	69 cm / 85	69 cm / 95
GC-15 (GeoB21351-1) Cetus MV, mudflow downslope: Depth [cmbsf] / Sample #					
413 cm / 86	413 cm / 96	313 cm / 87	313 cm / 97	213 cm / 88	213 cm / 98
113 cm / 89	113 cm / 99	13 cm / 90	13 cm / 100		
GC-16 (GeoB21353-1) Mud Vulcano Ridge: Depth [cmbsf] / Sample #					
242 cm / 101	242 cm / 111	142 cm / 102	142 cm / 112	42 cm / 103	42 cm / 113
GC-18 (GeoB21355-1) Mud Vulcano Ridge, older cone: Depth [cmbsf] / Sample #					
241 cm / 104	241 cm / 114	141 cm / 105	141 cm / 115	41 cm / 106	41 cm / 116
GC-19 (GeoB21360-1) Poseidon MV: Depth [cmbsf] / Sample #					
5 cm / 107	5 cm / 117	25 cm / 108	25 cm / 118	50 cm /109	50 cm / 119
75 cm / 110	75 cm / 120	100 cm / 121	100 cm / 131	150 cm / 122	150 cm / 132
200 cm / 123	200 cm / 133	250 cm / 124	250 cm / 134	300 cm / 125	300 cm / 135
350 cm / 126	350 cm / 136	400 cm / 127	400 cm / 137		
GC-20 (GeoB21361-1) MVR, in between mudflows: Depth [cmbsf] / Sample #					
448 cm / 128	448 cm / 138	348 cm / 129	348 cm / 139	248 cm / 130	248 cm / 140
148 cm / 141	148 cm / 151	48 cm / 142	48 cm / 152		
GC-21 (GeoB21363-1) Sartori MV, conduit: Depth [cmbsf] / Sample #					
5 cm / 143	5 cm / 153	25 cm / 144	25 cm / 154	50 cm / 145	50 cm / 155
75 cm / 146	75 cm / 156	100 cm / 147	100 cm / 157	150 cm / 148	150 cm / 158
200 cm / 149	200 cm / 159	250 cm / 150	250 cm / 160		
GC-22 (GeoB21366-1) Sartori MV, 2nd youngest mudflow: Depth [cmbsf] / Sample #					
405 cm / 161	405 cm / 171	305 cm / 162	305 cm / 172	205 cm / 163	205 cm / 173
105 cm / 164	105 cm / 174				

GC-23 (GeoB21367-1) Sartori MV, younger mudflow: Depth [cmbsf] / Sample #					
489 cm / 165	489 cm / 175	389 cm / 166	389 cm / 176	289 cm / 167	289 cm / 177
189 cm / 168	189 cm / 178	89 cm / 169	89 cm / 179		
GC-24 (GeoB21371-1) MVR, W-End MV flow: Depth [cmbsf] / Sample #					
327 cm / 181	227 cm / 182	127 cm / 183	27 cm / 184		

Table 6: Porosity samples taken during POS499.

GC-2 (GeoB21323-1) Venere MV, top mudflow: Depth [cmbsf] / Sample #					
25 cm / GL-1	50 cm / GL-2	75 cm / GL-3	100 cm / GL-4		
GC-3 (GeoB21324-1) Venere MV, near seep 1: Depth [cmbsf] / Sample #					
276 cm / GL-5	176 cm / GL-6	76 cm / GL 7			
GC-9 (GeoB21344-1)Cetus MV, central conduit: Depth [cmbsf] / Sample #					
10 cm / GL-8	20 cm / GL-9	30 cm / GL-10	40 cm / GL-11	50 cm / GL-12	75 cm / GL-13
100 cm / GL-14	125 cm / GL-15	140 cm / GL-16			
GC-10 (GeoB21345-1)Cetus MV, rim: Depth [cmbsf] / Sample #					
556 cm / GL-17	456 cm / GL-18	356 cm / GL-19	256 cm / GL-20	156 cm / GL-21	56 cm / GL-22
GC-11 (GeoB21346-1)Cetus MV, main flow: Depth [cmbsf] / Sample #					
74 cm / GL-23					
GC-12 (GeoB21347-1)Cetus MV, old flow: Depth [cmbsf] / Sample #					
248 cm / GL-24	148 cm / GL-25	48 cm / GL-26			
GC-13 (GeoB21349-1)Cetus MV, MV N of Cetus: Depth [cmbsf] / Sample #					
440 cm / GL-27	340 cm / GL-28	240 cm / GL-29	140 cm / GL-30	40 cm / GL-31	
GC-14 (GeoB21350-1)Cetus MV, mudflow of MV N of Cetus: Depth [cmbsf] / Sample #					
537 cm / GL-32	437 cm / GL-33	337 cm / GL-34	237 cm / GL-35	137 cm / GL-36	69 cm / GL-37
GC-15 (GeoB21351-1)Cetus MV, mudflow downslope: Depth [cmbsf] / Sample #					
413 cm / GL-38	313 cm / GL-39	213 cm / GL-40	113 cm / GL-41	13 cm / GL-42	
GC-16 (GeoB21353-1) Mud Vulcano Ridge: Depth [cmbsf] / Sample #					
242 cm / GL-43	142 cm / GL-44	42 cm / GL-45			

GC-18 (GeoB21355-1) Mud Vulcano Ridge, older cone: Depth [cmbsf] / Sample #					
241 cm / GL-46	141 cm / GL-47	41 cm / GL-48			
GC-19 (GeoB21360-1) Poseidon MV: Depth [cmbsf] / Sample #					
5 cm / GL-49	25 cm / GL-50	50 cm / GL-51	75 cm / GL-52	100 cm / GL-53	150 cm / GL-54
200 cm / GL-55	250 cm / GL-56	300 cm / GL-57	350 cm / GL-58	400 cm / GL-59	
GC-20 (GeoB21361-1) MVR, in between mudflows: Depth [cmbsf] / Sample #					
448 cm / GL-60	348 cm / GL-61	248 cm / GL-62	148 cm / GL-63	48 cm / GL-64	
GC-21 (GeoB21363-1) Sartori MV, conduit: Depth [cmbsf] / Sample #					
5 cm / GL-65	25 cm / GL-66	50 cm / GL-67	75 cm / GL-68	100 cm / GL-69	150 cm / GL-70
200 cm / GL-71	250 cm / GL-72				
GC-22 (GeoB21366-1) Sartori MV, 2nd youngest mudflow: Depth [cmbsf] / Sample #					
405 cm / GL-73	305 cm / GL-74	205 cm / GL-75	105 cm / GL-76		
GC-23 (GeoB21367-1) Sartori MV, younger mudflow: Depth [cmbsf] / Sample #					
489 cm / GL-77	389 cm / GL-78	289 cm / GL-79	189 cm / GL-80	89 cm / GL-81	
GC-24 (GeoB21371-1) MVR, W-End MV flow: Depth [cmbsf] / Sample #					
327 cm / GL-82	227 cm / GL-83	127 cm / GL 84	27 cm / GL-85		

9.2 Pore Water Sampling

(S. Buchheister, M. Loher, A. K. Bachmann)

9.2.1 Introduction

The main objective of the pore water program was to investigate the geochemical composition and seepage activity of different mud volcanoes and their involved fluids.

The pore water samples were taken with 5 cm rhizons and collected in acid washed 20 ml Luer-Lock syringes. The water was extracted during 8 to 12 hours at surrounding temperature. The collected water was split into different subsamples as shown in Table 7.

Table 7: Subsamples collected from rhizone extraction

Sample type	Amount [mL]	Treatment / Storage
Anions (SO_4^{2-}, Cl^-)	1 to 1,5	Mixed with 0,5 mL ZnAc-solution Stored in 2 mL Eppendorf cups at +4°C.
Nutrients	1,5 to 14	No treatment. Stored in 15 mL centrifuge tubes (nunc) at -20°C.

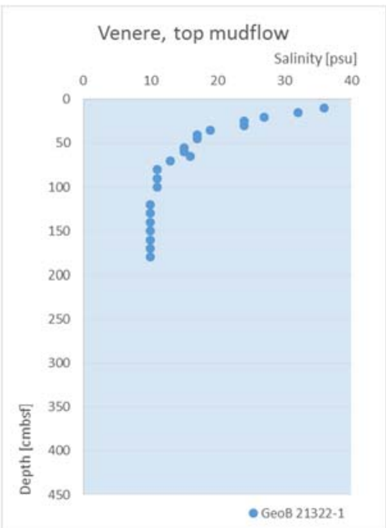
9.2.2 Shipboard Analysis

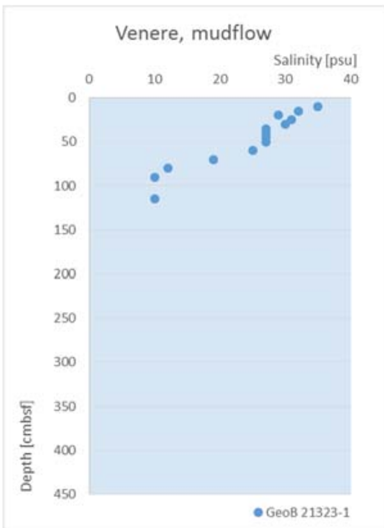
On board we were able to measure the salinity with an ATAGO Master-S/Millα handheld refractometer, with a limited resolution of 1 PSU.

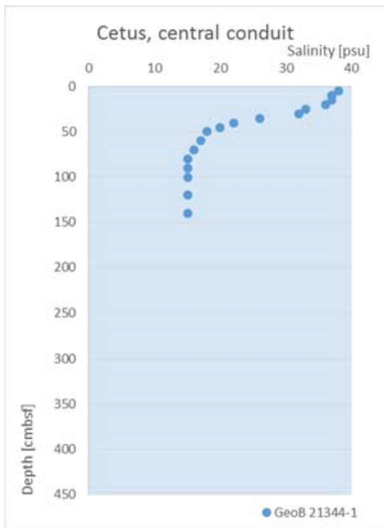
The presence of sulphate was investigated with a reaction between a drop of pore water with a barium chloride solution. In case sulphate is available it will react with the barium and form a poorly soluble salt, which precipitates as a white deposit according to the following equation:

$$Na_2SO_4\ (l) +\ BaCl_2\ (l)\ \rightarrow 2\ NaCl\ (l) + BaSO_4 \downarrow (s)$$

9.2.3 Preliminary Results







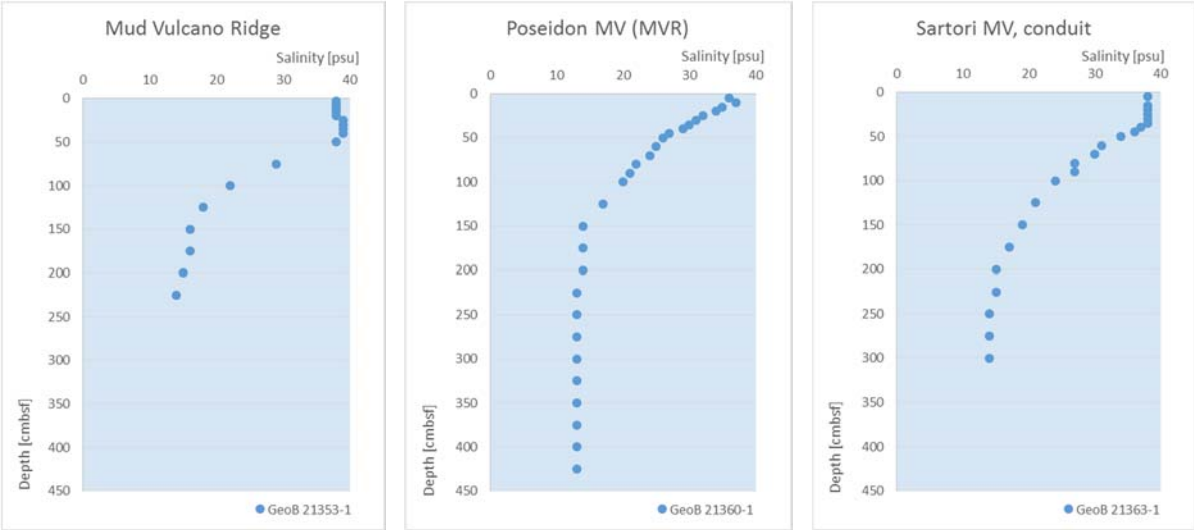


Fig. 44: Salinity profiles of pore water in sediments of all mud volcanoes investigated during POS499.

Table 8: Pore water samples for sulphate analysis.

GC-1 (GeoB21322-1) Venere MV, top mudflow: Depth [cmbsf] / Sample #					
10 cm / 221	15 cm / 222	20 cm / 223	25 cm / 224	30 cm / 225	35 cm / 226
40 cm / 227	45 cm / 228	55 cm / 229	60 cm / 230	65 cm / 231	70 cm / 232
80 cm / 233	90 cm / 234	120 cm / 235	130 cm / 236	150 cm / 237	160 cm / 238
170 cm / 239	180 cm / 240	190 cm / 241			
GC-2 (GeoB21323-1) Venere MV, flow: Depth [cmbsf] / Sample #					
10 cm / 242	15 cm / 243	20 cm / 244	25 cm / 245	30 cm / 246	35 cm / 247
40 cm / 248	45 cm / 249	50 cm / 250	60 cm / 251	70 cm / 252	80 cm / 253
90 cm / 254	100 cm 255	115 cm / 256			
GC-9 (GeoB21344-1) Cetus MV, central conduit: Depth [cmbsf] / Sample #					
5 cm / 257	10 cm / 258	15 cm / 259	20 cm / 260	25 cm / 261	30 cm / 262
35 cm / 263	40 cm / 264	45 cm / 265	50 cm / 266	60 cm / 267	70 cm / 268
80 cm / 269	90 cm / 270	100 cm / 271	120 cm / 272	140 cm / 273	
GC-16 (GeoB21353-1) Mud Vulcano Ridge: Depth [cmbsf] / Sample #					
3 cm / 274	6 cm / 275	9 cm / 276	12 cm / 277	15 cm / 278	20 cm / 279
25 cm / 280	30 cm / 281	35 cm / 282	40 cm / 283	50 cm / 284	75 cm / 285
100 cm / 286	125 cm / 287	150 cm / 288	175 cm / 289	200 cm / 290	225 cm / 291
GC-19 (GeoB21360-1) Poseidon MV (MVR): Depth [cmbsf] / Sample #					
5 cm / 292	10 cm / 293	15 cm / 294	20 cm / 295	25 cm / 296	30 cm / 297
35 cm / 298	40 cm / 299	45 cm / 300	50 cm / 301	60 cm / 302	70 cm / 303
80 cm / 304	90 c m / 305	100 cm / 306	125 cm / 307	150 cm / 308	175 cm / 309
200 cm / 310	225 cm / 311	250 cm / 312	275 cm / 313	300 cm / 314	325 cm / 315
350 cm / 316	375 cm / 317	400 cm / 318	425 cm / 319		

GC-21 (GeoB21363-1) Sartori MV, conduit: Depth [cmbsf] / Sample #					
5 cm / 320	15 cm / 321	20 cm / 322	25 cm / 323	30 cm / 324	35 cm / 325
40 cm / 326	45 cm / 327	50 cm / 328	60 cm / 329	70 cm / 330	80 cm / 331
90 cm / 332	100 cm / 333	125 cm / 334	150 cm / 335	175 cm / 336	200 cm / 337
225 cm / 338	250 cm / 339	275 cm / 340	300 cm / 341		

Table 9: Nutrient samples taken during POS499.

GC-1 (GeoB21322-1) Venere MV, top mudflow: Depth [cmbsf] / Sample #			
10 cm / 2	15 cm / 3	20 cm / 4	25-35 cm / 5-7
45-70 cm / 9-14	80-160 cm / 15-23		
GC-2 (GeoB21323-1) Venere MV, top flow: Depth [cmbsf] / Sample #			
10 cm / 27	15 cm / 28	20 cm /29	25-30 cm / 30-31
35 cm / 32	40 cm / 33	45 cm / 34	50-60 cm / 35-36
70 cm / 37			
GC-9 (GeoB21344-1) Cetus MV, central conduit: Depth [cmbsf] / Sample #			
5 cm / 42	10 cm / 43	15 cm / 44	20 cm / 45
25 cm / 46	30 cm / 47	35 cm / 48	40 cm / 49
45-60 cm / 50-52	70-140 cm / 53-58		
GC-16 (GeoB21353-1) Mud Vulcano Ridge: Depth [cmbsf] / Sample #			
3 cm / 59	6 cm / 60	9 cm / 61	12 cm / 62
15 cm / 63	20 cm / 64	25 cm / 65	30 cm / 66
35 cm / 67	40 cm / 68	50 cm / 69	75 cm / 70
100 cm / 71	125 cm / 72	150-175 cm / 73-74	200-225 cm / 75-76
GC-19 (GeoB21360-1) Poseidon MV (MVR): Depth [cmbsf] / Sample #			
5 cm / 77	10 cm / 78	15 cm / 79	20 cm / 80
25 cm / 81	30 cm / 82	35 cm / 83	40 cm / 84
45 cm / 85	50 cm / 86	60 cm / 87	70 cm / 88
80 cm / 89	90 cm / 90	100 cm / 91	125 cm / 92
150 cm / 93	175-200 cm / 94-95	225-250 cm / 96-97	275-300 cm / 98-99
325-350 cm / 100-101	375-400 cm / 102-103	425 cm / 104	
GC-21 (GeoB21363-1) Sartori MV, conduit: Depth [cmbsf] / Sample #			
5 cm / 105	15 cm / 106	20 cm / 107	25 cm / 108
30 cm / 109	35 cm / 110	40 cm / 111	45 cm / 112
50 cm / 113	60 cm / 114	70 cm / 115	80 cm / 116
90 cm / 117	100 cm / 118	125 cm / 119	150 cm / 120
175 cm / 121	225-250 cm / 123-124	275-300 cm / 125-126	

10 Heat Flow Measurements

(M. Loher)

10.1. Introduction

The mud breccia extruded by mud volcanoes often exhibits elevated sediment temperatures compared to the surrounding background sediments and ambient bottom waters. For example, the research expedition M112 by R/V METEOR in 2014 discovered that the Venere Mud Volcano actively extrudes mud breccia of temperatures well above 20°C indicating that this material is transported to the seafloor from great depths. Therefore, temperature measurements can be valuable datasets in order to test the current state of activity (dormancy or active extrusion) at mud volcanoes.

In order to investigate whether fresh mud is still being extruded at Venere Mud Volcano two years later, several gravity cores equipped with miniaturized temperature data loggers (MTLs; by ANTARES) were deployed during POS499. From the temperature data it will be possible to calculate a geothermal gradient by extrapolation of the measured temperature values.

10.2. Method and Set-up

At several stations the core barrel was equipped with up to seven MTLs to measure the temperatures of fresh mud breccia and older mud flow deposits. For this purpose it was possible to seal-off the gravity core barrel with a modified core catcher. This way, several GC deployments were possible without the need for a complete recovery on deck. The vessel could move to a new position with the GC elevated ca. 100 m above the seafloor. During POS499 only one series of temperature data was acquired this way (GC-T-1). Three deployments at Mud Volcano Ridge (GC-16, GC-18, GC-19) and one deployment at Sartori (GC-21) were carried out whereby a normal gravity core (plastic bag) was simultaneously collected for pore water analyses.

For all deployments the gravity corer was left 10 minutes in the sediment for the loggers to equilibrate. The MTLs have a resolution of approximately 0.001 K and an accuracy of 0.1 K. The sensors are programmed to continuously record temperature readings at an interval of one second for a maximum of 18 hours. They were mounted on a 6 m core barrel with a spacing of 0.5 m for the two lowermost loggers and 1 m for the remaining loggers and their specific housings were mounted by metal hose clamps in a spiral array. One logger was installed on top of the coring device in order to measure a reference bottom water temperature. A CTD station (GeoB21370-1) was used for calibration of the loggers, which will be done onshore. Results below derive from calibration between the MTLs in the water column, before penetration.

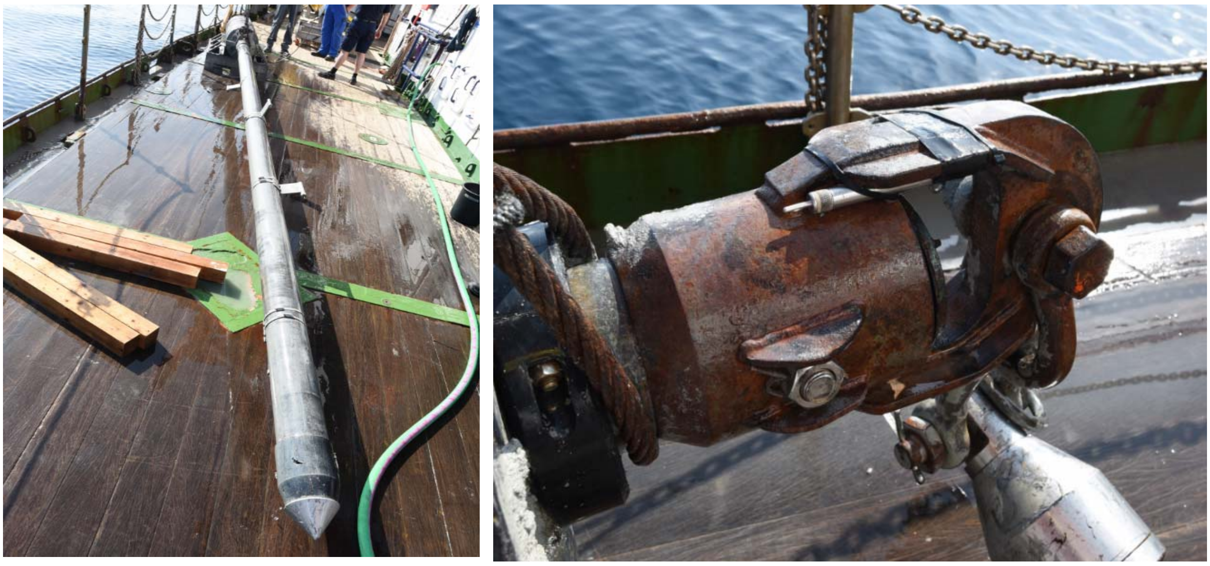


Fig 45: Setup of the MTLs on the gravity corer.

10.3 Preliminary Results

In-situ temperatures of mud breccia was obtained at the Venere MV, MV Ridge and Sartori MV. At Venere MV a transect across the active peak revealed elevated temperatures (Fig. 46). Specifically, in the area of the main conduit temperatures above 23°C were recorded. These findings are in accordance with results from cruise M112 where similar temperature data had been acquired. In comparison, both the MV Ridge and the Sartori MV only indicated weak temperature increases or values equal to the current bottom waters. Even though the gravity cores aimed for seemingly active conduits (as recognized by elevated backscatter values in AUV-derived backscatter data) the sediment temperatures were elevated by less than 0.3°C above the bottom water temperature (e.g. for Sartori, Fig. 47).

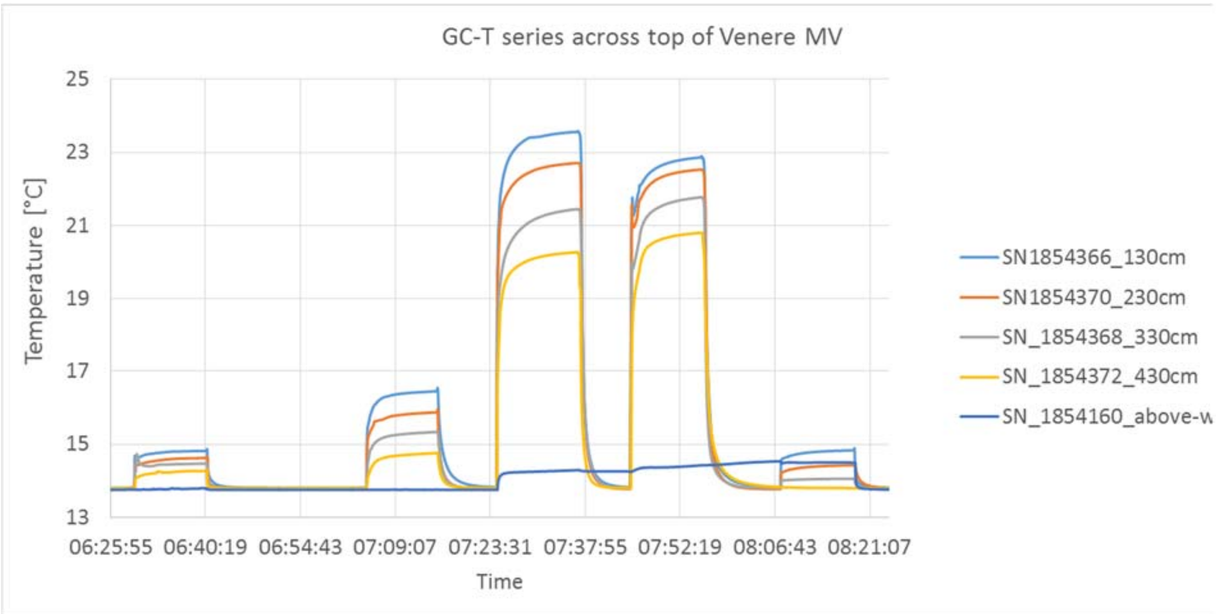


Fig. 46: Raw data of temperature values from the GC-T transect across Venere MV. The distance in cm indicated at the logger serial number indicates the distance from the core catcher (at the bottom of the core).

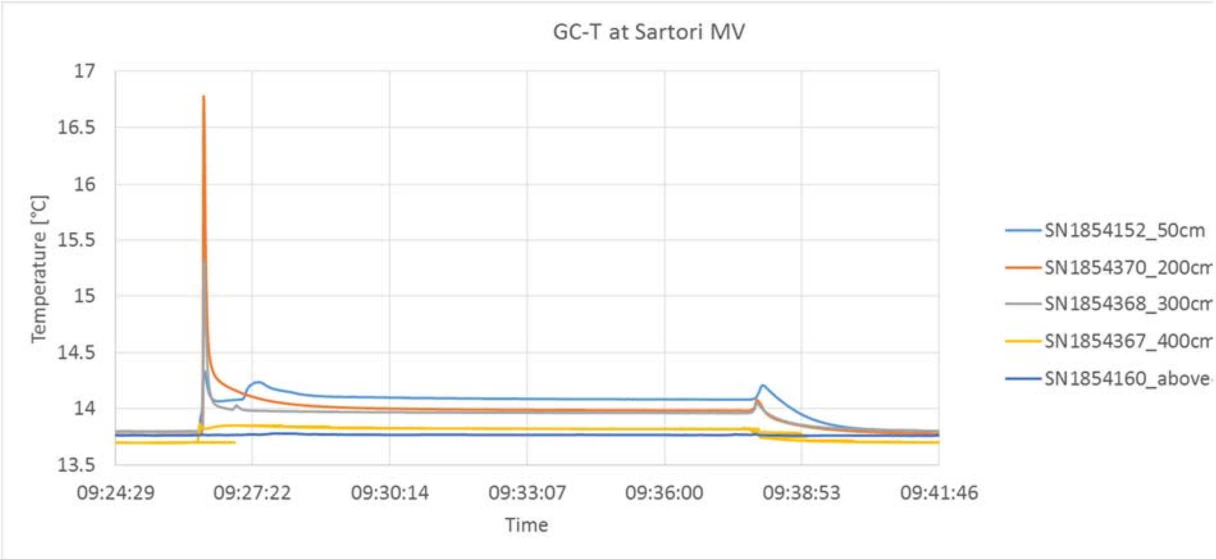


Fig. 47: Raw data of temperature values from the GC-T deployment at Sartori MV. The high peak on the left part of the diagram is attributed to the frictional heat upon sediment penetration. The distance in cm indicated at the logger serial number indicates the distance from the core catcher (at the bottom of the core).

Table 10: List of all stations where the gravity corer was equipped with MTLs.

GeoB	UTC Start	UTC End	PC Start	PC End	LAT (N)	LON (E)	Water-depth (m)	Rope max (m)	T max (kN)
21329-1	04:30:00	04:40:00	06:30:00	06:40:00	38°36.442	17°11.183	1488	1547	
21329-2	05:05:10	05:15:10	07:05:10	07:15:10	38°36.442	17°11.205	1486	1543	39
21329-3	05:25:15	05:35:07	07:25:15	07:35:07	38°36.444	17°11.221	1489	1565	35
21329-4	05:45:10	05:55:17	07:45:10	07:55:17	38°36.452	17°11.227	1475	1545	
21329-5	06:08:00	06:18:05	08:08:00	08:18:05	38°36.463	17°11.251	1489	1549	31
21353-1	07:42:00	07:52:00	09:42:00	09:52:00	38°17.778	17°42.149	1867	1951	37.2
21355-1	11:42:03	11:52:00	13:42:03	13:52:00	38°19.380	17°41.811	1900	1996	38
21360-1	11:09:50	11:20:15	13:09:50	13:20:15	38°18.921	17°42.849	1974	2074	
21363-1	07:26:45	07:37:30	09:26:45	09:37:30	38°12.343	17°36.956	1834	1921	38.8

11 Data and Sample Storage and Availability

Metadata of the cruise as well as the station list will be submitted to PANGAEA immediately after the cruise. Sediment cores are stored at the MARUM GeoB Core Repository. Samples, data and other information of the cruise are available upon request to the chief scientist Gerhard Bohrmann. In addition, data (raw and processed) will be submitted to PANGAEA along with the scientific publication.

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14 Appendix

14.1 Station List

Poseidon 499: Calabrian Mud Volcanoes — Station List

Date 2016	St. No.	Instrument	GeoB St. No.	Location	Time (UTC) Begin	on seafloor	off seafloor	End	Begin / on seafloor Latitude N	Longitude E	Water depth (m)	End / off seafloor Latitude N	Longitude E	Water depth (m)	Recovery Remarks
04.05.	126-1	CTD-1	21301-1	Background	15:30	15:57	-	16:16	38°01.831	16°26.385	1282	38°01.81	16°26.44	1282	For SVP to 1250 m
04/05.05.	127-1	MB-1	21302-1	Venere	18:12	-	-	06:39	38°10.27	16°38.01	1506	38°35.40	17°11.47	1559	Flare imaging
05.05.	128-1	MIC-1	21303-1	Venere MV	6:54	7:28	-	07:52	38°35.764	17°11.544	1574	38°35.745	17°11.511	1573	Wire length 1610 m, 1 liner lost. 25 cm recovery.
05.05.	129-1	MIC-2	21304-1	Venere MV	8:12	8:42	-	09:06	38°35.885	17°11.652	1559	38°35.884	17°11.646	1559	wire length 1604 m, 1 liner lost. 21 cm recovery.
05.05.	130-1	MIC-3	21305-1	Venere MV	9:51	10:21	-	10:48	38°35.930	17°11.814	1558	38°35.876	17°11.855	1563	wire length 1604 m. 38 cm recovery.
05.05.	131-1	MIC-4	21306-1	Venere MV	11:18	11:49	-	12:17	38°36.033	17°11.845	1569	38°35.992	17°11.844	1578	wire length 1605 m. 30 cm recovery.
05.05.	132-1	MIC-5	21307-1	Venere MV	12:43	13:13	-	13:40	38°36.103	17°11.810	1558	38°36.072	17°11.675	1545	wire length 1607 m. 27 cm recovery.
05.05.	133-1	MIC-6	21308-1	Venere MV	14:09	14:38	-	15:04	38°36.134	17°11.992	1569	38°36.143	17°12.033	1572	wire length 1609 m. 26 cm recovery.
05.05.	134-1	MIC-7	21309-1	Venere MV	15:23	15:52	-	15:19	38°35.837	17°11.911	1572	38°35.860	17°12.020	1575	wire length 1615 m.
05./06.05.	135-1	MB-2	21310-1	Venere MV	17:05	-	-	04:55	38°37.08	17°11.62	1532	38°35,48	17°11.99	1573	Flare imaging
06.05.	136-1	AUV-71	21311-1	Venere MV summit area	5:00	-	-	15:24	38°35.46	17°12.03		38°35.58	17°11.87		calibration successful. No waterdepth data recorded from ship.
06.05.	137-1	MB-3	21312-1	Venere MV	16:10	-	-	04:10	38°36.06	17°12.48	1568	38°36.34	17°11.86	1542	Flare imaging
07.05.	138-1	MIC-8	21313-1	Venere MV	4:11	4:40	-	05:35	38°36.334	17°11.842	1532	38°36.363	17°11.820	1535	wire length 1582 m. 21 cm recovery.
07.05.	139-1	MIC-9	21314-1	Venere MV	5:20	5:48	-	06:14	38°36.631	17°11.481	1497	38°36.626	17°11.509	1504	wire length 1540 m. 17 cm recovery.
07.05.	140-1	MIC-10	21315-1	Venere MV	6:32	7:01	-	07:28	38°36.780	17°11.575	1509	38°36.746	17°11.618	1510	wire length 1554 m. 24 cm recovery.
07.05.	141-1	MIC-11	21316-1	Venere MV	7:47	8:17	-	08:45	38°36.535	17°11.861	1513	38°36.534	17°11.873	1526	& CTD (100 m above ground), wire length 1554 m. 23 cm recovery.
07.05.	142-1	MIC-12	21317-1	Venere MV	9:11	9:38	-	10:03	38°36.661	17°11.104	1500	38°36.649	17°11.123	1496	wire length 1540 m. 12 cm recovery.
07.05.	143-1	MIC-13	21318-1	Venere MV	10:38	11:07	-	11:32	38°36.547	17°11.127	1477	38°36.555	17°11.152	1486	wire length 1526 m. 27 cm recovery.
07.05.	144-1	MIC-14	21319-1	Venere MV	12:08	12:41	-	13:13	38°36.341	17°10.832	1515	38°36.354	17°10.788	1513	wire length 1683 m, no sensible contact. 27cm recovery.
07.05.	145-1	MIC-15	21320-1	Venere MV	13:44	14:13	-	14:38	38°36.199	17°11.148	1516	38°36.260	17°11.144	1514	wire length 1557 m. 23 cm recovery.
07./08.05.	146-1	AUV-72	21321-1	Venere MV southern part	14:46	-	-	04:50	38°36.26	17°11.15	1513	38°36.25	17°13.31		successful
08.05.	147-1	GC-1	21322-1	Venere MV	5:47	6:16	-	06:45	38°36.462	17°11.223	1474	38°36.468	17°11.214	1499	wire length 1543 m. In bag.
08.05.	148-1	GC-2	21323-1	Venere MV	7:10	7:35	-	08:10	38°36.457	17°11.285	1494	38°36.469	17°11.287	1482	wire length 1550 m. In bag.
08.05.	149-1	GC-3	21324-1	Venere MV	8:34	9:02	-	09:26	38°37.053	17°11.627	1524	38°37.038	17°11.628	1523	wire length 1603 m. In liners.
08.05.	150-1	GC-4	21325-1	Venere MV		10:27	-	10:56	38°36.724	17°10.765	1513	38°36.708	17°10.745	1510	wire length 1588 m, no success (empty liner)
08.05.	151-1	GC-5	21326-1	Venere MV	11:56	12:24	-	12:54	38°36.086	17°12.364	1570	38°36.037	17°12.356	1566	wire length 1644 m. In liners.
08.05.	152-1	MIC-16	21327-1	Venere MV	13:23	13:53	-	14:18	38°36.214	17°12.111	1560	38°36.211	17°12.175	1570	wire length 1609 m. 24 cm recovery.
08./09.05.	153-1	MB-4	21328-1	NE Venere region	14:36	-	-	03:36	38°36.38	17°12.04	1533	38°36,06	17°12.01	1576	bathymetry survey
09.05.	154-1	GC-T-1	21329-1	Venere MV	4:02	4:30	4:40		38°36.442	17°11.183	1488				wire length 1547 m
09.05.	154-1	GC-T-1	21329-2	Venere MV		5:05	5:15		38°36.442	17°11.205	1486				wire length 1543 m, max T = 39 kN
09.05.	154-1	GC-T-1	21329-3	Venere MV		5:25	5:35		38°36.444	17°11.221	1489				wire length 1565 m, max T = 35 kN
09.05.	154-1	GC-T-1	21329-4	Venere MV		5:45	5:55		38°36.452	17°11.227	1475				wire length 1545 m. Temperature measuring successful.
09.05.	154-1	GC-T-1	21329-5	Venere MV		6:08	6:18	06:51	38°36.463	17°11.251	1489	38°36.458	17°11.266	1483	wire length 1549 m, max T = 31 kN. In liners.
09.05.	155-1	GC-6	21230-1	reference station	8:10	8:37	-	09:11	38°33.803	17°20.766	1543	38°33.768	17°20.831	1524	wire length 1623 m, max T = 34,5 kN. In liners. 386 cm recovery.
09.05.	156-1	GC-7	21331-1	near Venere MV	10:05	10:34	-	11:06	38°32.866	17°17.705	1589	38°32.893	17°17.748	1590	wire length 1670 m, max T = 32,1 kN. In liners. 301 cm revocery.
09.05.	157-1	GC-8	21332-1	near Venere MV	12:19	12:50	-	13:22	38°38.039	17°17.512	1610	38°38-032	17°17.466	1611	wire length 1692 m, max T = 36,4 kN. In liners. 518 cm recovery.
09./10.05	158-1	MB-5	21333-1	Venere MV flares	16:00	-	-	04:00	38°37.14	17°11.56	1538	38°36.41	17°11.63	1519	Flare imagination
10.05.	159-1	MIC-17	21334-1	Venere MV	4:11	4:38	-	05:04	38°37.083	17°11.561	1535	38°37.056	17°11.544	1535	wire length 1584 m. 21 cm recovery.
10.05.	160-1	MIC-18	21335-1	Venere MV	5:43	6:11	-	06:37	38°36.795	17°11.343	1507	38°36.812	17°11.277	1508	wire length 1550 m. 24 cm recovery.
10.05.	161-1	MIC-19	21336-1	Venere MV	6:57	7:24	-	07:50	38°36.488	17°11.986	1521	38°36.478	17°11.982	1520	wire length 1557 m. 25 cm recovery.
10.05.	162-1	MIC-20	21337-1	Venere MV	8:08	8:35	-	09:02	38°36.179	17°11.649	1535	38°36.116	17°11.633	1537	wire length 1582 m. 28 cm recovery.
10.05.	163-1	MIC-21	21338-1	Venere MV	9:16	9:46	-	10:12	38°35.901	17°11.644	1568	38°35.890	17°11.642	1561	22 cm recovery.
10.05.	164-1	MIC-22	21339-1	Venere MV	10:44	11:13	-	11:33	38°35.785	17°11.551	1569	38°35.799	17°11.481	1575	wire length 1612 m. 26 cm recovery.
10.05.	165-1	MIC-23	21340-1	Venere MV	11:52	12:21	-	12:41	38°35.843	17°11.209	1561	38°35.867	17°11.234	1559	wire length 1605 m. 24 cm recovery.

Appendix: Station List continued

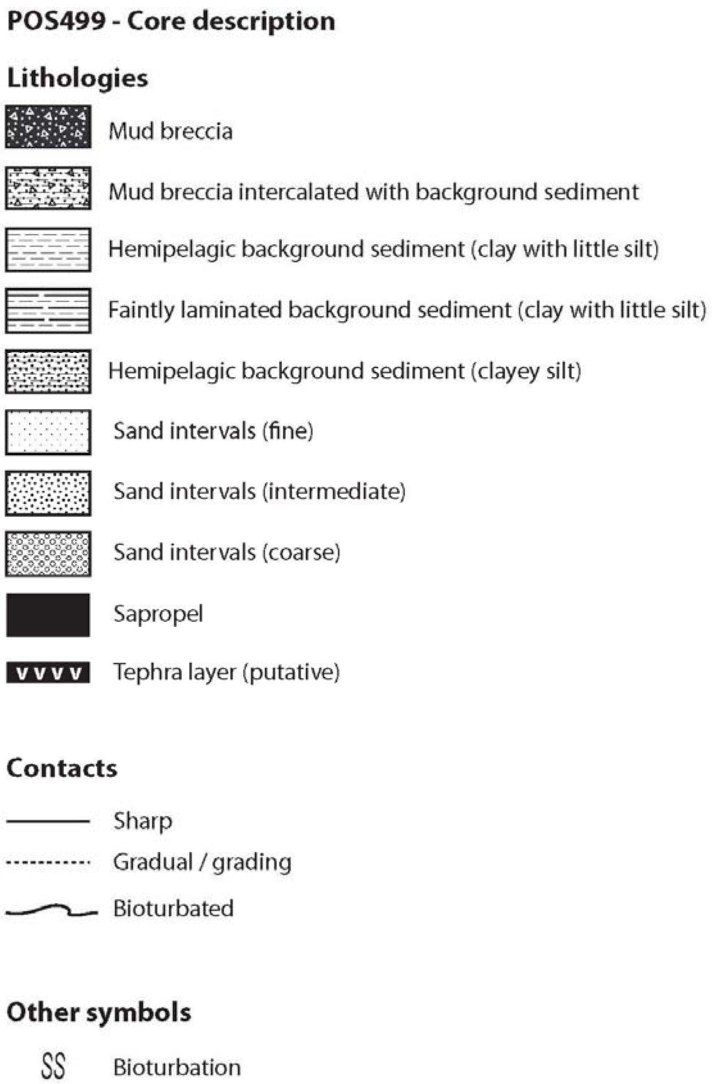
Poseidon 499: Calabrian Mud Volcanoes — Station List

Date 2016	St. No.	Instrument	GeoB St. No.	Location	Time (UTC) Begin	Time (UTC) on seafloor	Time (UTC) off seafloor	Time (UTC) End	Begin / on seafloor Latitude N	Begin / on seafloor Longitude E	Begin / on seafloor Water depth (m)	End / off seafloor Latitude N	End / off seafloor Longitude E	End / off seafloor Water depth (m)	Recovery Remarks
10.05.	166-1	MIC-24	21341-1	Venere MV	13:05	13:34	-	13:51	38°36.175	17°10.886	1523	38°36.173	17°10.867	1526	wire length 1566 m. 25 cm recovery.
13.05.	167-1	AUV-73	21342-1	Venere MV	6:11	-	-	18:23	38°37.17	17°09.95	1522	38°36.79	17°12.90		
13./14.05.	168-1	MB-6	21343-1	Transit Venere-Cetus MV	18:46	-	-	05:36	38°36.52	17°13.05	1560	37°52.69	17°27.96	2209	
14.05.	169-1	GC-9	21344-1	Cetus MV	6:14	6:58	-	07:40	37°52.807	17°27.739	2186	37°52.820	17°27.732	2185	wire length 2289 m, max T = 33,3kN. In bag. 140 cm recovery.
14.05.	170-1	GC-10	21345-1	Cetus MV	8:08	8:49	-	09:28	37°53.158	17°27.247	2217	37°53.194	17°27.242	2216	wire length 2333 m, max T = 36,8kN. In liners. 556 cm recovery.
14.05.	171-1	GC-11	21346-1	Cetus MV	10:24	11:32	-	12:16	37°52.751	17°30.291	2363	37°52.761	17°30.303	2364	& CTD (600 m above ground). wire length 2481 m, max T = 26,6kN. In liners. 74 cm recovery.
14.05.	172-1	GC-12	21347-1	Cetus MV	12:55	13:40	-	14:45	37°52.099	17°32.612	2615	37°52.212	17°32.570	2613	wire length 2579 m, max T = 50 kN. In liners. 248 cm recovery.
14./15.05.	173-1	AUV-74	21348-1	Cetus MV	16:01	-	-	05:23	37°53.33	17°26.38	2426	37°53.81	17°28.40		not successful. AUV came to surface at 20:30.
15.05.	174-1	GC-13	21349-1	Cetus MV	6:16	7:03	-	07:56	37°54.150	17°32.016	2220	37°54.135	17°32.033	2218	wire length 2329 m, max T = 40,7kN. In liners. 440 cm recovery.
15.05.	175-1	GC-14	21350-1	Cetus MV	8:27	9:04	-	09:56	37°54.126	17°31.490	2249	37°54.134	17°31.371	2248	wire length 2375 m, max T = 36kN. In liners. 537 cm recovery.
15.05.	176-1	GC-15	21351-1	Cetus MV	10:46	11:40	-	12:36	37°50.993	17°30.924	2554	38°51.059	17°30.875	2546	wire length 2717m, max T = 47kN. In liners. 413cm recovery.
15./16.05.	177-1	AUV-75	21352-1	Cetus MV	15:32	-	-	05:43	38°11.90	17°35.13	1941	38°11.54	17°37.07		
16.05.	178-1	GC-16	21353-1	Mud Volcano Ridge	7:08	7:42	7:52	08:36	38°17.778	17°42.149	1867	38°17.758	17°42.145	1863	MTLs attached (10min in sediment). wire length 1951m, max T = 37,2kN. In liners. 242 cm recovery.
16.05.	179-1	GC-17	21354-1	Mud Volcano Ridge Slope	9:10	9:53	-	10:36	38°18.936	17°43.540	2046	38°18.943	17°43.442	2035	wire length 2154 m, max T = 30kN. 24 cm recovery, no storage.
16.05.	180-1	GC-18	21355-1	Mud Volcano Ridge	11:07	11:42	11:52	12:35	38°19.380	17°41.811	1900	38°18.383	17°41.870	1906	MTLs attached (10 min in sediment). wire length 1996 m, max T = 38kN. In liners. 241 cm recovery.
16.05.	181-1	MIC-25	21356-1	Poseidon MV	13:11	13:51	-	14:23	38°18.921	17°42.892	1979	38°18.939	17°42.942	1974	wire length 2115 m. No sensible gorund contact. 23 cm recovery.
16./17.05.	182-1	AUV-76	21357-1	Mud Volcano Ridge	15:03	-	-	05:21	38°19.03	17°43.19		38°19.21	17°46.97		
17.05.	183-1	MIC-26	21358-1	Mud Volcano Ridge Slope	6:02	6:45	-	07:25	38°19.537	17°45.557	2354	38°19.533	17°45.595	2359	wire length 2444 m. 24 cm recovery.
17.05.	184-1	MIC-27	21359-1	Mud Volcano Ridge Slope	7:52	8:38	-	09:23	38°19.025	17°46.983	2573	38°19.086	17°46.998	2576	wire length 2662 m, 25 cm recovery.
17.05.	185-1	GC-19	21360-1	Poseidon MV	10:20	11:09	11:20	12:01	38°18.921	17°42.849	1974	38°19.005	17°42.879	1989	wire length 2074 m, max T = 34kN. In bag. 445 cm recovery.
17.05.	186-1	GC-20	21361-1	Mud Volcano Ridge Slope	12:49	13:29	-	14:10	38°19.322	17°45.906	2555				wire length 2565 m, T max = 43,1kN. In liners. 448 cm recovery. No position/depth recorded from ship.
17./18.05.	187-1	AUV-77	21362-1	Mud Volcano Ridge	15:17	-	-	05:23	38°18.83	17°42.83	1972	38°18.98	17°.43.37		
18.05.	188-1	GC-21	21363-1	Sartori MV	6:51	7:26	7:37	09:11	38°12.343	17°36.956	1834	38°12.582	17°36.866	1857	MTLs attached (10 min in sediment). wire length 1921 m, T max = 38,8kN. In bag. Ca. 300 cm recovery.
18.05.	189-1	MIC-28-1	21364-1	Sartori MV	9:16	10:00	-	10:29	38°12.547	17°36.750	1860	38°12.526	17°36.832	1856	wire length 1917 m. No recovery, 2 liners lost.
18.05.	189-2	MIC-28-2	21364-2	Sartori MV	10:39	11:14	-	11:36	38°12.588	17°36.697	1865	38°12.633	17°36.730	1867	wire length 1927 m, 29 cm recovery.
18./19.05.	190-1	AUV-78	21365-1	Cetus MV	15:20	-	-	05:24	37°53.21	17°27.04		37°52.84	17°30.79		
19.05.	191-1	GC-22	21366-1	Sartori MV	8:00	8:41	-	09:17	38°12.319	17°36.324	1891	38°12.331	17°36.292	1893	top 3-5 cm disturbed (missing). Wire length 1990 m, T max = 38kN. In liners. 405 cm recovery.
19.05.	192-1	GC-23	21367-1	Sartori MV	10:08	10:46	-	11:24	38°12.654	17°36.553	1885	38°12.641	17°36.591	1882	wire length 1985 m, T max = 38,4kN. In liners. 489 cm recovery.
19.05.	193-1	MIC-29	21368-1	Mud Volcano Ridge	12:35	13:09	-	13:28	38°17.556	17°37.934	1822	38°17.545	17°37.917	1815	wire length 1880 m, 24 cm recovery, 1 liner lost.
19.05.	194-1	AUV	-	Mud Volcano Ridge	-	-	-	-	-	-	-	-	-	-	AUV dive cancelled due to bad weather conditions
20.05.	195-1	AUV-79	21369-1	Mud Volcano Ridge	6:08	-	-	14:21	38°18.00	17°39.79		38°16.88	17°38.17		
21.05.	196-1	CTD-2	21370-1	Mud Volcano Ridge	4:00	4:07	4:29	04:43	38°17.613	17°37.907	1835	38°17.617	17°37.919	1834	Stop at 5 m for 5 min, then to 100 m with 0,7 m/s
21.05.	196-2	GC-24	21371-1	Mud Volcano Ridge	6:07	6:43	-	07:20	38°17.622	17°37.904	1835	38°17.645	17°37.848	1859	wire length 1925 m, T max = 45kN. In liners. 327 cm recovery.

Instruments

AUV SEAL 5000
CTD memory CTD Sea & Sun Technologies 48M
MB Multibeam echosounder 50kHz, ELAC Model SB3050
GC Gravity corer (3 m or 6 m barrel length)
GC-T Gravity corer + MTL
MIC Mini Corer

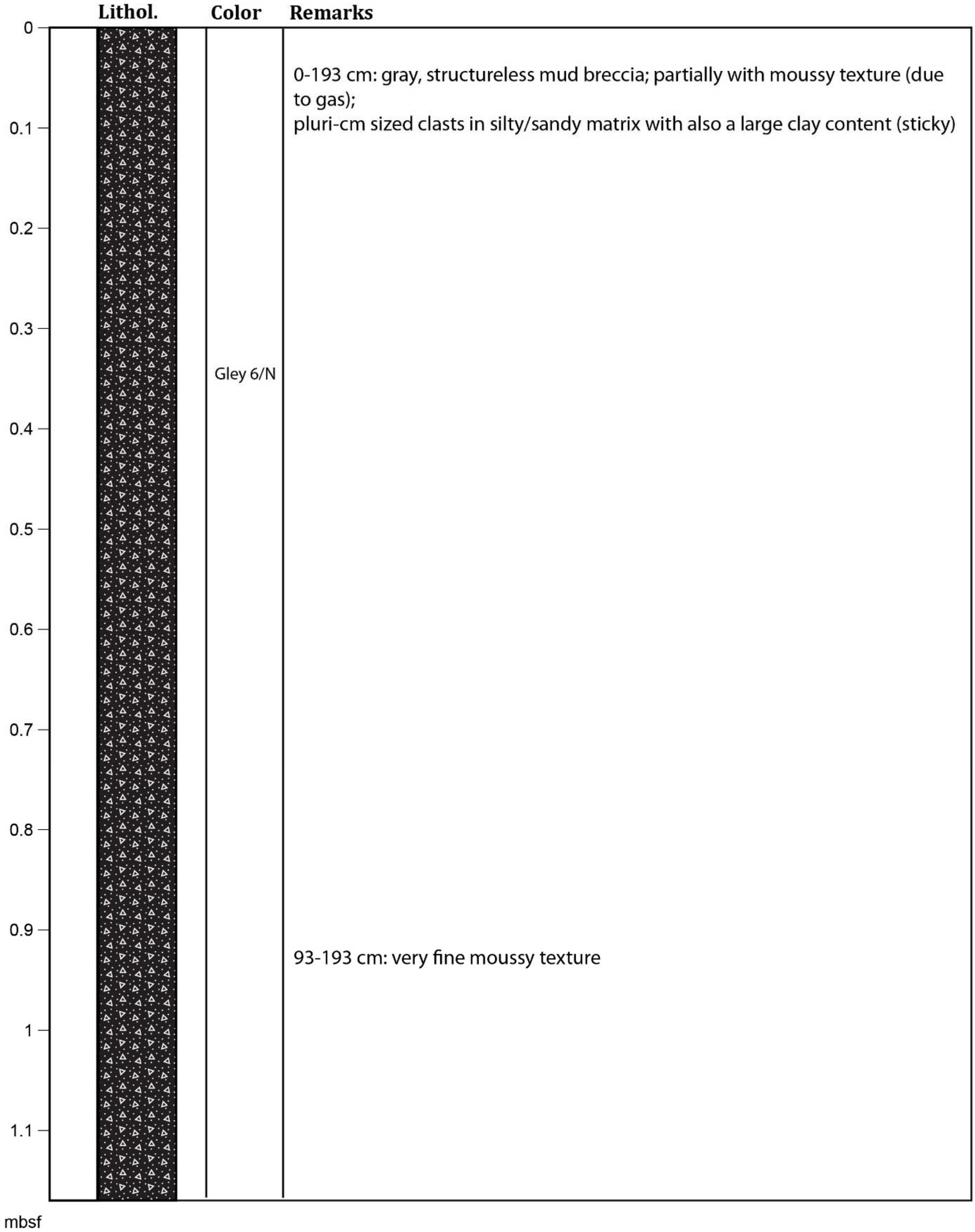
14.2 Core Descriptions



GeoB21322-1 (GC-1) Date of coring: 08.05.2016

Position: 38°36.462 N; 17°11.223 E
Water depth: 1474 m.b.s.f.
Core length: 193 cm

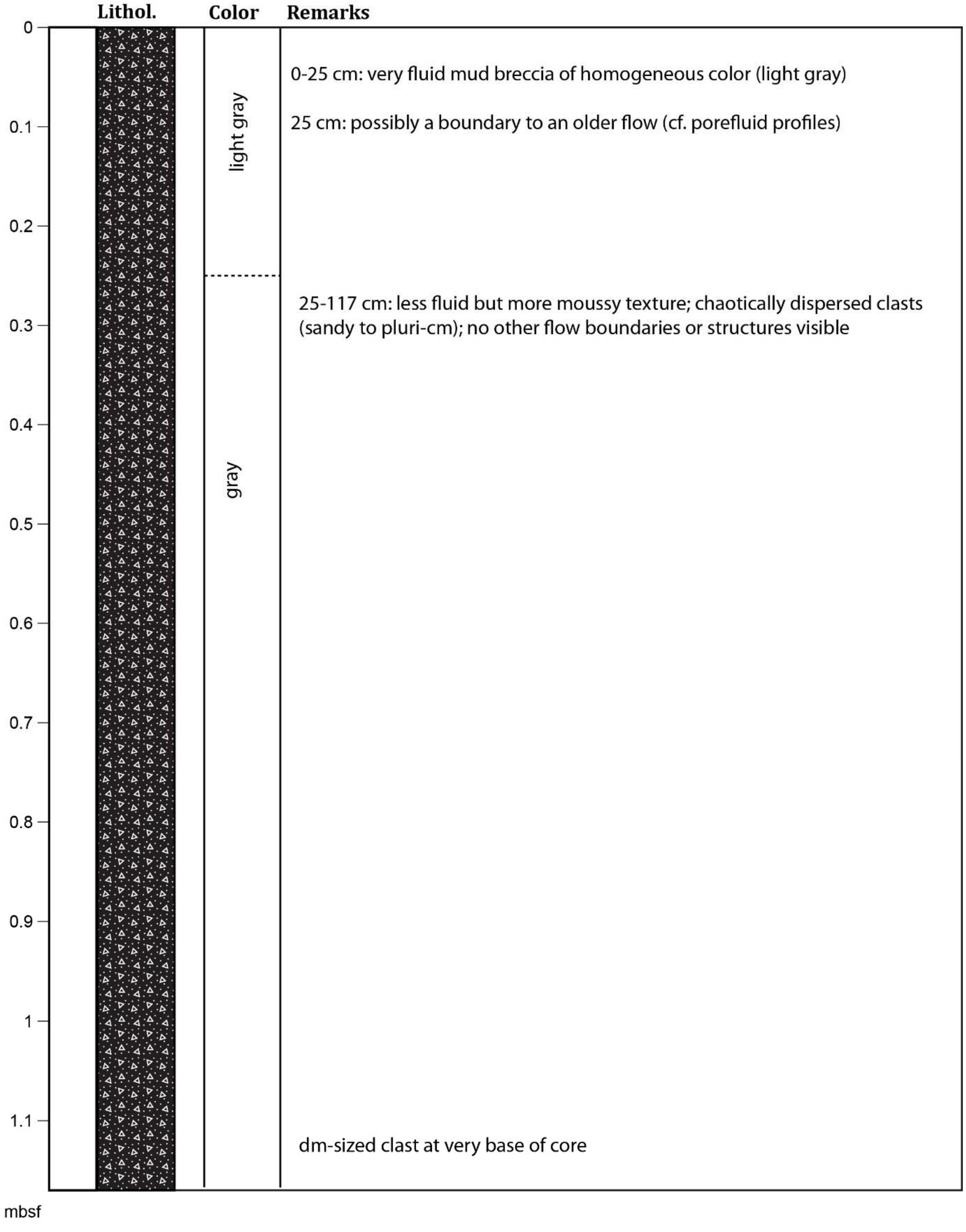
Type of core: Gravity core. Liner: Bag
Location: Venere MV, fresh outflow
General remarks:



GeoB21323-1 (GC-2) Date of coring: 08.05.2016

Position: 38°36.457 N; 17°11.285 E
Water depth: 1494 m.b.s.f.
Core length: 117 cm

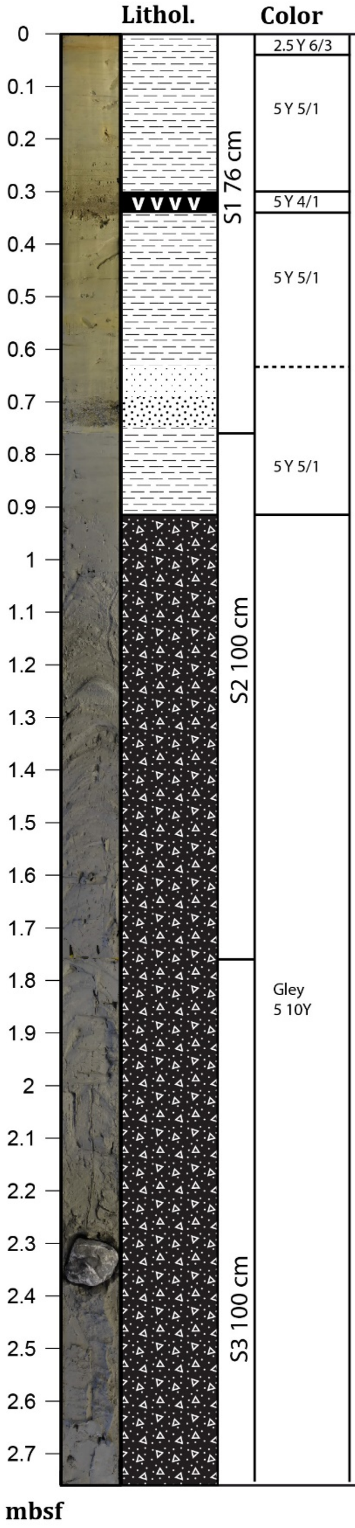
Type of core: Gravity core. Liner: Bag
Location: Venere MV, fresh outflow
General remarks:



GeoB21324-1 (GC-3) Date of coring: 08.05.2016

Position: 38°37.053 N; 17°11.627 E
Water depth: 1523 m.b.s.f.
Core length: 276 cm

Type of core: Gravity core. Liner: PVC
Location: Venere MV, near Flare 1 site
General remarks:



Remarks

0-4 cm: light yellowish brown clay with little silt, faintly laminated (< mm scale)

4-30 cm: gray, fine silty clay, unlaminated, medium HCl reaction

30-34 cm: dark gray silty interval (graded transition at top); slightly erosive base but sharp contact

33-63 cm: gray, fine silty clay, unlaminated, medium HCl reaction

50-54 cm: slightly more yellowish interval

63-69 cm: graded transition from silty to fine sandy

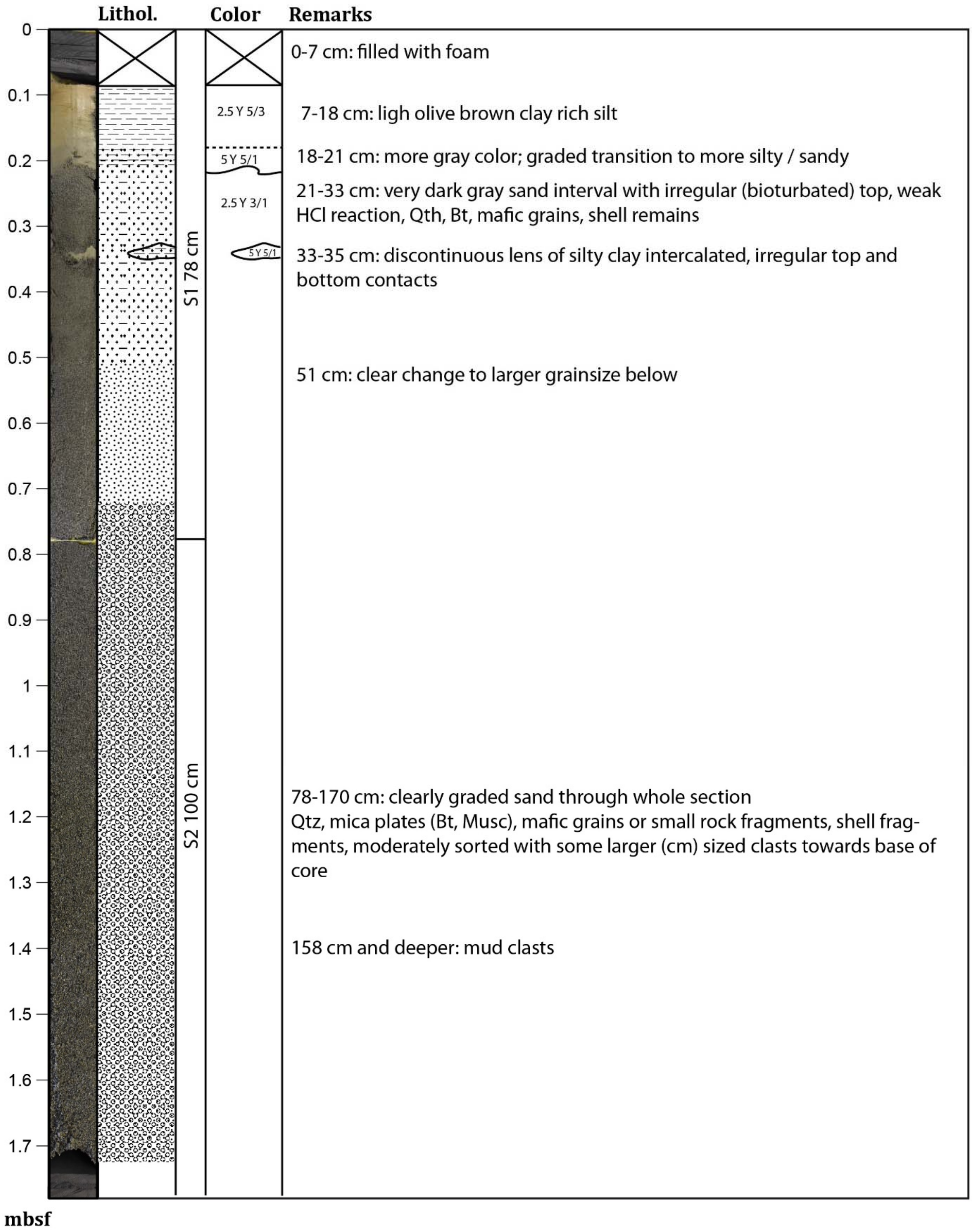
69-74 cm: sand layer with erosive base; Qtz, Bt, mafic grains, shell fragments

91.5-176 cm: clear textural boundary to mud breccia (but gradual colour change); strong HCl reaction; clay, silt, sand matrix with pluri-cm clasts (hard and friable) from light gray to dark or greenish

GeoB21326-1 (GC-5) Date of coring: 08.05.2016

Position: 38°36.086 N; 17°12.364 E
Water depth: 1570 m.b.s.f.
Core length: 178 cm

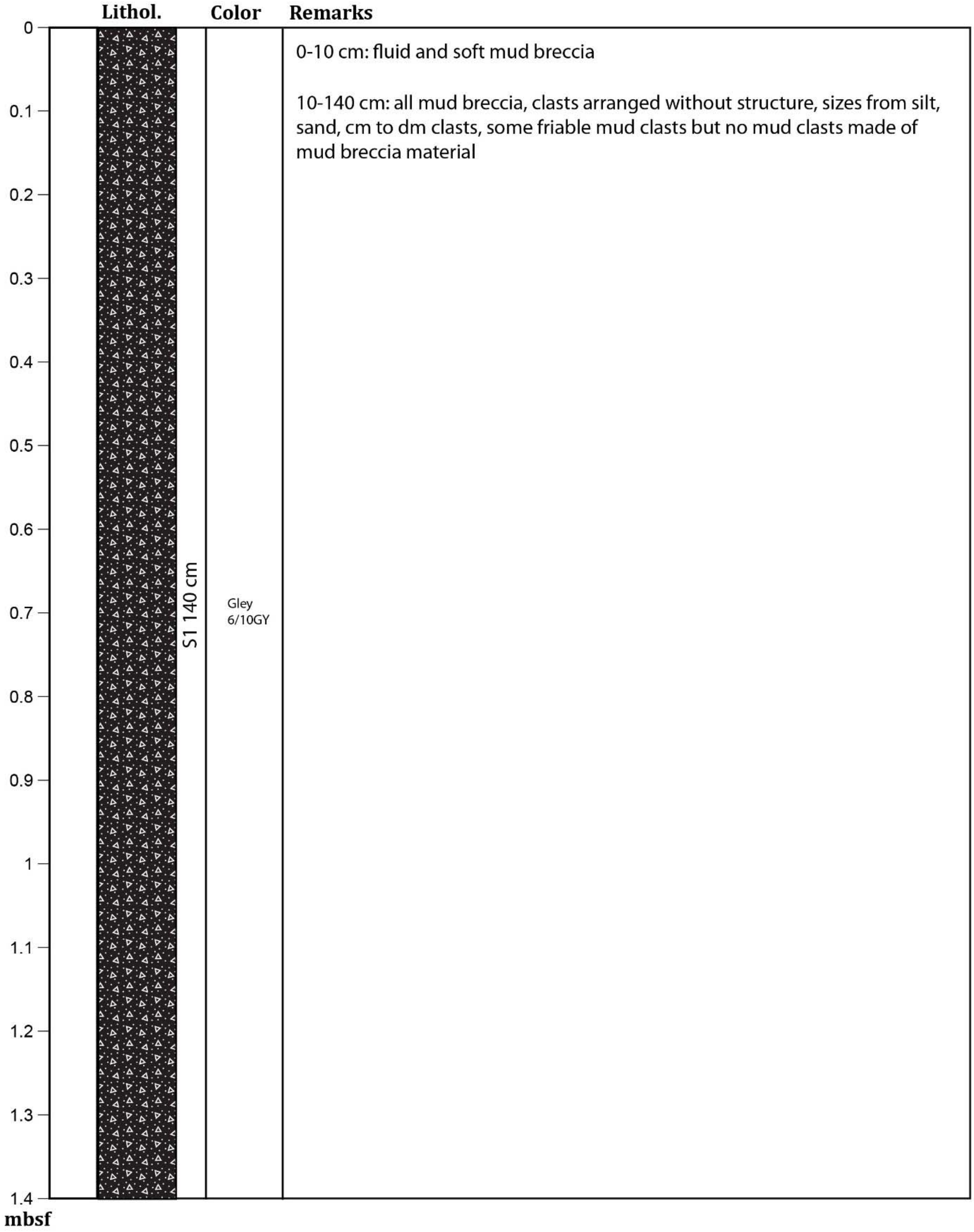
Type of core: Gravity core. Liner: PVC
Location: Venere MV, flat caldera
General remarks:



GeoB21344-1 (GC-9) Date of coring: 14.05.2016

Position: 37°52.807 N; 17°27.739 E
Water depth: 2186m.b.s.f.
Core length: 140 cm

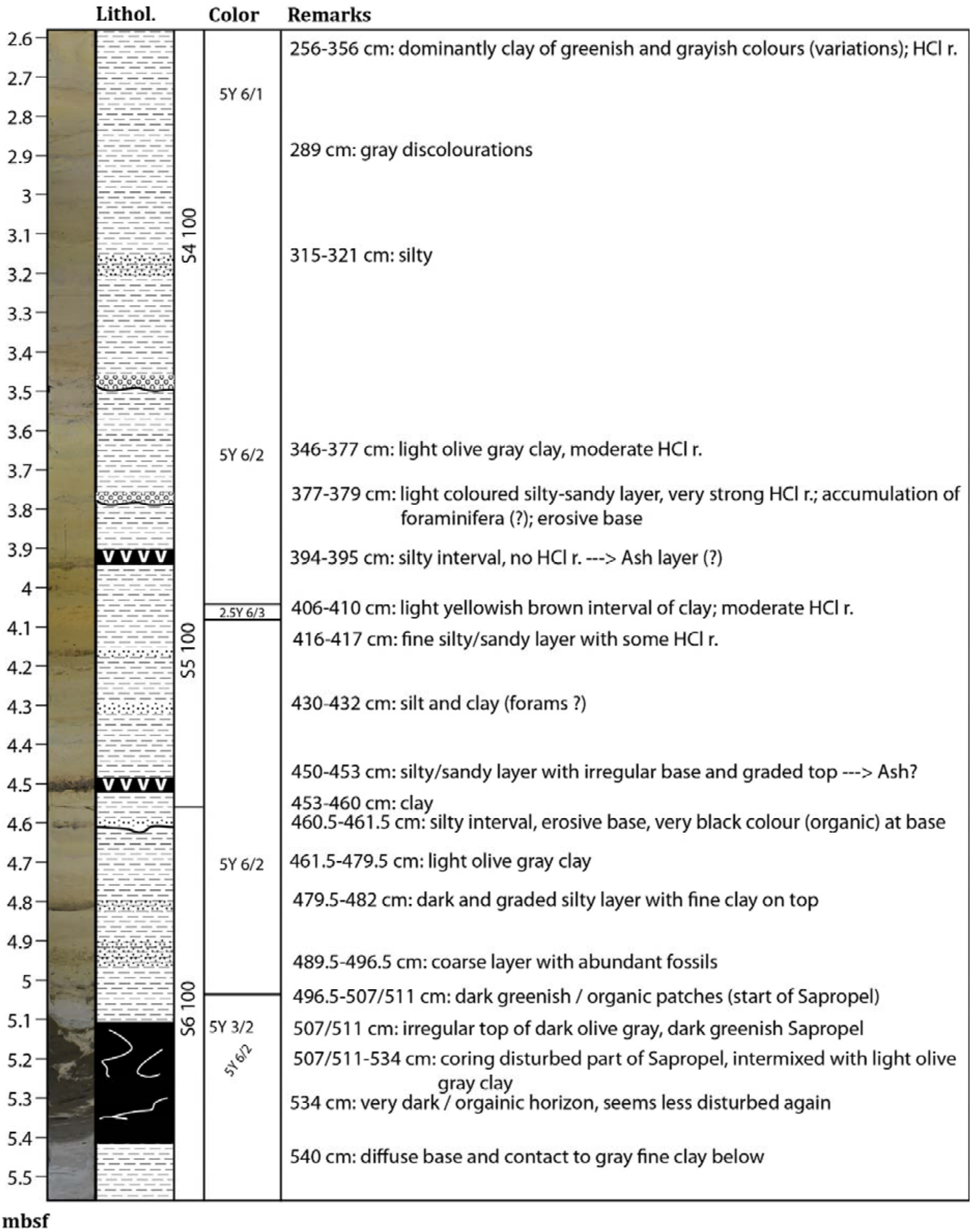
Type of core: Gravity core. Liner: Bag
Location: Cetus MV, central conduit
General remarks:



GeoB21345-1 (GC-10) Date of coring: 14.05.2016

Position: 37°53.158 N; 17°27.247 E
Water depth: 2217 m.b.s.f.
Core length: 556 cm

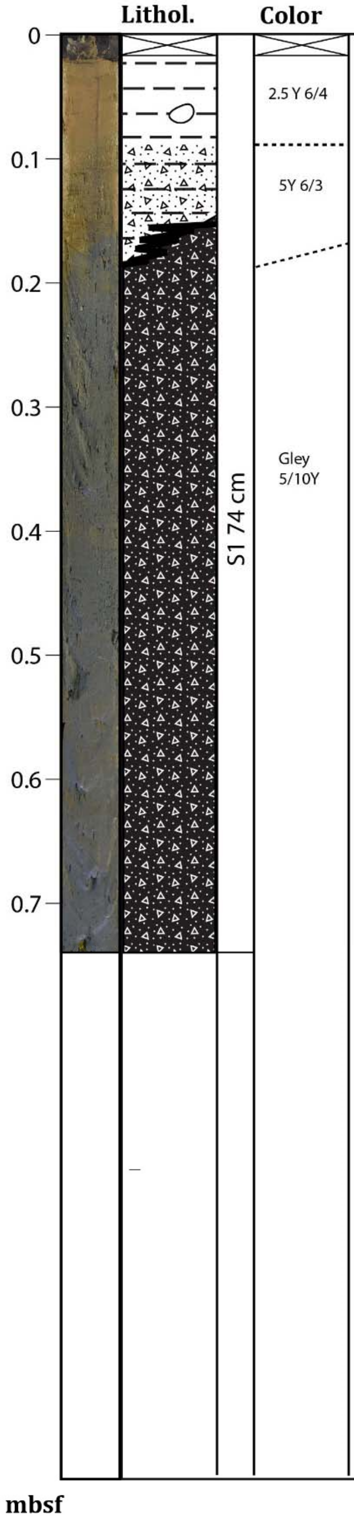
Type of core: Gravity core. Liner: PVC
Location: Cetus MV, outer rim caldera
General remarks:



GeoB21346-1 (GC-11) Date of coring: 14.05.2016

Position: 37°52.751 N; 17°30.291 E
Water depth: 2363 m.b.s.f.
Core length: 74 cm

Type of core: Gravity core. Liner: PVC
Location: Cetus MV, main flow
General remarks:



Remarks

0-2 cm: filled with foam

2-9 cm: light yellowish brown clay with little silt, unlaminated, cm-sized clast at 6.5 cm

9-17/19 cm: gradual transition to pale olive sandy silt with abundant clay (possibly an oxidised facies of mud breccia)

17/19 cm: inclined and irregular contact between light brown and greenish gray clay and silty mud breccia

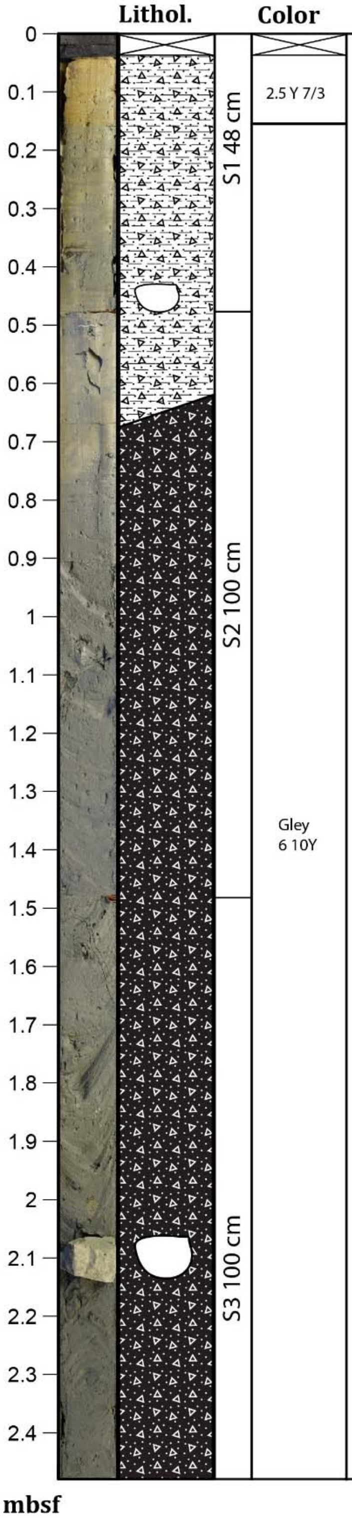
17/19-74 cm: greenish gray mud breccia (silt, fine sand, cm-clasts), moderate HCl reaction

50-74 cm: mud breccia texture more massive

GeoB21347-1 (GC-12) Date of coring: 14.05.2016

Position: 37°52.099 N; 17°32.612 E
Water depth: 2615 m.b.s.f.
Core length: 248 cm

Type of core: Gravity core. Liner: PVC
Location: Cetus MV, flow to plateau
General remarks:



Remarks

0-4 cm: filled with foam --> top probably disturbed / compacted

4-15.5 cm: pale yellow mud breccia (fine clasts, mm-tric); some bioturbation burrows, oxidised sediment (faint laminae with darker brown streaks)

15.5-48.5 cm: greenish gray mud breccia with streaks of lighter brownish / yellowish sediment

37-38 cm: dark (gray/black) streaks of silty material --> check for ash?

38-40 cm: porous / watery mud breccia (not the massive compact facies yet)

48-62/67 cm: mud breccia streaked with yellowish brown (background?) sediment; strong HCl reaction

62/67 cm: inclined and irregular contact; possibly 2 flows on top of each other

62/67-148 cm: massive greenish gray mud breccia, moderate HCl reaction

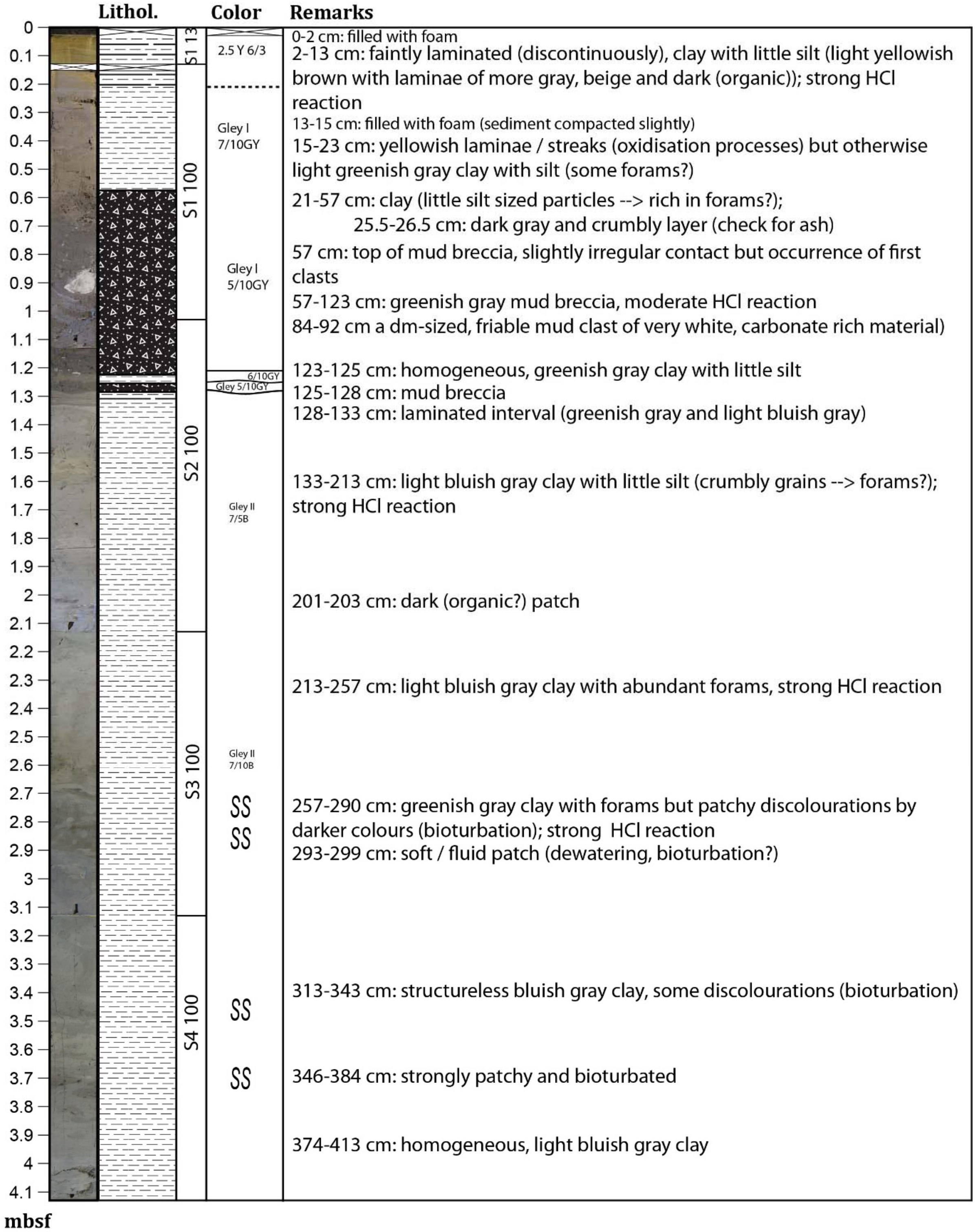
148-248 cm: very massive greenish gray mud breccia, very sticky clay with cm- to dm-sized clasts

202-208 cm: fine grained sandstone (bedding visible) with calcite (cf. separate sample bag)

GeoB21351-1 (GC-15) Date of coring: 15.05.2016

Position: 37°50.993 N; 17°30.924 E
Water depth: 2554 m.b.s.f.
Core length: 413 cm

Type of core: Gravity core. Liner: PVC
Location: Cetus MV, flow down cliff
General remarks:



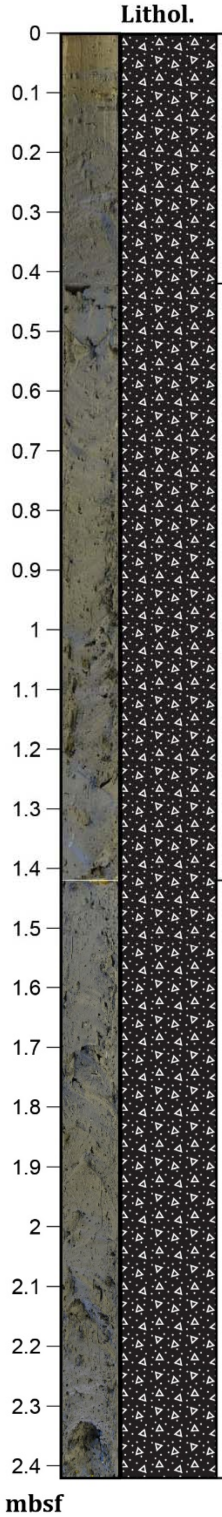
GeoB21353-1 (GC-16)

Date of coring: 16.05.2016

Position: 38°17.778 N; 17°42.149 E
Water depth: 1867m.b.s.f.
Core length: 242cm

Type of core: Gravity core. Liner: PVC
Location: MV Ridge, cone
General remarks:

Lithol. **Color** **Remarks**



S1 42

S2 100

S3 100

Color: Gley II 5 / 5PB

Remarks:

0-11 cm: light brown / yellowish mud breccia (oxidised), fine clasts

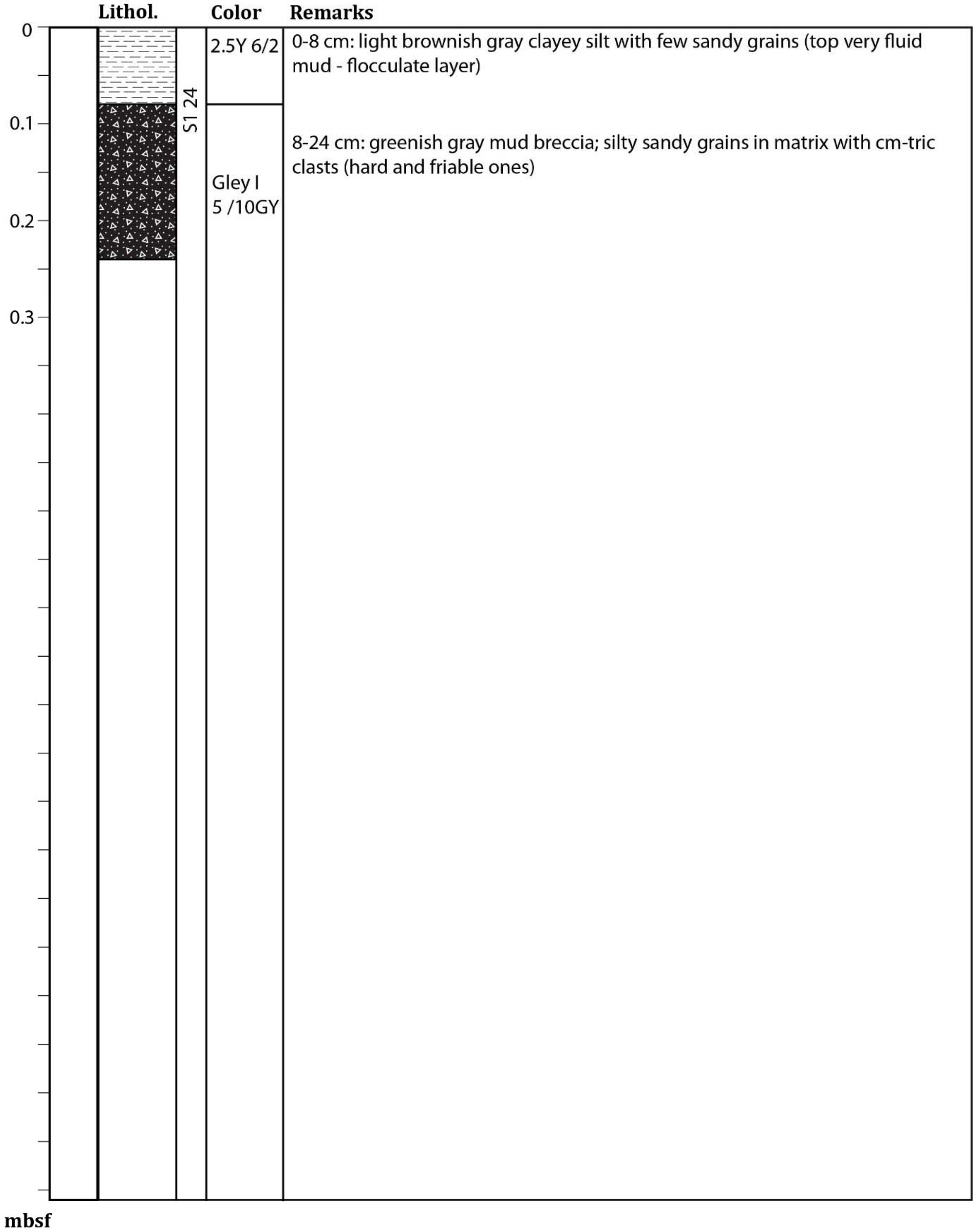
11-42 cm: chaotic and structureless mud breccia of bluish gray colour; moderate HCl reaction

42-242 cm: all mud breccia (friable sandstone clasts, shales, mud clasts) with moderate moussy structure

GeoB21354-1 (GC-17) Date of coring: 16.05.2016

Position: 38°18.936 N; 17°43.540 E
Water depth: 2046m.b.s.f.
Core length: 24 cm

Type of core: Gravity core. Liner: Bag
Location: MV Ridge Slope, flow on slope
General remarks:

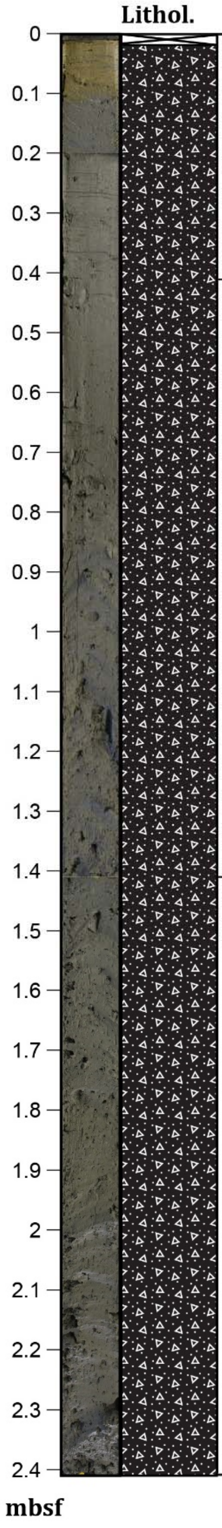


GeoB21355-1 (GC-18)

Date of coring: 16.05.2016

Position: 38°19.380 N; 17°41.811E
Water depth: 1900 m.b.s.f.
Core length: 241cm

Type of core: Gravity core. Liner: PVC
Location: Mud volcano Ridge, Cone
General remarks: + MTL



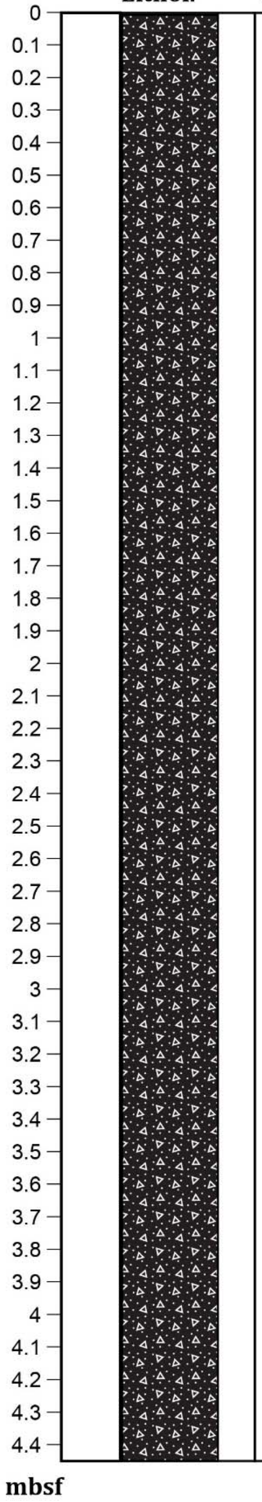
Section	Color	Remarks
S1 41	2.5Y 6/2	0-2 cm: foam 2-20 cm: light brownish gray mud breccia, structureless (mm-cm clasts); some friable clasts, moderate HCl reaction, oxidised appearance, light H2S smell
	Gley I 5/10Y	20-41 cm: greenish gray mud breccia with an irregular transition at top
S2 100		41-141 cm: continuated mud breccia, intensified H2S smell; from 54 cm maybe some more large clasts (cm-tric scale); moussy texture apparent towards base
S3 100		141-241 cm: mud breccia with moussy texture, strong H2S smell, cm-tric clasts

GeoB21360-1 (GC-19) Date of coring: 17.05.2016

Position: 38°18.921 N; 17°42.849 E
Water depth: 1974 m.b.s.f.
Core length: 445 cm

Type of core: Gravity core. Liner: Bag
Location: Poseidon MV, main conduit
General remarks: Clasts sampled by S. Ceramicola

Lithol. **Color** **Remarks**



0-5 cm: fine and fluid mud breccia, black sediment (reduced); H2S smell

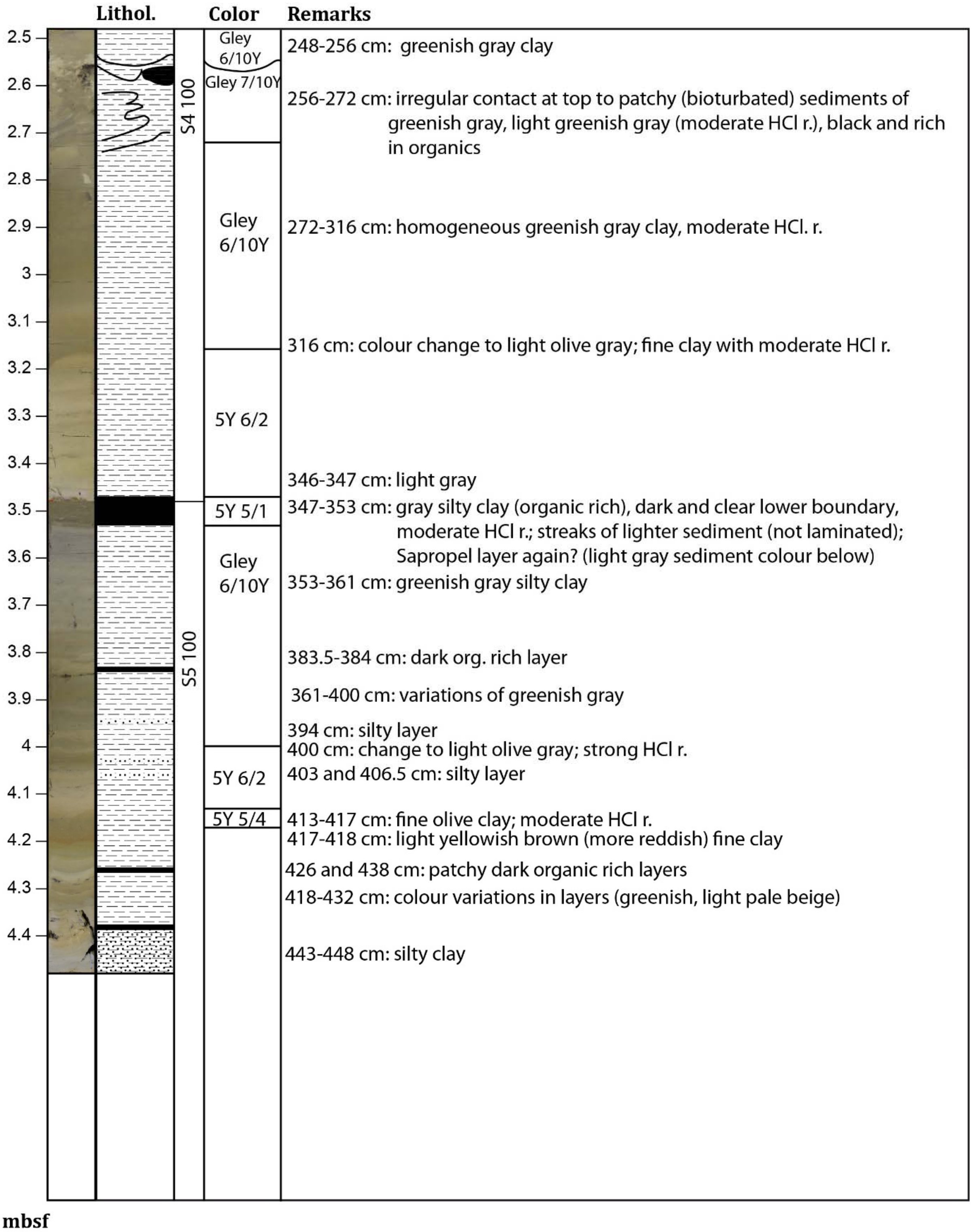
5-445 cm: structureless mud breccia; clasts from silt, sand to dm-sized clasts abundant friable clasts of not completely lithified mud/sediment, carbonates, sandstone, shale, abundant greenish gray clasts and corresponding mud; moussy texture (moderate)

no structures visible which might indicate the boundary to different flows

GeoB21361-1 (GC-20) Date of coring: 17.05.2016

Position: 38°19.322 N; 17°45.906 E
Water depth: ca. 2556 m.b.s.f.
Core length: 448 cm

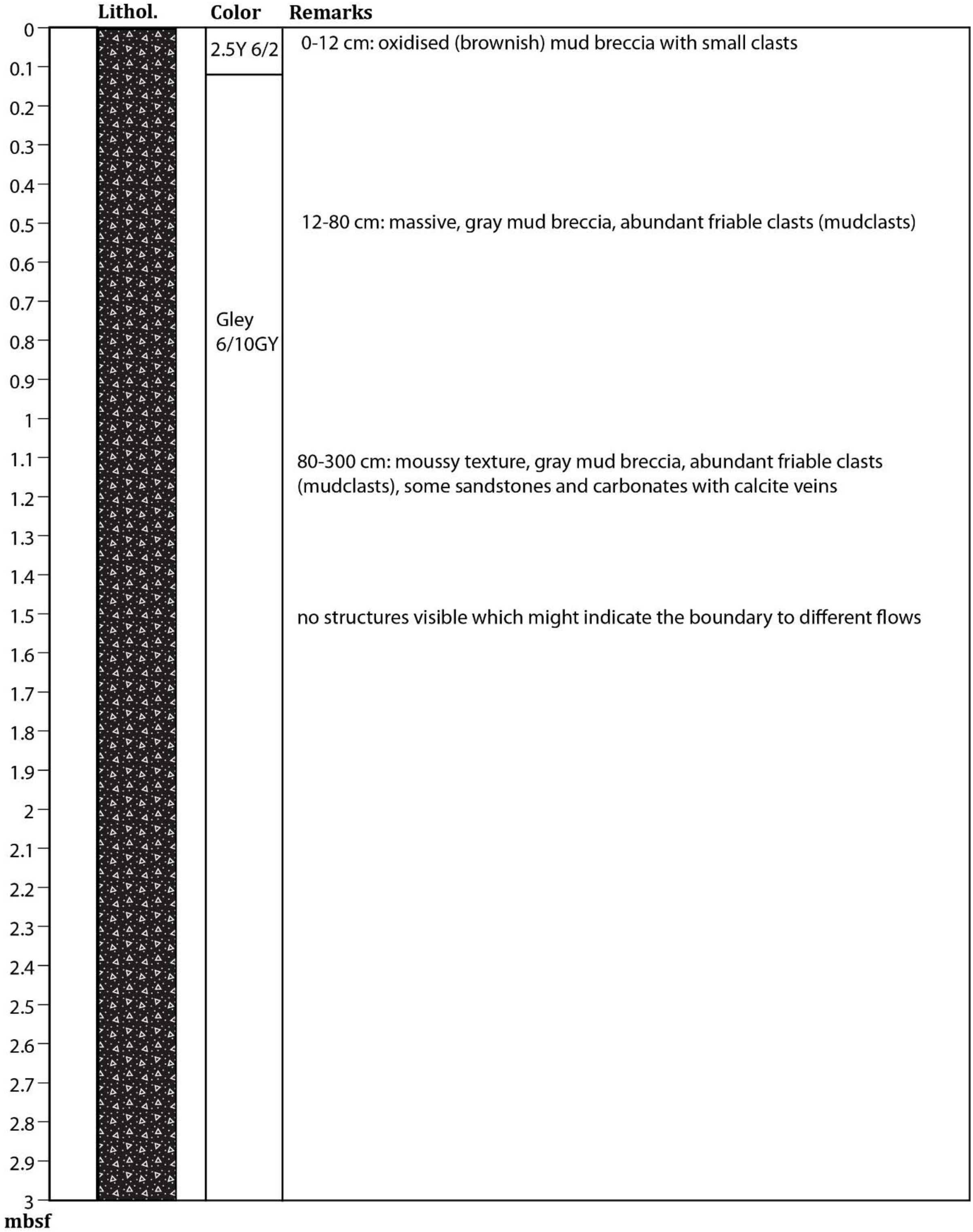
Type of core: Gravity core. Liner: PVC
Location: MV Ridge Slope, in between main flows
General remarks:



GeoB21363-1 (GC-21) Date of coring: 18.05.2016

Position: 38°12.343N; 17°36.956 E
Water depth: 1834 m.b.s.f.
Core length: 300 cm

Type of core: Gravity core. Liner: Bag
Location: Sartori MV, main conduit
General remarks: Clasts sampled by S. Ceramicola



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