Cruise Report

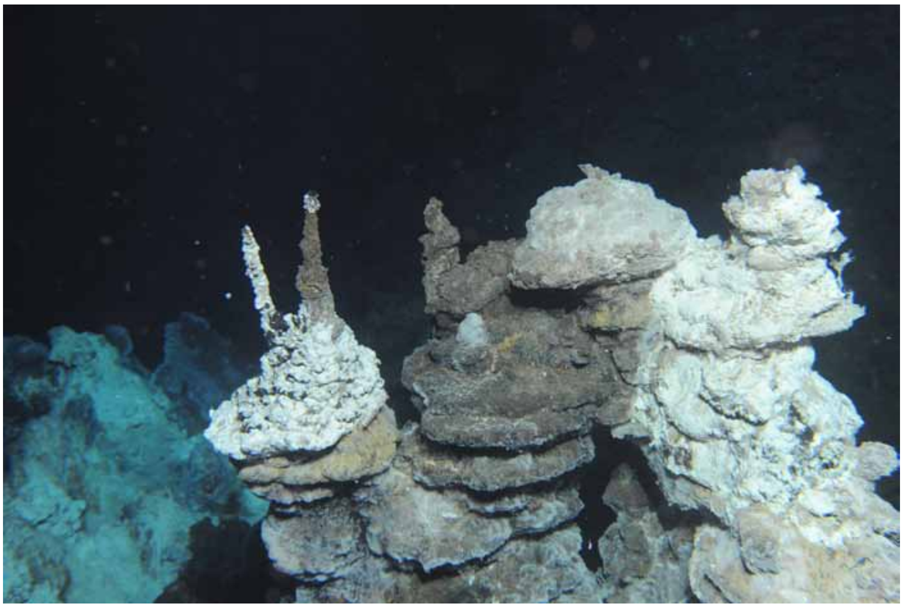
Jan Mayen vent fields (JMVF)

R/V G.O. Sars, **Expedition No. 2011108**/CGB2011

10. – 22. June 2011

Bergen – Bergen, Norway

Chief Scientist: Rolf B. Pedersen



Cruise report prepared by Tamara Baumberger

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1 Introduction

1.1 Participants

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Armann Höskuldsson (Scientist, University of Iceland, Iceland)

1.2 Cruise Objectives

The 2011 cruise to the Jan Mayen vent fields (JMVF) was part of the research activities at the Centre for Geobiology within the European research project ECO2. The main objectives of the expedition were 1) to test and improve procedures and techniques for seabed mapping and imaging, 2) to test and improve bubble plume detection and imaging techniques, 3) to constrain the CO_2 content of the gas emitted at the JMVF and to study potential hydrate formation and 4) to study dispersion of dissolved gases in the water column and its effect on the environment.

1.3 Background

1.3.1 Arctic Mid-Ocean Ridges

For the first two decades of hydrothermal exploration, hydrothermal activity at ultraslow ridges was thought to be little or even absent. However, the last 10 years have shown that hydrothermal systems are more abundant than expected at the AMOR (Figure 2.1), a representative of the ultra-slow spreading ridge class (below 20 mm/yr). Several workers reported the discovery of venting hydrothermal systems at the seafloor or hydrothermal anomalies in the water column [*Edmonds et al.*, 2003; *Pedersen et al.*, 2005; *Connelly et al.*, 2007; *Pedersen et al.*, 2010a; *Pedersen et al.*, 2010b]. The crust can become very thin or even missing in ultraslow environments what can result in a local exposure of the upper mantle to the seafloor [*Dick et al.*, 2003; *Michael et al.*, 2003]. Because there are also magmatic ridge segments present, is it likely that basalt-hosted and peridotite-hosted hydrothermal systems could be found in close vicinity. It was previously thought that low spreading rates and the thin crust at ultraslow-spreading ridges lead to a reduced magmatic heat budget and thus a lower number of vent fields than at faster spreading ridges. Nevertheless, relative to the available heat, there is increasing evidence for a larger degree of hydrothermal activity at the AMOR than previously thought.

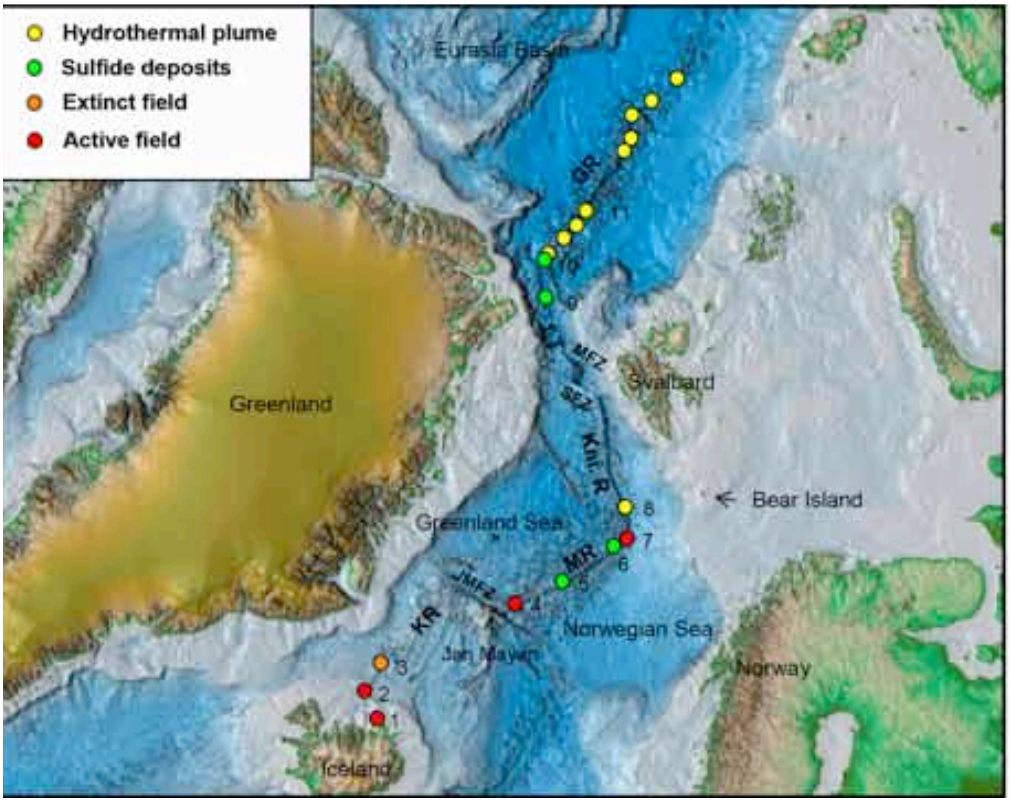

Figure 1: Map after Pedersen et al. [2010b] showing the Arctic Mid-Ocean Ridges with the locations of active and extinct vent field, sulfide deposits and hydrothermal plumes: **4 Jan Mayen vent fields**.

The AMOR has been defined as the ridge systems north of the Arctic Circle at 66°. The AMOR is 4000 km long and may be divided into six ridge segments: (1) the Kolbeinsey Ridge (540 km), (2) the Mohns Ridge (550 km), (3) the Knipovich Ridge (500 km), (4) the Molley Ridge (60 km), (5) the Lena Through (330 km), and (6) the Gakkel Ridge (1600 km). Between the Mohns Ridge and the Knipovich Ridge, a major change in the orientation takes place at about 74°N. The same was found at 83°C between the Lena Through and the Gakkel Ridge. In addition, the AMOR contains three major fracture zones. One of these is the Jan Mayen fracture zone (JMFZ) at 71°N [*Pedersen et al.*, 2010b].

1.3.2 Hydrothermal activity at the Mohns Ridge – Jan Mayen vent fields

Hydrothermal activity was detected at the Mohns Ridge in 2005. *Pedersen et al.* [2005] found two vent fields, named Trollveggen ("Troll Wall") and Soria Moria (Figure 2.2), near the southwestern end of the ridge. The two hydrothermal fields are located in the central part of the southernmost Mohns Ridge segment, not far from the JMFZ. Trollveggen is located about 5 km north of Soria Moria. Both are in relatively shallow waters of maximum 700 m water depth. Trollveggen is located along the eastern margin of a rift valley and consists of multiple high-temperature and diffuse flow venting sites. High-temperature venting up to 270°C (white smoker) occurs through talus deposits along the base of a normal fault at about 550 m water depth. Venting is observed at a length of about 1 km, and expresses local differences in intensity. Ten different major vent sites are present and each of them consists several chimney structures, reaching up to 10 m in height. These chimneys structures are composed of anhydrite, barite, sphalerite and pyrite [*Pedersen et al.*, 2010b]. The second vent field, Soria Moria, is located at the top of a volcanic ridge and high-temperature venting takes place at 700 m water depth. This volcanic ridge has grown on an older lava field made of massive lava flows and tubes among other, similar, volcanic ridges. Two different types of chimney compositions that are separated by a few hundred meters, are venting at Soria Moria. Several, up to 9 m tall sulfide chimneys vent high-temperature white smoker fluids and a more non-uniform type of chimneys constructions are venting fluids of lower temperature. These structures are composed of barite, silica, and secondarily pyrite, sphalerite and galena [*Pedersen et al.*, 2010b].

High-end endmember CO_2 concentrations in the high-temperature vent fluids as well as bubbles with high CO_2 contents exiting from the seafloor are characteristic for the JMVF. Thus, the JMVF are an optimal site to study natural CO_2 leakage and its geochemical and biological impact on the area.

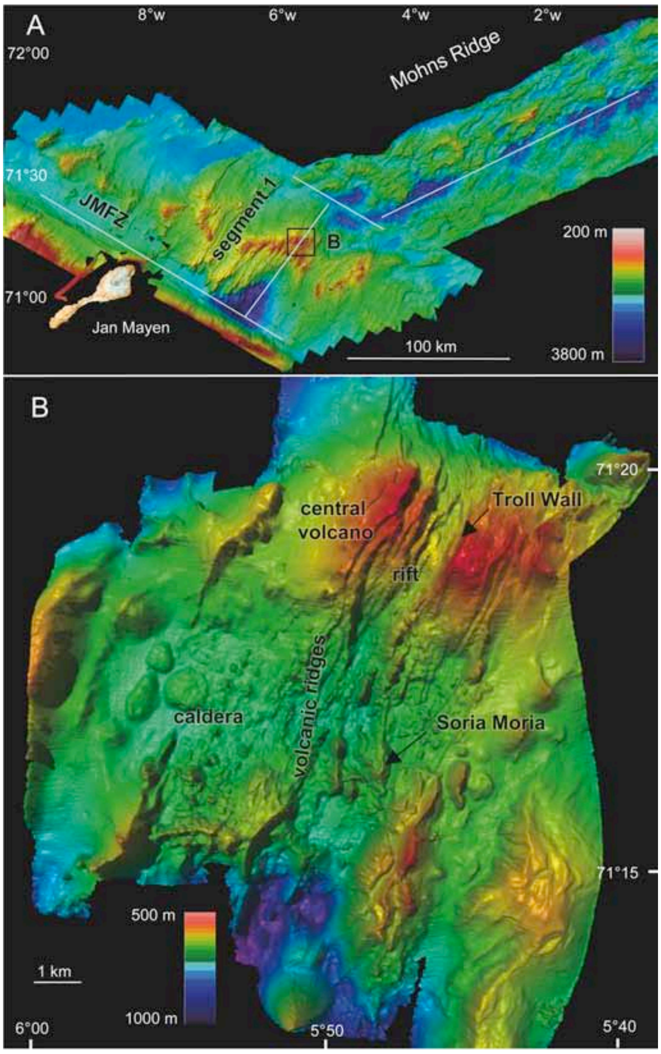

Figure 1: Bathymetric map from *Pedersen et al.* [2010b], showing location of the Jan Mayen Vent Fields (Troll Wall = Trollveggen and Soria Moria).

2 Cruise Logistics and Operations

2.1 Operational equipment

2.1.1 Multibeam Echosounder EM302

Bathymetric mapping was performed with an EM 302 multibeam echo sounder. The EM 302 uses a nominal sonar frequency of 30 kHz and is designed to do mapping from 10 m depths up to 7000 m. A transmit fan is split into individual sectors, each with active steering according to the vessel roll, pitch and heave, and each sounding is placed on a best fit on a line perpendicular to the survey line.

2.1.2 Singlebeam echo sounder EK60

The Simrad ER60 installed onboard the G.O. Sars is an echo sounder that can operate several echo sounder frequencies simultaneously ranging from 18 to 710 kHz. Data on this cruise were obtained by running an echo sounder frequency of 38 kHz.

2.1.3 Parametric Sub Bottom Profiler Topas PS 018

The G.O. Sars is equipped with a parametric sub bottom profiler Topas PS 018 operating at a primary frequency of 15 kHz (secondary 0.5 - 5 kHz) and a primary beam with of 3.5 degrees (secondary 5 degrees). It has a depth range of 30 to 10000 meters, a range resolution of less than 0.3 meters and a penetration capacity of over 150 meters.

2.1.4 ROV

During the cruise the ship was equipped with the ROV Bathysaurus II, which has a depth range of 4000 meters. The Bathysaurus II was equipped with the best manipulator arms available, state-of the-art positioning systems, and high-resolution digital camera for stills, and advanced digital video cameras. The ROV was equipped with an additional frame at its bottom and was thus able to transport more equipment.

2.1.4.1 Equipment of ROV

Temperature-probes: A temperature probe for the range of 150-500 °C was fixed to one of the manipulator arms to measure the vent fluid temperature in the active chimneys. An additional temperature probe for the range of 0-150 °C was used for diffusive flow in sediment or for measurements in microbial mats.

Water samplers: The water sampling system with two 1 litre titanium vent fluid samplers. Depending on the type of fluid sampled, these bottles were attached to a snorkel (high temperature vent fluids), a stick (sediment pore fluids), or a funnel (low temperature diffuse flow or gas bubbles sampling).

Gas samplers: Marv Lilley's four (~250 ml) gas tight samplers (GT) were used for gas sampling.

Biosyringe: A hydraulic sampling cylinder with a ~1 cm wide tube was used for sampling of biological mats.

Slurp gun: A slurp gun was used for collecting macro fauna.

Sampling box**:** An aluminum scuffle box was fixed to the frame of the ROV for collection of rock, sediment, and biology samples.

Push cores: Two pushcores in corresponding boxes were attached to the front of the ROV sampling box.

2.1.5 AUV

During the cruise the ship was equipped with the autonomous underwater vehicle (AUV) Hugin 1000 Hus (operated by FFI). The AUV hosted a high resolution interferometric synthetic aperture sonar (HISAS 1030) capable of providing high resolution images and detailed bathymety of the seafloor. The HISAS 1030 sonar mounted on the HUGIN AUV is an advanced interferometric sidescan sonar developed by Kongsberg Maritime. It consists of a transmitter and two vertically displaced receiver arrays configured as an interferometer. The HISAS is capable of synthetic aperture sonar (SAS) imaging, resulting in an obtainable image resolution better than 5x5 cm (depending on the conditions). High-resolution bathymetric maps are obtained by comparing the sidescan images formed at the two receiver arrays. The HISAS frequency range is approximately 60 to 120 kHz, with a bandwidth of 30-50kHz. In addition, the AUV was equipped with an EM 3002 multibeam echo sounder and with a black and white camera that allowed geo-referenced photo mosaicing.

2.1.6 CTD

For measurements of conductivity, temperature and depth (CTD) of the water column a Seabird 911plus with a SBE32 carousel with 12 Niskin bottles for water sampling, 5 L each, was used. Standard setup of the CTD is with SBE 4C conductivity sensor and SBE3plus temperature sensor.

2.1.7 Rock Dredging

A rock dredge was used for sampling the volcanic ridge.

2.2 Shipboard geochemical analysis and sample preparation

Selected dissolved gases, redox sensitive parameters and nutrients in vent fluids, water column and sediment pore water (e.g. H_2, CH_4, O_2, sulphide, alkalinity, pH, ammonium, NO_{tot}, PO_4, DIC) were measured onboard. In addition, samples for onshore analyses of other parameters (major and trace elements, stable isotopes, organic acids, nutrients) in fluids and solids (TIC, TOC, stable isotopes) were collected and preserved onboard.

2.2.1 Collection of pore water from sediment cores

Pore water sampling was carried out immediately after obtaining the push cores by using Rhizon samplers (Seeberg-Elverfeldt et al. 2005; Dickens et al. 2007) or by centrifuging (after microbial sampling) at intervals of 3 cm. Rhizon samplers, which use the vacuum produced by attached vacutainer tubes or syringes to extract the porewater, has recently been shown to be a more efficient method and to give higher resolution than other commonly used squeezer techniques such as Manheim Squeezer (Manheim 1966) and Reeburg Squeezer (Reeburg 1967). Rhizons are therefore more and more widely used.

2.2.2 Collection of gas bubbles

Gas bubbles leaking from the seafloor were collected by using a funnel connected to the Ti-major sampling bottles. Gas bubbles were collected as soon as a headspace in the funnel became clearly visible and the volume was big enough to fill the two 1 liter Ti-bottles. Depending on the number of gas bubble streams, the gas collection took up to one hour. During sampling, the gas was partly producing gas hydrates. To transfer the gas back into the gaseous phase and being able to sample it into the Ti-major sampling bottles, the ROV had to rise up. At about 80 m water depth, all gas hydrate was converted back into the gaseous phase and collected. These gas samples were then prepared for shipboard CH_4 and H_2 gas chromatography (SRI 8610C; description detectors below), and collected into gasbags for later on shore gas chromatography at UiB and into vacutainers for $\delta^{13}C_{CH4}$ analysis at the ETH Zürich.

2.2.3 Collection and analyses of dissolved gases (O_2, H_2, CH_4, higher hydrocarbons, He and H_2S)

Vent fluid: Dissolved gases in high-temperature vent fluids were collected with gas-tight fluid samplers. The total gas content in gas tight fluid samplers was extracted with a gas extraction line and collected for onshore analyses in the U.S.

CTD samples: Water column samples were collected with a CTD rosette package. For H_2 and CH_4 analyses 100 ml of each fluid sample were collected in a 140 ml syringe and added 40 ml helium gas. The fluid and gas were mixed well by shaking and left for at least 30 min at room temperature before the headspace gas in the syringe was analysed onboard by using a TOGA SRI 8610C gas chromatograph (GC) equipped with a highly sensitive He-pulsed discharge detector (PDD) for hydrogen analyses and with a flame ionization detector (FID) for methane analyses provided by the University of Washington (M. Lilley). Gas cylinders with 5.0 He (carrier gas, 2 x 50L), 5.0 H_2 (1 x 50L) and synthetic air (2 x 50L) were connected to the gas pipeline system in the gas central room on the ship (regulators onboard). Helium was additionally purified before entering the GC. The sampling and analytical precision, determined through replicate draws, was about 3% of the measured concentrations.

Immediately upon recovery of the CTD sampling package, air-free water samples were flushed through 24-inch-long sections of refrigeration grade Cu tubing with duplicate half-sections cold-weld sealed for later laboratory determinations of He concentrations at NOAA/PMEL Helium Isotope Laboratory in Newport, Or USA (Young and Lupton, 1983).

Dissolved O_2 concentrations were measured using a needle-type fiber-optic O_2-microsensor (O2-optode from PreSens, Germany). Measurement time was 1 minute.

Sediment push cores: For H_2 and CH_4 analyses 5 ml of sediment was collected with a 10 ml tip cut plastic syringe at intervals of 10 cm and added to a 140 ml syringe immediately after the cores were split. The syringe was then filled to 100ml with a 1.2 M NaCl solution with sodium azide (0.1%) and 40 ml helium, and the content was mixed by shaking and left for at least half an hour at room temperature before the headspace gas was analysed by using a GC as described above.

Concentrations of dissolved sulphide in pore water were analysed on-board by photometric methods by a 4-channels Quaatro Continuous Flow Analyzer (Seal Analytical) using the methylene blue method.

Dissolved O_2 concentrations were measured in extracted pore water using a needle-type fiber-optic O_2-microsensor (O2-optode from PreSens, Germany). Measurement time was 1 minute.

2.2.4 Collection and analyses of pH, alkalinity, nutrients, anions and cation samples

Aliquots of vent fluid, porewater and water column samples were analysed onboard for pH, alkalinity, nutrients, anions and cations.

Aliquots were first analysed for pH and then for alkalinity. The pH measurements were performed by using a Methrom 826 pH mobile pH meter. The samples were collected in 60 ml Nalgene bottles with coned caps. During sampling the bottles were overflowed with approximately three times the sample volume and filled completely to avoid air in the bottle. All samples were put in a water bath for half an hour prior to measure to ensure equal temperature conditions. The measurement of the pH was done in a closed system to avoid outgassing of CO_2. Calibration of the system was done daily, using Methrom disposable buffers (pH 4, 7 and 9). Two parallels were always analysed for the CTD samples while the ROV samples were analysed without parallels.

Alkalinity was measured through a dynamic titration by a Methrom 888 Titrando titrator and the Tiamo^{TM} software. The following settings were used during the titration: measuring point density 2, endpoint recognition 30 mV, minimum waiting time 5 seconds, maximum waiting time 36 seconds, minimum increment 2µm, maximum dosing rate 3 ml/min. Endpoint evaluation were performed with a minimum ERC of 20, the last endpoint was used for alkalinity calculation. The acid used for the titration was 0.1 N HCl and the sample volume was 100 ml for CTD samples and between 25 and 80 ml for ROV samples. The following formula was used for the calculation of the alkalinity

Alkalinity = volume acid * acid concentration * 1000 / sample volume

From GS11 CTD 9 and onwards two parallels were measured for the CTD samples. Due to large variation between parallels possibly due to interference from thruster and/or other instruments in the lab, the instrument was moved to another lab. From GS11 CTD 10 and onwards the variation between parallels decreased. Whether the variation between samples was due to disturbance from thruster and/or instruments from the lab or simply is due to variations within the sampling bottle is difficult to determine.

Concentrations of ammonium, nitrate/nitrite and phosphate in vent fluids, water column and pore water were analyzed on-board by photometric methods using a 4-channels Quaatro Continuous Flow Analyzer (Seal Analytical). For ammonium the indophenol methods were used, respectively. Nitrate was reduced to nitrite by a Cu-Cd reduction coil, and nitrite was then detected as a red complex. For phosphate the blue phosphor-molybdenum method was applied.

For onshore ion chromatography (IC) analyses at UiB of Cl, SO_4^{2-}, and Br^- aliquots of vent fluid, water column and pore water samples were filtered (0.2 µm) and collected on 15 and 30 ml sized plastic bottles and stored in the fridge at ~ 4°C.

For onshore inductively coupled plasma optical emission spectrometry (ICP-OES) analyses at UiB of alkali elements (Li, Na, K), alkali earth elements (Mg, Ca, Sr, Ba), and other elements (e.g. Mn, Fe, Si, Al, B, Ti, heavy metals) aliquots of vent fluid, water column and pore water samples were filtered (0.2 μm) and collected on 15-100 ml sized acid clean plastic bottles, acidified by adding ultra pure nitric acid to a final concentration of 3%, and stored in the fridge at ~ 4°C.

For onshore analyses of nitrate, nitrite and phosphor by using a continuous flow analyzer at UiB, aliquots of vent fluid, water column and pore water samples were filtered (0.2 μm) and collected on 15 and 30 ml sized amber plastic bottles and stored in the freezer at ~ 20°C. In addition, aliquots of ~1 ml were collected in 3 ml sized glass bottles and stored in the freezer at ~ 20°C for analyses of organic acids.

2.2.5 Collection of samples for stable isotopes

For stable heavy (Fe, Zn, Cr) isotope analyses at UiB selected vent fluid and pore water samples were filtered (0.2 μm) and collected on acid cleaned plastic containers, acidified by adding ultra pure nitric acid to a final concentration of 2.5%, and stored in the fridge at ~ 4°C.

Vent fluid and pore water aliquots as well as water column samples for background seawater concentrations were furthermore collected for analyses of stable sulphur isotope composition of sulphide and sulphate, for water isotope composition (H and O), for B isotope composition and for carbon isotope composition of DIC in Zürich and Pisa. Samples for H, O and B isotope analyses were untreated and stored in amber plastic bottles of 30 ml. For S stable isotope measurements, Cd-acetate was added to precipitate CdS and preserve the sample in amber plastic bottles. For DIC stable isotopes analyses, 0.2 to 1 ml filtered (0.2 μm) sample was injected into prepared (5 drops of melted phosphoric acid, flushed with He) vacutainers without having air contact. All samples, except for DIC which was stored at room temperature, were stored in the fridge at ~ 4°C.

2.2.6 Collection of solid materials

Sediment and chimney samples for analyses of total inorganic carbon (TIC), total carbon (TC), and the stable carbon isotopic composition ($\delta^{13}C_{TIC}$ and $\delta^{13}C_{TOC}$) were collected in organic sampling bags or wrapped in sterilized aluminum foil (400°C, 16 hours) and stored at

-80°C for later analyses in Zürich. All used instruments were cleaned beforehand with DCM.

In addition, samples of hydrothermal deposits were also collected for heavy stable isotope analyses.

3 Cruise Activities and Initial Results

3.1 Survey log GS 11

label	name	resp person	description	date/time	latitude	longitude	depth (m)
Topas-01	108-1	Rolf Pedersen	Start of line	2011-06-11 02:45	60°07.15`N	4°41.23`E	320
			End of line	2011-06-11 10:35	63°35.38`N	1°15.92`E	
CTD-01	108-2	Tamara Baumberger	Deployd	2011-06-13 12:40	65°35.68`N	0°49.48`W	3105
			Recovered	2011-06-13 14:30	65°35.68`N	0°49.48`W	3105
Topas-02	108-3	Rolf Pedersen	Start of line	2011-06-13 22:41	70°38.06`N	7°20.08`W	1500
			End of line	2011-06-14 06:32	70°50.86`N	9°07.77`W	
ROV-01	108-4	Several	Deployd	2011-06-14 17:00	71°17.85`N	5°46.42`W	525
			Recovered	2011-06-14 17:50	71°17.85`N	5°46.42`W	525
CTD-02	108-5	Tamara Baumberger	Deployd	2011-06-14 18:52	71°16.02`N	5°46.49`W	710
			Recovered	2011-06-14 19:34	71°16.02`N	5°46.49`W	710
EM-01	108-6	Rolf Pedersen	Start of line	2011-06-14 20:05	71°16.02`N	5°46.49`W	710
			End of line	2011-06-14 21:00	71°15.83`N	5°50.46`W	
AUV-1	108-7	Rolf Pedersen	Deployd	2011-06-14 21:18	71°17.06`N	5°50.48`W	772
			Recovered	2011-06-15 09:10	71°19.74`N	5°45.81`W	740
CTD-03	108-8	Tamara Baumberger	Deployd	2011-06-15 10:30	71°17.86`N	5°46.30`W	460
			Recovered	2011-06-15 11:00	71°17.86`N	5°46.30`W	460
ROV-02	108-9	Several	Deployd	2011-06-15 11:10	71°17.80`N	5°46.44`W	497
			Recovered	2011-06-15 16:32	71°17.80`N	5°46.44`W	497
CTD-04	108-10	Tamara Baumberger	Deployd	2011-06-15 16:40	71°17.86`N	5°46.30`W	454
			Recovered	2011-06-15 17:16	71°17.86`N	5°46.30`W	454
CTD-05	108-11	Tamara Baumberger	Deployd	2011-06-15 18:00	71°17.86`N	5°46.30`W	454
			Recovered	2011-06-15 18:29	71°17.86`N	5°46.30`W	454
CTD-06	108-12	Tamara Baumberger	Deployd	2011-06-15 18:40	71°17.86`N	5°46.30`W	454
			Recovered	2011-06-15 19:15	71°17.86`N	5°46.30`W	454
ROV-03	108-13	Several	Deployd	2011-06-15 19:45	71°17.84`N	5°46.41`W	528
			Recovered	2011-06-15 22:57	71°17.84`N	5°46.41`W	528
AUV-02	108-14	Rolf Pedersen	Deployd	2011-06-16 00:36	71°14.71`N	5°48.21`W	665
			Recovered	2011-06-16 11:30	71°16.09`N	5°51.85`W	718
ROV-04	108-15	Several	Deployd	2011-06-16 13:13	71°17.84`N	5°46.41`W	521
			Recovered	2011-06-16 16:45	71°17.84`N	5°46.41`W	521
ROV-05	108-16	Several	Deployd	2011-06-16 17:15	71°17.84`N	5°46.41`W	520
			Recovered	2011-06-16 23:10	71°17.84`N	5°46.41`W	520
MN-01	108-17	Bernt Rydland	Deployd	2011-06-16 23:10	71°17.84`N	5°46.41`W	530
			Recovered	2011-06-16 23:55	71°17.84`N	5°46.41`W	530
MN-02	108-18	Bernt Rydland	Deployd	2011-06-17 00:50	71°17.84`N	5°46.41`W	530
			Recovered	2011-06-17 01:43	71°17.84`N	5°46.41`W	530

DR-01	108-19	Rolf Pedersen	Deployd	2011-06-17 02:05	71°16.72`N	5°49.23`W	640
			Recovered	2011-06-17 03:07	71°16.70`N	5°48.85`W	
DR-02	108-20	Rolf Pedersen	Deployd	2011-06-17 03:22	71°17.09`N	5°44.38`W	682
			Recovered	2011-06-17 04:38	71°17.12`N	5°44.91`W	610
DR-03	108-21	Rolf Pedersen	Deployd	2011-06-17 05:14	71°17.02`N	5°44.30`W	710
			Recovered	2011-06-17 06:05	71°17.10`N	5°44.88`W	630
DR-04	108-22	Rolf Pedersen	Deployd	2011-06-17 06:32	71°16.72`N	5°49.23`W	725
			Recovered	2011-06-17 07:50	71°16.71`N	5°49.08`W	660
CTD-07	108-23	Tamara Baumberger	Deployd	2011-06-17 08:40	71°16.23`N	5°43.23`W	698
			Recovered	2011-06-17 09:05	71°16.23`N	5°43.23`W	698
CTD-08	108-24	Tamara Baumberger	Deployd	2011-06-17 09:16	71°16.23`N	5°43.23`W	698
			Recovered	2011-06-17 09:52	71°16.23`N	5°43.23`W	698
ROV-06	108-25	Several	Deployd	2011-06-17 13:07	71°17.93`N	5°46.78`W	593
			Recovered	2011-06-17 16:30	71°17.93`N	5°46.78`W	593
ROV-07	108-26	Several	Deployd	2011-06-17 19:39	71°17.82'N	5°46.47`W	585
			Recovered	2011-06-17 23:40	71°17.93`N	5°46.78`W	593
AUV-03	108-27	Rolf Pedersen	Deployd	2011-06-18 00:17	71°19.43`N	5°44.68`W	570
			Recovered	2011-06-18 11:05	71°19.18`N	5°44.11`W	540
ROV-08	108-28	Several	Deployd	2011-06-18 12:20	71°15.68`N	5°48.85`W	645
			Recovered	2011-06-18 17:20	71°15.68`N	5°48.85`W	645
MN-03	108-29	Bernt Rydland	Deployd	2011-06-18 17:45	71°16.23`N	5°43.23`W	698
			Recovered	2011-06-18 18:25	71°16.23`N	5°43.23`W	698
MN-04	108-30	Bernt Rydland	Deployd	2011-06-18 18:50	71°16.23`N	5°43.23`W	698
			Recovered	2011-06-18 19:40	71°16.23`N	5°43.23`W	698
ROV-09	108-31	Several	Deployd	2011-06-18 20:53	71°15.69`N	5°48.81`W	643
			Recovered	2011-06-18 23:20	71°15.69`N	5°48.81`W	643
EM-02	108-32	Rolf Pedersen	Start of line	2011-06-19 00:08	71°14.02`N	5°46.49`W	748
			End of line	2011-06-19 09:12	71°14.02`N	5°55.23`W	730
CTD-09	108-33	Tamara Baumberger	Deployd	2011-06-19 09:32	71°15.70`N	5°48.81`W	642
			Recovered	2011-06-19 10:09	71°15.70`N	5°48.81`W	642
ROV-10	108-34	Several	Deployd	2011-06-19 10:34	71°15.56`N	5°48.87`W	700
			Recovered	2011-06-19 13:40	71°15.56`N	5°48.87`W	700
EM-03	108-35	Rolf Pedersen	Start of line	2011-06-19 14:00	71°17.62`N	5°45.39`W	484
			End of line	2011-06-19 14:45	71°18.17`N	5°47.91`W	493
CTD-10	108-36	Tamara Baumberger	Deployd	2011-06-19 15:03	71°17.84`N	5°46.41`W	521
			Recovered	2011-06-19 15:40	71°17.84`N	5°46.41`W	521
ROV-11	108-37	Several	Deployd	2011-06-19 16:02	71°17.83`N	5°46.37`W	491
			Recovered	2011-06-19 19:10	71°17.83`N	5°46.37`W	491
CTD-11	108-38	Tamara Baumberger	Deployd	2011-06-19 19:37	71°17.15`N	6°14.19`W	601
			Recovered	2011-06-19 20:03	71°17.15`N	6°14.19`W	601
Topas-03	108-39	Rolf Pedersen	Start of line	2011-06-21 09:57	65°48.15`N	0°52.15`W	3277
			End of line	2011-06-22 14:15	60°27.53`N	4°16.18`E	310

3.2 Monitoring with multibeam and single beam echo sounder

Multiple echo sounder profiles were obtained during this cruise. Thereby gas bubbles being naturally released in the water column by the Jan Mayen vent fields were detected by the echo sounder systems. The detectable gas flares rose around 500 m from the seafloor. Additionally, high-resolution bathymetry was performed for detailed mapping of the Jan Mayen vent fields.

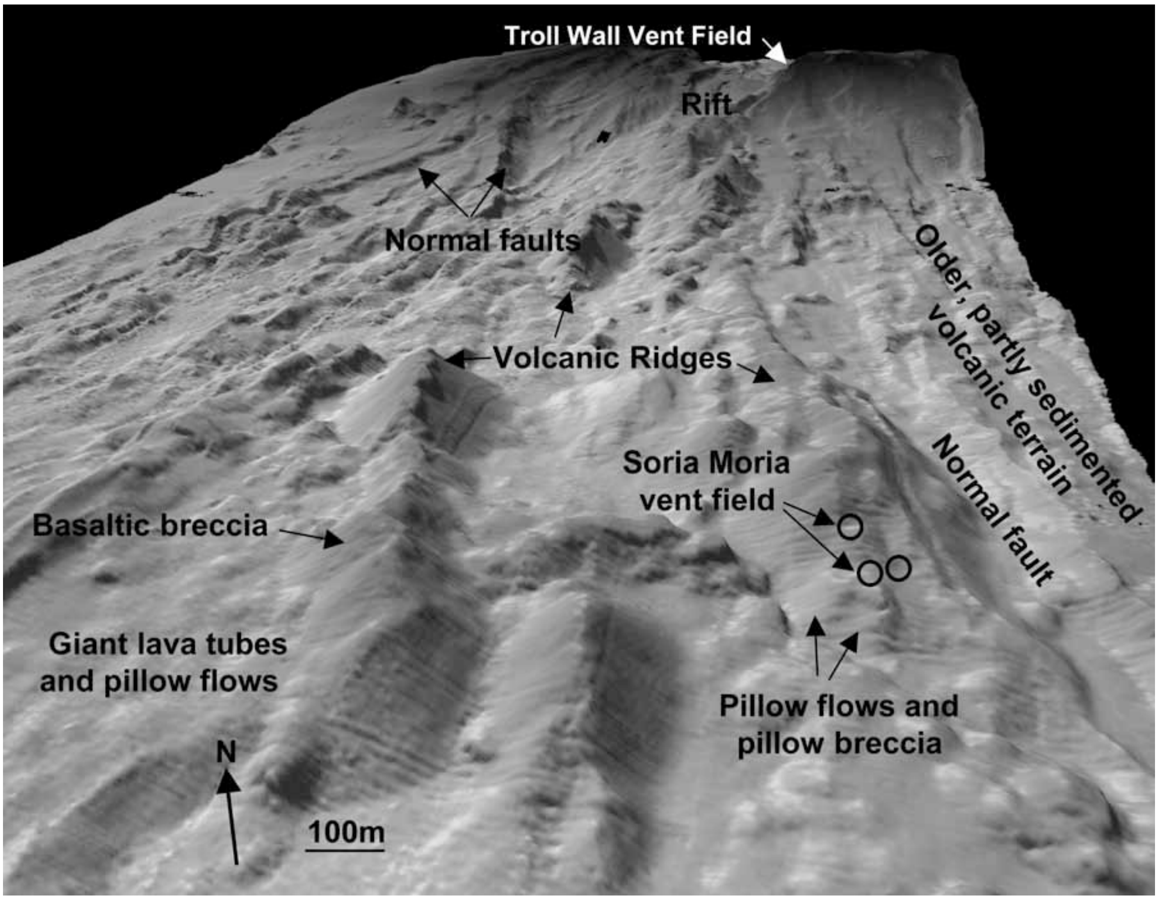

Figure 3: Multibeam bathymetry showing the volcanic terrain and the position of the vent fields (10 m grid).

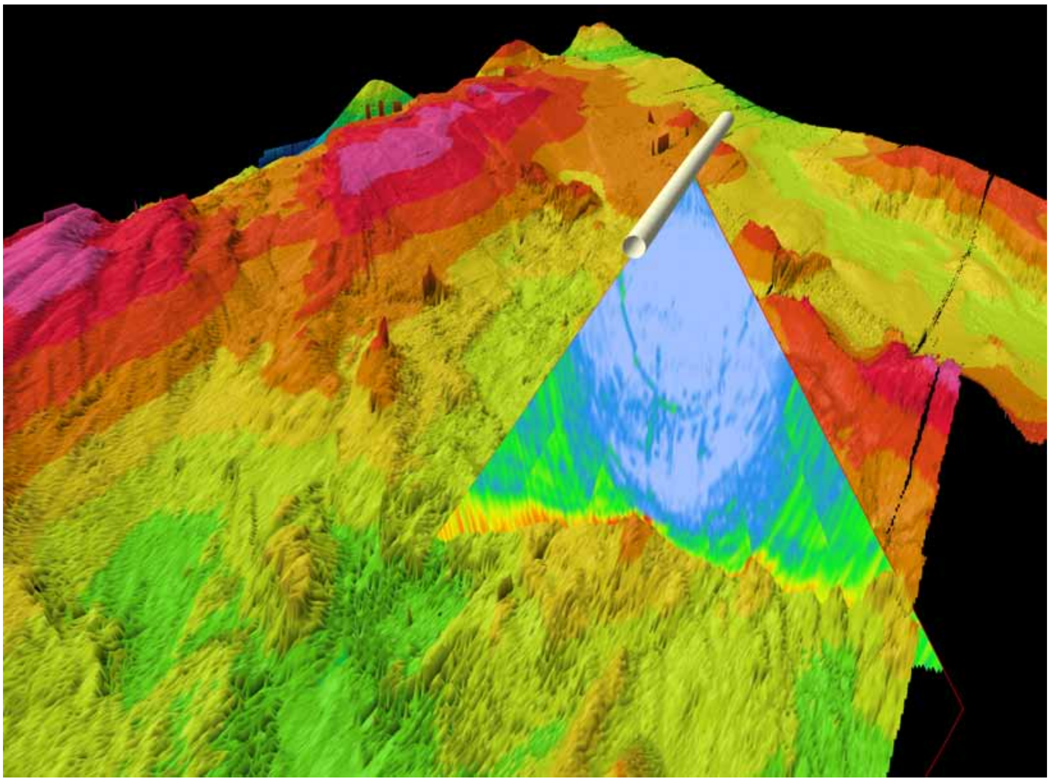

Figure 4: Detection of seabed gas-escape by multibeam echo sounder system (EM 302)

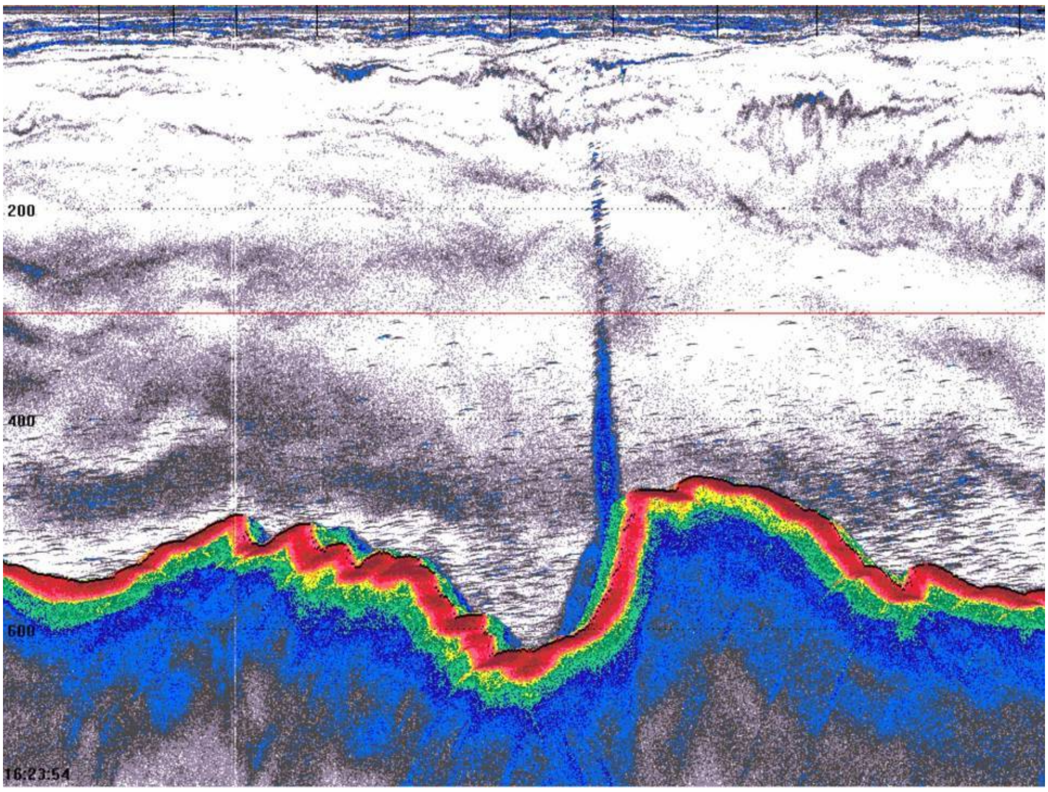

Figure 5: E-W echo sounder profile of a bubble plume above Trollveggen at 550 m water depth (Simrad ER60; 38 kHz). Single bubbles rising up towards the surface were observed.

3.3 AUV synthetic aperture sonar (SAS) and photographic imaging

Several successful AUV-dives were completed leading to 10 cm scale imaging of the seafloor with the high resolution synthetic aperture sonar (HiSAS). Thereby, the possibility to see chimney structures and their shadows are a highlight. In the areas, where chimney structures were identified, the images are slightly blurry, probably pointing to bubbles or fluids rising up. As the topography is very demanding, it is challenging to exclude all artifacts. Thus, more shore-based studies of the data set are needed. Additionally, sub-cm scale photographic imaging was performed with the AUV, followed by photo-mosaicing (shore-based).

Figure 6: AUV-based SAS-imaging showing the detection of fluid escape features (blue arrows) at the Soria Moria, Jan Mayen vent fields.

3.4 CTD operations

The primary objectives of the CTD operations were to conduct vertical cast above Trollveggen and Soria Moria to constrain the influence of focused and diffuse venting on the water column chemistry and on macro biology. A total of 11 casts were conducted during this cruise, whereas 1 was for operational calibration, 5 for biological investigations and 5 for geochemical analyses (2 Trollveggen, 1 Soria Moria, 1 cast 1.5 km north of Soria Moria and 1 cast in background seawater).

Table 1: Type of analysis for CTD water samples

Sample Type	**Abbreviation**	**Number of samples**	**Responsible**
Helium isotopes	^{3}He	24	Marvin Lilley, *UW*
Methane and hydrogen	CH_4, H_2	60	Tamara Baumberger, *ETHZ*
pH	pH	70	Hildegunn Almelid, *CGB*
Alkalinity	Alk	70	Ingeborg Økland, *CGB*
Oxygen	O_2	70	Benny Eickmann, *CGB*
Ammonium	NH_4^+	70	Ingunn Thorseth, *CGB*
Sulphide	H_2S	70	Ingunn Thorseth, *CGB*
Nutrients	Nut	70	Ingunn Thorseth, *CGB*
Anions, cations	Majors	70	Ingunn Thorseth, *CGB*
Macrobiology	Bio	6 depths	Bernt Rydland, *CGB*

Table 2: Distribution of collected CTD water samples

Cast	StaName	Date/Time (Norw)	3He	CH4, H2	pH	Alk	O	NH4+	H2S	Nut	Majors	Bio	Comment	Latitude	Longitude
1	11-02-CTD-01	13.06.11 / 12:40			10	10	10	10	10	10	10		for calibration	65°35.68' N	0°49.48'W
2	11-05-CTD-02	14.06.11 / 18:52		12	12	12	12	12	12	12	12		1.5 km N of SoMo	71°16.02`N	5°46.49`W
3	11-08-CTD-03	15.06.11 / 10:30	12	12	12	12	12	12	12	12	12		Trollveggen	71°17.86`N	5°46.30`W
4	11-10-CTD-04	15.06.11 / 16:40										3	Trollveggen	71°17.86`N	5°46.30`W
5	11-11-CTD-05	15.06.11 / 18:00										vol+	Trollveggen	71°17.86`N	5°46.30`W
6	11-12-CTD-06	15.06.11 / 18:40										vol+	Trollveggen	71°17.86`N	5°46.30`W
7	11-23-CTD-07	17.06.11 / 08:40										3	Reference Bio	71°16.23`N	5°43.23`W
8	11-24-CTD-08	17.06.11 / 09:16										vol+	Reference Bio	71°16.23`N	5°43.23`W
9	11-33-CTD-09	19.06.11 / 10:32	12	12	12	12	12	12	12	12	12		Soria Moria	71°15.70`N	5°48.81`W
10	11-36-CTD-10	19.06.11 / 15:03		12	12	12	12	12	12	12	12		Trollveggen	71°17.84`N	5°46.41`W
11	11-38-CTD-11	19.06.11 / 10:34		12	12	12	12	12	12	12	12		Background	71°17.15`N	6°14.19`W
		Total	**24**	**60**	**70**	**70**	**70**	**70**	**70**	**70**	**70**	**6**			

3.4.1 Preliminary results from CTD samples

Dissolved gases

Trollveggen: Two vertical casts (GS11-CTD-03 and GS11-CTD-10) for water and dissolved gas chemistry as well as 3 vertical casts (GS11-CTD-04, GS11-CTD-05 and GS11-CTD-06) for biological filtering of water masses were conducted above the Trollveggen vent field to investigate the corresponding hydrothermal plume. The water column profile taken above the steep Trollveggen at June 15th showed highly enriched dissolved CH_4 concentrations between the seafloor (deepest bottle at 440 m) and about 300 m water depth whereas H_2 concentrations were much lower, but still enriched. Between 300 and 150 m water depth, a highly enriched H_2 plume was present and CH_4 was back to lower concentrations apart from slight enrichments at the H_2 peak concentrations. The H_2 plume was split in two peak concentrations at 260 and 200 m water depth, respectively. That plume pattern in the water column points to two distinctive sources for CH_4 and H_2. Hydrogen is likely derived from the Trollveggen vent field or from a vent field not yet discovered. A likely source for the CH_4 enrichments is microbial production and diffusive fluid flow at the seafloor. At June 19th, CH_4 was still enriched close to the seafloor and H_2 concentrations were enhanced, compared to background values, at 340 m water depth but both were lower concentrated than 4 days earlier. Because it is not likely that both sources ceased in this time, changing water currents and very local dissolved gas releases can be a reason for the observed lower concentrations.

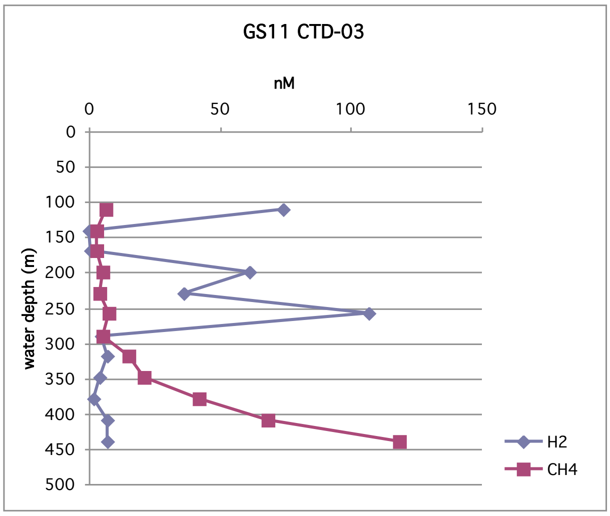

Figure 8: CTD cast GS11 CTD-03 above the Trollveggen vent field

Soria Moria: One cast was conducted over the Soria Moria vent fields. It showed a similar profile as at Trollveggen, but was lower in concentrations. The H_2 peaks were seen at 400 and 250 m and 100 and 200 water depth, respectively.

In the cast 1.5 km north of Soria Moria, high H_2 concentrations were measured at four distinct water depths. These depths were 690 m, 600 to 450 m, 350 to 200 m and 150 m. At the same depths, the CH_4 concentrations were considerably enriched over background. These water column anomalies were likely pointing to focused hydrothermal venting in the area. There was no clear evidence for diffuse fluid flow.

pH and alkalinity

The only CTD that show a clear anomaly in both pH and alkalinity is GS11 CTD 10 (Trollveggen), which shows a positive anomaly in the pH just below 300 m and a positive anomaly in alkalinity just above 300 m. The other samples either show some variation between parallel runs or do not show any anomalies.

3.5 ROV Dives

In total, 11 ROV dives were conducted during this cruise to the Jan Mayen vent fields. Dive GS11-ROV01 was interrupted after 20 minutes because of a loss of the video control. Dives GS11-ROV02 to GS11-ROV05 as well as GS11-ROV07 and GS11-ROV11 were conducted at the Trollveggen vent field. Within these dives, GS11-ROV04 was the only one, were pure gas was sampled. Dive GS11-ROV06 was conducted at Gallionella Garden. Dives GS11-ROV08 and GS11-ROV09 were both at the Soria Moria I vent field and GS11-ROV10 was performed at the Soria Moria II vent field to obtain high-temperature vent fluid samples from a chimney structure named Lilleputt. Due to technical problems during dive GS11-ROV08, it was not possible to obtain any gas-tight or Ti-bottle fluid samples and sampling was repeated in another dive.

Table 3: Summary ROV dives

Location		Depth	Samples				Comments
G.O.Sars start		Start Dive	Gas	Fluids	Solids	Biology	
GS11-ROV01	71°17.85`N 5°46.42`W	525					Dive starts 17:00; at bottom 17:28; dive ends 17:50; lost video control
GS11-ROV02	71°17.80`N 5°46.44`W	497	x	x		x	Trollveggen. Dive starts; 11:10 at bottom ; 11:25 Samples: 2 Gastights, 1 Major, 1 BS, soft mats with bulldozer, 1 slurge for animals (didn't work properly) ; dive ends: 16:32
GS11-ROV03	71°17.84`N 5°46.41`W	528		x	x	x	Trollveggen. Dive starts; 19:45 at bottom ; 20:19 Samples: 2 Major, 1 BS (yellow mat); put out 3 incubation experiments from Ida and 1 amphipod trap from Hans Tore, sediment sample; dive ends: 22.57
GS11-ROV04	71°17.84`N 5°46.41`W	521	x				Trollveggen. Dive starts; 13:13, at bottom; 13:46. Gas bobble collection at 562m 14:35, dive ends: 16:45. Surfaced due to gas samples. Sample: Bottle 1 (1l) totally in gas bag (size 2l). Bottle 2 400 ml in Syringes, the rest in gas bag (Size 1l).
GS11-ROV05	71°17.84`N 5°46.41`W	520	x	x	x	x	Trollveggen. Dive starts; 17:15, at bottom; 17:35 dive ends: 22:40 Samples: 4 gastights, 2 major fluid samples of diffuse flow above microbial mats and tower-like structure in valley, 1 BS, Scoop with macrobio and sediments
GS11-ROV06	71°17.93`N 5°46.78`W	593		x	x	x	Gallionella Garden. Dive starts 13:07;, at bottom; dive ends: 16:30. Samples: 1 BS, 1 major fluid sample from diffuse flow in sediments, 2 push cores, 1 scoop for macrobio.
GS11-ROV07	71°17.82'N 5°46.47`W		x	x		x	Trollveggen; Dive starts 19:39 ; at bottom; dive ends: 23:40 . Samples: 2 gas-tight samples, 2 Major samples, 1 BS, re-collecting the amphipod trap, 1 scoop for macrobio
GS11-ROV08	71°15.68`N 5°48.85`W	645			x	x	Soria Moria 1; Dive starts12:20 ; at bottom 12:56 ; dive ends: 17:20. Samples: 2 gastights from high-temp field (empty), 2 major fluid samples (empty), 1 BS from flange, big piece from flange, macrofauna with slurge.

GS11-ROV09	71°15.69`N 5°48.81`W	643			x		Soria Moria 1; Dive starts 20:53; at bottom 21:40 ; dive ends: 23:20. Samples: 1 pillow basalt, 1 sulfide chimney
GS11-ROV10	71°15.56`N 5°48.87`W	700	x	x		x	Soria Moria 2; Dive starts 10:34 ; at bottom ; dive ends: 13:40. Samples: 1 BS, 2 Major of high-T vent fluid, 2 gas tights
GS11-ROV11	71°17.83`N 5°46.37`W	491	x	x		x	Trollveggen; Dive starts: 16:02, at bottom:16:35, dive ends:, Samples: 2 Major, 1BS, 2 gas tights

3.5.1 Collection of gas tight samples

Marv Lilley

Five high temperature water samples were collected from Trollveggen and three from Soria Moria II. Multiple sub-samples were taken from each sample for shore laboratory analyses for gas concentrations and isotopic composition.

At Trollveggen, we collected a low temperature sample just above what appeared to be hydrate tubes. We also collected a sample just above the sediments in an area of active bubbling and a sample from within the sediments at this same site. Again, multiple sub-samples were taken of each for concentration and isotopic analyses.

We also collected gas from an actively bubbling area at Trollveggen and sealed several sub-samples. These gas samples will be subjected concentration and isotopic analyses.

Table 4: Gas tight samples

Gas Tight Samples from Jan Mayen (GO Sars 2011)

DIVE#	Sampler	VENT	Depth	Lat E -005	Lon N 071	Time (Local)	Temperature	Tot Gas Mmol/Kg
2	GT 6	Trollveggen	562	46.366800	17.888580	14:58	<150	34.09
2	GT 7	Trollveggen	562	46.366800	17.888580	14:59	<150	40.85
4	Bubbles	Trollveggen	562	46.442645	17.840261	14:29		
5	GT 16	TV 5/1	555	46.431627	17.837117	20:28	157	7.33
5	GT 10	TV 5/1	555	46.431627	17.837117	20:30	157	7.78
7	GT 7	TV 5/2	555	46.444517	17.835296	21:10	157	15.18
7	GT 9	Hydrate Tubes				21:52		7.92
10	GT 17	Soria Moria II	712	48.911123	17.557925	12:28	167	118.15
10	GT 11	Soria Moria II	712	48.911123	17.557925	12;29	167	152.87
10	GT 7	Soria Moria II	712	48.911123	17.557925	12:22	167	90.21
11	GT 16	TV above Seds	564	48.448260	17.842311	17:38		13.99
11	GT 12	TV in Seds	564	48.448260	17.842311	17:42	90	8.76

3.5.2 Collection and preliminary results from Ti major bottle samples

During ROV-01, ROV-08 and ROV-09 no fluids were collected due to technical and/or operational problems.

One high-temperature vent fluid sample was collected at Trollveggen (GS11 ROV-02) and two high-temperature vent fluid samples were obtained at Soria Moria II (Lilleputt; GS11 ROV-10). Both were split in aliquots to conduct water chemistry analysis, both shipboard and later in on shore laboratories (ion chromatography, ICP-OES, light and heavy (only Lilleputt) stable isotopes).

At Trollveggen (GS11-ROV-04), gas from an actively bubbling area was collected. During sample collection at the seafloor at 561 m water depth, gas hydrate was formed in the sample funnel (figure 6). To convert the hydrate back in a gas phase, the ROV had to rise for pressure release. At about 150 m water depth, big bubbles start to build. Most of the gas hydrate finally melted at 82 m water depth. The melting process looked like a flame.

One aliquot was measured shipboard for H_2 and CH_4 concentrations. Other aliquots will be analysed onshore for concentrations and isotopic composition. Preliminary results of the gas composition measured shipboard by gas chromatography are 6 % CH_4 and 0.3 % H_2.

Figure 9: Gas sampling and hydrate formation at Trollveggen

At Trollveggen several low temperature samples were obtained (GS11 ROV-03, GS11 ROV-05, GS11-ROV-07, GS11 ROV-11). Two samples were collected just above the sediment in an area of active bubbling (GS11 ROV-07-1 and GS11 ROV11-1) and two samples were obtained from within the sediments at the same site located in the valley (GS11 ROV-07-2 and GS11 ROV11-2). In addition, two samples were taken above bacterial mats in the wall. One sample was collected on the upper part of the wall (GS11 ROV-03-2) and one further down (GS11 ROV-03-1). Low-temperature sample were also taken above bacterial mats in the valley (GS11 ROV-05-1) as well as above a slightly more focused diffuse flow close to the bacterial mat site (GS11 ROV-05-2). All samples were analysed shipboard for dissolved gases and water chemistry. The highest CH_4 concentration was measured in the actively bubbly sediment area (GS11 ROV-07-2). In addition, aliquots for on shore stable isotope analysis were collected.

At Gallionella Garden (GS11 ROV-06), low temperature fluids were sampled in reddish coloured sediment (ironoxides and ironhydroxides). The dissolved gas content in this sample was around 100 nM for both CH_4 and H_2.

Of the ROV samples GS11 ROV 10-1 has the lowest pH (4.165), for this sample it was not possible to measure the alkalinity. This sample was not analysed for shipboard dissolved gases.

Table 5: Sample log and distribution of Ti major bottle samples

Dive	Sample name	Date	Total volume (ml)	CH4, H2	S,O,H, B iso	DIC iso	Sal	pH	Alk	O	NH4+	H2S	Nut	Major	Heavy Stable Iso	Micro Bio	Temperature °C	Comment	Depth (m)	Latitude	Longitude
2	GS11 ROV 2-Major 1	15.06.11	444		x	x	x	x	x	x	x	x	x	x			< 150°C	Trollveggen	562	71°17.888580 N	5°46.366800 W
3	GS11 ROV 3-Major 1	15.06.11	446	x	x	x		x	x	x	x	x	x	x				TV, above micr mat, upper wall			
3	GS11 ROV 3-Major 2	15.06.11	310	x	x	x		x	x	x	x	x	x	x				TV, above micr mat, lower wall			
4	GS11 ROV 4-Major 2	16.06.11	2000	x														Gas Bubbles	562	71°17.839162 N	5°46.443303 W
5	GS11 ROV 5-Major 1	16.06.11	842	x	x	x	x	x	x	x	x	x	x	x				TV, above bac mat	559	71°17.839780 N	5°46.433135 W
5	GS11 ROV 5-Major 2	16.06.11	490	x	x	x	x	x	x	x	x	x	x	x				TV, above bac mat	558	71°17.839488 N	5°46.430006 W
6	GS11 ROV 6-Major 1	17.06.11													x		3-4°C	Gallionella Garden, in seds	615	71°17.993347 N	5°46.869551 W
6	GS11 ROV 6-Major 2	17.06.11	781	x	x	x	x	x	x	x	x	x	x	x			3-4°C	Gallionella Garden, in seds	615	71°17.993347 N	5°46.869551 W
7	GS11 ROV 7-Major 1	17.06.11	582	x	x	x		x	x	x	x	x	x	x				TV, above seds			
7	GS11 ROV 7-Major 2	17.06.11	474	x	x	x		x	x	x	x	x	x	x				TV, in seds, fizzy sample			
10	GS11 ROV 10-Major 1	19.06.11													x		167°C	Soria Moria II, Lilleputt	712	71°17.557925 N	5°48.911123 W
10	GS11 ROV 10-Major 2	19.06.11	937		x	x	x	x	x	x	x	x	x	x		x	167°C	Soria Moria II, Lilleputt	712	71°17.557925 N	5°48.911123 W
11	GS11 ROV 11-Major 1	19.06.11	906	x	x	x		x	x	x	x	x	x	x		x		TV, above Seds	564	71°17.842311 N	5°48.448260 W
11	GS11 ROV 11-Major 2	19.06.11	800	x	x	x		x	x	x	x	x	x	x		x	90°C	TV, in Seds	564	71°17.842311 N	5°48.448260 W

3.6 Rock dredging

Three successful dredges were performed during the Jan Mayen cruise in 2011. They were located east and west of the vent field areas. The collected rocks were not investigated during the cruise, but packed immediately after recovery and later shipped to UiB.

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