Mareano Chemistry Programme

Deep-sea Sediment Sampling and Analytical Methodology at the Arctic Mid-Ocean Ridge System

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Figure 1: Sediment core sampling with an ROV-operated push corer system.

Contents

1 Introduction 5

2 Sample equipment and sample collection 5

2.1 Remotely Operated Vehicle (ROV) 7

2.1.1 Push corer chemical sampling 7

2.1.2 Blade corer chemical sampling 10

3 Analyses 10

4 Reporting of results 11

5 References 12

Overview of Figures/ Tables

Figure 1: Sediment core sampling with an ROV-operated push corer system. 1
Figure 2: Chemistry Sampling equipment on the Norwegian shelf.. 6
Figure 3: Chemistry sampling equipment in the deep sea. 6
Figure 4: ROV PC sampling procedure with Ægir 6000.. 8
Figure 5: PC sample handling. 9
Figure 6: ROV BL chemical sampling 10

Abbreviations

Abbreviation	Full term
GRTS	Generalized Random Tessellation Stratified
AMOR	Arctic Mid-Ocean Ridge
CECs	Contaminants of Emerging Concern
BC	Box corer
MC	Multicorer
PC	Push corer
BL	Blade corer
ROV	Remotely operated vehicle
TMS	Tethered Management system
OD	Outer Diameter
ID	Inner Diameter
L	length
SFO	Seabed Field Observer
XRI	X-Ray Imaging
TC	Total Carbon
TOC	Total Organic Carbon
TS	Total Sulfur
MICADAS	Mini Carbon Dating System
AWI	Alfred Wegener Institute

1 Introduction

As part of the Mareano Chemistry programme, the Geological Survey of Norway (NGU) and the Institute of Marine Research (IMR) conduct sampling of seabed sediments during annual sampling campaigns, collecting bathymetric, biological, geological and chemical data. Since 2005 Mareano has primarily operated on the Norwegian continental shelf and slope with a typical depth range of 100-2000 m. After the completion of acoustic surveys in 2019, Mareano has been responsible for sampling and follow up surveys in deeper waters of the Norwegian sea (average depth: 2744 m, min 408 m, max 5569 m at Molloy Deep) at and near the Arctic Mid-Ocean Ridge (AMOR). Samples are analysed for various physical parameters, inorganic contaminants (NGU) as well as organic contaminants, including contaminants of emerging concern (CECs), microplastics and radioactive nuclides (IMR).

This document is intended as a supplement to the Mareano Chemistry Programme Method Document and describes the sampling strategies and procedures adapted for deep-sea sediments, as well as analytical approaches specific to deep-sea studies. Deep-sea sampling differs from sampling on the continental shelf: it is considerably more time-consuming due to the greater water depths, while the different sedimentary environment requires adapted sampling procedures.

Method descriptions for typical sampling and analyses on continental shelves are presented in detail in the Mareano Chemistry Method Document available on the Mareano website:

Methods document for the Chemistry Program

2 Sample equipment and sample collection

Sampling sites, referred to as full stations, are selected using detailed bathymetric and backscatter maps obtained from multibeam echo sounders, along with a statistical Generalized Random Tessellation Stratified (GRTS) sampling design. Generally, for every 1000 km^2, two full stations are collected for geology and biology. On full stations with soft sediment, cores are also retrieved for analysis of seabed chemistry. The sampling density for chemistry core collection is 1 station for every 2000 km^2. For chemical sampling purposes, the focus is on sites with fine-grained sediments as these are assumed to represent stable sedimentation environments. The most suitable cores used for full analysis are chosen post-cruise, based on the sedimentary environment on-site and the sample quality. The general procedures for sampling, sample handling and equipment used in the Mareano Chemistry Programme are described in the Mareano Chemistry Programme Method Document. This chapter focuses on equipment and procedures specific to chemical sampling in deep-sea areas. On the Norwegian shelf, surface sediments are collected using a box corer (BC) for the purpose of CECs analyses, whereas whole-core samples are collected with a multicorer (MC) at full stations (Figure 2). In the deep sea, these vessel-based gears are replaced by ROV-operated gears (Figure 3), push corer (PC) and bladecorer (BL), as described in section 2.1.

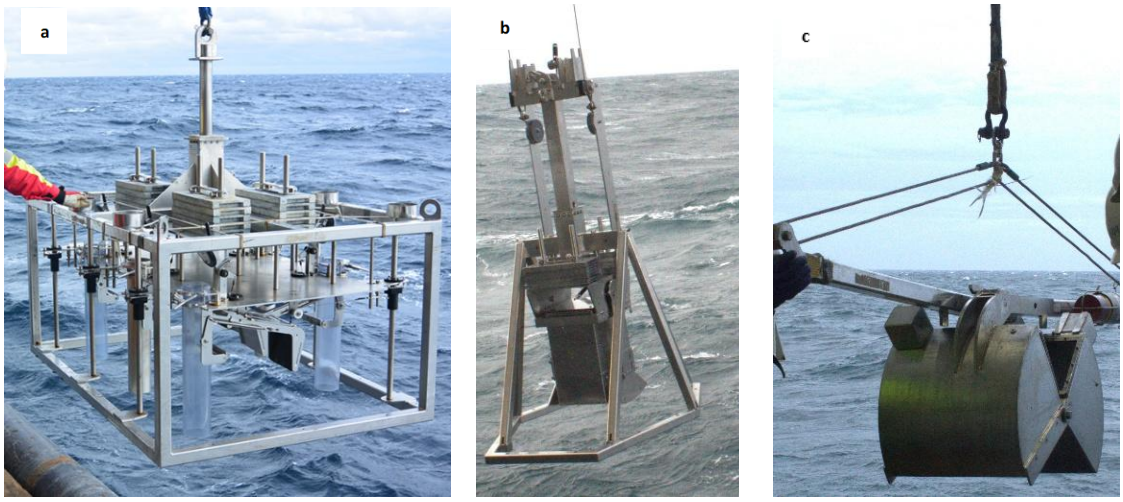


Figure 2: Chemistry Sampling equipment on the Norwegian shelf. a) Loaded Multicorer (MC) containing 4 PVC tubes and 2 steel tubes to retrieve whole-core sediment samples at full-stations. b) Box-corer (BC) used to retrieve surface sediment samples for CEC analyses at selected stations. It is also used in case the multicorer cannot be deployed in unsuitable weather conditions. c) Van Veen Grab used to replace MC in unfavourable weather conditions or coarse sediments.

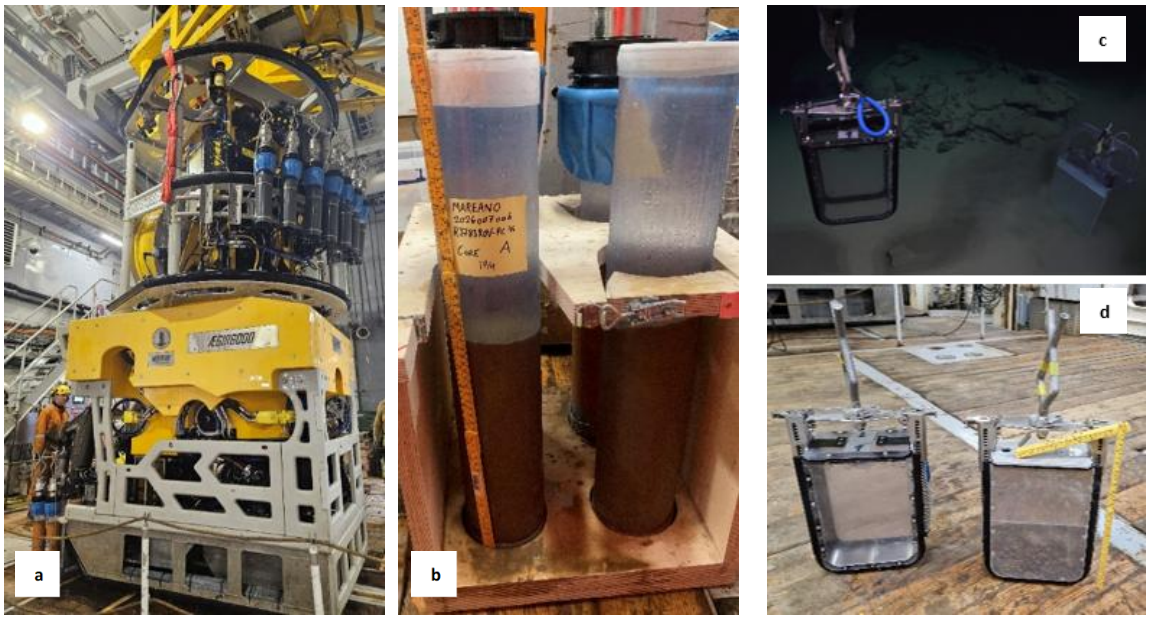


Figure 3: Chemistry sampling equipment in the deep sea. a) ROV Ægir 6000 used for all sampling in the deep sea. Chemistry push corers (PC) are attached to the Tethered Management System (TMS) on the top right of the image. The two push corers on the bottom left are used for qualitative sediment descriptions. b) Examples of 2 whole-core PVC push corers retrieved for chemical analyses. c) Bladecorer (BL) filmed during sampling of the seabed. d) Example of BL retrieved for analyses of CECs.

2.1 Remotely Operated Vehicle (ROV)

Typical Mareano cruises on the Norwegian shelf use a towed camera system (Chimaera), or an ROV for filming. At the deep-sea survey sites these are replaced by the ROV Ægir 6000 and ROV-operated gears (BL and PCs) are used for chemistry sampling. Vessel-based gears are taken along as backup. For methodology on vessel-based gears and more detailed sampling descriptions see:

Methods document for the Chemistry Program

ROV Ægir 6000 is equipped with the following gear for chemical sampling:

- 2 aluminium PCs mounted on the TMS – OD=110mm, ID =106mm, L=600mm
- 6 PVC PCs mounted on the TMS - OD=110mm, ID =100mm, L=600mm
- 2 BL with aluminium plates, 32 cm high, 25 cm long and 10 cm wide

Additionally, smaller aluminium and PVC tubes are taken along as backup. These yielded too little sample material in the first deep-sea cruise (2025007011) and were thus replaced with larger PCs.

2.1.1 Push corer chemical sampling

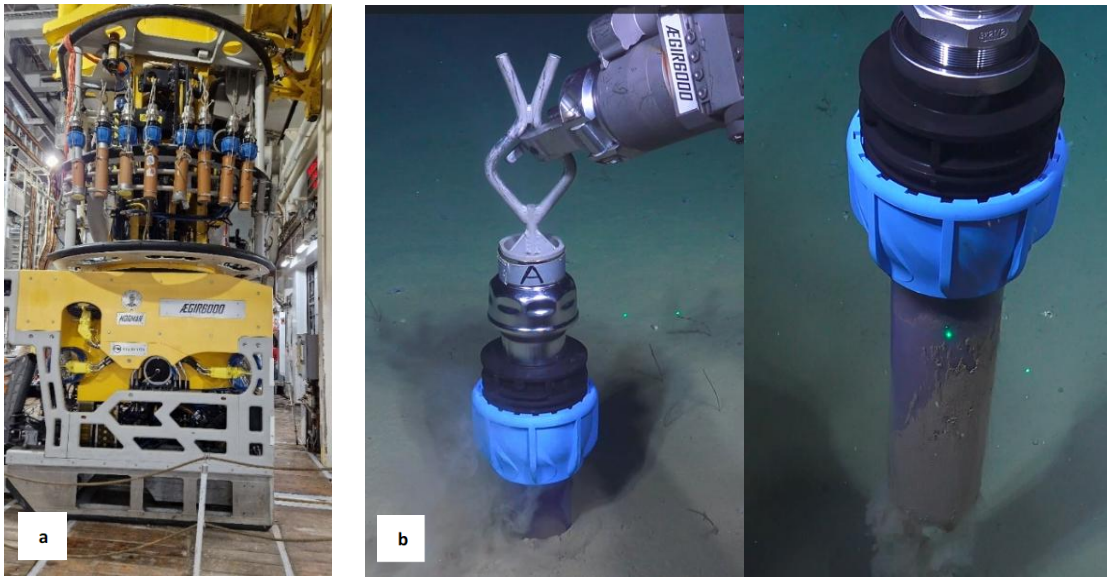
At each full station, a minimum of seven push corers (PC) are collected one at a time, while being filmed (see Figure 5). During sampling, the manipulator arm of the ROV slowly pushes the PC vertically into the seabed, capturing the sediment column retained by suction. The PC is then placed into its casing, and the next PC is collected. During sampling, the coordinates, labels and running Event IDs of each individual PC is recorded on the SFO (Seabed Field Observer) system. Once the ROV is up on deck, the 7 cores are stabilised in a customized wooden box (see Figure 5). Before each core is assigned their label, all cores are retrieved from their casing and closed both on the top and bottom to be measured. Samples are quality-checked by ensuring the sediments are undisturbed, intact and have a water column filled to the brim of the tube. At each full station, 3 PVC and 1 aluminium core need to be approved. The quality control options for aluminium cores on deck are limited and their degree of being undisturbed and intact can only be assumed by association with the PVC cores.

The sediment depths are recorded on a printed deck log form, and cores are divided into their categories (Table 1). Scaled and labelled pictures are taken and all cores, apart for core A and B are sealed and stored cooled and upright, ensuring a full water column to avoid disturbances during handling.

The sub-sampling strategy for the Norwegian Sea deep sea is slicing the cores into 0.5 cm slices in the top 10 cm of the cores and 1 cm thick slices in the rest of the core. This is different from the sub-sampling for the Norwegian shelf, where the sediment core is sliced into 1 cm intervals throughout. Pictures of undisturbed surface of Core A are taken, whereafter it is sliced with plastic slicers as described above. While slicing, structural and sedimentary changes are recorded in the deck log form as well as ArcGIS Survey123 on an iPad. Samples are labelled and stored in Ziplock bags and are frozen at approximately -20 °°C. Upon arrival at NGU, these are analysed for inorganic components and sedimentary characteristics after being freeze-dried. See Table 1 for the application of each core.

Undisturbed surface pictures of Core B are taken, whereafter it is sliced with metal slicers according to the same subsampling strategy. Samples are labelled and stored in aluminium foil and frozen at -20 °°C. Upon arrival at IMR, these are analysed for organic contaminants after being air-dried.

The sealed remaining cores (C, D, E/F and G) will be used for XRI (core C), radioactive components (core D), microplastic analyses (core E and F) and as a reserve (core G).



c

Platform	Survey123 class	Equipment	Abbreviation
Ægir 6000	Push core	Push core	ROV-PC
	ROV-sediment sampling	Scoop	ROV-SC
		Frankenscoop	ROV-FS
		Spade	ROV-SH
		Net	ROV-NE
	ROV-arm	Claw/Arm	ROV-CL
	Blade corer	Blade corer	ROV-BL
From the vessel	Grab	Van Veen Grab	GR
	Multicorer	Multicorer	MC
	Boxcorer	Boxcorer	BC
	Gravity corer	Gravity corer	GC

Labelling

R-station →	Equipment →	Event/Equipment nr. →	Sample ID
R3222	Grab	43	R3222GR43
R3333	Multicorer	09	R3333MC09
R3444	Push core	123	R3444ROV-PC123

Figure 4: ROV PC sampling procedure with Ægir 6000. a) 8 PCs within their brown casing attached to a TMS. 7 PCs will be collected for analyses. b) PC sampling on the seabed is recorded. c) Labelling scheme and abbreviations for different equipment types. Cores are labelled as follows: Cruise number, Sample ID, Core label (A-G), NGU number. The Sample ID is composed of the following: R-station, Equipment followed by its running Event number.

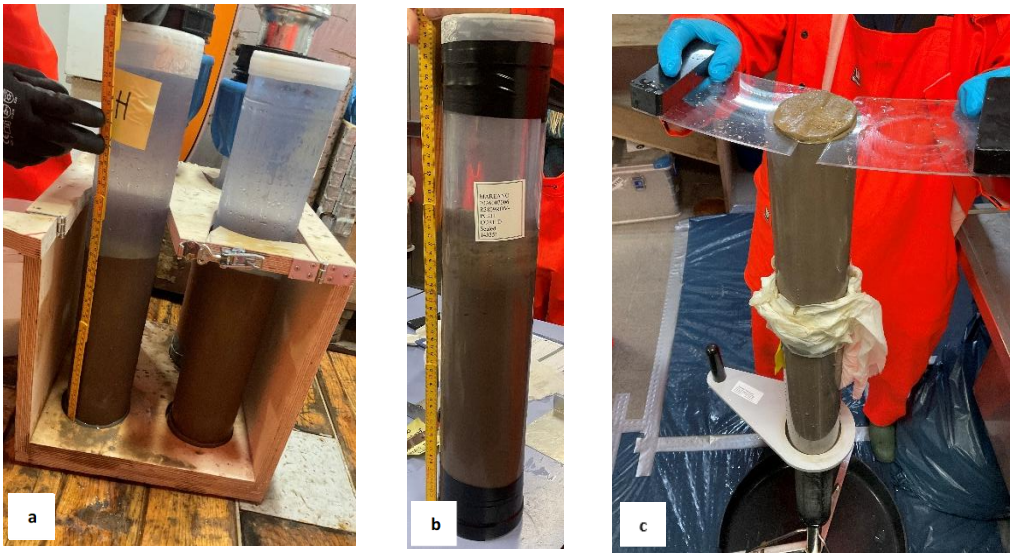


Figure 5: PC sample handling. a) Cores are closed, measured and quality assured before given a label. Note: Label H corresponds to the ROV label not the final chemistry label. b) Sealed core to be stored cooled and upright at NGU. c) Core A sliced into 0.5 cm intervals with a plastic slicer until 10 cm, whereafter it is sliced into 1 cm intervals

Table 1: Labelling of sediment cores according to application and selection criteria. Table has been adapted from the continental shelf document to fit in accordance with deep-sea sampling procedures and shows similarities.

Labelling	Selection Criteria	Tube Material	Application	Pretreatment	Owner
Core A	Longest core	PVC	Inorganic chemistry: Inorganic contaminants, sediment characteristics (grain size, ^{210}Pb, ^{137}Cs, ^{14}C)	Sliced on board to 0.5 cm intervals until 10 cm, whereafter it is sliced to 1 cm intervals. Frozen at -20 ˚C. Freeze-dried on arrival at the laboratory	NGU
Core B	Second-longest core	PVC	Hydrocarbons and persistent organic pollutants	Sliced on board as above and frozen at -20 ˚C. Air-dried on arrival at the laboratory	IMR
Core C		PVC	XRI	Tubes are sealed and stored upright, with water column filled to the brim.	NGU
Core D	2nd Shortest Core	PVC	Radioactive components	This core is usually not used	NGU/IMR
Core E		Aluminium	Microplastic analysis	Sealed and stored upright	NGU/IMR
Core F		Aluminium	Microplastic analysis	Sealed and stored upright	NGU/IMR
Core G	Shortest core	PVC	Extra core for storage	Sealed and stored upright	NGU

2.1.2 Blade corer chemical sampling

Sediment samples for the analysis of CECs are taken with blade corers (BL) equipped with metal side panels. The side panels consist of two plates each, a top and a bottom half. The middle line between those plates indicates the maximum desired sampling depth. This is to retain an undisturbed sediment surface when removing the top plate on deck for sub-sampling. To obtain enough sample material, 2 BLs are collected at selected full stations while being filmed (See figure 6). After receiving the BL onboard, these are taken to the side on deck unopened until the chemist is available to collect the sample. Other personnel on deck are asked to keep away (as far as the operation on deck allows) while the chemist collects the samples. To retrieve the sample, the upper plate of the side panel is removed, and the surface is inspected for disturbances. Further retrieval of the samples and sub-sampling are performed in accordance with the procedure for box corer samples described in Method document available on the Mareano website:

Methods document for the Chemistry Program

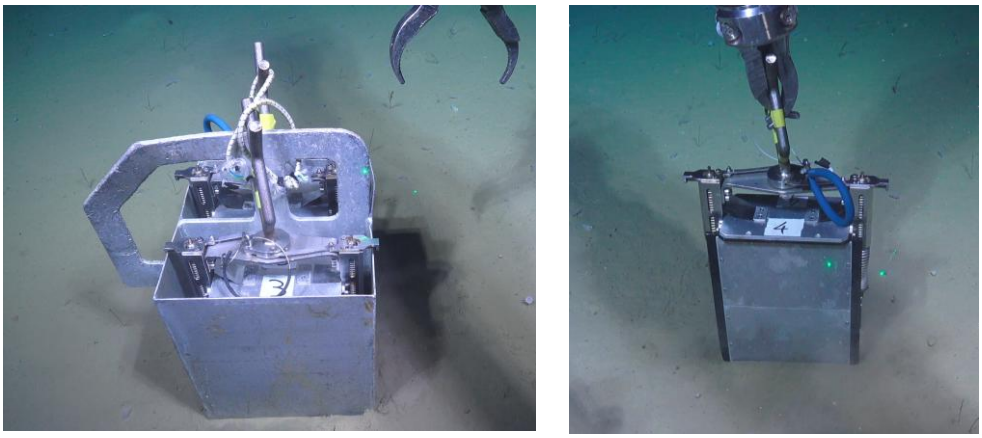


Figure 6: ROV BL chemical sampling

3 Analyses

Upon arrival at the respective laboratories (NGU/ IMR); all samples are either air or freeze-dried. As mentioned previously, in general, for every 1000 km^2, two full stations are selected for biological, geological and chemical sampling. Of these two full-stations, one station is chosen for whole core chemical analysis whereas the other is analysed for its surface sediment (0-0.5 cm) only. For the whole-core chemical analyses appropriate depth intervals are chosen and analysed.

The most suitable stations are chosen for whole-core analyses based on evaluation including, but not limited to XRI images, backscatter, bathymetry, sediment type and sedimentary environments.

The Analyses package for the deep-sea follows the same procedure and standard package as MARENO analyses on the continental shelf. The only additional analysis on deep-sea sediments samples includes ^{14}C dating of planktonic foraminifera. For more detailed information on the standard Mareano analyses packages, see Methods document for the Chemistry Program.

The responsibilities for carrying out the analyses on the samples of seabed sediments are divided between NGU and IMR as follows:

Analyses performed or commissioned by NGU:

- XRI scans
- Freeze drying: Moisture content
- Grain size distribution
- Inorganic elements: - Major and trace elements, including inorganic contaminants: As, Cd, Cr, Cu, Hg, Ni, Pb, Zn
- Total Carbon content (TC), Total Organic Carbon (TOC), Total Sulphur (TS)
- Dating of sediments: ^{210}Pb and ^{137}Cs. Commissioned by NGU from the Gamma Dating Centre (GDC) at the University of Copenhagen.
- ^{14}C dating of planktonic foraminifera. Commissioned by NGU, analyses are done by MICADAS (Mini Carbon Dating System) at the Alfred Wegener Institute (AWI) in Bremerhaven.
- Microplastic analyses: Joint by NGU and IMR. Sub-sampling is performed at NGU, whereas analyses are performed by IMR.

Analyses performed or commissioned by IMR:

- Hydrocarbons: polycyclic aromatic hydrocarbons (PAH) and total hydrocarbon content (THC)
- Brominated Flame retardants (PBDE)
- Chlorinated pollutants (PCB and pesticides)
- CECs (PFAS, alkylphenols and alkylphenol ethoxylates, bisphenol A (BPA), dechloranes, organophosphorus flame retardants (PFR), chlorinated paraffins and siloxanes). The four latter groups of CECs are commissioned by IMR from NILU
- Microplastic analyses

4 Reporting of results

Mareano is a national program for mapping the seabed on the Norwegian continental shelf, initiated in 2005. The first sediment samples were collected in 2006. Results of measurements of sediment characteristics and inorganic contaminants (NGU) and of organic contaminants (IMR) from previous years are reported at www.mareano.no/resultater/geokjemirapporter . The results are also available in the form of maps at Mareano kartklient and as a downloadable data file (Mareano's chemistry database for Norwegian offshore areas, MarChem) at MarChem

Cruise reports from Mareanos first two cruises to the Arctic-Mid-Ocean Ridge (2025007011 and 2026007006) can be found here:

https://www.hi.no/en/hi/nettrapporter/toktrapport-en-2025-11

https://www.hi.no/en/hi/nettrapporter/toktrapport-en-2026-17

5 References

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