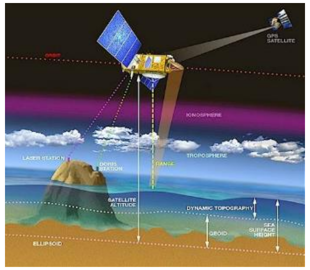
Rapport: Havbunnsmineraler - Testinfrastruktur

Vedlegg C

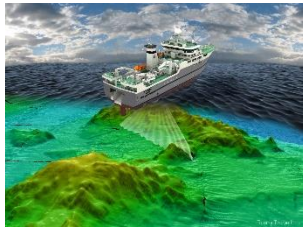
- Eksisterende infrastruktur Norge
- Planlagt infrastruktur Norge
- Eksisterende infrastruktur Europa
- Mer detaljer om prosjekter og infrastruktur i Europa
- Mer detaljer om prosjekter og infrastruktur i Japan

Eksisterende infrastruktur Norge

Norwegian Ocean Observation Laboratory



Remote Sensing

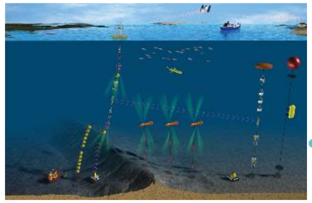


Research Vessels

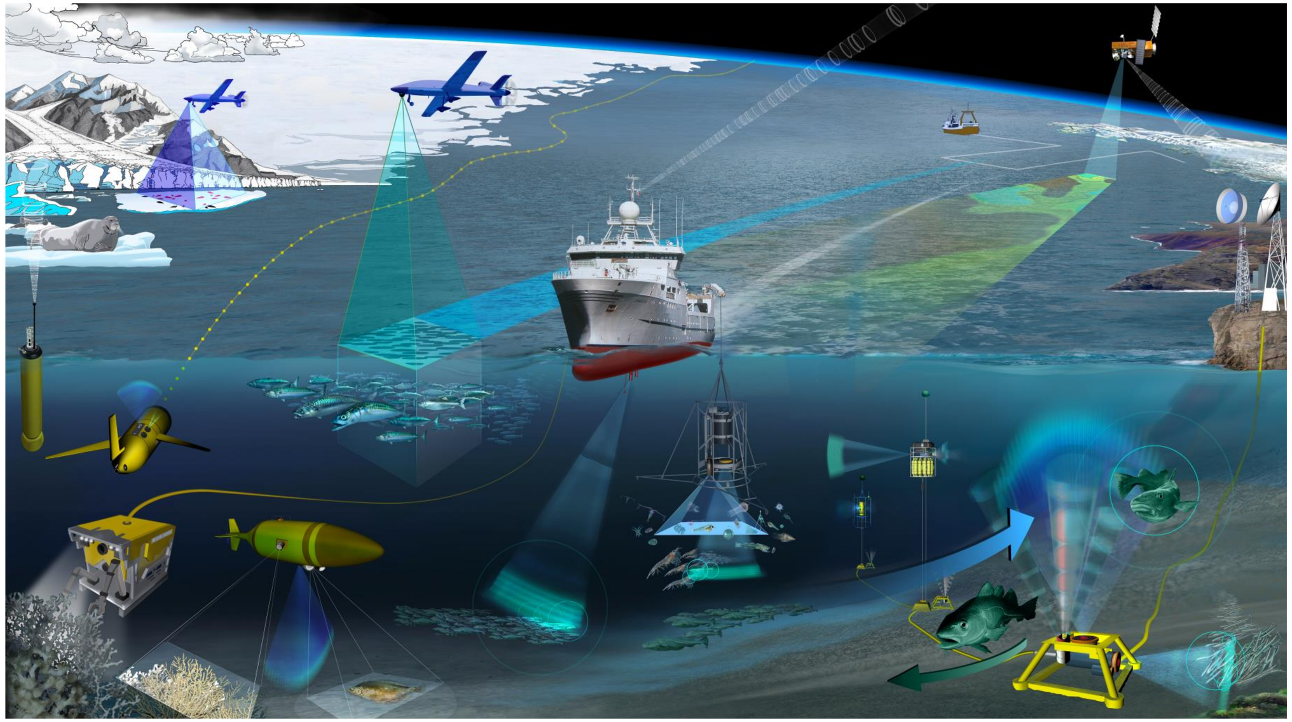
Norwegian Marine Robotics Facility (NORMAR)

Hugin AUV collaboration NORMAR-II

Sailbouy



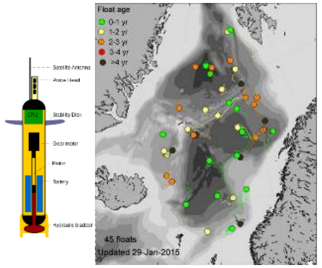
Norwegian Atlantic Current Observatory (NACO)



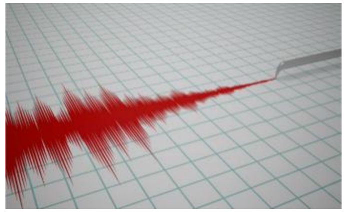
https://www.uib.no/en/oceanlab

NorGliders

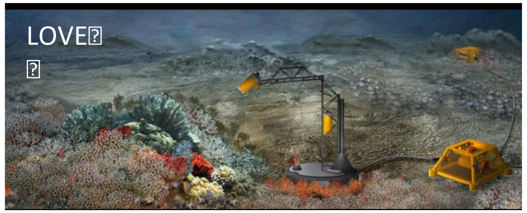
NorArgo



European Plate Observing System (EPOS)



Lofoten-Vesterålen Cabled Observatory (LoVe)



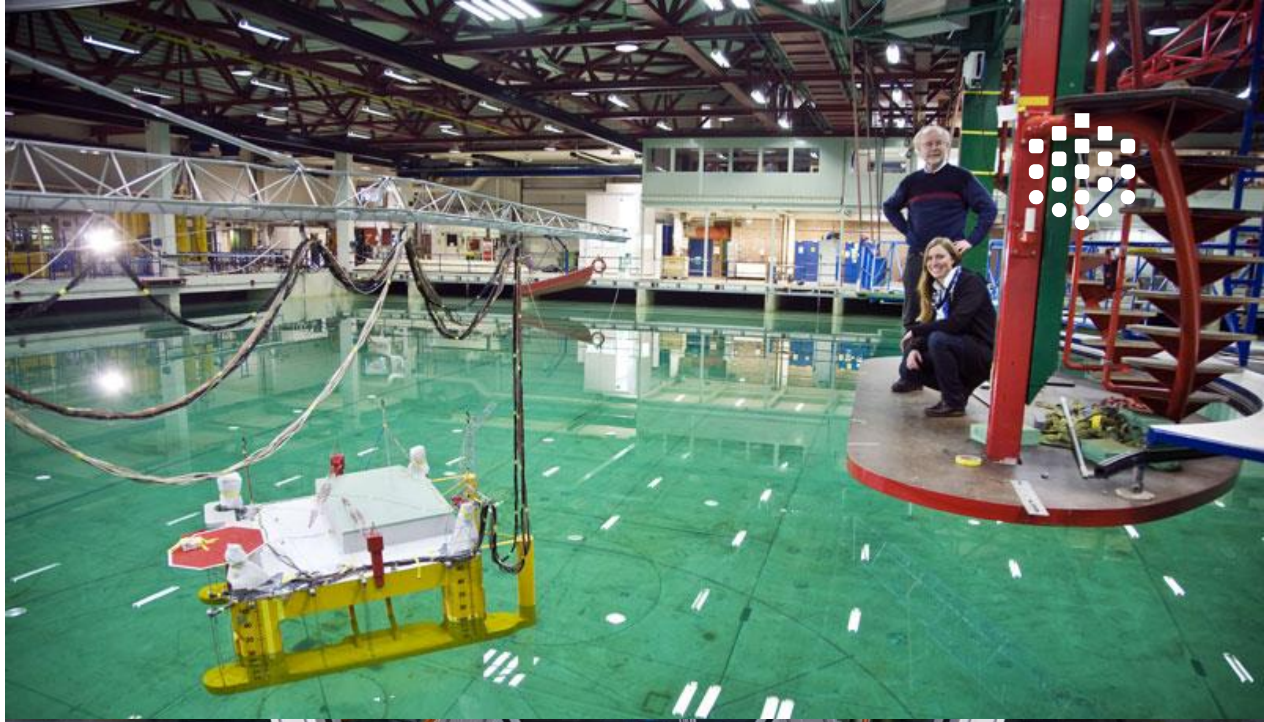
Ocean Laboratory

- Ocean Basin
  - L=80m
  - W=50m
  - Depth=0-10m
  - Max wave height = 0.9m

- Towing Tank
  - L=360m
  - W=10.5m
  - Max Speed = 10m/s
  - Max wave height = 0.9m

https://www.sintef.no/en/all-laboratories/ocean-laboratory/

SINTEF NTNU




AUR-Lab
Satellite
Ocean Space Centre
Tyholt
NTNU
TBS and
Fjordlab
Nidelva
Ladehammeren
Buoy
Buoy
Manifold
Harald AUV
Fast response boat
Remus AUV
Eelume
Subsea charging
and docking plate
Deep water AUV
ROV
Acoustic network
Gunnerus
Applied Underwater Robotics Laboratory (AUR-Lab)
Department of Marine Technology
Norwegian University of Science and Technology
E-mail: martinl@ntnu.no

AURLab - NTNU

Oppredningslaboratorium - NTNU

https://www.ntnu.no/igp/lab/oppredning

Laboratorier ved instituttet

- Kjemisk-/mineralogisk laboratorium
- Mikroskoperingslaboratoriet
- Elektronmikroskoplaboratoriet
- Oppredningslaboratoriet
- Sliplaboratoriet
- Ingeniørgeologisk laboratorium
- Bergmekanisk laboratorium
- Magnetometrisk laboratorium
- Reservoarlaboratoriet
- Forsøkshall
- Schlumberger geolab
- Idun cluster
- MiMaC - Norwegian Laboratory for Mineral and Materials Characterisation
- Datalaboratorier

Verksteder

- Mekanisk verksted
- Elektronikkverksted

ReSiTec

- Crushing/milling for mineral liberation
- Classification
- Hydrometallurgical equipment
- Heat treatment / drying
- Measurement Equipment

https://www.resitec.no/

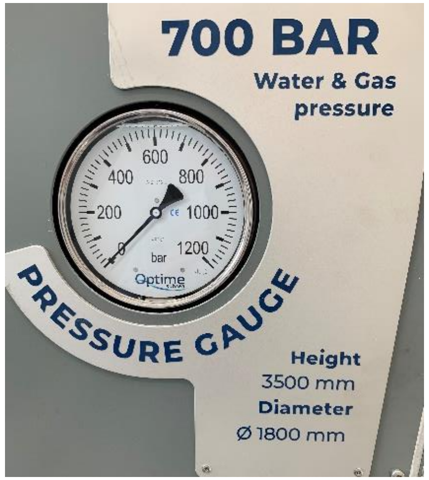
FUTURE MATERIALS

NORSK KATAPULT SENTER





World largest chambers in their pressure class



https://www.nui.no/pressure-testing/

OCEAN INNOVATION | NORWEGIAN CATAPULT CENTRE

nui

Tilgjengelig infrastruktur

- https://www.oceaninnovation.no/infrastruktur/

- https://www.futurematerials.no/utstyrspark/
- https://www.resitec.no/ https://www.resitec.no/about-resitec/future-materials-as/ (50-100%)

- https://www.ntnu.no/igp/lab/oppredning
- www.ntnu.edu/aur-lab
- www.ntnu.edu/oceanlab

- www.oceanspacecentre.no (Typisk fra 0-80%)
- https://www.sintef.no/laboratorier/flerfaselaboratoriet/

- https://www.uib.no/en/geo/128115/%C3%A6gir6000-rov
- https://www.uib.no/node/112288/teknologiske-muligheter

- https://www.nui.no/test-and-analysis/ (100% for eksterne kunder)
- Tau Autonomy Centre: https://tacchallenge.com/

- FFI: AUV tilgjengelig for medlemmer i HUGIN-HUS konsortier og andre. (Tilgjengelighet usikker. Noe gammel/slitt og utdatert)

- https://www.dnv.com/services/underwater-working-machines-1714 (teoretisk mye ledig)
- https://www.dnv.com/oilgas/laboratories-test-sites/

- https://www.norceresearch.no/en/testsentre-og-laboratorier

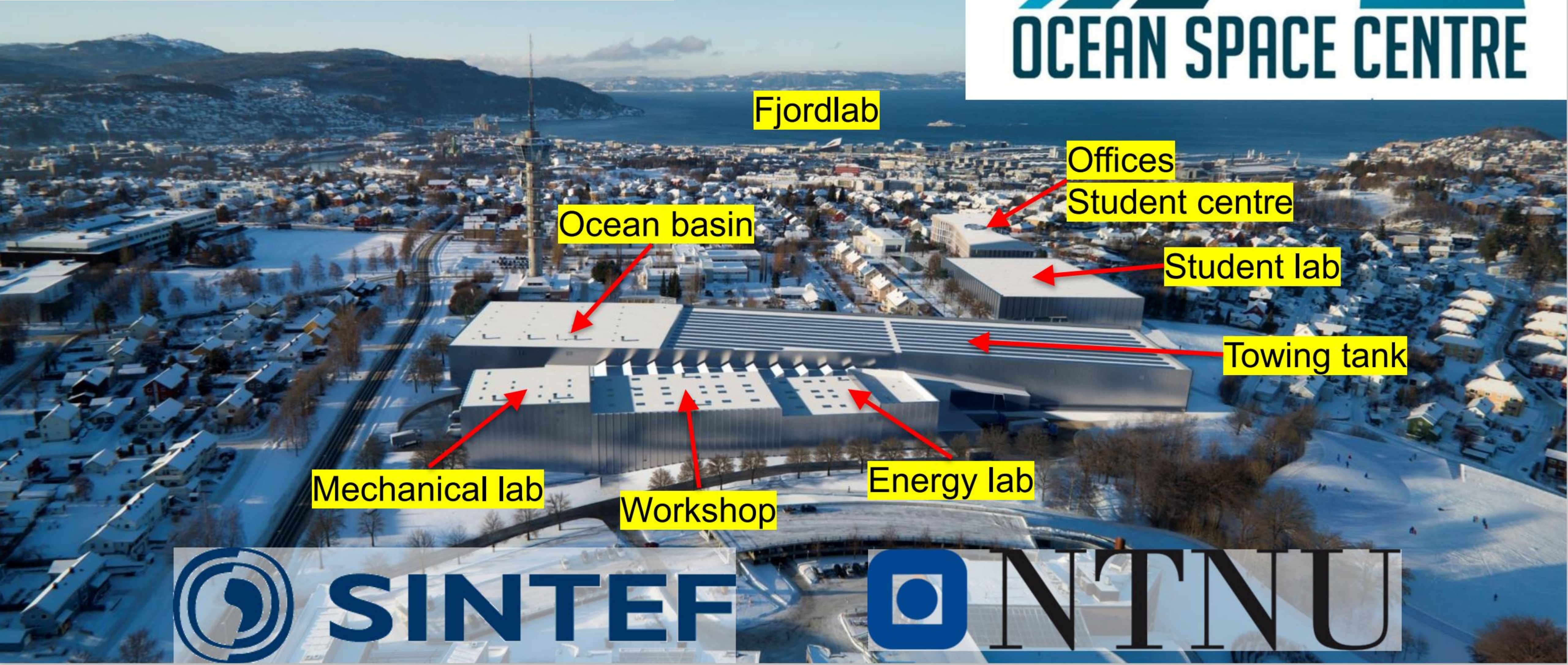
- https://www.gceocean.no/focus-areas/competence-and-infrastructure/rdi-infrastructure/

- Bedrifter har også relevante fasiliteter, men primært for prosjekt hvor de deltar selv

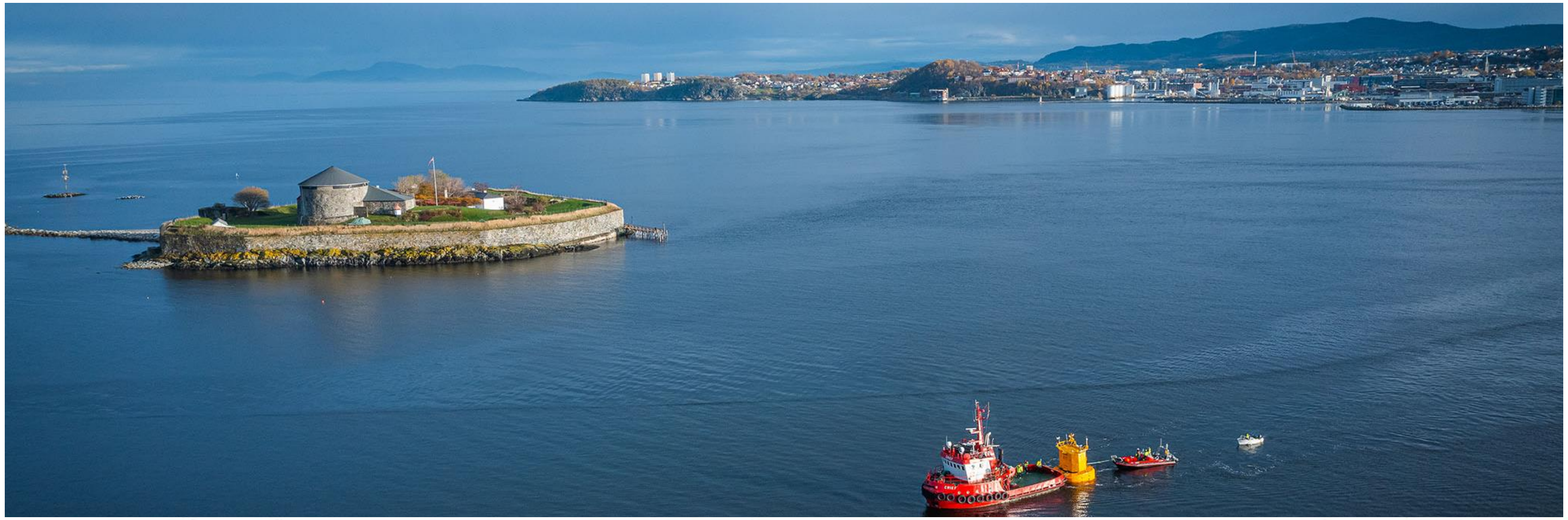
Planlagt infrastruktur Norge

Ocean Space Centre

Start building 2022+



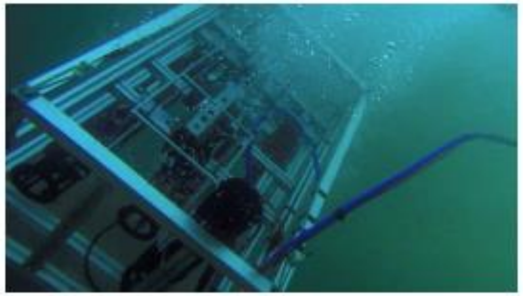
NTNU OceanLab



OceanLab Node 1: Subsea Facility

OceanLab Node 2: National Test Area for Autonomous Vessels

OceanLab Node 3: Aquaculture



OceanLab Node 4: Marine Observatory

https://www.ntnu.edu/oceanlab

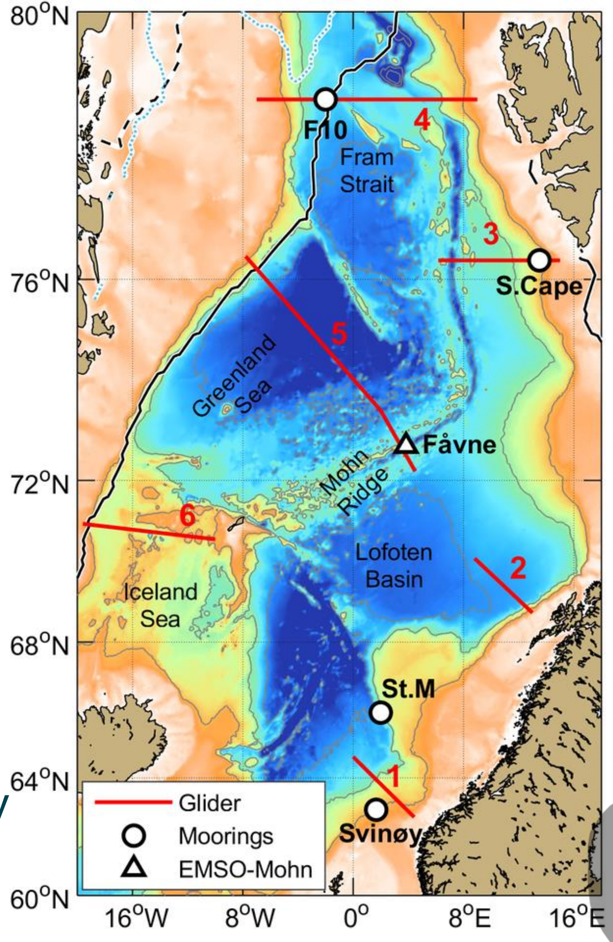
EMSO - Mohn

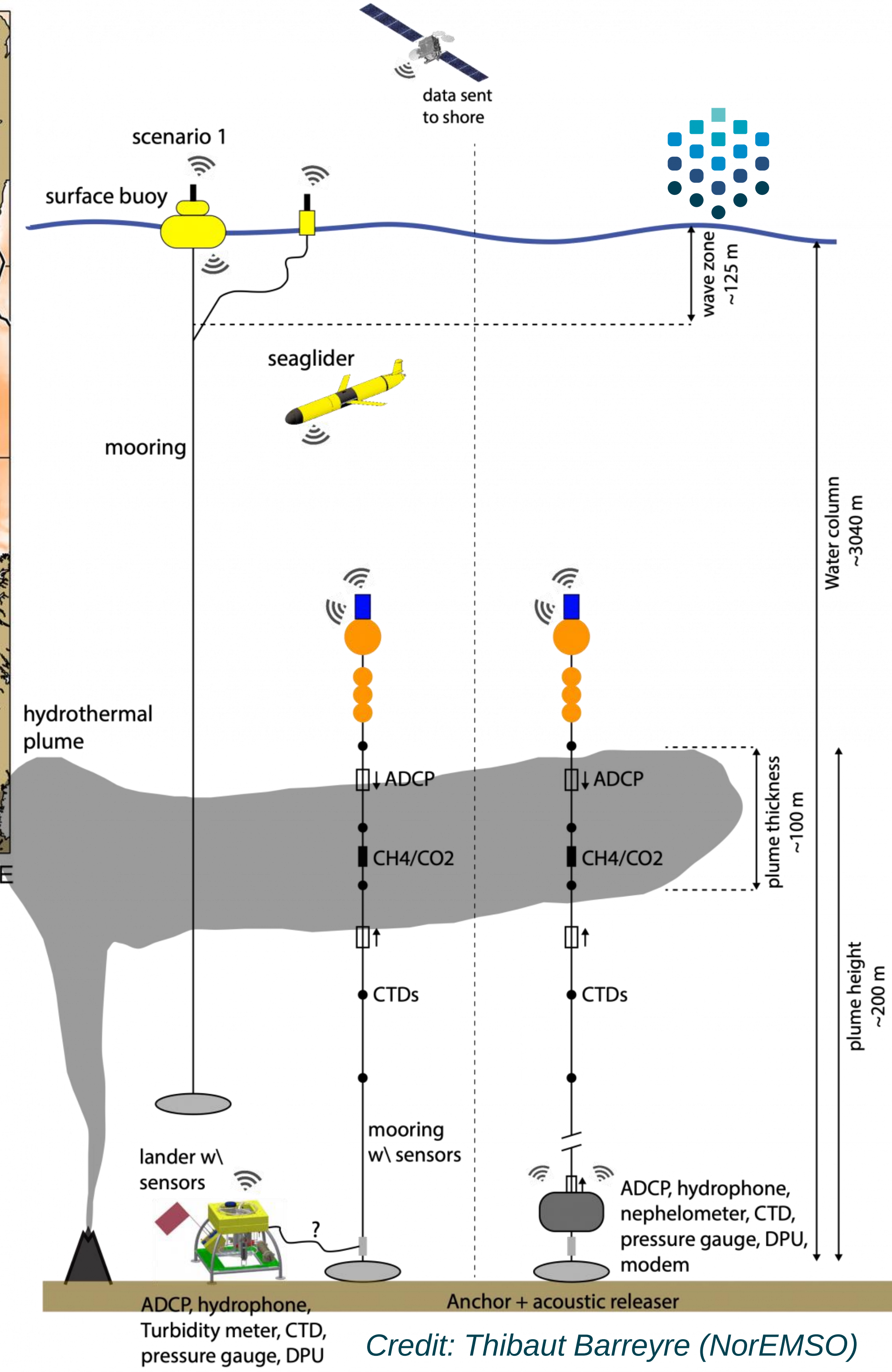
- Mohn Rigde
- Fåvne hydrothermal field
- Water depth: 3050m
- 600km west of Norway

- Operated by University in Bergen
- Supported by Research Council of Norway
- 1st deployment summer 2022

- Scientific objectives: Understand the dynamical coupling and feedbacks between the hydrothermal plume with crustal and oceanographic phenomena to quantify

- Part of NorEMSO





Credit: Thibaut Barreyre (NorEMSO)

https://emso.eu/observatories-node/nordic-seas/

Eksisterende infrastruktur i Europa

Oppsummering med innspill fra kartlegging utført av SINTEF
Mer detaljer i påfølgende slides

Utstyr & fasiliteter i Europa

- Det finnes mye utstyr og testinfrastruktur i Europa.
- Disse er spesielt relevant å se på for større og mer spesialiserte tester av komponenter og utstyr.
- Spesielt kan dette være relevant for:
  - Testing av pumper/stigerør
  - Testing av nodul-oppsamler
  - Testområder med ulike karakteristika
- For forskningsskip og tilhørende utstyr finner man en god oversikt over tilgjengelig utstyr i Europa på: https://www.eurofleets.eu/
- Planlagte forskningstokt er vist på siden: https://www.marinefacilitiesplanning.com/

- I påfølgende sider er noen av de mest relevante områdene/fasilitetene listet.

https://www.eurofleets.eu/

INESC TEC Portugal – VAMOS-project


Vertical lifting - Freberg, Germany

- 136 meter long (high) riser
- The largest vertical test section ever built in Europe dedicated to the vertical transport of solids.
- Vertical transport of sand, gravel and real (crushed and sized) manganese nodules
- Mineshaft in Freiberg, Germany

- Used for Blue Mining (2014-2018)
- A team of IHC (Netherlands) and TUBAF (Germany) engineers and scientists investigated the validity of the models used in the transport simulations with a focus on the occurrence of density waves, the frictional losses in the vertical riser and control techniques for the pump system.

Nodule collector - Delft

- Nodule collector testing

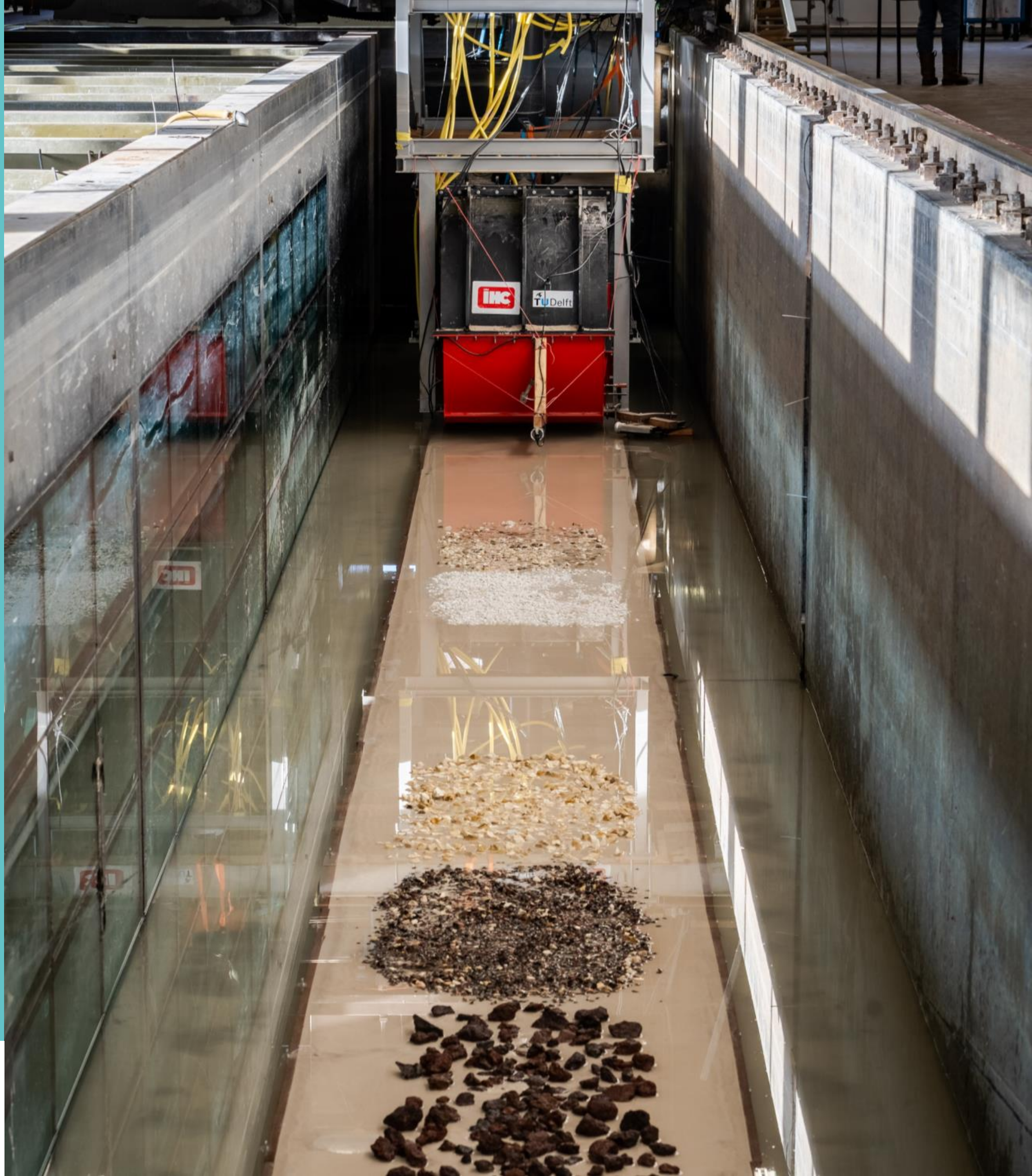
- Blue Nodules (2016-2020)
- Blue Harvesting (2019-2022)

- A true scale model of the hydraulic collector was tested in the Deltares test facility in Delft, The Netherlands.

- A test bed was prepared using lava stones to represent polymetallic nodules and fine sand to represent the underlying seabed sediment.

- https://www.deltares.nl/en/facilities/

Deltares

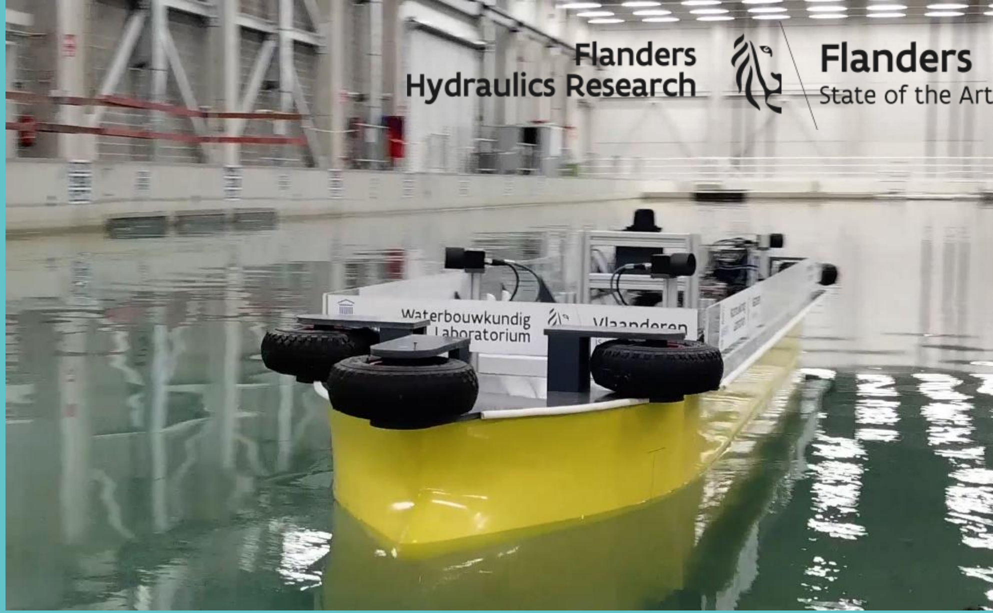


Netherland and Belgium

- Flanders Hydraulic Research Labaratory – Antwerpen
- New research facility in Ostend
  - Towing tank
  - Wave basin
  - Virtual Tour

- MARIN – Nederland
  - Facilities Leaflets
  - Facilities

- POMMEC - HYTECH
  - Detailed overview



Málaga Bight

- Used for Blue Nodules test in 2018
- Seabed and bottom water characteristics in the area comparable to those encountered in the nodule-rich areas of the deep Pacific Ocean
- Fine-grained cohesive sediment, and weakly stratified and relatively transparent bottom water, with gentle bottom current regime.
- Gentle slope of only 1-2° inclination
- Depth range of 200-500 meter

“The land-locked Norwegian fjords might present a favourable exception, but an application to the Norwegian authorities for conducting the field test in 2017 in one of those fjords with the Dutch RV Pelagia was rejected on grounds of potentially negative impact on the marine environment”

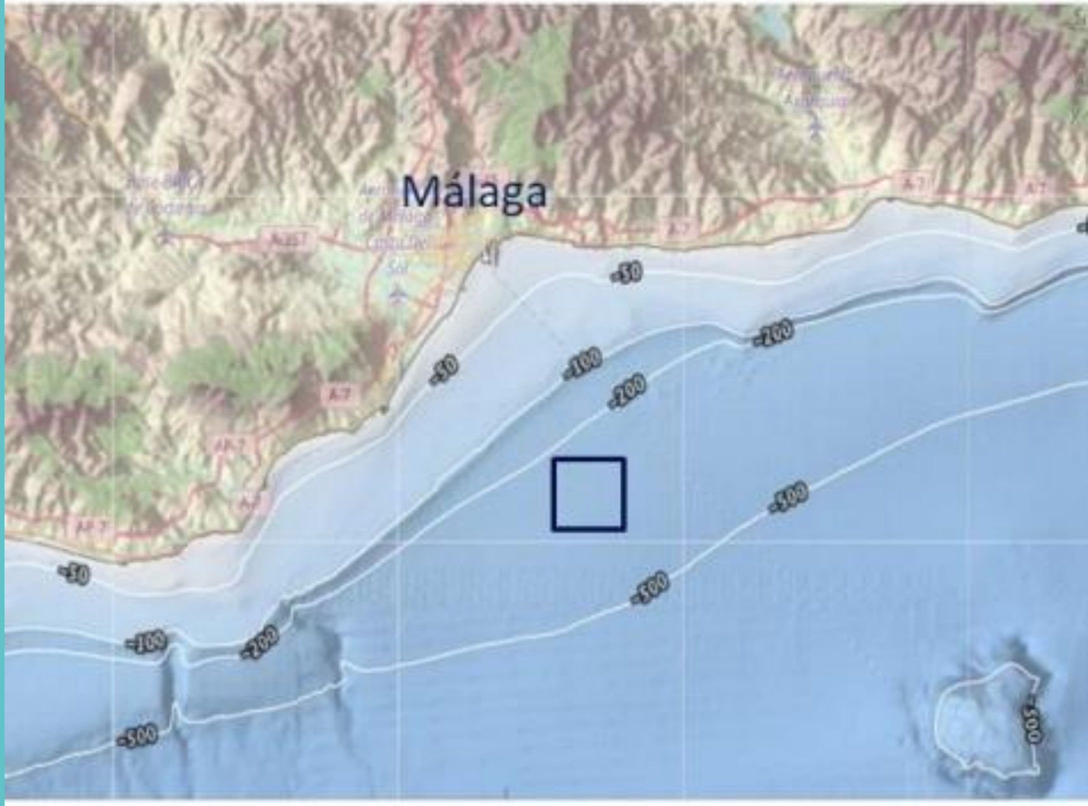


Photo Alberto Serrano. Launch of Apollo II Blue Nodules test 2019

Portugal

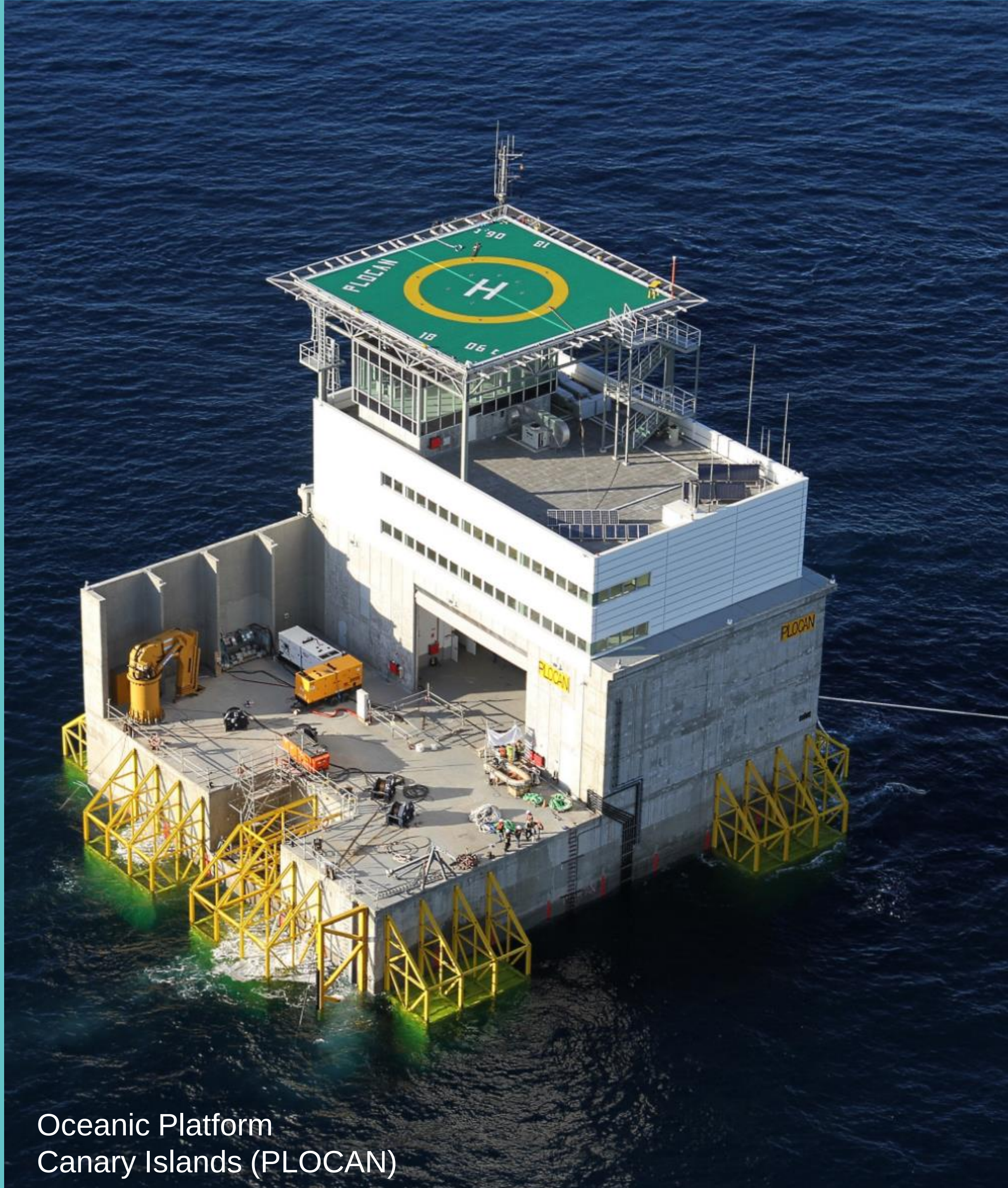
- INESC TEC i Portugal har en oversvømt gruve som blir brukt til testing og teknologiutvikling.
- Spesielt fokus på utvikling av robotikk og autonomi.
- Området har bland annet vært brukt i VAMOS-projektet (Viable Alternative Operation System)
- INESC TEC er prosjektleder og koordinator for TRIDEN - prosjektet *(Technology based impact assessment tool foR sustaInable, transparent Deep sEa miNing exploraTion and exploitation).* Fått tilsagn på €14M fra EU med planlagt oppstart tidlig i 2023.
- https://www.inesctec.pt/en


INESC TEC. Oversvømt gruve i Portugal brukt til utstyrstesting

INESC TEC Portugal – VAMOS-project

PLOCAN

- PLOCAN is a multipurpose technical-scientific service infrastructure that provides support for research, technological development and innovation in the marine and maritime sectors, available to public and private users.
- PLOCAN offers both onshore and offshore experimental facilities and laboratories, operational throughout the whole year thanks to the Canary Islands excellent climatic conditions.
- PLOCAN also brings a broad experience in large national and EU marine/maritime projects.
- https://www.plocan.eu/en/
- http://obsplatforms.plocan.eu/



Oceanic Platform
Canary Islands (PLOCAN)

Mer detaljer
Prosjekt og infrastruktur i Europa

Kartlegging utført av SINTEF

EUROPEISK INFRASTRUKTUR – MARINE MINERALER - VERSJON 2

GSR

- ProCat (2016-2019)
- Objective – Pre-prototype nodule collector (Patania I)
- Two phases
- ProCat 1 (2016-2017)
- ProCat 2 (2017-2019)

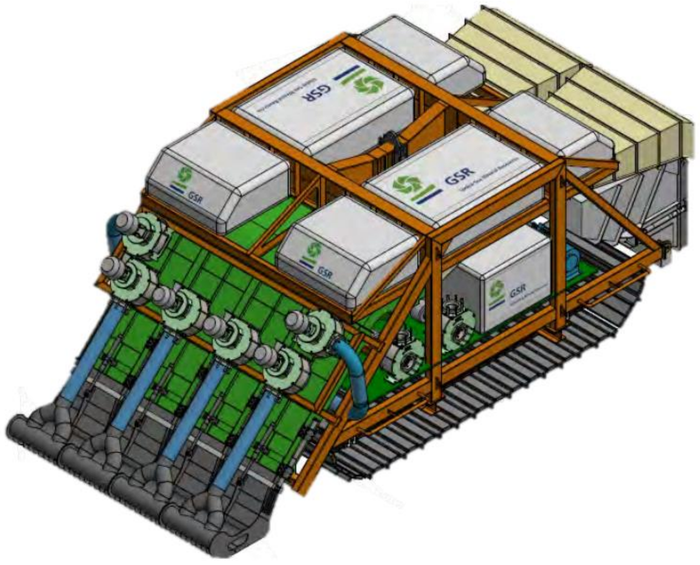
ProCat 1 (2016-2017)

- Separate parallel testing of the collection mechanism and driving mechanism - Tracked Soil Testing Device (TSTD).
- Manoeuvrability (trafficability) test - done in-situ
- Collection mechanism - tested in a laboratory
- Phase 1 - Completed successfully in September 2017.
- TSTD tested in-situ across the **deep seafloor of Belgium's Global Sea Mineral Resources and Germany's Institute for Geosciences and Natural Resources lease blocks (4500m depth)**
- Patania was an experimental 'Soil Testing Device' - Did not collect any nodules or soil samples.
- Main objective was to acquire in-situ terramechanical parameters that would enable GSR to develop an optimized design of the pre-prototype Patania II.

SINTEF


PATANIA
GSR
DEME
AGENTSCHAP INNOVEREN & ONDERNEMEN
DEME
AGENTSCHAP INNOVEREN & ONDERNEMEN

ProCat1 (2016-2017)



- The construction of the Patania started in October 2016. By the end of February 2017, the Factory Acceptance Test (FAT) tests and subsequent mud and wet trials were completed.

- In June 2017, during the GSRNOD17 campaign in the CCFZ, in-situ experiments were conducted. The tests with the TSTD Patania had the following objectives:

  1. Evaluation of the overall performance of a tracked vehicle on the seabed of the CCFZ.

  2. Speed variances and effect on traction and slippage

  3. In-situ pressure-sinkage relationship (terramechanical test)

  4. Ex-situ shear stress - shear displacement relationships (terramechanical test)

  5. In-situ thrust – slip relationship (terramechanical test)

  6. Quantitative and qualitative measurements of sediment dispersion generated by the tracks (environmental)

  7. Qualitative measurements of sediment dispersion generated by a horizontal water flow parallel to the seabed (environmental)

ProCat II (2017-2019)

- ProCat2 delivered the PPV, Patania II, and continued the development of Patania I by adding a collector suction head for testing the pickup collection methodology.
- The hydraulic lift concept, although tested in the 1970s by the Ocean Management Inc. (OMI) consortium, has fundamental engineering uncertainties:
- (1) How great is the pick-up efficiency and how much energy (and thus water) is required to reach that efficiency?
- (2) How is the seabed affected by the hydraulic lift collector; what is the expected depth of penetration?
- In order to answer these questions, GSR conducted an extensive series of laboratory tests in collaboration with **the Flanders Hydraulic Research Laboratory in Antwerp**. The design of the tested collector head was based on a pre-design study using Computational Fluid Dynamics (CFD).

ProCat2 (2017-2019)

- The pre-prototype vehicle Patania II is an active pick-up system which is broken down into four major subsystems:

  (1) Nodule collection system: the nodule collection system consists of the collector head, the jet water pumps and all sensors to monitor the suction process. The design of the collector head is based on the results obtained from the laboratory tests.

  (2) Propulsion system: a two-track system will be used for the propulsion system. The terramechanical values measured in-situ with the TSTD Patania were used for the design of the propulsion system.

  (3) Nodule separation and discharge system: there will not be a riser to pump the collected nodules to the surface vessel. Hence, a dumping system is incorporated into the design of the vehicle.

  (4) Vehicle systems: this part comprises all components for the proper functioning of the vehicle. This includes hydraulic power units (HPUs), telemetry, buoyancy, etc.

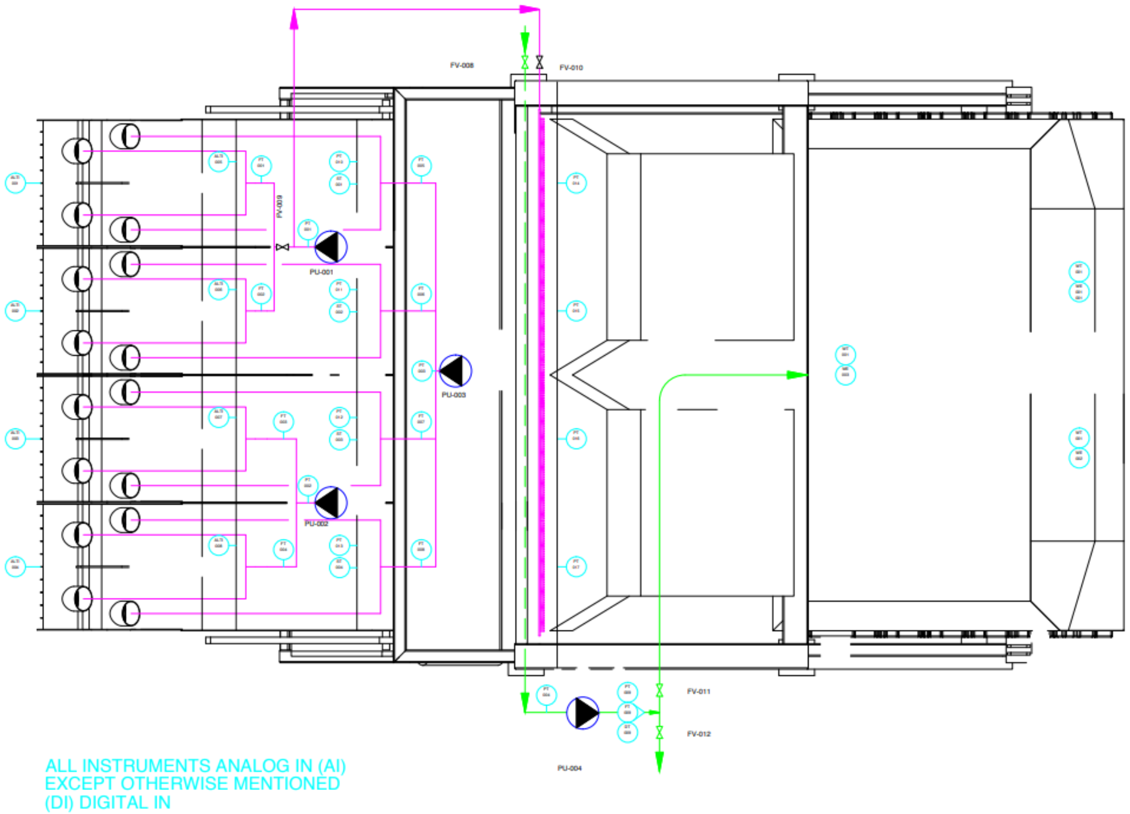


Figure 12: Collector pump lay-out

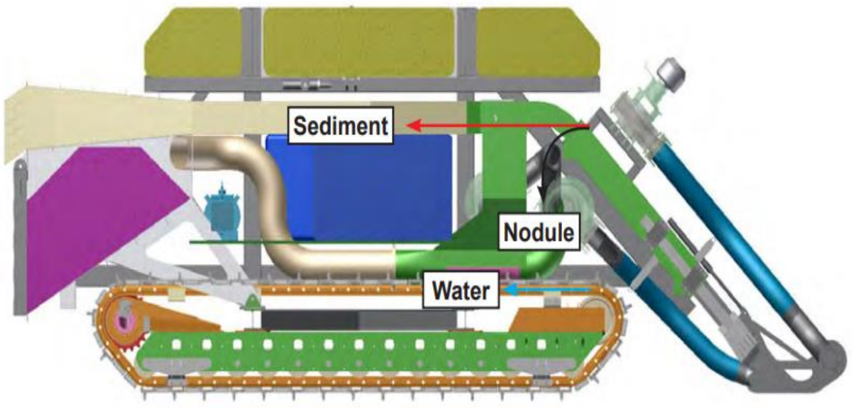


Figure 13: Nodule separation system

SINTEF

ProCat2 (2017-2019)

- Results from laboratory tests show four main control parameters as determining the collection process:

  (1) The pick-up jet velocity

  (2) The transport jet velocity

  (3) The height of the collector above the seabed

  (4) The collector's forward speed

- Patania II was designed so that these parameters can vary during the in-situ collection process.

- The nodule collection system is based on the results of the laboratory tests as described in the appendix of this report (see 12.1.4, Laboratory tests with the hydraulic collector, pp. 230)

SINTEF

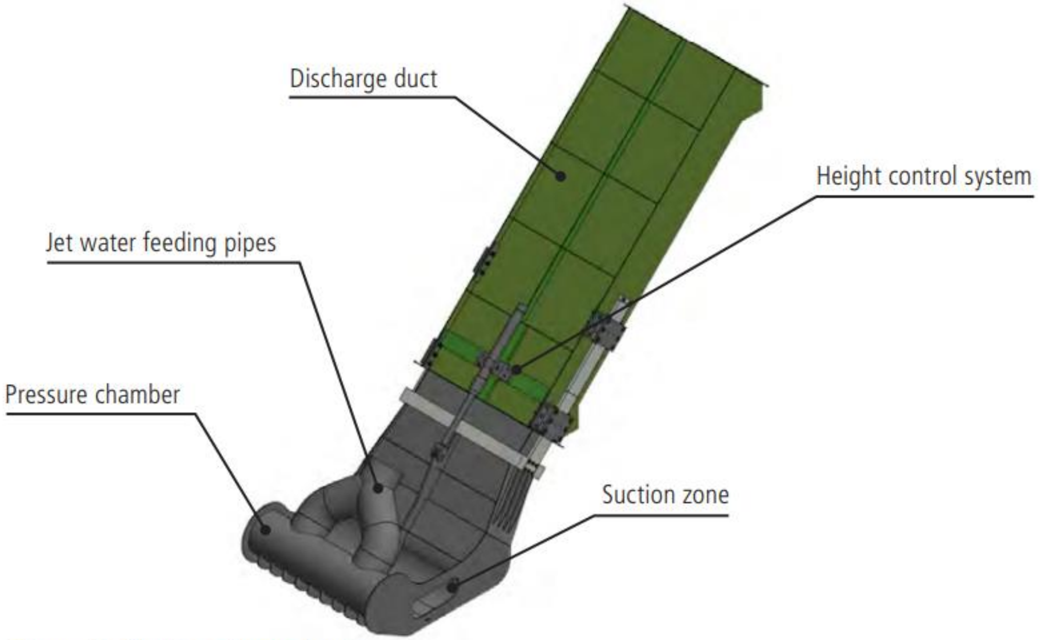


Figure 10: Nodule collector head

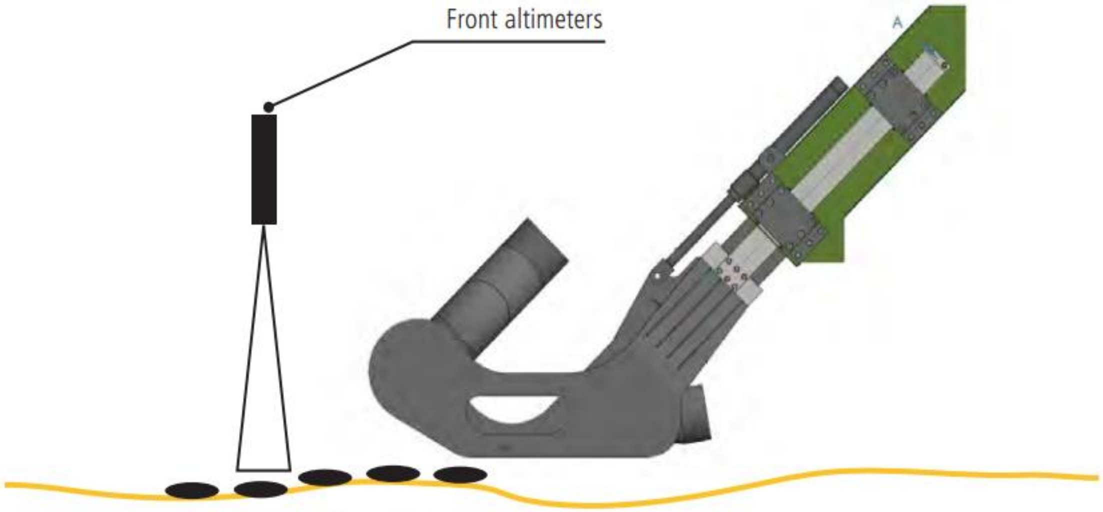


Figure 11: Collector head height control

ProCat2 (2017-2019)

- The seagoing campaign to the CCFZ, GSRNOD19, had its focus on the deployment of the pre-prototype mining vehicle.
- The campaign consisted of two distinct legs, **Deep Sea Functionality Testing in CCFZ** and **GSRNOD19 impact experiment and component validation**.
- The first leg, the functionality testing, was to mitigate any technical issues before the actual operations within the framework of the JPI-Oceans MiningImpact 2 program.
- Subsequently, the GSRNOD19 campaign had 2 major operational modes:

  (1) First operational mode: In-situ validation and optimization of the nodule collection system as tested in the laboratory (GSR technical department). Focus on the optimization of the collection process.

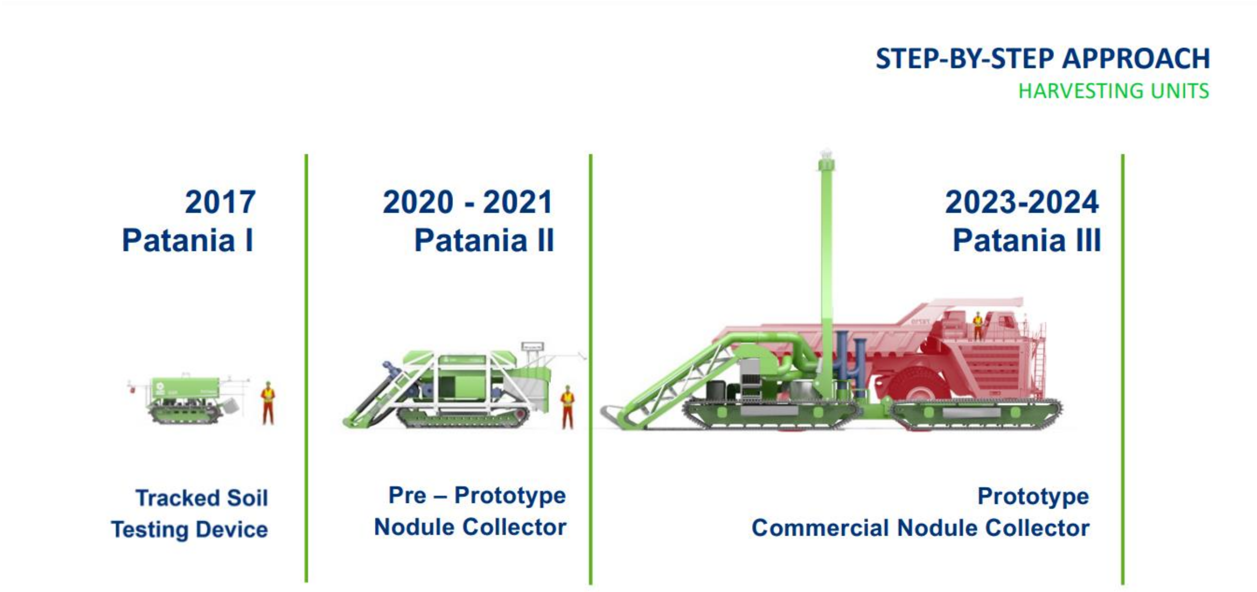
  (2) Second operational mode: Environmental impact experiment in the context of the **JPI-O MiningImpact 2** collaboration. The objective of the experiment was to assess the impact of the sediment plume generated by the PPV and to assess the short (scale of days)- and long (scale of months or year)-term impact on the ecosystem.

Patania II

Patania II

- Finished in 2019 and has since been tested in different ways.
- **First test (2019):** The test followed the trial of Patania I in 2017, which crawled along the ocean bed at a depth of 4,500 meters. Patania II collected nodules as well as traversed the seabed. This test was done by GSR in conjunction with **Ghent University.**
- **Atlantic Expedition (22 June – 19 July 2020):** Validation of launch & recovery system and hyperbaric test. Depth: 4500 meters, no touch-down on seabed. In the same period, trafficability assessment in **Belgian EEZ** at a depth of 28 meters.
- **Patania II trial in CCZ (February – May 2021):** Collected nodules, also this at 4500 meters depth. During the first trials the vessel spent approximately 50 hours on the seabed.
- Later during the trials, the vessel became disconnected from the 5km cable connecting it to GSRs ship and was disconnected for two days before being recovered.

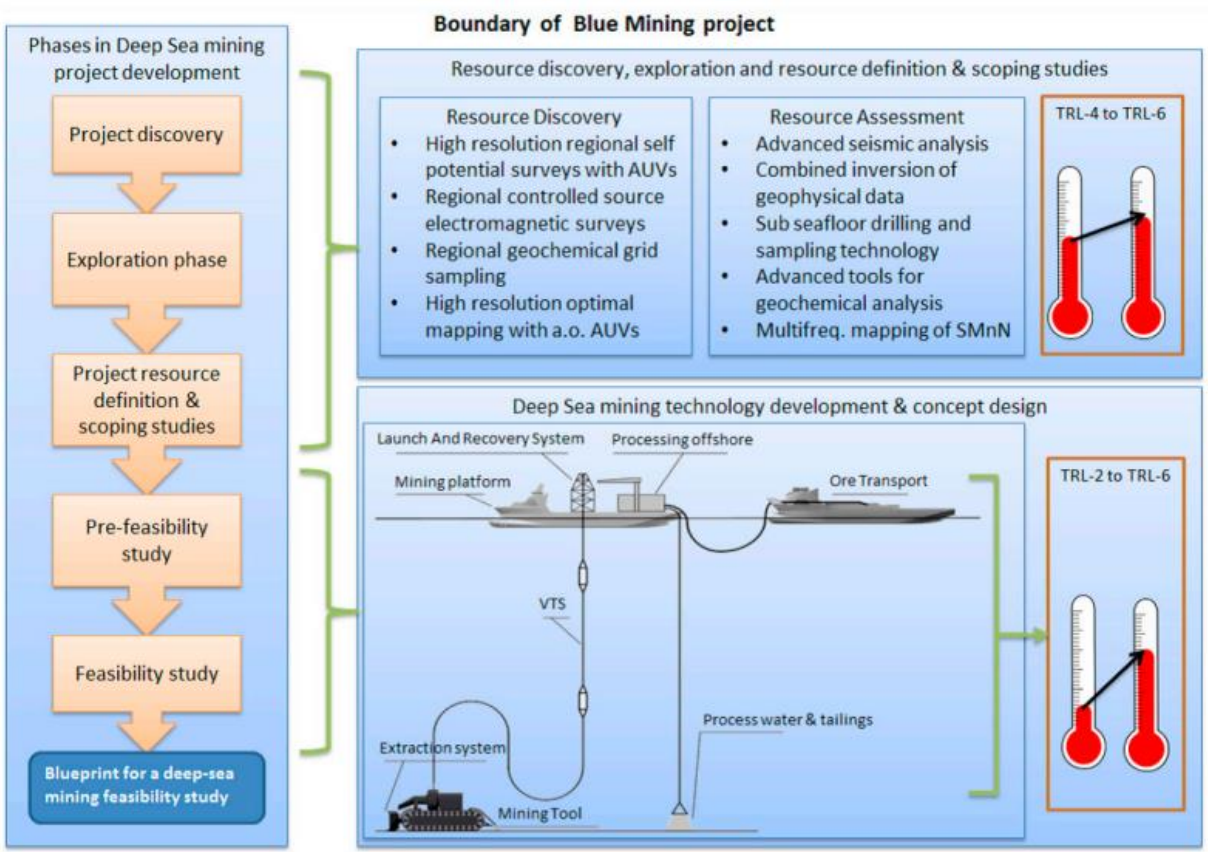
Patania III (Sometime in 2023)



- While Patania II collected nodules, it was not connected to a riser to transport the nodules to the surface. Patania III will do this.

Blue Mining (2014-2018)

IHC
UNIRESEARCH
2H offshore
mhwirth
BGR Bundesanstalt für Geowissenschaften und Rohstoffe
Dredging International
ULISBOA Universidade de Lisboa
GEOMAR
SEA Europe Ships & Maritime Equipment Association
RAMBØLL IMS
MARIN
IHC MTI
NERC Science of the Environment
NTNU – Trondheim Norwegian University of Science and Technology
TNO innovation for life
RWTH Aachen University
TU Delft Delft University of Technology
Technische Universität Bergakademie Freiberg
University of Southampton



Blue Mining 2014-2018

- The overall objective was to provide breakthrough solutions for a sustainable deep sea mining value chain.
- This means to develop the technical capabilities to adequately and cost-effectively discover, assess and extract deep sea mineral deposits up to water depths of 6000 meters
- *"The control over these three capabilities is the key for access to raw materials, for decreasing EU dependency on resource imports and for strengthening Europe's mining sector and their technology providers".*

SINTEF

DEVELOPMENT OF BOOSTER STATION TECHNOLOGY AND THE DEEP-SEA SPECIAL MOTOR:

- One of the key technologies in the (Vertical transfer system) VTS is the booster station.
- The centrifugal pump booster station concept as developed in Blue Mining consists of two centrifugal pumps and several valves, assembled in member-type frame.
- Deep sea conditions pose special requirements on all components due to the extreme pressures at large water depths.
- Within Blue Mining a Deep-Sea Special Motor has been developed and tested on laboratory scale **(RDM Rotterdam)** and in the field **(Mangersfjorden, Norway).**
- The motor is completely filled and cooled with sea water due to its open structure, thus it does not require any lubricants minimizing the environmental pressure of the motor.

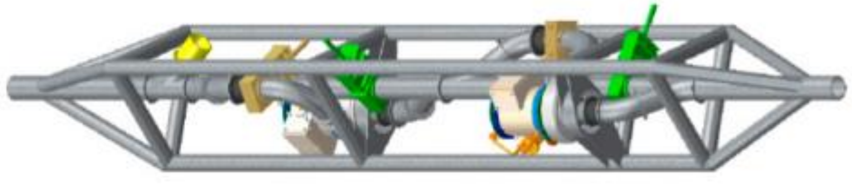


FIG. 8. MEMBER TYPE CONCEPT BOOSTER STATION FOR THE VTS, CONSISTING OF TWO CENTRIFUGAL DREDGE PUMPS AND SEVERAL VALVES.

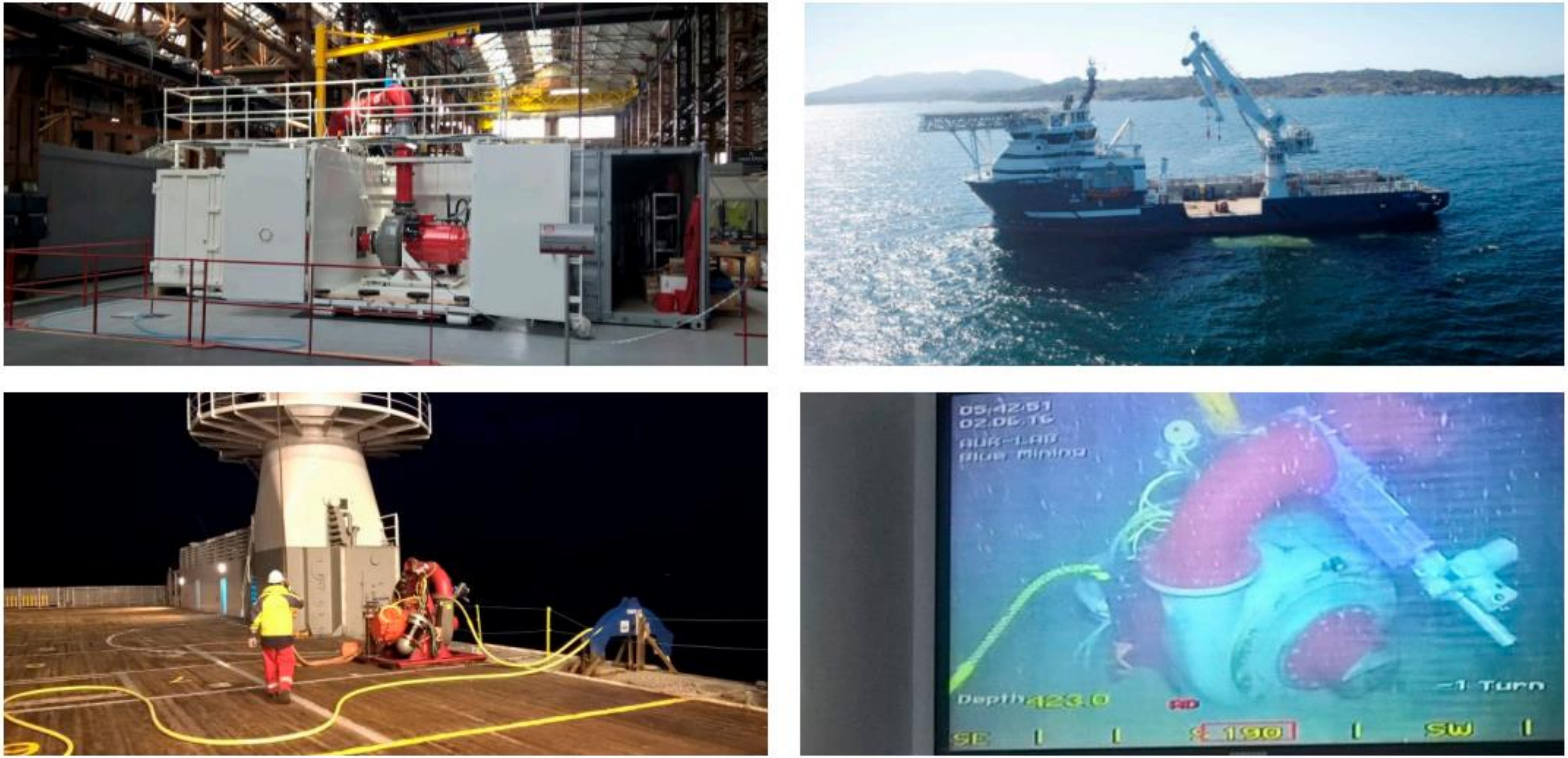
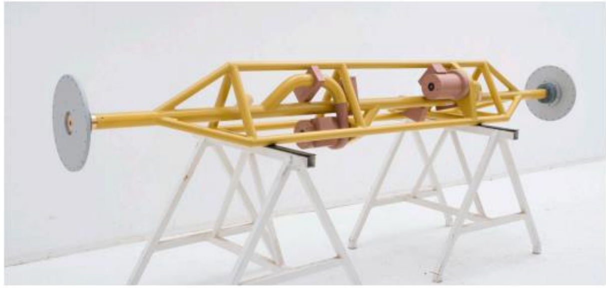


FIG. 9. TESTING THE DEEP SEA SPECIAL MOTOR AT THE RDM ROTTERDAM TEST FACILITY (TOP LEFT) AND ON THE TAURUS (TOP RIGHT, BOTTOM LEFT) IN MANGERSFJORDEN. BOTTOM RIGHT THE UNDERWATER CAMERA VIEW ON THE MOTOR-PUMP COMBINATION.

Riser Dynamics



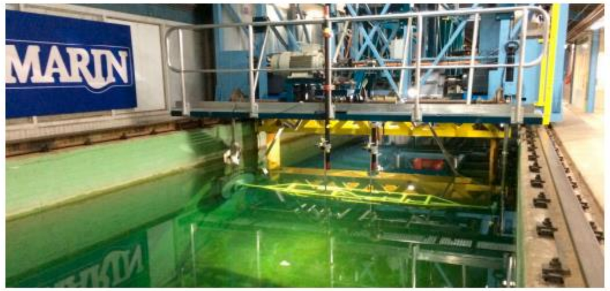


FIG. 10. SCALE 1:6 BOOSTER STATION TESTED IN THE MARIN BASIN TO FIND THE HYDRODYNAMIC COEFFICIENTS WHICH ARE NECESSARY FOR CFD MODELLING OF RISER DYNAMICS.

- The vertical transport system will be subjected to a variety of external loads.
- A wake-oscillator model is implemented with which time-domain simulations can be conducted for deep-sea mining riser systems. This model requires hydrodynamic coefficients as input, which can be determined with model tests or CFD calculations.
- In Blue Mining the booster station has been tested in the **MARIN test basin (Netherlands)** on a scale 1 to 6 in order to find the appropriate hydrodynamic coefficients.

Vertical Hydraulic Transport System (1)

- Deep knowledge of transport processes is a prerequisite for a clog free vertical transport system. Research efforts consequently focused on computational modelling of the long-distance vertical transport, backed by laboratory scale experiments of specific phenomena.
- After finishing the laboratory experiments there was a need to take a next step in the scale of experiments to increase confidence and understanding.
- Besides that, one of the unresolved issues at the start of Blue Mining was the occurrence of density waves, a topic that needed to be revisited
- These plugs could be a showstopper for the mining operation, so methods for prediction would be a valuable competence in flow assurance analysis.

Vertical Hydraulic Transport System (2)

- In order to get more clarity on these density waves, two directions were chosen in Blue Mining.

- The first direction aimed for numerical modelling of the phenomenon with CFD (a 2D Immersed Boundary Method). In 2017 this method proved successful in qualitatively mimicking the occurrence of density waves as shown below, making it a promising technique for actual prediction of waves during operational conditions.

- The second direction was an investigation into vertical transport of sand, gravel and real (crushed and sized) manganese nodules in a 136-meter-long riser in a mineshaft in **Freiberg, Germany.** This test setup is unique in its size: it is the largest vertical test section ever built in Europe dedicated to the vertical transport of solids. A team of **IHC (Netherlands)** and **TUBAF (Germany)** engineers and scientists investigated the validity of the models used in the transport simulations with a focus on the occurrence of density waves, the frictional losses in the vertical riser and control techniques for the pump system.

SINTEF

Ship to Ship Transfer

- The minerals from the mining vessel are transferred to the transport vessel via a floating hose. Dedicated computer codes were used to quantify the motions (displacement, velocity, and acceleration) of the floating hose connections on the mining vessel and the transport vessel.
- From an Engineering point of view the calculated motions enable them to specify design requirements for the ship-to-ship transfer hose and its launch and recovery system. This to obtain the wanted offloading operability.
- To minimize false decisions regarding the start or stop of ship-to-ship transfer operations the Blue Mining project developed a dedicated operator decision support tool. Field tests in offshore wave conditions were performed to substantiate the Technology Readiness Level of a ship-to-ship transfer operation via a high-capacity floating line.
- All parameters collected during the field test in one synchronized data set. Amongst others wind, wave and vessel motion data was collected for wave heights up to 4.5 m.

Blue Nodules (2016-2020)

Blue Nodules (2016-2020)

- The main aim of the Blue Nodules project was to develop and prove the concept and feasibility of technology for environmentally responsible and industrially viable mining of deep-sea polymetallic nodules.
- During the Blue Nodules project, a nodule collection system, propulsion system and umbilical were developed to a level that saw them being able to be tested in a realistic marine environment.
- After initial design and laboratory testing of various system components in 2016 and 2017, the developed systems were integrated in 2018 in Apollo II, a pre-prototype nodule collection vehicle assembled for the purpose of testing the systems in a relevant marine environment.
- Following two field tests with Apollo II in summer 2018 and 2019 in **Málaga Bight, offshore southern Spain**, the next step would be to test the systems integrated into Apollo II in the operational environment of the **Clarion Clipperton Zone (CCZ)**.

SINTEF

Initial design

- An initial design of the hydraulic collector was developed within the Blue Nodules project based on theoretical calculations of the physical principles of the collector.
- Computational Fluid Dynamics (CFD) simulations were then performed to validate the calculations and to optimise the design of the collector.
- The design is considered to be optimal when all nodules are lifted with the lowest possible jet flow.
- A true scale model of the hydraulic collector was tested in **the Deltares test facility in Delft, The Netherlands.** For the tests, a test bed was prepared using lava stones to represent polymetallic nodules and fine sand to represent the underlying seabed sediment.

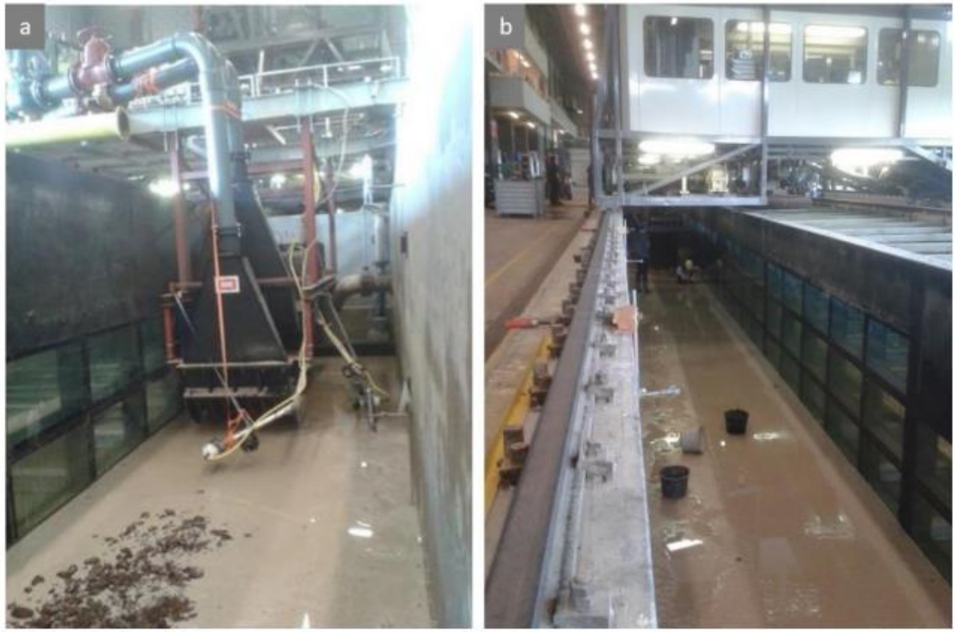


Figure 3.4. Full-scale lab testing of the hydraulic nodule collector at the Deltares test facility in Delft, The Netherlands. a: The prepared test bed, made of lava stones on fine sand, with the collector in the background; b: the test bed after the collector has passed over it. Photo Henko de Stigter.

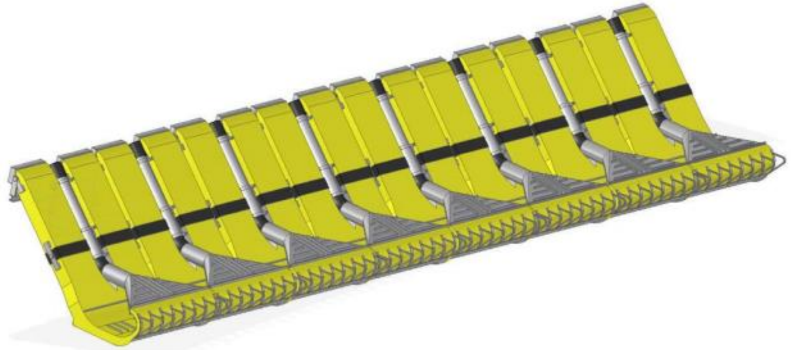


Figure 3.3. Artist impression of full-scale hydraulic collector, composed of 8 separate 2 m wide units. The pre-prototype nodule collection vehicle Apollo II is equipped with one half-scale unit. Reproduced from Blue Nodules Deliverable 2.2.

Apollo II field tests (2018-2019)

- **Málaga Bight** was chosen in 2018 as suitable for the Blue Nodules field tests, taking into account the availability of seabed and bottom water characteristics in the area comparable to those encountered in the nodule-rich areas of the deep Pacific Ocean, yet in relatively shallow water of 200-500 m depth, in a region with high probability of favourable sea state, and in relative proximity to **IHC Hytech in The Netherlands** where the Apollo II vehicle was assembled.
- Environmental characteristics critical for the field test include the very gently inclined seabed covered with fine-grained cohesive sediment, and weakly stratified and relatively transparent bottom water, with gentle bottom current regime.
- The land-locked Norwegian fjords might present a favourable exception, but an application to the Norwegian authorities for conducting the field test in 2017 in one of those fjords with the Dutch RV Pelagia was rejected on grounds of potentially negative impact on the marine environment.
- In consultation with marine geologists of the **Institute of Marine Sciences (ICM-CSIC) in Barcelona**, Málaga Bight was identified as the most suitable area for the test, in the first place because of the particularly gentle slope of only 1- 2° inclination in the depth range of 200-500 m.
- After the successful field test of 2018, it was decided that the second field test would be conducted in the same area in Málaga Bight, in order to ensure comparable baseline conditions for the tests.

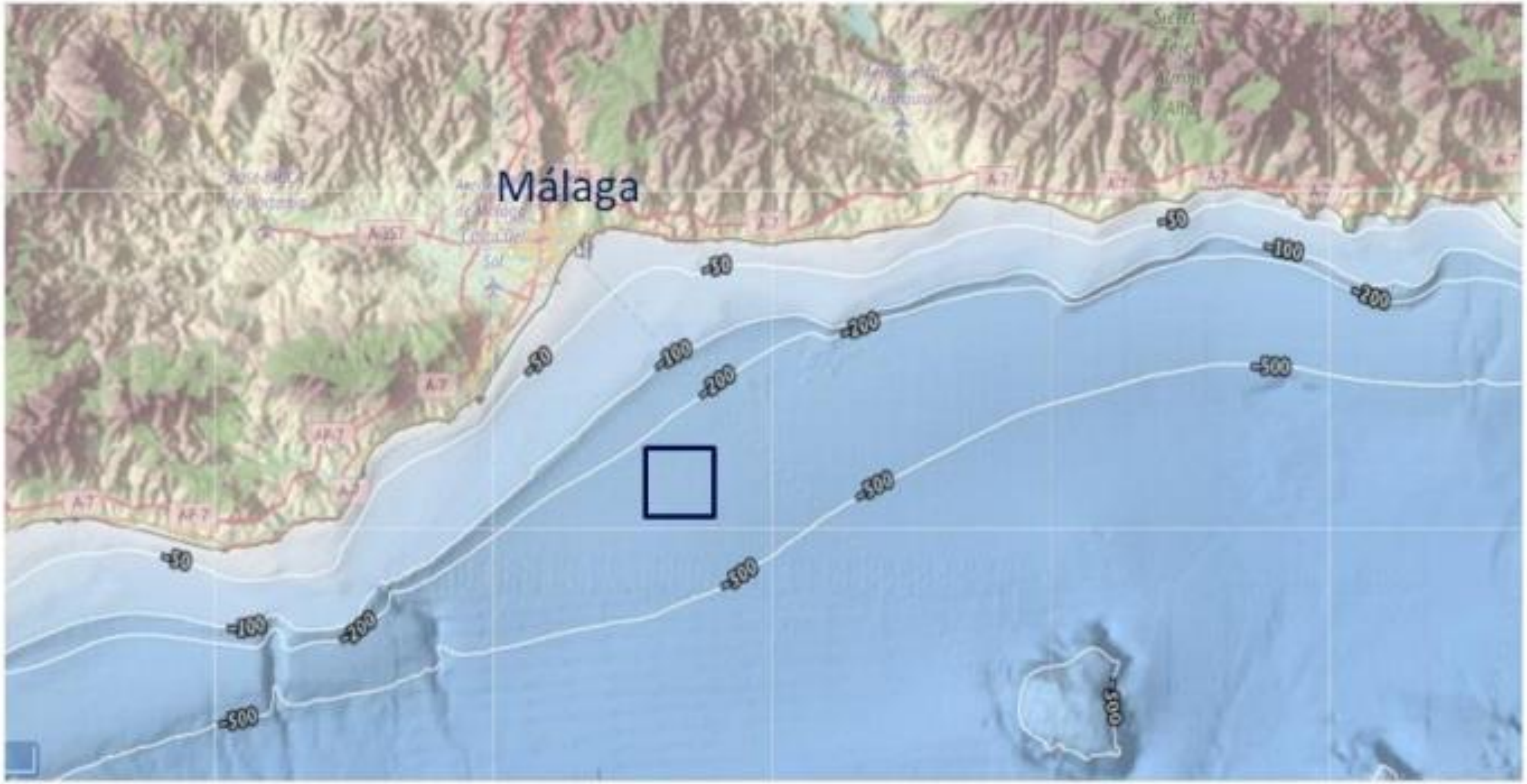


Figure 3.1. Location of the field test area in Málaga Bight.

SINTEF

Apollo II field tests (2018-2019)

- The aim of the two Blue Nodules field tests was to assess the technical and environmental performance of the nodule collector system, propulsion system and umbilical, integrated in the Apollo II, in a relevant marine environment.

- The Apollo II vehicle, connected to the ship via an umbilical cable for hoisting, power supply and data exchange, was to that end lowered on weakly sloping muddy seabed in about 300 m water depth to carry out a series of technical tests regarding the manoeuvring and operational control of the vehicle, in particular:

  - Tractive effort of tracks, velocity, performance, and power
  - Turning accuracy, performance, and power
  - Accuracy of measuring positioning and ability to drive a straight line
  - Automatic heading control system
  - Accuracy of forward velocity versus setpoint
  - Sinking in seabed sediment
  - Amount of sediment taken up by hydraulic collector

Apollo II field tests (2018-2019)

- Minimizing environmental impact was an important goal of the Blue Nodules project, and therefore assessment of environmental effects arising from the operation of the propulsion and collector systems was an integral part of the test program, in particular regarding:

- Deformation of the surface sediment
- Mobilization of surface sediment
- Dispersion of mobilized sediment in sediment plume
- Redeposition of mobilized sediment
- Underwater noise

SINTEF

Apollo II field test 1 (2018)

- The first Blue Nodules field test conducted in 2018 yielded very satisfying results, especially considering that it was the first time that the integrated system was tested in open sea at 300 m water depth.
- Apollo II was launched and recovered several times, and for the total duration of 128 hours that the vehicle was in the water the electronical control system remained fully functional.
- During four test runs Apollo II drove a total distance of 5 km over soft, muddy seabed, following a trajectory which included both straight sections and turns, and reaching a maximum forward speed of 0.55 m s-1.
- The hydraulic collector, however, failed after having functioned well for a while, due to an electrical short-circuit in the collector pump motor. Additional problems were malfunctioning compasses on the vehicle, lack of angle limiters to prevent jamming of the steering system and compromised manoeuvrability of the vehicle due to drag on the umbilical.
- The field test further demonstrated the need for a remotely operable height adjustment of the collector, and provisions for safe launch and recovery under less favourable sea state conditions.

Apollo II field test 1 (2018)

- Regarding environmental effects, the field test of 2018 yielded valuable insight in the lateral and vertical dispersion of the sediment plume produced by Apollo II, and in concentrations of suspended particles within and outside the plume.
- Plume monitoring was done through ROV video observation and through measurements performed with sensors mounted on ROV and CTD and on static moorings.
- The untimely failure of the hydraulic collector, however, frustrated designated tests for recording of the fully developed plume. It was also noted that a single line of moored sensors provided insufficient insight in the lateral dispersion of the plume.
- The imprint produced by Apollo II tracks and collector on the seabed was investigated through ROV video imagery, but attempts to sample the disturbed seabed sediment with video-guided boxcorer failed due to poor visibility near the bottom.
- Finally, underwater noise produced by Apollo II could not be recorded, as the acoustic recorder which UPC meant to provide for the field test was unavailable due to customs issues.

Apollo II field test 2 (2019)

- The Blue Nodules Second Field Test was conducted from 9 to 26 August 2019.
- A day-to-day description of events during the 2019 tests can be found in this report from page 28 to page 42, and page 64 to page 70.

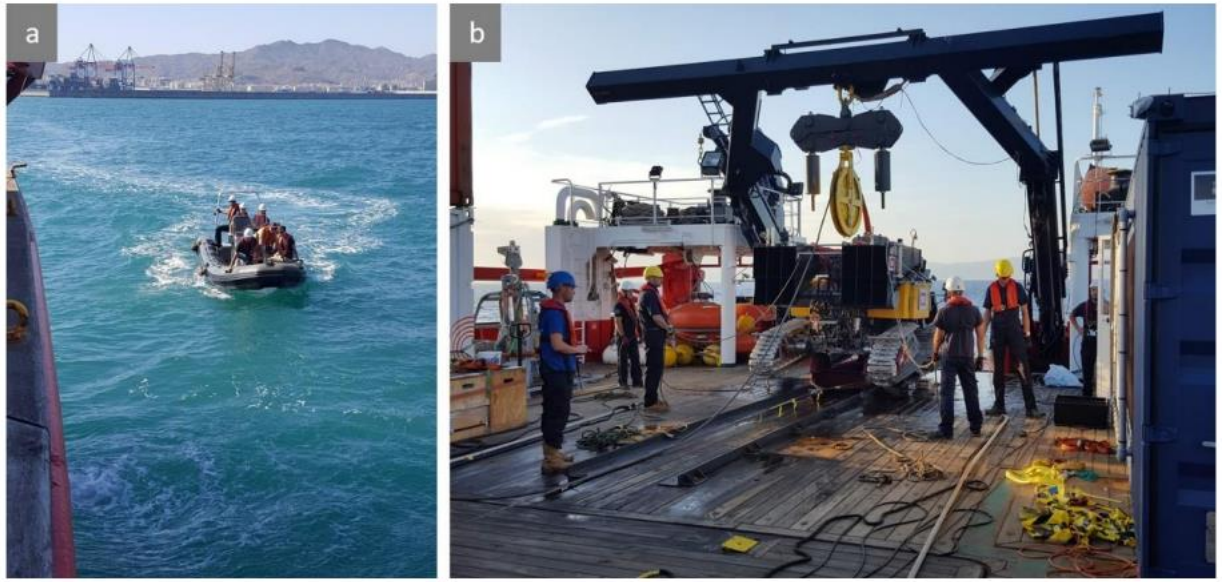


Figure 5.7. (a) RIB returning from the port of Málaga where three members of the Blue Nodules team were picked up from shore. (b) Apollo II ready for immersion test in Málaga Bight. Photos Henko de Stigter.

Figure 3.2. Launch of Apollo II during the Blue Nodules field test of 2019 in Málaga Bight. Photo Alberto Serrano.

SINTEF

Figure 5.1. Cruise track.

Blue Harvesting (2019 - 2022)

TU Delft

IHC

RWTH AACHEN UNIVERSITY

ICM Institute of Marine Sciences

AARHUS UNIVERSITY

NIOZ Royal Netherlands Institute for Sea Research

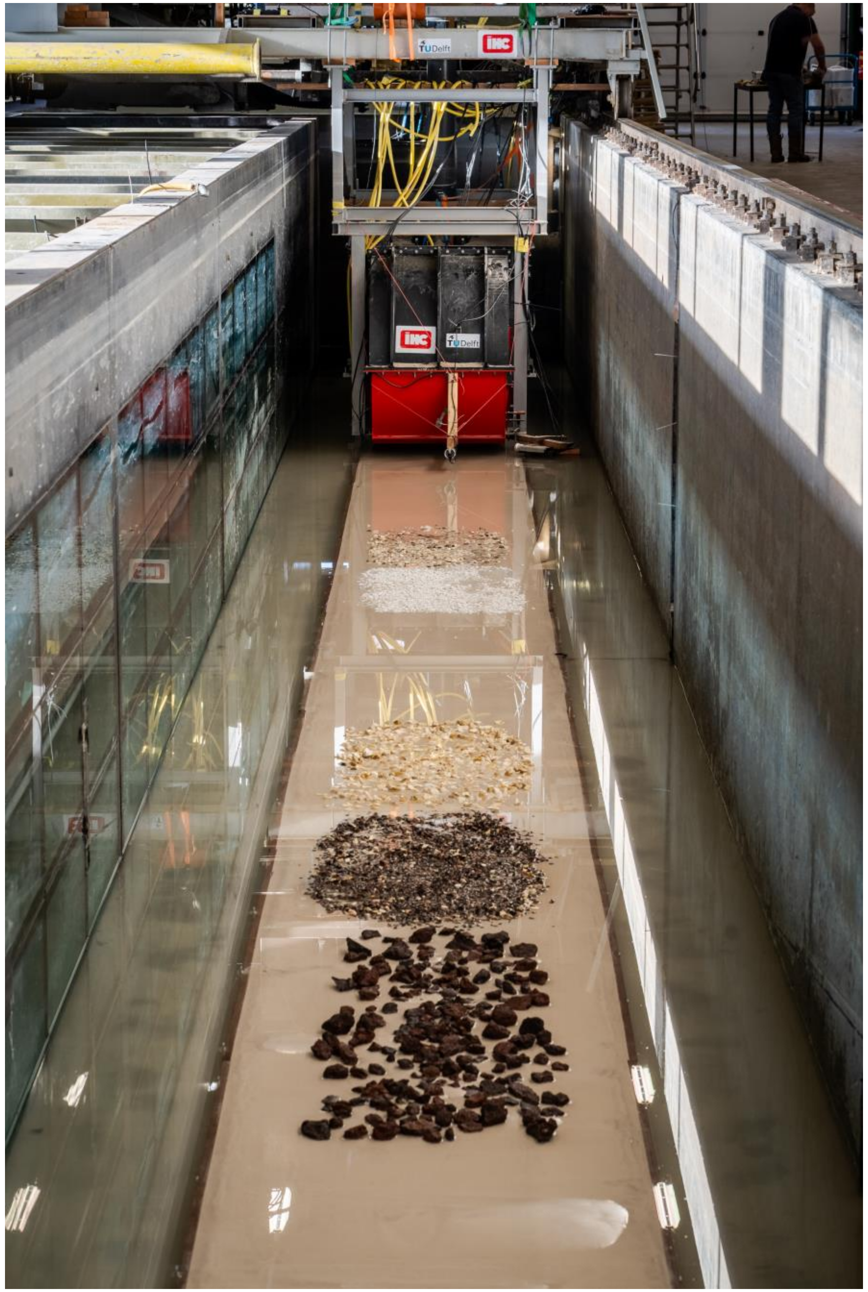
JACOBS UNIVERSITY

UPC UNIVERSITAT POLITÈCNICA DE CATALUNYA BARCELONATECH

seascape consultants ltd

Blue Harvesting (2019 – 2022)

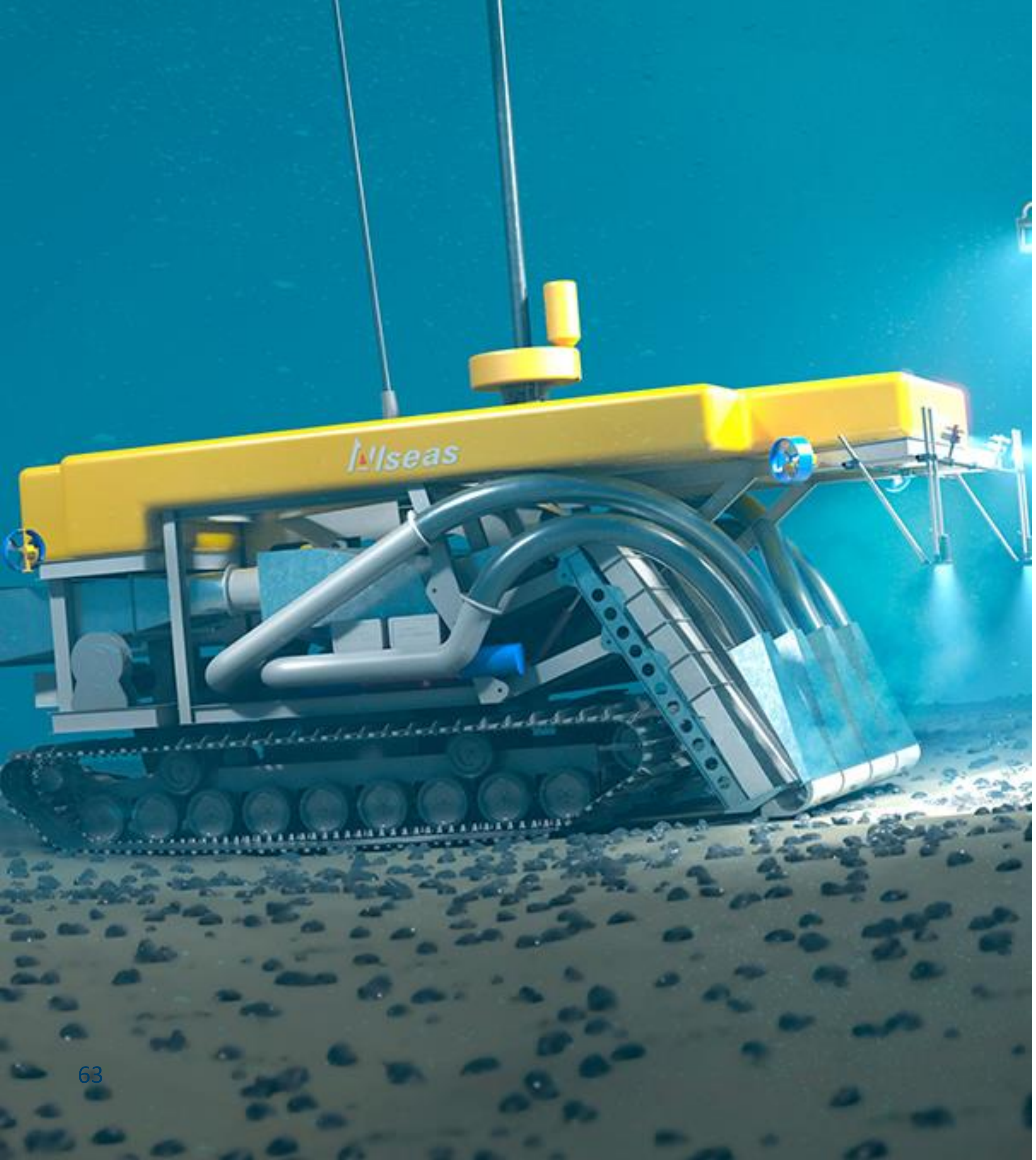
- The Blue Harvesting build forth on the Blue Nodules project. The project began its work in 2019.
- The project set out to make a step in enabling deep sea mining while minimizing its environmental impact. It aims to design, build, and test a hydraulic nodule collector in an operational environment, being a poly-metallic nodule field in the **NE Atlantic**, while minimizing its environmental impact.
- Within this project, most effort will be spent on reducing the plume generation and dispersion caused by the hydraulic nodule collector.
- Project coordinator Rudy Helmons (TU Delft) says: *"The three-year project can be regarded as a success if the full-scale hydraulic nodule collector performs successfully in its operational environment, while setting a new benchmark regarding its environmental performance."*
- A test in the Northeast Atlantic Ocean was done in the summer of 2021 but the results are not available.



SINTEF

AllSeas & TMC

- AllSeas and The Metals Company (TMC) have successfully completed several tests for its nodule collector, a project they have been working on since 2019.



Deployment and wet test commisioning (April 2022)

- TMC said it had together with AllSeas, completed the deployment and wet-test commissioning of their pilot robotic nodule collector vehicle at the **Port of Rotterdam.**
- Covering a distance of 4553 meters, AllSeas engineers drove the vehicle forwards and backwards at different speeds, and in different directions. In addition, tests were undertaken to raise and lower the adjustable collector heads, another critical function.

SINTEF

Deepwater test (Early May 2022)

- Describing the deepwater tests, TMC said:

- *"Engineers successfully lowered the AllSeas-designed collector vehicle to the seafloor at depths of 2,470 meters, marking the first time the vehicle had been subjected to ultra-deep-water temperatures and pressures. Engineers then subjected the vehicle to extensive testing of its various pumps and critical mobility functions, driving 1,018 meters across the seafloor."*

- The pilot nodule collector vehicle was deployed from the Hidden Gem vessel and lowered to the seafloor.

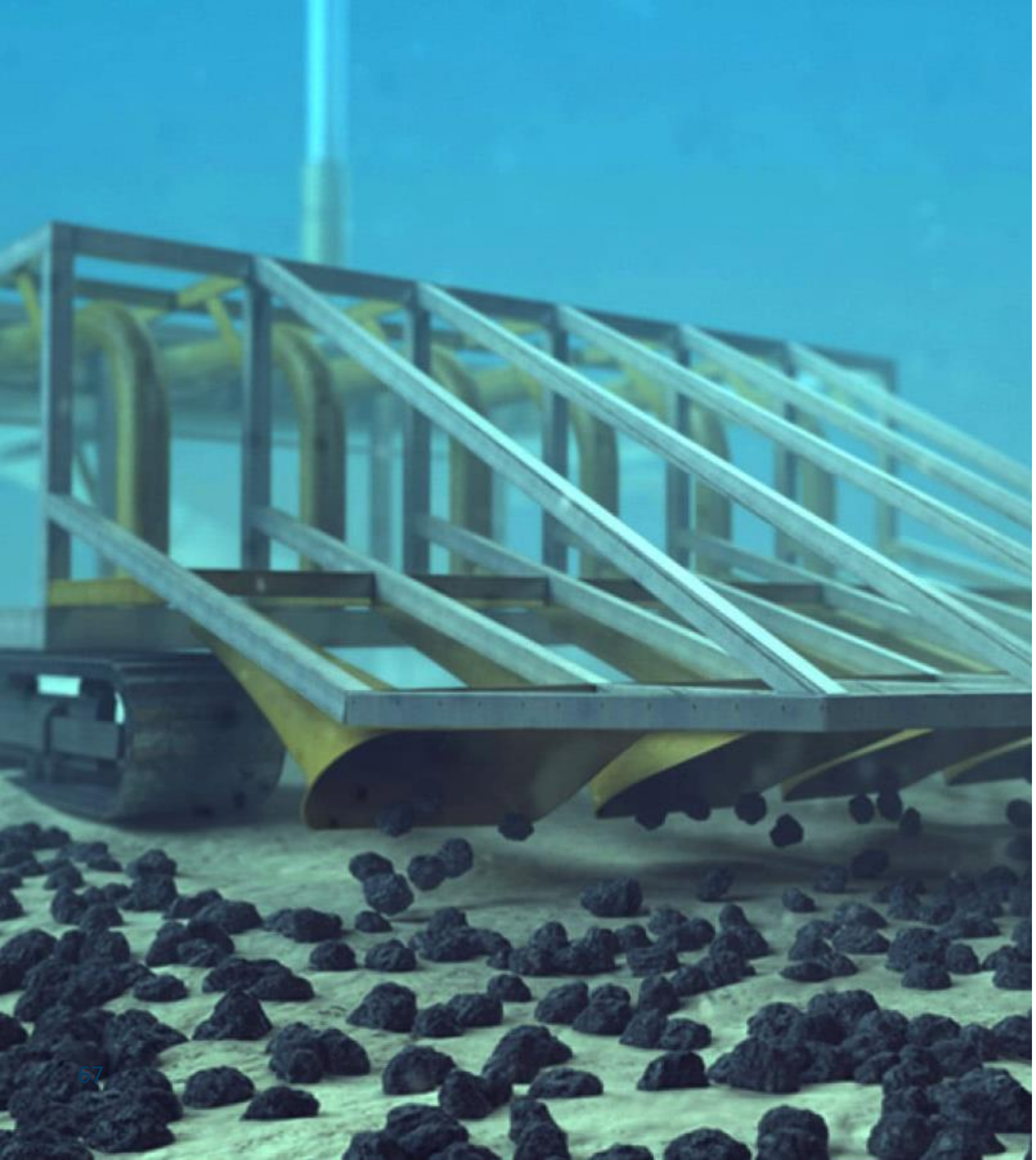
SINTEF

Riser pipe and jumper hose test (Late May 2022)

- Engineers aboard the Hidden Gem vessel deployed the flexible jumper hose, connected it to the base of the riser and then launched the pilot riser, lowering the assembly to a depth of around 650m meters.
- Using the remotely operated vehicle (ROV) installed on the Hidden Gem, engineers then made a sub-sea connection between the jumper hose and collector vehicle which was previously deployed to the seafloor in 745m water depth.
- AllSeas used the derrick onboard the former drillship for at-sea construction of the pilot riser system which will ultimately extend to 4km deep when deployed later this year in the **Clarion Clipperton Zone (CCZ) of the Pacific Ocean.**

Future plans

- All trials to date are in preparation for full pilot nodule collection system trials later this year (2022) over an 8 km2 section of the **NORI-D contract area in the Clarion Clipperton Zone.**
- The test is expected to happen at 5000 m depth and was greenlit by the International Seabed Authority on the 7th of September 2022. Approximately 3,600 tonnes of polymetallic nodules are expected to be collected during the trial, with an expected conclusion in the fourth quarter of 2022. This will be the first such test of its sort in the Clarion Clipperton Zone since the 1970s.
- In March 2022, TMC signed a non-binding Memorandum of Understanding with Epsilon Carbon to complete a pre-feasibility study for a commercial-scale deep-sea nodule processing plant in India called Project Zero Plant.



Development of the technology

- AllSeas developed and manufactured the core nodule collection technology and surrounding mechanical assembly for the subsea vehicle in-house.
- Seatools brought the nodule collector alive by the delivery of the entire hydraulic, electronic, and control system. This included the entire development trajectory including design, building, qualification, and testing.
- Although Seatools could draw upon its experience and toolbox developed through similar kinds of projects from the past, still a significant part of the project concerned the development and qualification of new technological elements.
- For instance, in order for AllSeas to be able to extensively monitor and control the equipment, process, and environment, Seatools extended its technology base with a new range of sensors.

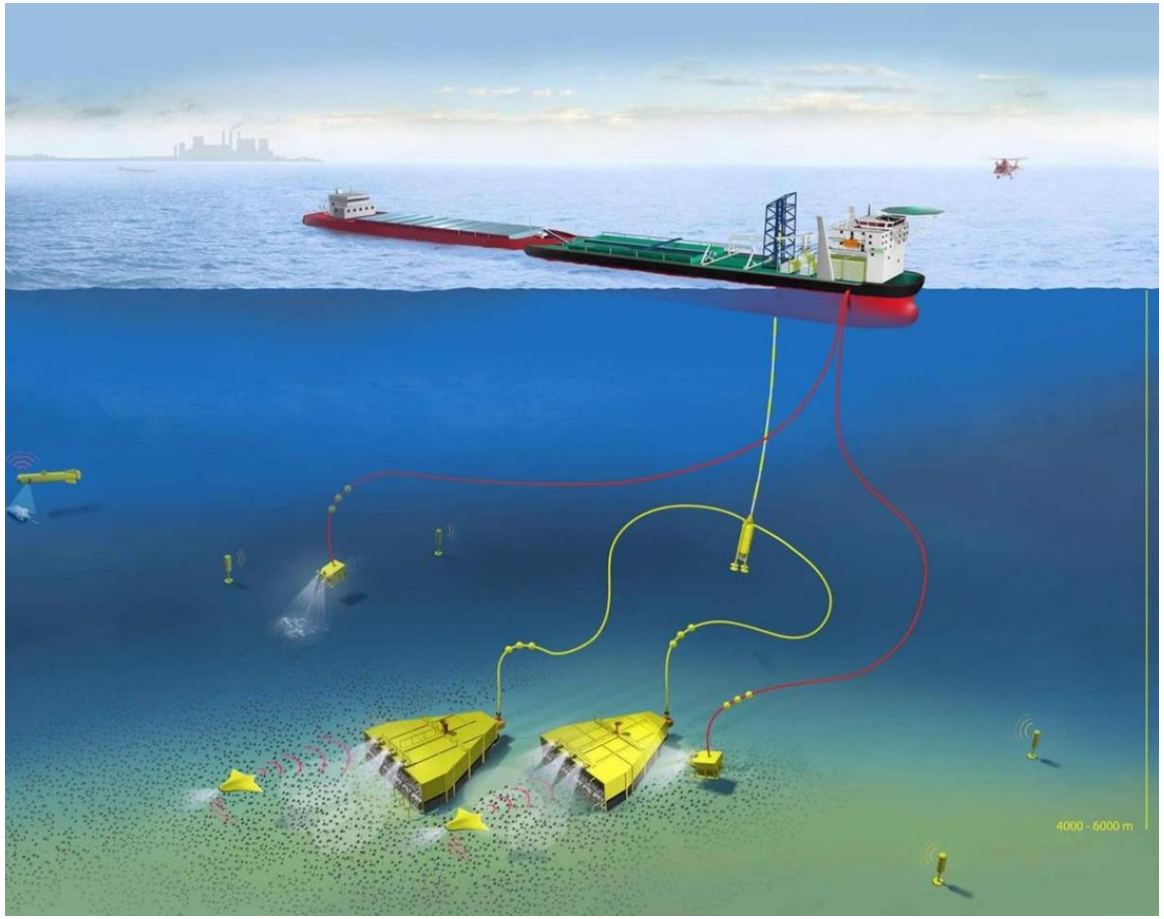
Blue Atlantis

- Aimed to establish the world's only deep-sea mining test facility, covering RTD, mining tests, standards development, and market access support. The consortium had 45 partners from 8 European countries along the entire value chain.

- Leadership was split between **German and Portuguese actors**. Location around the **Azores Archipelago.**

- Further information is hard to find, **but** it seems like an important project.

- https://single-market-economy.ec.europa.eu/sectors/raw-materials/eip/raw-materials-commitment/innovative-mining-marine-mineral-resources-european-pilot-mining-test-atlantic-tools-facilities_en

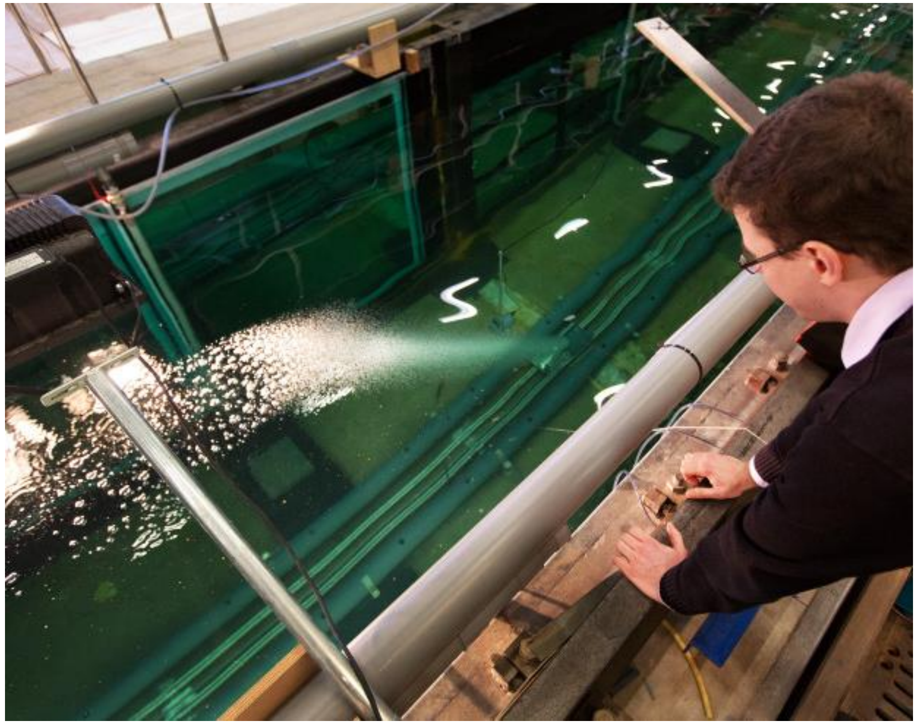


Deltares

Deltares

- Data Facilities:
  - iD LAB: - Interactive data research laboratory
  - Global river flow forecast service
- Hydro Facilities:
  - Atlantic Basin
  - Pacific Basin
  - Scheldt Flume
  - Delta Basin
  - Delta Flume
  - Intake and Outfall Basin
  - Lock Facility
  - Alpha Loop
  - Advanced Measurement Techniques
  - Custom-made hydrodynamic instruments
  - Standard Measuring Instruments
- Geo Facilities
  - Geo Field Laboratory
  - Geo Model Laboratory
  - Deltares GeoCentrifuge
  - Geotechnical Laboratory
  - Geophysics facilities on land and at sea
- Geo/Hydro Facilities:
  - Biogeochemical Laboratory
  - Physical Laboratory
  - **Water and Soil Flume**
- Link to everything

Deltares – Water and Soil Fume

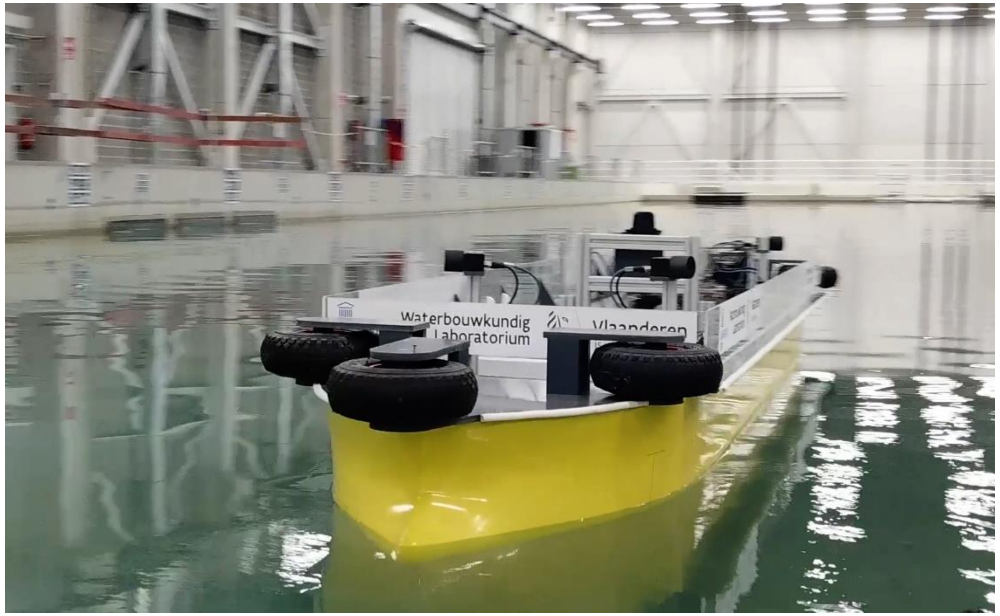


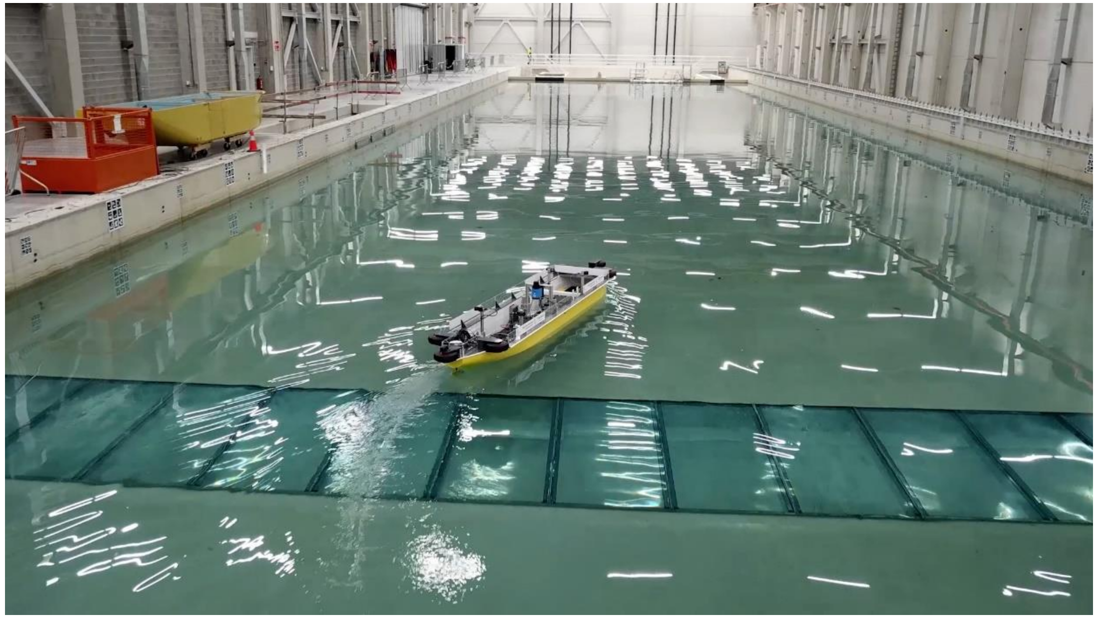
- **The Water Soil Flume (WSF) of Deltares is often used by our partners from the maritime, energy, dredging, and mining industry. This experimental facility is the go-to facility for soft soil-related R&D and innovations.**
- **Some of the unique features of WSF are:**

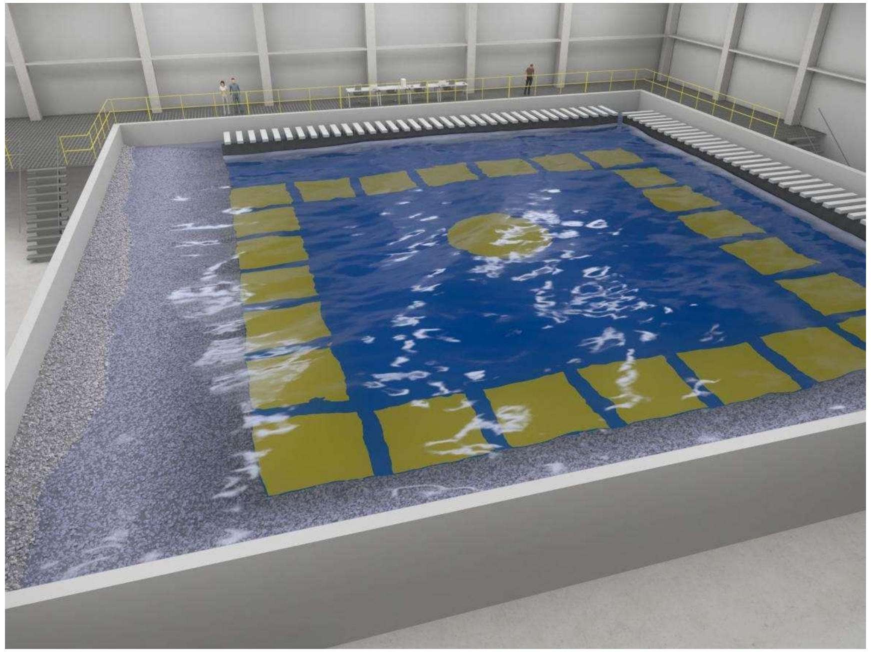
  - The in-ground concrete flume (50 m length, 5.5 m width, 2.5 m depth)
  - The carriage and rail system on top of the in-ground concrete flume
  - The unique possibility of using sand and mud (cohesive sediment) in the flume.
  - The clay factory with a production capacity of about 12 tons/day of clay.
  - The sand conditioning machine
  - The hexapod platform
  - The Plexiglas flume (25m length, 0.5m width, 0.7m depth).
  - And plenty of measurement devices to monitor and characterize properties of the soft soil-water mixture

Flanders Hydraulic Research Labaratory - Antwerpen

- In September 2016, the Government of Flanders decided to build a new research facility in Ostend with a towing tank and a wave basin. In 2023 these facilities shall be operational.
- The new towing tank have a total length of 174 m (of which 136 m useful length for testing), a width of 20 m and a maximum water depth of 1 m. In addition to this water level, waves with an amplitude up to 20 cm can be generated. The ship model designed for use in this towing tank has an overall maximum length of 8 m and a width of 1.5 m.
- In contrast to the current towing tank, the new towing tank have observation windows and an observation tunnel to easily visualise the flow next to and beneath the ship model. The fully automatic towing carriage will offer the same features as the current towing tank and additional functionalities are still being considered.
- The Coastal and Water Basin is a cooperation between the Universities of Ghent and Leuven and Flanders Hydraulics Research. In this 30 x 30 m² wave basin, scale models may be subjected to waves as well as currents and wind. Various wave paddles will allow a multi-directional wave climate to be created in combination with maximum currents of 0.4 m/s. Wind loads up to a maximum speed of 70 km/h can also be applied. The basin can be utilised in a wide range of fields and markets such as wave and tidal power, offshore engineering, coastal engineering or wave/current-vegetation interactions.
- Virtual Tour


Waterbouwkundig
Laboratorium
Vlaanderen





Other facilities and tools

- Numerical modelling
- Physical modelling
- Ship manoeuvring simulators
- Measurement techniques and instruments
- Sedimentological laboratory

Marin

- Facilities Leaflets
- Facilities
- Basin:
  - Seakeeping and Manoeuvring Basin
  - Concept Basin
  - Offshore Basin
  - Depressurised Wave Basin
  - Shallow-Water Basin
  - Deep-Water Basin
  - Caviation Tunnel
  - Atmosphere
  - Zero Emission Lab

- Numerical facilities
  - MARCLUS4
  - MARCLUS5
- Software tools
- Measurement Techniques
  - High Speed Video
  - Particle Image Velocimetry (PIV)
  - Multi Component Transducers For Propeller Loads
  - Outdoor Equipment

Pommec-Hytech

- As of December 2021, the companies formerly known as Pommec BV and IHC Hytech BV have merged into Pommec-Hytech.
- The expertise of Pommec includes field installation, commissioning & Testing, Service and Lifecycle support for all Pommec products and leading Industries Brands. This varies from stand-alone equipment to highly engineering and integrated systems.
- Available services:
  – Operational Support
  – Survey & Inspection
  – Maintenance
  – Parts
  – Training
- Detailed overview.

SINTEF

Teknologi for et bedre samfunn

Mer detaljer
Prosjekt og infrastruktur i Japan

Kartlegging utført av SINTEF

JAPAN

OVERVIEW DEEP-SEA MINING

Development of exploration and production techniques

Japan Oil, Gas and Metals National Corporation

- **Remote sensing exploration techniques:**

  - JOGMEC has developed mineral exploration techniques to identify hydrothermal alteration zone by using optical sensors data, and also realized geology discrimination techniques to promote the efficient mineral exploration in vegetated areas by using SAR data.

- **Geophysical exploration techniques:**

  - JOGMEC has researched and developed "SQUITEM", which increases the depth and accuracy of exploration. "SQUITEM" is a transient electromagnetics (TEM) system using the High Temperature Superconductive Quantum Interface Device (HT SQUID) magnetometers.
  - Until now, SQUITEM already applied to more than 10 exploration projects all over the world.

- **Development of hydrometallurgical technology using bioleaching, in Chile:**

  - JOGMEC is performing search and evaluation of microorganisms and column leaching tests and, based on the test data, carrying out validation tests at a pilot plant in Chile, using locally produced copper ore.

Development of metal recycling and refining technology

- **Development of technology for recovering rare metals from waste small electronic and electric appliances:**

  - Small electronic and electric appliances contain base metals such as copper and zinc, precious metals including gold, as well as rare metals such as tantalum and cobalt.

  - JOGMEC has been carrying out tests for recovering these metals from waste small electronic and electrical appliances and fact-finding surveys, as well as basic tests for establishing the flow for recovering rare metals.

  - Since 2012, JOGMEC has also been developing recycling technology for recovering tantalum and cobalt.

Exploration and technological development for deep seabed polymetallic sulphides

- From 1985 to 2003, JOGMEC carried out surveys for polymetallic sulphides in the East Pacific Rise, the Okinawa Trough and the Izu-Bonin back-arc basin.
- JOGMEC has conducted resource estimate surveys since 2008 in the Okinawa Trough. In 2012, JOGMEC started drilling survey using on board drilling machine system of the research vessel “Hakurei”.
- In addition, JOGMEC successfully carried out the world’s first crawl and mining test using a small test mining machine in 2012 also the world’s first pilot test of excavating and ore lifting for seafloor polymetallic sulphides under the sea area in 2017.

Exploration activities for cobalt-rich ferromanganese crusts

- Since 1987, JOGMEC has conducted surveys for cobalt-rich ferromanganese crusts in the Area in the western Pacific Ocean.
- Based on the survey results and after screening by the International Seabed Authority (ISA), JOGMEC acquired exclusive exploration rights to an area (3000 km2) in international waters 600 km southeast of Minami Torishima (Marcus Island) in 2014.
- JOGMEC is conducting the exploration work with environmental impact assessment and technical development for production technology on the basis of the contract with ISA.

Exploration activities for manganese nodules

- JOGMEC carried out surveys in the ocean southeast of Hawaii, known as Clarion-Clipperton fracture zone and resource assessment surveys from 1975 to 1996.
- Based on the results, JOGMEC acquired a manganese nodule exploration area of 75,000km2 in December 1987, pursuant to the United Nations Convention on the Law of the Sea.
- JOGMEC resumed surveys in this exploration area in 2011.

2017 Pilot Test: Development of the ore collecting test machine

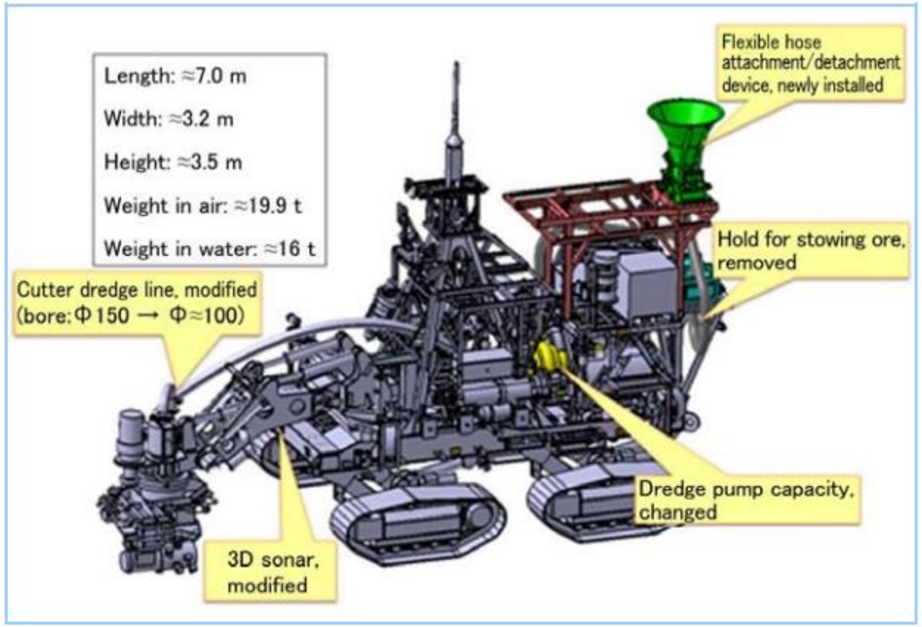


Figure 2 Modifications made to the Ore collecting test machine
The dredge pump and line of the Mining Element Engineering Test Machine were modified and a device to connect the flexible hose was newly installed.

- Before the pilot test, a Mining Element Engineering Test Machine was built, with the aim of obtaining technical data related to the seabed mining unit.
- Completed in 2012, the Mining Element Engineering Test Machine underwent testing including offshore trials, and both technical data and subsea operation data were collected.
- The ore collecting test machine used in the pilot test was a modified unit of this Mining Element Engineering Test Machine

Excavator dredging head

- A 2-axis cutter head, which was the excavator dredging head of the Mining Element Engineering Test Machine, was also used as the excavator head of the ore collecting test machine.
- The 2-axis cutter head can be rotated and consists of two spinning cutter drums positioned opposite to each other. With the rotational and spinning movements, excavated ore is gathered at the center of the excavator head where the dredging mouth is positioned.
- The excavated ore is then sucked through the mouth for slurry transport.
- The bore of the dredge line in the ore collecting test machine was changed to $\phi \approx 100$ from ϕ 150, making it consistent with the riser pipe (inner diameter of ≈100 mm).

Dredging system

- In the Mining Element Engineering Test Machine, dredged ore is stowed in the hold at the rear of the machine and is recovered by the ship together with the machine itself. However, in the case of the ore collecting test machine, dredged ore is slurry transported via the flexible hose to the submersible pump unit which is positioned 50 m above the ore collecting test machine.
- The slurry flow velocity is to be maintained at the level required for lifting ore. The flow rate and head of the dredge pump were adjusted according to the modifications made in the piping system of the ore collecting test machine. The dredge line bore size of the ore collecting test machine was $\phi \approx 100$.
- After the hold for stowing ore was removed, the dredge line was connected to a flexible hose attachment/detachment device. The flexible hose can be attached to the ore collecting test machine by dropping the metal fitting at the end of the flexible hose from above into the cone of the attachment/detachment device and fixing the metal fitting with a hydraulic cylinder. An abrasion-resistant rubber hose with an inner diameter of $\phi \approx 100$ was used as the flexible hose.

Dock test

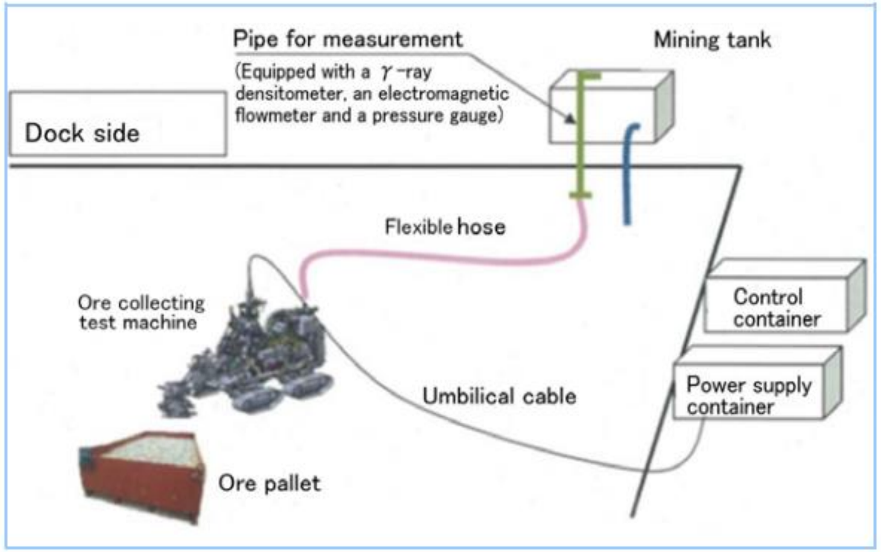


Figure 3 Dock test overview
An ore pallet was placed at the bottom of the dock. The ore collecting test machine excavated/dredged and slurry-transported the dredged ore to the mining tank at dockside.

- The dock test was conducted to examine the dredged slurry transport performance of the modified ore collecting test machine.
- In this test, the ore collecting test machine dredged crushed rocks that were placed in the ore pallet at the bottom of the dock, and transported them as a slurry via a flexible hose to the mining tank at dockside.
- The flow rate, pressure and slurry concentration were measured at the onshore measurement site after setting up a pipe for measurement.

Dock test

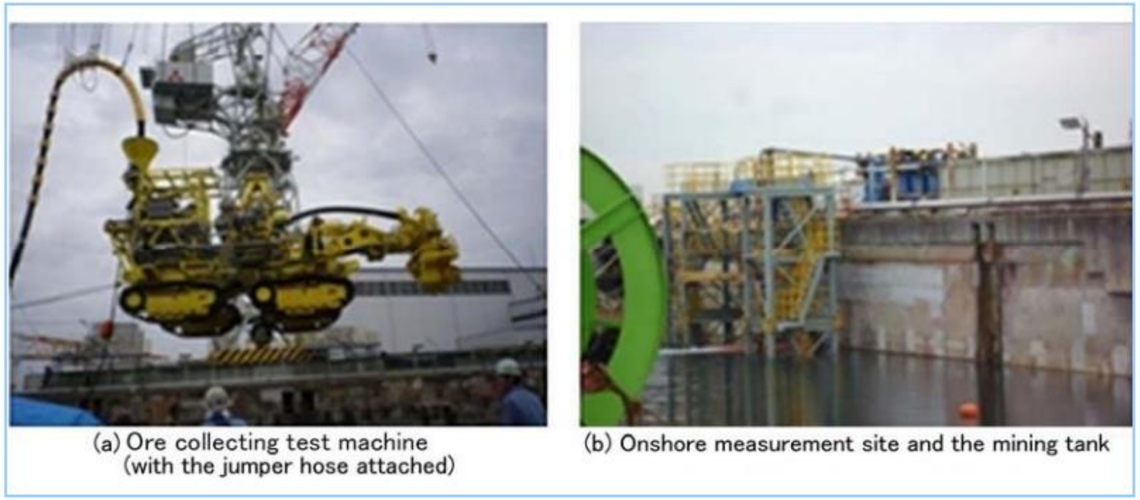


Figure 4 Dock test
(a) The ore collecting test machine, moving in the air with the flexible hose attached to the flexible hose attachment/detachment device
(b) The onshore measurement site and the mining tank at dockside. The pipe allocated for measurement is the vertical part of the piping erected from the water surface. The mining tank is placed at dockside.

- The following knowledge was acquired from the results of the test:

  - It is possible for the ore collecting test machine to excavate/dredge and lift the dredged ore through the flexible hose.

  - Although the depth of excavation and the boom swing speed are the two factors that determine the concentration of slurry, the concentration can be controlled by adjusting the depth of excavation. The influence of boom swing speed is small.

  - The ore collecting test machine needs to be fitted with a γ-ray densitometer, because it is necessary to know the concentration at the time of excavation to realize stable control over the concentration (Subsequently, a γ-ray densitometer was installed).

SINTEF

Development of the submersible pump system

- The submersible pump measured 3 m (L) x 3 m (W) x 7 m (H) and weighed approximately 28 tons in the air.

- The submersible pump unit consisted of two pumps placed in parallel, with one rotating clockwise and the other counterclockwise, thereby enabling them to counteract each other's torque. Installed on the top of the submersible pump unit was a riser adapter to connect to the riser pipe, which was supported by a gimbal structure. When the pump turned off, ore in the riser pipe would be discharged by the stone ejection mechanism.

- A negative-pressure prevention device was installed at the inlet of the submersible pump, which aimed to prevent the occurrence of negative pressure by opening a bypass valve at the time of the occurrence of an interruption in the flow of the flexible hose. The flexible hose was attached at the bottom of the submersible pump unit via the flexible hose detachment device, by which the flexible hose could be detached from the unit when it could not be disconnected from the ore collecting test machine. The number of rotations of the submersible pump was controlled by the inverter on the ship, while monitoring the voltage and current. For the monitoring of the conditions of the submersible pump unit, the flow rate, concentration, and pressure were monitored on the ship, whereas pressure monitoring was carried out at both the upstream and downstream sides of the subsea slurry pump unit.

- Power supply to the submersible pump unit was carried out using an umbilical cable. The umbilical cable had two motor power supply lines and a single control power supply line (a total of three lines). The motor was supplied with high voltage power that was boosted to 6000 V.

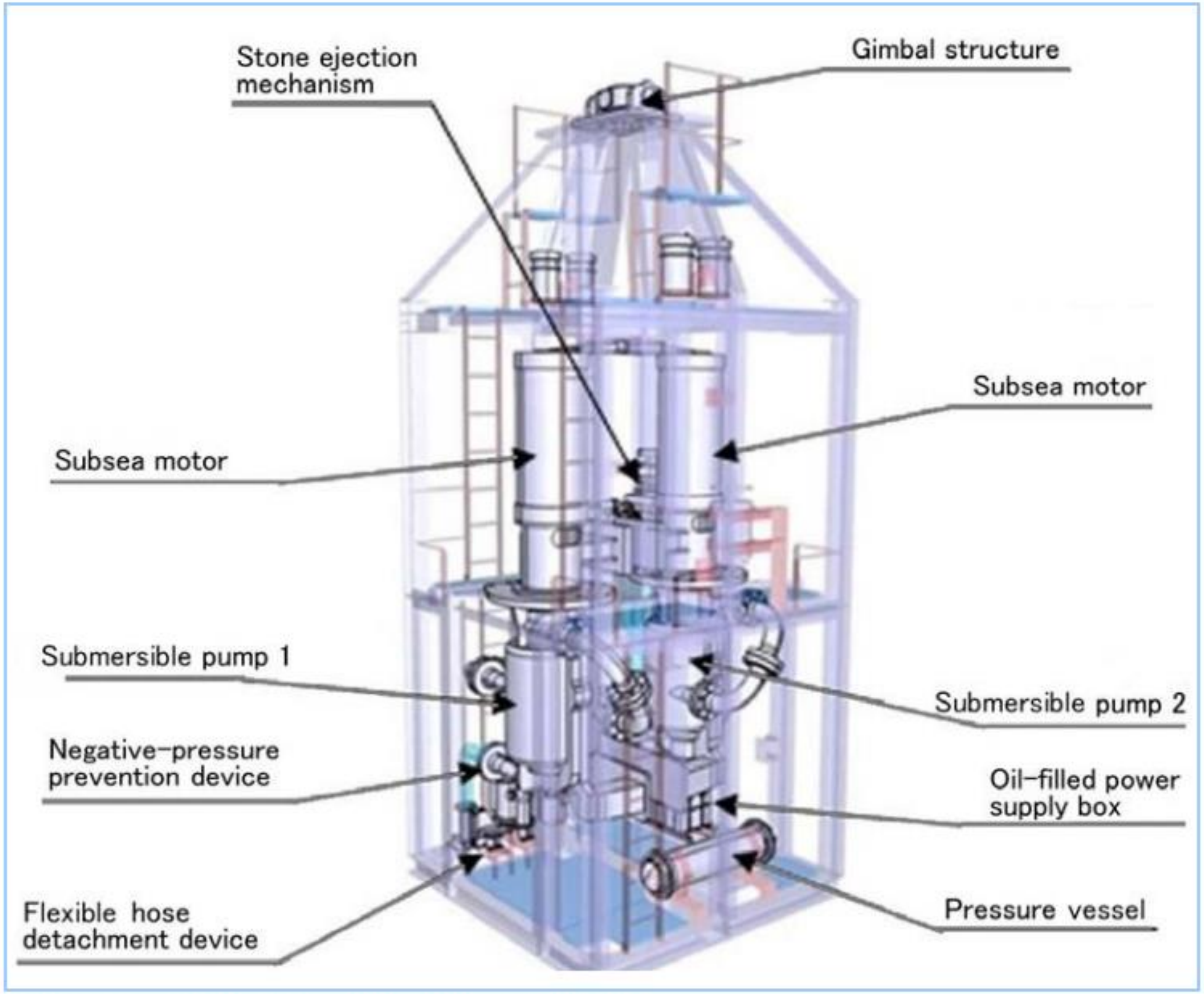
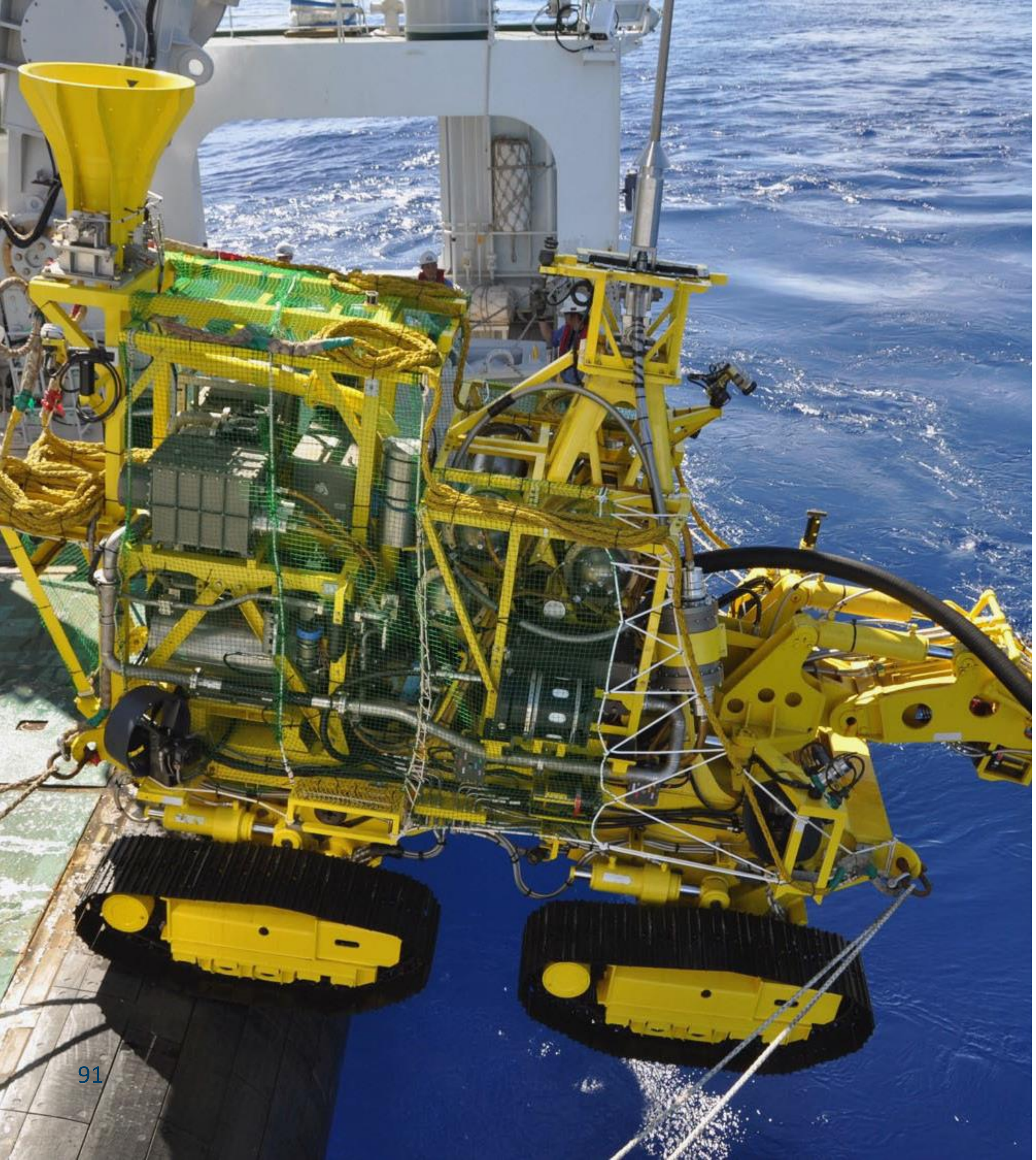


Figure 5 Submersible pump unit configuration
The submersible pump unit mainly consists of the submersible pumps, pressure vessel, stone ejection mechanism, negative-pressure prevention device, and flexible hose detachment device.



Pilot Test 2017 (1)

- The pilot test was commenced in mid-August 2017. The ore collecting test machine was on board the marine resource research vessel “Hakurei,” while the submersible pump unit was on board the ore lifting support vessel.
- The two vessels separately navigated toward the waters off Okinawa and rendezvoused at the test location.
- The test started with the ore collecting test machine landing on the seabed at the test point (where crushed ore had been piled beforehand) and being connected to the flexible hose coming down from the submersible pump unit, which was followed by the formation of a catenary.
- After operating the test system using seawater (i.e., without ore) as a preliminary check, the slurry ore lifting test was commenced.

Pilot Test 2017 (2)

Figure 6 Submersible pump unit
The submersible pump unit is mounted on the moon pool hatch cover of the ore lifting support vessel.

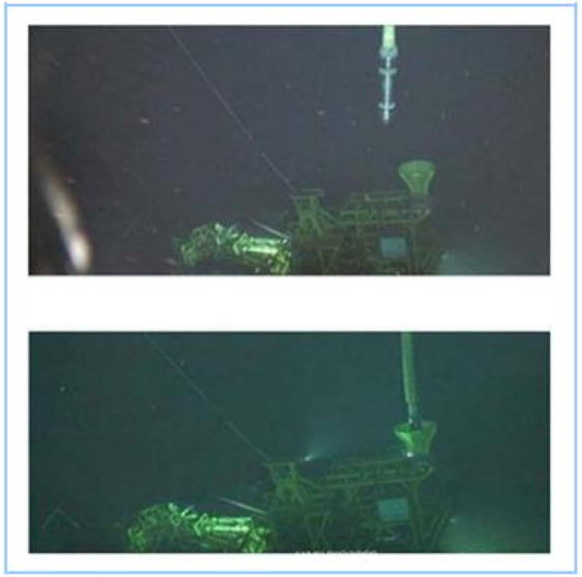


Figure 7 Ore collecting test machine and the flexible hose before and after attachment
The flexible hose was being manipulated by monitoring through ROV to get it closer and attach to the ore collecting test machine on the seabed (above).
Immediately after the flexible hose was successfully attached to the ore collecting test machine on the seabed (below).

- To collect data, the slurry ore lifting test was conducted by lifting slurry ore for several minutes and repeating about a dozen times.
- The test started from slurry at a low concentration and was continued by gradually increasing the amount. The concentration at the time of excavation and dredging was primarily controlled through the depth of excavation by the ore collecting test machine.
- The highest concentration in the ore lifting test was produced by excavating to the depth of 100 mm and approximately 6% was recorded as the average concentration in the riser pipe.
- Monitoring the γ-ray densitometer, which was mounted on the ore collecting test machine, enabled the concentration to be regulated to a certain extent.
- When a sudden, increased concentration is observed, it can be suppressed by swinging the boom and stopping excavation further down. The γ-ray densitometer of the ore collecting test machine was useful when controlling the concentration.

Pilot Test 2017 (3)

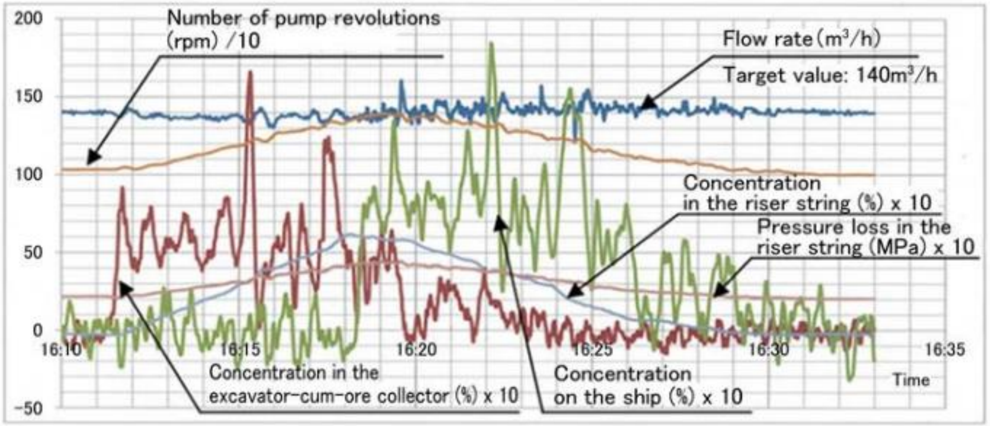


Figure 8 Slurry ore lifting test and automatic flow rate control results
As the slurry concentration changes, the pumping load changes. However, the flow rate was successfully maintained in the neighborhood of the target level by following the load change and automatically adjusting the number of pump revolutions.

- It takes about 7 minutes to raise ore to the ship after being dredged by the ore collecting test machine. During this time, the concentration in the riser pipe increases and the pressure loss in the riser pipe increases.
- Although the number of rotations of the submersible pump can be controlled either manually or automatically, automatic control has been selected because it is impossible to manually handle load fluctuations during slurry ore lifting.
- During the ore lifting test, the flow rate was successfully maintained within the approximate range of the target level (140 m3 /h) ± 5 m3 /h.

SINTEF

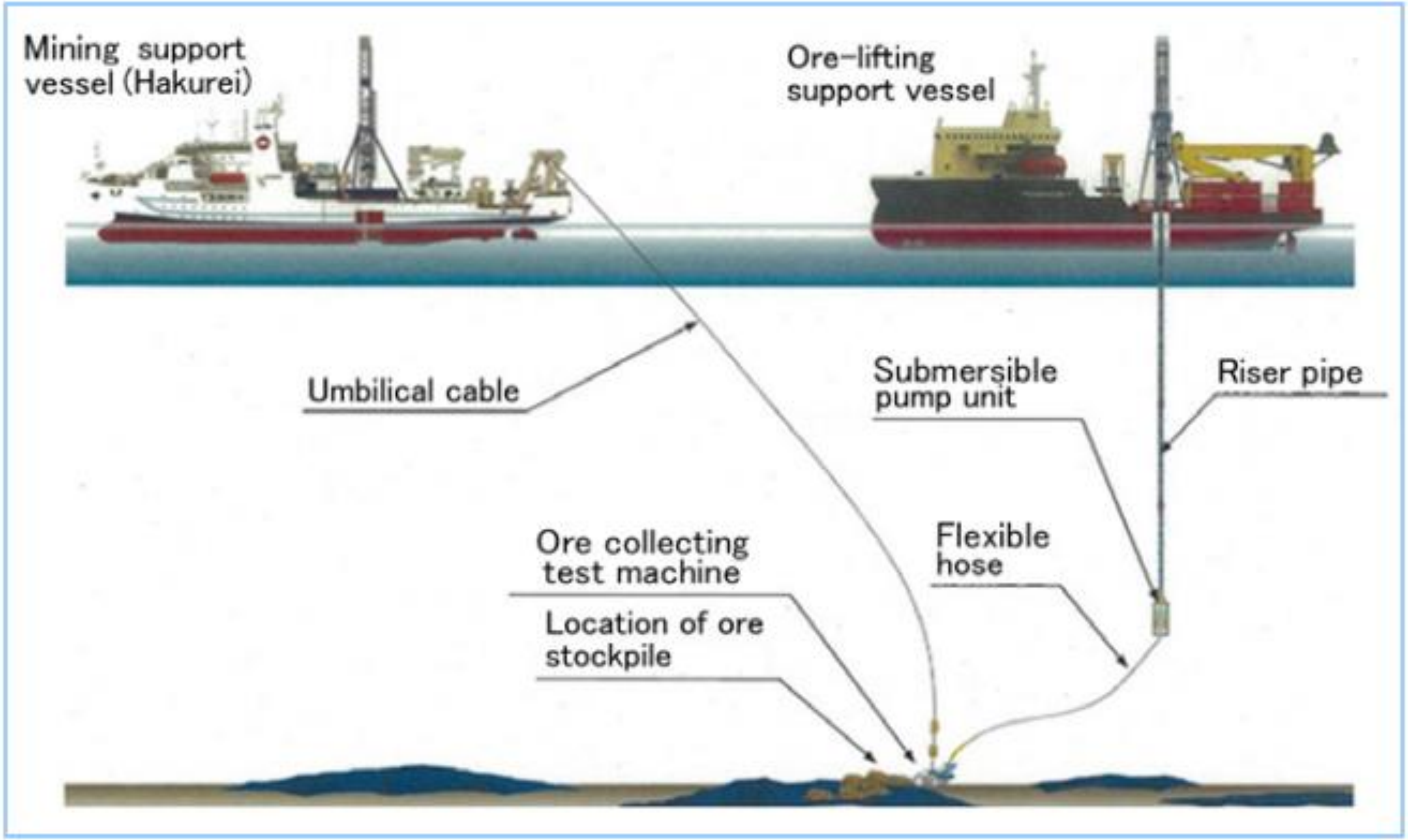
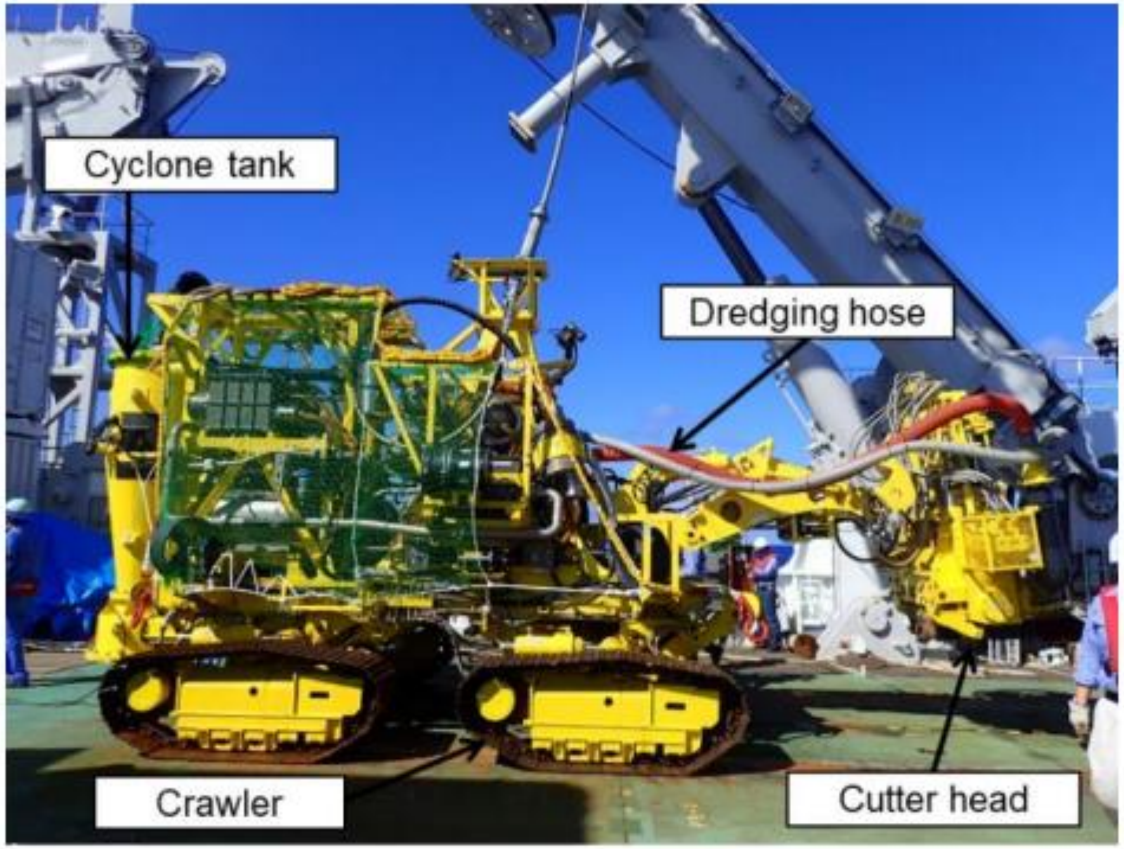


Figure 1 Schematic diagram of the pilot test system

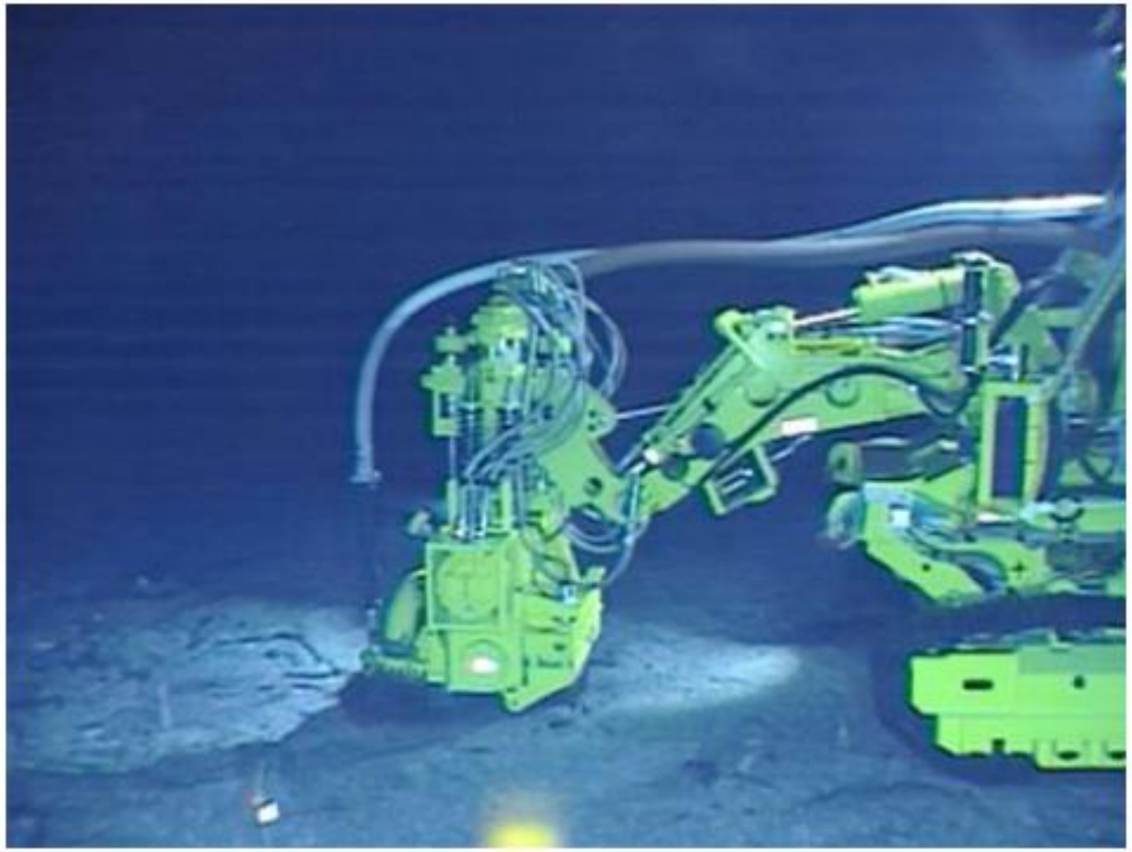
The excavation and ore lifting test was carried out by simultaneously deploying two ships (i.e., the mining support vessel and the ore lifting support vessel).

Excavation Test 2020

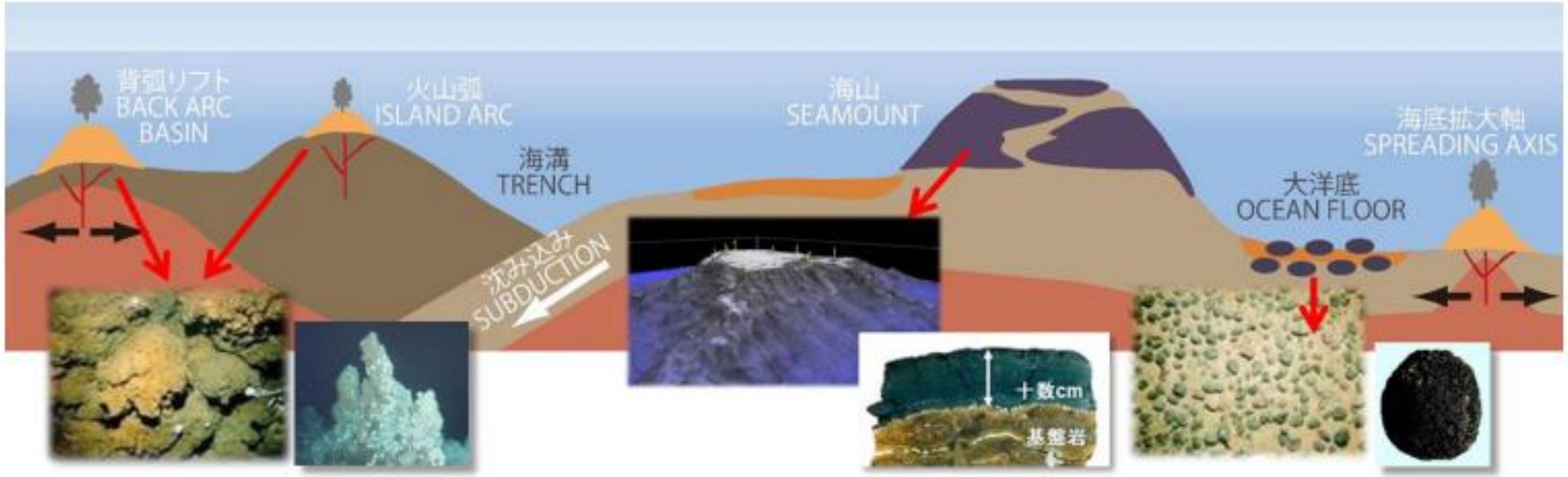
- After reviewing a detailed environmental impact, JOGMEC, commissioned by the Japan Ministry of Economy, Trade and Industry (METI), conducted the world's first successful excavation test of a cobalt-rich crust on the seabed of Japan's exclusive economic zone (EEZ)
- The tests were held under various conditions, including over sloping and sandy seabed. The team also carefully monitored for any impact on the surrounding environment, prior, during, and following the excavation of the crust to rule out any serious environmental impact.
- Using a crust-excavation testing machine, JOGMEC collected 649 kilograms of cobalt and nickel-rich seabed crust aboard the marine resource research vessel "Hakurei" in July 2020.
- The traction and collection system appear identical, with only apparent changes to the cutting head and the addition of a dredging hose. A cyclone tank has been connected to the rear of the vehicle where it previously held what appeared to be a collection hopper.
- As such, this project represents less a technological advancement in the extraction of ore from the deep ocean than a priority shift from seafloor massive sulphides to cobalt-rich crusts. JOGMEC noted that the Takuya 5 seamount could meet Japan's demand for cobalt for the next 88 years and its demand for nickel for the next 12 years.



Crust-excavation testing machine



The machine on the seabed



	Seafloor hydrothermal deposit	Cobalt rich crust	Manganese nodule
Characteristics	Polymetallic massive sulfide ore deposits formed by precipitation of metal components contained in hot water ejected from the seafloor	A manganese oxide with a thickness of about several millimeters to over ten centimeters that covers basement rocks from the summit to the slope of the seamount	An ellipsoid manganese oxide distributed on the seafloor with size of 2 to 15 diameters
Located area	Okinawa, Izu/ Ogasawara	Minami-Tori-shima Island	The Pacific
Containing metals	Copper, lead, zinc, gold, silver	Cobalt, nickel, copper, platinum, manganese etc.	Copper, nickel, cobalt, manganese etc.
Sea depth	700 to 2,000 meters	800 to 2,400 meters	4,000 to 6,000 meters

SINTEF

JOGMEC cooperation partners

- Deep Ocean Resources Development (DORD)
- National Institute of Maritime, Port and Aviation Technology (MPAT) *(Forøvrig er 3/10 av deres største internasjonale samarbeidspartnere norske universiteter, UiO, UiT, UNIS)*
- Mitsubishi Heavy Industry
- Mitsubishi Shipbuilding
- Nippon Steel
- Sumikin Engineering Co
- Shimizu Corporation
- Sumitomo Metal Mining Co
- Fukada Salvage & Marine Works Co
- Mitsui Miike Machinery Co

Other important actors

- Japan Agency for Marine-Earth Science and Technology (JAMESTEC)
- National Institute of Advanced Industrial Science and Technology (AIST)
- Research and Development Partnership for Next Generation Technology of Marine Resources Survey (J-MARES)
- The University of Tokyo
- Kochi University

Deep Ocean Resources Development (DORD)

- DORD has been actively involved with research and surveys on deep seabed mineral resources since early 1980's as the sole deep seabed mineral resources exploration company in Japan.
- Main achievements include independent prospecting surveys by a research vessel for polymetallic nodules from 1983, as well as exploration surveys, including analysis and assessment of the data obtained, until 1996 in the area within the Clarion-Clipperton Fracture Zone (CCZ) in the Pacific Ocean, of which license for polymetallic nodule exploration was acquired in 1987.
- Other areas of experience cover surveys on polymetallic sulphides and cobalt-rich ferromanganese, environmental impact studies, and development of deep-sea survey equipment that were entrusted by the Ministry of Economy, Trade and Industry (METI) and Japan Oil, Gas and Metals National Corporation (JOGMEC), and a mineral resource survey for the countries of the South Pacific Applied Geoscience Commission as an official development assistance project.
- Entrusted by the METI and JOGMEC, DORD has been conducting prospecting and exploration activities for polymetallic nodules in the CCZ by securing an exploration license with the International Seabed Authority (ISA) in 2001.
- https://www.dord.co.jp/english/index.html

DORD technology

Deep Ocean Resources Development

- Mining system:

  - DORD is considering to adopt a self-propelled ore collector system with a structure that moves while pulling a flexible riser (FR), which enables accurate route control. Although it has not been conducted in the marine environment, a paddle wheel type is currently under consideration as a collection method. By tentatively setting the internal diameter of the FR at 200 mm, the pump capacity and lifted quantity was calculated and the results of lifted quantity was approximately 3,300 t(wet)/day per one set of collector. From this results, it is assumed that three sets of mining system will be required to reach an annual lifting quantity of three million t(wet)/year.

- Metallurgical processing:

  - DORD has been working on development and verification of technologies to safely and efficiently extract base metals and rare metals such as copper, nickel, and cobalt contained in polymetallic nodules, as well as examination of selectable options.

- Economic evalutations:

  - From the viewpoint of the economic viability that is most important for commercial development of deep-sea mineral resources, DORD has been working on economic evaluations, focusing on the processing cost which accounts for about 70% of the development costs of polymetallic nodules, including uncertainties such as everyday metal price fluctuations.

Innovative Deep Sea Resources Survey Technologies - Ongoing cross-ministerial Strategic Innovation Promotion program (SIP Program)

- The objective of this program is to develop technologies for the marine resources at the sea bottom at a depth of around 6,000 m
- This program aims to survey the geological features of the sea floor and make a rough estimate of the amount of rare-earth element deposits in the Minami-Torishima area. This program also aims to develop an engineering system for effectively retrieving concentrated rare-earth element deposits from under the sea floor in the deep sea. Technological challenges with respect to future marine resources development also include the simultaneous operation of multiple autonomous underwater vehicles (AUVs) to enable effective surveying covering wide areas in the deep sea.
- Expect to develop the world's first survey and retrieval system for deep sea resources containing rare-earth elements. The technologies developed will be integrated into a system for various applications and transferred to industry to make the impossible possible.
- https://www.jamstec.go.jp/sip2/e/

Participating organizations

Japan Agency for Marine-Earth Science and Technology (JAMSTEC)

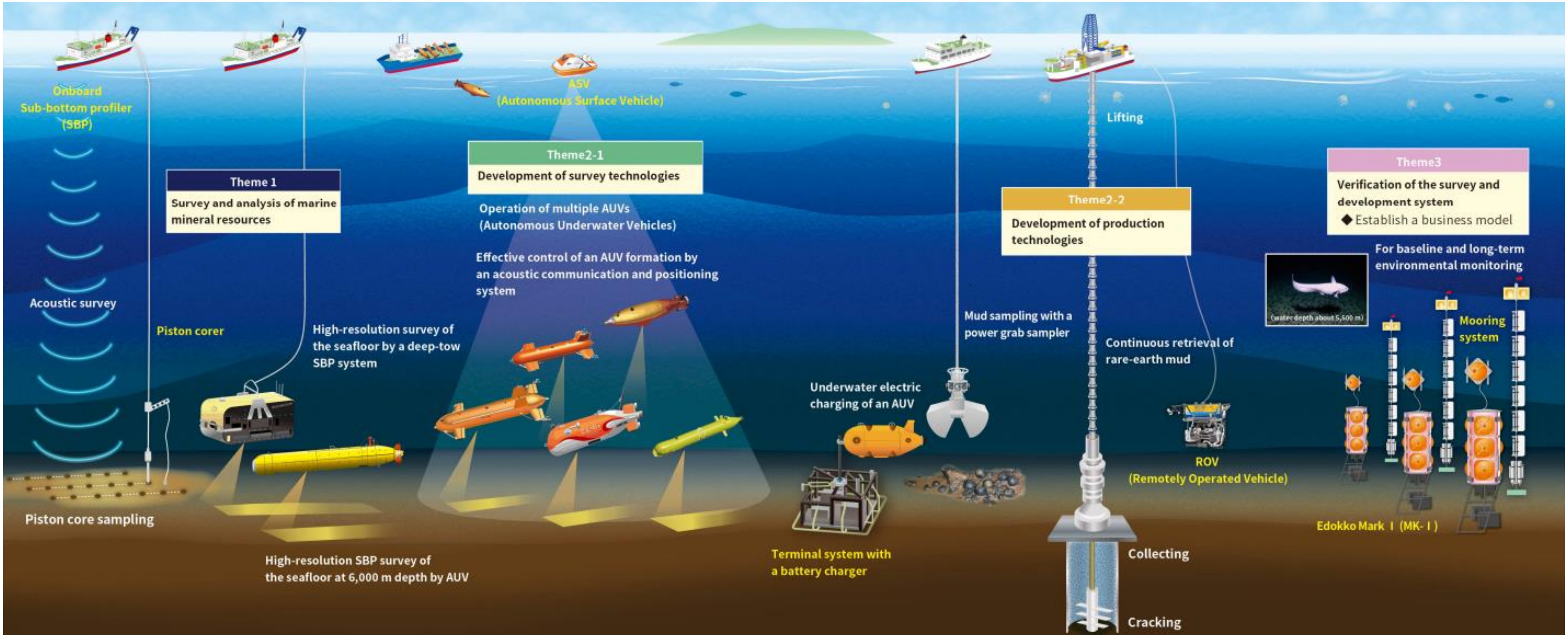
National Institute of Advanced Industrial Science and Technology (AIST)

National Institute of Maritime, Port and Aviation Technology (MPAT)

Research and Development Partnership for Next Generation Technology of Marine Resources Survey (J-MARES)

The University of Tokyo

Kochi University

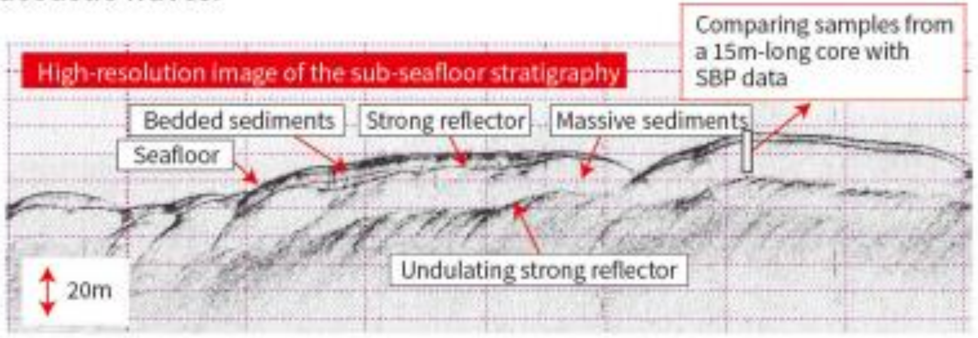


Onboard
Sub-bottom profiler
(SBP)
Acoustic survey
Piston corer
Piston core sampling
Theme 1
Survey and analysis of marine mineral resources
High-resolution survey of the seafloor by a deep-tow SBP system
High-resolution SBP survey of the seafloor at 6,000 m depth by AUV
ASV
(Autonomous Surface Vehicle)
Theme2-1
Development of survey technologies
Operation of multiple AUVs
(Autonomous Underwater Vehicles)
Effective control of an AUV formation by an acoustic communication and positioning system
Underwater electric charging of an AUV
Terminal system with a battery charger
Mud sampling with a power grab sampler
Lifting
Theme2-2
Development of production technologies
Continuous retrieval of rare-earth mud
ROV
(Remotely Operated Vehicle)
Collecting
Cracking
Theme3
Verification of the survey and development system
◆ Establish a business model
For baseline and long-term environmental monitoring
Mooring system
Edokko Mark Ⅰ (MK-Ⅰ)

Theme 1 Survey and analysis of marine mineral resources

■ Estimation of deposits with the onboard sub-bottom profiler

Under theme 1, we are surveying the seafloor surrounding Minamitori Island with a sub-bottom profiler (SBP) during research cruises. The sub-bottom profiling system identifies and characterizes layers of sediment below the seafloor, including those with high concentrations of rare-earth elements (REEs), by detecting reflected acoustic waves.



Cross section of geological structure beneath the floor of the deep sea

■ Identification of high-concentration layers by collecting geological samples

By collecting core samples and integrating the sample analysis data with data obtained by the SBP, we will be able to estimate with greater accuracy the amounts of rare-earth minerals in the deep sea around Minamitori Island.

Theme 2-1 Development of survey technologiess

<Operation of multiple Autonomous Underwater Vehicles (AUVs) and a deep-sea terminal system with a battery charger>

■ Operation of multiple AUVs

We are developing an acoustic system for the operation of multiple AUVs by integrating "communication" and "positioning" functions, and developing a technology for controlling multiple AUVs during sea-bottom surveys with high efficiency and high precision.

■ Terminal system for recharging AUV batteries in the deep sea

To facilitate long-term operation of the AUVs in the deep sea, we are developing a deep-sea terminal system for docking the AUVs and recharging their batteries and also for transferring data.

SINTEF

Theme 2-2 Development of production technologies

<Technology for collecting and lifting rare-earth deposits>

■ Determination of the total assembly design of equipment for cracking and pulverizing solidified deposits and collecting and lifting the cracked deposits

Establishing production technology for the retrieval of deep-sea resources is a huge challenge.

We are employing the Deep-Sea Drilling Vessel Chikyu, with its long pipes and mud circulation system, to implement a conceptual design by taking into consideration the results of simulations and land-based experiments.

■ Characterization of the physical properties of the geological formation bearing the rare-earth deposits

Under theme 2-2, the important technologies that make it possible to develop rare-earth resources in the deep sea have three components: "cracking," "collecting," and "lifting." We acquire basic data for each of these components by identifying geological features of the layers bearing rare-earth deposits.

■ Simulation

We are reviewing the design and performance of an underwater pump and hydrocyclone. We are also investigating various scenarios by conducting computer simulations of this system.

Theme 3 Verification of the survey and development system

■ Survey of market trends and formulation of a business model

Under theme3, we have been surveying the most recent trends in the demand for rare-earth elements in domestic and international markets as well as the feasibility of a commercial operation.

■ Environmental measures

To achieve sustainable development of marine resources, we have been conducting environmental monitoring in the target area using the environmental impact assessment method established during the first period of the SIP. We are continuing this monitoring with the Edokko Mark Ⅰ ecosystem observation system and a mooring system for observing bottom layer flows. This observation method has been proposed as an International Organization for Standardization (ISO) standard. We are also coordinating an international training course for administrators and engineers from Pacific Island countries.

「Geological survey of the deep seafloor off Minamitori Island」

We have conducted a survey using the sub-bottom profiler (SBP) on board research vessels along survey lines with a total length of more than 10,000 km to narrow down potential areas of rare-earth deposits. We have identified sediment layers covering an undulating strong reflector 20–30 m below the seafloor by examining stratigraphic images obtained with the SBP. We have succeeded in obtaining high-resolution SBP images by using a deep tow system, which is operated at 100 m above the deep seafloor.

For geological core analysis, we have obtained piston cores from more than 50 sites located at intervals of 7 km and measured concentrations of rare-earth elements in core samples. We are attempting to ascertain the relationship between the distribution and layer thickness of rare-earth sediments and their quality in the deep sea off Minamitori Island.

Collected cores

Retrieving a piston core

SINTEF

「Sampling of a large amount of rare-earth sediments for composition tests」

We sampled a substantial amount of rare-earth sediment from the deep seafloor in the Minamitori Island area. Rare-earth sediment was retrieved with a power grab sampler with the help of on-line video images. The power grab operation was conducted twice, and more than 3 m3 of sediments were retrieved from the seafloor at a water depth of more than 5,000 m. The collected sediment samples will be used for composition tests to obtain basic data for research and development.

Sampling with a power grab

Collected rare-earth sediment sample
(The black spheres are manganese nodules)

Sampling by the power grab at a water depth of about 5,000 m

Retrieval of the power grab after sample collection

「Sea trials of the acoustic/positioning system and formation control」

We conducted sea trials for acoustic communication for the operation of multiple AUVs. The ASV HUBSea relays information on the location and status of the AUVs by converting the wireless signal from the mother ship to an acoustic signal that is communicated to two AUVs, Jinbei and Yumeiruka.

Through the successful completion of a sea trial, we verified the effectiveness of the acoustic communication and positioning system for the operation of multiple AUVs. We also completed another sea trial to demonstrate control of a formation of two AUVs.

Our goal for multiple AUV operation is to successfully operate five AUVs using a newly developed ASV by FY2022, the last year of the project.

The operation of multiple AUVs is expected to enable underwater surveys for deep-sea exploration to be completed faster and with more precision overall. This technology is also expected to have a large impact on various industries through the development of multiple control technologies for different types of AUVs.

Sea trial of acoustic communication among the AUVs, the ASV, and the mother ship

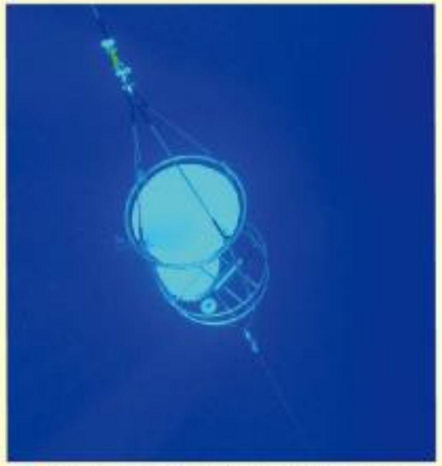
Sea trial for formation control of AUVs

「Starting a baseline survey for environmental monitoring」

It is important to understand the potential impact on the marine environment of mineral resource development in the deep sea. Thus, we have started a long-term program of environmental monitoring around the potential development sites.
For this baseline survey, we are using an observation instrument with an attached camera called the Edokko Mark Ⅰ-365, which was developed during the first period of the SIP by JAMSTEC with the collaboration and craftmanship of small businesses in the Tokyo area as a free-fall probe for the deep sea. The Edokko Mark Ⅰ can obtain continuous observations for a year in the deep sea and is expected to capture disturbances caused by sediment sampling and changes to the ecosystem.
Measurements of water currents, temperature, turbidity, and settling particles by a mooring system also provide important baseline reference information for deep-sea exploration.
These methods for assessing environmental impact established in the SIP first period are being proposed as a global ISO standard.

Images of living organisms on the deep seafloor captured by the Edokko Mark Ⅰ-365

The Edokko Mark Ⅰ-365



Mooring observation system with attached sediment trap

SINTEF

SINTEF

Teknologi for et bedre samfunn