16 November 2017
Biblioteca Almeida Garret
Porto, Portugal

STRONG MAR

2017 STRONGMAR CONFERENCE

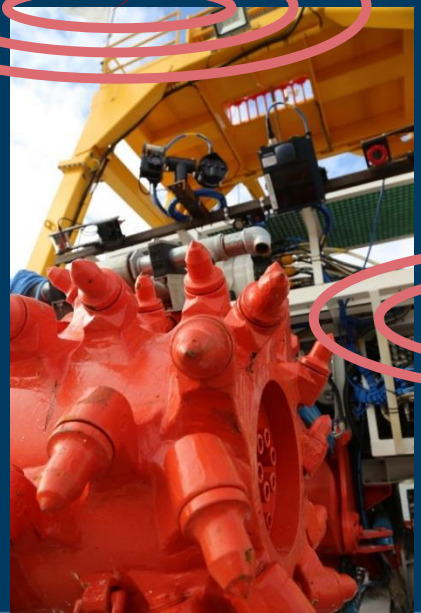
A SEA OF TECHNOLOGY

INESCTEC www.strongmar.eu

Underwater Mining

Stef Kapusniak SMD

Inland & Offshore



Inland underwater mining

¡VAMOS! key data…

Start date	: 1st February 2015
End date	: 31st July 2018
Duration	: 42 months
Original Budget	: €11.2 to12.7m
Funding	: € 9.2m
Number of participants	: 17

out of 9 European countries

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 642477".

Original Participants…

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Objectives…

1) **Specify and develop a prototype** underwater, remotely controlled, mining machine with associated launch and recovery equipment.
2) **Enhance currently available underwater sensing, spatial awareness, navigational and positioning technology** to enable safe and confident operation of the equipment in an enclosed mine environment.
3) **Conduct field trials** with the prototype equipment in abandoned and inactive mine sites with a range of rock types and at a range of submerged depths.
4) **Evaluate the productivity and cost of operation** on a multivariate basis and in a scalable manner to enable mineability and economic reassessment of the EU's mineral reserves.
5) **Encourage market up-take** by defining and overcoming the practicalities of the concept, proving the operational viability of the proposed techniques and developing a computer based tool which enables confident cost estimation of mining with the technique.

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¡VAMOS! virtual view…

Virtual operational view from fusion of multiple sensory sources, allowing remote operation at night and in turbid water.

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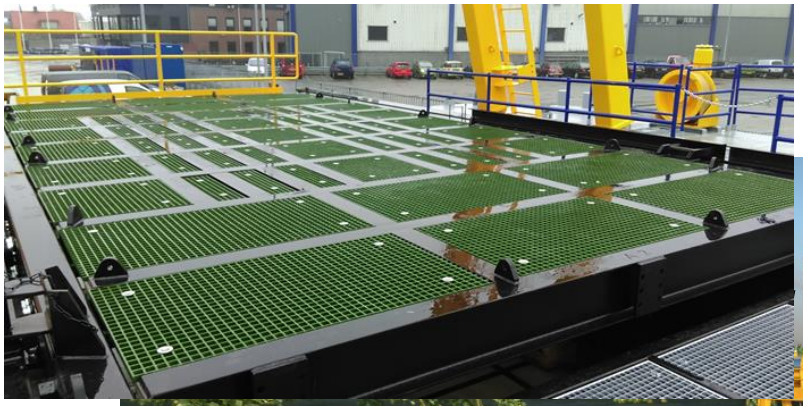
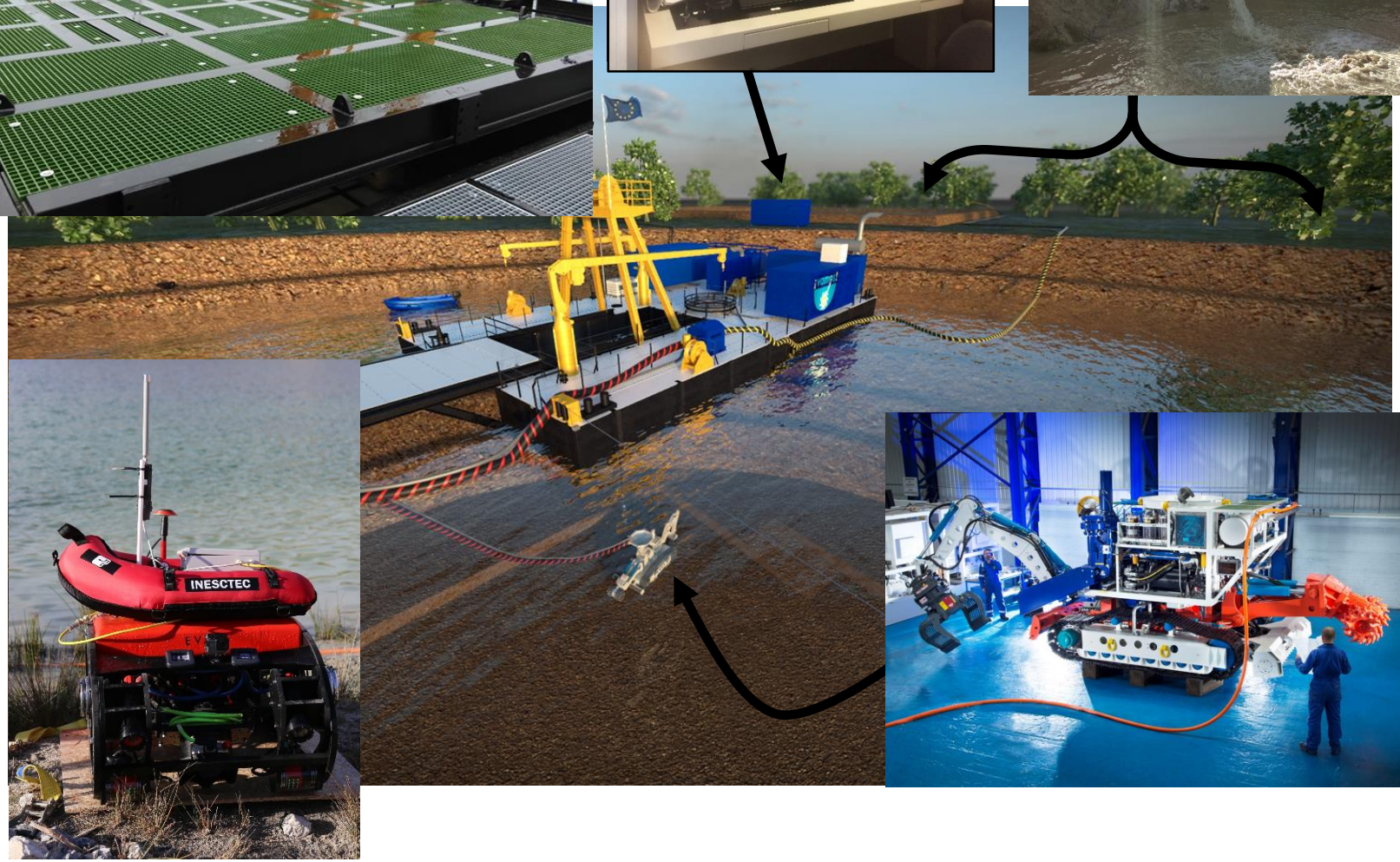
Prototype developed…





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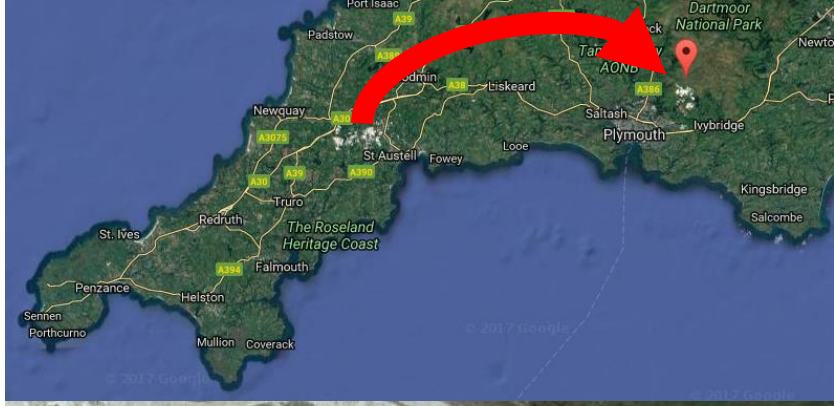
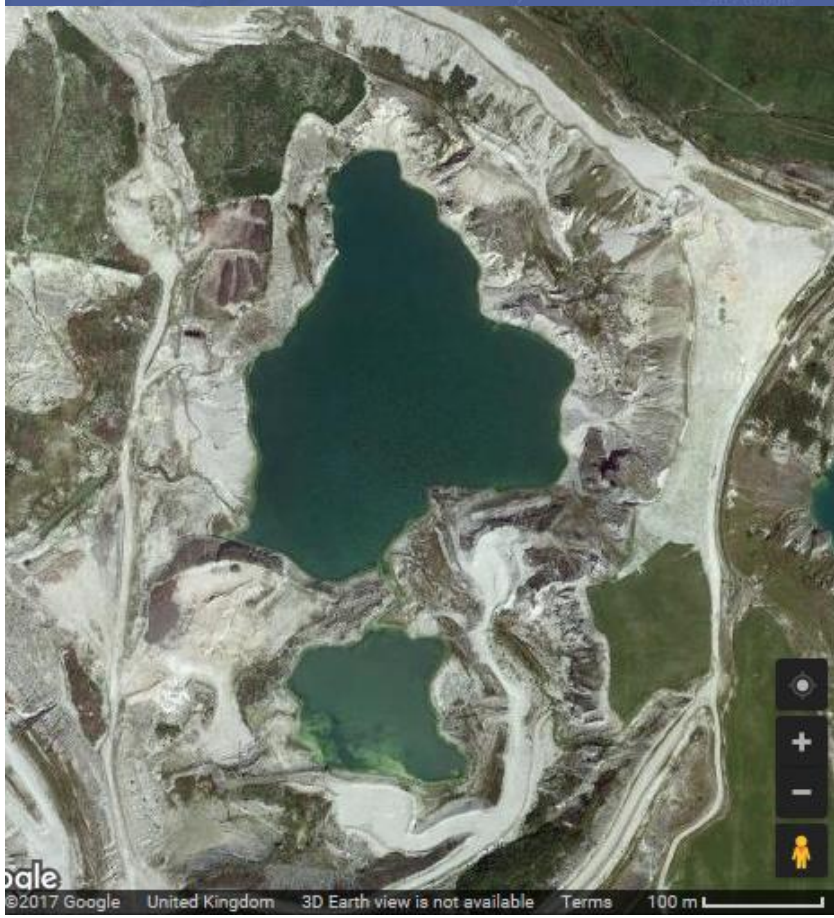
Grade measurement using LIBS…

- Built library using calibrated test samples and range of known ores
- Conducted blind testing to prove validity
- As sample tests have grown, spectral recognition has increased accuracy

Site alternatives…

- Imerys (site owner) asked us to move from Cornwall to Devon to the Whitehill North Yeo mine at Lee Moor
  - Similar material properties (range of soft to hard cutting conditions)
  - But shallower (supposedly 45m)
- Field-test planning changed to reflect
- Bathymetry showed that water depth was shallower than advised (approx. 20m)
- Choice was either to…
  - Proceed at Lee Moor **TEST SITE 1**
  - Find another site and finish late





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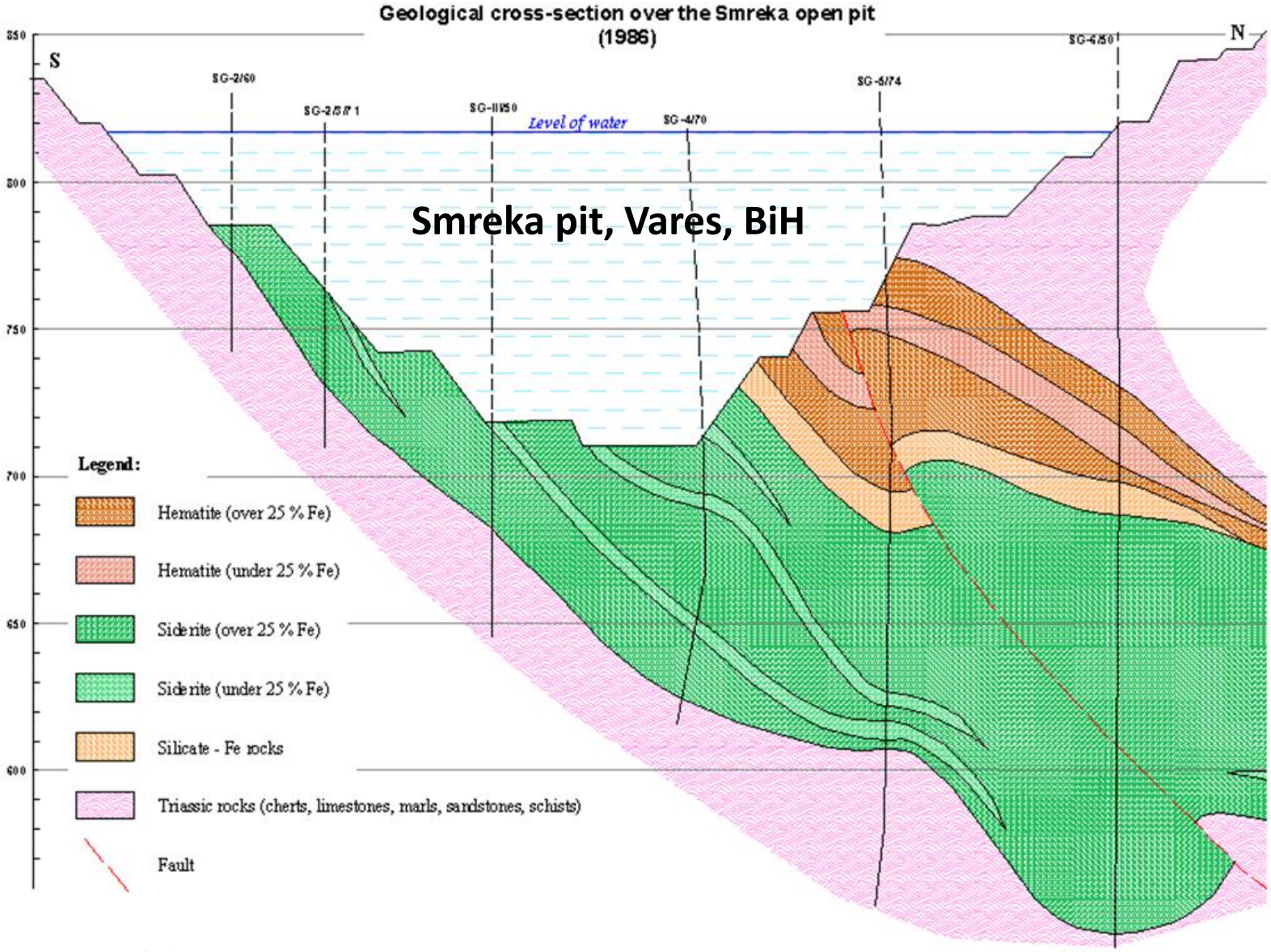
TEST SITE 2



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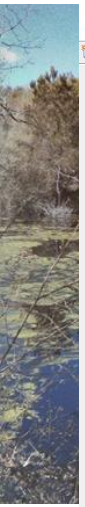
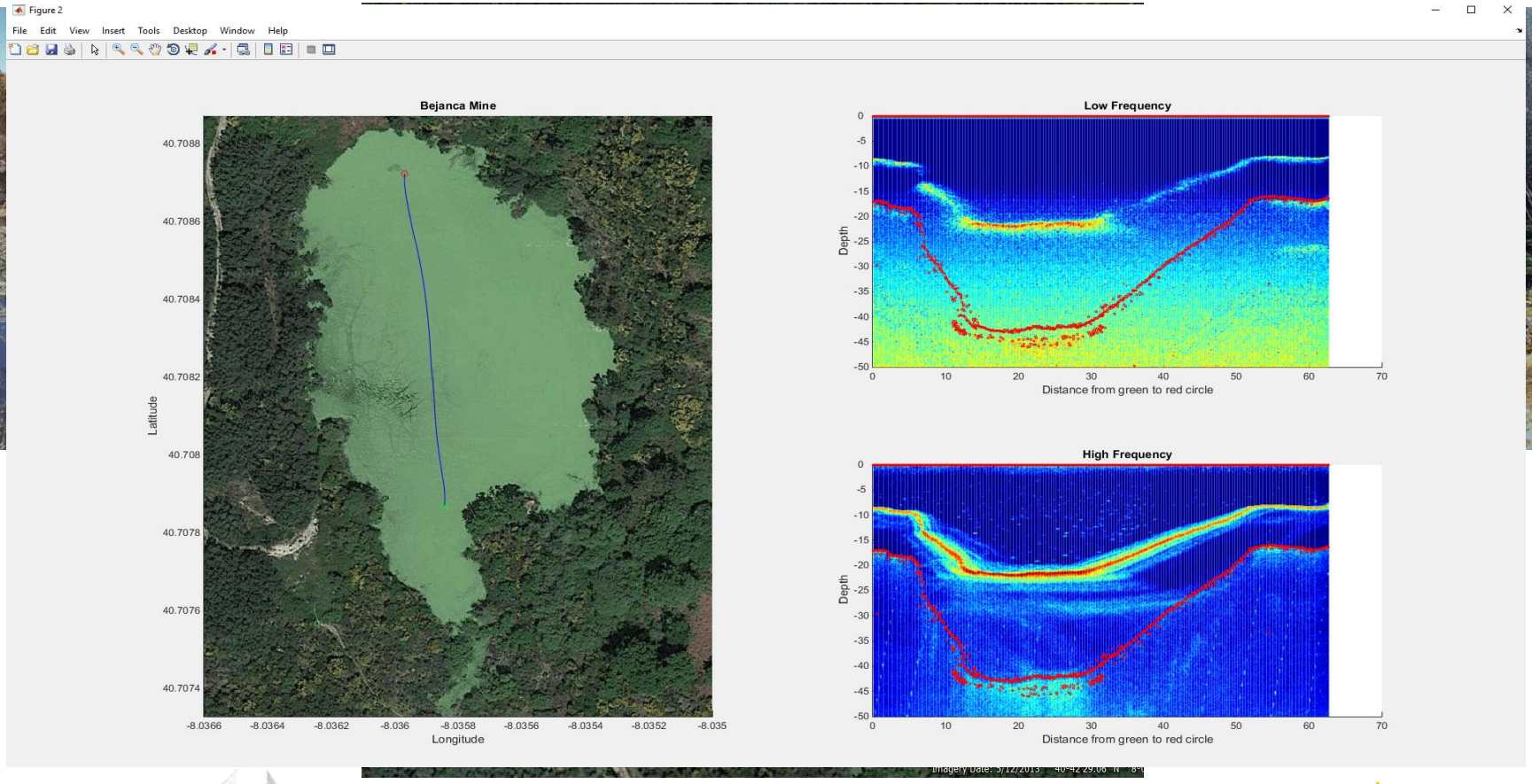
In the meantime INESC tested the PNA systems in advance in Bejanca (Northern Portugal)…

- NB – full trials at Bejanca previously ruled out due to inaccessibility for larger equipment





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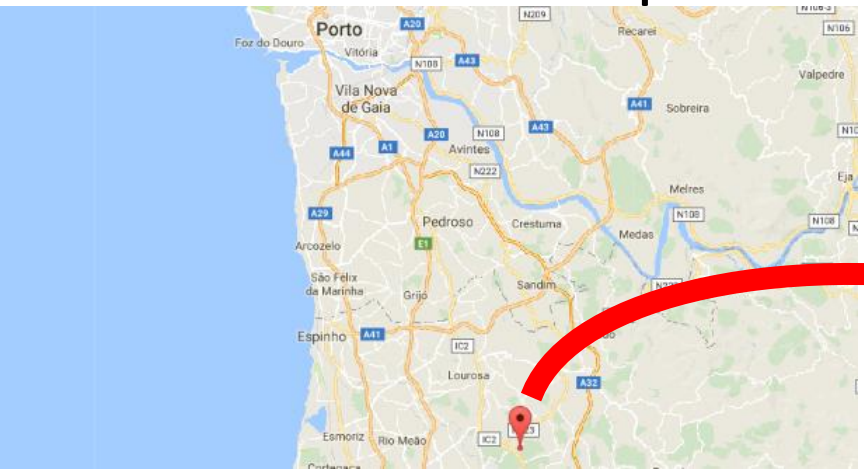
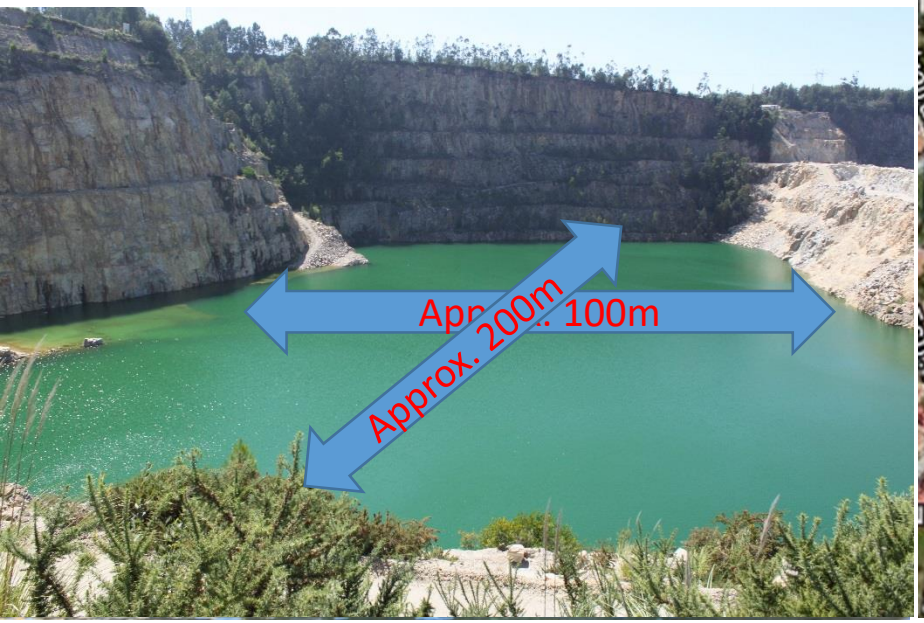
Potential reserve/contingency site…

- In case we have import or other problems in Bosnia





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First full equipment trial site...
(Whitehill North Yeo Pit at Lee Moor in Devon)

Significant soft areas and difficulties setting up crane pad…

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Excavating conditions…

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Saturated sediments, requiring import of fill material and re-compaction of ground…

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Site teams have persisted…

…enabling…

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Site set up complete...

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LARV modules linked together and deck equipment built up…

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Mobilisation of MV…

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Connection of hoses…

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Installation of PNA systems…

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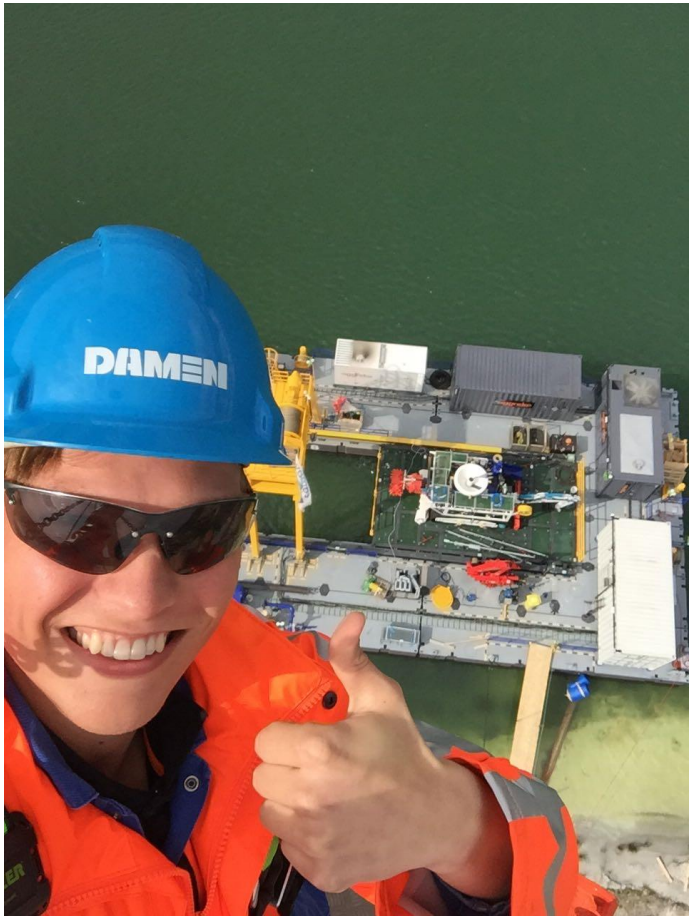
Site set-up and equipment integration completed...



…from a mechanical and electrical perspective.

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Anchors installed and LARV launched…

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Launched AUV, bathymetry and topography survey…

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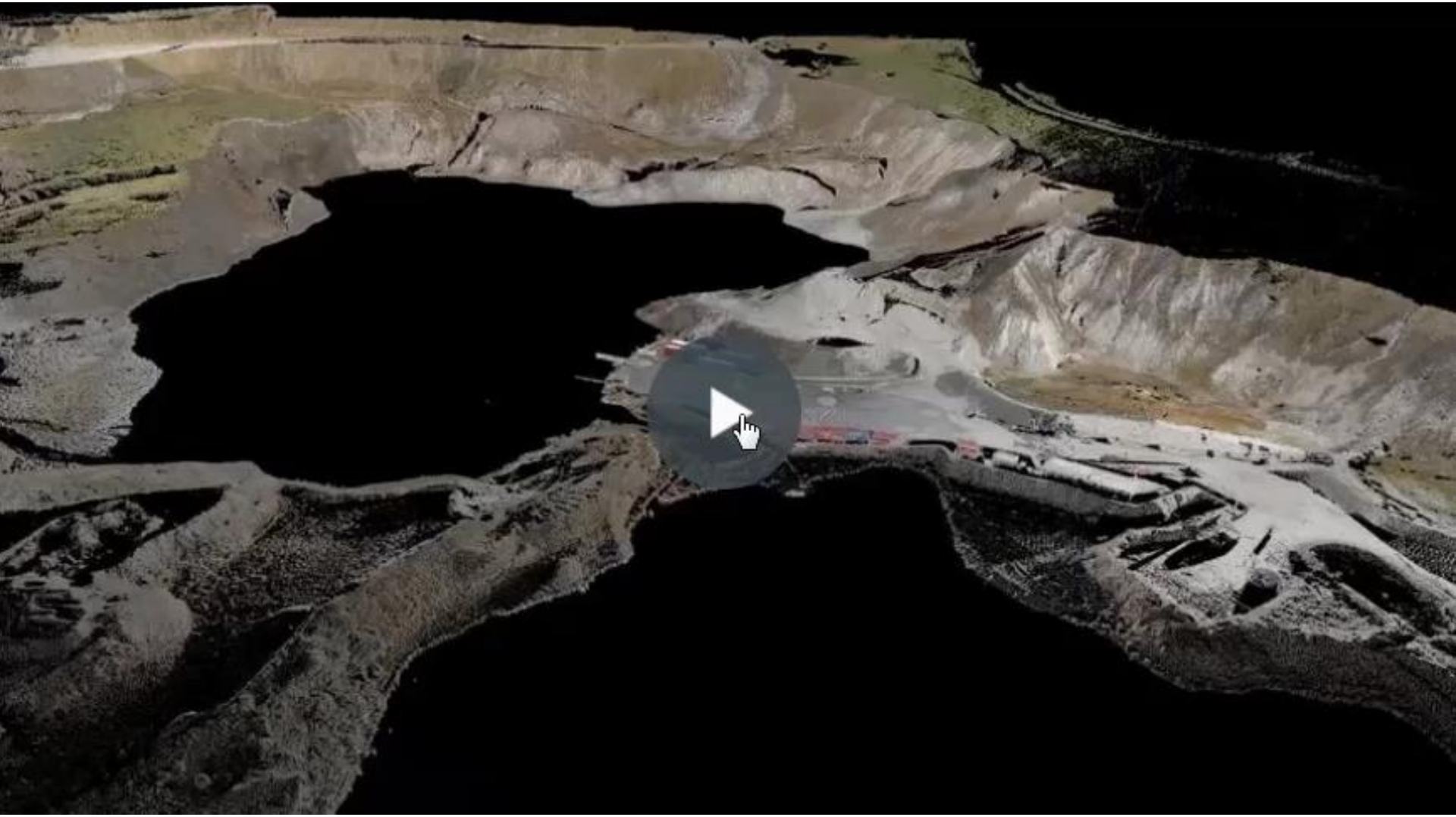
Virtual reality view…



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Real life view…

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LARV floated out…

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Swamp tracks…

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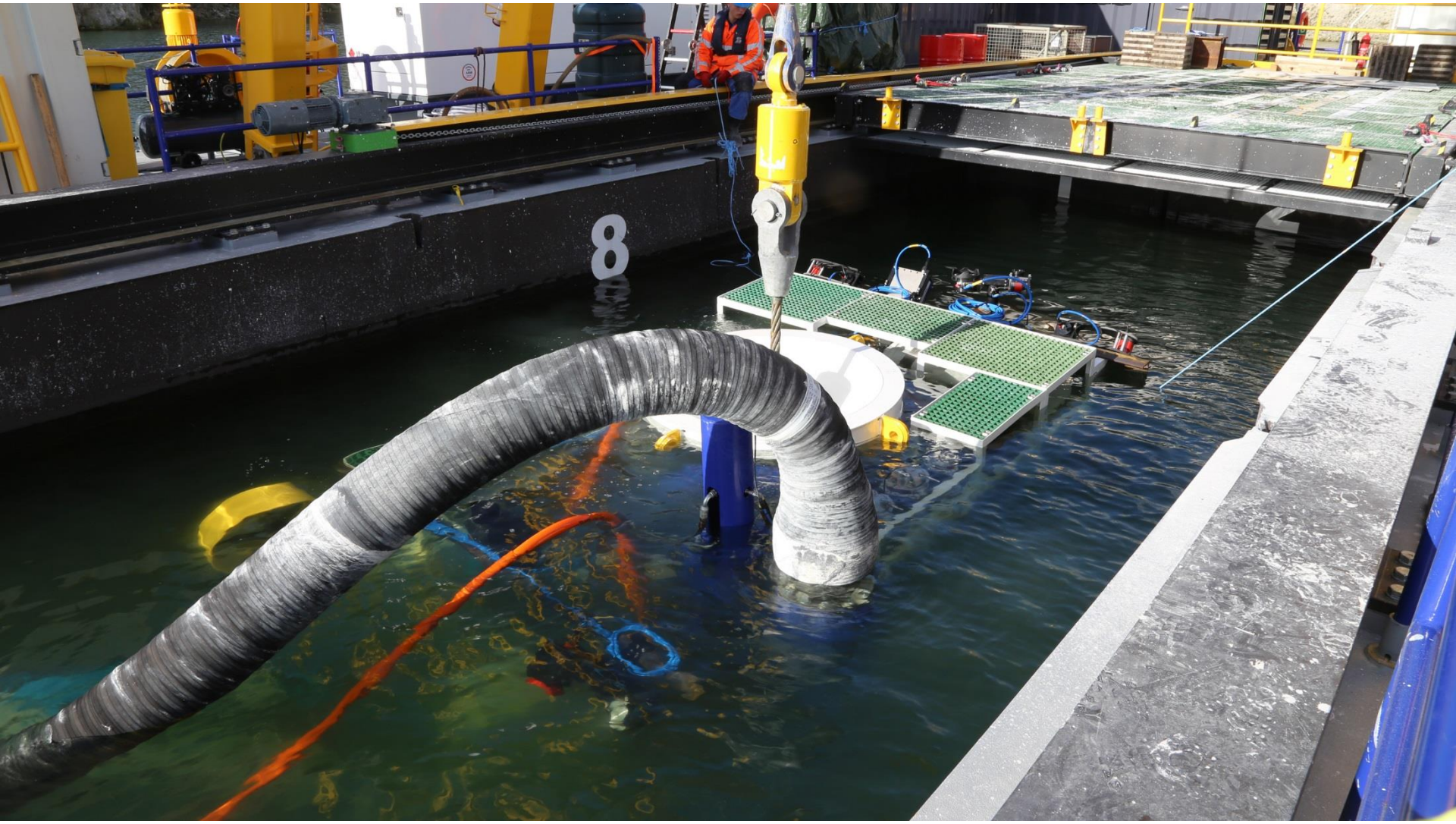
MV launched through the U-section…



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Recovery of MV…

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Sliding maintenance deck works well…

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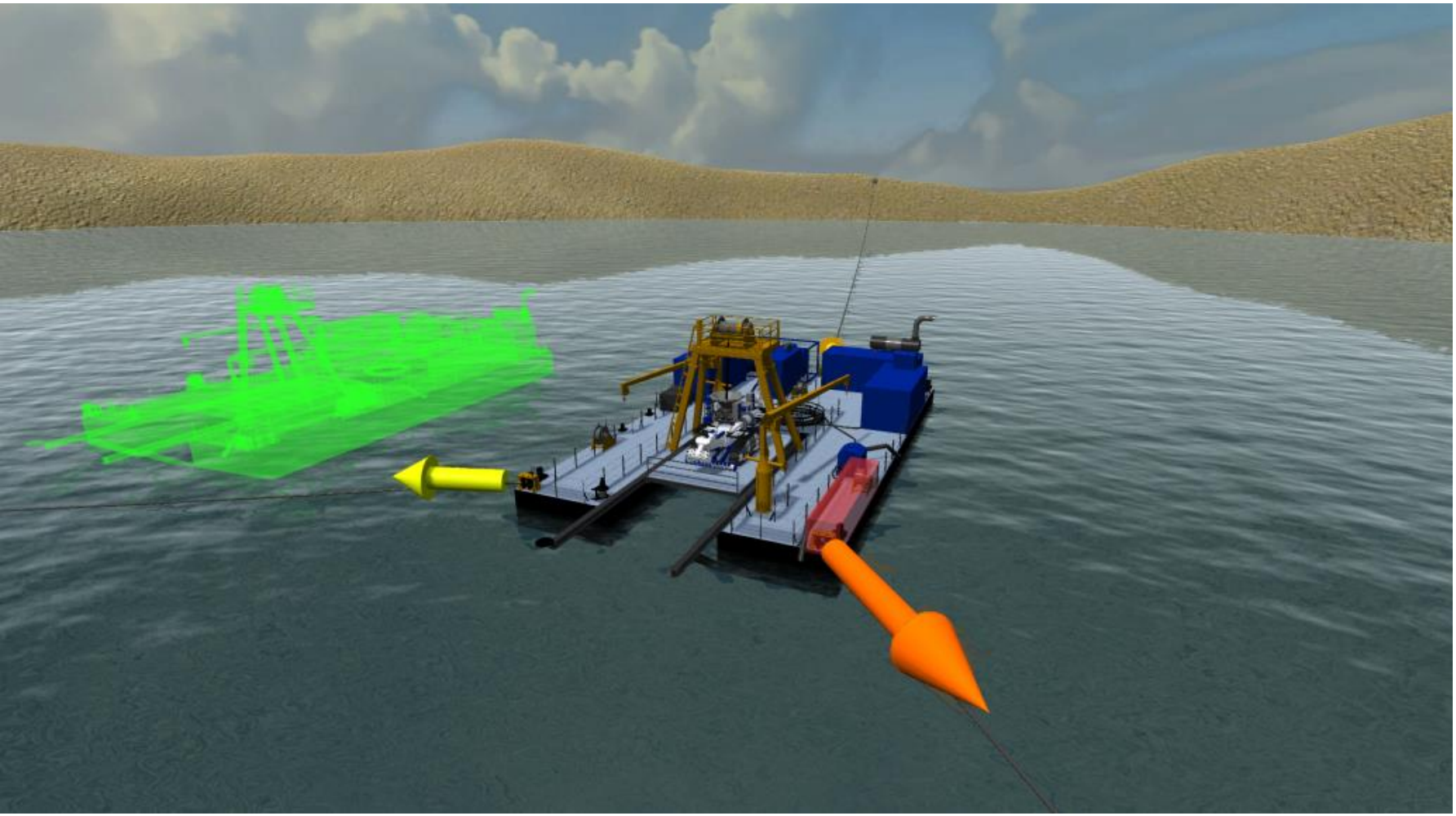
Positioning of launch and recovery vessel…



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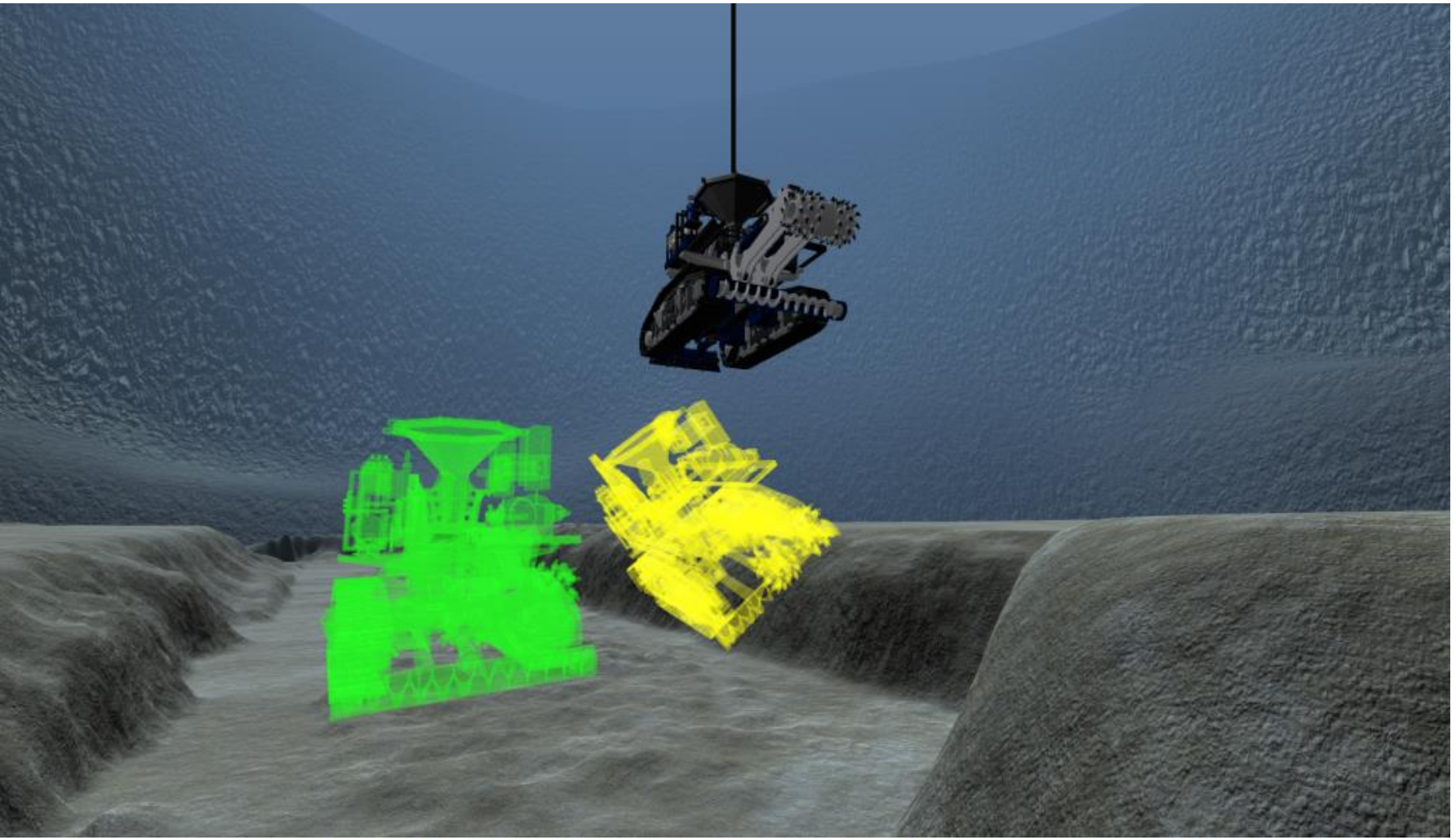
Landing the mining vehicle…



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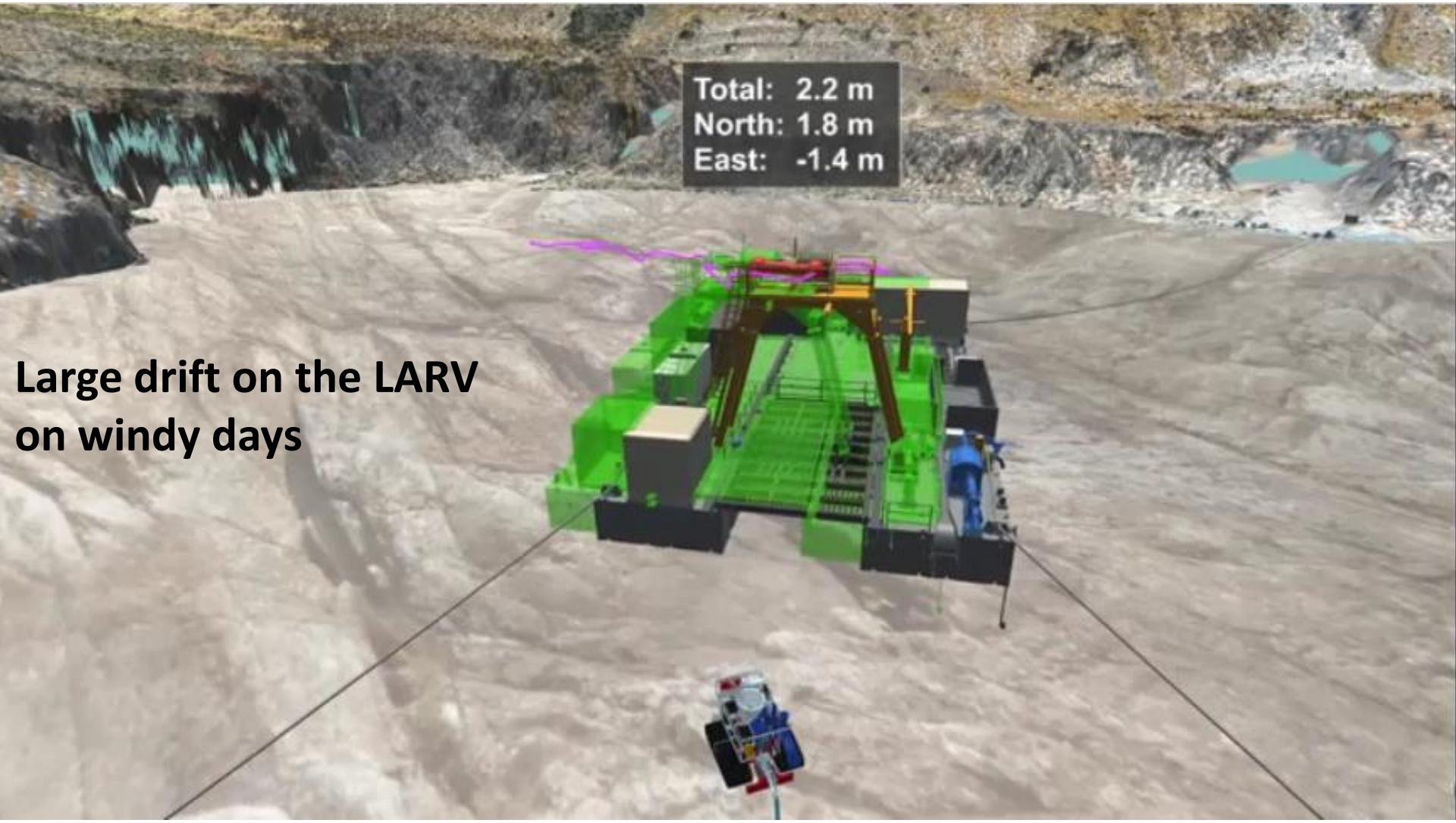
Positioning the LARV…



Large drift on the LARV on windy days

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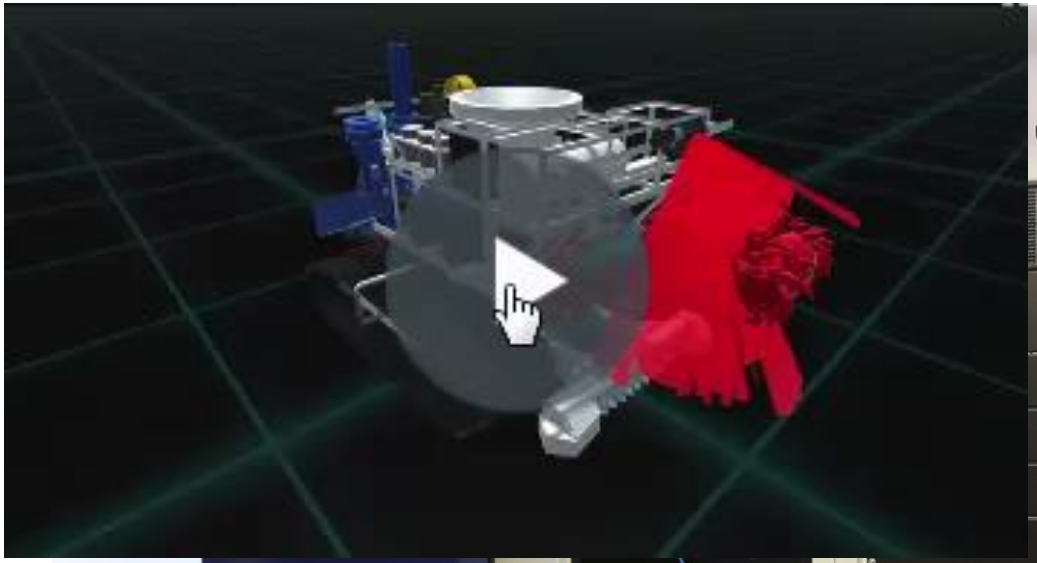
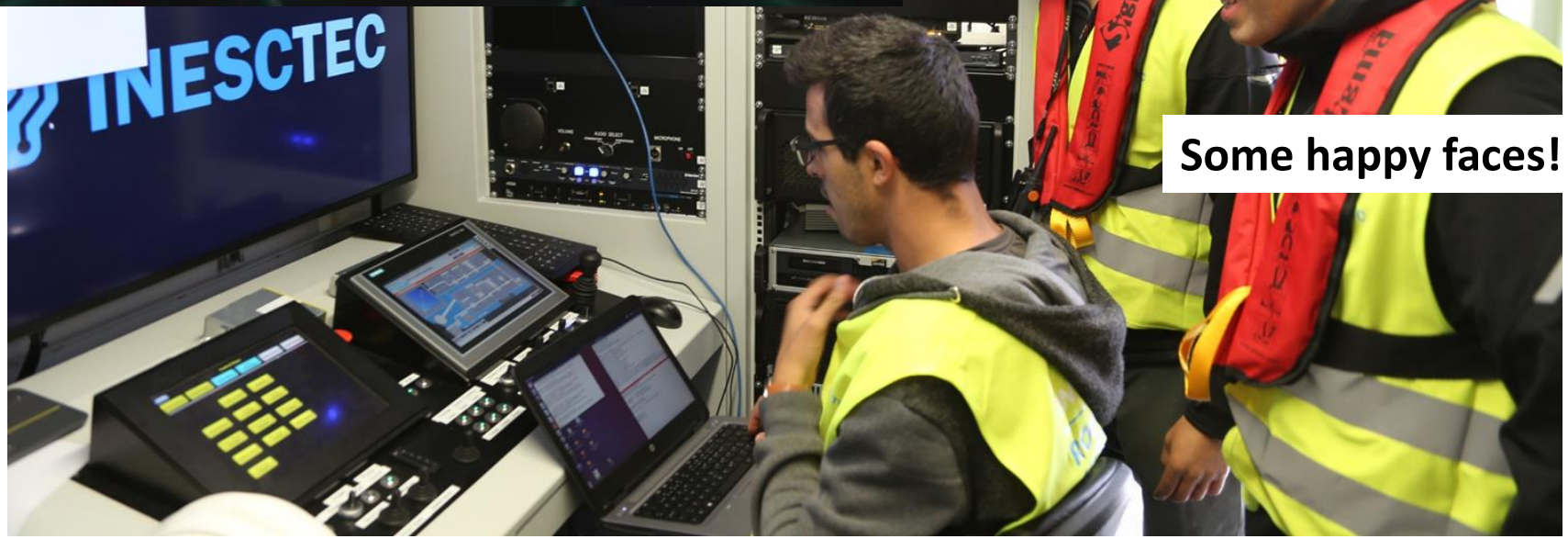
PNA system testing…



M3 multi-beam sonar on the pan & tilt unit working

Some worried faces!



Some happy faces!

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We have a working system...

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Positive outcomes…

- **Managed to overcome civils problems and get good access into the Lee Moor pit**
  Thanks to some key individuals from different partners working in a highly cooperative manner
- **LIBS**
  Library expanding, mineral differentiation capability increasing. Site owner very interested in ability to measure lithium content in waste material
- **M3 multi-beam combined with SBL systems managed to map new workface**
  Through highly turbid water with fine particle suspension (“Milky water”)
- **MV/Tracks/undercarriage works well**
  Manoeuvrability good
- **LARV and winch systems worked well**
  Upgradable for industrial scale to provide more power and control response
- **Slurry hose systems work well so far**
- **Blockage clearance system**
  “Spit-out” facility worked well
- **ECON**
  Combined electrical systems interfaced well
- **Control Cabin**
  Integrated control systems worked well
- **Real time imaging/VR**
  Managed to process data in almost real time and provide good images to pilots

- **Managed to cut material and measure volume and time**
- **Will process this data in T5.4**
- **Enabling costing and productivity extrapolation to industrial scale for WP6**

Next steps…

Smreka pit, Vares, BiH

- Need to accelerate our survey and define a robust test plan
  - in the light of our experiences so far
  - Based on more detailed bathymetric and physical information
- Need to improve PNA system in terms of auto-tuning
- Improved design of collection auger
- Advance and prove reliability of…
  - Aqua-hitch hydraulic tool connector
  - Pumping system
  - Conductance tomography system
- Wear monitoring system
- Continue development of LIBS system and ore recognition library

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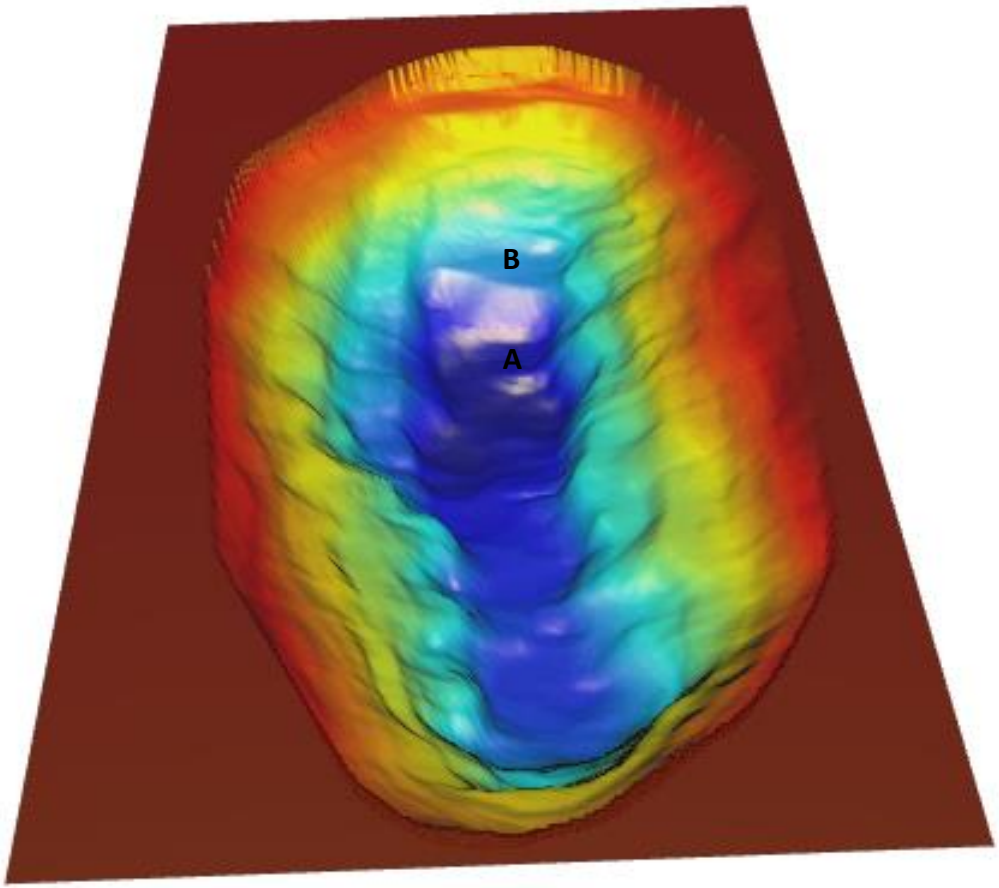
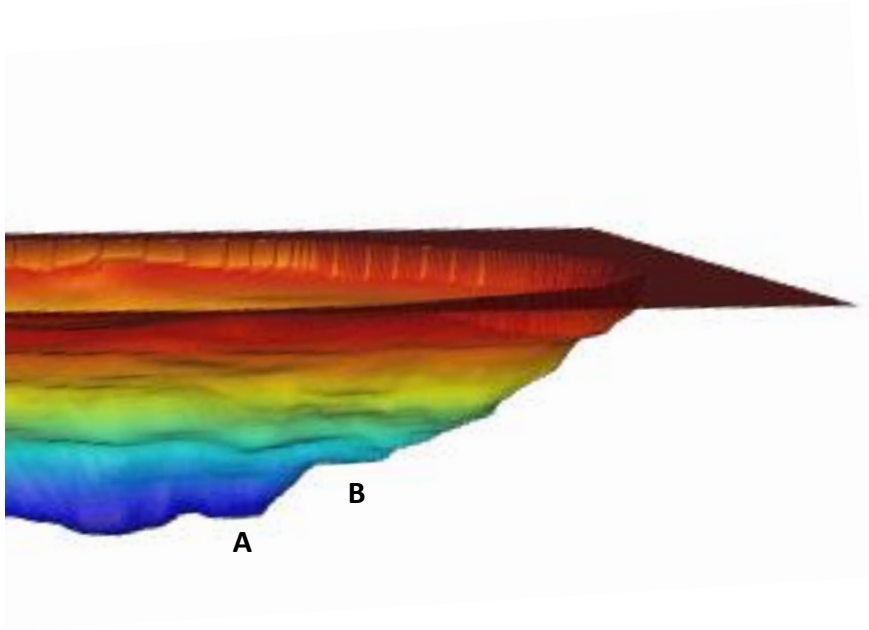
Low resolution sweep from Bosnia





Bathymetry shows flat bench areas and steep slopes
Consistent with expected bench areas and minimum silt

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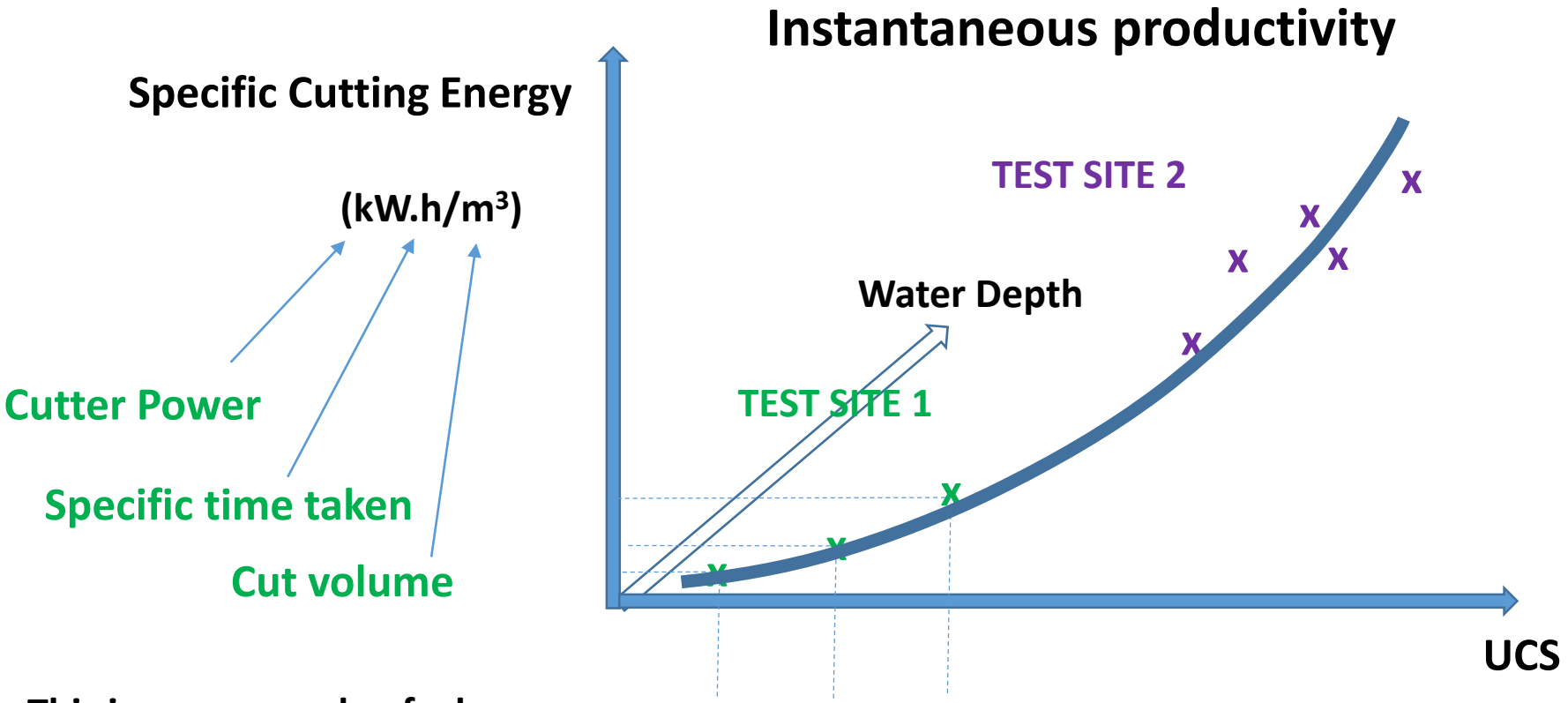
Processing of test results…



This is one example of a key parameter which feeds nett productivity and costing in WP6

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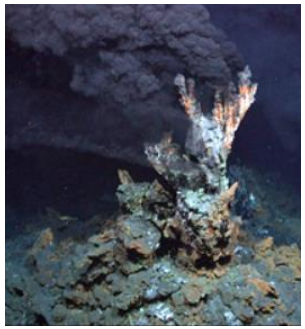
Subsea Mining resources…

- There is now a focus on deeper offshore mining deposits - similar to the move to extract oil and gas from deeper waters…



SMS

- Red Sea muds
- Bismarck Sea
- Okinawa Trough
- SW Pacific Islands
- Canaries/Azores
- Mediterranean Sea
- Island territories across the world

Polymetallic Nodules

- Indian Ocean
- SW Pacific Islands
- Clarion/Clippert on fracture zone
- Bay of Finland
- Black Sea

Ferro-manganese crusts

- Lots of areas on seamounts and guyots

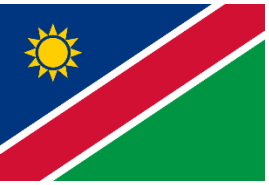
Diamond & gold bearing gravels

- Namibia
- Alaska

Rock Phosphate

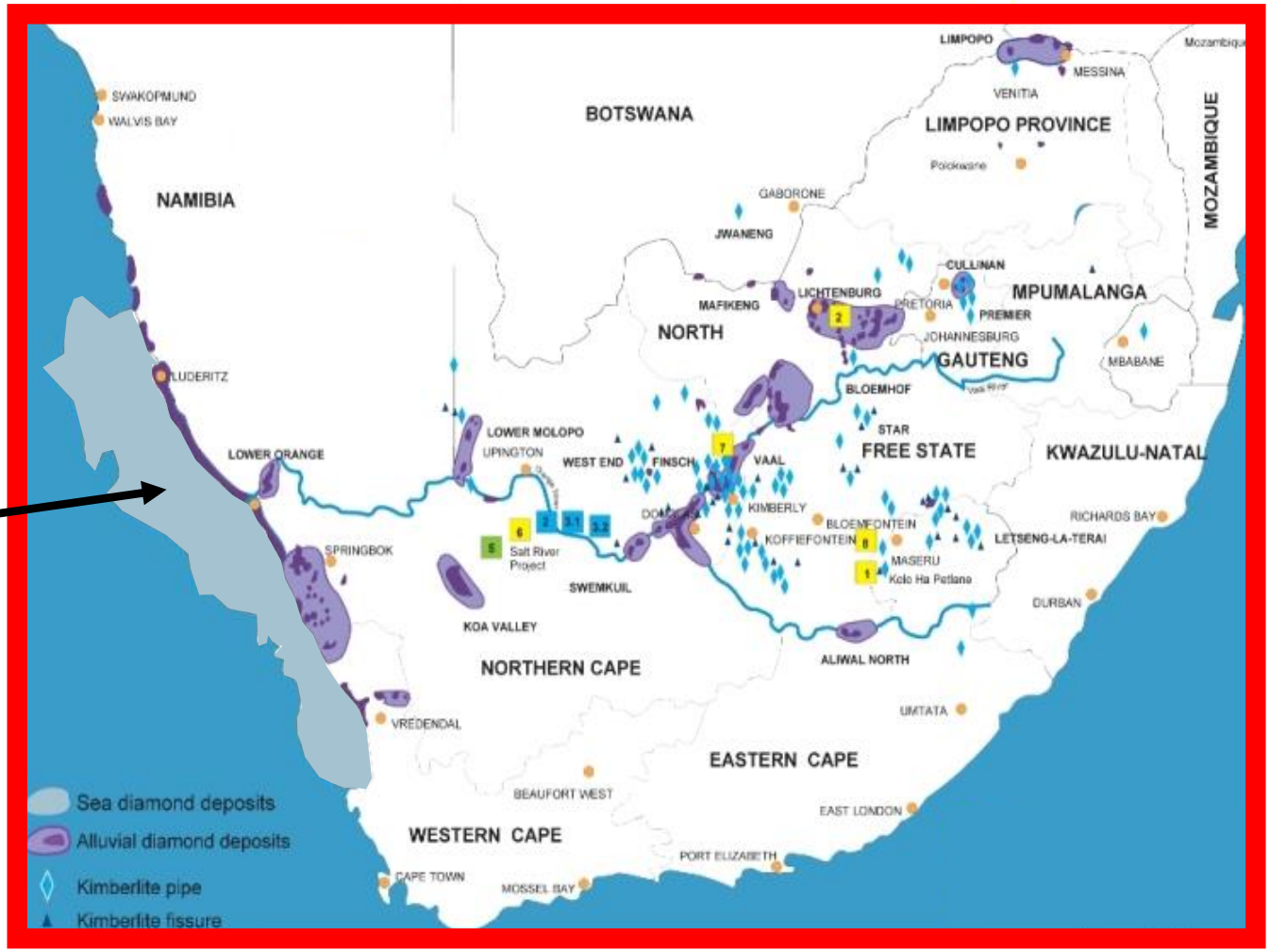
- Namibia
- Chatham Rise
- Mexico

Shallower deposits…



Namibia…

Offshore mining of alluvial diamond deposits – to 150m depth



Distribution of kimberlite pipes, fissures, alluvial and offshore deposits

Nearshore alluvial mining…

Namibia…

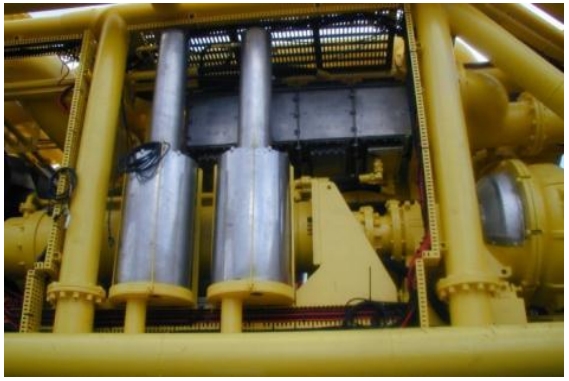
Successful underwater alluvial mining machines

MK I Crawler

MK II Crawler

MK IV Crawler

Electronics Pod



Hydraulic Oil Compensators

Crawler Equipment

Namibia…

Successful underwater alluvial mining platforms

MV Peace in Africa

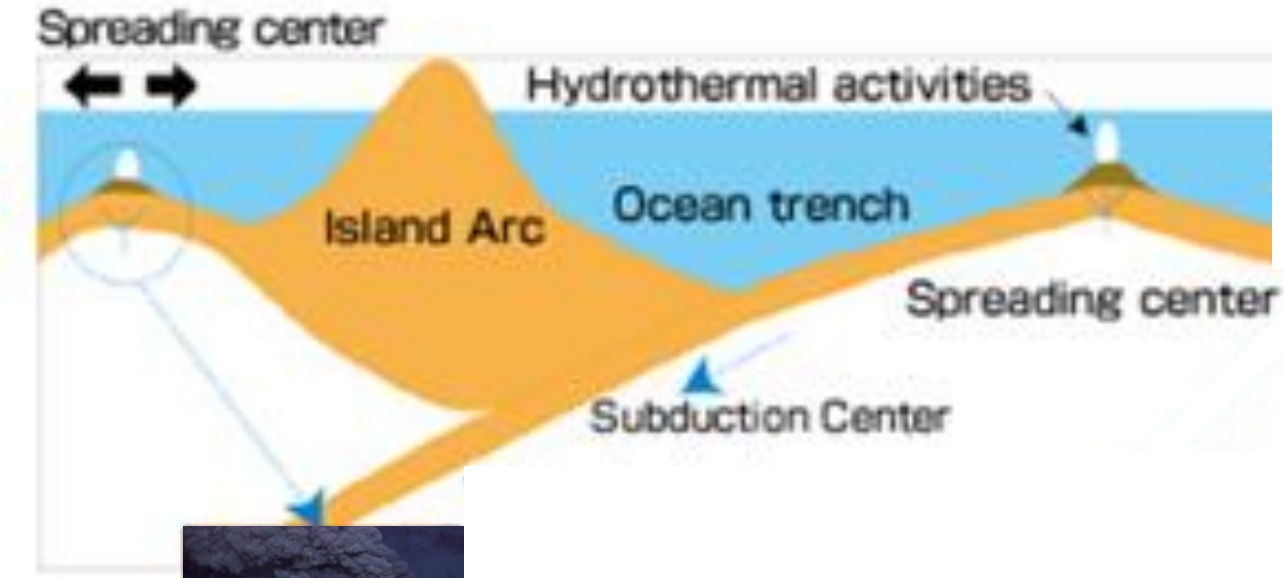
MV Sakawe Explorer

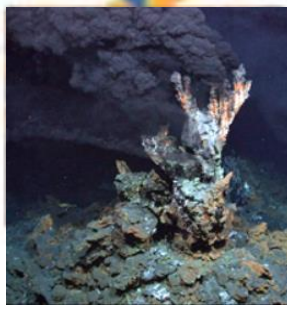
MV Kovambo

MV Ya Toivo

SMS deposits

Found in spreading centres and plate boundary areas around the world

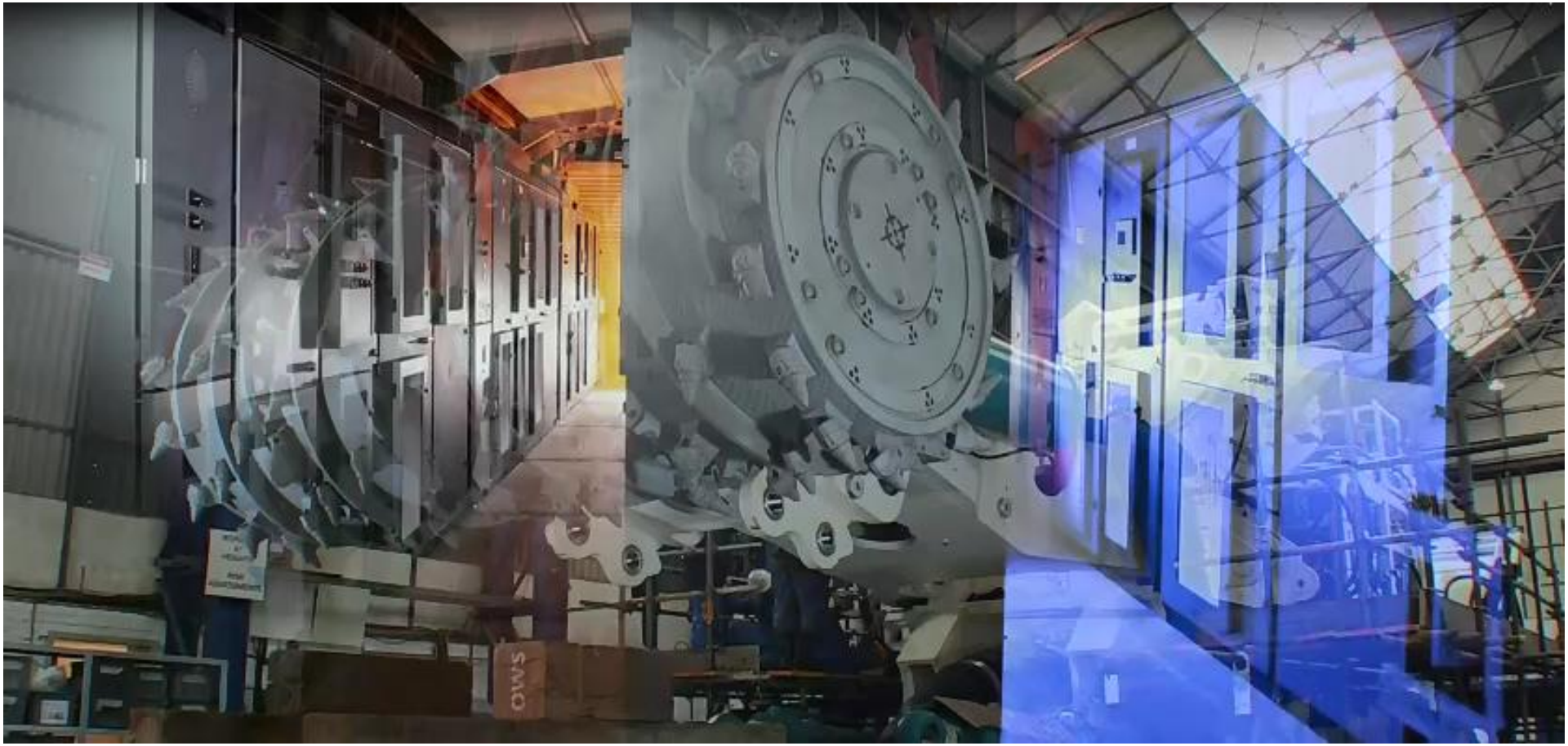




- **Hydrothermal deposits, typically up to 3,000m deep, But some can be much shallower.**

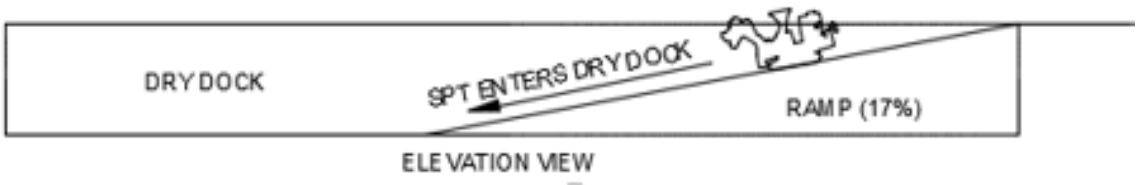
Papua New Guinea…

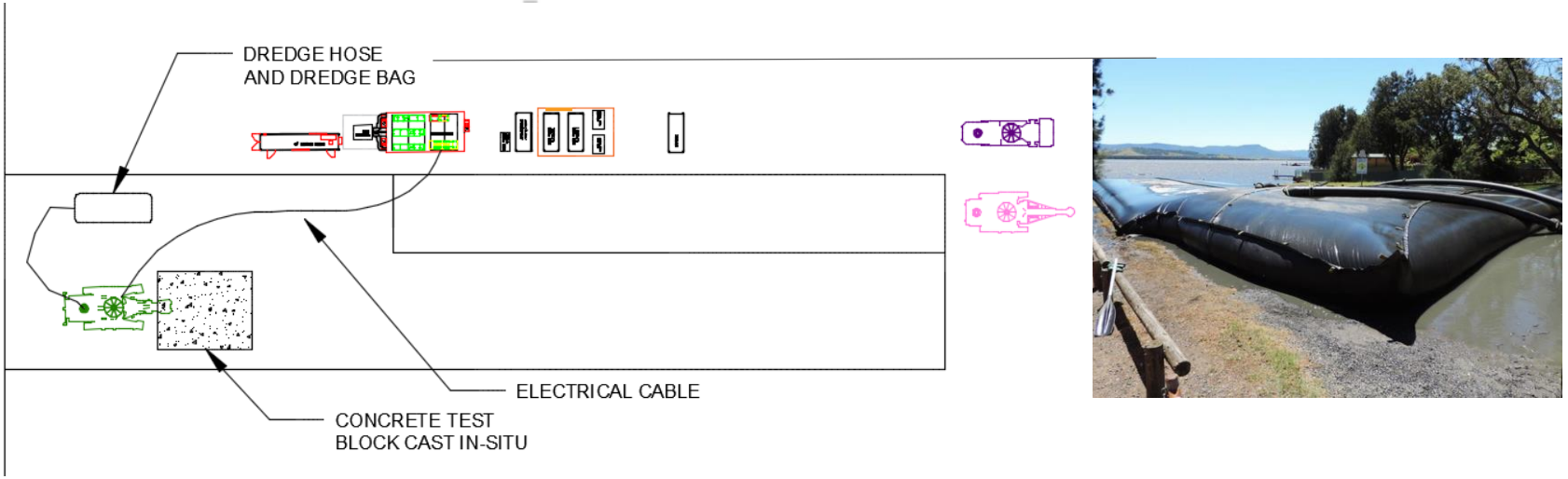
Power & Control



Wet testing plan…

Machines moved from Duqm, Oman to Motukea Island, Papua New Guinea for wet testing in a dry dock





Japan…

Two Types of Pilot-scale Mining Machines

Scale model of 1/20, with 20 t in air due to constraints of lifting/recovery capacity of Hakurei A-frame

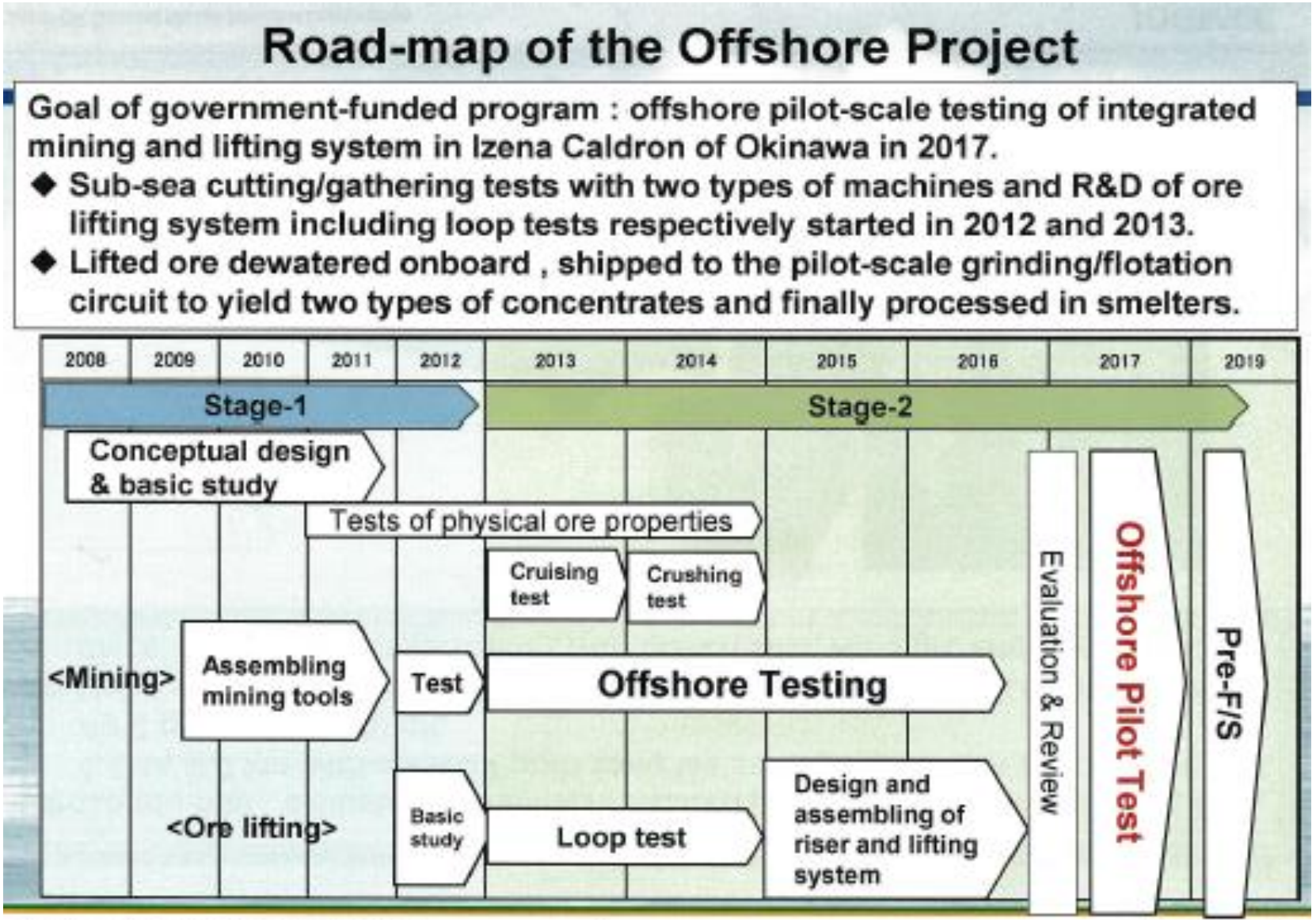
- Cutter head : multi-axis or drum type
- Drive : four crawlers
- Simultaneous cutting and gathering

(Designed and assembled by Mitsubishi Heavy Industry & Kayaba)

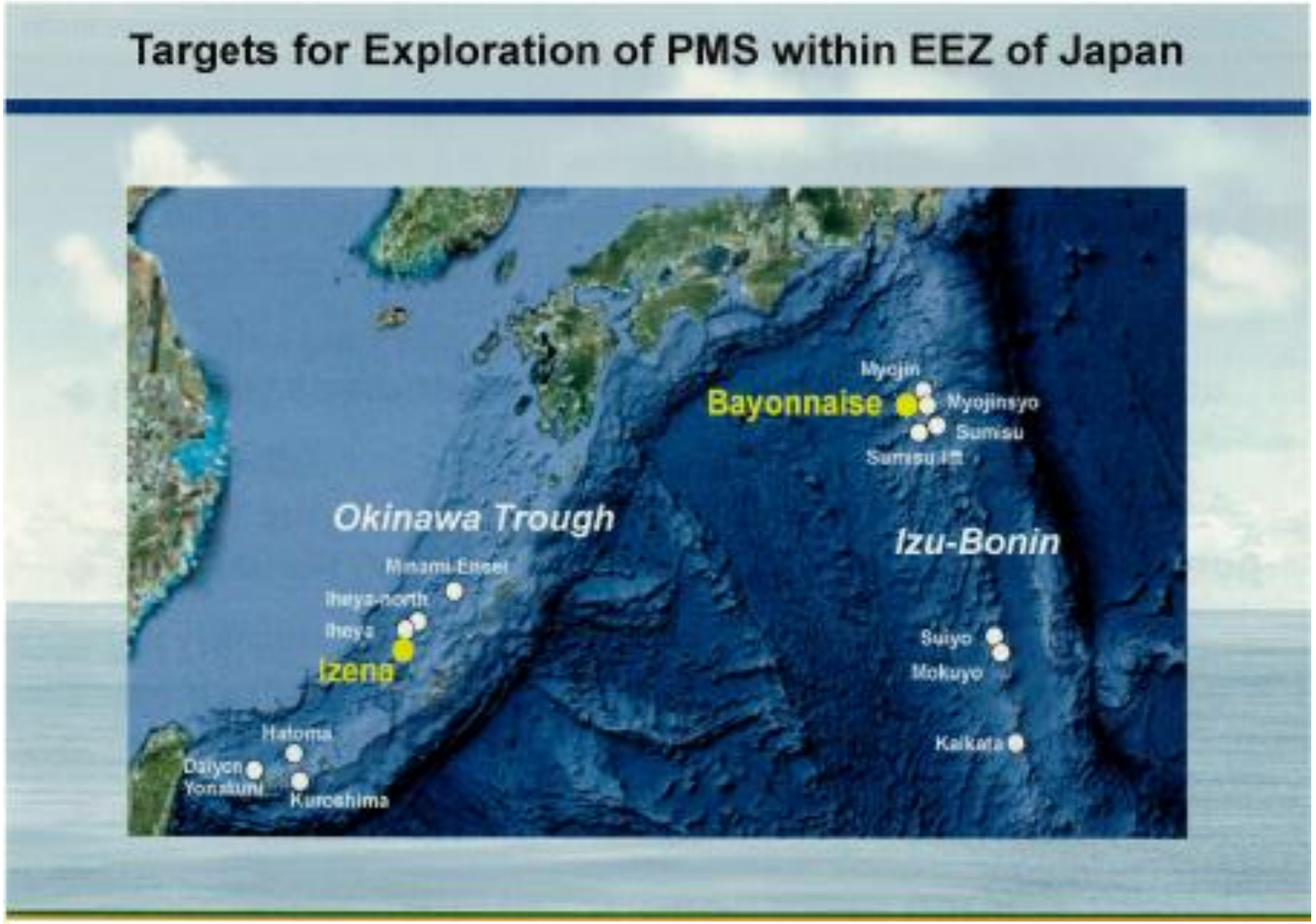
- Cutter head : road header type
- Drive : two crawlers
- Separately cutting and gathering

(Designed and assembled by Mitsui-Miike Machinery)

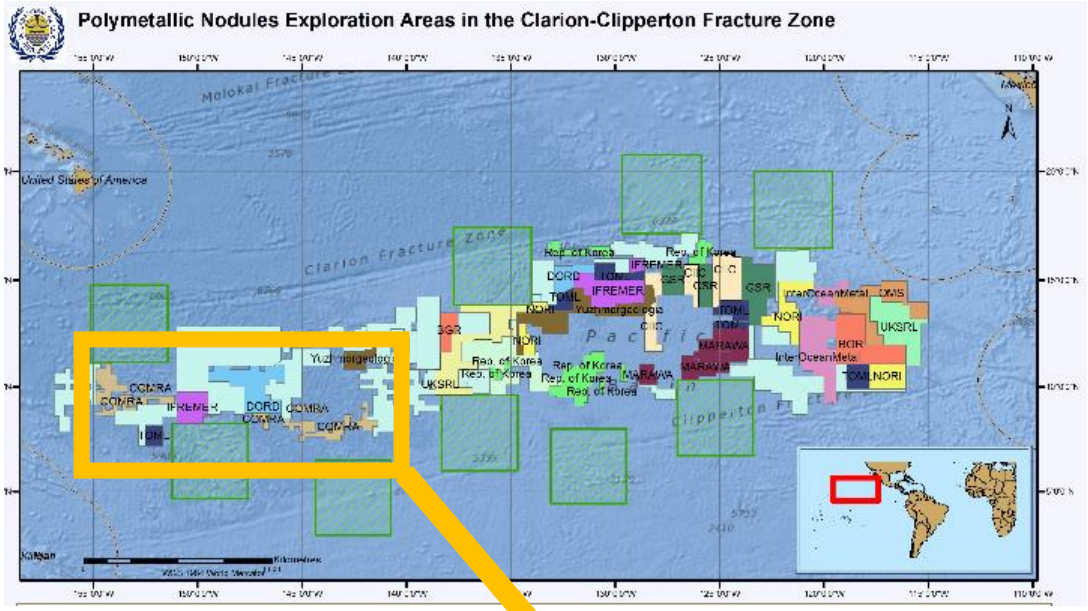
Japan…


Road-map of the Offshore Project
Goal of government-funded program : offshore pilot-scale testing of integrated mining and lifting system in Izena Caldron of Okinawa in 2017.
◆ Sub-sea cutting/gathering tests with two types of machines and R&D of ore lifting system including loop tests respectively started in 2012 and 2013.
◆ Lifted ore dewatered onboard , shipped to the pilot-scale grinding/flotation circuit to yield two types of concentrates and finally processed in smelters.
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2019
Stage-1
Stage-2
Conceptual design & basic study
Tests of physical ore properties
Cruising test
Crushing test
<Mining>
Assembling mining tools
Test
Offshore Testing
<Ore lifting>
Basic study
Loop test
Design and assembling of riser and lifting system
Evaluation & Review
Offshore Pilot Test
Pre-F/S

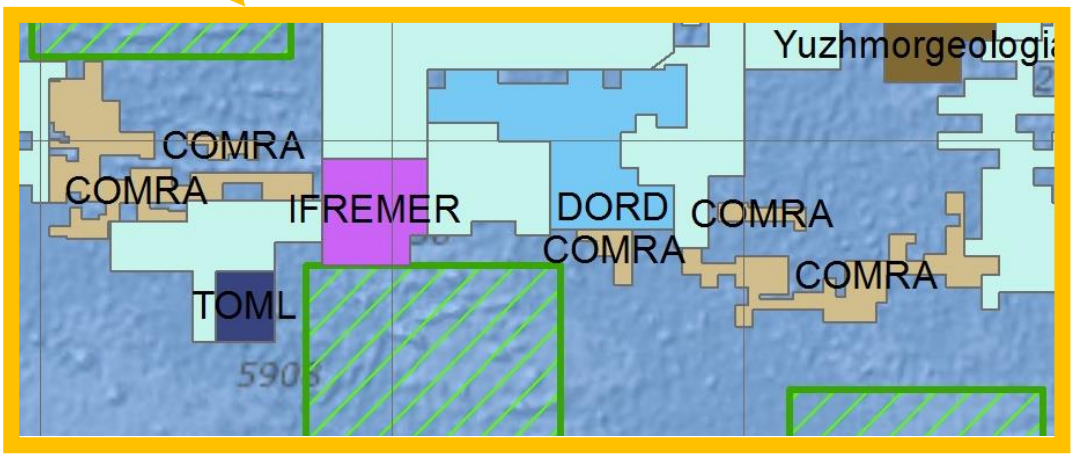
Japan…


Targets for Exploration of PMS within EEZ of Japan
Myojin
Bayonnaise
Myojinsyo
Sumisu
Okinawa Trough
Izu-Bonin
Minami-Ensei
Iheya-north
Iheya
Izena
Suiyo
Mokuyo
Hatoma
Kaikata
Daiyon Yonaguni
Kurashima

Polymetallic Nodules…



- First lease taken by COMRA
- Second lease recently taken by China's Minmetals



South Korea…

Nodule mining prototypes

- Potato-picker design
- Tested to 1400m

MineRo 1 test robot

MineRo 2

KIOST
KOREA INSTITUTE OF OCEAN SCIENCE & TECHNOLOGY

Note that the Koreans have moved to 4-track system due to low bearing capacity of the sediments

India…

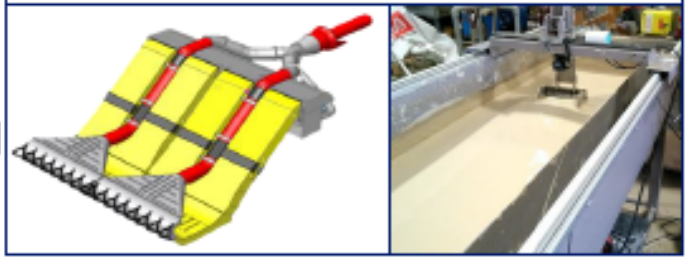
Nodule mining prototypes

Some sub-assembly tests carried out at 5,000m

European Union…

Tracked Vehicle Development

Collector Development



Prototype Test Vehicle

2016 / 2017
- Factory testing
- Autonomous testing
- Laboratory test to validate soil interaction model

2016 / 2017
- Mechanical & hydraulic collector
- Laboratory tests to determine the most suitable

September 2017
- Testing in the North Sea
- Traction & collector tests
- Environmental monitoring

2017 / 2018
- Evaluate North Sea Testing results
- Establish improvements required
- Design and implement improvements

Improved Prototype Test Vehicle

September 2018
- Testing in the North Sea

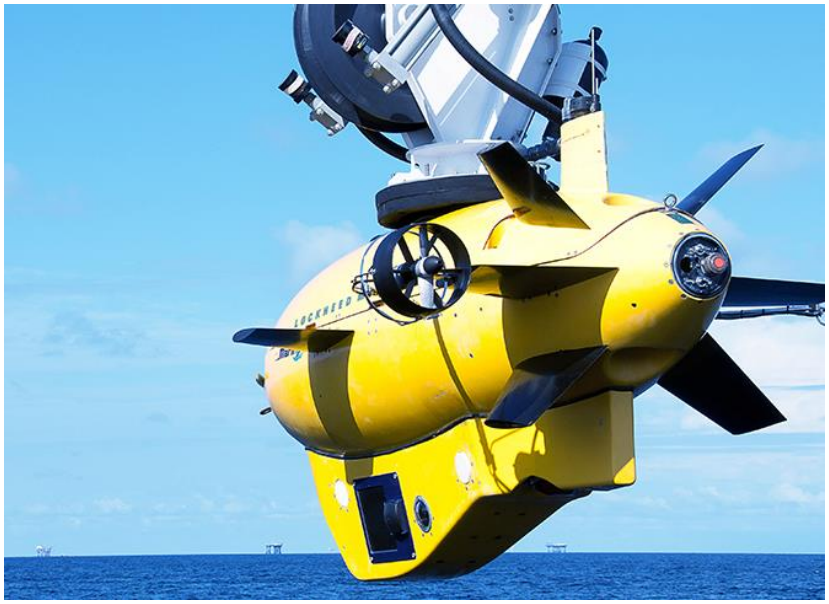
September 2019
- Testing in the Clarion Clipperton Zone

Blue nodules project, multi-country involvement

Ukraine – nodule miner concept…

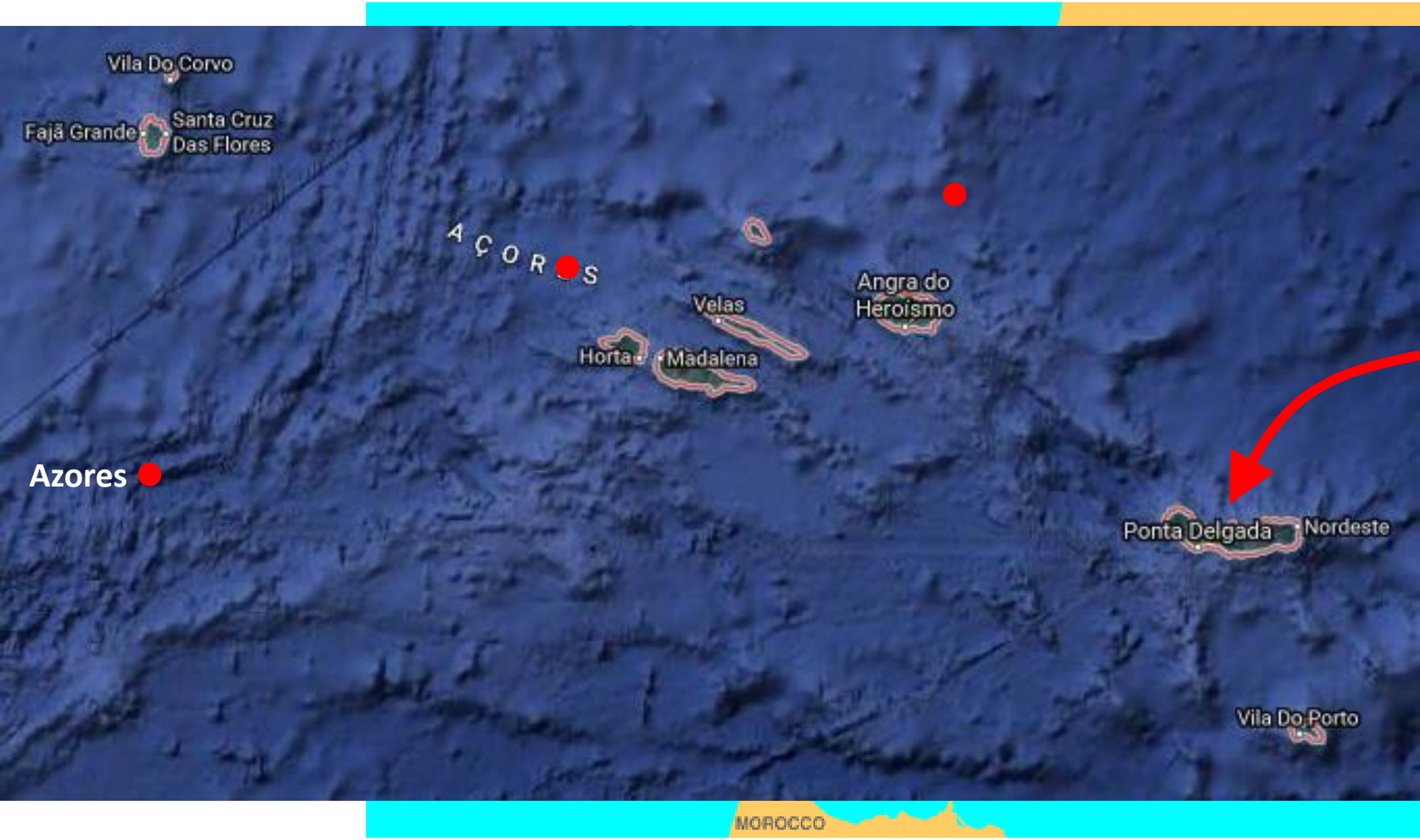
United Kingdom…

Subsidiary UK Seabed Resources

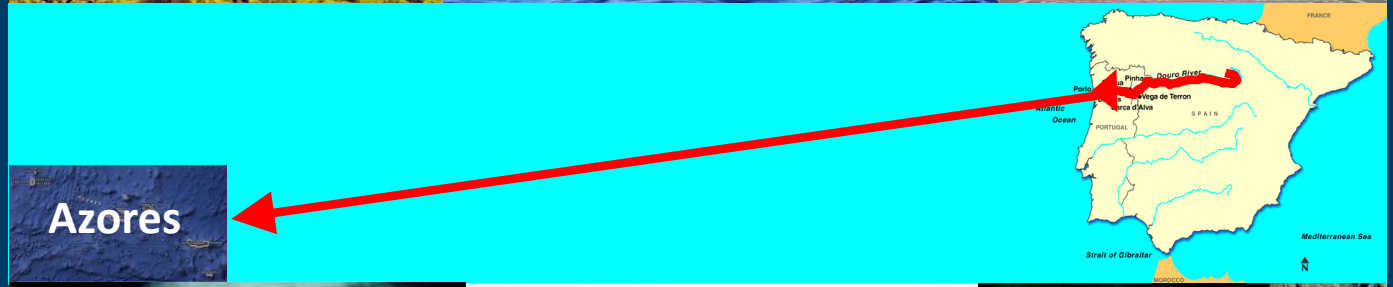


Exploration lease for nodules in CCZ – under UK membership of UNCLOS

Places to see…



My wife's thoughts…



My thoughts…

One thing we both agree on…

Obrigado