NORI ISA Side Event

An update on the NORI-D Polymetallic Nodule Project and latest data on the environmental impacts of nodule collection

Kingston, Jamaica

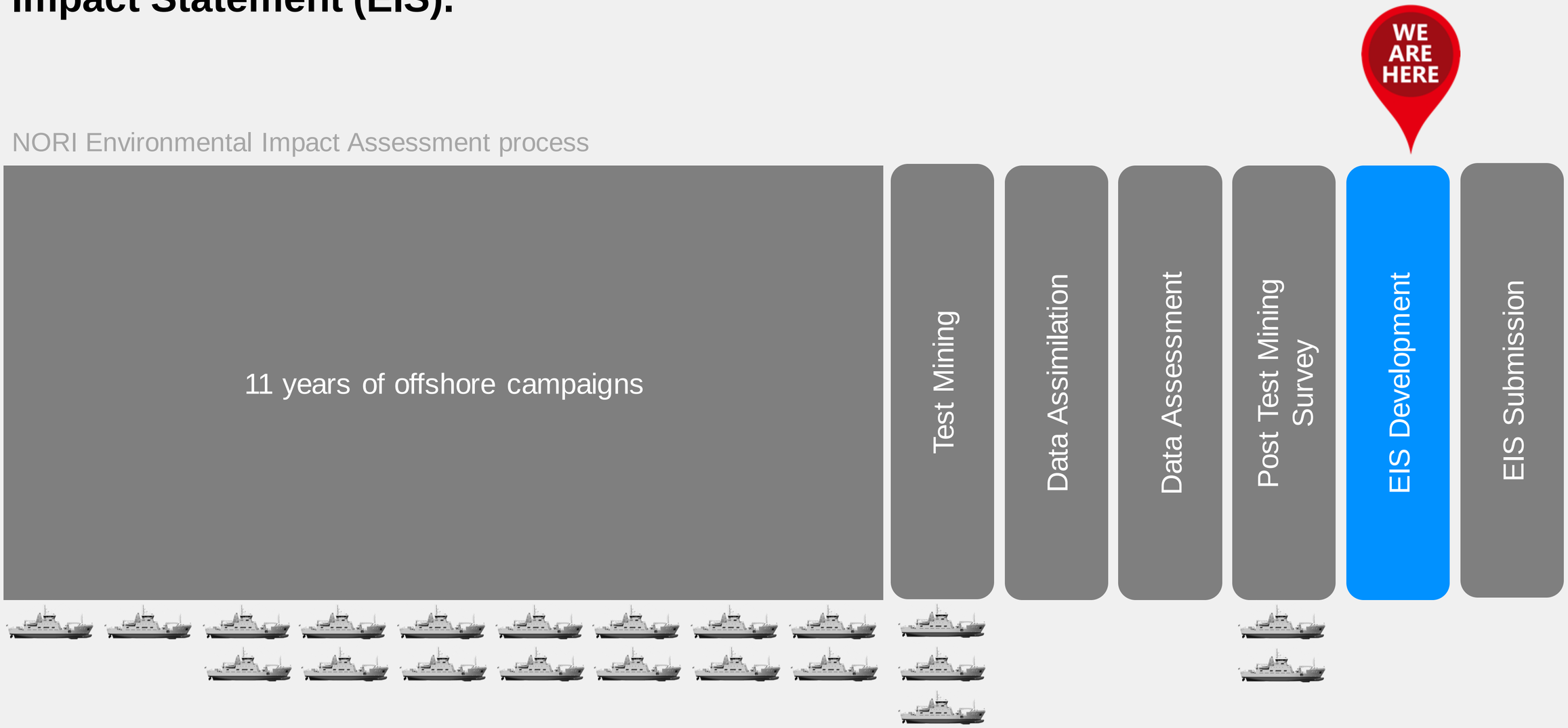
March 2025

Agenda.

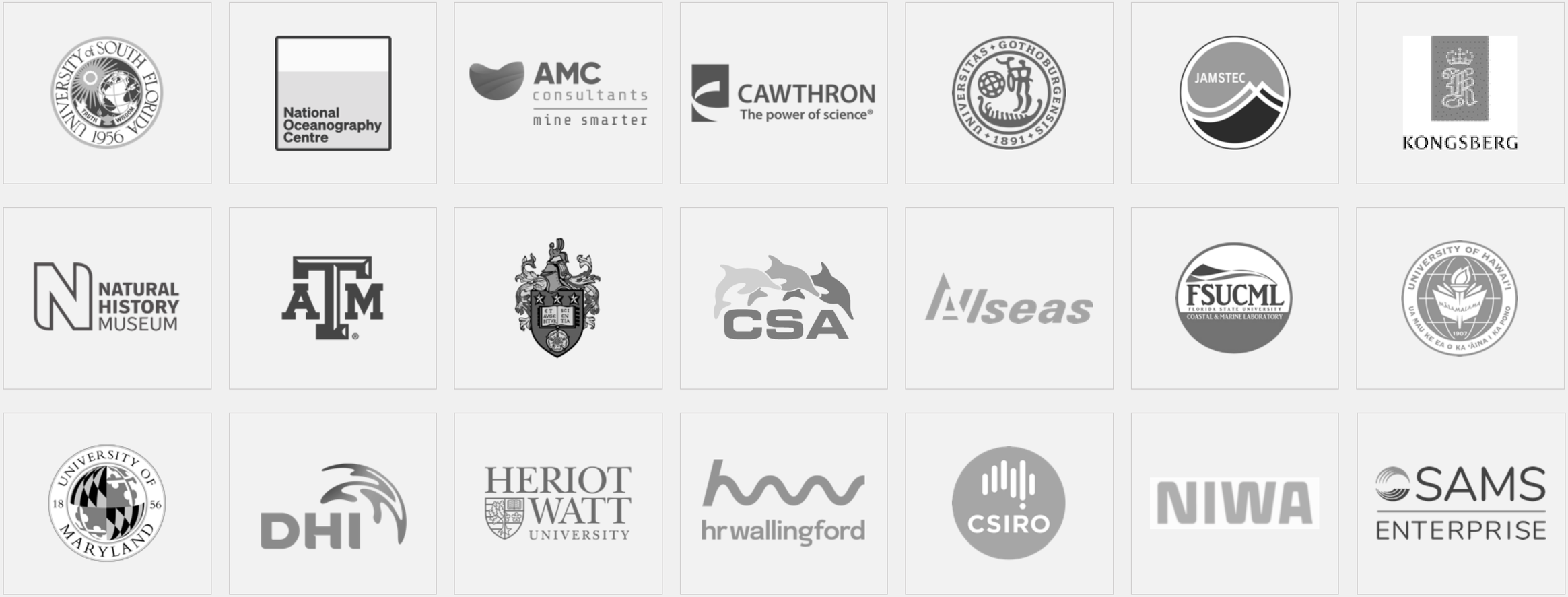
Time	Topic	Presenter
30 minutes	Environmental & Social Impact Assessment (ESIA)	Corey McLachlan, Head of Stakeholder Engagement
15 minutes	Onshore processing update	
15 minutes	Q&A	

We are in the final stages of developing our Environmental Impact Statement (EIS).

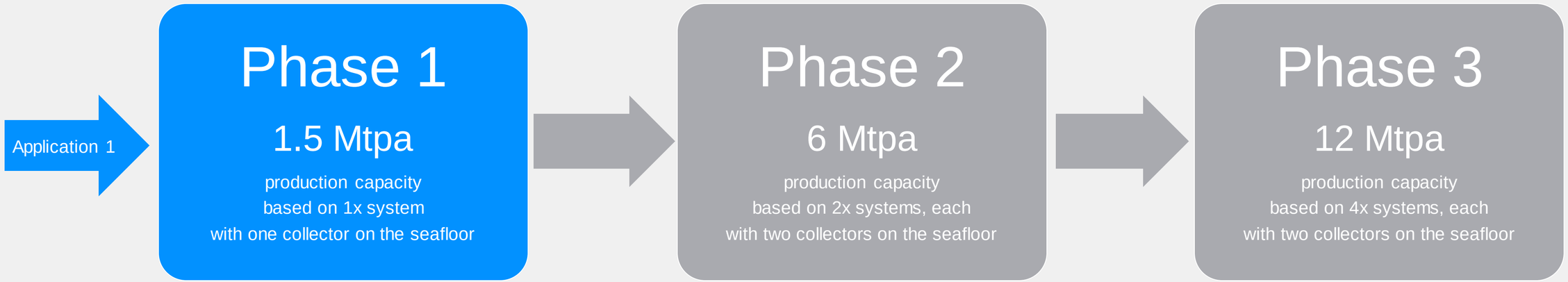
NORI Environmental Impact Assessment process



>20 organizations engaged &
~1 petabyte of data collected.



We are taking a precautionary approach to scaling up production (1/2).

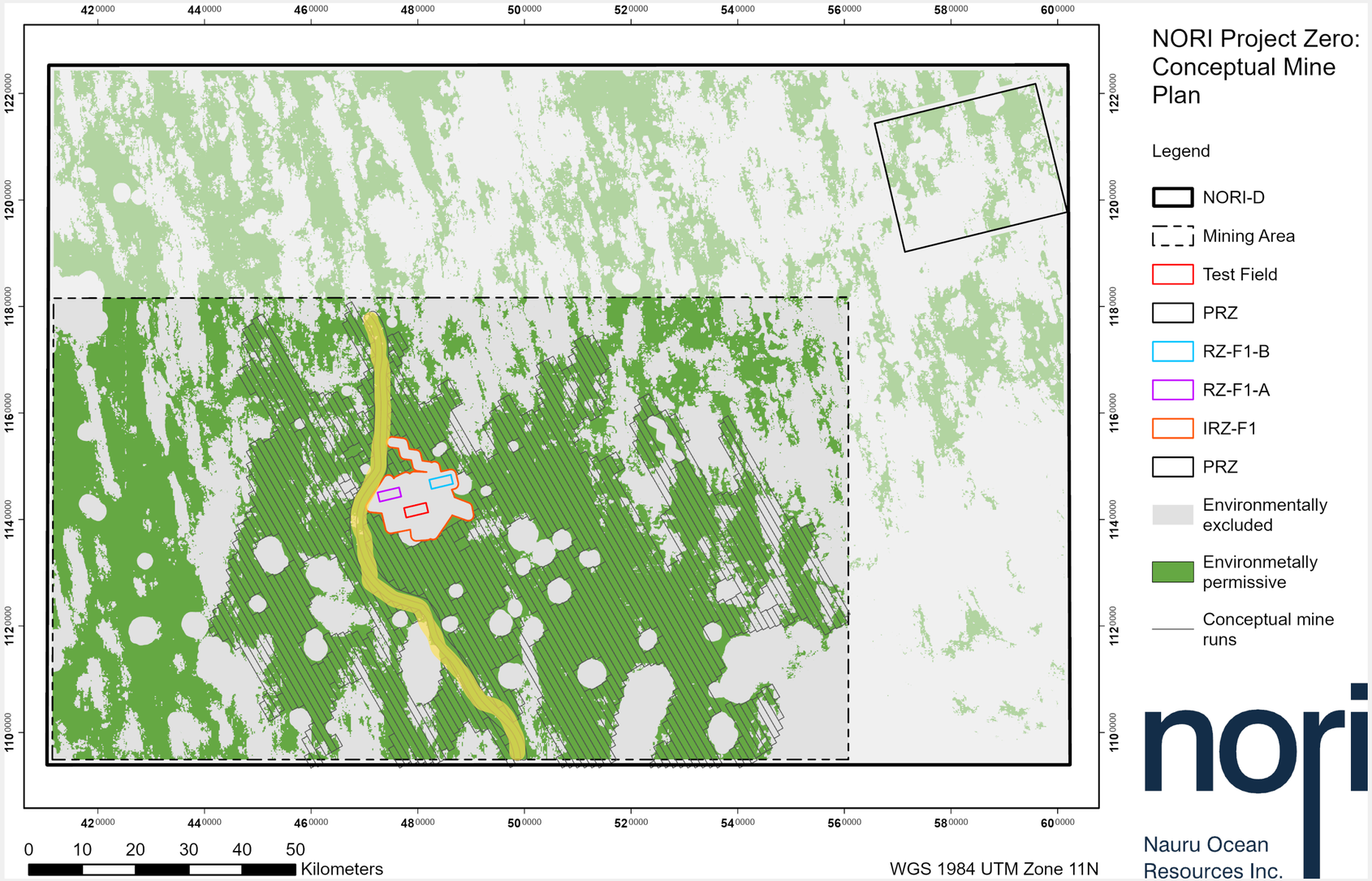


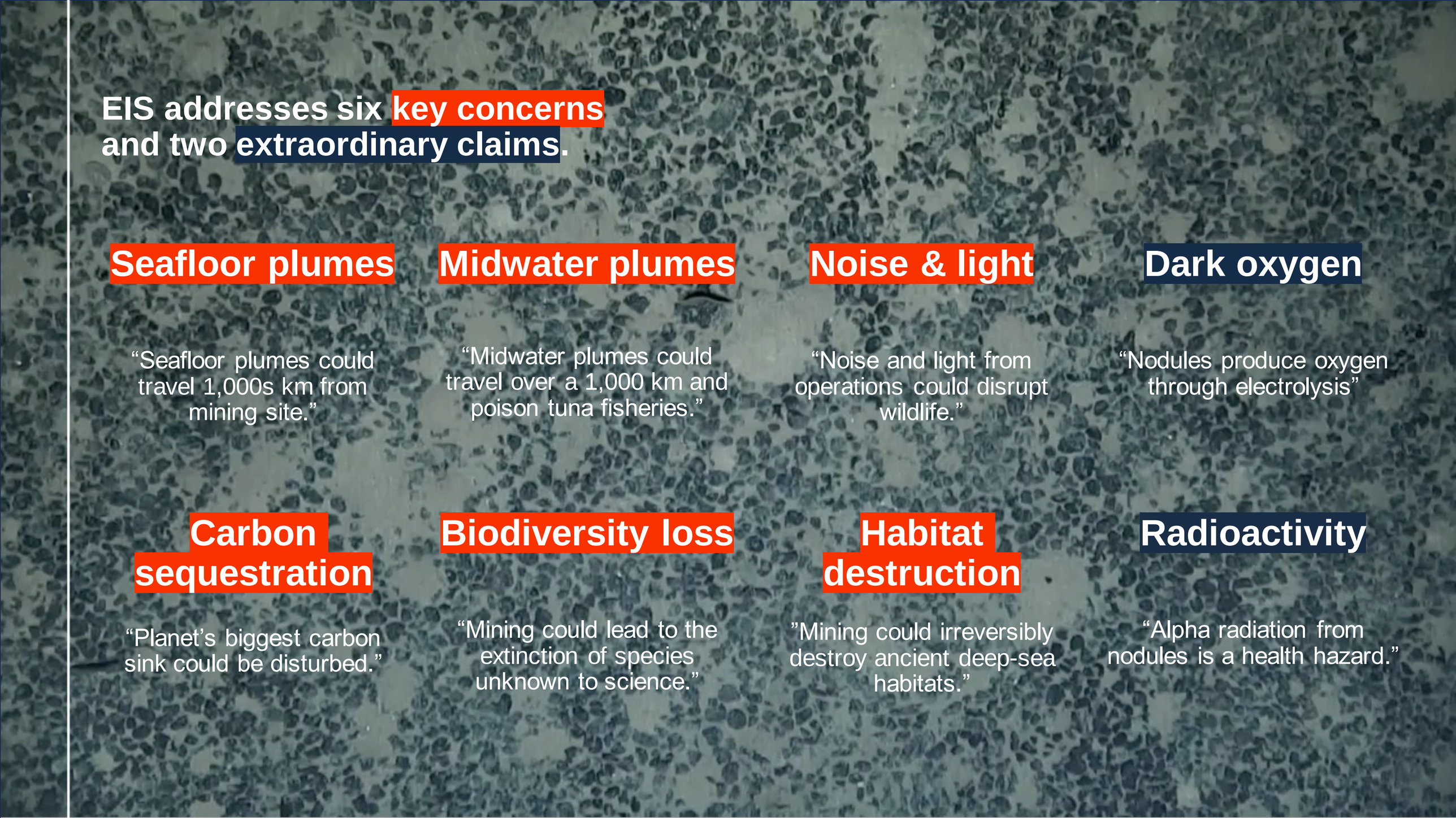
NORI's application is for a system with production capacity of 1.5 million tonnes per annum (Mtpa) of wet nodules to be deployed on a sub-area of NORI-D (Project Zero).

Our first production system will have the capacity to collect 3 Mtpa. However, we plan to start with a single collector deployed on the seafloor at any given time and collect additional environmental data before applying for permit to use the 3Mtpa system with two collectors deployed in parallel

We are taking a precautionary approach to scaling up production (2/2).

NORI-D / Project Zero / Phase 1 / Mine path - 18 months





EIS addresses six key concerns and two extraordinary claims.

Seafloor plumes

"Seafloor plumes could travel 1,000s km from mining site."

Midwater plumes

"Midwater plumes could travel over a 1,000 km and poison tuna fisheries."

Noise & light

"Noise and light from operations could disrupt wildlife."

Dark oxygen

"Nodules produce oxygen through electrolysis"

Carbon sequestration

"Planet's biggest carbon sink could be disturbed."

Biodiversity loss

"Mining could lead to the extinction of species unknown to science."

Habitat destruction

"Mining could irreversibly destroy ancient deep-sea habitats."

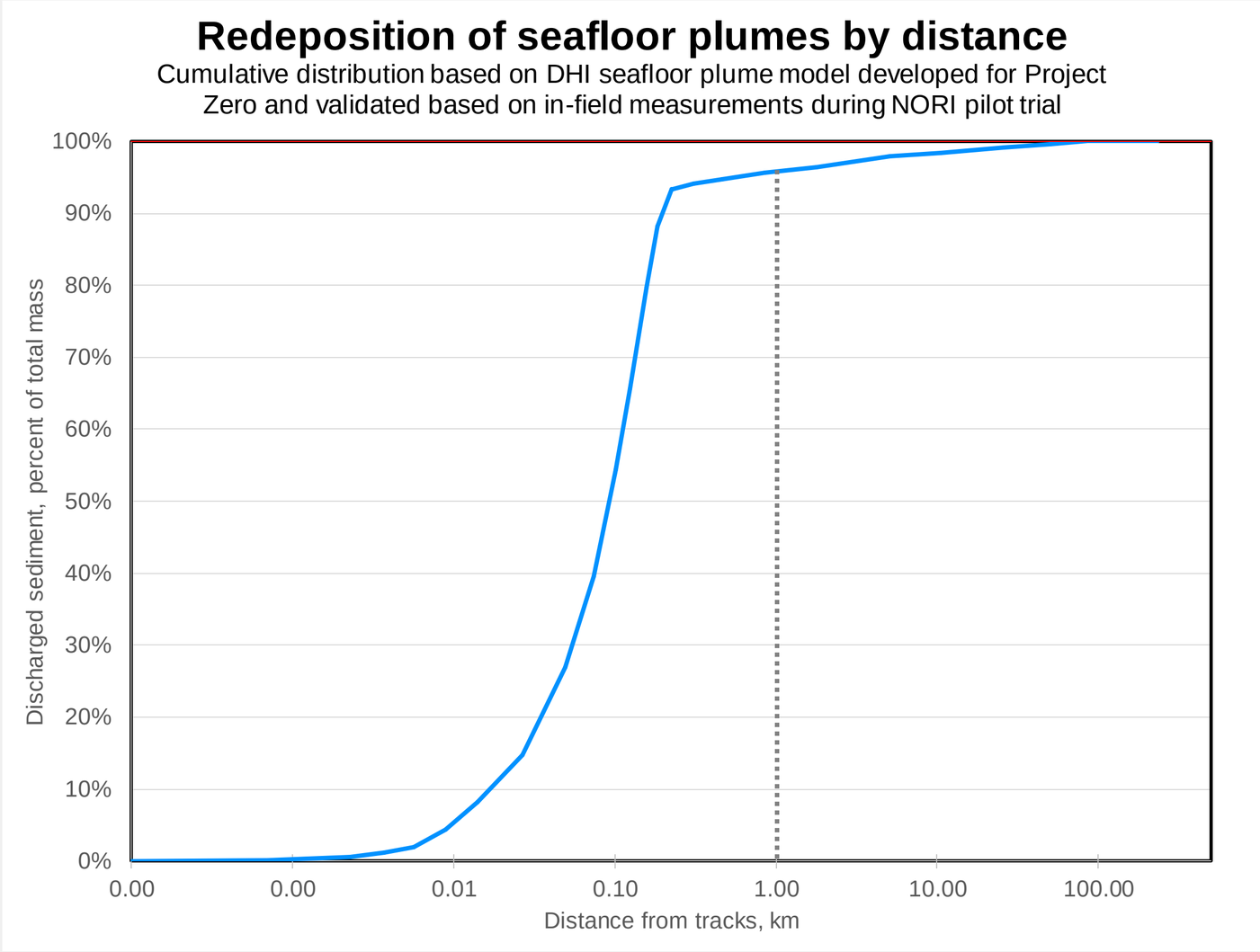
Radioactivity

"Alpha radiation from nodules is a health hazard."

Seafloor plumes will not travel 1,000s of km — most mass resettles within 1 km.

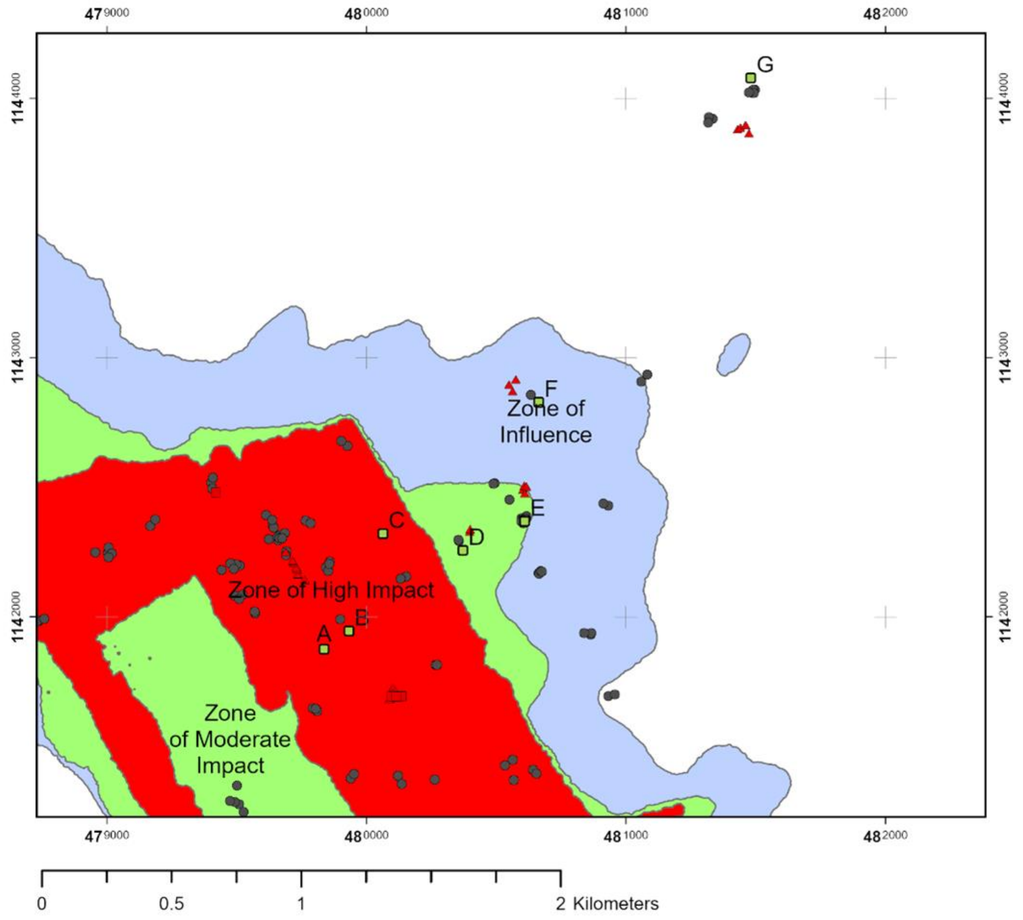
Near field
- Vast majority of sediment (>95%) resettles within 1 km of the collector tracks
- Mobilized sediment is a density-driven flow, redeposition is aided by flocculation

Far field
- Mobilized sediment is colloidal material that didn't flocculate, redeposition is characterized by extremely low thickness (micron scale of thinner than human hair)



Seafloor plume blanketing with high impact (>5mm) is limited to 100s of meters.

Zones of Impact measured during NORI pilot trial



Cathx photos
C8_BC
C8_MC
C5 & C7 Sites

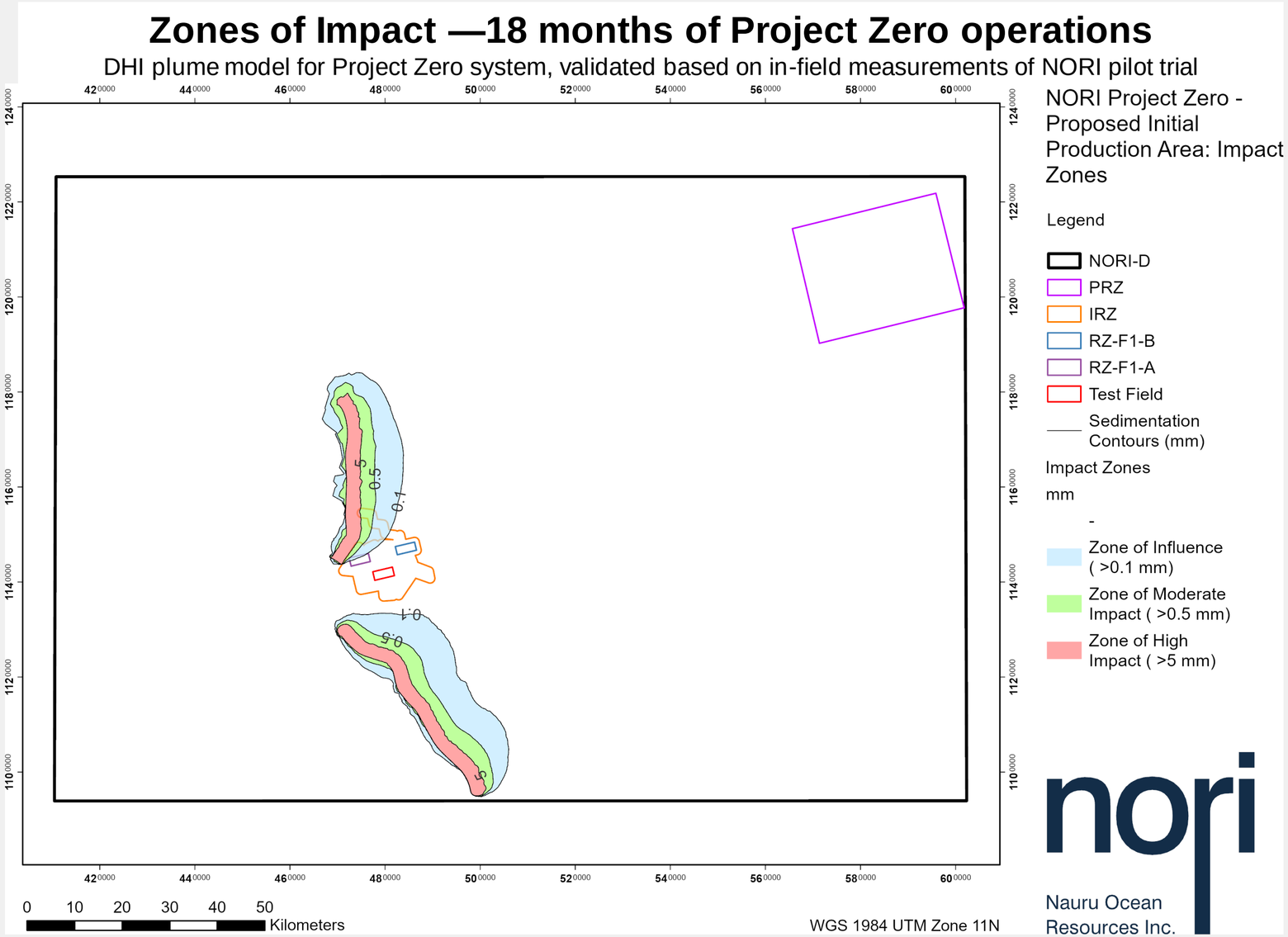
ZONES OF IMPACT

High Impact
>5mm

Moderate Impact
5-0.5mm

Influence
0.5-0.1mm

Seafloor plumes’ zones of impact (red and green) are constrained to several kms after 18 months of operations.



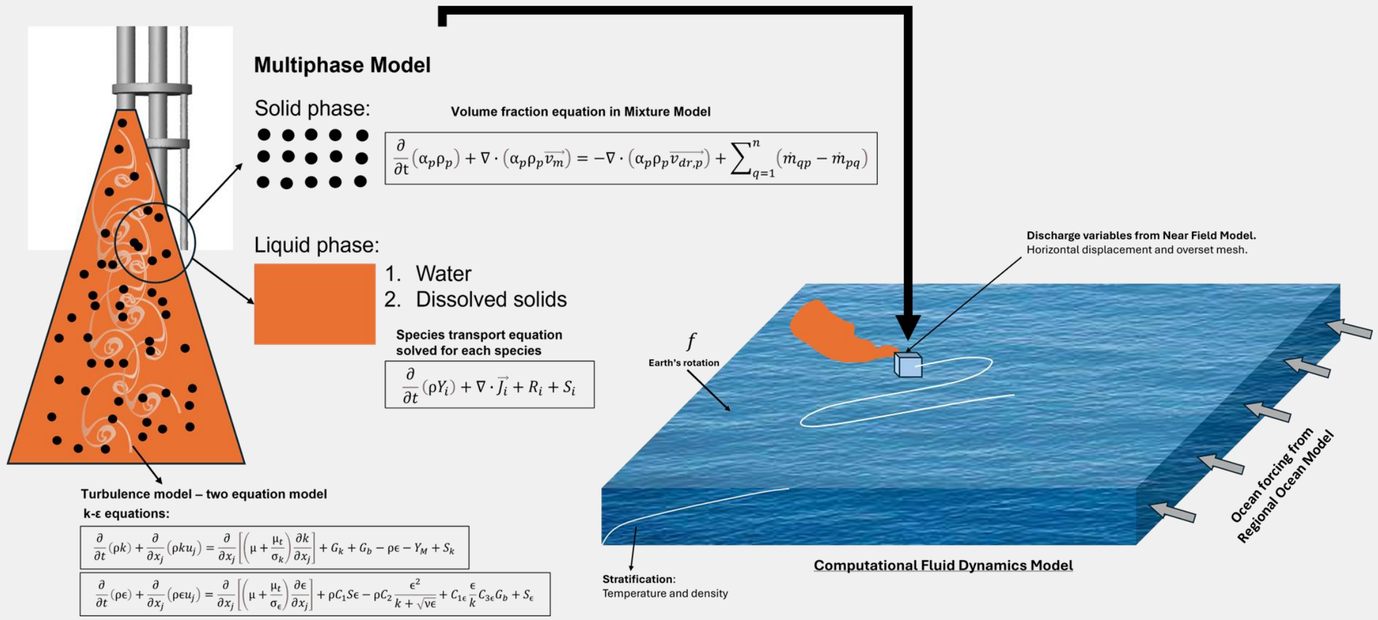
Midwater plumes were modelled using a multiphase model.

NORI Multiphase Sediment Plume Model

- **Solid Phase:** Includes equations for specific sediment volume fractions
- **Liquid Phase:** Consists of water and dissolved solids

- Incorporates Earth's rotation effects
- Includes ocean stratification
- Accounts for ocean currents, temperature, and salinity, using NORI empirical data and General Ocean Global Models

- All models have been validated using field data from NORI test mining and exhibit high levels of fidelity



Midwater plumes will not travel 1,000s of km — but rapidly dilute to within natural range of background variation within 10s of km.

Speed of dilution

In-field measurements of how quickly midwater plume diluted to background during NORI pilot trial.

Dispersal distance

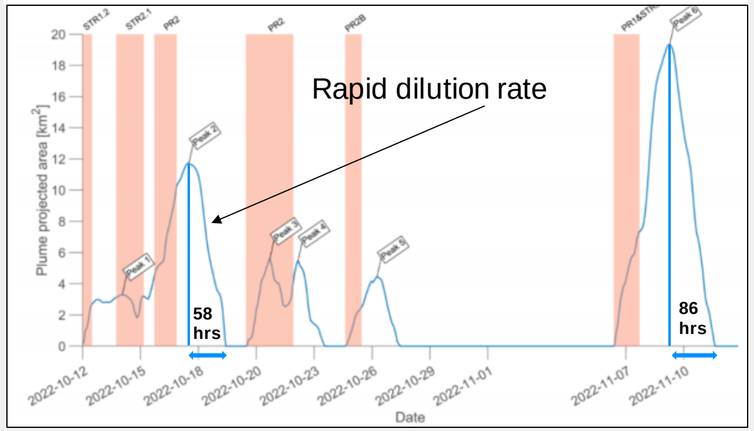
Plume model developed for Project Zero and validated based on in-field measurements of NORI pilot trial
The cut-off selected for mid-water plume modelling is the upper limit of natural range of Total Suspened Solids (TSS) variation of 0.07 mg/l. For reference, permissible TSS in drinking water as per Australian drinking water guidelines is 500 mg/l or >7,000x higher.

During pilot, plumes diluted to background within 2-4 days.

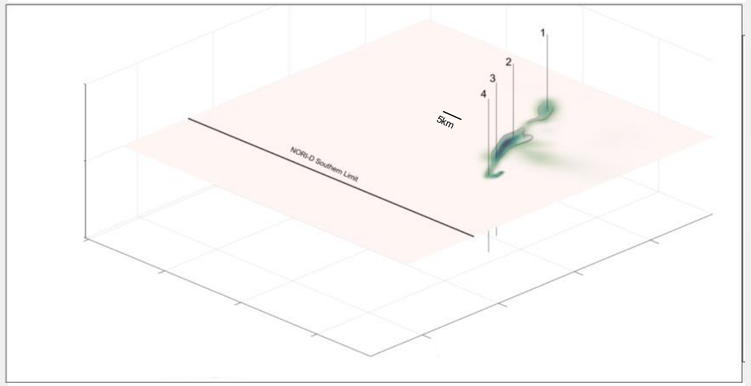
Horizontally, plumes dispersed several kms before reaching natural background variation.

Vertically, plumes dispersed 10s-100s of meters before reaching natural background variation.

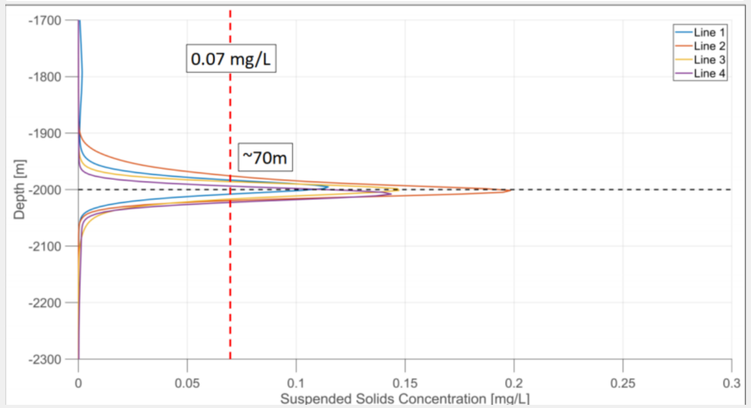
Rates of dilution of TSS to background, hours



Horizontal dispersal of TSS, km



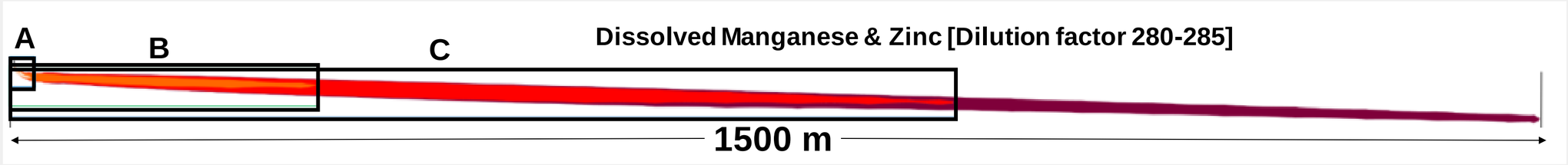
Vertical dispersal of TSS plume, meters

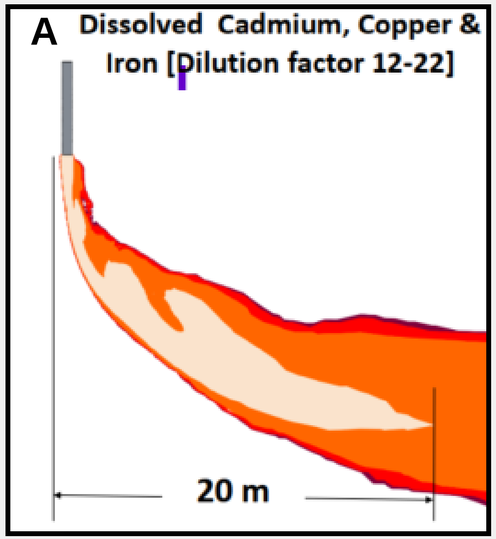


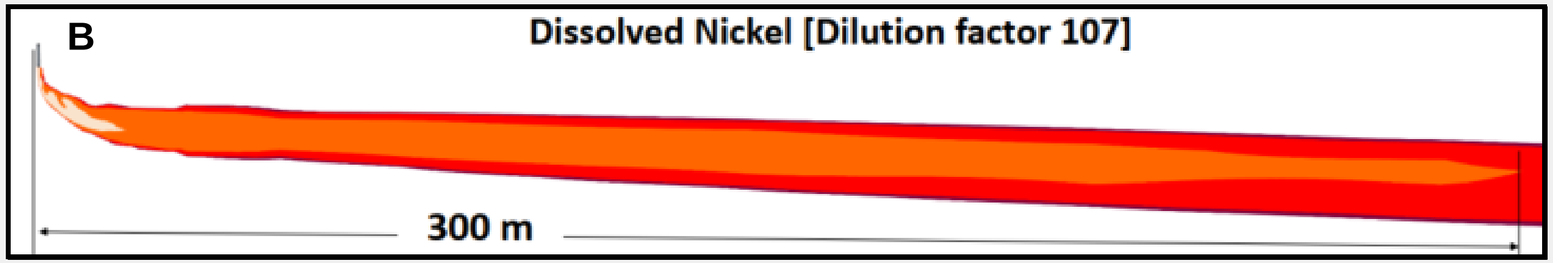
Dissolved metals in midwater plumes dilute to background within 1.5 km of source.

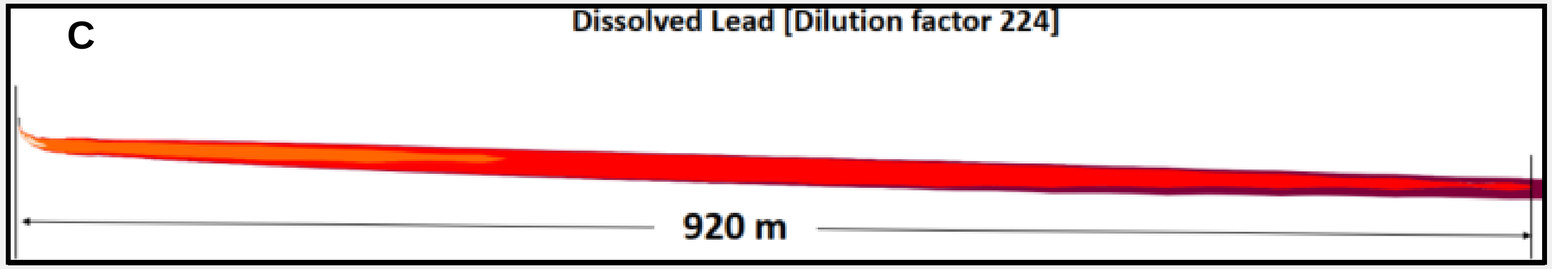
Dissolved Metal Fraction	*Source Concentration [mg/L]	**Background Concentrations [mg/L]	***Dilution Fraction [%]
Dissolved Iron	0.004042941	0.00041300	21.63
Dissolved Zinc	0.033787371	0.00066800	284.48
Dissolved Nickel	0.027864648	7600	106.89
Dissolved Copper	0.011814123	[illegible]2000	20.12
Dissolved Cadmium (114)	0.000390544	0.00011100	11.53
Dissolved Lead	0.000084952	0.00000212	223.26
Dissolved Manganese	0.060401914	0.00070700	279.68

*, ** References are in progress; *** Dilution factor required for the source concentration to return to background levels.





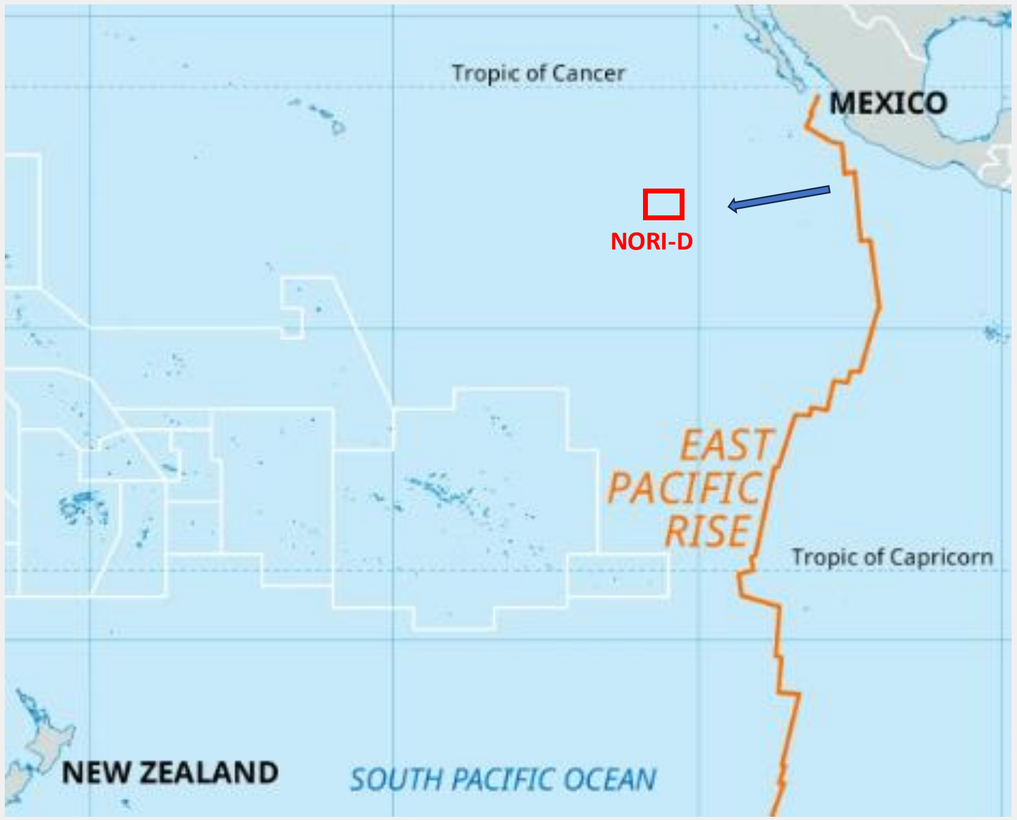




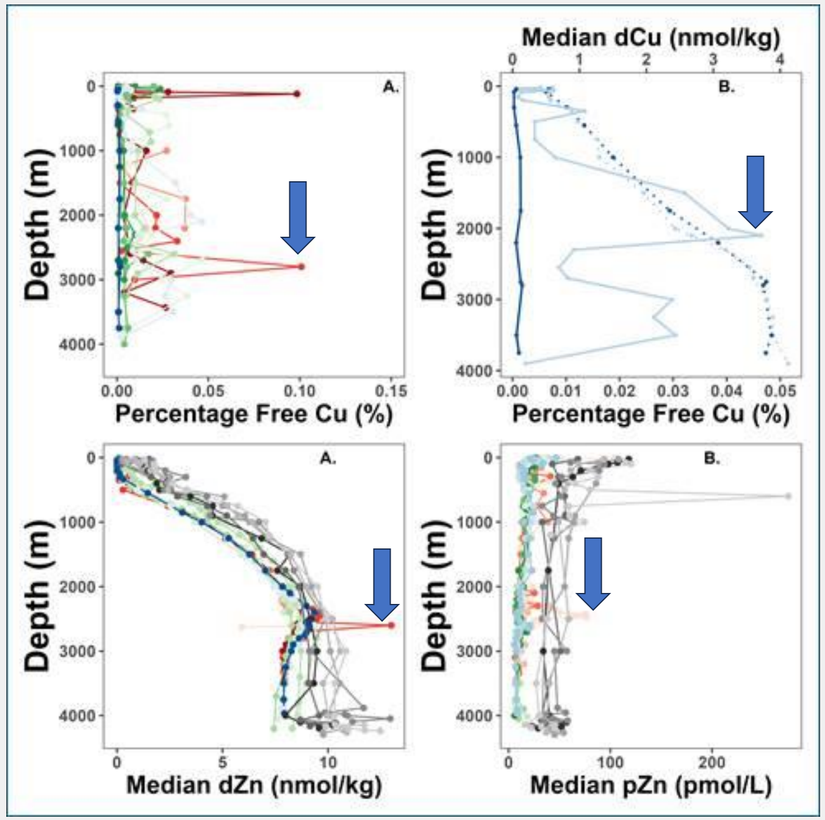
Source: *Source concentration values derived from technical report submitted to NORI by Texas A&M University; **Background concentration values derived from data contained in multiple peer-reviewed papers, compiled here as an element of NORI's Environmental Impact Statement.

Pelagic organisms impacted by midwater plumes already experience spikes in metal concentrations from East Pacific Rise (EPR).

The EPR is a linear submarine volcanic chain on the floor of the southeastern Pacific Ocean, roughly paralleling the west coast of South America.



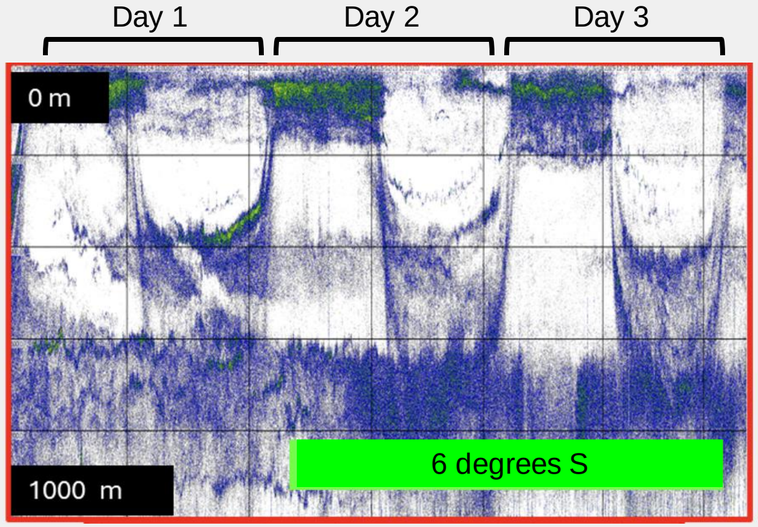
The volcanic activity of the EPR appears to be the source of periodic spikes in metal concentrations at NORI-D at 2000 – 3000 m depth.



Midwater plumes released at 2,000m depth are unlikely to impact tuna fisheries.

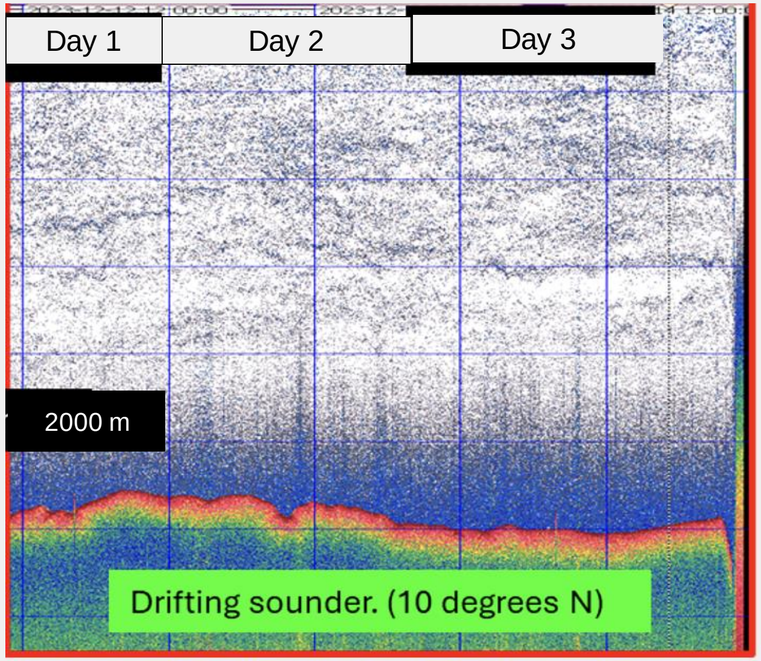
Vertical biomass migration during day-night cycle
Acoustic measurements in the upper 1,000m at a reference site in December 2015

Key takeaways:
- Most vertical migration of mesopelagic organisms takes place in the top 500 m, with some biomass migrating as far down as 800-900 m
- Very limited biomass is found below 1,000m as most lives above the Oxygen Minimum Layer



Observed biomass concentrations
Acoustic measurements using drifting sounder at 2,000m in NORI-D site, December 2023

Key takeaways:
- No day-night biomass migration observed at 2,000 m
- Releasing midwater plume at 2,000m below the layers with high biomass and below the lower limit of day-night migration will minimise the risk of bioaccumulation of metals in the food web
- Dissolved metal concentrations dilute to background within 1,500 m. Model for bioaccumulation in commercial fish species is currently under development by CSIRO

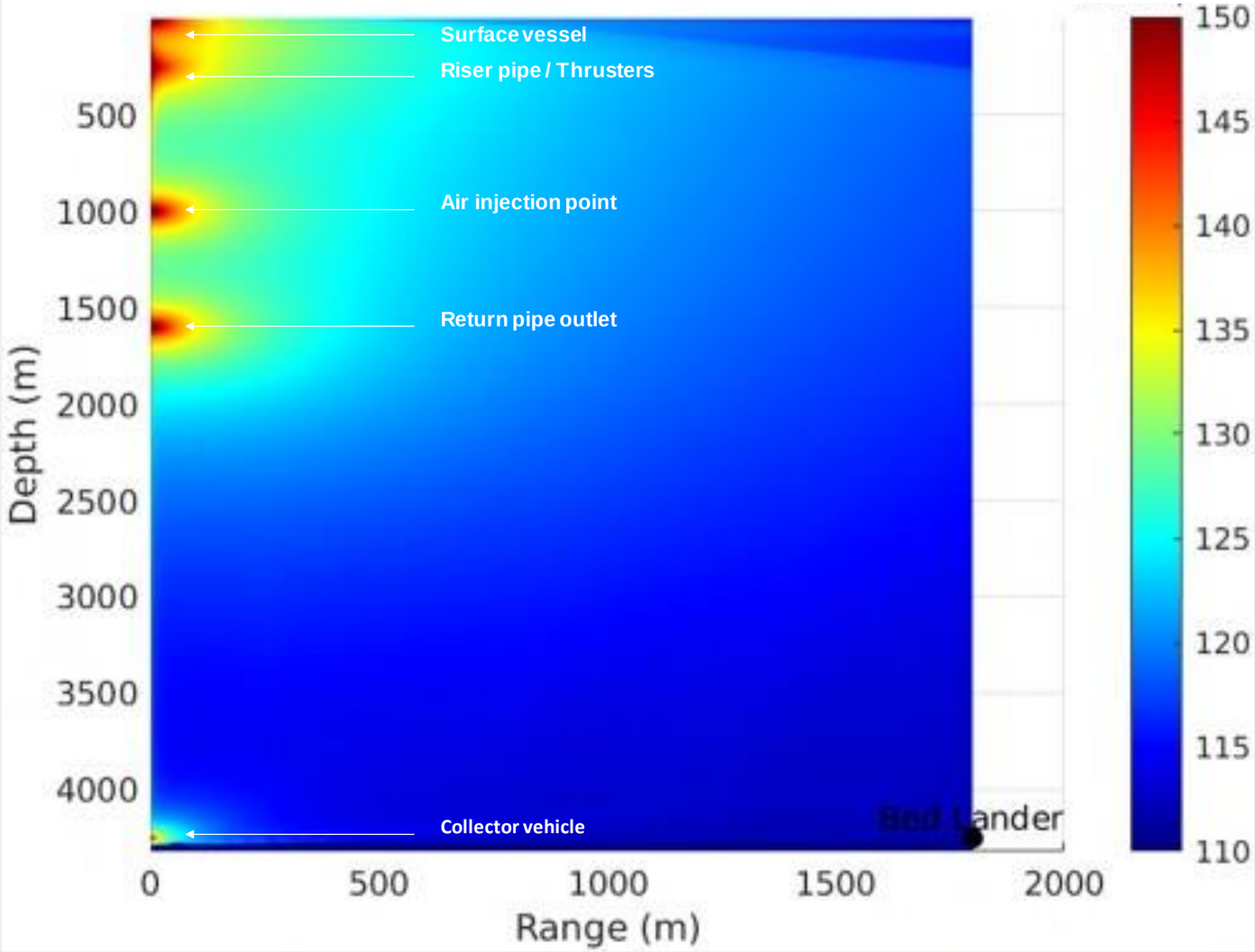


Noise measured during pilot was highest from the surface vessel.

- Empirical noise data was collected during test mining using an array of hydrophones
- Results show that the main noise source is from the diesel engines and dynamic positioning (DP) thrusters of the Hidden Gem during transits and repositioning

Noise measurements during NORI test mining

Used to validate noise model developed for Project Zero commercial system by Scottish Association for Marine Science (SAMS)

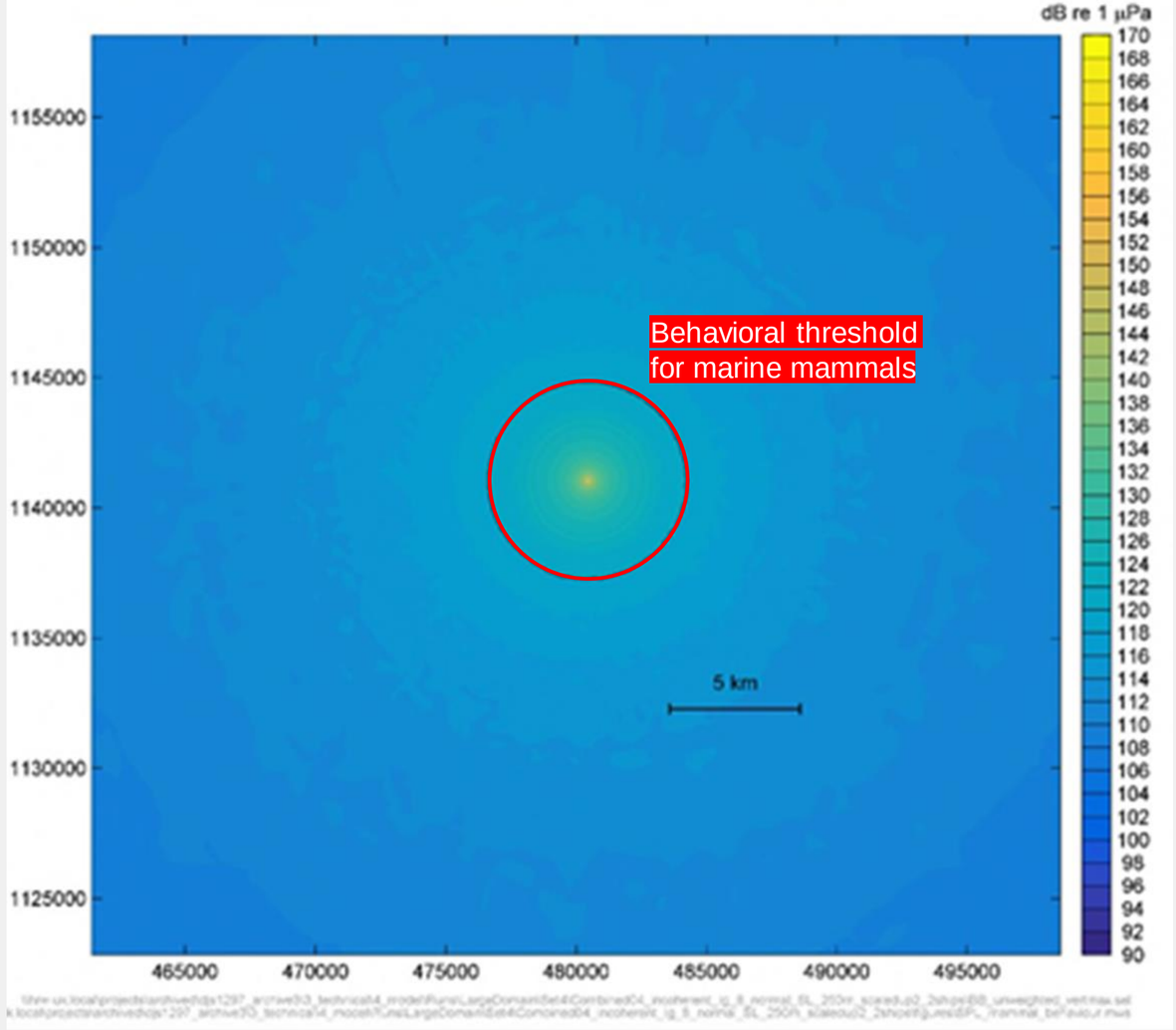


Project Zero noise footprint above NOAA behavioral threshold for marine mammals is constrained to 3.8 km radius.

- A noise model was developed by the Scottish Association for Marine Science (SAMS) using data from test mining
- In line with NOAA thresholds, behavioral effects on marine mammals were assumed to occur above a threshold of 120 dB re 1 µPa for continuous sources (NMFS, 2018)
- Modelling predicts that noise levels > 120 dB will be experienced within a 3.8 km radius of the production vessel

Noise generation during Project Zero

Based on noise model developed by Scottish Association for Marine Science (SAMS)
Operational scenario: Hidden Gem production vessel collecting nodules



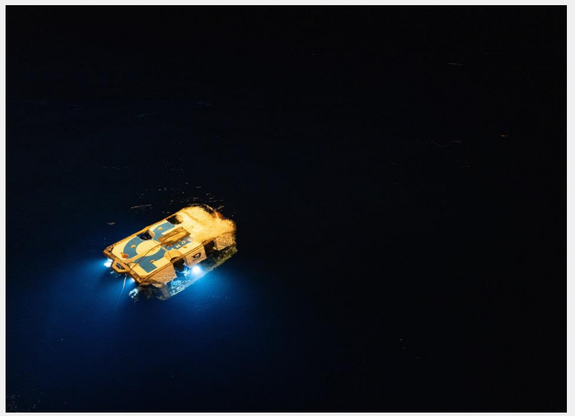
Source: NMFS (National Marine Fisheries Service). (2018). Revisions to: Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing (Version 2.0): Underwater Thresholds for Onset of Permanent and Temporary Threshold Shifts. U.S. Dept. of Commerce. NOAA. NOAA Technical Memorandum NMFS-OPR-59, 167 p.

Light is generated by the surface vessel, collector and ROVs/AUVs.

- Sources of light at the surface and in the epipelagic zone will be from production vessels. The Hidden Gem is the primary source of Artificial Light at Night (ALAN)

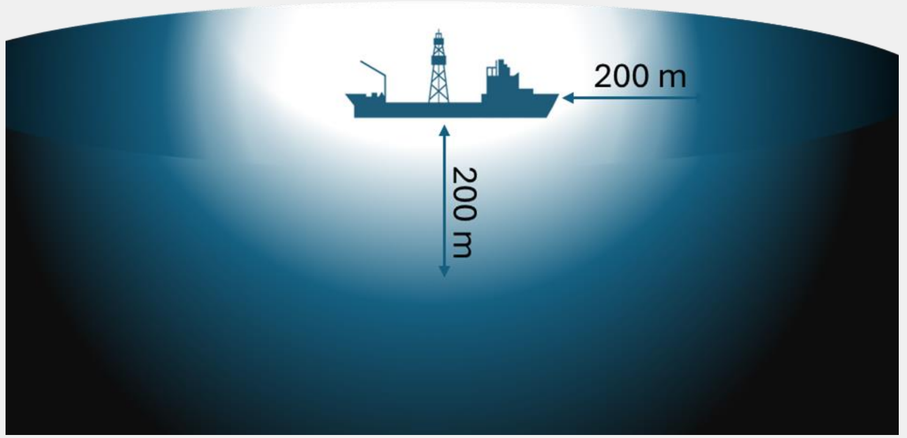
- ROVs, AUVs, and the collector vehicle are equipped with lights to illuminate video feeds for the operators. As the vehicles descend through the water column, they temporarily introduce light into the mesopelagic and bathypelagic zones

- The collector vehicle is the primary source of light at the seafloor

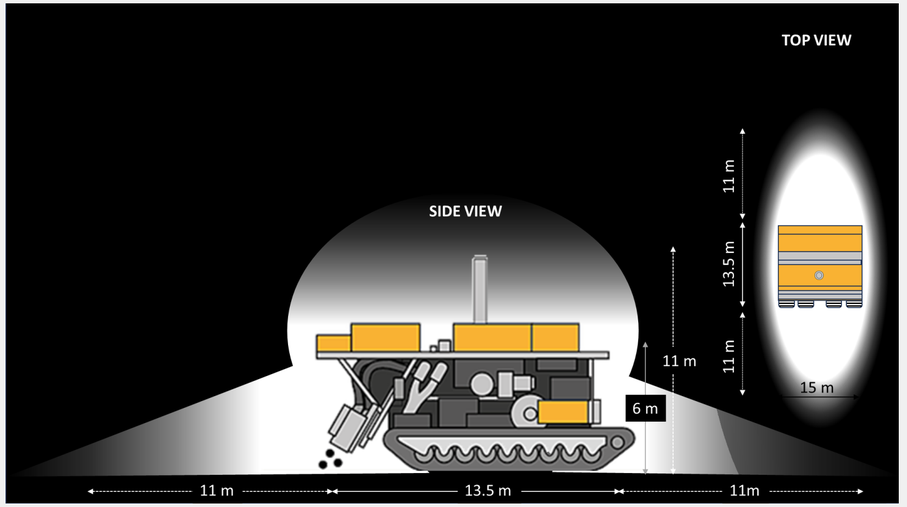


Light footprint will be constrained to 200m radius on the surface and 11m on the seafloor.

Light from the surface vessel
Normal working light from a vessel may disrupt fish and zooplankton behaviour down to at least 200m depth across an area of > 0.125 km^2 around the ship (Berge et al., 2020). This equates to a circular pool of light around the vessel with a radius of approximately 200m extending to a 200m depth.



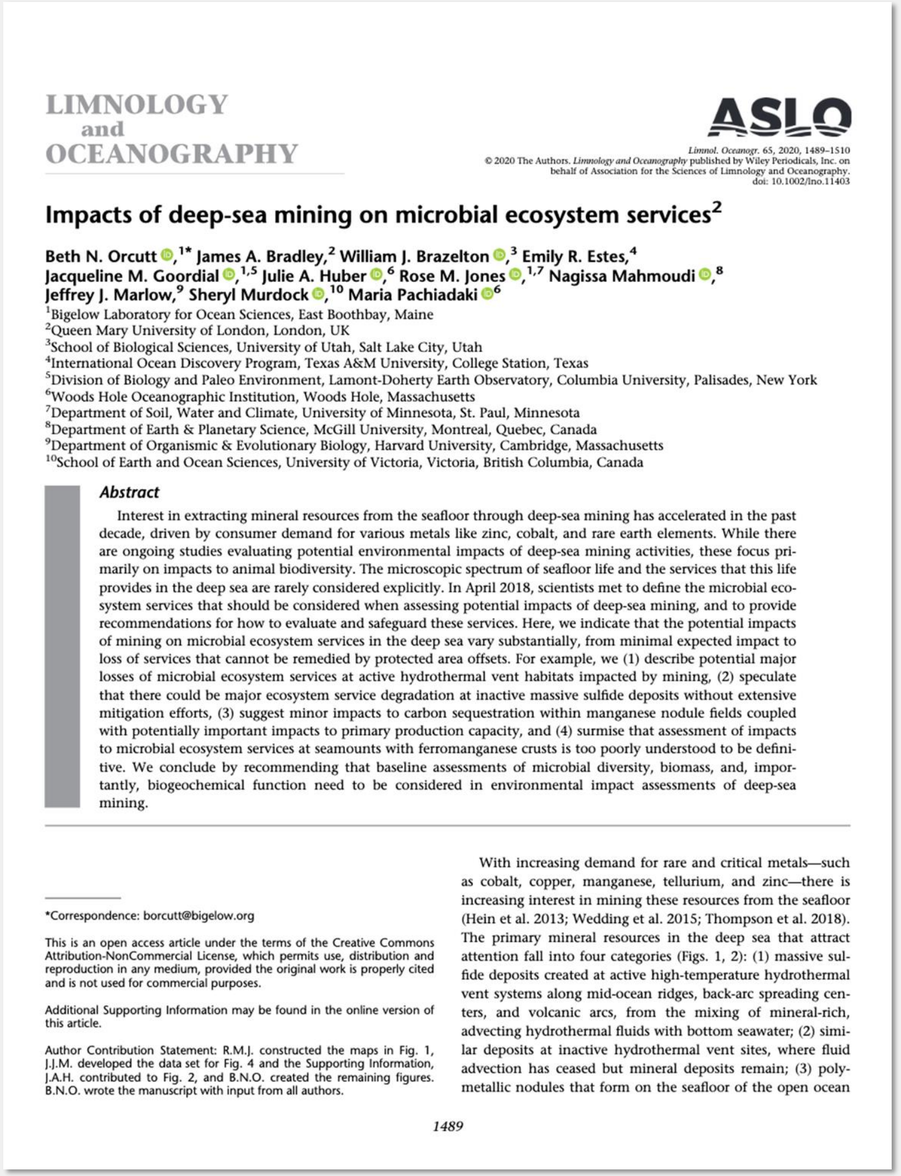
Light from seafloor collector
During test mining, the lighting system on the prototype collector vehicle emitted a 10m-long horizontal cone of light at the front and back of the vehicle, which lofted approximately 4m into the water column. Light spill from the sides of the collector was low as the lighting systems are directed to the front and rear only. Applying these metrics to the full-scale commercial vehicle, a pool of light measuring 11 m to the front and rear with 5 m of loft is anticipated.



Carbon sequestration will not be materially impacted.

“Proposed mining of these nodule-bearing sediments and resulting resuspension of particles and organic matter will have a trivial impact on the ecosystem service of carbon sequestration.”
Orcutt, B.N., et al. (2020)

“…the localized nature and relatively small scale of potential disturbances make a substantial impact on the global carbon cycle unlikely.”
ISA Fact-check 2024/1



LIMNOLOGY and OCEANOGRAPHY

ASLO

Limnol. Oceanogr. 65, 2020, 1489–1510

doi: 10.1002/lno.11403

Impacts of deep-sea mining on microbial ecosystem services[2]

Beth N. Orcutt,[1*] James A. Bradley,[2] William J. Brazelton,[3] Emily R. Estes,[4] Jacqueline M. Goordial,[1,5] Julie A. Huber,[6] Rose M. Jones,[1,7] Nagissa Mahmoudi,[8] Jeffrey J. Marlow,[9] Sheryl Murdock,[10] Maria Pachiadaki[6]

[1]Bigelow Laboratory for Ocean Sciences, East Boothbay, Maine
[2]Queen Mary University of London, London, UK
[3]School of Biological Sciences, University of Utah, Salt Lake City, Utah
[4]International Ocean Discovery Program, Texas A&M University, College Station, Texas
[5]Division of Biology and Paleo Environment, Lamont-Doherty Earth Observatory, Columbia University, Palisades, New York
[6]Woods Hole Oceanographic Institution, Woods Hole, Massachusetts
[7]Department of Soil, Water and Climate, University of Minnesota, St. Paul, Minnesota
[8]Department of Earth & Planetary Science, McGill University, Montreal, Quebec, Canada
[9]Department of Organismic & Evolutionary Biology, Harvard University, Cambridge, Massachusetts
[10]School of Earth and Ocean Sciences, University of Victoria, Victoria, British Columbia, Canada

Abstract

Interest in extracting mineral resources from the seafloor through deep-sea mining has accelerated in the past decade, driven by consumer demand for various metals like zinc, cobalt, and rare earth elements. While there are ongoing studies evaluating potential environmental impacts of deep-sea mining activities, these focus primarily on impacts to animal biodiversity. The microscopic spectrum of seafloor life and the services that this life provides in the deep sea are rarely considered explicitly. In April 2018, scientists met to define the microbial ecosystem services that should be considered when assessing potential impacts of deep-sea mining, and to provide recommendations for how to evaluate and safeguard these services. Here, we indicate that the potential impacts of mining on microbial ecosystem services in the deep sea vary substantially, from minimal expected impact to loss of services that cannot be remedied by protected area offsets. For example, we (1) describe potential major losses of microbial ecosystem services at active hydrothermal vent habitats impacted by mining, (2) speculate that there could be major ecosystem service degradation at inactive massive sulfide deposits without extensive mitigation efforts, (3) suggest minor impacts to carbon sequestration within manganese nodule fields coupled with potentially important impacts to primary production capacity, and (4) surmise that assessment of impacts to microbial ecosystem services at seamounts with ferromanganese crusts is too poorly understood to be definitive. We conclude by recommending that baseline assessments of microbial diversity, biomass, and, importantly, biogeochemical function need to be considered in environmental impact assessments of deep-sea mining.

*Correspondence: borcutt@bigelow.org

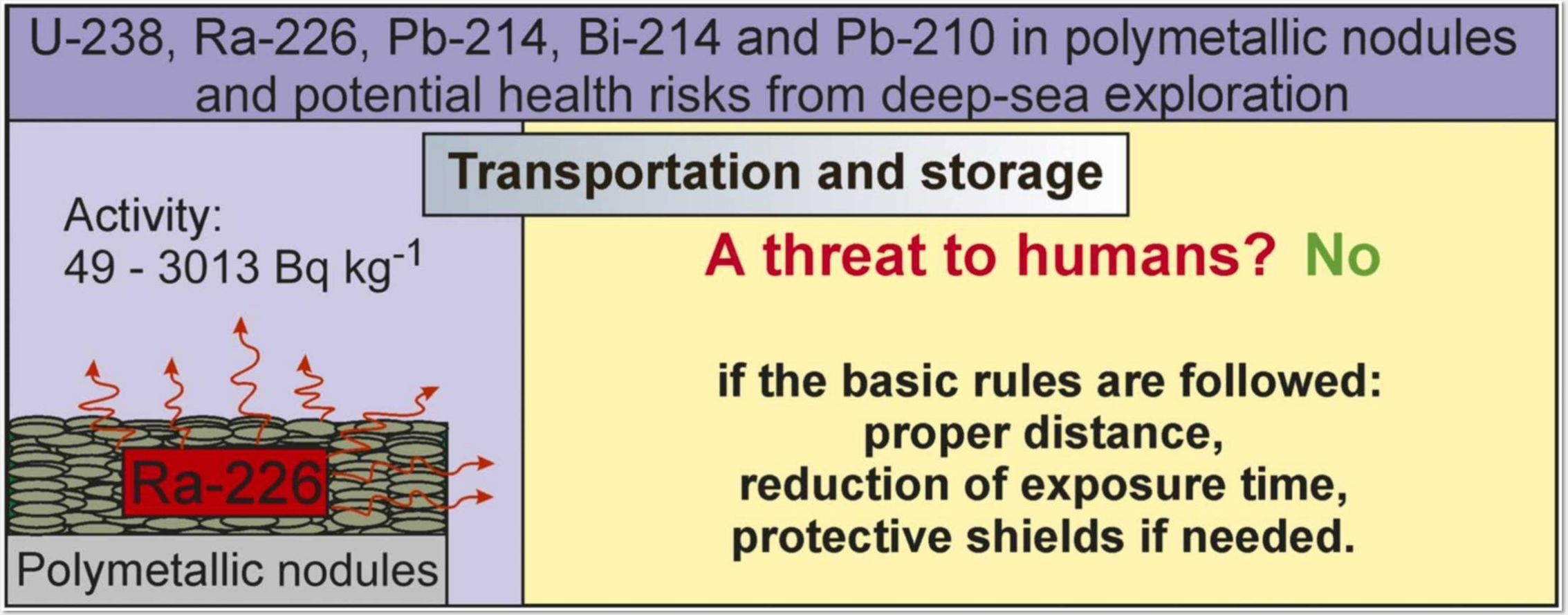
Additional Supporting Information may be found in the online version of this article.

Author Contribution Statement: R.M.J. constructed the maps in Fig. 1, J.J.M. developed the data set for Fig. 4 and the Supporting Information, J.A.H. contributed to Fig. 2, and B.N.O. created the remaining figures. B.N.O. wrote the manuscript with input from all authors.

With increasing demand for rare and critical metals—such as cobalt, copper, manganese, tellurium, and zinc—there is increasing interest in mining these resources from the seafloor (Hein et al. 2013; Wedding et al. 2015; Thompson et al. 2018). The primary mineral resources in the deep sea that attract attention fall into four categories (Figs. 1, 2): (1) massive sulfide deposits created at active high-temperature hydrothermal vent systems along mid-ocean ridges, back-arc spreading centers, and volcanic arcs, from the mixing of mineral-rich, advecting hydrothermal fluids with bottom seawater; (2) similar deposits at inactive hydrothermal vent sites, where fluid advection has ceased but mineral deposits remain; (3) polymetallic nodules that form on the seafloor of the open ocean

Source: International Seabed Authority, Fact Check, “The carbon cycle in the Area”, July 2024. Retrieved from: https://www.isa.org.jm/isa-fact-check-2024-1/; Orcutt, B. N., J. A. Bradley, W. J. Brazelton, and others. 2020. Impacts of deep-sea mining on microbial ecosystem services. Limnology and Oceanography 65: 1489–1510. Retrieved from: doi:10.1002/lno.11403.

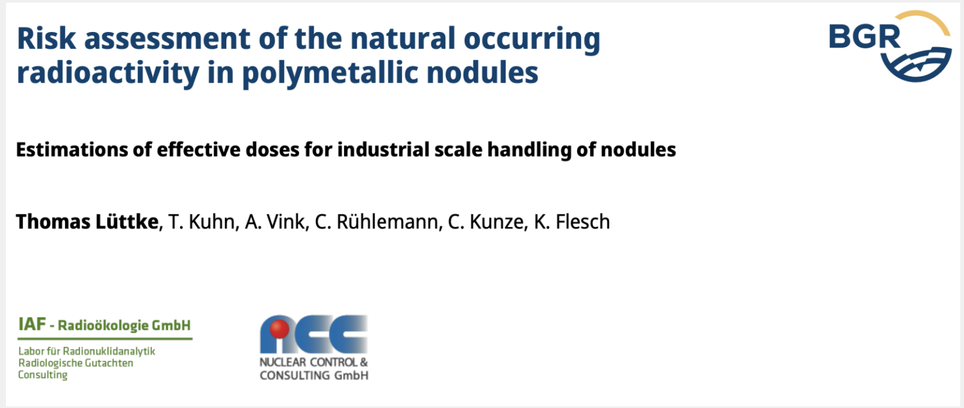
Alpha radiation from nodules is not expected to be a health hazard (1/2).



Source: Dołhańczuk-Śródka, A., Kłos, A., Janecki, D., Ziembik, Z., Skowronek, A., Strzelecka, A., ... & Abramowski, T. (2024). Assessment of natural radioactivity levels in polymetallic nodules and potential health risks from deep-sea mining. Journal of Hazardous Materials, 480, 136494.

Alpha radiation from nodules is not expected to be a health hazard (2/2).

- In response to a 2023 paper by Volz et al. claiming alpha radiation from nodules posed health risks to workers, scientists at Germany's Institute for Geosciences and Natural Resources (BGR) published their assessment of the paper's claims in a presentation to the ISA
- BGR reported that though the authors used the correct measurements, the context and interpretation of these results was wrong
- No exceptional risk is expected from the handling of nodules with the effective dose easily limited to below 1 mSv/a
- Even in the worst-case scenario, the effective dose is well below the limit for workers of 20 mSv/a
- Academics conclude that the paper was the cause of much "avoidable hysteria"



The claim that nodules produce dark oxygen has attracted a record of five rebuttals.

Questioning Dark Oxygen Production in the Deep-sea Ferromanganese Nodule Field

Kentaro Nakamura

Published: 2024-10-04
Subjects: Earth Sciences, Geochemistry, Geology, Oceanography

Previous studies have concluded that the natural process where oxygen is consumed as decomposition of organic matter that supplied from shallow waters occurs on the deep-sea floor. Sweetman et al.1 presented the surprising observation that deep-sea ferromanganese nodules generate oxygen, which they labelled as dark oxygen production. The authors claimed that oxygen was generated through the [...]

Pre-print

Critical Review of the Article: "Evidence of Dark Oxygen Production at the Abyssal Seafloor" by Sweetman et al. in Nat. Geosci. 1–3 (2024)

Lars-Kristian Lunde Trellevik, Alden Denny, Werner Svellingen

Published: 2024-08-12
Subjects: Geochemistry

This review examines the findings and methodologies presented in Sweetman et al. (2024) (hereafter referred to as 'the paper'). The paper presents findings contrasting those of all previous comparable work and has stirred international debate pertaining to deep-sea minerals. We identify significant issues in data collection, validation, and interpretation including unvalidated data collection [...]

In peer-review with Nature Geoscience

Is Abyssal Dark Oxygen Production Even Possible at All?

Angel Cuesta, Marcel Jaspars

Published: 2025-03-10
Subjects: Chemistry, Environmental Sciences, Oceanography and Atmospheric Sciences and Meteorology, Physical Sciences and Mathematics

Physical principles need to be respected when interpreting controversial findings such as the production of abyssal oxygen. Such extraordinary claims must be analysed carefully before a large [...]

Pre-print, submitted to Nature Geoscience

Contributions to the discussion of novel detection of dark oxygen production at the abyssal seafloor

Patrick Downes, Leigh Marsh, Joaquim Bento, et al.

Published: 2024-09-18
Subjects: Biogeochemistry, Earth Sciences

There is an overwhelming consensus between researchers based on a vast body of peer-reviewed literature that deep sea ecosystems constitute an oxygen sink. Specific studies on abyssal seafloor regions that contain polymetallic nodules have also confirmed this result. In contrast to this well-founded and longstanding paradigm, Sweetman et al. claim to provide evidence to support a hypothesis that [...]

Peer reviewed, pending publication in Nature Geoscience

Rebuttal of Sweetman, A.K., Smith, A.J., de Jonge, D.S.W. et al. Evidence of dark oxygen production at the abyssal seafloor. Nat. Geosci. (2024). https://doi.org/10.1038/s41561-024-01480-8

Anders Tengberg, Per Hall, Mikhail Kononets

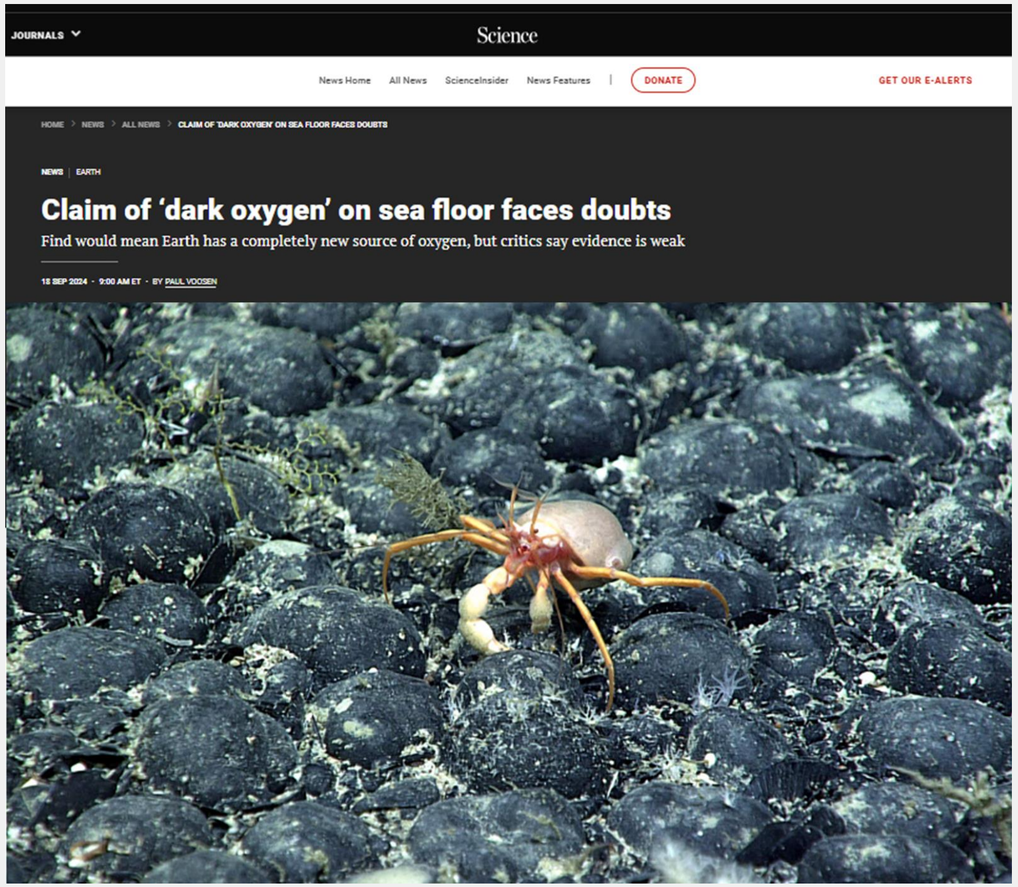
Published: 2024-10-04
Subjects: Life Sciences

A rebuttal of this paper was submitted to Nature Geoscience The paper by Sweetman et al. (2024) is criticized for poor-quality lander incubation experiments, leading to faulty oxygen flux measurements. The authors misinterpret results and make unsupported speculations, raising serious concerns about the methodology, data handling, and overall conclusions of the study.

Pre-print, in preparation for submission to Nature Geoscience

To date five rebuttals have been released by leading experts in the field – All attribute observations to poor scientific technique and lack of QA/QC

Rebuttals suggest Dark oxygen more readily explained by poor scientific technique and lack of QA/QC.



Contents lists available at ScienceDirect

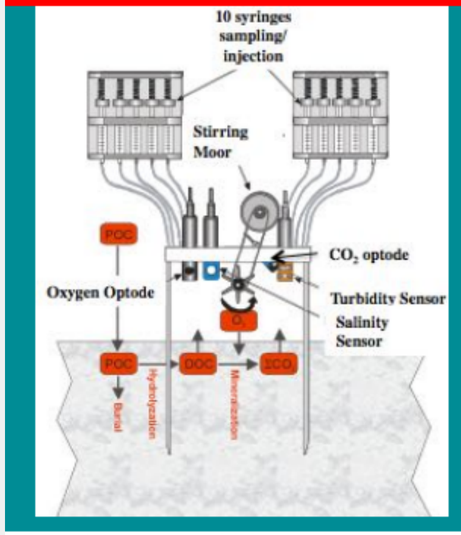
Journal of Marine Systems

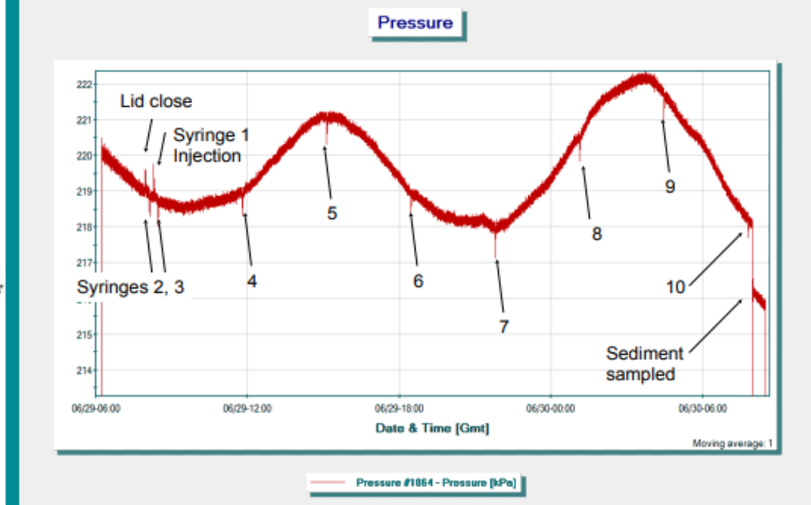
journal homepage: www.elsevier.com/locate/jmarsys

In situ incubations with the Gothenburg benthic chamber landers: Applications and quality control

Mikhail Kononets [a,*], Anders Tengberg [a], Madeleine Nilsson [a,1], Nils Ekeroth [a,2], Astrid Hylén [a], Elizabeth K. Robertson [a], Sebastiaan van de Velde [b,c], Stefano Bonaglia [a,d], Tobias Rütting [e], Sven Blomqvist [d], Per O.J. Hall [a]

Pressure sensor gives additional QC: Feed back on event triggering & turbulence





An autonomous vehicle needs sensors inside and outside incubation chambers to assure correct functioning.
Timing of syringe sampling in Sweetman et al is wrong = No understanding of lander functioning

Source: Voosen, P. (2024, September 20). Claim of seafloor 'dark oxygen' faces doubts. Science. Retrieved at: https://www.science.org/content/article/claim-seafloor-dark-oxygen-faces-doubts; Kononets, M., Tengberg, A., Nilsson, M., Ekeroth, N., Hylén, A., Robertson, E. K., van de Velde, S., Bonaglia, S., Rütting, T., Blomqvist, S., & Hall, P. O. J. (2021). In situ incubations with the Gothenburg benthic chamber landers: Applications and quality control. Journal of Marine Systems, 214, 103475. https://doi.org/10.1016/j.jmarsys.2020.103475

Assessment of social and cultural heritage impacts nearly complete.

PRELIMINARY FINDINGS
The SIA and CHIA Reports and Management Plans are being finalized and will be publicly disclosed as part of part of the NORI Project's EIS.

- **Tangible Cultural Heritage (TCH):** No significant TCH impacts identified within the project's area of influence. Potential risk in the future (i.e., project expansion) can be mitigated through expert screening of bathymetry data for TCH, and chance find procedures

- **Intangible Cultural Heritage (ICH):** No ICH under threat

- **Directly affected communities:** No negative impacts identified due to location with no human settlements nearby as well as efforts to effectively manage and contain environmental impacts such as perceived impacts to fisheries/local fishing livelihoods

- **Free, Prior, and Informed Consent (FPC) trigger:** Based on current findings, the project does not intersect with Indigenous rights or lands requiring FPIC under international frameworks

- **Human activities:** The project is not anticipated to significantly interfere with existing marine users like shipping, fishing, tourism, and subsea cable operations - due to its location

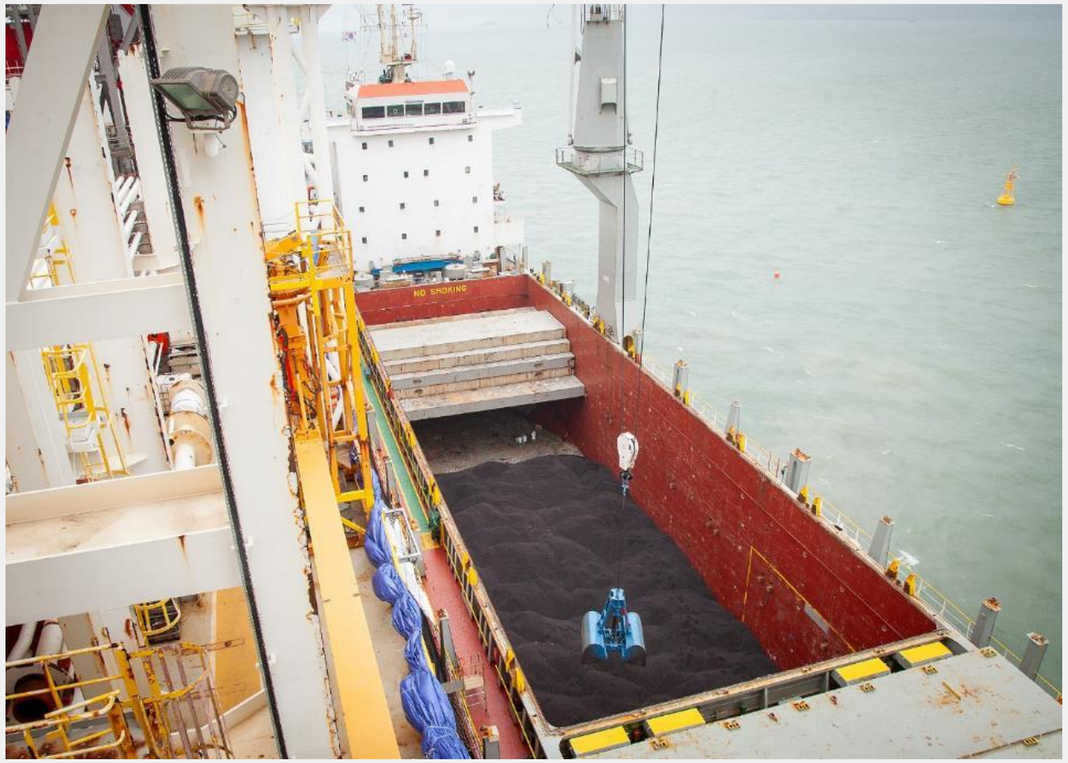
- **Socio-economic contributions:** The project is expected to deliver economic benefits as well as offer training and capacity building opportunities to the sponsoring state and ISA

14 stakeholder meetings were held in Nauru and Tonga over 16 days in July 2024 to share information about the CHIA and discuss tangible and intangible cultural heritage in relation to the project

Onshore Processing Update

Industrial-scale processing of nodules collected during 2022 test mining is underway at our partner PAMCO's operational facility in Japan.

Collect | Transport / offload | Calcine | Smelt | Convert | Refine



Nodules in vessel hold, preparing for offload at PAMCO in Japan
2,000 tonnes from the 2022 offshore collection test were brought to PAMCO in Japan for industrial scale trials. Nodules were transported through Mokpo port in South Korea.

Nodule stockpile at PAMCO after offload

PAMCO successfully calcined & smelted nodules into high-grade metal alloy and manganese silicate.

Collect | Transport / offload | Calcine | Smelt | Convert | Refine

PAMCO Rotary Kiln #6, dedicated for TMC use for industrial trials and when operations commence

Calcine exits the Rotary Kiln #6 during industrial scale calcining campaign

Sept-Dec 2024

About 1,500 tonnes of the nodules collected during 2022 test mining were processed through this kiln into calcine in September 2024.

PAMCO successfully calcined & smelted nodules into high-grade metal alloy and manganese silicate (Cont.)

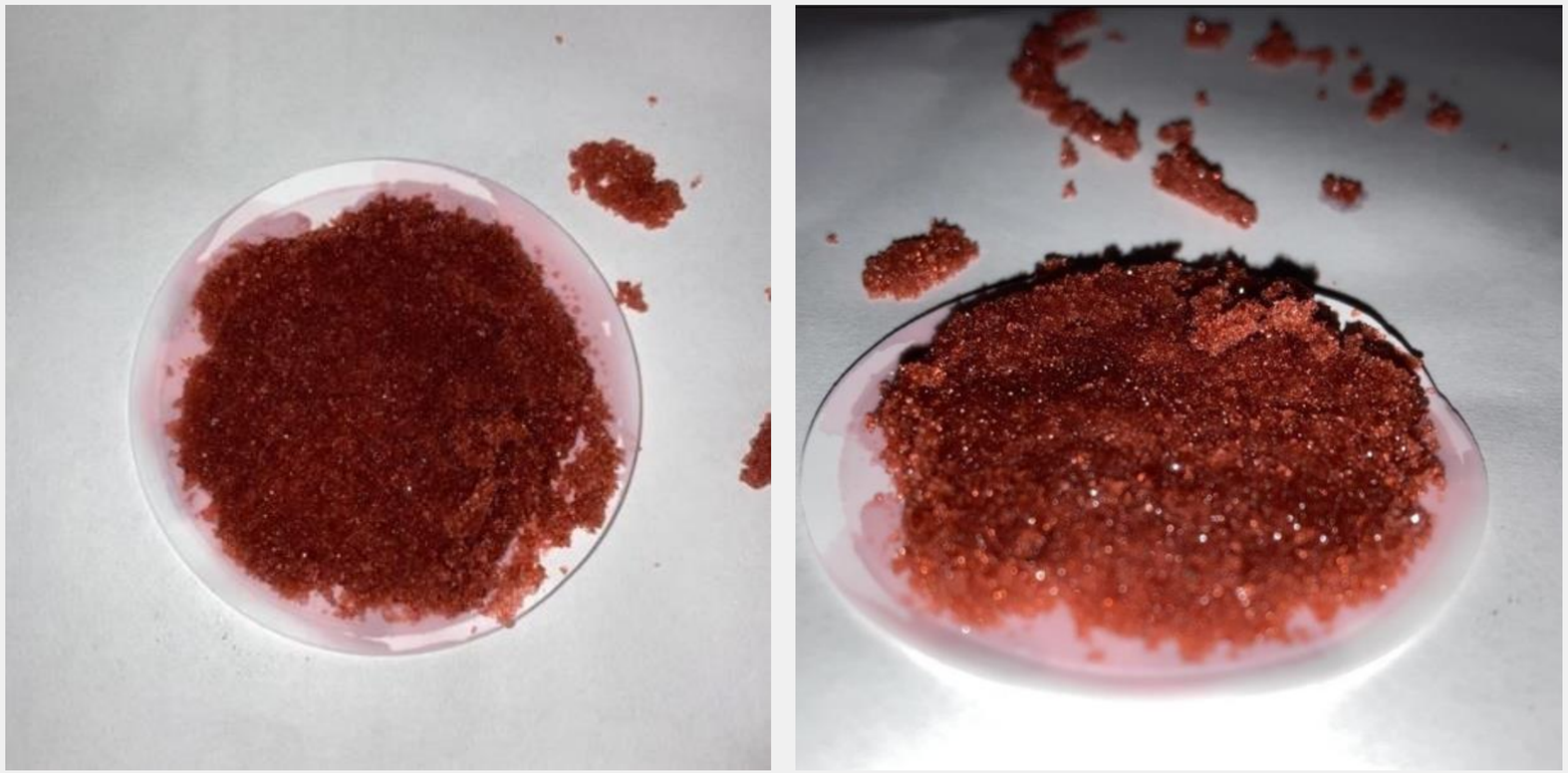
January-February 2025

Calcine material was smelted inside an Electric Arc Furnace into high-grade nickel-copper-cobalt alloy and manganese silicate products.

The process data and operational experience gathered will inform expected definitive processing agreements between the parties.

High-grade nickel-cobalt-copper alloy poured into ladles after smelting

We have also completed bench-scale testing of the hydrometallurgical refining of our production flowsheet.



First photos of cobalt sulfate generated at SGS as part of hydrometallurgical testing program

- Following the successful production of Nickel Sulfate at the end of 2023, NORI generated the first known Cobalt Sulfate derived exclusively from polymetallic nodules in Q1 2024
- Initial compositions are in line with available battery grade specifications, indicating NORI's resource is suitable for battery and energy transition markets
- Bench-scale test work completed at SGS Canada laboratory in Lakefield, Ontario, Canada


the
metals company
nori
Thank you.