SCALE AND NATURE OF IMPACTS FROM MINING SEAFLOOR POLYMETALLIC SULPHIDE DEPOSITS

SUMMARY OF LATEST RESEARCH FROM THE iATLANTIC PROJECT

October 2022

Key points:

- Modelling studies in the Azores region project that sediment plumes from seafloor polymetallic sulphide (PMS) mining operations may disperse beyond the licensed mining areas, reaching the flanks and summits of nearby topographic features and extending into the bathypelagic, mesopelagic, and epipelagic environments.
- Sediment particles contained within such plumes can have sub-lethal and lethal effects on benthic sessile suspension- and filter-feeding fauna (such as deep-water corals) by impairing feeding and respiration.
- Toxic metals within this suspended sediment – such as copper – bioaccumulate in coral tissues and skeletons. Subsequent coral death may be due to a combination of the toxic and mechanical effects of PMS particles.
- Delayed mortality in corals exposed even to low concentrations of copper in seawater indicates that some coral species may not recover from the effects of PMS mining plumes. Delayed ecosystem impacts must be considered when predicting the effects of environmental disturbances, such as deep-sea mining, on cold-water coral communities.

Image: Cold-water coral garden commonly found on seamount summits of the Azores, comprising Dentomuricea *aff.* meteor, Acanthogorgia *sp. and* Viminella flagellum. *Image © IMAR/Okeanos-UAz, Azor drift-cam.*

iAtlantic
INTEGRATED ASSESSMENT OF ATLANTIC MARINE ECOSYSTEMS IN SPACE AND TIME

SCALE AND NATURE OF IMPACTS FROM MINING SEAFLOOR POLYMETALLIC SULPHIDE DEPOSITS

It is increasingly suggested that deep-sea polymetallic sulphide (PMS) deposits could become an important source of mineral resources. These mining operations will remove the targeted substrate, producing potentially toxic sediment plumes both from the *in situ* seabed excavation and from the wastewater pumped from surface processing vessels back down to just above the seafloor. However, the extent and nature of ecosystem impacts resulting from these plumes has until now been unclear. A series of studies carried out by researchers at IMAR/ Okeanos University of the Azores set out to determine the extent of the area that would potentially be affected by these plumes, and the nature of the direct impacts on seafloor ecosystems such as cold-water corals. Results have recently been published in three peer-reviewed papers and are summarised here.

1. How much of the ocean might be impacted by the plumes generated by PMS mining operations?

Using the Azores region as a case study, **Morato et al. (2022)** used a three-dimensional hydrodynamic model alongside a theoretical commercial PMS mining operation on the Mid-Atlantic Ridge to simulate the potential dispersal of plumes from different parts of the mining process, and to assess the scale of their potential impacts. Taking into account the plumes originating from excavation at the seafloor as well as from the near-seafloor discharge of wastewater and sediment from ore processing vessels, the models predicted dispersal of large horizontal and vertical plumes containing sediment concentrations above the established acceptable threshold[1]. Persistent plumes (temporal frequency >50%, i.e., 6 months out of 12 months) were projected to disperse an average linear distance up to 20 km and cover an area up to 150 km^2, equivalent to 10,000 football fields. They were also shown to extend more than 800 m up into the water column from the seafloor.

The model predicted that the plumes above the established concentration thresholds, regardless of temporal frequency, could travel further than 100 km and impact more than 10,000 km^2.

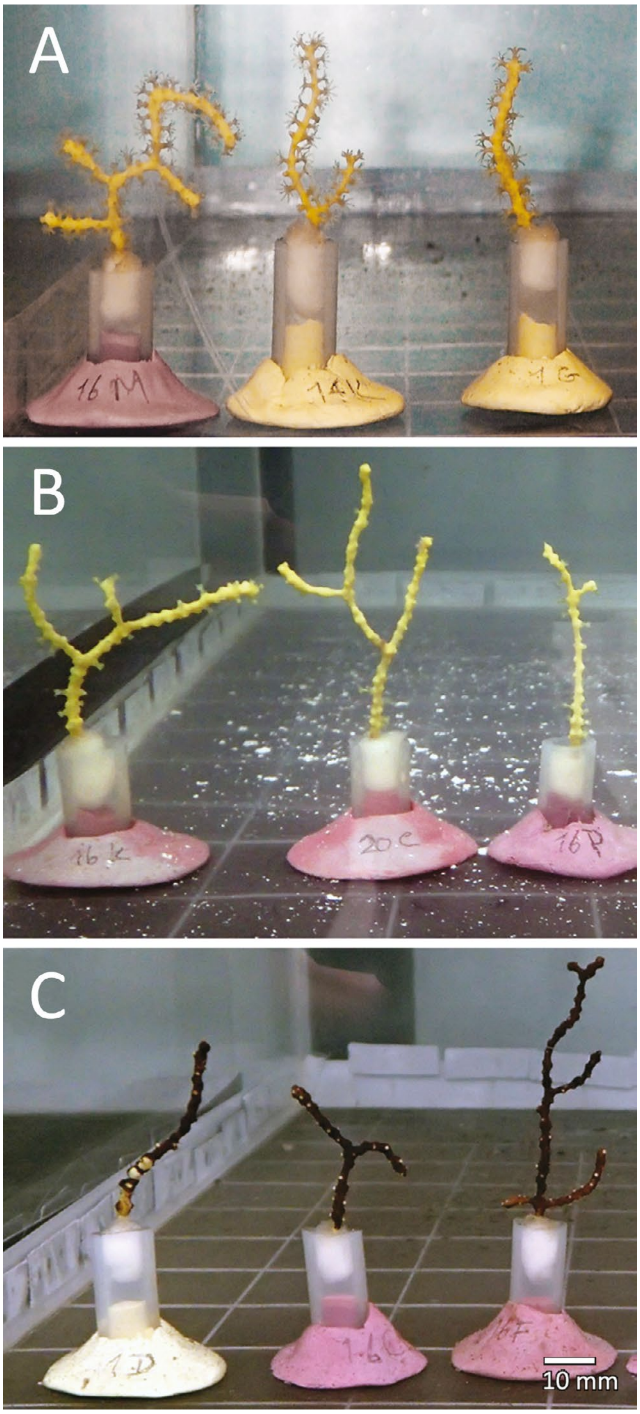
The model also showed that plumes may disperse beyond the licensed mining areas, reaching the flanks and summits of nearby topographic features and extending into the bathypelagic, mesopelagic, and epipelagic environments. This will most likely affect local biodiversity, productivity, species abundance and ecosystem services, as well as the marine food webs and ecosystem functioning in both benthic and pelagic ecosystems. In the Azores region, results showed that the area of plume dispersal overlaps with the predicted distribution of cold-water corals and with existing fishing activities. These impacts are of particular concern in regions where local communities are highly dependent on the deep sea and its biological resources.

2. How will sediment plumes from PMS mining affect deep-sea ecosystems?

Most of the deep seafloor away from the continental margins, with few exceptions, is known to have low concentrations of suspended solids (<0.01 mg/L). Exposure to elevated levels of suspended sediments in the water column can have sub-lethal and lethal effects on benthic sessile suspension- and filter-feeding fauna (such as deep-water corals) by impairing feeding and respiration. Therefore, the introduction of sediments into the water column from mining operations could have considerable impacts on these animals.

In an aquarium experiment by **Carreiro-Silva et al. (2022)**, the cold-water octocoral, *Dentomuricea* aff. *meteor* was continuously exposed to suspended sediment particles over a four-week period. Corals were exposed to three experimental treatments: (1) control conditions (no added sediments); (2) suspended polymetallic sulphide (PMS) particles generated from crushed inactive hydrothermal vent chimney rock; (3) suspended quartz particles. The two particle treatments were designed to distinguish between potential mechanical and toxicological effects of mining particles.

[1] The threshold for the purpose of this study was set at a concentration of solids in the return sediment discharge plume and in the *in situ* excavation sediment plume of 1.2 mg/L and a 5,000-fold dilution of the return water discharge plume.



Above: The coral Dentomuricea *aff.* meteor *after 3 days of exposure to the different treatments: (A) control, (B) quartz particles, and (C) PMS particles. Images reproduced with permission from Carreiro-Silva et al. (2022).*

Both particle types were delivered at a concentration of 25 mg/L, but achieved suspended concentrations of 2-3 mg/L for the PMS and 15-18 mg/L for the quartz particles due to their different particle densities.

Results revealed a significant increase in dissolved cobalt, copper and manganese concentrations in the PMS treatment water, resulting from the oxidation of sulphides in contact with seawater. Within a short time (3-5 days), corals exposed to PMS experienced a rapid physical accumulation of particles in their tissues, preventing the coral from extending its polyps and feeding. Over time, PMS exposure resulted in the bioaccumulation of copper in the coral's tissues and skeletons, physiological stress and changes in energy metabolism, and ultimately in the smothering and necrosis of tissues, with death of all corals occurring after 27 days of PMS treatment.

Analyses of corals exposed only to quartz particles suggested that the mechanical effect of particles was also damaging – eliciting cellular stress and immune responses – possibly as a reaction to the abrasive effect of the particles on coral tissues. Therefore, the high mortality of corals recorded in the PMS treatment may be a result of combined and potentially synergistic mechanical and toxicological effects of the PMS particles.

Low suspended particle concentrations (1.2-4 mg/L) are the most widespread levels projected by the model simulations of dispersing PMS dewatering sediment plumes at the Mid Atlantic Ridge around the Azores. The model simulations revealed that sediment plumes containing more sediment than the 25 mg/L threshold (the initial concentration used in the aquarium experiment) would likely be restricted to a small area of about 0.6 km^2 around the discharge point due to heavy particles settling out quickly. However, the dispersal of plumes containing 2-3 mg/L suspended sediment (the actual achieved experimental concentration) is predicted to affect an area of 25-150 km^2 around the discharge point. This study is therefore considered to be an accurate simulation of a particle emissions scenario, where most of the particles settle close to the discharge point and only a small fraction travels to distant areas influencing other neighbouring environments. However, despite the relatively low concentrations of PMS particles used in this aquarium experiment, it resulted in coral death within a short period of time (13-27 days). This suggests that the persistent plume definition in Morato et al. (2022) should be revised from 6 months to one month, and that the consequent estimates of plume dispersal footprint could be much larger. Due to their slow growth and long life histories, deep-sea organisms recover slowly from disturbance, so impacts from human activities on these ecosystems are expected to be long lasting.

3. Can corals recover from PMS exposure?

In a separate experiment, **Martins et al. (2022)** evaluated the response of the common whip coral *Viminella flagellum* to short-term acute copper (Cu) exposure – copper being one of the most toxic metals to be released into seawater during SMS mining operations. Corals were exposed to varying concentrations of copper over a 96-hour period and then returned to normal aquarium conditions to assess their recovery capacity.

During the short-term Cu exposure, corals retracted their polyps but there were no mortalities. However, one week after exposure the first signs of tissue loss (and consequently death) occurred in the corals that were exposed to the lowest concentrations of Cu (60 and 150 µg/L). Two weeks after exposure, the corals subjected to Cu concentrations of 250 and 450 µg/L showed similar damage and died, followed a week later by the corals exposed to 600 µg/L Cu. All corals were dead three weeks after exposure.

These results show that the coral *V. flagellum* is able to resist acute copper exposure over a 96-hour timeframe but is unable to recover when returned to ambient conditions. This demonstrates that experimental timescales and delayed mortality must be considered when predicting the effects of environmental disturbances, such as deep-sea mining, on cold-water coral communities.

4. Next steps in this research

Research into the impacts of PMS mining on deep-sea ecosystems is ongoing. Ocean warming, acidification and deoxygenation may affect the dispersal and toxicity of metals associated with PMS mining, and climate-induced changes in the movement of deep water masses should be considered in future mining plume dispersal studies.

The next step for the team at IMAR/Okeanos University of the Azores is to understand the cumulative impacts of deep-sea mining on ecosystems that are already stressed by climate change. Experiments to investigate this are already under way, with results expected in early 2023.

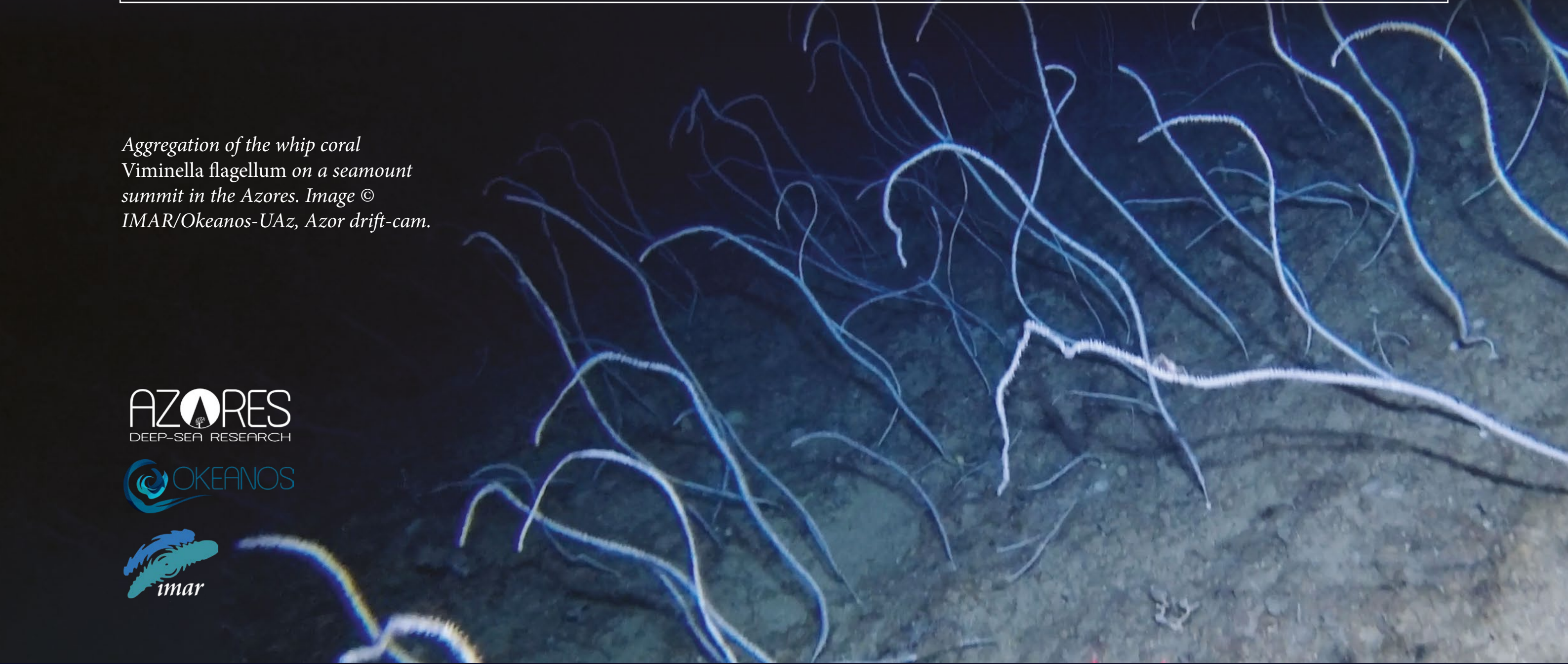
In addition, new research aims to deliver toxicity experiments that simulate mining impacts under natural high-pressure conditions, giving a more accurate view of the physiological responses of coral ecosystems in the deep sea.

This summary of latest research is based on three recent peer-reviewed publications (all open access):

Morato T, Juliano M, Pham CK, Carreiro-Silva M, Martins I and Colaço A (2022) Modelling the dispersion of seafloor massive sulphide mining plumes in the Mid Atlantic Ridge around the Azores. Front. Mar. Sci. 9:910940. doi: 10.3389/fmars.2022.910940

Carreiro-Silva M, Martins I, Riou V, Raimundo J, Caetano M, Bettencourt R, Rakka M, Cerqueira T, Godinho A, Morato T and Colaço A (2022) Mechanical and toxicological effects of deep-sea mining sediment plumes on a habitat-forming cold-water octocoral. Front. Mar. Sci. 9:915650. doi: 10.3389/fmars.2022.915650

Martins I, Godinho A, Rakka M and Carreiro-Silva M (2022) Beyond deep-sea mining sublethal effects: Delayed mortality from acute Cu exposure of the cold-water octocoral *Viminella flagellum*. Marine Pollution Bulletin 183, doi: 10.1016/j.marpolbul.2022.114051



Aggregation of the whip coral Viminella flagellum *on a seamount summit in the Azores. Image © IMAR/Okeanos-UAz, Azor drift-cam.*

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