BLUE PERIL

A VISUAL INVESTIGATION OF DEEP SEA MINING IN THE PACIFIC

TECHNICAL NOTE

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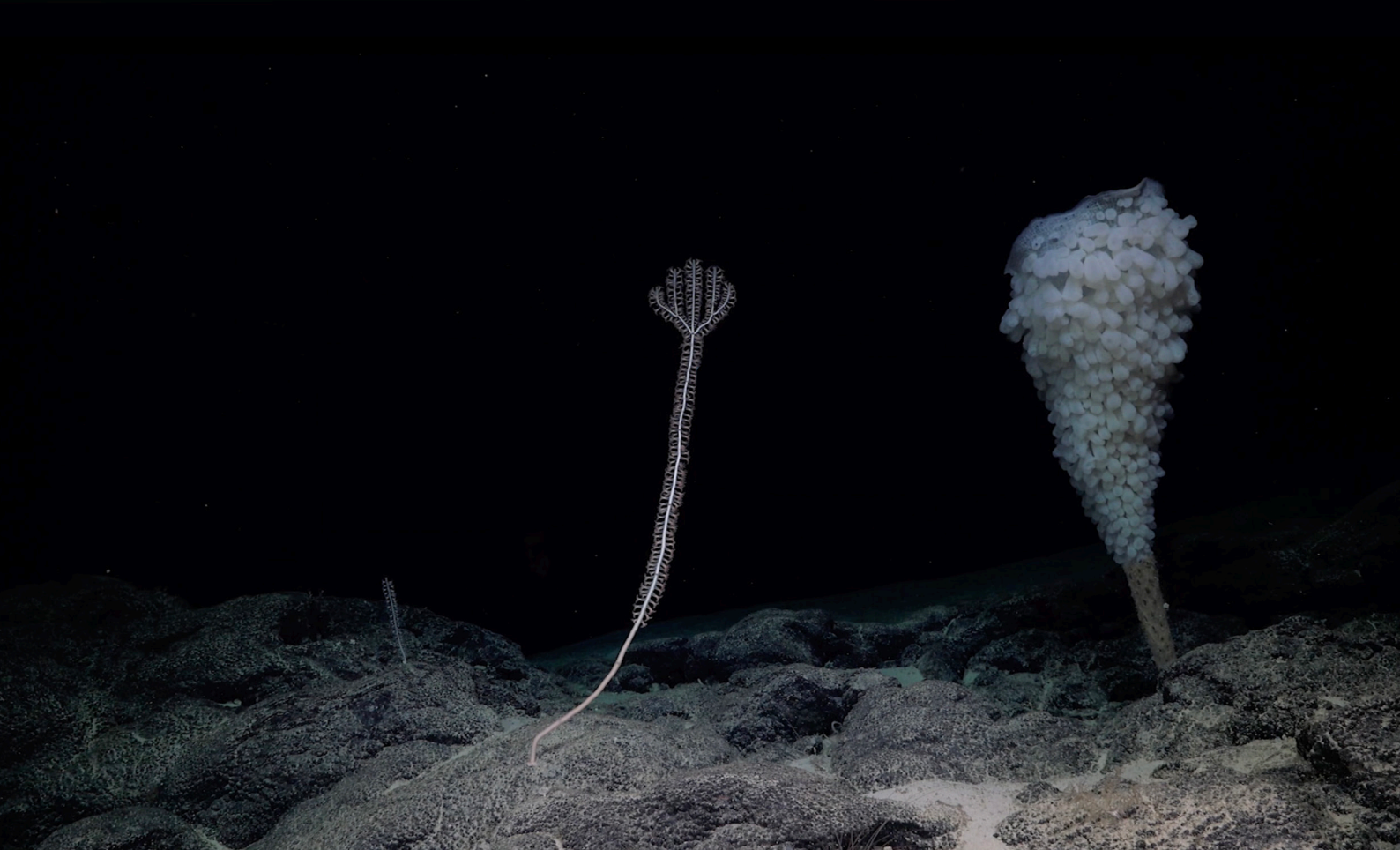

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Oceanographic Modelling of Benthic and Midwater Plumes Predicted for Deep Mining Planned by The Metals Company in the Clarion Clipperton Zone of the Pacific Ocean

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FRONT COVER: Still from Blue Peril video. Image: NOAA

1 Purpose of this paper

This paper accompanies the Blue Peril video. It describes the methods used to simulate the benthic and mid-water plumes that would be created by The Metals Company (TMC) in the Clarion Clipperton Zone (CCZ) of the Pacific Ocean south east of Hawaii.

The benthic plume is simulated for TMC's NORI D licence area, sponsored by Nauru. The mid-water plume is simulated as waste discharged at a depth of just over 1000 meters within TMC's licence area sponsored by Tonga.

The simulations indicate the area of ocean that could be expected to be impacted by the each of the plumes. They are based on estimates of horizontal currents and settling rates for particles, taken from the scientific literature of the past two decades (see Purkiani et al, 2021 for a useful discussion based on the abyssal northeast Pacific). While the horizontal currents, and hence the impacted areas, can be predicted with confidence (refer to discussion in section 4), the sedimentation rates are less certain. The estimates used here are taken from the scientific literature but neither the rate of production of sediment nor the settling rate can be known with certainty as independent in situ tests have not yet been conducted.

There are many unknowns relating to the deep ocean and to deep sea mining. Ecosystems, ecological, physical and chemical processes are poorly understood, while mining sediment production rates and characteristics are uncertain

A polymetallic nodule from the Pacific Ocean. Image: Velizar Gordeev

2 Sediment particle tracking methods

In modelling the plumes, we follow virtual 'tracers' as they travel in accordance with the flow of ocean currents. Each numerical tracer simulates the trajectory of a single sediment particle as it travels along a predicted path under the influence of the model currents.

The horizontal currents incorporated into our modelling are derived from the global ocean model GLORYS, operated by Mercator Ocean International (see GLORYS, 2022), which is part of the Copernicus Marine Environmental Monitoring Service (CMEMS). This is the marine service of the Copernicus Program of the European Union. The CMEMS website states: "GLORYS produces and distributes global ocean reanalyses at eddy-permitting (1/4°) resolution that aim to describe the mean and time-varying state of the ocean circulation, including a part of the mesoscale eddy field, over recent past decades with a focus on the period since when satellite altimetry measurements of sea level provide reliable information on ocean eddies (i.e., from 1993 to present)." The resolution of the model currents is 1/12°, or about ten kilometres.

OpenDrift (Dagestad, 2018) was used for tracking the drift of virtual tracers in the model currents. OpenDrift is an open-source framework for particle tracking, created primarily by the Norwegian Meteorological Institute. It is used to follow the pathways and transformations of various types of objects and substances in the ocean or in the atmosphere. For example, prediction of oil drift and weathering, search and rescue, plankton transport (fish eggs and larvae) for stock assessments, and microplastics suspended in the ocean.

Both CMEMS and OpenDrift are widely published and considered to be state of the art models and software tools.

Estimates of the mean benthic and outfall settling rates vary widely in the published literature, depending on assumptions regarding grain size, flocculation, and other factors (see Section 3). Estimates can range across two orders of magnitude between 8x10-5 to 4x10-3 m/s (Gillard et al, 2019) and 2x10-5 to 7x10-3 m/s (Oebius et al, 2021).

The vertical movement of the tracers was simulated by assigning each tracer a settling rate, equal to a mean plus or minus a random offset within one standard deviation of the mean, to provide a realistic distribution.

3 The footprint of the benthic sedimentation

According to Muñoz-Royo et al, 2021, the dynamics in the turbulent near-field (near the collector) acts to reduce flocculation, thereby reducing the settling rate. We did not attempt to resolve the near field. The effect of turbulence is primarily to increase dilution, which spreads the source region horizontally by a few tens of meters.

The only experiment we were able to identify that assesses the extent of sediment settlement is an environmental impact assessment of a prototype nodule collector (Federal Institute for Geosciences and Natural Resources, 2017). It found that 90% of the suspended particles created by artificial disturbance of the sea floor had settled within a radius of 2 km from the impact area.

However, the two order of magnitude range of estimates of settling rates (noted above in Section 2) means there could be a two order of magnitude range in possible footprints. Thus, the prototype nodule collector sedimentation footprint could vary between 2 km and 200 km, depending on the settling rate, which is unknown (see Spearman et al, 2020). Moreover, if the prototype were moving across the sea

floor as would an operating nodule collector, it might travel up to 100 km in a year possibly resulting in an annual sedimentation footprint of 10,000 sq. km.

The full sized nodule collectors are anticipated to be significantly larger than the prototype and expected to be operating with 2 or more in tandem.

The following factors affect the footprint of the benthic sedimentation:

- Increased currents (increased "horizontal advection")
- Increased grain size increases settlement rate, which decreases footprint (via gravity).
- Increased flocculation increases settlement rate, which decreases footprint (via gravity).
- Increased sediment production at collector increases footprint
- Increased diffusivity/turbulence decreases settlement rate, which increases footprint.
- Sediment resuspension will carry previously settled particles further, increasing footprint.
- The sediment production rate which depends on the size and operational characteristics of the nodule mining vehicle itself.

4 Details of the CMEMS horizontal currents used to model midwater and benthic plume dispersal

The ocean currents were taken from the CMEMS Mercator reanalysis, which interpolates from the original 75 levels to 30 levels. The thickness of the surface layer is about 1 meter thick, but deeper layers become thicker. The layer near 100 meters depth is close to 10 meters, and the layer thicknesses increase to about 400 meters near the bottom (below around 5000 metres depth).

For the benthic plume, we used the velocity at the deepest layer above bottom within the area. The bottom four layers in the reanalysis are at 4405 m, 4833 m, 5274 m, and 5728m. In the CCZ study area the depth ranges from about 4400 to 5800 metres.

For the waste outfall discharge midwater plume, we used the currents from the 1062 m and deeper levels. Virtual tracers were released at 1062 metres and allowed to sink to levels with different currents, which are generally slower due to the fact that midocean currents normally decrease with depth.

Modern ocean model currents are the best available estimates of actual ocean currents, but caution must be exercised. Over the CCZ (which covers some 4.5 million km2), it is entirely possible that there is not a single profiling current meter available to assimilate into global ocean models like CMEMS. Most of the data is derived from satellites, which sample only the surface.

There have been some observations in the CCZ which demonstrate correlation between larger-scale surface disturbances and the increased eddy kinetic energy observed by bottom-mounted current meters. In addition, the general characteristics of global models have proven accurate, for example typical horizontal speeds, mean flow directions, stratification, and gradual reduction of speed with depth. Still, the paucity of actual deep ocean current observations, means the CMEMs currents remain estimates.

5 Simulation experiments

More than 50 virtual tracer experiments were run to ensure consistency and repeatability. Tracers were released at different depths, latitudes and longitudes, and at different numbers and geometry. In some experiments tracers were released within a polygonal area, rather than at a single point. None of these factors materially affected the sediment plume distribution, supporting our assumption that the near-field dynamics is not critical to the wider outcome. The moderate adjustments we made resulted in little difference to the visualisation.

The following figures illustrate typical results from the 50+ experiments.

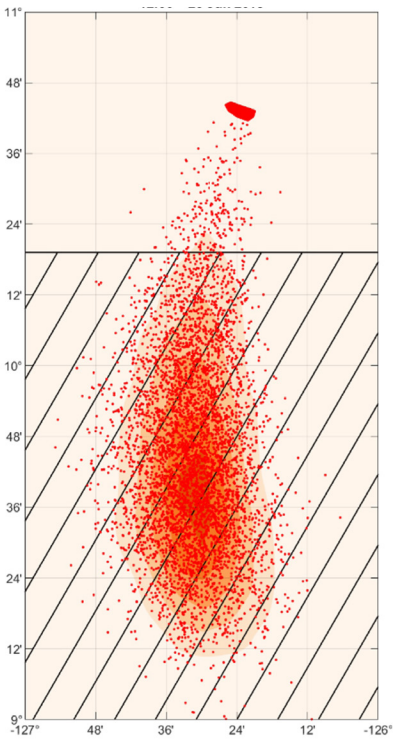
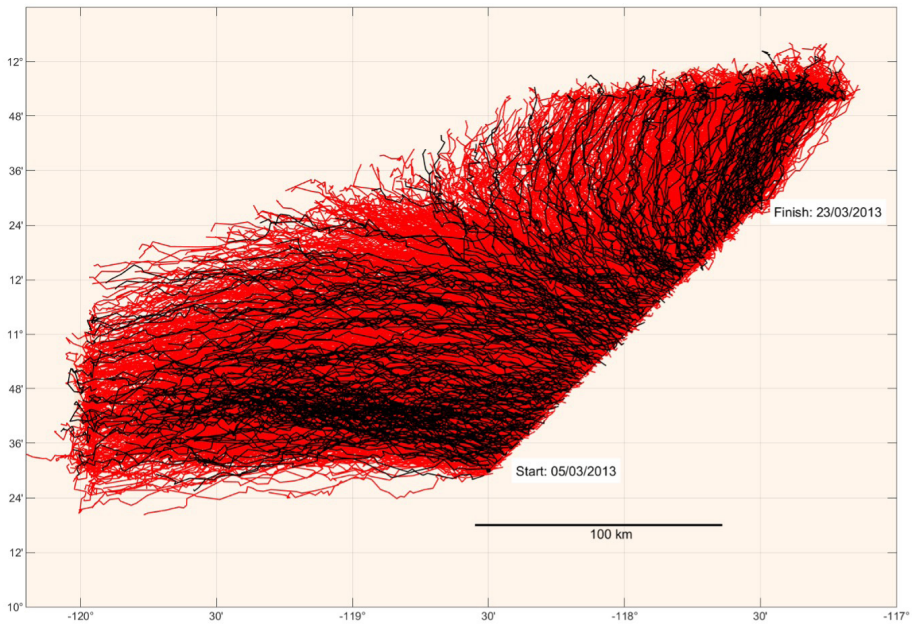
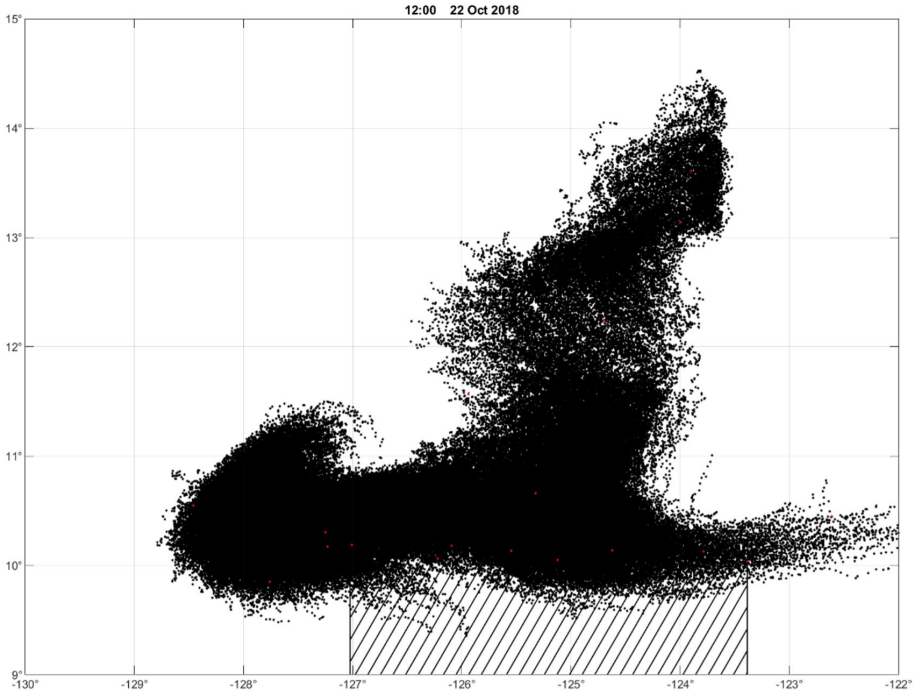


Fig 1. (left) The final distribution of tracers (after settling) from an 18-day experiment in which 6000 tracers were released instantaneously 8 meters from the seafloor from a polygon situated just north of APEI 9. The tracers were evenly distributed within the polygon.

Fig 2. (below) The area covered by sediments created by a collector moving from "Start" to "Finish" over an 18-day period.

Fig 3. (p.5) Area of settlement after 50 days from an outfall at 1500 m from surface.





6 Concluding remarks

There are many unknowns relating to the deep ocean and to deep sea mining (Chin and Hari 2020). Ecosystems, ecological, physical and chemical processes are poorly understood, while mining sediment production rates and characteristics are uncertain (Spearman, 2020). Professor Matthew Alford of the Scripps Institution of Oceanography and the University of California, San Diego stated "(the) ability to map the geography of the impact of sea floor mining is a crucial unknown right now" (Gallagher, 2019).

The modelling presented in Blue Peril is based on the best publicly available data and on dozens of experiments varying the inputs. A fully verified study would require a high level of resources to undertake years of careful research, modelling, and experimentation. Such a study is yet to be completed. We offer our results as independent, scientifically valid predictions.

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