nature portfolio

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Reporting Summary

Nature Portfolio wishes to improve the reproducibility of the work that we publish. This form provides structure for consistency and transparency in reporting. For further information on Nature Portfolio policies, see our Editorial Policies and the Editorial Policy Checklist.

Statistics

For all statistical analyses, confirm that the following items are present in the figure legend, table legend, main text, or Methods section.

n/a	Confirmed	
☐	☒	The exact sample size (*n*) for each experimental group/condition, given as a discrete number and unit of measurement
☐	☒	A statement on whether measurements were taken from distinct samples or whether the same sample was measured repeatedly
☐	☒	The statistical test(s) used AND whether they are one- or two-sided *Only common tests should be described solely by name; describe more complex techniques in the Methods section.*
☐	☒	A description of all covariates tested
☐	☒	A description of any assumptions or corrections, such as tests of normality and adjustment for multiple comparisons
☐	☒	A full description of the statistical parameters including central tendency (e.g. means) or other basic estimates (e.g. regression coefficient) AND variation (e.g. standard deviation) or associated estimates of uncertainty (e.g. confidence intervals)
☐	☒	For null hypothesis testing, the test statistic (e.g. *F*, *t*, *r*) with confidence intervals, effect sizes, degrees of freedom and *P* value noted *Give P values as exact values whenever suitable.*
☒	☐	For Bayesian analysis, information on the choice of priors and Markov chain Monte Carlo settings
☒	☐	For hierarchical and complex designs, identification of the appropriate level for tests and full reporting of outcomes
☒	☐	Estimates of effect sizes (e.g. Cohen's *d*, Pearson's *r*), indicating how they were calculated

Our web collection on statistics for biologists contains articles on many of the points above.

Software and code

Policy information about availability of computer code

Data collection	*Provide a description of all commercial, open source and custom code used to collect the data in this study, specifying the version used OR state that no software was used.*
Data analysis	All statistical analyses and data visualizations were performed using R statistical software (version 4.1.1). The ggplot2 package was used to create plots, including bar plots and raincloud plots, to visualize the distribution and variability of 234Thxs activities across sampling sites and campaigns. Spatial maps depicting the sampling locations and 234Thxs activities were created using QGIS (version 3.32). Ocean Data View (version 5.8.2) was used to generate Supplementary Figure S1 using the public data repository from GEOTRACES.

For manuscripts utilizing custom algorithms or software that are central to the research but not yet described in published literature, software must be made available to editors and reviewers. We strongly encourage code deposition in a community repository (e.g. GitHub). See the Nature Portfolio guidelines for submitting code & software for further information.

Data

Policy information about availability of data

All manuscripts must include a data availability statement. This statement should provide the following information, where applicable:

- Accession codes, unique identifiers, or web links for publicly available datasets
- A description of any restrictions on data availability
- For clinical datasets or third party data, please ensure that the statement adheres to our policy

All data supporting the findings of this study are provided in the Supplementary Information. The raw data underlying figures and tables are available in the attached Supplementary files.

Research involving human participants, their data, or biological material

Policy information about studies with human participants or human data. See also policy information about sex, gender (identity/presentation), and sexual orientation and race, ethnicity and racism.

Reporting on sex and gender	N/A
Reporting on race, ethnicity, or other socially relevant groupings	N/A
Population characteristics	N/A
Recruitment	N/A
Ethics oversight	N/A

Note that full information on the approval of the study protocol must also be provided in the manuscript.

Field-specific reporting

Please select the one below that is the best fit for your research. If you are not sure, read the appropriate sections before making your selection.

☐ Life sciences ☐ Behavioural & social sciences ☒ Ecological, evolutionary & environmental sciences

For a reference copy of the document with all sections, see nature.com/documents/nr-reporting-summary-flat.pdf

Ecological, evolutionary & environmental sciences study design

All studies must disclose on these points even when the disclosure is negative.

Study description	This study investigated the spatial extent of sediment plume deposition from deep-sea mining activities using 234Th as a geochemical tracer. The sampling design included two baseline campaigns (May-June 2021, n=34; August-October 2022, n=26) and one post-PCV test campaign (November-December 2022). The post-PCV campaign employed a spatial gradient sampling approach with sites at increasing distances from the mining tracks: control reference zone (6 km NW, n=4), directly mined area (TF_007, n=5), 200m from tracks (TF_032, n=2), 500m from tracks (TF_025, n=5), 1km from tracks (TF_033, n=1), 2km from tracks (STM_174, n=3), and 3km from tracks (STM_173, n=3). The study utilized a hierarchical design where distance measurements were nested within post-PCV sampling (temporal sampling → distance gradient → replicates). Sampling sites were strategically positioned based on plume modeling and current measurements. All samples were analyzed from the 0-1 cm depth interval.
Research sample	The research sample consisted of surface sediments (0-1 cm depth) collected from the abyssal plain of the Clarion-Clipperton Zone (CCZ), in the eastern-central Pacific Ocean. Sampling was conducted specifically within the NORI-D contract area, a polymetallic nodule field currently under exploration for future commercial deep-sea mining. This area was selected because it represents an active test site for seabed mineral extraction. Surface sediments were collected using a multicorer device, which allows for undisturbed recovery of the sediment-water interface. This sampling method was critical to preserve the vertical structure of the sediment column and to enable accurate measurements of recent particle deposition. The 0-1 cm interval was chosen as the analytical focus because it captures recent sedimentation within the time window detectable by excess 234Th, a naturally occurring radioisotope with a half-life of 24.1 days. This makes it particularly sensitive to short-term changes in particle flux and deposition associated with mining-induced sediment plumes. No biological organisms were manipulated or studied directly in this analysis.
Sampling strategy	Sample sizes were determined by operational and logistical constraints of deep-sea sampling rather than statistical power calculations. Baseline sampling was designed to capture natural variability across two campaigns (n=34 in 2021, n=26 in 2022), with sample numbers maximized within ship-time limitations. For the post-PCV test campaign, sample numbers at each distance from the mining tracks were determined by combining operational constraints with the need to capture spatial variability. Higher replication was prioritized at key sites: the directly mined area (n=5) to assess immediate impact, 500m from tracks (n=5) where initial plume modeling suggested significant deposition, and the control site (n=4) to establish contemporary background conditions. Lower replication at other distances (n=1-3) reflected both operational limitations and the goal of maximizing spatial coverage to determine the extent of plume influence. This sampling strategy proved sufficient to detect statistically significant differences in 234Thxs activities between impacted and non-impacted sites.
Data collection	Sediment cores were collected using an Oktopus GmbH 20-core multicore system operated from the research vessel. Upon recovery, shipboard scientists photographed cores and assessed their quality using a standardized QA/QC matrix. The 0-1 cm interval was sampled at sea by trained technicians using pre-cut polycarbonate rings and archived in Whirlpak bags. Samples were frozen at sea and subsequently freeze-dried before analysis. Gamma spectroscopy measurements of 234Th were conducted by radiochemists at the laboratory using Canberra High-Purity Germanium Coaxial Planar and Well Photon Detectors. Activities were recorded automatically by the detector software and corrected for counting time, detector efficiency, and self-absorption using the IAEA-447

	standard. All data were recorded in electronic laboratory notebooks and compiled in spreadsheets with appropriate metadata including sample IDs, collection dates, analysis dates, and measurement parameters.
Timing and spatial scale	Data collection occurred during three distinct campaigns in the NORI-D contract area of the CCZ (9.8-11.2°N, 116-118°W). Baseline sampling was conducted during two campaigns: May-June 2021 and August-October 2022. The post-PCV test sampling occurred in November-December 2022, within days to weeks after the October 2022 mining test. This timing was specifically chosen to capture the 234Th signal from mining-induced sedimentation, given the isotope's 24.1-day half-life. The spatial scale of sampling extended from the directly mined area to 3 km along the plume transport direction, with an additional control site at 6 km northwest. This spatial coverage was designed to encompass the predicted extent of plume deposition based on modeling results. The two baseline campaigns, separated by approximately one year, were designed to assess natural temporal variability in 234Th activities.
Data exclusions	No 234Th data were excluded from the analyses. All collected cores that passed the initial QA/QC matrix for core quality (examining criteria such as undisturbed stratigraphy, intact sediment-water interface, and absence of nodule drag) were analyzed and included. All gamma spectroscopy measurements that met the standard counting criteria were incorporated into the final dataset. While some sampling sites had different numbers of replicates due to operational constraints, no collected data points were excluded from statistical analyses. Although 210Pb data were also collected during gamma spectroscopy measurements, these results were reserved for future studies as this work focused specifically on using short-lived 234Th as a tracer for recent sedimentation events.
Reproducibility	The gamma spectroscopy measurements included analysis of the IAEA-447 standard to verify detector calibration and measurement reproducibility. For surface sediment samples, replicate cores from the same sites (where available) demonstrated consistent 234Thxs activities within expected analytical uncertainty. All sample measurements were successfully completed with no failed attempts.
Randomization	Randomization was not applicable to this study design. Sample locations were strategically selected based on plume modeling and current measurements to capture the spatial gradient of mining-induced sedimentation. The control site location was specifically chosen to be outside the predicted plume path (6 km northwest of mining activity). Within each sampling site, individual multicore drops were positioned based on seafloor bathymetry and operational requirements rather than random allocation. This non-random design was necessary to test our hypothesis about the spatial extent of plume deposition and to ensure adequate sampling of the impact gradient.
Blinding	Blinding was not possible for sample collection as the location of mining tracks and distance from impact were necessary operational knowledge for sampling. However, samples were coded with unique identifiers during processing and laboratory analysis. While analysts were aware that samples came from a mining impact study, they were not informed of specific sample locations or sampling dates during gamma spectroscopy measurements and data processing. Complete blinding was not critical for this study as the measurements relied on gamma detector readings, which are not subject to observer bias.

Did the study involve field work? ☒ Yes ☐ No

Field work, collection and transport

Field conditions	Field work was conducted in the eastern equatorial Pacific Ocean (9.8-11.2°N, 116-118°W) at water depths of 4,248-4,336 m. Bottom water conditions at sampling depths were stable, with temperatures around 1.5°C. Surface conditions included typical equatorial weather patterns with high temperatures and periodic rainfall, though these did not impact deep-water sampling operations. All field operations followed established Health, Safety and Environment protocols, including detailed Hazard Identification and Risk Assessments (HIRAs) for deep-sea equipment deployment and sample handling. Ship operations and sampling were conducted 24 hours per day, with work schedules adjusted to ensure adequate rest periods for all personnel.
Location	All sampling was conducted in the NORI-D contract area of the Clarion-Clipperton Zone (CCZ) in the eastern-central Pacific Ocean, between 9.8-11.2°N latitude and 116-118°W longitude. The study area comprised abyssal plain depths ranging from 4,248 to 4,336 m, with the collector test area showing minimal bathymetric variation (less than 20 m depth difference). The control reference zone was established approximately 6 km northwest of the mining tracks at comparable water depths. All sampling locations were within the CCZ, which spans from 5° to 20°N and 115° to 160°W, between the Clarion and Clipperton fracture zones.
Access & import/export	Sampling was conducted under International Seabed Authority (ISA) regulations within the NORI-D contract area. All sediment samples were non-biological and non-hazardous, consisting of freeze-dried abyssal plain sediments. Sample collection and transport followed ISA protocols for contractor activities in the Area. Samples were properly documented and cleared through U.S. Customs at the Port of San Diego before transport to Eckerd College (Florida) for radiochemical analysis. All necessary documentation for international transport of scientific samples was maintained throughout the chain of custody.
Disturbance	This study was conducted within the framework of a planned mining vehicle test, and our sampling activities caused minimal additional disturbance beyond the test itself. The multicore sampling method was specifically chosen to minimize seafloor disruption, collecting discrete sediment cores with minimal disturbance to the sediment-water interface. Each multicore deployment impacted approximately 0.007 m^2 of seafloor (8 tubes of 95 mm diameter each). Sample collection in the directly mined area was guided by ROV to ensure cores were taken precisely within existing tracks, avoiding the creation of new disturbance.

Reporting for specific materials, systems and methods

We require information from authors about some types of materials, experimental systems and methods used in many studies. Here, indicate whether each material, system or method listed is relevant to your study. If you are not sure if a list item applies to your research, read the appropriate section before selecting a response.

Materials & experimental systems

n/a	Involved in the study
☒	☐ Antibodies
☒	☐ Eukaryotic cell lines
☒	☐ Palaeontology and archaeology
☒	☐ Animals and other organisms
☒	☐ Clinical data
☒	☐ Dual use research of concern
☒	☐ Plants

Methods

n/a	Involved in the study
☒	☐ ChIP-seq
☒	☐ Flow cytometry
☒	☐ MRI-based neuroimaging

Plants

Seed stocks	NA
Novel plant genotypes	NA
Authentication	NA