Supplementary Material

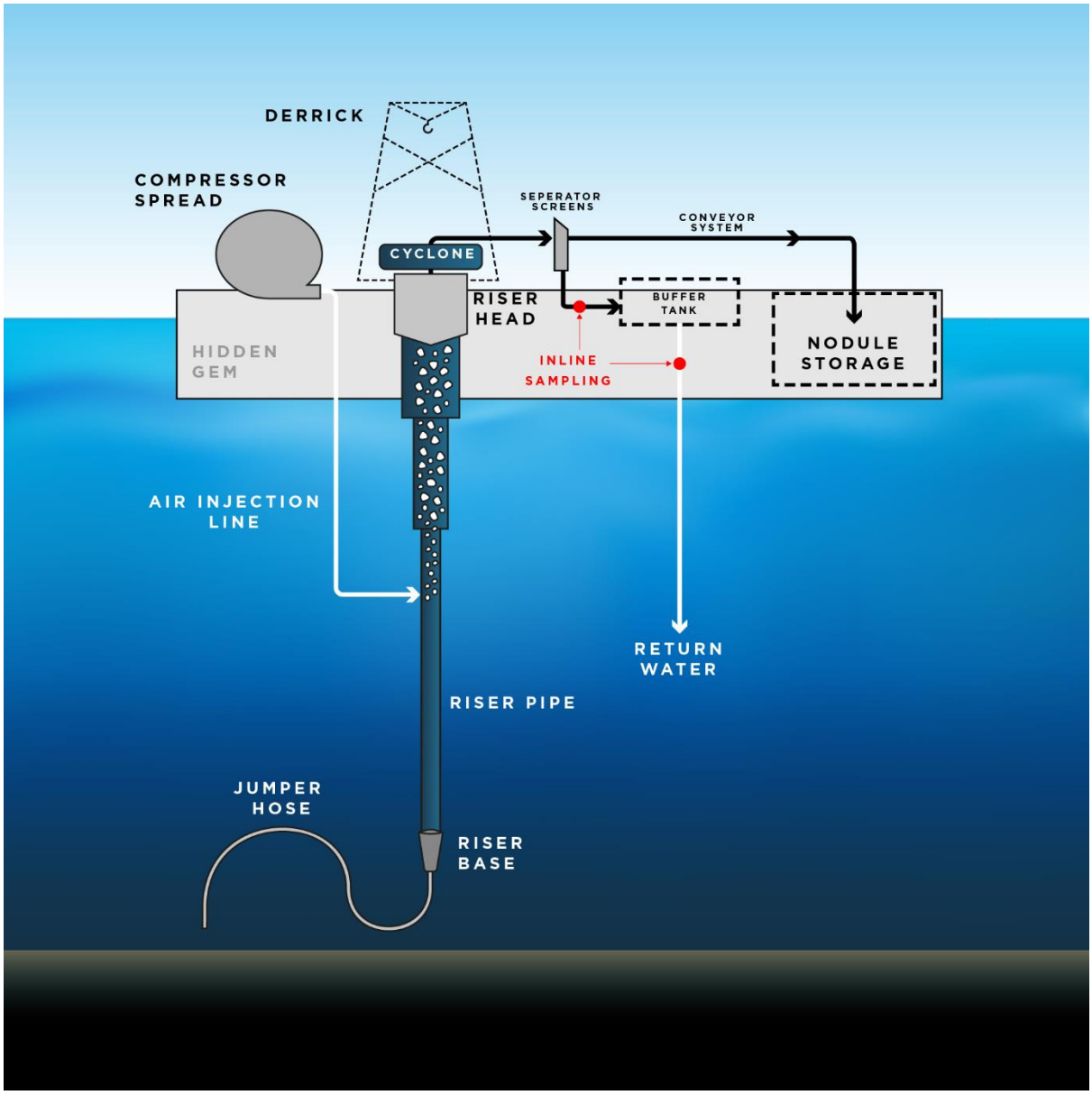


Figure S1. Schematic of nodule handling and storage onboard the *Hidden Gem*, showing the arrival of the nodule-water-sediment slurry transported from the seabed through the vertical riser system and its entry into the riser head. At the riser head, the slurry passes through a cyclone to reduce flow velocity prior to mechanical screening, where nodules are separated from fine sediment and seawater before transfer to the vibrating separator screen and conveyor system for storage. Residual slurry, consisting of sediment, nodule fragments, and seawater, is routed to a buffer prior to discharge via the return pipe.

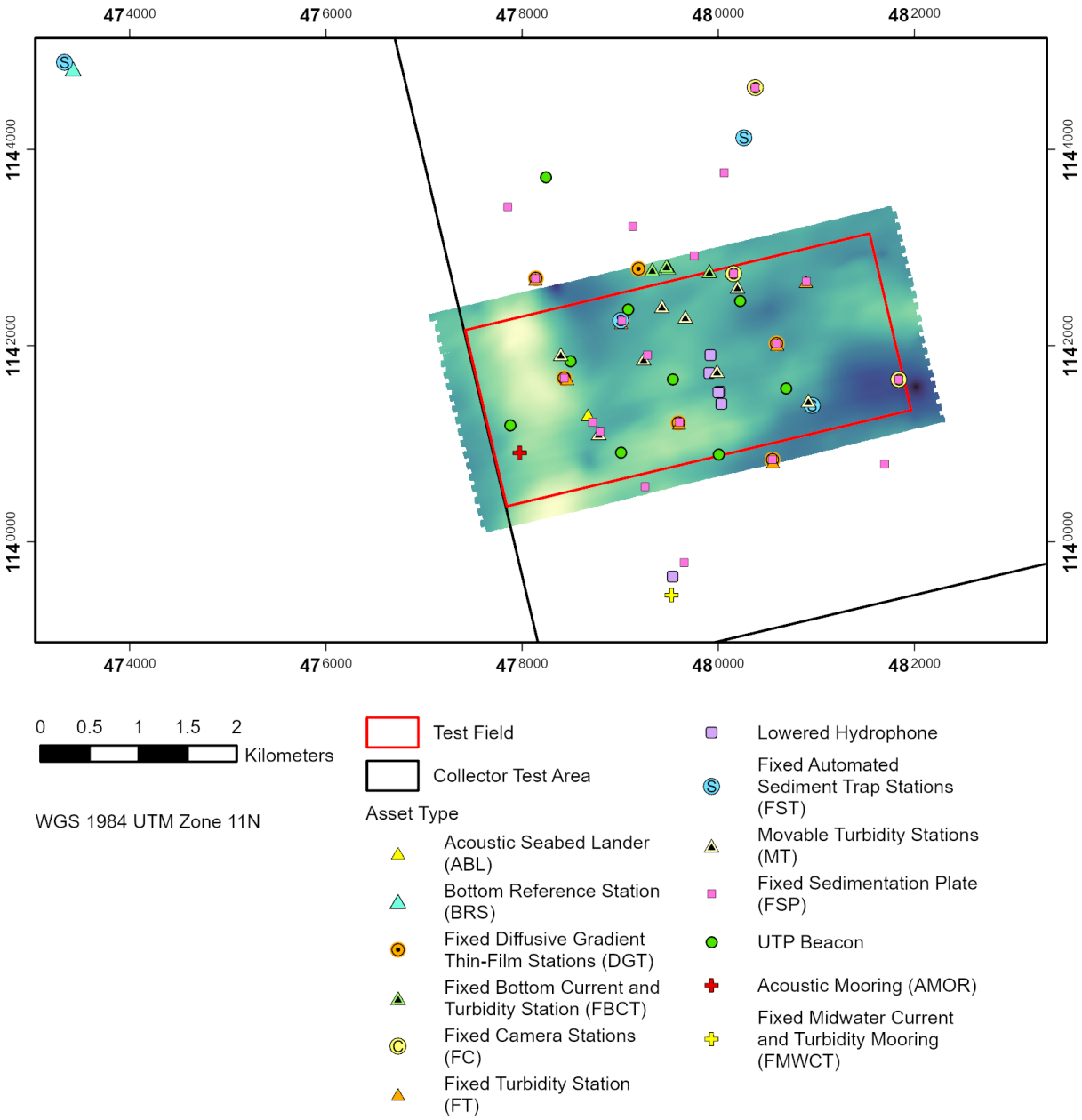


Figure S2. Locations of all seafloor assets and UTP beacons deployed during the pre-test mining monitoring phase.

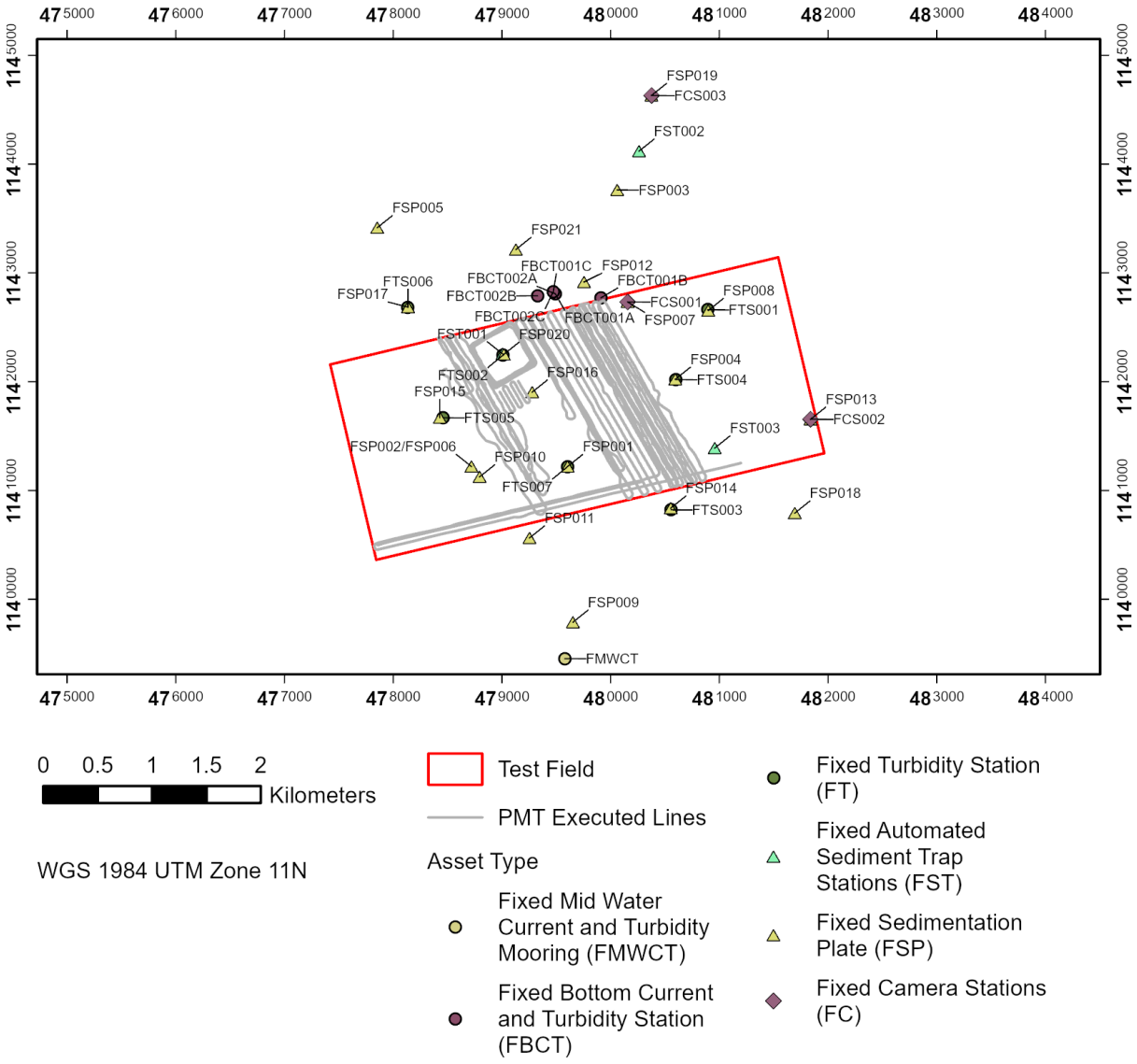


Figure S3. Locations of plume monitoring seafloor assets deployed during the pre-test mining monitoring phase.

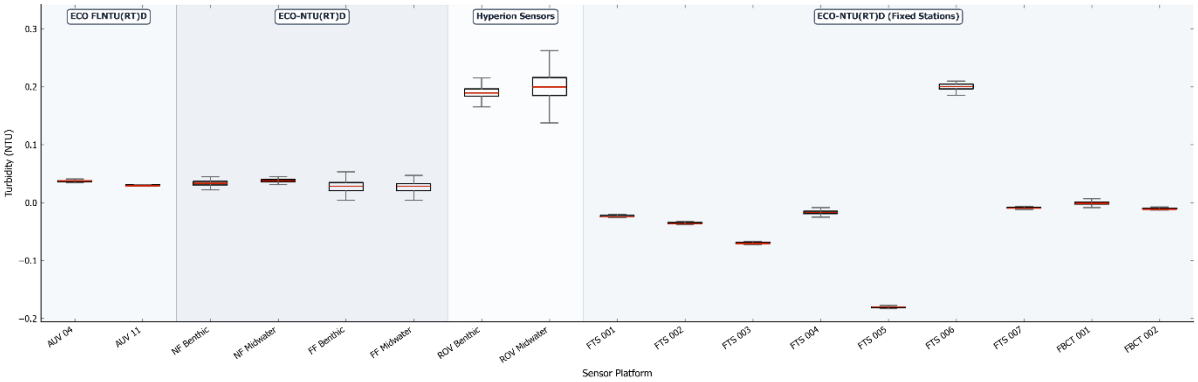


Figure S4. Turbidity recorded within the baseline window (n = 200 sequential observations) used to derive the empirical detection threshold for each sensor, grouped by sensor type: WET Labs ECO FLNTU(RT)D (AUVs), WET Labs ECO-NTU(RT)D (ROVs), Hyperion sensors (ROV Niskin rosette) and WET Labs ECO-NTU(RT)D (fixed stations). NF and FF refer to the near-field and far-field ROVs, respectively, with separate benthic and midwater deployments. ROV Benthic and ROV Midwater show the baseline records of the ten Hyperion sensors on the ROV Niskin rosette within the benthic (>4,200 m) and midwater (1,100–1,400 m) depth intervals. Tukey box plots: boxes show the 25th–75th percentiles, red lines the median, and whiskers 1.5 × interquartile range.

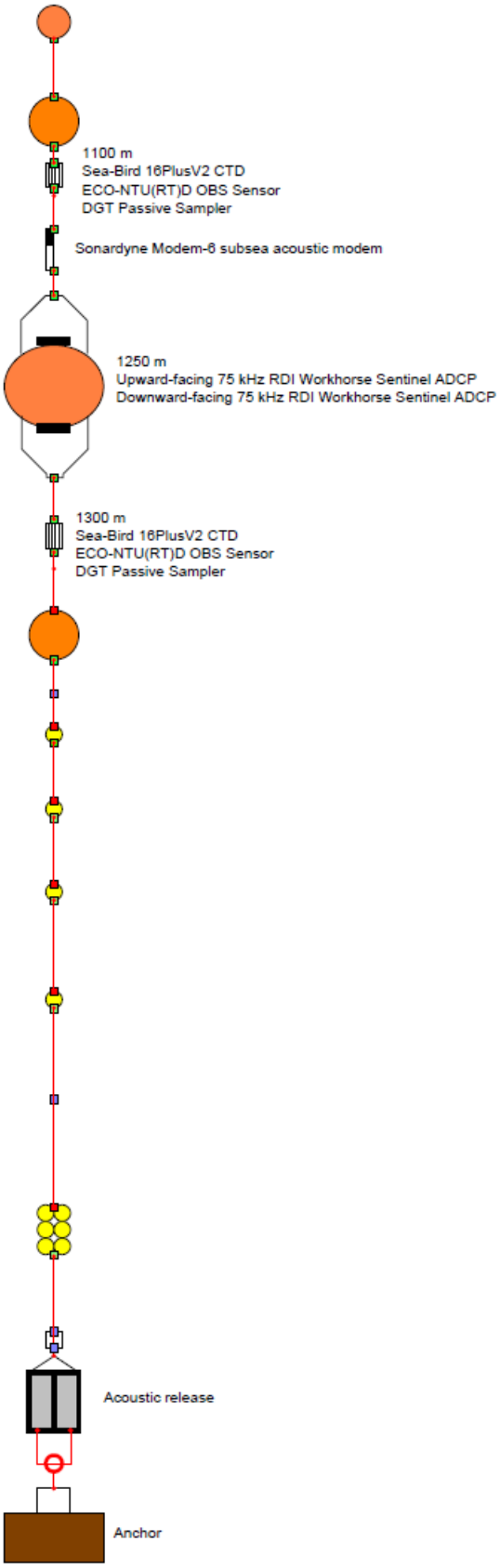


Figure S5. Schematic of the fixed midwater current and turbidity mooring (not to scale).

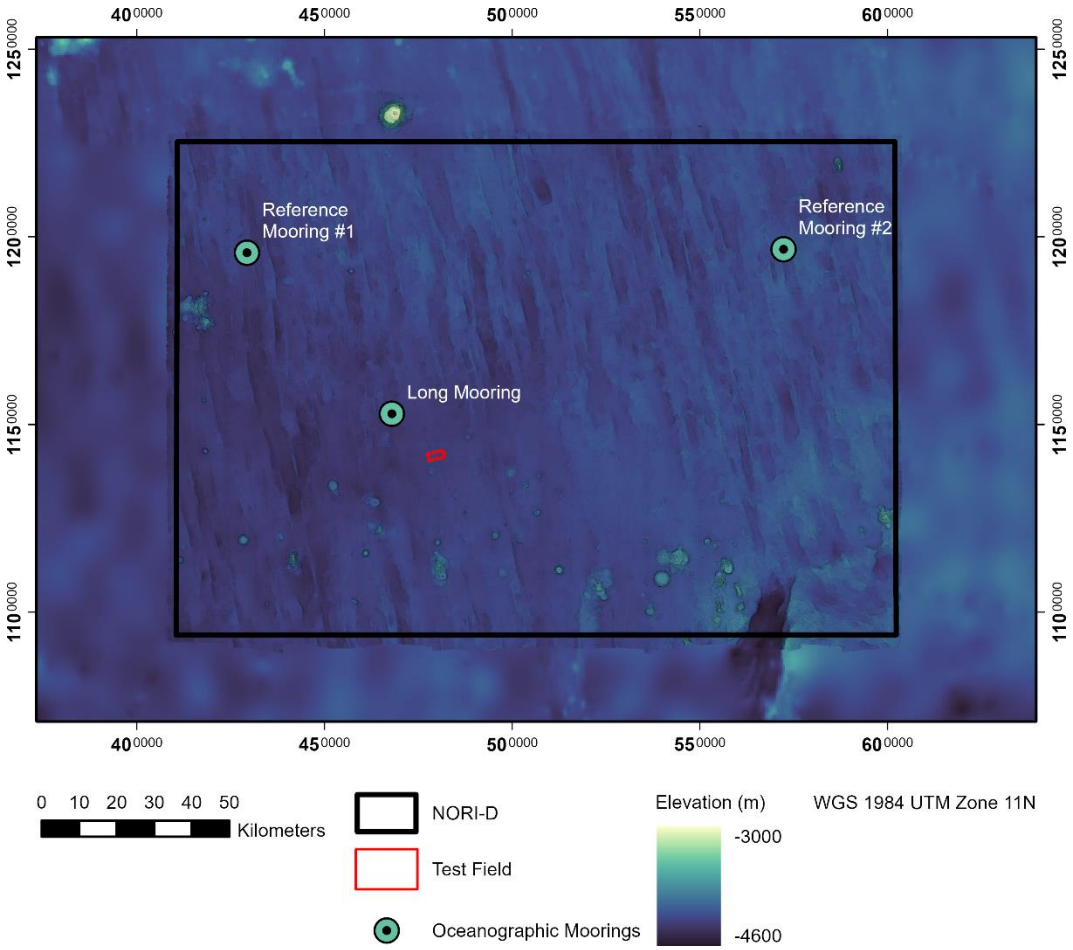


Figure S6. Locations of long-term oceanographic moorings re-deployed during post-test mining monitoring.

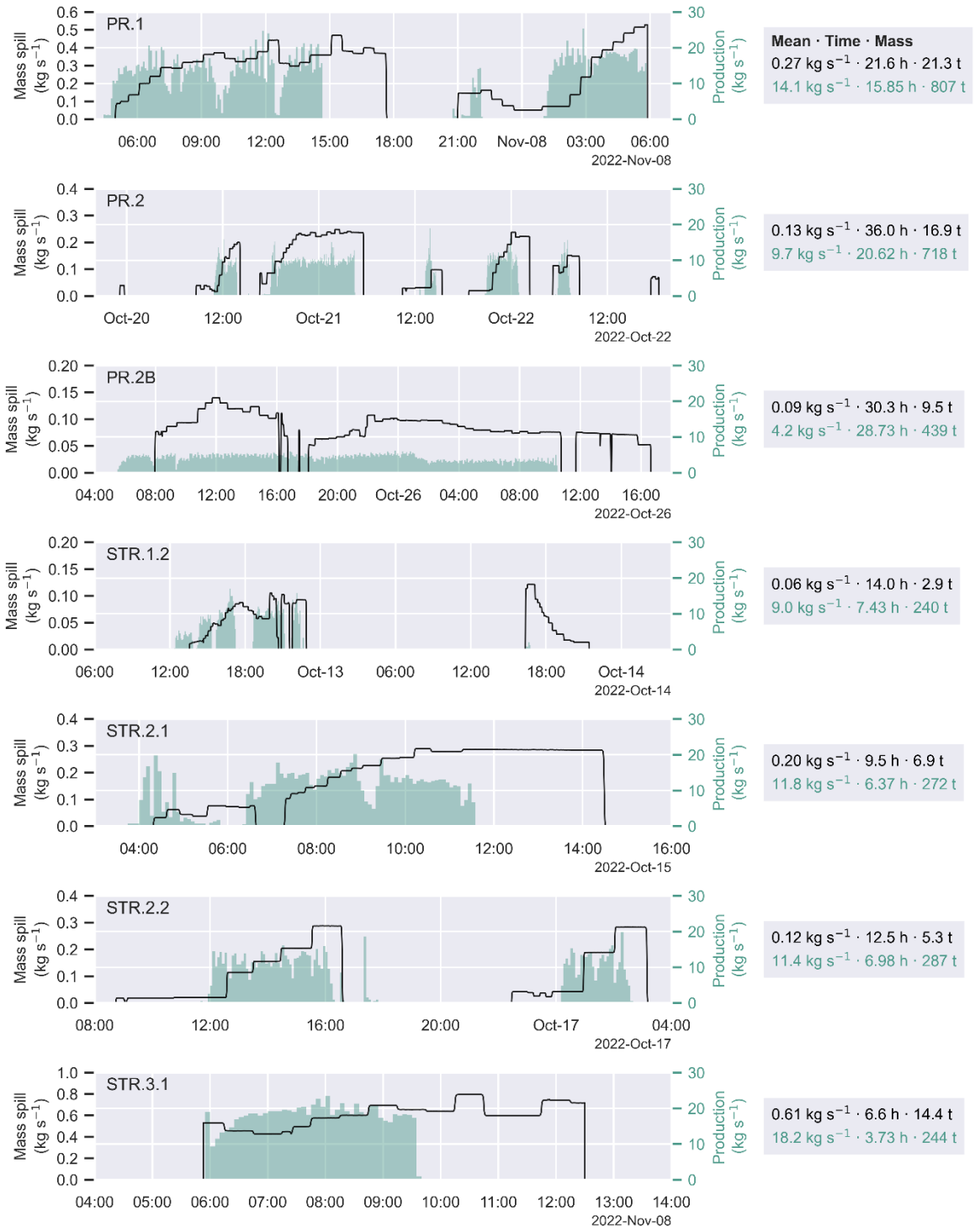


Figure S7. Midwater discharge mass spill rate and surface nodule production rate during individual test-mining runs. Black lines show the 10-second binned mass spill rate (left axis). Teal shading shows the 5-minute binned nodule production rate measured by the conveyor belt scale on the *Hidden Gem* (right axis). Annotation boxes give, for each run, the mean rate, active time and total mass for midwater discharge spill (black) and nodule production (teal). Mean rates are calculated over periods of active discharge or active production, so they exclude interruptions. Production mass is the total recorded by the conveyor belt scale for each run.

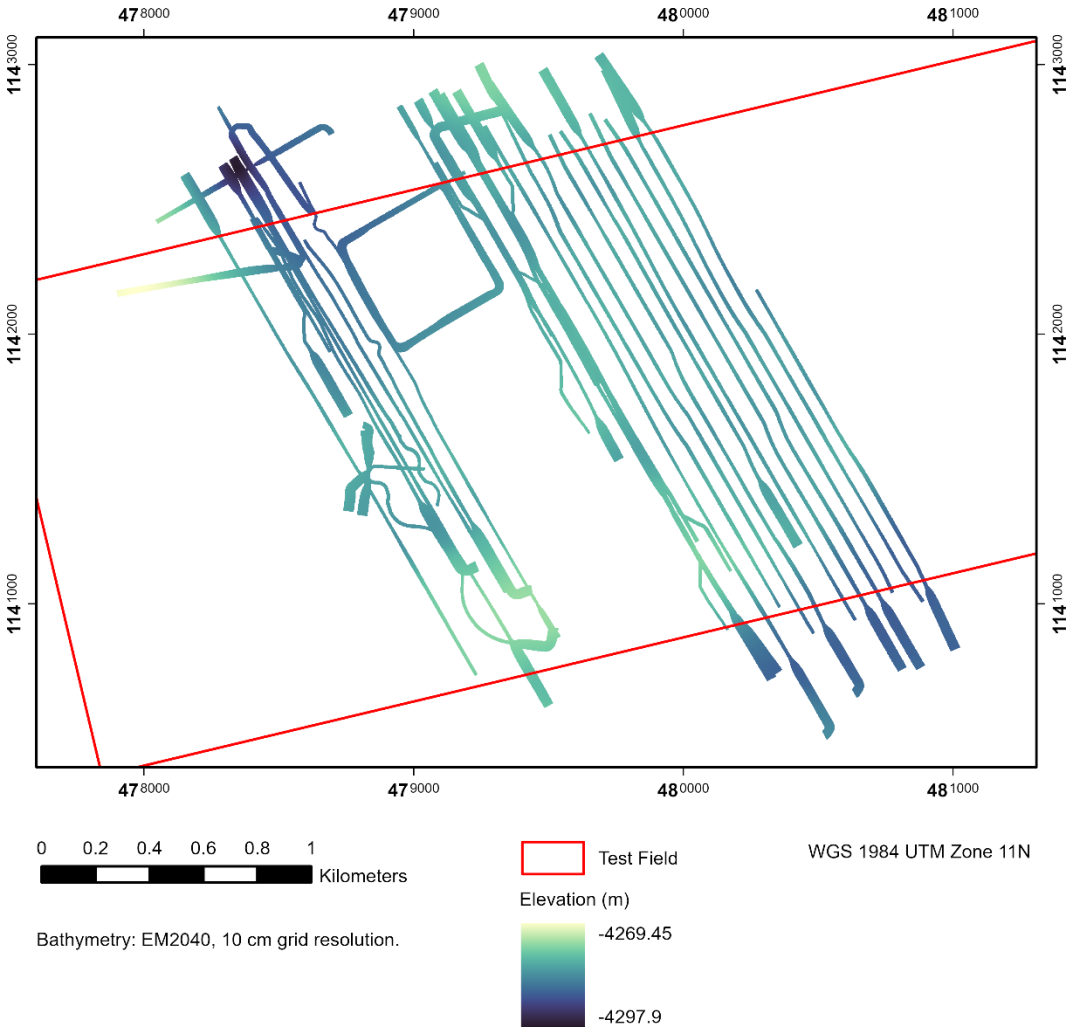


Figure S8. Pre-test mining nested high-resolution AUV survey: MBES bathymetry.

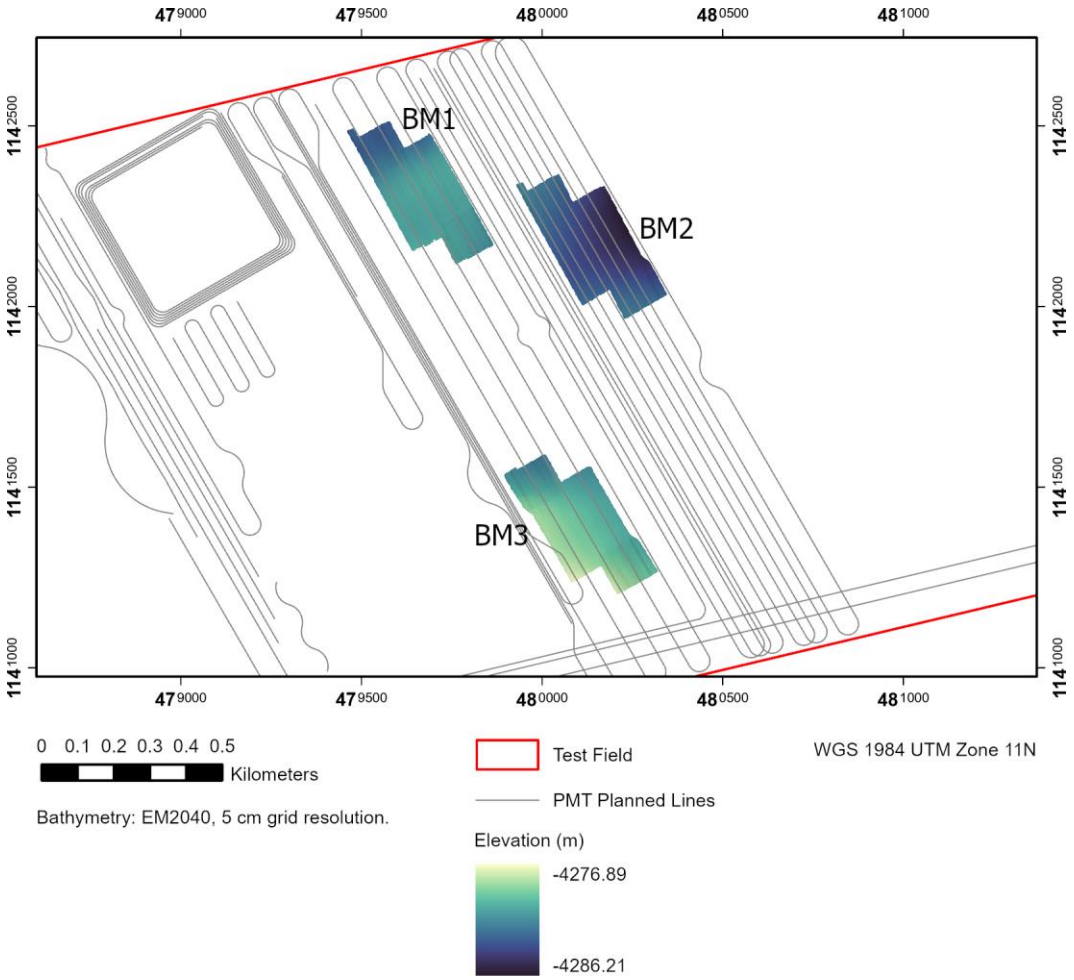


Figure S9. Pre-test mining AUV mosaic survey: MBES bathymetry.

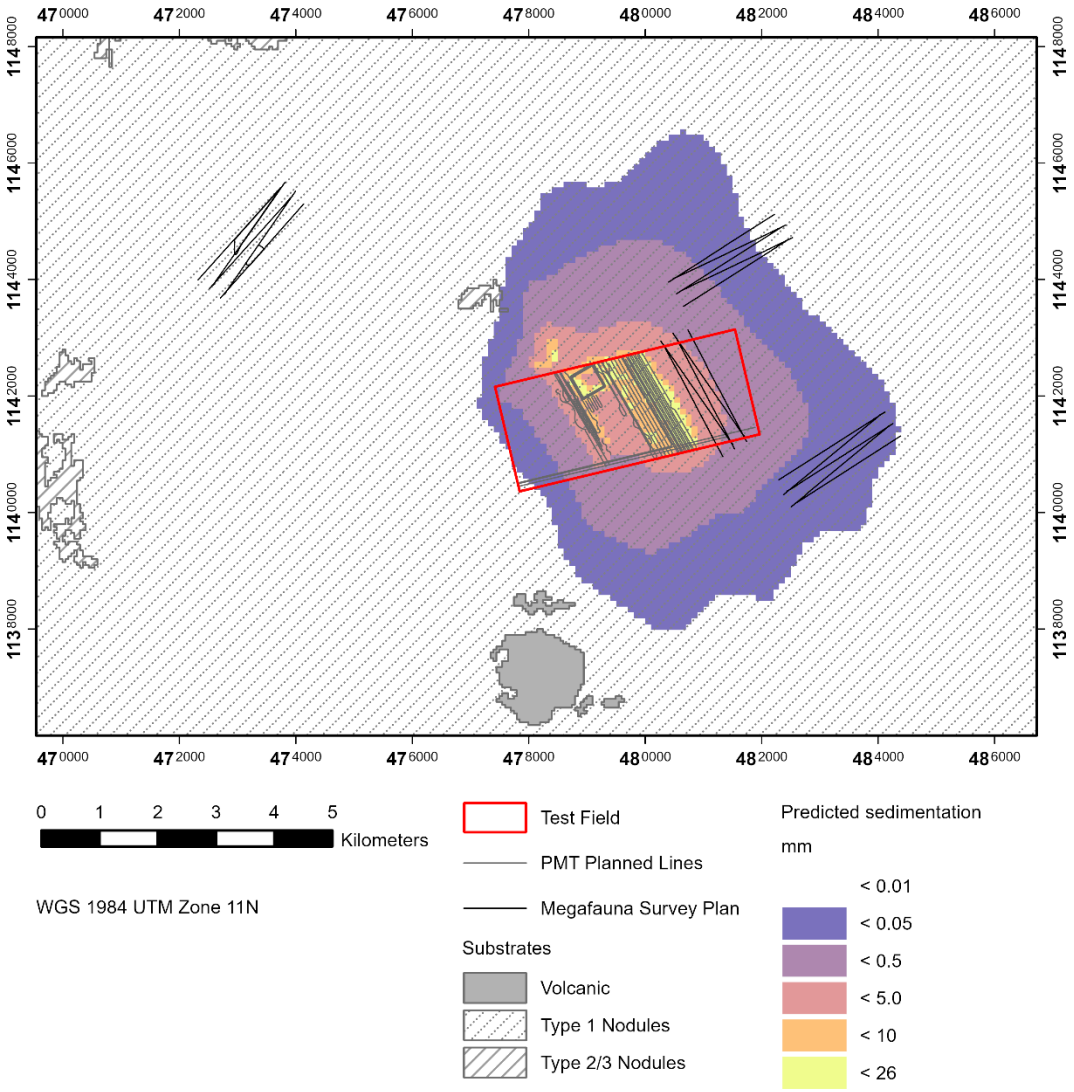


Figure S10. Pre-test mining AUV megafauna survey lines.

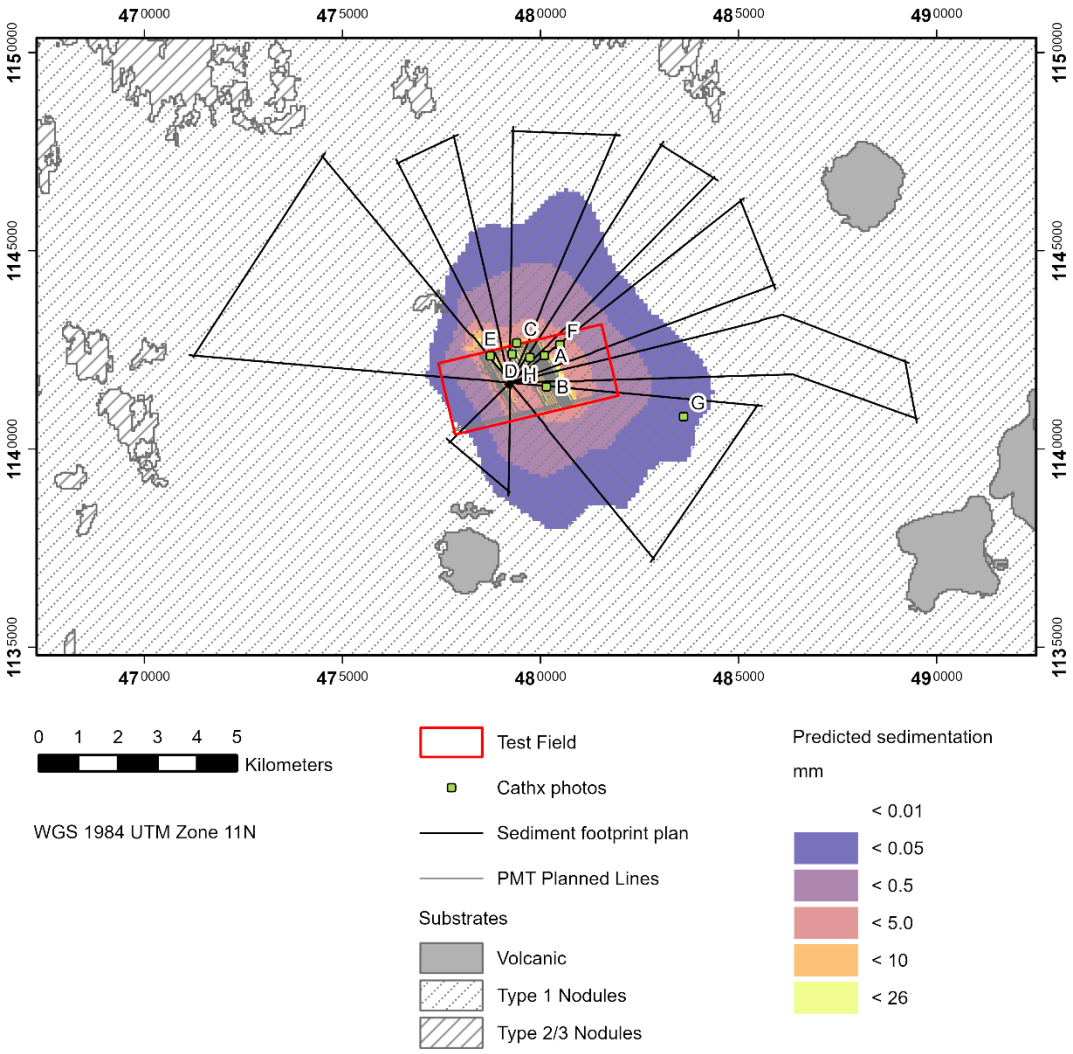


Figure S11. Pre-test mining AUV sedimentation survey lines.

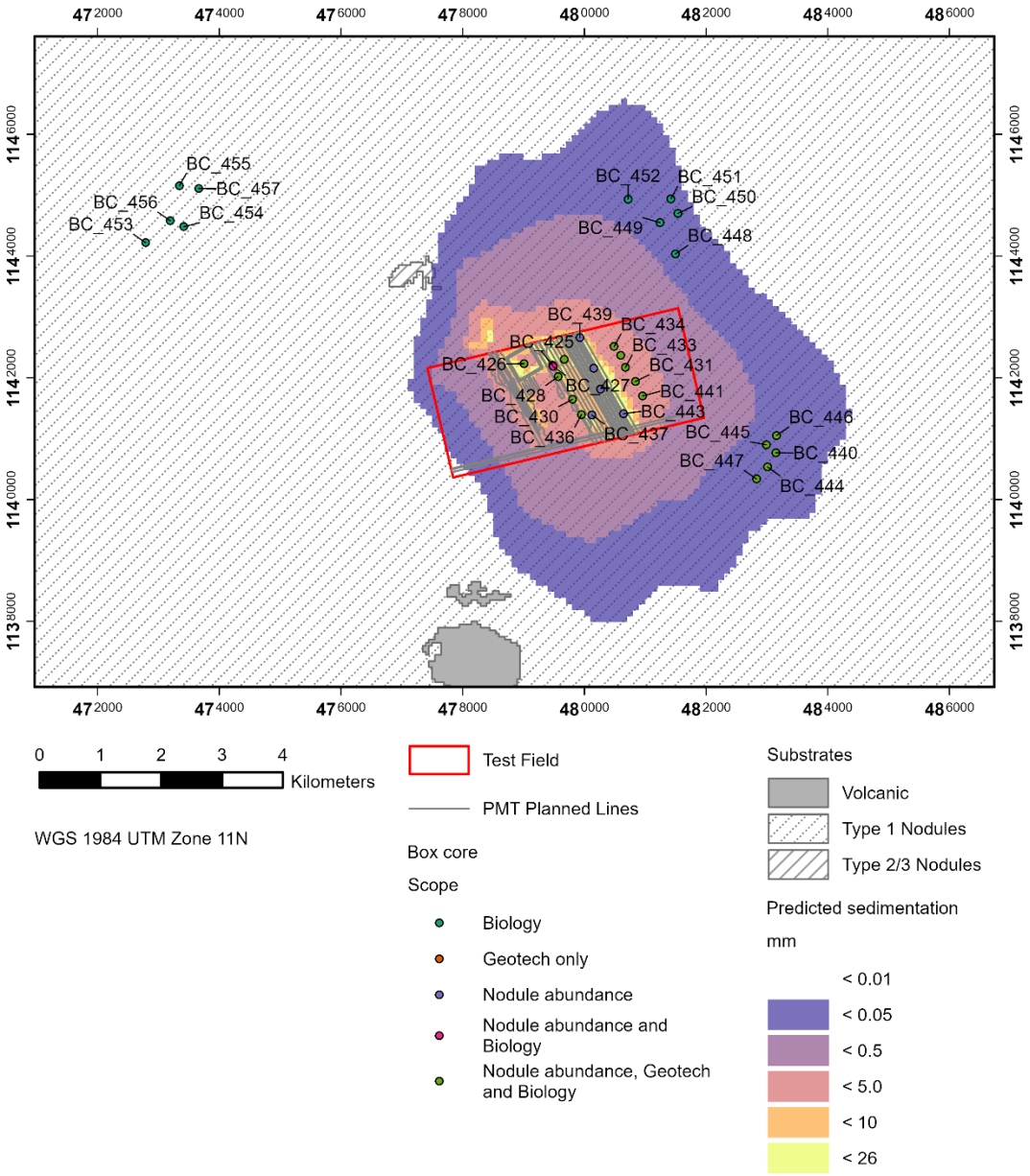


Figure S12. Locations of box core deployments during the pre-test mining monitoring phase

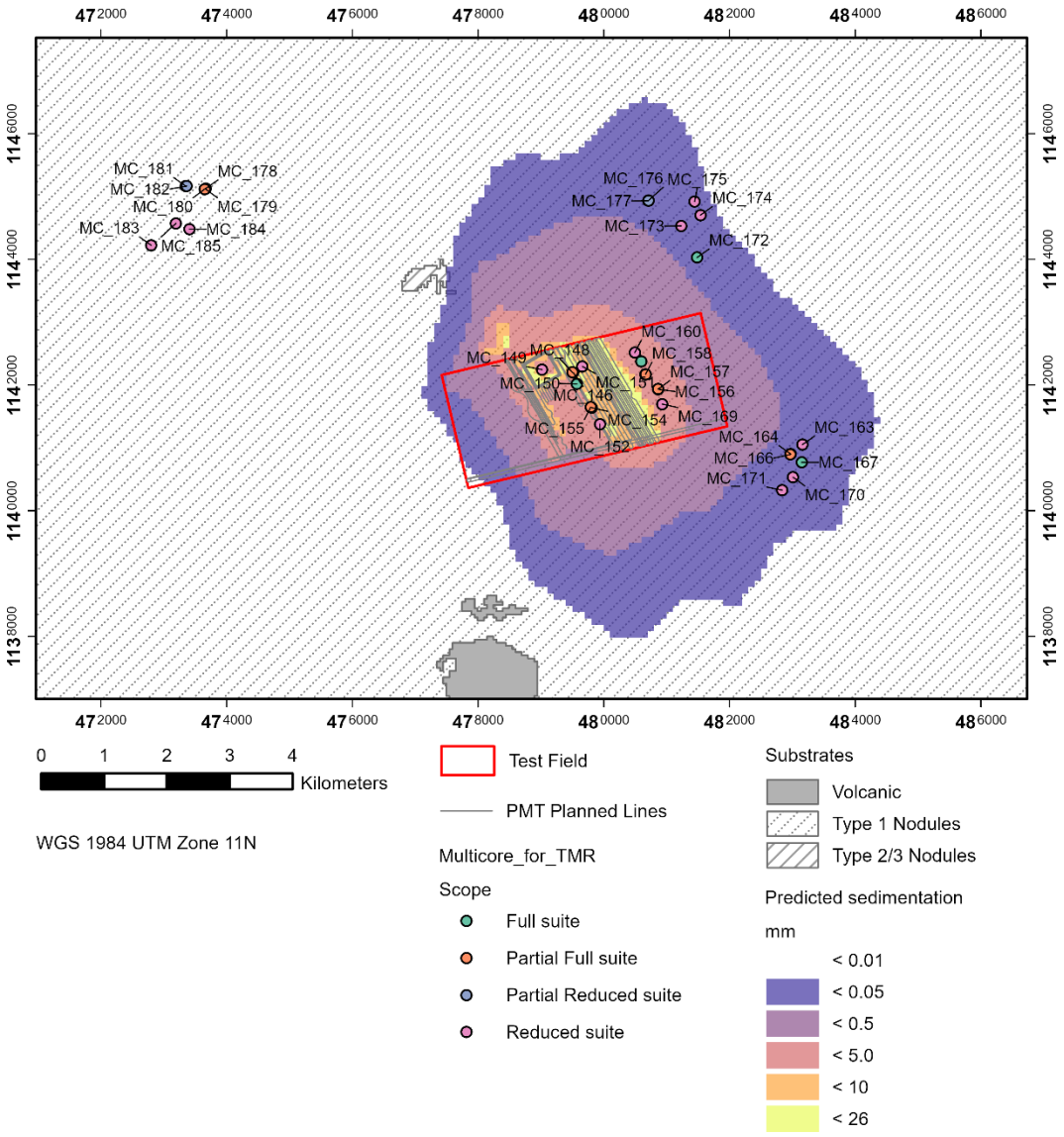


Figure S13. Locations of multicore deployments during the pre-test mining monitoring phase.

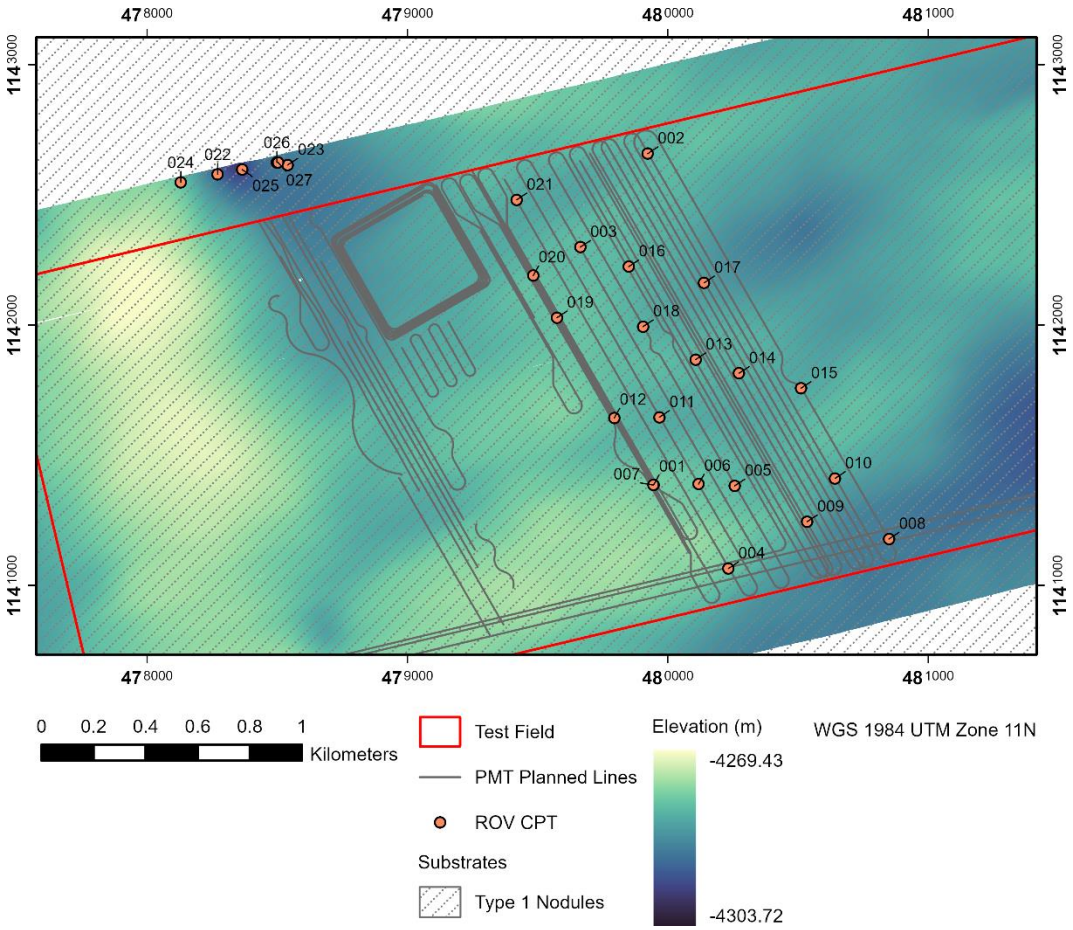


Figure S14. Locations of ROV mounted cone-penetration tests during the pre-test mining monitoring.

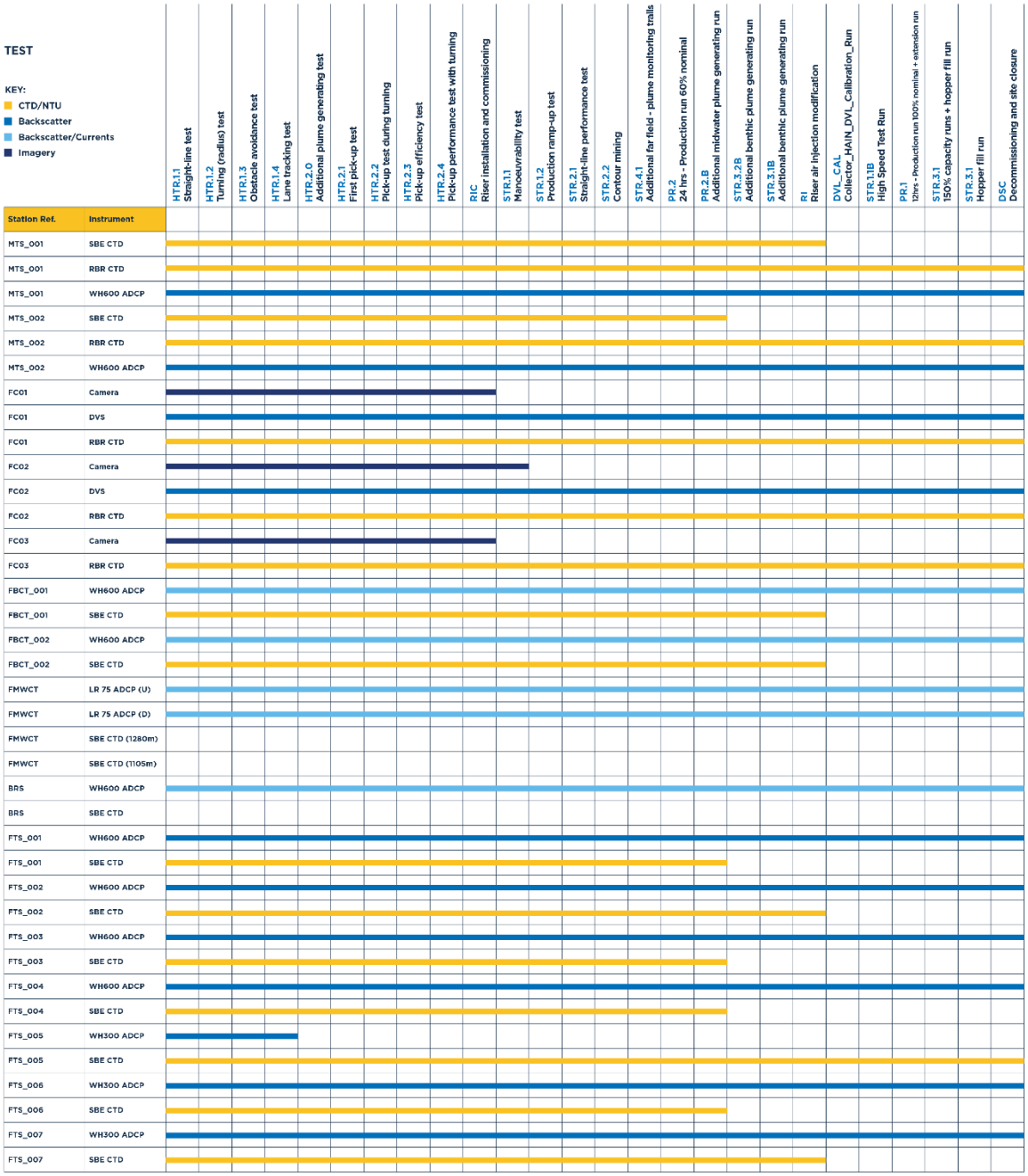


Figure S15. Temporal monitoring coverage provided by each seafloor monitoring asset relative to individual test mining runs.

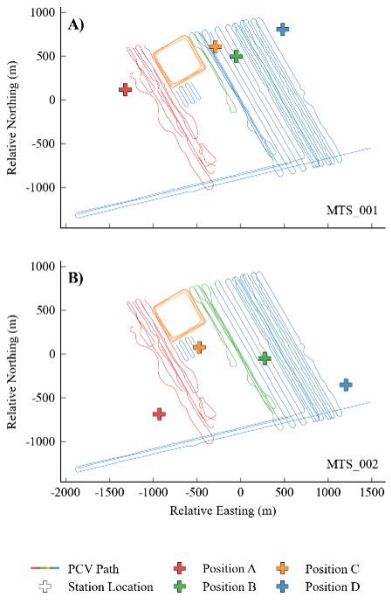


Figure S16. Locations of movable turbidity stations (MTS) throughout the program. Station locations are shown as colored crosses, with each deployment location corresponding to a different color, and PCV path during the station deployment duration highlighted in corresponding color. Relative positions calculated based on the center of the PCV path. (A) MTS_001 locations. (B) MTS_002.

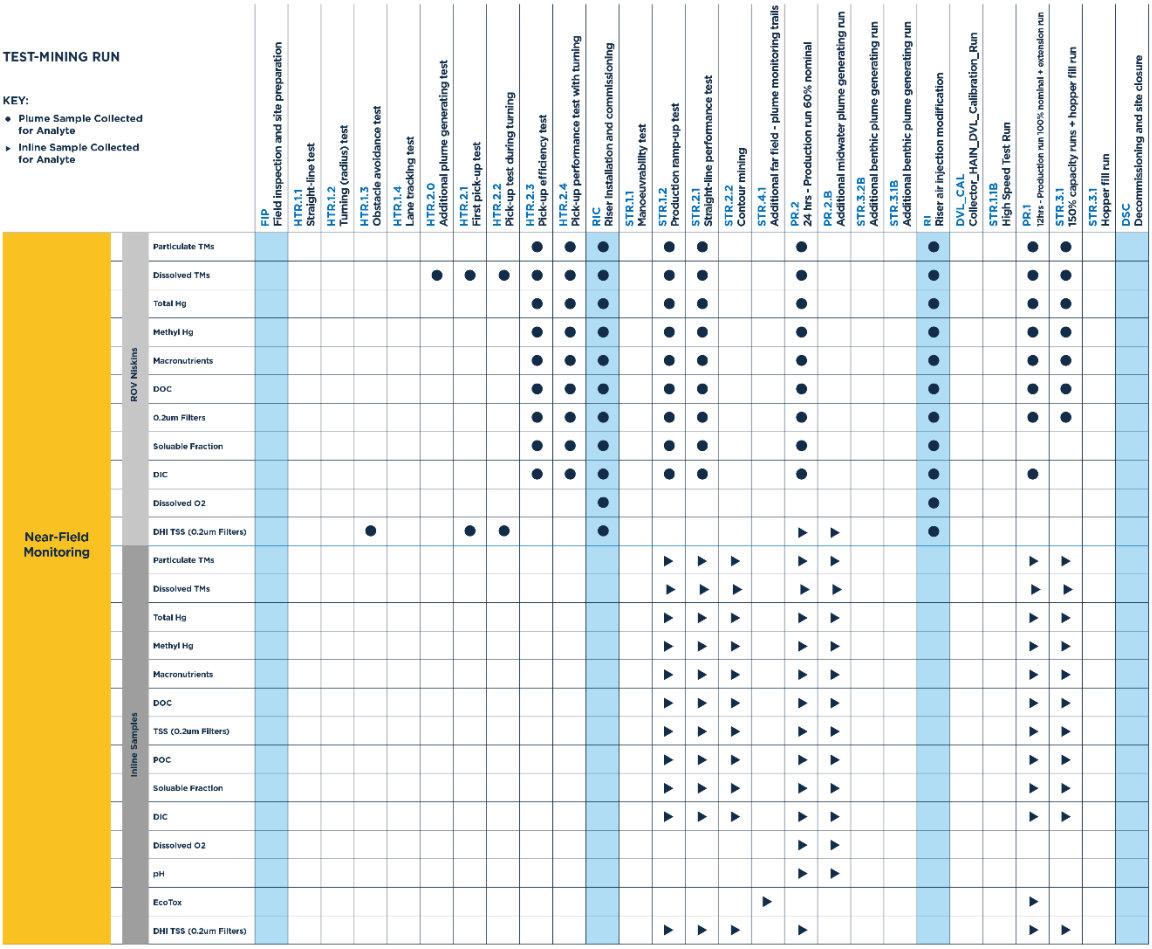


Figure S17. Near-field water sample coverage. The specific sampling techniques are outlined on the left. *Particulate TMs* refers to particulate trace metals, and *dissolved TMs* refers to dissolved trace metals. *Total Hg* refers to total mercury, and *methyl Hg* refers to methylmercury. *DOC* refers to dissolved organic carbon. *0.2 um filters* indicates samples passed through a 0.2 µm filter, while *soluble fraction* refers to samples kept for soluble fraction analysis. *DIC* refers to dissolved inorganic carbon. *Macronutrients* refers to dissolved inorganic nutrients (e.g., nitrate, nitrite, phosphate, and silicate). *pH* refers to seawater pH measurements, and *dissolved oxygen* refers to discrete water-column oxygen samples. *Ecotox* refers to samples collected for onshore ecotoxicology exposure experiments. These analyses were conducted by Texas A&M University and the University of Hawaii. *DHI TSS* refers to samples collected for total suspended solids (TSS) analysis by DHI.

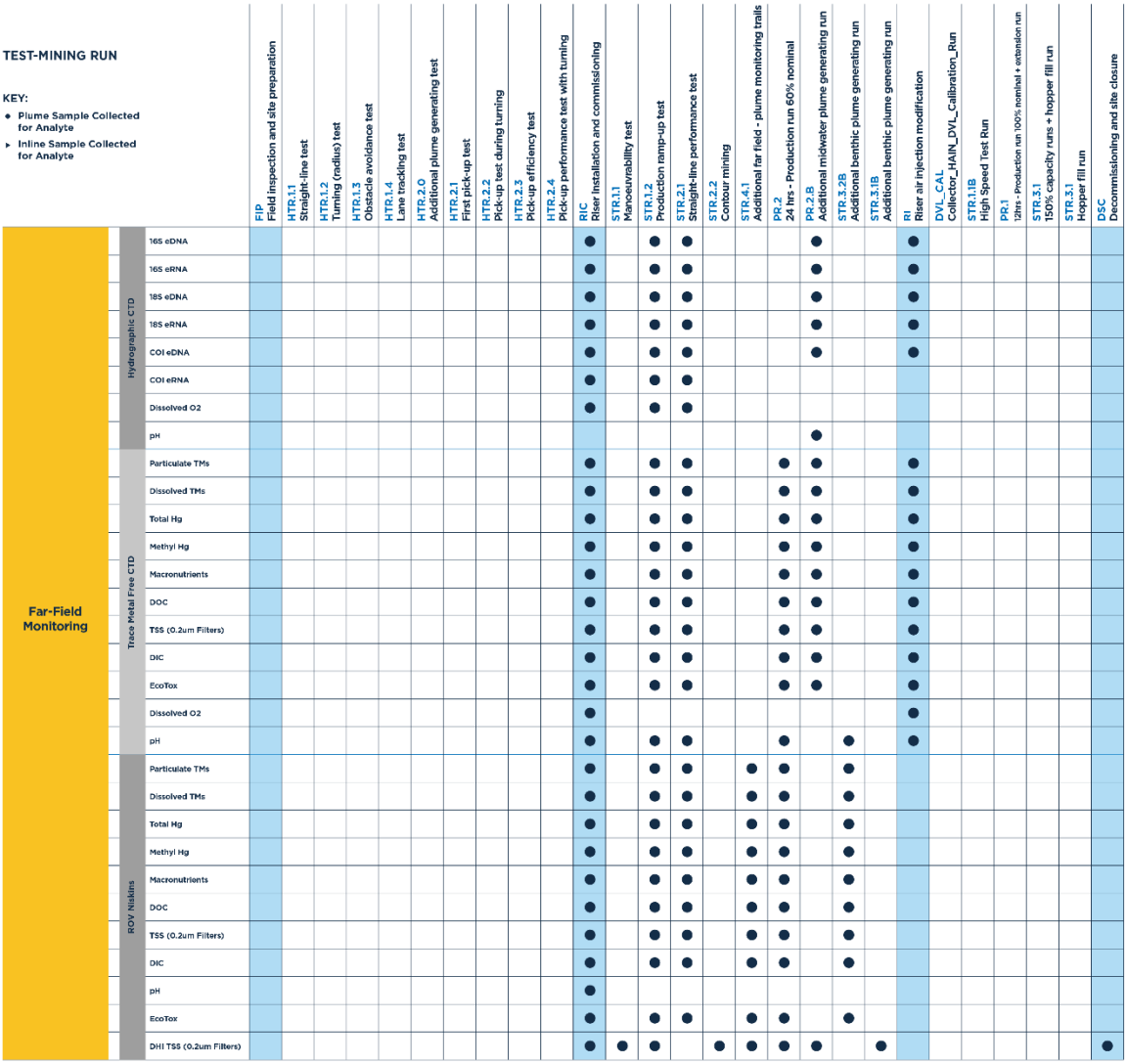


Figure S18. Far-field water sample coverage. The specific sampling techniques are outlined on the left. *Particulate TMs* and *dissolved TMs* refer to particulate and dissolved trace metals, respectively. *Total Hg* refers to total mercury and *methyl Hg* to methylmercury. *DOC* denotes dissolved organic carbon. *0.2 µm filters* indicates samples passed through a 0.2 µm filter, and *soluble fraction* refers to samples retained for particulate and soluble fraction analysis. *DIC* denotes dissolved inorganic carbon. *Macronutrients* refers to dissolved inorganic nutrients (e.g., nitrate, nitrite, phosphate, and silicate). *pH* refers to seawater pH measurements, and *dissolved oxygen* refers to discrete water-column oxygen samples. *Ecotox* refers to samples collected for onshore ecotoxicology exposure experiments. These analyses were conducted by Texas A&M University and the University of Hawaii. *DHI TSS* refers to samples collected for total suspended solids (TSS) analysis by DHI. *18S eDNA*, *16S eDNA*, and *COI eDNA* refer to environmental DNA targeting the 18S rRNA gene, 16S rRNA gene, and cytochrome c oxidase subunit I (COI) gene, respectively. *18S eRNA*, *16S eRNA*, and *COI eRNA* refer to environmental RNA targeting the same genetic markers. Cawthron Institute led the eDNA and eRNA sampling.

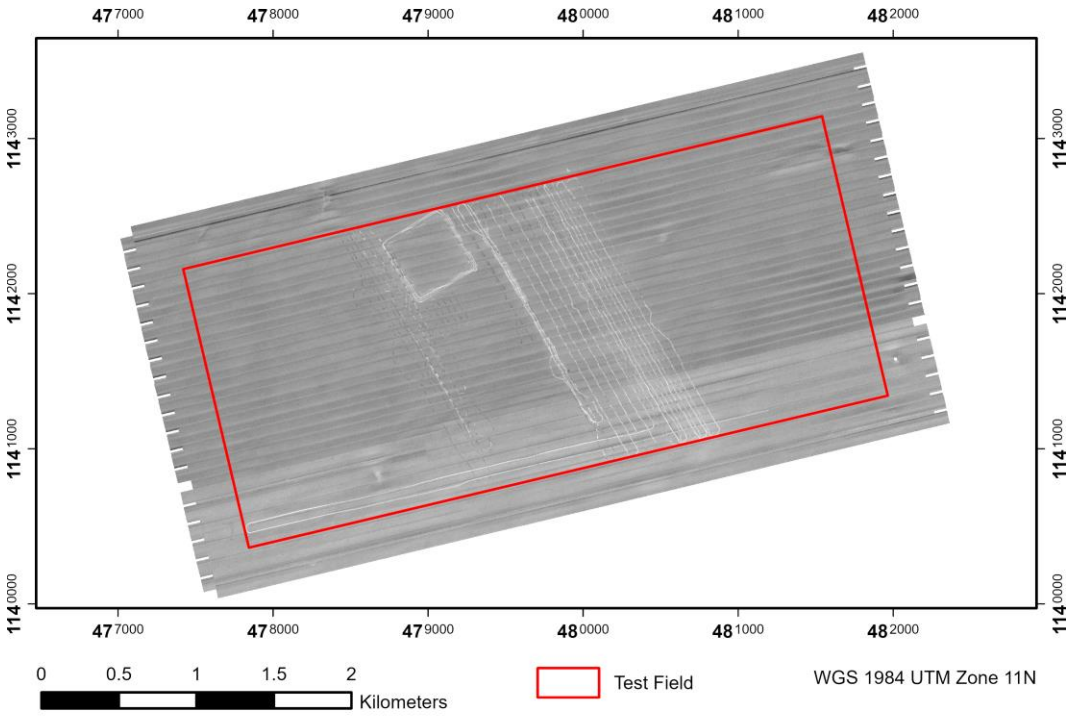


Figure S19. Post-test mining full-site geophysical survey: AUV-side scan sonar data.

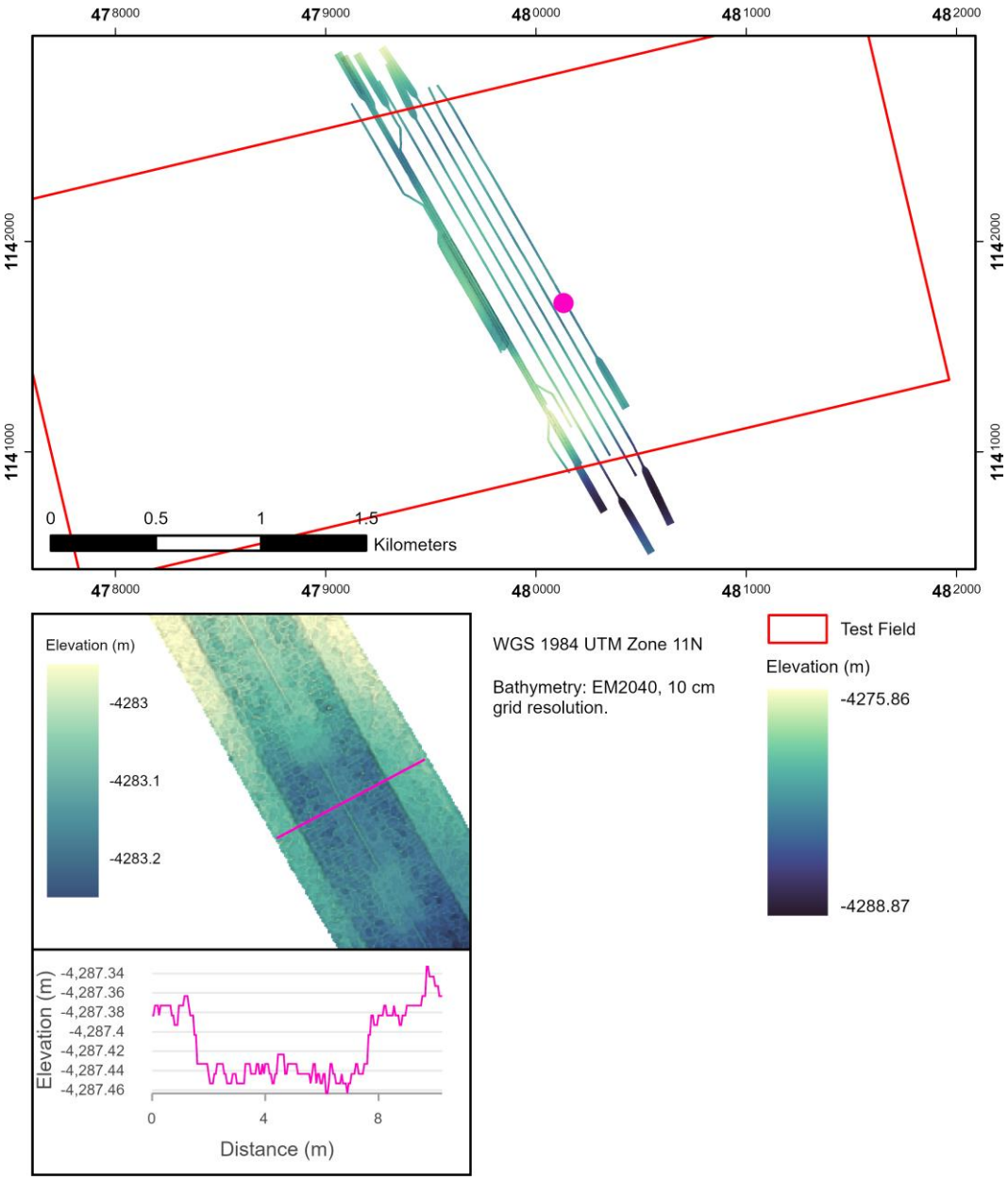


Figure S20. Post-test mining nested high-resolution survey: AUV-mounted MBES data.

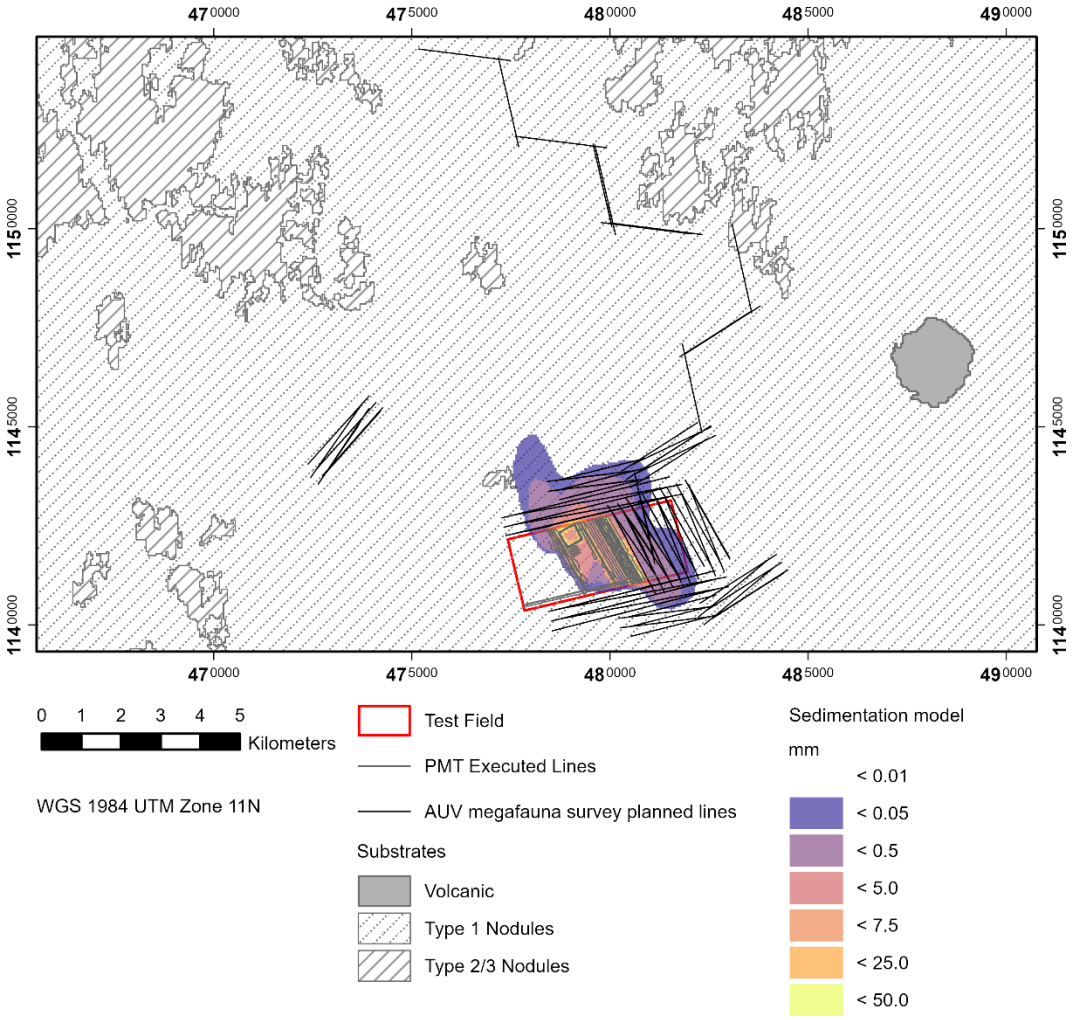


Figure S21. Post-test mining AUV megafauna survey. Sedimentation thicknesses are derived from the preliminary hindcast model used to inform post-test mining survey designs.

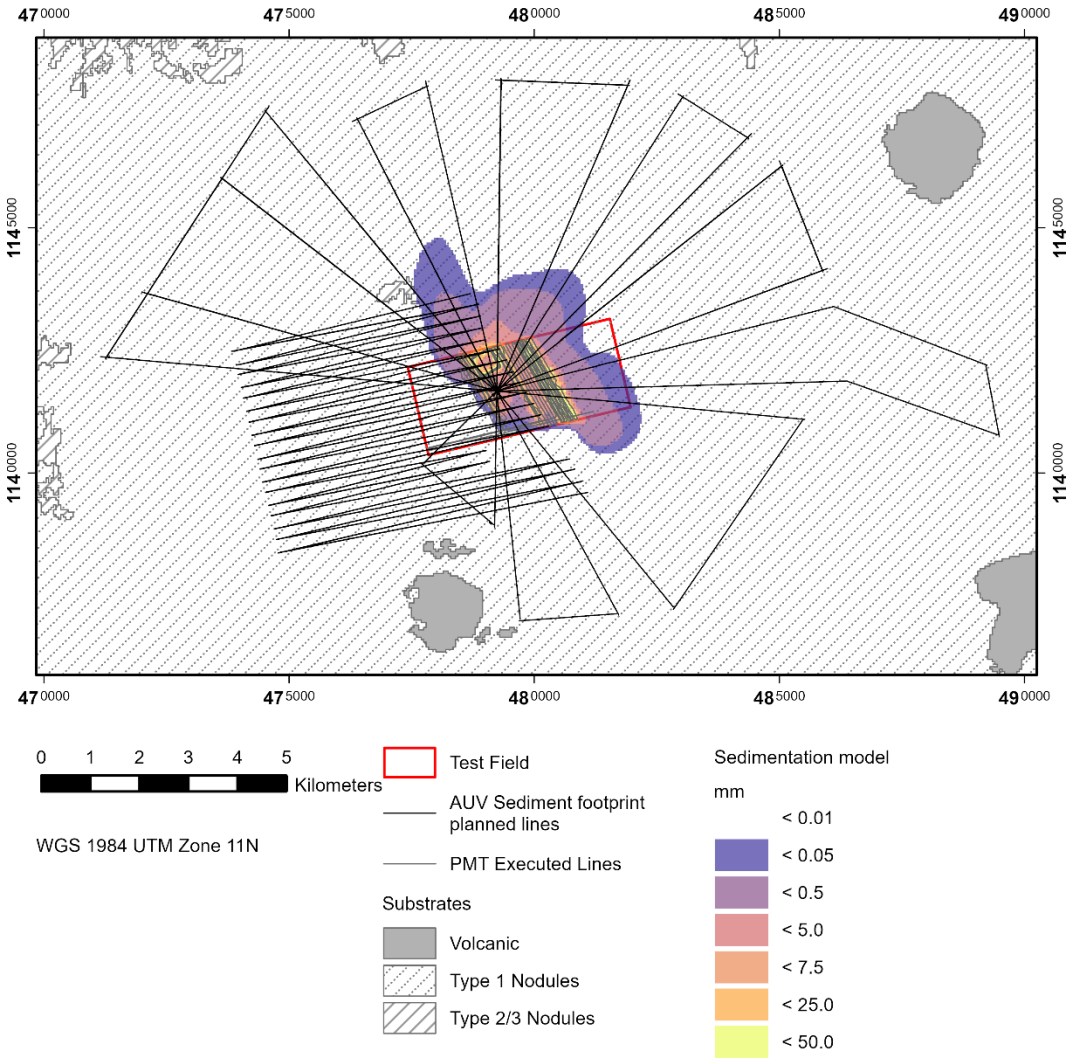


Figure S22. Post-test mining AUV sedimentation survey.

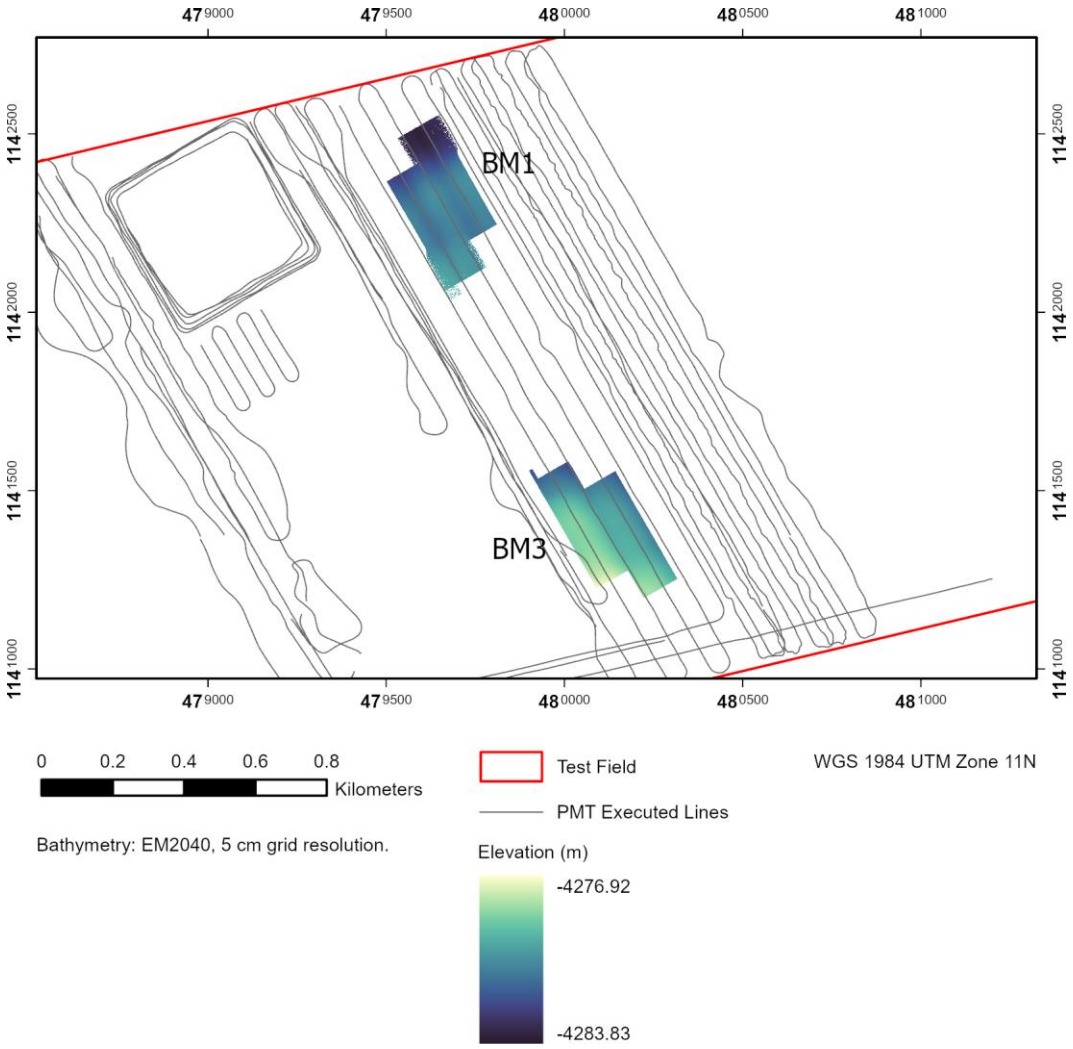


Figure S23. Post-test mining high-resolution MBES mosaic surveys.

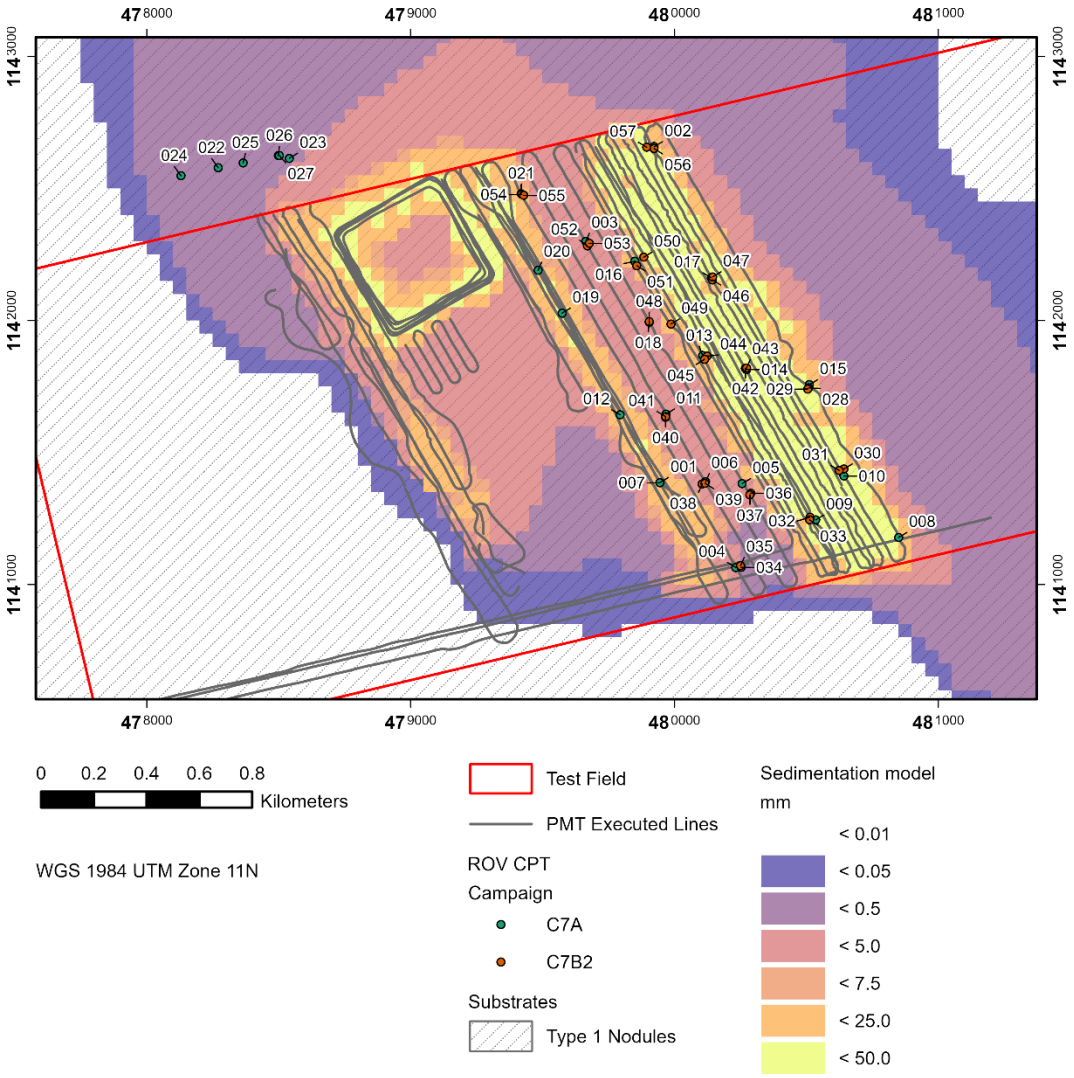


Figure S24. Locations of ROV-CPT deployments during post-test mining monitoring.

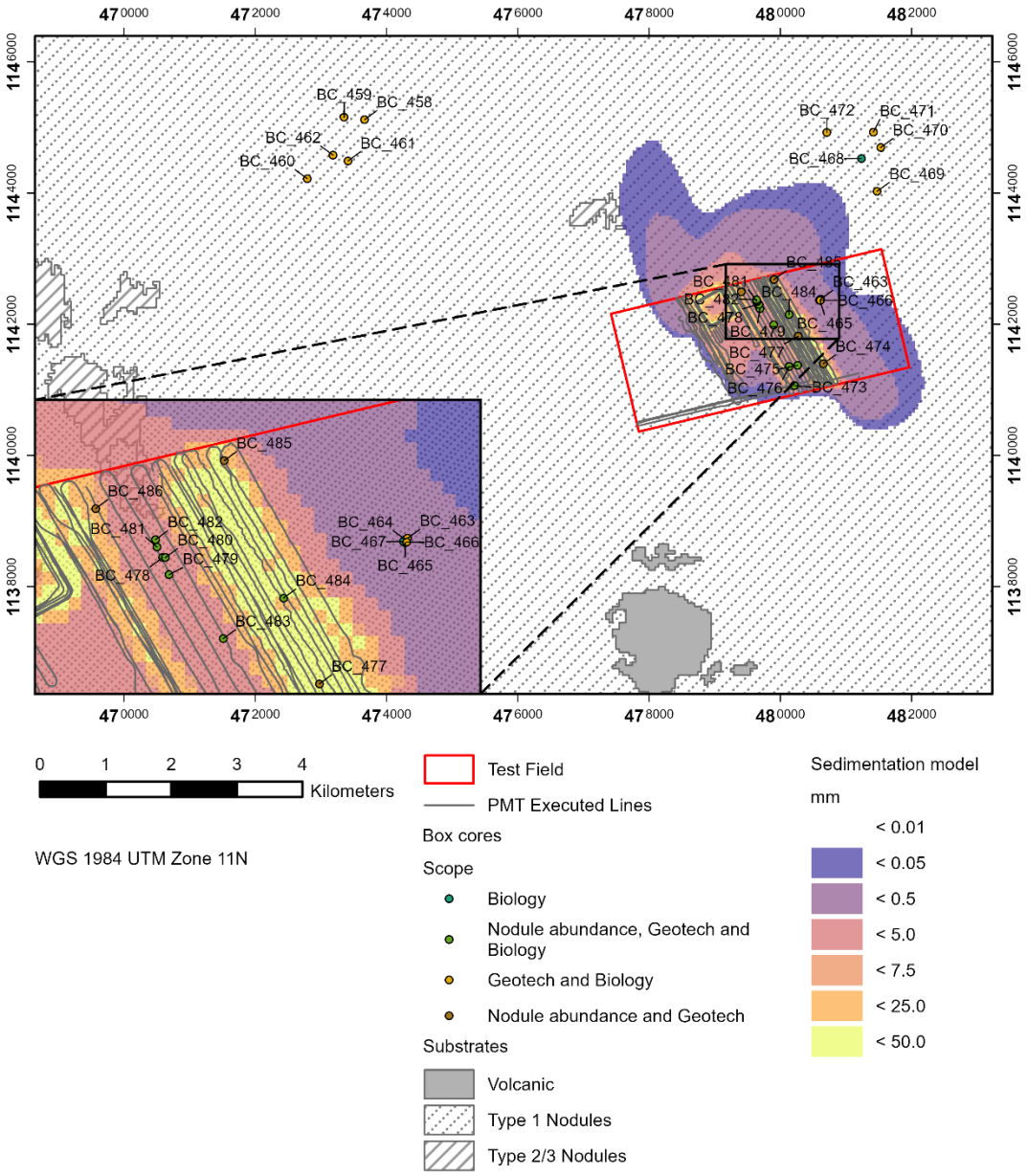


Figure S25. Locations of box corer deployments during post-test mining monitoring.

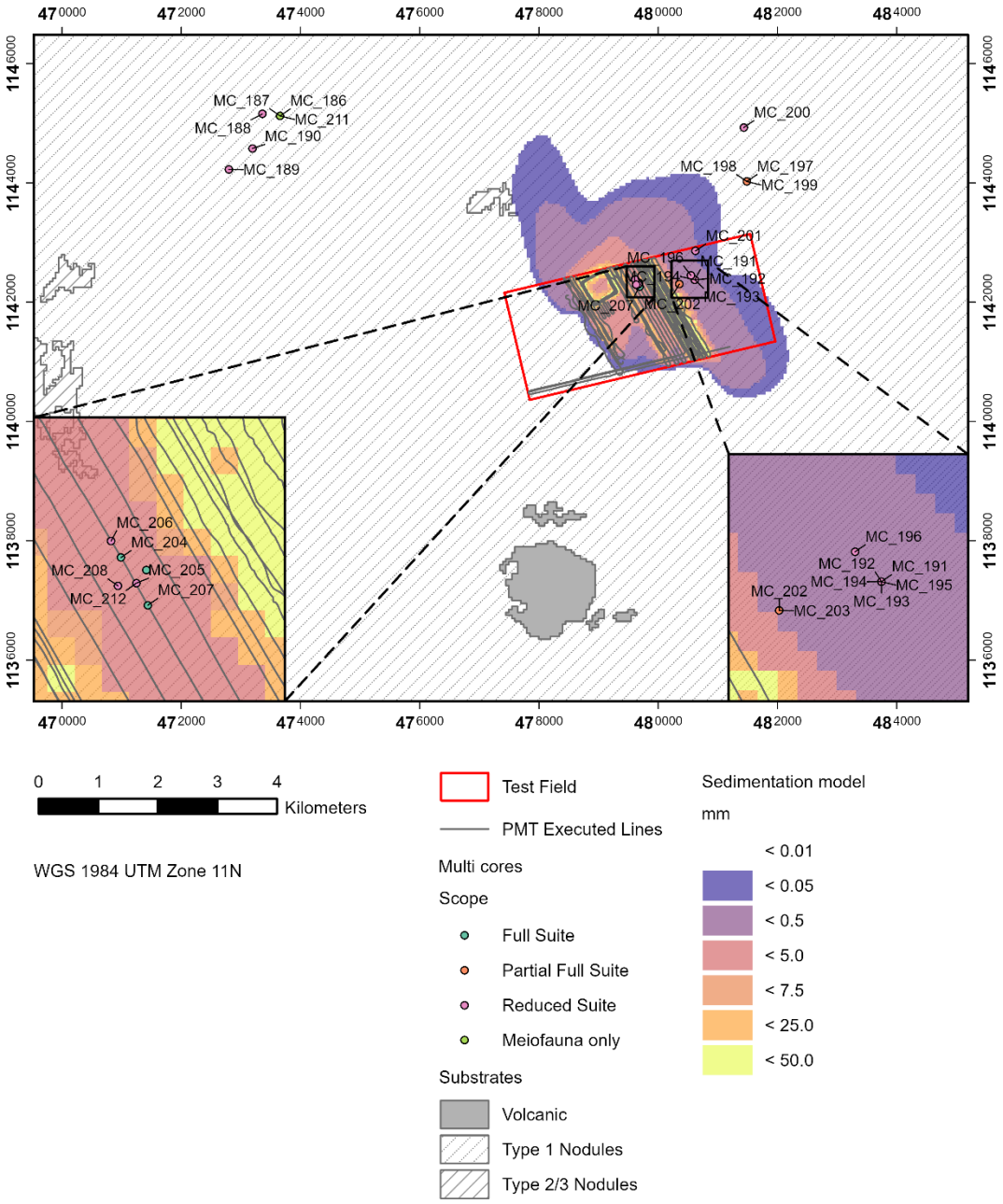


Figure S26. Locations of multicorer deployments during post-test mining monitoring.