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## Ocean Resources Development & Coastal Zone Management

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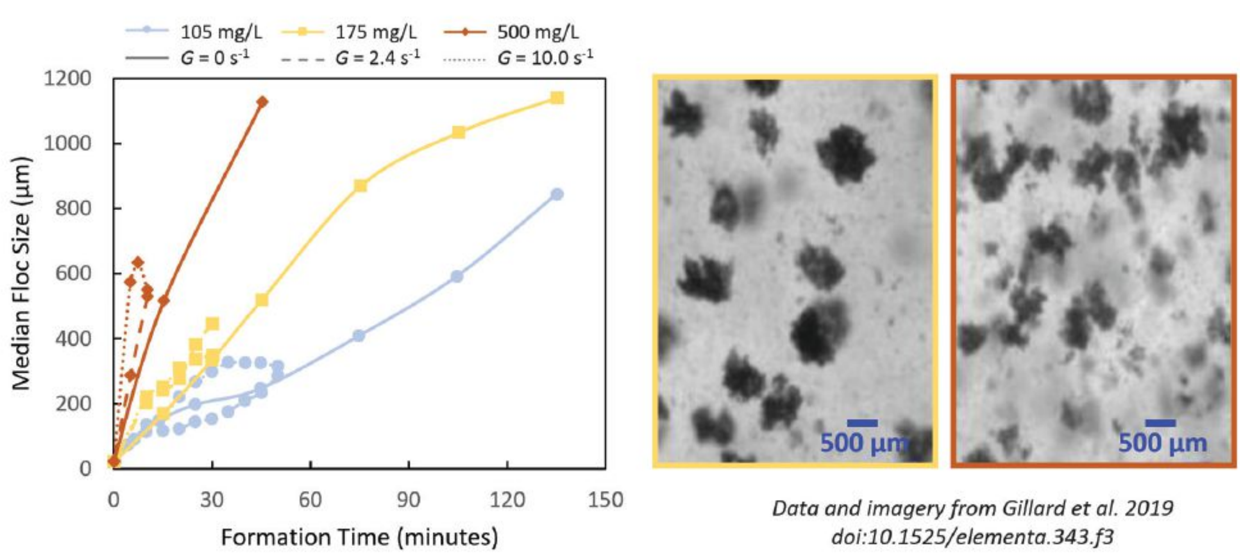
# Monitoring Deep-Sea Mining's Effects

## *New Instrument to Measure Sediment Properties in Mining Plumes*

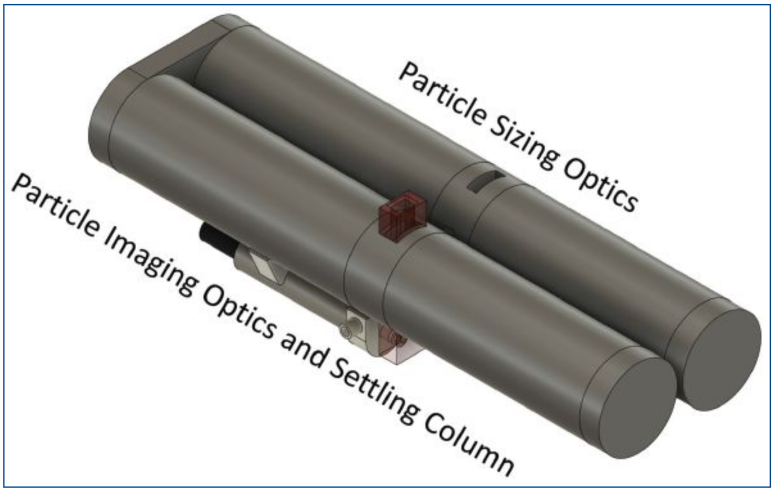
**By Dr. Wayne Homer Slade • Dr. Thomas Peacock • Dr. Matthew Alford**

With the significant development of exploratory deep-sea mining activities, the demand for routine environmental monitoring in the deep sea has become pressing. Today, no commercial instrumentation exists that can monitor the parameters of importance for regulators and operators. A collaboration led by Sequoia Scientific Inc., the Massachusetts Institute of Technology (MIT) and Scripps Institution of Oceanography (SIO) has been funded to develop a commercial instrument for deep-sea environmental monitoring of mining activity.

The past decade has seen a substantial increase in activities surrounding the potential development of a global deep-sea mining industry, with numerous governments and private companies developing research and engineering programs (see also Peacock and Alford, *Scientific American*, May 2018). The driving force for this industry is the existence in the abyssal ocean of vast reserves of minerals such as cobalt, nickel, copper and manganese—crucial components in advanced battery and clean energy technology for decarbonization of global economies. The minerals exist in a variety of forms in the deep ocean, including as polymetallic nodules, baseball-sized rocks lying on the seabed. Extraction methods involve driving a collector vehicle that harvests the nodules and a riser




***Sediments from a candidate mining site were subjected to varying shear in the lab while observing particle size over time. Flocs readily form via settling as well as shear aggregation. Left panel: median floc size as a function of formation time, plotted for different initial concentrations (line color) and shear rate (line style). Middle and right panels: images of flocs formed during the experiment. Data and imagery adapted from Gillard et al (2019), CC BY 4.0 License, https://doi.org/10.1525/elementa.343.f3.***




*Submersible instrument housing concept with particle sizing imaging optics. Settling column is used to measure size-settling velocity distribution. In this concept, a pump is shown for flushing and pulling a sample into the column.*

system that transports the nodules to the ocean surface.

A key concern surrounding deep-sea mining is the extent of the sediment plumes that will be generated by seafloor mining activities and how they will impact deep-sea benthic habitats. There is great uncertainty in predicting the scale of such plumes. The challenge is that given the persistent lack of funding for abyssal research, there is currently no technology capable of making the necessary in-situ measurements of suspended sediment properties (particle size distribution, settling velocity, concentration) that underlie plume prediction.

**Regulatory Challenges**

Exploration and exploitation regulations of the International Seabed Authority (ISA, see for example ISBA/25/LTC/6/Rev.1) dictate that anyone granted permission to operate on the seabed in international waters must gather environmental data on the properties of suspended sediment. Contractor field studies to date (for example, impact studies published by exploratory contractors GSR and BGR in 2018) and laboratory studies have provided some insight into the nature of the sediment that will be disturbed and transported by the water column. Typical particle sizes are in the range 5 to 50 microns, with a strong propensity to form 100 microns to millimeter-scale flocs with settling speeds in the range of 0.1 to 1 mm per second. However, the data obtained have been determined in lab-based environments, i.e., after the sediment has been removed from the ocean and the particle size distribution and packaging in and out of flocs has been disturbed. Currently no in-situ data exist, nor is there instrumentation to measure these sediment properties, and in real time, at depths of 6,000 m.

**Current State of the Art**

The current state-of-the-art technology for in-situ and/or real-time monitoring of the properties and concentrations of sediment in the deep ocean is very limited. The standard approach since the late 1970s has been to use sediment trap technology that collects particles falling toward the seafloor, custom camera or video technology that can image particles, or laser diffraction-based instruments, such as Sequoia's LISST-100X and LISST-200X systems.

The basic sediment trap consists of a broad funnel with a collecting jar at the bottom. The funnel opening covers a standard area (typically 0.25 sq. m) and has baffles at the top to keep out very large objects. The traps are clamped to moorings at specific depths (e.g., 2,000 m to quantify flux from the euphotic zone, 500 and 10 m above the bottom to characterize flux to the bottom), or directly above the bottom boundary layer where they can catch sediment near the ocean bottom. Such sediment traps are currently the only means for scientists to get hard data about the amounts and kinds of material transported to the deep ocean.

Sediment traps must be returned to shore for analysis and, for practical purposes, have no reasonable spatio-temporal resolution. One effort to advance the capabilities of sediment traps is the Sediment Event Senor (SES) system developed at the Monterey Bay Aquarium Research Institute (MBARI) in California. This system introduced a mechanical cycling imaging and cleaning platform to allow a sediment trap to be reused many times and build up a time series of data. As with a standard sediment trap system, however, the size of the device imposes operational limitations and it also has no real-time capability.

For estuarine and near-coastal systems, the purpose-built INSSEV (IN Situ SEttling Velocity) and INSSECT (IN situ Size and SEttling Column Tripod) systems, which are deployable settling chambers with imaging capability, have been used to make in-situ measurements of particle size distributions and settling speeds, but these have never been modified for use in the deep ocean.

The LISST-STX was a laser-diffraction based system for measuring settling velocity in water depths down to 300 m. It was manufactured by Sequoia Scientific from 1998 to 2016. This is the only settling velocity instrument that has ever been commercially available; a total of 58 units were manufactured and sold.

Eisma developed a suspension camera in combination with an image analysis program to measure in-situ particle size of suspended matter with diameters of 4 microns and larger, capable of going down to 4,000 m (and with some adjustments down to 7,000 m). This general approach of using a floc camera or video system to measure particle size and/or settling velocity has been developed and deployed by a number of research groups over the past few decades and is well established.

All systems described above suffer from two major shortcomings: They have never been made commercially available (except the LISST-STX), and they cannot provide real-time or near-real-time data at high temporal resolution (measurement frequency of minutes or seconds) to the surface. To our knowledge, no underwater equipment manufacturer today offers a commercially available deep-sea settling velocity instrument. The only commercially available systems for PSD measurements in the deep sea are the LISST-Deep instrument system developed by Sequoia (rated to 4,000 m) and the HoloSea holographic camera from 4Deep in Halifax, Canada. The latter has a 500-m standard rating; however, 4Deep can provide custom models with a 5,000-m rating.

**Developing a Solution**

The state-of-the-art instrumentation is insufficient for the in-situ measurements of suspended sediment properties (particle size distribution, settling velocity, concentration) needed for plume prediction. The U.S. Department of Energy's Advanced Research Projects Agency-Energy (ARPA-E) recognized that these parameters were missing for responsible development and monitoring of deep-sea mining operations. Consequently, in a Small Business Innovation Research (SBIR) call in 2019, ARPA-E called for proposals to address these shortcomings.

Answering the call, Sequoia, MIT and SIO formed an R&D partnership that was subsequently awarded a grant to address this technology gap. The goal of the R&D project is to develop sensor technology capable of operating at depths of 6,000 m that can provide baseline environmental data prior to operations and underpin environmental monitoring and modeling of deep-sea polymetallic nodule mining operations. Specifically, an instrument system that can provide real-time or near-real-time measurement of in-situ particle size distribution, settling velocity and concentration will be developed for integration on common deep-sea platforms, e.g., moorings, bottom landers and autonomous vehicles.

The partnership's approach is to perform a systematic and progressive technology R&D program that advances existing laser scattering, settling column and particle imaging technology for application to the deep-ocean environment at an operating depth of 6,000 m. Laser scattering technology will be developed to tackle the demands of operating in the deep-ocean environment for the purpose of making near-real-time measurements of particles smaller than 20 to 40 microns. In combination, image-based technology capable of measuring particle/floc sizes larger than approximately 40 microns and their associated settling speed will be packaged for the deep ocean. Both technologies will be combined into a single instrument package for integration with AUV, ROV and deep-ocean mooring mountings.

Broadly, technology development will be led by Sequoia. Once a prototype system has been collaboratively developed by the team and initially tested at Sequoia, MIT will test instrument performance and benchmark it against standard lab-based methods for measuring particle (including floc) size distribution and settling velocity as a function of particle size. Upon completion of these tests, the system will be adapted into a custom deep-ocean housing and SIO will test its performance at full operational pressure. The project team will then participate in preliminary ocean trials, initially deploying the instrument at depths down to 1,000 to 2,000 m, and afterward in an actual deep-sea mining exploration campaign or prototype collector test. Testing and refinement of a prototype instrument is expected during late 2021 into early 2022, followed by commercial availability in late 2022.

Besides the potential user base in the deep-sea mining industry, future users of the proposed new sensor could come from the ocean science, oil and gas, sediment transport, and coastal engineering sectors. An instrumentation package that can measure particle size, concentration and settling velocity in real time or near real time would be potentially attractive for scientists, managers and engineers in these sectors. For further information, contact Sequoia Scientific at: info@sequoiasci.com.

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**References**

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