

Susumu Honjo (Area of photo is 1.1 x 1.5 millimeters)

One of the first photographs of a sediment trap sample shows cylindrical fecal pellets and other aggregates, planktonic tests (round white objects), transparent snail-like pteropod shells, radiolarians, and diatoms. The first deep-sea sediment trap was recovered on February 20, 1977, from 5,367 meters on the Sohm Abyssal Plain in the Sargasso Sea. As Sus Honjo and colleagues viewed the samples under a microscope, they confirmed a theory and began to solve the mystery of how benthic animals receive nourishment from surface waters in “packages” that descend through the water column.

## Marine Snow and Fecal Pellets: The Spring Rain of Food to the Abyss

Until about 130 years ago, scholars believed that no life could exist in the deep ocean. The abyss was simply too dark and cold to sustain life. The discovery of many animals living in the abyssal environment by Sir Charles Wyville Thompson during HMS *Challenger's* 1872–1876 circumnavigation stunned the late 19th century scientific community far more than we can now imagine.

Major questions immediately emerged: How do deep sea animals obtain food so far from the ocean's surface where plants, the base of the ecosystem, grow? Do they all just wait until a whale corpse is occasionally delivered to the abyss? These questions were only answered fairly recently.

Twentieth century progress in oceanography resulted in further confusion. Microscopic particles suspended in the water column seemed so small and light that it was believed they should take hundreds, perhaps thousands, of years to

settle through the water column. And what happens to labile (unstable) matter, particularly organic particles from dead, broken plankton cells? Scientists could not understand why coccoliths, the delicately architected calcite shells of phytoplankton, only several micrometers in size, were preserved on the deep ocean floor just beneath the area where they were produced. Why were they not carried far from their source by currents, and how could they even exist there when chemistry clearly indicates they should be dissolved during their several-century trip to the bottom?

A WHOI experiment in the deep Sargasso Sea two decades ago shed light on this century-old question. Ship-board observation of the first successfully recovered sediment trap samples from 5 kilometers deep revealed that particles originating in the euphotic (light) zone aggregate: The fine, light particles do not settle individually but are

repackaged into larger particles that settle to the deep sea at a much greater speed. Among the Sargasso Sea aggregates, we found an abundance of fecal pellets from upper ocean zooplankton. Viewing one of the fecal pellets under an electron microscope, I was fascinated to find it full of perfectly preserved coccoliths and undigested, many-celled organelles. Some oil droplets were obviously much lighter than seawater!

Because filter-feeding zooplankton are concerned only with the size of their food and graze phytoplankton almost indiscriminately, indigestible coccoliths and diatom frustules are concentrated in their fecal pellets. Many zooplankton fecal pellets are covered with a thin coating material. Although individual particles sink very slowly or are even buoyant, when they are bundled into a tight package and ballasted with particles of calcite—one of the densest materials produced in the ocean—they sink as rapidly as 100 to 200 meters a day.

Soon after World War II, scientists at Hokkaido University built an early submersible, named Kuroshio, to dive in the ocean north of Japan. Wherever they beamed a search light, they saw “snowflakes” dancing from the disturbance caused by the submersible. K. Kato and N. Suzuki named this phenomenon “marine snow.” More recently, the author and former MIT/WHOI Joint Program student Vernon Asper, now at the University of Southern Mississippi, have worked with WHOI engineers to construct an optical instrument to measure the size and density of marine snow all the way down through the water column. Cindy Pilska, who did her Ph.D. research at WHOI while a Harvard University Student and is now at the University of Maine, has found that fecal pellets alone cannot transport the amount of organic carbon known to exist in the deep ocean, and that the density of suspended particles in the water

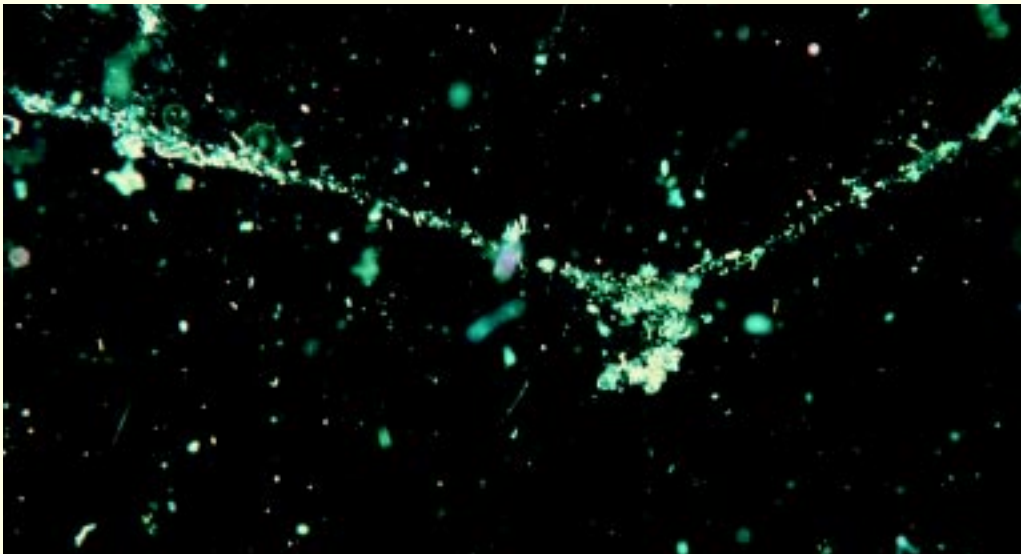
column remains at a steady state. One hypothesis is that the vertical transport mechanism may be the combination of rapidly descending fecal pellets and aggregates as well as individually settling, relatively large particles such as planktonic foraminifera and diatoms. All of these together form “marine snow.”

Many marine snow “flakes” are sticky and fibrous like a crumbled spider net, and particles easily adhere to them, forming aggregates. An aggregate begins to sink when it attracts fecal pellets, foraminifera tests, airborne dust, and other heavier particles. As it descends, more suspended particles are added, making the aggregate even heavier and thus faster moving. An aggregate may break apart, spilling its contents into the water, but soon the spilled particles are picked up or “scavenged” by other falling aggregates. Thus aggregates are reorganized constantly with individual particles jumping on and off them before they arrive on the ocean floor. Meanwhile, a large portion of the organic matter in marine snow is recycled by microorganisms and upper and middle water column animals who again generate fecal pellets.

The removal of carbon from the ocean’s euphotic layer to its interior carbon “sink” is critical to the process that keeps Earth’s carbon cycle in order. We have learned that the speed of carbon settling to the ocean’s interior is very rapid: Particles can travel from surface waters to the abyss in only a few days or weeks (see Arabian Sea article on page 24). Nature accomplishes this process ingeniously by wrapping labile organic carbon up in a package and ballasting it with calcium carbonate, which causes it to settle at high speed to the deep ocean environment.

Sir Charles Wyville Thompson would have been happy to know this!

—Sus Honjo



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**A component of “marine snow” was captured at 55 meters in Monterey Bay, California, by a light scattering optical device that also counts and estimates the size of individual particles contained in a cubic meter of water. The view includes individually settling fecal pellets as well as amorphous aggregates that look like white flakes, which are a half to several millimeters in diameter and often host a large number of fecal pellets. Zooplankton produce the weblike material that helps agglutinate particles to form aggregates.**