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Diving for the Sedimentary Record of Multiyear Sea Ice

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How is sediment transported to the seafloor along coastlines where the sea ice rarely melts? Are there distinctive characteristics of the resulting deposits that label them as accumulating in this setting that is so sensitive to climate change?

Our project—aimed at determining the sedimentary, bioturbation, and taphomomic (fossilization) processes in Explorers Cove, Antarctica (Figure 1), and characterizing the resulting sedimentary record—depends on material collected by divers who descend through holes melted through the sea ice. Our dive team retrieved experiments deployed for two years to assess the rates of bioturbation and sedimentation and to determine the rate of dissolution of scallop shells and brittle star ossicles, the high-magnesium calcite components of the animal's endoskeleton. The divers also collected shallow cores (< 1 m long), made video transects, and took photos of quadrats, allowing quantitative assessment of sediment disturbance, especially bioturbation, and abundance of epifaunal animals (and thus abundance of skeletal remains), as well as the abundance of outsized clasts (Figure 2).

The emerging picture suggests that poorly sorted sediment, mainly sand, is transported to the seafloor primarily via ephemeral meltwater streams and deltaic processes (Murray et al., 2012). Similarity in grain size distributions of sediment from the delta and from the seafloor indicates the importance of the fluvial/deltaic system in delivering sediment to the seafloor in spite of the small stream discharge and temporal restriction of flow to a few summer months at most.

Explorers Cove is located at the mouth of Taylor Valley, a sediment-rich, ice-free valley where wind transports sediment onto the sea ice (Figure 1). Within a hundred meters offshore, the sea ice sediment typically is coarser than that on the underlying seafloor. This grain size difference suggests that transport through the sea ice is not the dominant mode of sediment delivery, although divers observed sediment streaming downward through cracks in the sea ice; perhaps during rare years of total sea ice melting, sea ice sediment is deposited offshore as the ice is blown further out into McMurdo Sound.

The multiyear sea ice reduces light and thus photosynthesis, and also dampens waves and inhibits sediment resuspension by physical processes. This unusually quiet, relatively oligotrophic, Explorers Cove setting harbors giant tree forams and other agglutinated forams typically found at bathyal and abyssal depths (e.g., Bowser et al., 1995; Gooday et al., 1996). In very shallow local waters, platelets of anchor ice form in the sediment and extend upward into the water column; clams, starfish and urchins nestle among the plates of ice (Figure 2). In the absence of anchor ice, the epifauna, particularly scallops and brittle stars, churn the upper centimeters of sediment at a rate that exceeds the rate of sedimentation or physical reworking (Figure 3). Scallops typically swim using water jets as an escape mechanism, but *Adamussium colbecki*, the Antarctic scallop in Explorers Cove, also "squirts" while barely moving (Stockton et al., 1984). This squirting resuspends sediment, making it available to the suspension-feeding scallop, and forms divots that are abundant on the seafloor (Figure 2; Broach et al., 2011; McClintock et al., 2010). The common brittle star *Ophionotus victoriae* disrupts the sediment by burying itself shallowly, by plowing through the sediment, and by gouging the sediment as it walks. Like *Adamussium colbecki*, this brittle star leaves no distinctive biogenic structures indicating the identity of the bioturbator or that the sediment was homogenized by biogenic rather than physical processes.

Scallops and brittle stars are two of the three most common animals in Explorers Cove (e.g., Cummings et al., 2006), yet shell fragments and ossicles are rare in the shallow cores that divers have retrieved from there. In fact, there is less calcareous skeletal material observed in the cores than is predicted

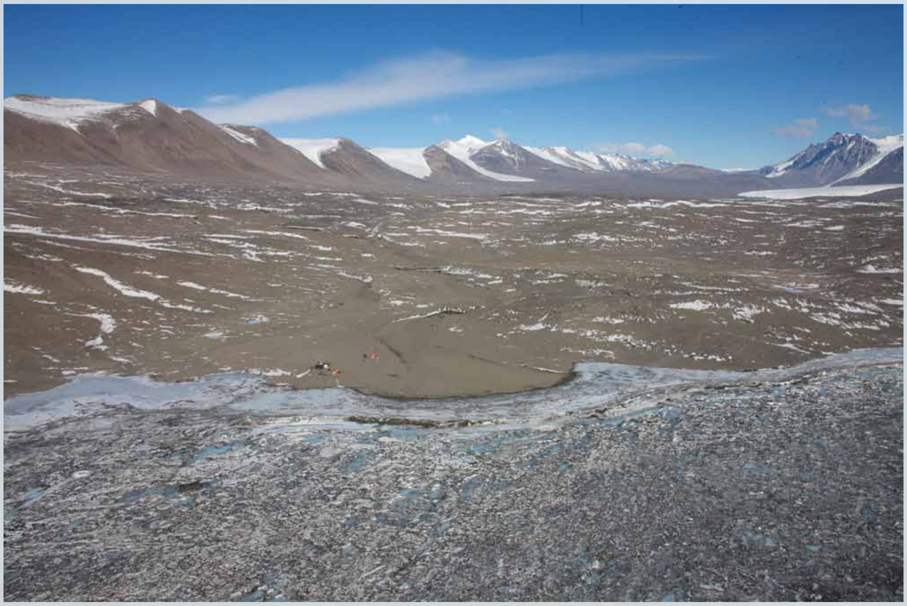

Figure 1. Aerial view of Explorers Cove (–77.563368, 163.58632) at the mouth of Taylor Valley, Antarctica, showing the delta built by the ephemeral Wales Stream, the moat that melts during most (if not all) summers, and the sediment accumulated on the sea ice in the nine years since its last melting.

Figure 2. Diver-emplaced 1 m^2 quadrat and video transect (white tape extending across entire image) on seafloor in Explorers Cove. The starfish, scallops, sea urchin, and nudibranch in the quadrant are perched on anchor ice extending upward from the sediment. The 1 m long ribbon-like form in the background is a predatory nemertean worm.

by models based on brittle star and scallop densities and life history strategies, suggesting that the calcite may dissolve in the cold water. Results of dissolution experiments in which brittle star ossicles were left on or near the seafloor support this scenario; recovered ossicles showed significant dissolution after two years (Walker, 2011). The low rate of sedimentation and the continual resuspension of sediment by animal activity keep ossicles and shells near the sediment-water interface where dissolution is most likely to occur.

The sedimentary record accumulating in shallow water under multiyear sea ice consists of massive sand with very rare fragments of shells and ossicles, yielding scant evidence of the bioturbators that homogenized the sediment. This investigation—which depended on samples collected by divers—provides an actualistic model for recognition of subsea ice marine facies that can be applied to interpretation of cores deposited in climatically sensitive polar glacial marine environments.

Figure 3. Photo of Explorers Cove seafloor (~ 20 m depth) taken by a diver. The Antarctic scallop in right foreground is in a divot it excavated by rapidly expelling water. Above the scallop is the abundant and active brittle star *Ophionotus victoriae*; these two animals continually disrupt the upper few centimeters of sediment. A white nudibranch is above the brittle star. To the left of the scallop is a pencil urchin with spines encrusted by a white sponge.

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