Bioturbation in Lower Cambrian Siliciclastics: Investigating the Early Evolution of Biogenic Sedimentary Fabrics

During the Neoproterozoic-Cambrian transition, bioturbation became more plentiful, complex, and physically disruptive as a direct consequence of the Cambrian radiation of marine invertebrates. This increase in biogenic sediment disturbance transformed substrates and dramatically expanded available ecospace. In particular, microbial mats, which were ubiquitous on Proterozoic seafloors, virtually disappeared from open marine environments by the end of the Cambrian Period. Seilacher and Pflüger (1994) proposed a scenario in which benthic metazoans acquired evolutionary adaptations during the Cambrian explosion that allowed them to burrow vertically through microbially-bound sediments. As bioturbation depth and intensity increased, the layered structure of the microbial mats was disrupted, and the substrate became softer and more suitable for colonization at greater depths. The Cambrian transition from microbial-mat-dominated to more typically-Phanerozoic substrates has been termed the “agronomic revolution” (Seilacher and Pflüger 1994) to emphasize the active role that benthic metazoans played in shaping substrate conditions. In the wake of the agronomic revolution, mat development was relegated to marginal environments, and the substrate took on characteristics more typical of the Phanerozoic, notably improved nutrient distribution and an indistinct sediment-water interface. Organisms unsuited for the new substrate conditions either adapted or became extinct. These and other ecological and evolutionary effects of the agronomic revolution are reflected in the record of body and trace fossils and have collectively been termed the “Cambrian substrate revolution” (Bottjer et al. 2000).

Understanding how the agronomic revolution unfolded is challenging due to the nature of the Lower Cambrian body fossil record. Mineralized skeletons had not yet become common among benthic metazoans in the Early Cambrian, and the remains of soft-bodied organisms are not preserved in most Lower Cambrian deposits. Lower Cambrian Lagerstätten, such as the Chengjiang Biota in southern China, offer rare glimpses of the diverse array of soft-bodied forms that inhabited Early Cambrian marine environments. However, the best and most widely available source of information concerning the behavioral patterns of Early Cambrian benthic metazoans is the ichnofossil record. Ichnofossils, or trace fossils, are the preserved products of animal behavior and do not require exceptional conditions for preservation. Studying the distribution and abundance of specific types of trace fossils in Lower Cambrian rocks provides the most accurate picture available of the role soft-bodied organisms may have played in altering Early Cambrian ecosystems.

The overall goal of this project was to determine how and to what extent benthic marine organisms altered the sedimentary fabric of shallow subtidal siliciclastic substrates beginning in the Early Cambrian, when significant bioturbation first evolved. A preliminary investigation was undertaken of bioturbation in siliciclastic shallow subtidal marine strata of the Lower Cambrian succession in the White-Inyo Mountains, California, USA. To place the resulting data in a broader paleoenvironmental context, fieldwork was conducted in the Lower Cambrian succession of Death Valley, California-Nevada, which represents a proximal equivalent of the White-Inyo Mountains succession.

At each locality in the Death Valley region, numerous one-meter-thick intervals of outcrop were studied. Sedimentary characteristics and ichnofabric indices (Droser and Bottjer, 1986) were logged from vertical exposures, and bedding plane bioturbation indices (Miller and Smail, 1997) were recorded from bedding planes according to observed bioturbation intensity. In addition, the presence of individual ichnogenera and variations in sedimentary characteristics were recorded. To provide a quantitative assessment of bioturbation intensity, photographs of studied bedding planes were analyzed digitally using a newly-developed grid-based technique, the intersection method, to calculate the percentage area of each surface that contains bioturbation. Samples collected at 10cm intervals from one-meter-thick studied sections of outcrop were processed using x-radiography and petrography to obtain additional information concerning ichnofabric and sedimentary features. IAS funding supported the preparation of thin sections from all Death Valley area samples and a portion of the fieldwork in Death Valley.

Quantitative bedding plane data from the Lower Cambrian succession in the Death Valley region are broadly distributed but also display a robust cluster between 5-25 percent bioturbation. In addition, the maximum percentage of bedding plane bioturbation increases up-section. Such a pattern can be expected from a Lower Cambrian bioturbation dataset, which reflects both the early stages of benthic community development and the onset of the agronomic revolution. Simple horizontal *Planolites*-type burrows are the most common identifiable trace fossils on bedding planes of the distal lower and upper members of the Wood Canyon Formation. Unexpectedly, however, infaunal bioturbation is visible within x-radiographs and thin sections of samples collected a few meters above the Precambrian-Cambrian boundary from the lower member of the Wood Canyon Formation. Thus, bioturbation-induced sediment disruption was already imparting an effect on shallow marine siliciclastic substrates early in the Early Cambrian in the Death Valley region.

Vertical bioturbation, primarily in the form of *Skolithos* traces, dominates the high-energy nearshore and shoreface deposits of the middle member Wood Canyon Formation and Zabriskie Quartzite. However, vertical burrows are also abundant in the more distal, heterolithic upper member of the Wood Canyon Formation. The latter observation suggests that early adaptations to burrowing vertically into finer-grained material may have originated in shallow marine environments in the Early Cambrian.

Plots of bedding plane bioturbation index data from the Lower Cambrian successions in the Death Valley region and the White-Inyo Mountains both resemble bell curves. However, significant facies-related differences are expected to emerge when quantitative bedding plane data from the two successions are compared. Re-analysis, using the intersection grid method, of all digital bedding plane photographs from the White-Inyo Mountains succession is nearing completion. A manuscript is being prepared based on the results of this work.

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Sincerely,

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