KECK GEOLOGY CONSORTIUM

21ST KECK RESEARCH SYMPOSIUM IN GEOLOGY SHORT CONTRIBUTIONS

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Sedimentary Environments and Paleoecology of Proterozoic and Cambrian "Avalonian" Strata in the United States
Mark McMenamin (Mount Holyoke College) and Jack Beuthin (U of Pittsburgh, Johnstown)
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Development and Analysis of Millennial-Scale Tree Ring Records from Glacier Bay National Park and Preserve, Alaska (Glacier Bay)
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The Biogeochemistry and Environmental History of Bioluminescent Bays, Vieques, Puerto Rico
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ENVIRONMENTAL ANALYSIS OF THE NEOPROTEROZOIC CAMBRIDGE ARGILLITE, BOSTON BASIN, MASSACHUSETTS

KENNETH O'DONNELL: Beloit College
Research Advisor: Carl Mendelson

INTRODUCTION

The Cambridge Argillite (CA) of the Boston Bay Group accumulated between 570 and 542 million years ago as part of the island-arc Avalonia, which collided with eastern North America in the early Paleozoic. The CA contains hundreds of *Aspidella terranovica*, an enigmatic circular body fossil and member of the soft-bodied Ediacaran biota. This unit is therefore essential to understanding the living habits and habitat of *Aspidella*. Here I attempt to construct the depositional history of the CA and discuss environmental implications for Ediacaran life.

The CA is a 2- to 7-km-thick succession of interlaminated black shale and sandstone (McMenamin, 2004; personal observation; Fig. 1). Socci and Smith (1990) developed facies models for the Boston Bay Group, interpreting the CA as a deep-water, low-density turbidite. They focused on the underlying Roxbury Conglomerate, overlooking (in my opinion) the variety of fine-grained facies present in the CA. Bailey (2002) supported turbidite deposition on a distal pro-fan delta slope. However, features from a newly described outcrop reported herein and recent studies in clay deposition suggest different environmental constraints on the CA, and may significantly change our understanding of the environmental context of certain members of the Ediacaran biota.

METHODS

Field work was conducted at Hewitt's Cove, near Boston, Massachusetts, at a previously undescribed outcrop, here called the K-Locality (See Lavarreda, this volume). The 17 m outcrop was divided into nine informal units (horizons). Horizon boundaries were created according to visible differences in outcrop, such as gradational contacts and erosion. Preliminary measurements were conducted with a Brunton compass and Jacob's Staff. Samples were catalogued by their horizon and distance above horizon base (e.g., K1/1.25 = K1 horizon, 1.25 m above the base of K1).

Microfacies analysis was performed on slabbed and thin-sectioned samples on large format (~ 7.5 × 5 cm) slides at 30 μm thickness using dissecting and petrographic microscopes. Small format (2.5 × 4 × 0.05 cm) thick-sections were observed using JEOL JSM-5900LV SEM backscatter detection and energy dispersive spectrometry to detect organic material and very fine-grained features.

RESULTS

Microfacies and Stratigraphic Analysis

Flügel (1982) formally identified microfacies as all sedimentological and paleontological criteria classifiable in thin-sections, slabs, and hand samples. Sedimentary features found at the K-Locality were divided into fine-grained (clay to fine silt) and coarse-grained (coarse silt to sand) categories. These categories were subdivided according to sedimentary structures and the nature of stratal contacts (Table 1). The CA at the K-Locality is dominated by interlaminated black shale and silt-sandstone (Fig. 1). Laminae are any strata less than 1 cm thick (McKee and Weir, 1953). Microlaminae are defined here as very thin (< 0.5 mm), laterally continuous layers distinguished on the basis of particle size and composition.

At the base, K1 exhibits sharp planar to wavy lami-

Table 1. Microfacies in the Cambridge Argillite.

Category	Subcategories	Microfacies	Notation	Associated Processes (Reineck & Singh, 1980; Stow & Shanmugam, 1980; Schieber, 2007)
Coarse-grained	Sedimentary Structures	Structureless	C_s	Turbidity current (T_7); debris flow; fast dewatering of sediments
		Normal Grading	C_g	Turbidity current (T_0-T_6); suspension settling; periodic silting of delta distributaries; waning current activity on intertidal flats
		Cross-bedded	C_{md}	Tidal deposition; turbidity current (T_1 if cross-laminated sandstone with fading ripples); fluctuating flow in fluvial deposition; wave action
	Stratal Contacts	Lenticular	C_l	Tidal deposition; Turbidity current (T_0); wave action
		Wavy	C_w	Tidal deposition; wave action
		Uneven	C_{sc}	Turbidity current (T_0); unequal loading; liquefaction; differential deposition; tidal deposition; fluvial deposition
		Planar	C_p	Tidal deposition; Turbidity current (T_3); varve deposition
Fine-grained	Sedimentary Structures	Normal Grading	F_g	Turbidity current (T_0-T_6); suspension settling; periodic silting of delta distributaries; waning current activity on intertidal flats
		Structureless	F_s	Turbidity current (T_7); debris flow; fast dewatering of sediments
		Cross-laminated	F_c	Clay floccule deposition; tidal deposition;
		Microlaminated	F_m	Tidal deposition; suspension settling; varve deposition
	Stratal Contacts	Planar	F_p	Tidal deposition; Turbidity current (T_3); varve deposition
		Wavy	F_w	Tidal deposition
		Uneven	F_{sc}	Turbidity current (T_0); unequal loading; liquefaction; differential deposition; tidal deposition; fluvial deposition
Other features	Lonestone	Dropstone	L	Iceberg-rafting; glacial deposition
	Deformed	Convoluted	D	Turbidity current (T_1, T_5); differential liquefaction during seismic event; debris flow; shear action from currents; fluvial deposition and flooding
Other features	Thick-thin layers	Thick-Thin pair	T	Tidal deposition; rhythmic deposition; varve deposition
	White silt layer	White silt	W	Microbial mat diagenesis; slumping; low-density debris flow; turbidity current (?; T_1)
	Opaque Layer	Opaque	O	Microbial mat decomposition; differential deposition from varying grain sizes and compositions

nae and intermittent microlaminae bundles. Low-angle cross-laminae occur, but most laminae are parallel. Convoluted white silt layers occur regularly. Overlying one silt layer, laminae are inclined 15°. Lonestones (3 – 8 cm) occur toward the top of the horizon.

K1 grades into K2, a laminated argillite with lenticular silt/sand laminae. Wavy and scour contacts are most common in K2, with some planar contacts. Load casts and mud-drapes are common, with some lonestones (3 – 8 cm) present.

K2 weathers into K3, which exhibits common mud drapes and planar to wavy contacts with some scour and sparse thin sand beds. Low-amplitude climbing ripples and low-angle cross-laminae (< 2 mm) also occur.

The K4 horizon exhibits planar thick (4 – 6 mm) clay and thin (1 – 2 mm) silt/sand laminae. The base and top are sharp; the boundary with K5 is uneven. Layers are typically microlaminated and rhythmic. Thick coarse silt/sand laminae (~ 5 mm) occur with common argillite clasts and planar contacts. White silt layers occur somewhat regularly.

Alternating thin clay and silt/sand beds compose the K6 horizon. The base is sharp and uneven, with a gradational top. Load structures and scour are common, and sand beds grade into clay and exhibit indistinct wavy and cross-lamination. Overlying K6, K7 comprises highly convoluted, even laminae with common microlaminae. Argillaceous lonestones (3 – 8 cm) occur. The top of K7 is truncated.

The K8 horizon has a sharp base and erosional top characterized by a thin sand bed (~ 2 cm) with a

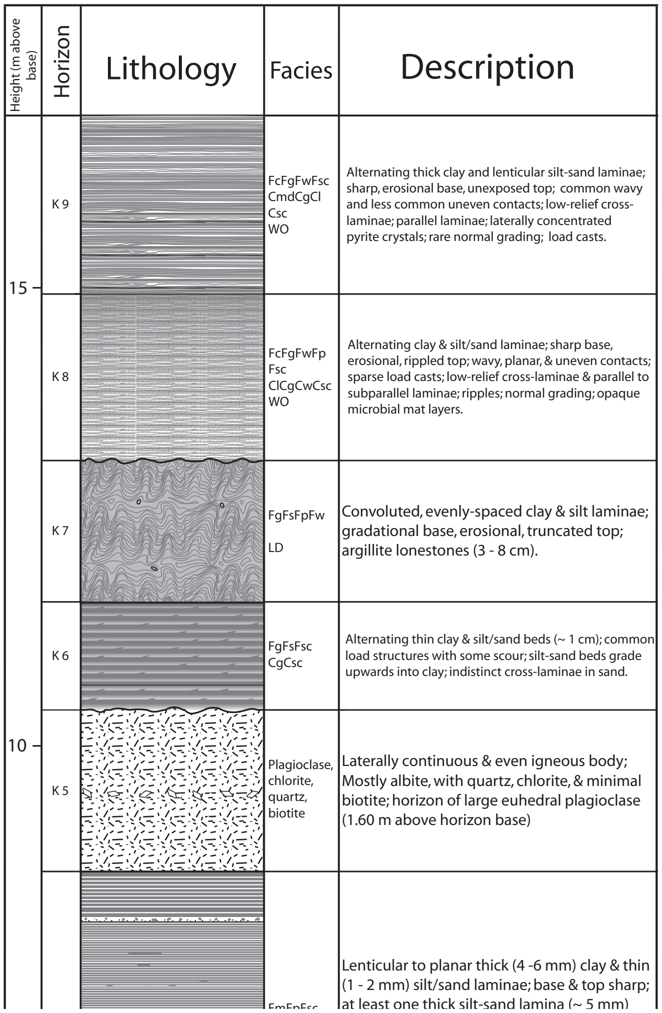

Figure 1. Stratigraphic column of K-Locality.

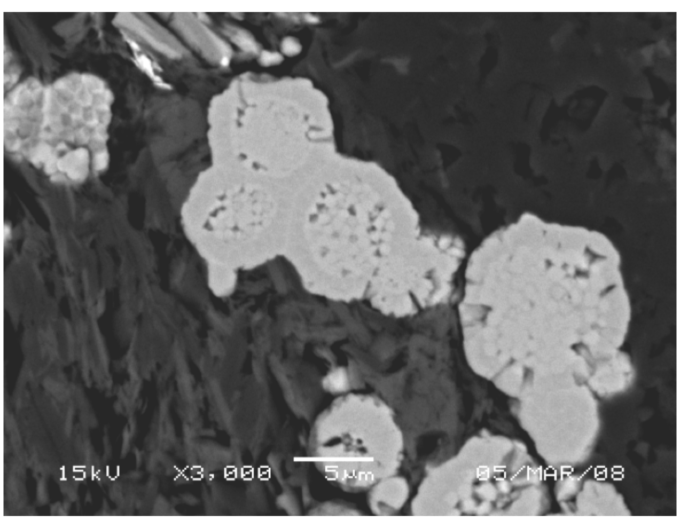

Figure 2. Fused pyrite framboids from K3 horizon could indicate reoxygenation of sediments after deposition.

rippled top contact. Wavy and uneven contacts are common within this horizon, with some planar contacts. Low-angle cross-laminae, low-amplitude ripples, and parallel to subparallel laminae dominate the horizon with some sparse normal grading.

The K9 horizon has a sharp erosional base; the top is not exposed at Hewitt's Cove. Parallel wavy contacts are common. Load casts and mud-drapes are common in silt/sand lenses, as are low-angle cross-laminae. Normal grading is sparse, but regular.

Microscopic Microfacies Analysis

In all horizons except for K4, K5, and K6, framboidal pyrite occurs. Average mean framboid size below K5 ranges from 4 – 8 µm, whereas framboids above K6 are larger, typically 10.07 ± 1.39 µm, comprising sub-micron-size euhedral octahedral crystals. Framboids found in K3 are overgrown, typically fused by radial overgrowths (Fig. 2). Euhedral pyrite crystals (5 – >400 µm) occur with silica inclusions. Other minerals found include monazite and zircon (< 20 µm).

DISCUSSION AND CONCLUSIONS

The models for low-density turbidite facies are tenuously supported when compared to microfacies of the CA. Common scour and loading, micro-cross and parallel laminae, infrequent fading ripples, and normal grading could constitute a possible Stow sequence, but none of these facies occur in a succession that truly models a Stow sequence (Stow and Shanmugam, 1980; Fig. 3). Socci and Smith (1990) invoke suspension settling after turbidite events to account for numerous shale intervals in the CA.

However, clay deposition does not depend on slack-water conditions. Schieber (2007) was able to form significant clay deposits in flow conditions of up to 25 cm/s using kaolinite clay. Schieber (1990) and de Raaf et al. (1977) both described ancient storm deposits composed of black shale.

Lonestones also provide strong evidence for glacial influence on deposition. Dropstones present in K1,

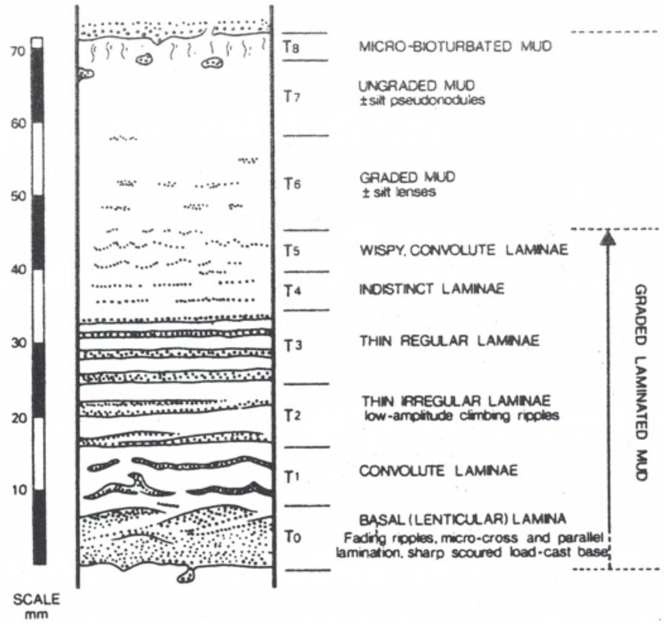

Figure 3. Facies sequence for low-density turbidites. Adapted from Stow and Shanmugam (1980).

K2, and K7 are not necessarily depth indicators, but shorefast sea ice could have trapped icebergs close to shore (Dowdeswell et al., 2000). Since the CA was deposited at the conclusion of a major glaciation, perhaps melting ice released dropstones and produced fine-grained laminae from suspension settling close to shore (Ó Cofaigh and Dowdeswell, 2001). Low-relief cross and parallel laminae and sharp wavy to planar contacts could indicate reactivation surfaces in fluctuating flow conditions. Horizons K1 – K4, K8, and K9 all exhibit concave-upward mud drapes. Whereas mud drapes are not accounted for in turbidite facies, they do occur in tidal and deltaic environments. Reactivation surfaces and regularly occurring thick-thin laminae could indicate a tidal environment (Kvale, 1998). In deltaic environments, flow may vary seasonally. Glacial deposition from iceberg rafting could be responsible for the unclear rhythmicity that occurs in these horizons.

The K4 horizon contains possible storm-deposited laminae: argillite clasts and low-scour surfaces could be caused by mild storms. The sand layer contains subangular coarse silt- to fine sand-sized grains. Fading ripples and possible rip-up clasts in other laminae could also be storm indicators. Intermittent storm events could also disturb or erase a tidal signature.

According to energy dispersive spectrometry, the white silt laminae contain iron, aluminum, silicon, and phosphate. According to Schieber et al. (2000), microbial mats in silica-rich water can precipitate silt-sized silica derived from opaline skeletons of benthic plankton in early diagenesis. Guo et al. (2007) discussed chert layers forming from biogenic silica precipitated from siliceous plankton above the redox boundary in the Liuchapo chert and Jiumenchong Formation of the Sangtao Group, which has been dated to the Ediacaran-Cambrian boundary. Poorly preserved structures that could be phosphatized microbes are also present (Fig. 4). These hints of biologic activity are consistent with a shallow-water interpretation, although there is no compelling evidence for photosynthetic microbes.

Detrital monazite and authigenic framboidal pyrite are also present. Detrital monazite is commonly associated with fluvial and beach environments. Though very fine-grained, it is possible that the monazite indicates a nearshore environment. The framboidal pyrite could be a significant paleo-oxygenation indicator (Wignall, 1998; Hawkins and Rimmer, 2002). Wilkin et al. (1996) state that wide size distributions could indicate formation at, or just below, a fluctuating redox boundary. Framboid overgrowths below K5 could indicate the reoxygenation of sediments after deposition (Schieber,

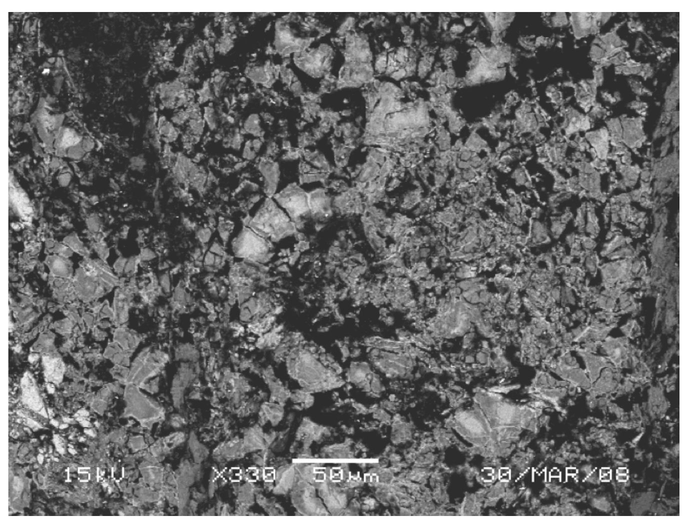

Figure 4. Unidentified segmented structure present in weathered phosphate.

2008). The lateral concentration of many framboids in K3 and K8 could suggest microbial mat activity between unconsolidated sediments, which could provide possible support for the Death Mask theory of Ediacaran preservation (Gehling, 1999).

A shallow-water interpretation of the Cambridge Argillite may require a re-evaluation of the habitat of certain Ediacarans (e.g. *Aspidella*). While there is evidence to support a deep-water, low-density turbidite interpretation of the CA, there is clearly evidence that supports alternative interpretations. More samples from the CA must be gathered and studied directly in order to understand its depositional environment.

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