

KECK GEOLOGY CONSORTIUM

21ST KECK RESEARCH SYMPOSIUM IN GEOLOGY SHORT CONTRIBUTIONS

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Dr Andrew P. de Wet, Editor
Keck Director
Franklin & Marshall College

Keck Geology Consortium
Franklin & Marshall College
PO Box 3003, Lancaster Pa, 17603

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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)
Students: Evan Anderson, Anna Lavarreda, Ken O'Donnell, Walter Persons, Jessica Williams

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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JOHN D. BEUTHIN: University of Pittsburgh, Johnstown

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Research Advisor: C. Frederick Lohrengel II

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Keck Geology Consortium
Franklin & Marshall College
PO Box 3003, Lancaster Pa, 17603
Keckgeology.org

A PETROGRAPHIC AND SEM-EDS ANALYSIS OF *ASPIDELLA*-BEARING SILTSTONES AND SLATES OF THE CAMBRIDGE ARGILLITE, BOSTON BAY GROUP, MASSACHUSETTS

EVAN PELZNER ANDERSON: University of Mary Washington
Research Advisor: Jodie L. Hayob

INTRODUCTION

Argillites within the Cambridge Formation of the Boston Bay Group have been known for quite some time to contain ring-like structures, generally interpreted to be body fossils of the Vendian organism *Aspidella* (Billings, 1872; Clark, 1923; Bailey & Bland, 2001; McMenamin, 2004). Cross-sections made through these ring structures have thin, dark, seemingly opaque laminations that usually run parallel to bedding, forming broad planar surfaces. Some of these dark layers demarcate the fossil surfaces, but others do not. In either case, the material of the thin dark layers has been interpreted to be a preserved pyritized biomat (Baily & Bland, 2001) which entombed the *Aspidella*, or was perhaps the organic remains of the fossil itself.

The interpretation of the dark layers as pyritized biomats is not supported by data obtained in the present study, which began in the summer of 2007 when fresh float and in situ samples of rock bearing *Aspidella* were collected from the southern side of Boston Harbor. Energy dispersive spectrometry (EDS) with a Scanning Electron Microscope (SEM) reveals that the dark laminae contain no sulfur, unlike what would be expected from a pyritized layer. Further analysis of these rocks revealed the presence of small framboids, possibly of organic origin.

The focus of the current study is a mineralogical and petrological investigation of these rocks to determine the composition and distribution of the dark laminae, ring structures, framboids, and the surrounding sediment and matrix. We also attempt to constrain the extent to which the rocks were altered at elevated pressures and temperatures during burial.

METHODS

Three rocks were studied in detail for this investigation. The first rock is an argillite float (BB-NB-A) that was found at Nahant Beach. This rock is almost certainly Cambridge Argillite due to the presence of numerous small ring-structures on its surface. The second rock, also a float, is a slate (BB-HC-C) containing ring-structures that was collected from a beach on Slate Island, just to the north of Hewitt's Cove in Boston Harbor. The third rock, an argillite labeled BB-HC-A, was collected in situ from rocks containing numerous ring structures of varying sizes at Hewitt's Cove at a site known as the Bland Locality. All three rocks were slabbed and thin-sectioned. A total of 17 slides were returned.

Petrographic analysis was conducted using a Nikon petrographic microscope with both transmitted and reflected light capabilities at magnifications ranging from 50x to 400x. Selected thin sections were further analyzed with a Hitachi S3400N Variable-Pressure SEM. Elemental content was analyzed with EDS using the INCA program by Oxford Instruments. Acquisition time was 80 seconds for all spectra. The slides were uncoated and observed in variable pressure mode at 60 Pa at 20 to 30 kV.

RESULTS

Petrographic analysis reveals the sediment from all three localities to be bimodal in nature. The first sediment type is a siltstone rich in very fine sand to coarse silt-sized quartz (interpreted to be igneous in origin) and plagioclase clasts. Sericite and opaque, or seemingly opaque, minerals are also present.

About 50% of the quartz grains have altered to chert, and many of the feldspars have altered to sericite or undetermined clay minerals. EDS analysis indicates that the matrix is a combination of chlorite and iron-rich clay or phengite, of medium silt size or smaller. The second sediment type is a mudstone comprised of clays and chlorite that are medium silt size or smaller. Both the silt and the mud sediment types have a variety of accessory minerals, such as rutile and titanite (sphene), scattered throughout, many of which appear to be weakly reflective.

Cambridge Argillite Float, Nahant Beach, BB-

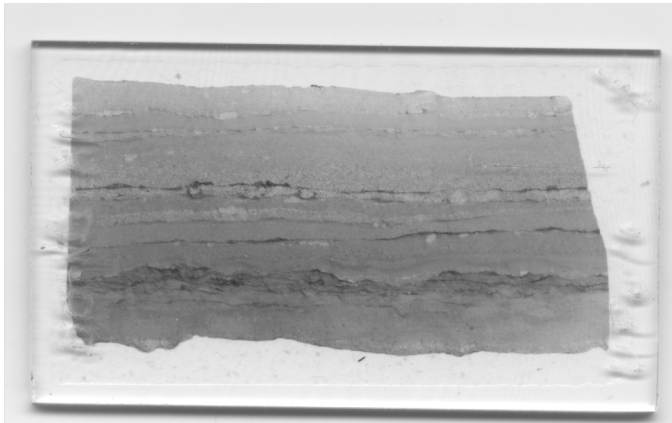


Figure 1. Slide BB-NB-A1c, a cross section through the Cambridge Argillite float found at Nahant Bay. Note the wavy, at times touching and interbraiding, dark laminae in the bottom half of the thin section. The slide is a standard 22mm x 40mm thin section.

NB-A

Two thin sections were made of this sample, both of which are argillite dominated by the mudstone-type matrix (Fig. 1). Silty laminations, where present, usually grade into mud at the top of the laminae. Small lenses of silt are also present, as well as lenses of calcite. In one distinct 2-3 mm thick layer, numerous dark laminae of varying thicknesses were observed that interbraid with one another. Numerous crystals of chlorite are present, displaying characteristic anomalous blue birefringence. Reflected light microscopy revealed a pale yellow, reflective mineral comprising segments of some of the dark layers. An estimate of the composition of these reflective segments has not been determined because

neither of the slides have been analyzed with SEM-EDS yet.

Hewitt's Cove Argillite, BB-HC-A

A total of 11 thin sections were made from the in situ sample BB-HC-A, including many with *Aspidella* cross-sections. These cross-sections were cut both parallel and perpendicular to the fossil's long axis. There are approximately equal amounts of silt and mud in these samples. Some laminae are dominated by silt, some by mud, and others grade upward from silt into mud. Usually, *Aspidella* are found on silty beds directly overlain by muddy laminae (Fig. 2). The distribution of pale yellow reflective minerals was similar to BB-NB-A, with small segments of some dark laminae exhibiting reflectivity. Chlorite crystals are present, but in smaller numbers than in BB-NB-A, and BB-HC-A contains more sericite. The matrix is composed of chlorite and iron-rich phengite. Calcite lenses are also present, usually in association with a dark lamina. Pyrite framboids were observed under the petrographic microscope

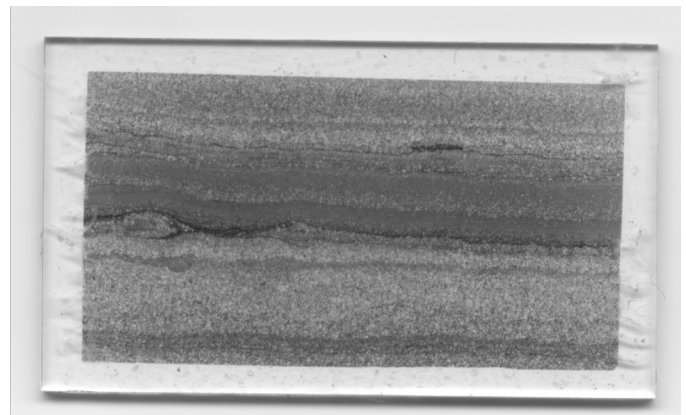


Figure 2. Slide BB-HC-A4e, a cross section taken perpendicular to the long axis of an *Aspidella* from the Hewitt's Cove Argillite. The *Aspidella* is visible here as the double lens structure in the center left of the image. The ring-structure lies on top of a coarser silty sequence, and appears to push up overlying fine sequences. Scale is the same as in Figure 1.

at magnifications of 100x or higher. This was a significant finding and will be discussed in more detail in the section "Framboids."

EDS analysis demonstrated no significant difference in composition between the non-reflective portions of the dark laminae and the matrix, although more investigation is needed. Visual inspection of Figure 3 shows that the reflective portion of the dark lamina (e.g., bright contrast on center left side of image) is contiguous with the non-reflective, clay-rich portion of the same layer. The pale reflective mineral present in the dark layer shown in Figure 3 is a silicate that contains cerium, neodymium, and possibly lanthanum, and thus is likely allanite. Accessory minerals present in the Hewitt's Cove Argillite, as suggested by EDS, include rutile, ilmenite, zircon, and apatite.



Figure 3. A dark lamina in BB-HC-A6a from the Hewitt's Cove Argillite as seen in a back-scattered electron (BSE) image acquired with a VP-SEM. The brightly contrasting minerals in the center of the photograph indicate the location of the dark lamina. EDS analysis of this layer suggests the bright minerals are allanite. This lamina contains a ring structure to the left of the photograph. The scale bar is 100 μm .

Framboids

Small pyrite framboids were found in most of the eleven thin sections from Hewitt's Cove (Fig. 4); thus far, framboids have not been found in slides from the other two rocks. The pyrite is bright yellow in reflected light, and EDS analysis confirms the abundance of both sulfur and iron. The framboids range from 20 to 30 micrometers in diameter, with individual pyrite grains no more than a micron or

two in width. About a third of the individual pyrite crystals appear to be subhedral cubes, others are almost spherical, or have irregular grain boundaries. These 1-2 μm pyrite grains are found both singly and in groups, comprising spherical framboids, or seemingly split open and scattered.

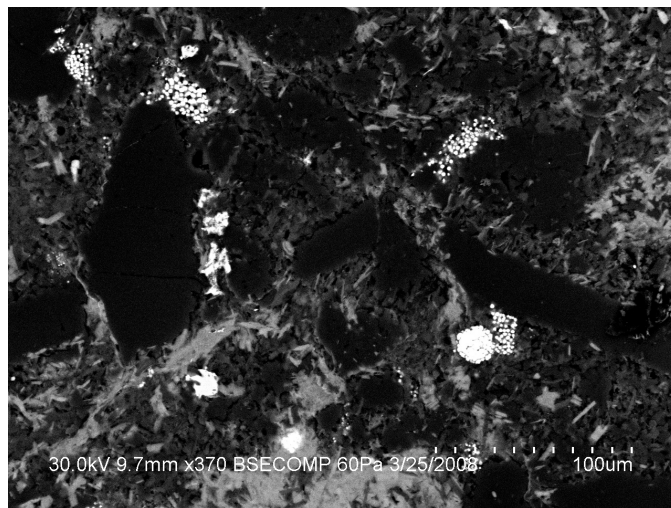


Figure 4. A cluster of pyrite framboids in slide BB-HC-A6a from Hewitt's Cove, as seen in a BSE image acquired with a VP-SEM. Some of the framboids are intact, others appear to have broken apart, scattering the component pyrite grains. The large dark grains are mostly quartz. The scale bar is 100 μm .

In one slide, BB-HC-A6a, many of the framboidal crystals have dark centers, as shown in Figure 5. EDS analysis indicates that these framboids are rich in iron, but poor or entirely lacking in sulfur. Energy dispersive spectra also demonstrate that the more distinct the dark center of a framboid crystal, the richer in iron and poorer in sulfur it is. Many of these individual grains have a triangular or rhombohedral shape. The chemical composition indicated by EDS, combined with the shape of the grains, suggest that these framboids are made of hematite. These hematite framboids were located in a group of framboids, and were found toward the left and right ends of the cluster; the framboids in the center of the cluster, however, were rich in both iron and sulfur.

The dark laminae in most slides, including those with *Aspidella*, were scrutinized and no framboids

have been found within the *Aspidella* structures, or in any of the dark laminae. However, the framboids were most frequently found within silty regions a few millimeters above and/or below dark layers.

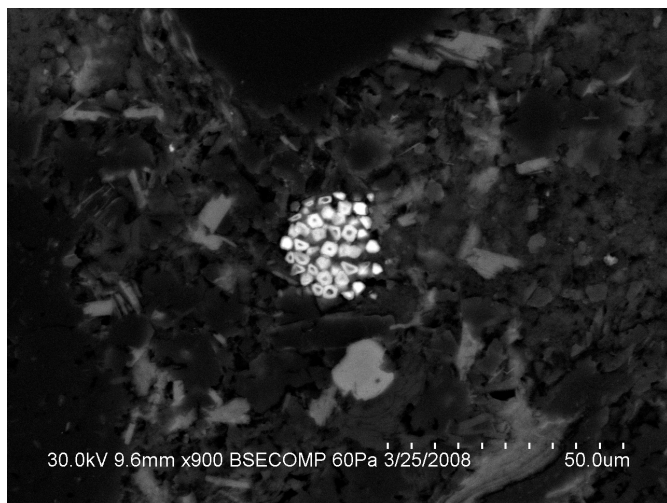


Figure 5. A BSE image taken with a VP-SEM of a framboid from BB-HC-A6a of the Hewitt's Cove Argillite. Individual crystals are dark in their centers. The crystals have a high iron content, but little to no sulfur. The composition and apparent rhombohedral shape of the individual grains suggests the framboid is made of secondary hematite. The scale bar is 50 μm .

Slate Island Float, BB-HC-C

A total of four thin sections were prepared of this slate. The clay grains showed strong foliation and the silt grains elongation parallel to foliation. The mineralogical content of BB-HC-C was similar to the less deformed BB-NB-A and BB-HC-A samples. EDS analysis of isolated accessory minerals that were pale yellow under reflected light microscopy suggests that some are allanite and others are titanite (sphene). Euhedral apatite is also present as an accessory phase. Unlike rocks from the other two localities, almost all the dark laminae were composed of a weakly reflective pale yellow mineral. EDS analysis suggests that these layers, rich in titanium and silica, are sphene. No pyrite framboids were found in BB-HC-C.

DISCUSSION

Nature of Diagenesis

Critical for the interpretation of *Aspidella* as a fossil is the observation that the rocks of the Cambridge Argillite are not so deformed as to preclude the preservation of fossils. The siltstones and slates have clearly undergone considerable recrystallization; the individual phengite and chlorite minerals are rather large in size and are almost certainly recrystallized, and many grains of quartz have been either converted into chert or show extensive dissolution surfaces on their faces. The abundance of chlorite and phengite suggests that although the alteration is likely diagenetic, conditions approached the lower limits of metamorphism. The textures and mineralogy indicate that rocks of the Cambridge Argillite were buried to a depth between approximately 3.5 and 5 km, and were heated to temperatures between approximately 175°C and 250°C. The presence of foliation textures in the slate indicates it has undergone greater deformation than the argillite, as would be expected. Fossils could certainly be preserved in either of these environments, and microfossils have indeed been found in the Cambridge Argillite by Lenk et al. (1982) from tunnel excavation samples under the city of Boston.

Nature of the Framboids

While a biogenic origin cannot be confirmed or refuted at present, the framboids seem to be primary to the rock. No sulfur bearing veins or lenses have been discovered anywhere in any of the samples. Any sulfur that is present in the rocks is likely primary. More investigation is needed to determine if there truly is a preferential occurrence of the framboids around the dark layers, and to determine whether or not the framboids are biological in origin. A pseudo-membrane was present around a pair of framboids in slide BB-HC-A7c, similar to a pyritized *Sphaerocongregus variabilis* reported by Moorman (1974) and needs to be explored further. Iron-rich/sulfur-poor framboids in thin section BB-HC-A6a are composed largely of subhedral grains. These grains have a rhombohedral shape consistent

with hematite. Subhedral to euhedral crystals in a sedimentary rock are usually indicative of recrystallization, so the hematite “framboids” are probably a replacement of earlier pyrite framboids. Regardless, the framboids in general remain the most significant discovery of this investigation.

Nature of The Dark Laminae

This investigation sought to determine the composition and origin of dark laminae within Cambridge Formation rocks containing *Aspidella*. At this point, we conclude that the majority of the dark layers are not comprised of opaque minerals, and do not appear to be preserved biomats as was previously proposed (Bailey & Bland, 2001; Bailey, 2002). These dark laminae contain neither sulfur, necessary for pyrite, nor mineralogical carbon, indicative of directly preserved organic material. Furthermore, the dark layers are not truly opaque. Close observation with transmitted and reflected light microscopy and SEM-EDS analysis indicates that the layers are probably just a mixture of fine clays and accessory minerals, like allanite or sphene. These accessory minerals may be detrital heavy minerals. The relatively large amounts of plagioclase in the silt, up to 10% of the larger fraction of clasts, suggest that the sediment was not very mature. Immature sediments may also have a relatively large proportion of accessory minerals survive the erosional process, and in this case they were deposited in the silt layers and in the dark laminae.

Before firm conclusions can be made about the origin of the dark layers and their relation to *Aspidella*, dark laminae from more samples of the in situ Hewitt's Cove Argillite need to be studied. Future work might also include an analysis of the total organic content present in the argillite. A high organic content would be encouraging for the interpretation of the dark laminae as organic structures, even if these organics are no longer preserved in the laminae themselves. A large organic content could also prompt an analysis of the Hewitt's Cove Argillite for a possible microfossil suite.

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