The Geochemistry and Petrology of the Bald Hill Bentonites in Southwestern Pennsylvania

Chris Howard, Aleya Shreckengost, and Ryan Kerrigan

Department of Energy and Earth Resources, University of Pittsburgh at Johnstown, Johnstown, PA 15904

Johnstown Campus

Dept. of Energy and Earth Resources

Abstract

The early Devonian (middle Lochkovian) Bald Hill Bentonites (BHBs) of central Appalachia have been examined through field, geochemical, and petrographic analyses to determine their tectonomagmatic setting. To the best of our knowledge, minimal trace element geochemistry exists on these K-bentonites; obtaining trace element geochemistry allowed for the testing of petrogenetic models/hypotheses to determine the type-eruptive source of the bentonites. Field work was undertaken at the New Paris Limestone Quarry in southwestern Pennsylvania, where three BHB units (BHB-B, BHB-B', and BHB-C; respectively, oldest-to-youngest) outcropped in mined sections of the Helderberg group. The BHB-B unit was observed to be ~1 ft thick and consists of basal calcite nodules, a stratified section, and an upper arkosic layer. A previously unidentified BHB unit (BHB-B') is situated between other known BHB units (BHB-B and BHB-C) and has been examined during this study. Both BHB-B' and BHB-C were observed to be ~3 in thick and consisted of only a stratified section. Representative samples were collected and submitted for bulk whole rock geochemical analyses for major, minor, and trace elements as well as thin-section production. Geochemical results were examined on multi-element variation (spider) diagrams, petrologic rock description plots, and petrogenetic discrimination diagrams. Major element data exhibit a shift in composition from felsic to mafic as the bentonite units get younger (from trachyandesite-andesite to foiditic), suggesting that progressive eruptions became increasingly more silica undersaturated. Rare Earth Element (REE) geochemistry plotted with respect to chondrite reveals a slight HREE enrichment, creating an overall broad U-shaped trend which could be attributed to secondary hydrothermal alteration. Trace element data plotted on petrogenetic discrimination diagrams supports that the magma composition likely originated from a volcanic island arc with some data plotting in the collisional source field. The timing and geochemistry support an association with early Acadian volcanic island arcs colliding with the eastern margin of North America and could provide insight on the tectonomagmatic dynamics of this orogenic event.

Background and Geologic Setting

Figure 1. New Paris Limestone Quarry.

Methods

- Field Work
- Bulk whole rock geochemistry was acquired from Act Labs in Canada by Fusion ICP and ICP/MS
- Thin sections created through National Petrographic in Texas

The New Paris Quarry is a retired open-pit mining operation situated along the northwest limb of the Chestnut Ridge anticline in the eastern portion of the Allegheny Plateau. Exposed in the highwall is the boundary between the upper Silurian and lower Devonian (~420 Ma), shallow marine, Helderberg limestones. Within these limestones, three bentonite layers had been previously identified: Bald Hill Bentonite A (not exposed at this locality), Bald Hill Bentonite B (BHB-B), and Bald Hill Bentonite C (BHB-C)[1]. This study describes the presence of Bald Hill Bentonite B, Bald Hill Bentonite C, and another previously unknown ash layer classified as Bentonite B'. The volcanic activity responsible for the deposition of these ash layers is unclear as the East Coast was undergoing dynamic tectonic activity[2]. The paleogeographic history of New Paris Quarry is that of a shallow marine extension of the Iapetus Ocean after the Taconic orogeny (450 Ma) created the Appalachian basin. Bald Hill Bentonite A has been dated at 417.6 Ma[3] and Bald Hill Bentonite C has been dated at 417 Ma[4], making it unlikely that the Taconic orogeny (~450 Ma) is responsible for their deposition. These bentonites have been suggested to have Island Arc origins[5,1] in relation to the Acadian Orogeny[6,7].

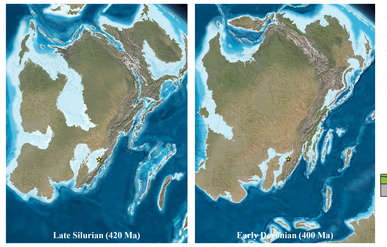
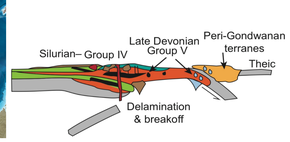


Figure 2. Paleogeographic maps of Laurentia and the closing of the Iapetus Ocean[8] due to Peri-Gondwanan Island Arcs with Group IV tectonomagmatic setting[2].



Field Description

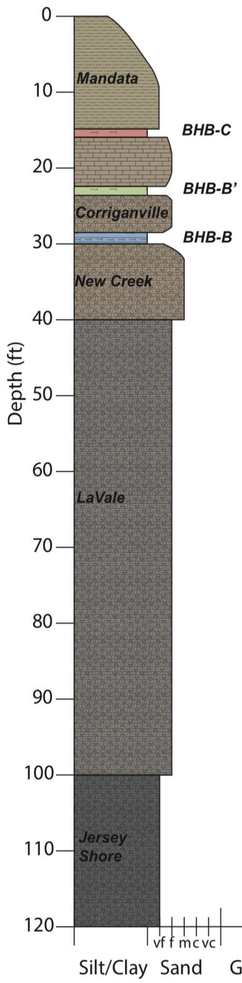
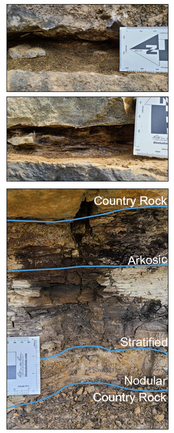


Figure 3. Stratigraphic column depicting the strata visible at the New Paris Limestone Quarry. Depth scale is set from the top of quarry (ground) to the bottom of the quarry. The Bald Hill Bentonites are labeled and marked with blue, green, and red.



BHB-C is a 10 cm finely laminated layer with a dark brown to black color and punky texture containing wide, flat nodules and calcite veins overlain by phosphate nodules. ***Samples: NPQ23-009, NPQ23-011***

BHB-B' is 5 to 10 cm thick, dark orange to brownish black color containing wide nodules. This unit is previously undescribed in the literature despite previous field studies[4,1]. ***Samples: NPQ23-008, NPQ23-010***

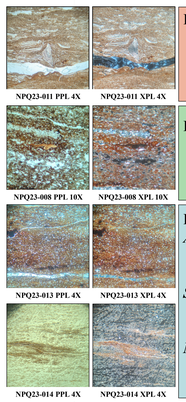
BHB-B is split into 3 distinct layers:

Arkosic: The top 5 to 8 cm in layer is a highly weathered, coarse-grained, competent, arkosic layer. The layer weathers to a light buff to a greenish-beige with the fresh surface being dark brown to black. ***Samples: NPQ23-013***

Stratified: The middle 15 to 24 cm layer is finely laminated, fissile; minor fossils present. The layer weathers to a whitish-beige to buff with the fresh surface being orange brown to dark grey. ***Samples: NPQ23-005, NPQ23-014***

Nodular: The bottom 8 to 13 cm layer is dense with calcite nodules (up to 8 cm in diameter) and clayey mud that contort the BHB-B lithified layer. Thought to be reworked ash in the marine setting. ***Samples: NPQ23-001***

Petrography



BHB-C has a very fine-grained light brown matrix. Several possible fiamme structures could be present. There is significant crystal deformation within this layer. The majority of the minerals were too fine-grained within the matrix to be identified.

BHB-B' has a laminated, fine-grained, red-brown matrix with calcite veins. Some fiamme structures may be present. Recrystallized minerals exhibit 4th to 5th order birefringence with hematite halos.

BHB-B

Arkosic: This layer has a densely fine-grained, dark to orange brown matrix with no distinguishable mineral content outside of secondary calcite.

Stratified: The laminated, very fine-grained matrix of this layer has a high fine grain calcite content with hematite phenocrysts and hematite halos

Nodular: No thin sections were made of the nodule unit as they were determined to be entirely made of calcite. Geochemical analyses support this determination.

Major element geochemistry

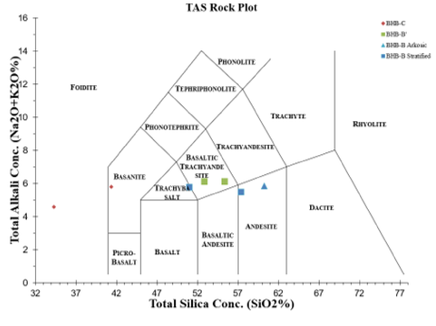


Figure 4. Major element geochemistry is plotted on a Total Alkali versus Silica petrologic rock diagram to determine the origins of the parent rock. BHB-B, BHB-B', and BHB-C plot, respectively, as andesite and potassic trachybasalt, basaltic trachyandesite, and basanite to foidite. The data shows a trend in the BHBs from felsic to mafic, suggesting progressive silica desaturation within a single magma chamber or are from a series of volcanic eruptions from a variety of volcanic centers.

Trace Element Geochemistry

Figure 5

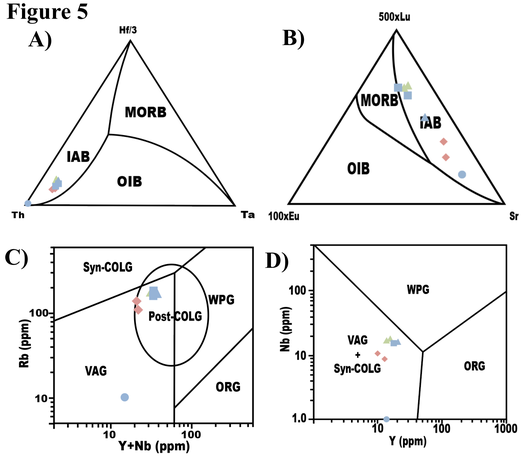


Figure 5, A – D. Trace element data plotted on basaltic and granitic petrogenetic discrimination diagrams to determine the origins of the ash. Blue represents BHB-B, split into the three sections: Triangles for arkosic, squares for stratified, and circles for nodular. Green represents BHB-B' and Red signifies BHB-C.

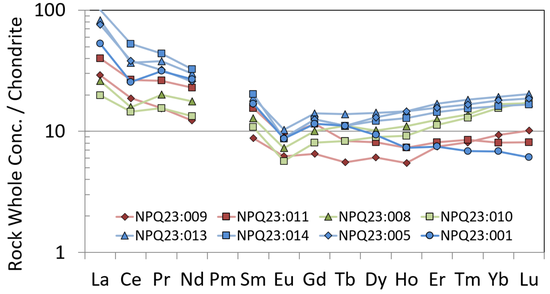


Figure 6. Trace element geochemistry of each sample, with respect to chondrite, is plotted on the multi-element variation "spider" diagram following a normal negative trend with an increase in HREEs. The blue, green, and red lines represent BHB-B, BHB-B', and BHB-C samples, respectively. Promethium was not tested for, leaving a gap in data.

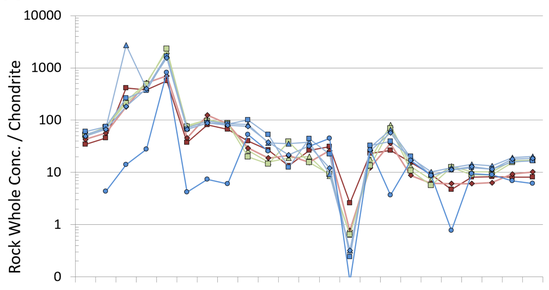


Figure 7. Minor and trace elements, corrected against Chondrite, plotted on a multi-element spider diagram. All samples are well-behaved and show a regular negative trend from the minor to Light Rare Earth Elements, with the NPQ23-001 being the only poorly behaved sample. Additionally, there is consistent phosphorous depletion within all the samples.

Table 1. Basalts

Plot type	Overall answer
Ti50-V-Sc*6[11]	MORB
Ti-V[12]	Half IAB, Half MORB
Ti/40-Si/1000-Sr[11]	Half IAB, Half MORB
TiO_2– Al_2O_3[13]	IAB
Nb*25-Na/100-Sr[14]	IAB
TiO_2-FeO/(FeO+MgO)[15]	IAB
Zr-Ti[16]	IAB
Y-Cr[10]	IAT
Nb*2-Zr/4-Y[14]	OIB
TiO_2-MnO*10-P_2O_5*10[17]	OIT and OIB
Ti/100-Zr-Y*3[11]	Everything Basalt

Table 2. Granites

Plot type	Overall answer
Yb-Ta[10]	ORG
Yb+Ta-Rb[10]	VAG
Y+Nb-Rb[10]	Post-COLG
Y-Nb[10]	VAG+Syn-COLG

Tables 1 and 2:
Tables 1 and 2 are the results from other basaltic and granitic petrogenetic discrimination diagrams that were also plotted, but not pictured. Having this variety of discrimination plots allowed for ruling out sample biases and interpretive errors as well as expressing statistical trends.

Petrogenesis and petrogenetic discrimination diagrams:
Shown are two groups of petrogenetic discrimination diagrams: basaltic and granitic. Basaltic and granitic diagrams differ in uses and elemental composition. Basaltic diagrams are used for lava flows while granitic are used for magma chambers. The use of both types in this project is due to the lack of discrimination diagrams specific to bentonites. Shown in these diagrams that the Bald Hill Bentonites fall, on average, in the Island Arc and Volcanic Arc with some collisional signatures.

Discussion

- Previous studies done at this locality[1] have determined that the oldest BHB, BHB-A, is within the subsurface and is inaccessible for this project.
- The trend of felsic to mafic composition on the TAS plot could suggest multiple centers of volcanic activity or an influx of mafic material within the magma chamber.
- The spider diagram exhibits a negative trend from LREEs to HREEs normal for Island Arc signatures. The increase of HREEs in some samples could be due to low-temperature hydrothermal alteration at this locality.
- Although there is variability within the results of the petrogenetic discrimination diagrams, the statistical average within those results describes the BHBs as having Island Arc and collisional origins.
- During the closing of the Iapetus Ocean and the Acadian orogeny, multiple peri-Gondwanan island arcs collided with maritime Canada and with upper New England resulting significant volcanic activity having the potential of being the magmatic source of these bentonites.

Conclusions

- Geochemically fingerprinted and described the previously unobserved BHB-B'
- The data supports and strengthens previous studies' conclusions[1,5,6,7] that the Bald Hill Bentonites have an Island Arc origin
- With the geochemical values now available, it is possible to conduct further research into the tectonomagmatic source of this series of bentonites.

Acknowledgements & References

This project was funded through the Presidential Mentorship Grant for Spring 2023 through the University of Pittsburgh at Johnstown. We would like to personally thank Adam Ianno (Pennsylvania Bureau of Geologic Survey), Chris Coughenour (Pitt-Johnstown Energy and Earth Resources), and Steve Lindberg (Pitt-Johnstown Energy and Earth Resources) for their valuable assistance throughout the entirety of this project.

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