U/Pb Zircon Geochronology of the Bald Hill Bentonite Suite at the New Paris Quarry in Southwestern Pennsylvania

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Abstract

Throughout the central Appalachians a series of bentonite layers, called the Bald Hill Bentonites (BHBs), were deposited during the early Devonian; although no absolute ages are currently known, radiometric isotope dating could provide these dates. Three bentonite layers of the BHBs are recognized: BHB A, B, and C (from oldest to youngest, respectively). Fieldwork at the New Paris Limestone quarry, a retired limestone quarry in southwestern Pennsylvania, identified BHB B and BHB C layers to be present and revealed a previously undescribed bentonite layer, BHB B', between them. A reportedly equivalent bentonite unit to BHB A is present in New York, where it returned a 417 Ma date. This led to the previous conclusion that all the BHBs are ~417 Ma, although no work has been done to conclude this. Each bentonite layer (BHB B, B', and C) was sampled and submitted to ZirChron for zircon extraction and U/Pb radiometric isotopic analyses. These data provide age constraints for each of these layers and determines if BHB B' is truly a new layer or if the stratigraphy of these bentonites at this locality was incorrectly identified and needs to be revised. With these dates and geochemical data, correlation across state borders is possible and can provide further information towards finding the source(s) of these layers. Additionally, the rate of sedimentation of the Helderberg limestones can be determined based off the age constraints of the BHBs and the thickness of the material between those layers. From these dates, sedimentation rates, previous geochemical data, and interstate correlations, it provides a clearer image of the tectonic history impacting the region.

Background and Geologic Setting

Figure 1. New Paris Limestone Quarry located in southwestern PA. Depicted is the upper bench after the retirement of the Quarry.

Methods

- Field Work
- U/Pb ages acquired by CA-ID-TIMS analysis through ZirChron in Washington State

New Paris Quarry is a retired open-pit mining operation situated along the northwest limb of the Deer Park 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 (BHB-A), Bald Hill Bentonite B (BHB-B), and Bald Hill Bentonite C (BHB-C)[1]. Last year at this location, Bald Hill Bentonite B, Bald Hill Bentonite C, and another previously unknown ash layer classified as Bentonite B' were described. The volcanic activity responsible for the deposition of these ash layers are thought to originate from collisional volcanic island arcs, possibly related to the earliest onset of the Acadian orogeny[1-6] or the end of the Salinic orogeny of New England and maritime Canada between 440 and 421 Ma[7,8], both of which resulted in volcanic activity in the Devonian[1-8]. 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 (not exposed at this locality) has been previously dated at 417.6 Ma from Cherry Valley, NY[3,9] and Bald Hill Bentonite C been speculated to be around 417 Ma[4], making it unlikely that the Taconic orogeny (~450 Ma) is responsible for their deposition.

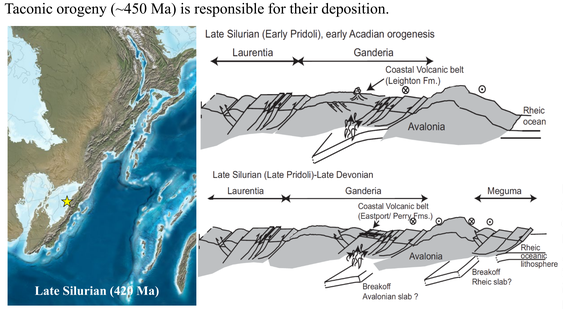

Figure 2. Paleogeographic map of Laurentia during the Late Silurian period[10] followed by a simplified tectonic model of early Acadian orogenesis beginning in the early Pridoli stage. During this time, the plate subducts beneath the North American plate, accreting the Avalonia terrane. Shortly after the accretion, the slab breaks off and delaminates, resulting in early Devonian volcanism in maritime Canada and New England[8].

Field Description

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, NPQ24-002***

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, NPQ24-003***

BHB-B is a 30 to 50 cm thick layer with diverse internal strata, ranging from an arkosic composition at the top, laminated and fissile strata, to a reworked and contorted nodular layer along the bottom. ***Samples: NPQ23-005, NPQ23-013, NPQ23-014***

Conodont samples (1kg) were taken at the base of the lowermost bench near the contact between the LaVale and Jersey Shore members, just below BHB-B, and above and below BHB-C. (Photo of Lochkovian *Lanea omoalpha*[14], present in samples)

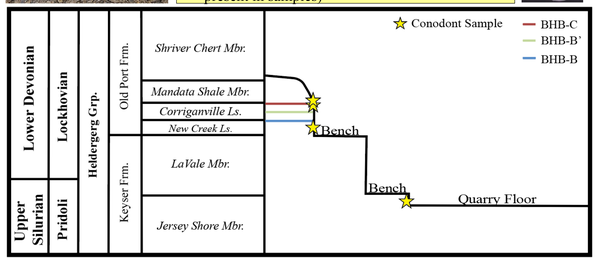

Figure 3. Modified Chronostratigraphic column and New Paris Quarry[11] showing the benches of the quarry, BHB layers, and Conodont Sampling (Coughenour unpub. data, 2025)

Geochronology

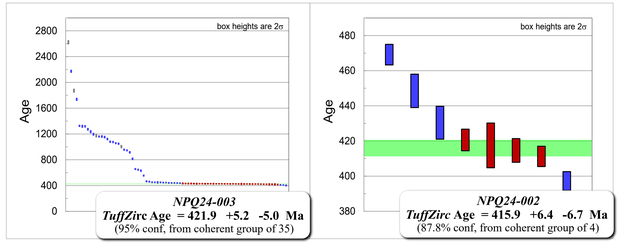

Figure 8. Concordia age weighted mean plot of BHB-C (NPQ24-002) and BHB-B' (NPQ24-003). Each box encompasses 2 standard deviation error, the red boxes mark the overlap age within specified confidence interval. BHB-B' reports an average age of 421.9 +5.2/-5.0 Ma within a 95% confidence interval across 35 of 84 total samples. BHB-C reports an average age of 415.9 +6.4/-6.7 Ma within an 87.8% confidence interval across 4 of 66 total samples.

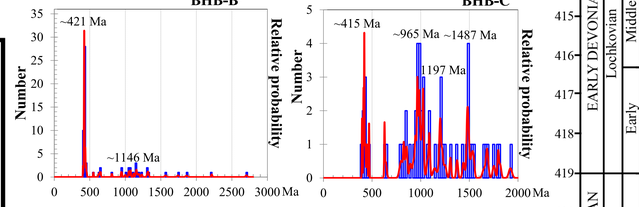

Figure 9. Relative probability plot of BHB-C (NPQ24-002) and BHB-B' (NPQ24-003) showing age trends within the concordia ages and representative sample count (red trendline) overlying a zircon age distribution histogram (blue). BHB-C shows an overwhelming trend of ~421 Ma. BHB-B' shows a high probability of ~415 Ma with inherited signatures. The trends within this sample are not as strong due to the distribution of data throughout the histogram.

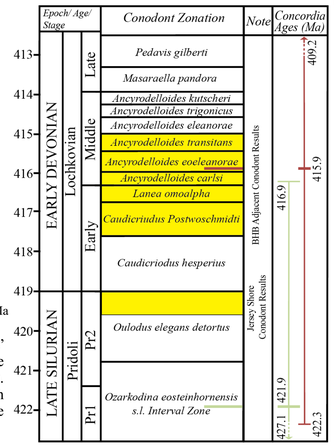

Figure 10. Modified Conodont Zonation diagram[15,16] with conodont intervals (yellow) (Coughenour unpub. data, 2025) and the radiometric dates of BHB-C (red) and BHB-B' (green). The conodont zones present are the uppermost *O. elegans detortus* of the Pridoli stage in the Silurian in the Jersey Shore samples. The samples surrounding the BHBs resulted in conodot samples within the *C. postwoschmidti* to *A. transitans* interval zone.

Possible Sources

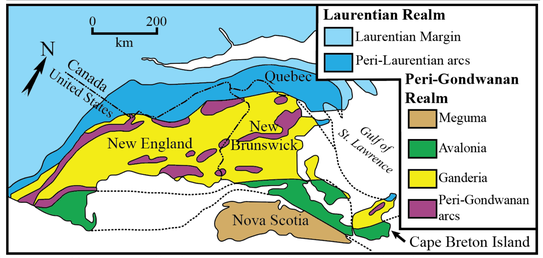

Figure 11. A generalized terrane map of New England and the easternmost Canadian provinces after the Acadian orogeny[17]. Along the Avalonia - Ganderia boundary, volcanics relating to subduction slab delamination and breakoff resulted creating the coastal volcanic belt throughout Maine, New Brunswick, and Cape Breton Island[8].

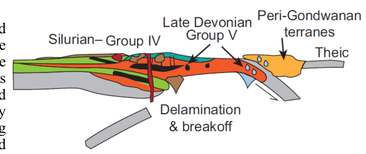

Figure 12. A generalized tectonic diagram of the Acadian orogeny in the Appalachian Mountains depicting Silurian and Devonian igneous activity resulting from subducting slab delamination and breakoff[13].

Discussion

- Previous studies[1-6] have shown that the BHBs have a relation to the onset of the Acadian orogeny.
- BHB-B' shows significant inherited signatures, possibly from detrital material, bioturbation, or depositional influences leading to a lower confidence in the age.
- The Conodont zonation lies within the overlap of both the radiometric dates, and from the location of the samples, it is possible to refine the ages of the BHBs.
- Comparing the petrogenetic discrimination diagrams of the BHBs to both Appalachian tectonic groups and New Brunswick volcanic centers, a trend of post-collisional volcanic arcs can be seen.
- In the Pridoli stage of the Silurian, the Salinic orogeny (the accretion of Ganderia along the Laurentian margin) resulted in volcanic activity within the Ganderian terrane just before the Acadian orogeny began in maritime Canada[7,8], having the potential to be a source of these bentonites.
- During 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

- Inherited signatures within BHB-C show that the melt possibly originated in an old crust where it absorbed discordant zircons
- New ages are presented for BHB-C (415.9 +6.4/-6.7 Ma) and BHB-B' (421.9 +5.2/-5.0 Ma), with the conodont biostratigraphy, the ages have the possibility to be refined further
- Based on geochemical trends, ages, and tectonic activity, the origin for these bentonites lies in northern Appalachia, northern New England, or maritime Canada

Major, Minor, and Trace Geochemistry

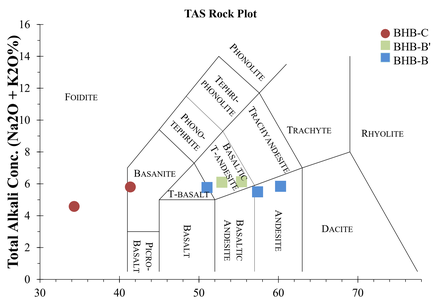

Figure 4. Major element geochemistry is plotted on a Total Alkali versus Silica petrologic rock diagram to determine the origins of the parent rock. BHB-B, BHB-B', and BHB-C plot, respectively, as Andesite and Potassic Trachybasalt, Basaltic Trachyandesite, and Basanite to Foidite. The data shows a trend in the BHBs from felsic to mafic suggesting that these bentonites are from a series of volcanic eruptions from a variety of volcanic centers.

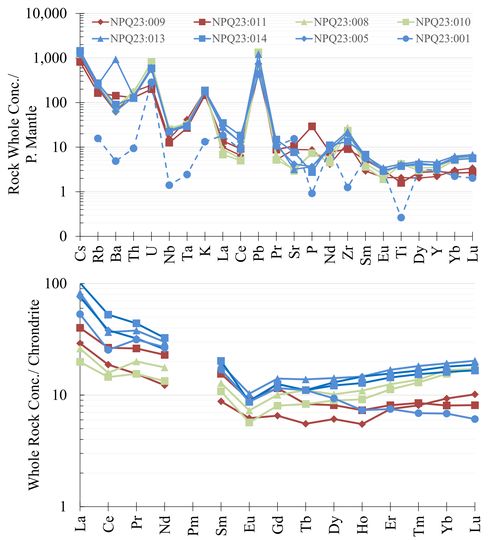

Figure 5. Minor, Trace (Top), and REE (bottom) multi-element ("spider") plots of the samples of the BHBs showing a normal, negative trend from minor to Heavy Rare Earth Elements (HREEs). The data is well-behaved outside of NPQ23-001 which was a calcite nodule used as a control. Pb, U, K, Zr, and HREEs are uniformly enriched in these samples. Pm was not tested for, leaving a gap in data.

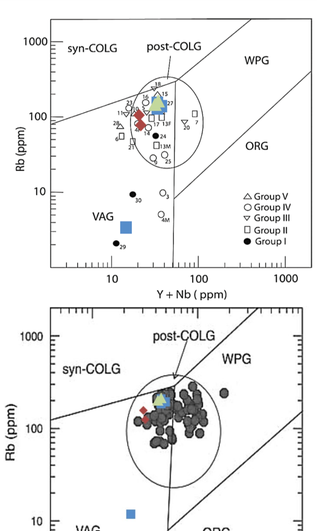

Figure 6. Trace element data plotted granitic petrogenetic discrimination diagrams[12] to determine the origins of the ash and compare to known tectonic settings[13]. Blue represents BHB-B, Green represents BHB-B', and Red signifies BHB-C. The known tectonic settings are represented as the groups. The group closely related to the BHBs are Group IV (late Silurian subduction and slab breakoff) and V (early Devonian plutonism).

Figure 7. Trace element data plotted granitic[12] petrogenetic discrimination diagrams to determine the origins of the ash and compare to known tectonic settings[13]. Blue represents BHB-B, Green represents BHB-B', and Red signifies BHB-C. The dark circles are samples from New Brunswick late Silurian to early Devonian plutons originating from the Salinic orogeny[7]. The data shows consistency between BHBs and the plutonic samples.

Acknowledgements, References, Digital Copy

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