Petrogenesis of Ultramafic Bodies in the Pennsylvanian Piedmont

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Abstract

The structural, petrologic, and geochemical significance of a group of enigmatic ultramafic bodies in the Piedmont Province in southeastern Pennsylvania have been examined to determine their origin and petrological significance. The Piedmont Province of the Appalachian Mountain Belt is composed of several suites of metamorphic and igneous rocks that owe their origin to the collision of multiple terranes on the east coast of North America approximately 1100 to 450 million years ago (Mya). Significant geologic investigations have been completed within this area, however, a series of rock bodies have eluded proper characterization. The ultramafic bodies are elongate pods (1.5 to 0.5 miles long and 0.5 to 0.1 miles thick) and altered to varying degrees. Several theories have been proposed to explain the origin of the bodies: pieces of ocean floor caught within a tectonic collision; igneous rocks that diapirically rose from the mantle below; or part of a magma chamber associated with the terranes that collided with North America ~450 Mya.

Over a dozen ultramafic bodies were examined in the field and samples were collected for petrological and geochemical analyses for major and trace elements. Most bodies are completely serpentinized, however, some exhibit a complex “onion skin” morphology creating zones of alteration from the country rock to the core of the body. The alteration zones allow for the modeling of fluid alteration and infiltration during metamorphism. Areas of intense alteration indicate significant metasomatic reactions with the aluminum-rich country rock as shown by the presence of garnet, kyanite, and corundum in localized zones. Internal shear is present in some of the bodies resulting in duplication of alteration zones. Plotting trace element geochemical data on petrologic discrimination diagrams yield an arc signature supporting the hypothesis that these bodies originated from an ultramafic differentiate at the base of an arc system.

Objectives

The scientific objectives of this study attempt to address the following questions:

- How did these exotic (mantle-derived) rocks become situated in the crust?
- What was the original source of these rocks?
- How do these rocks fit into the complex geologic history of the Pennsylvanian Piedmont?
- The rocks exhibit varying degrees of alteration:
  - What is the nature of the alteration?
  - How does the alteration and deformation fit into the overall history of the region?

Methods

The following methods are employed in this study:

- Detailed Geologic Field Mapping
- Petrographic Assessment of Rock Thin Sections
- Electron Beam Analyses
  - Energy Dispersive Spectroscopy (EDS)
  - Wavelength Dispersive Spectroscopy (WDS)
- X-ray Diffraction (XRD)
- Inductively Coupled Plasma Mass Spectrometer (ICP-MS)
- X-Ray Fluorescence (XRF)

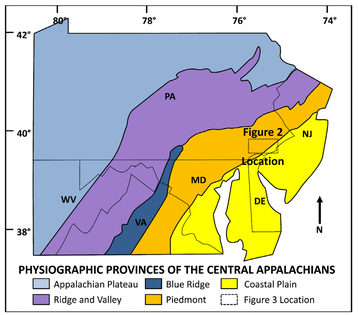


Figure 1. Physiographic Provinces of the central Appalachians. The study site (box present in southeast Pennsylvania) is located in the Piedmont Province of the Appalachian Mountains (shown in orange.

Field Geology and Petrography

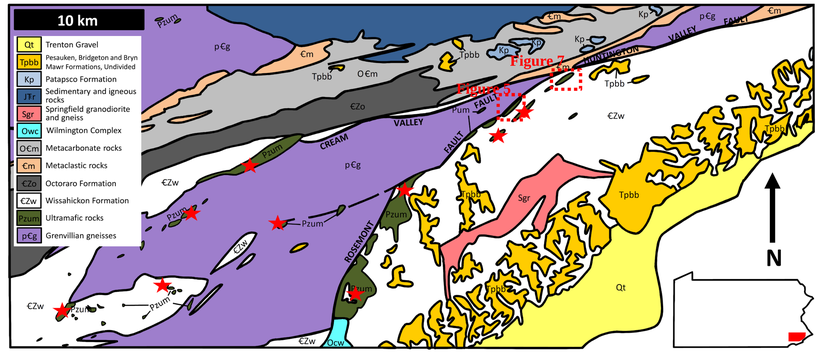


Figure 2. Generalized geologic map of a portion of the central Pennsylvania Piedmont. Modified after Bobsyshell (2006).

Paleogeographic Maps

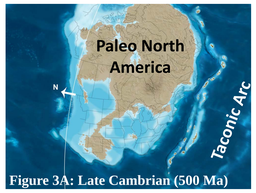


Figure 3A: Late Cambrian (500 Ma)

Figure 3B: Middle Ordovician (470 Ma)

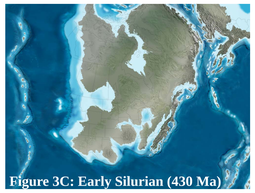


Figure 3C: Early Silurian (430 Ma)

Figure 3. Paleogeographic depictions of the North America based on the geology and tectonics data **(A)** Late Cambrian (500 Ma) the proto-Taconic arc is situated of the east coast **(B)** Middle Ordovician (470 Ma) the Taconic arc is near collision with North America, **(C)** Early Silurian (430 Ma) collision occurs. (Blakey, 2016)

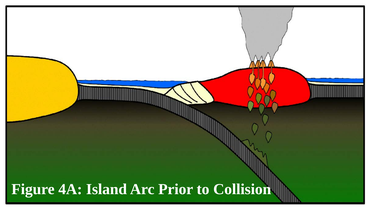


Figure 4A: Island Arc Prior to Collision

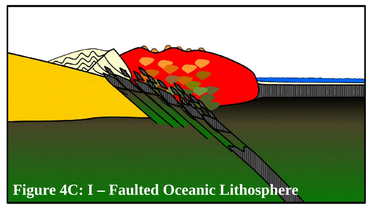


Figure 4C: I – Faulted Oceanic Lithosphere

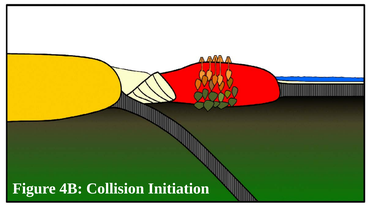


Figure 4B: Collision Initiation

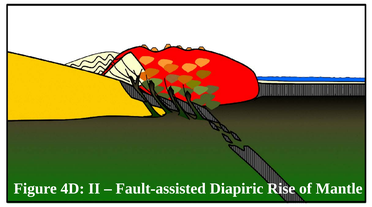


Figure 4D: II – Fault-assisted Diapiric Rise of Mantle

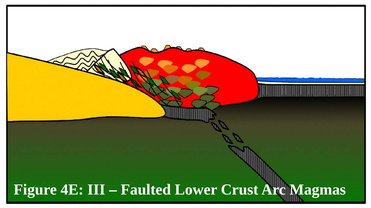


Figure 4E: III – Faulted Lower Crust Arc Magmas

Figure 4. Geologic Cross Sections of the east coast of North America during the Cambrian to Silurian periods (~500 – 430 Ma) showing various possible configurations of the plate mechanics. **(A)** A subduction zone producing a island arc (the Taconic Arc *in Red*); **(B)** Convergent collision of the island arc with the North America Continent (*yellow*); **(C)** Scenario I: oceanic lithosphere is obducted on to the continent; **(D)** Scenario II: Faulted oceanic lithosphere allows for the diapiric rise of mantle material along weak fault planes; **(E)** Scenario III: Collision induced faulting and obduction of lower crustal magmas.

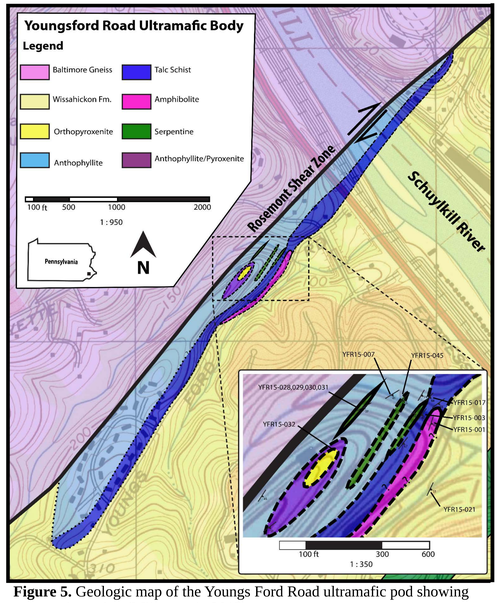


Figure 5. Geologic map of the Youngs Ford Road ultramafic pod showing concentric zoning (Miller et al., 2015).

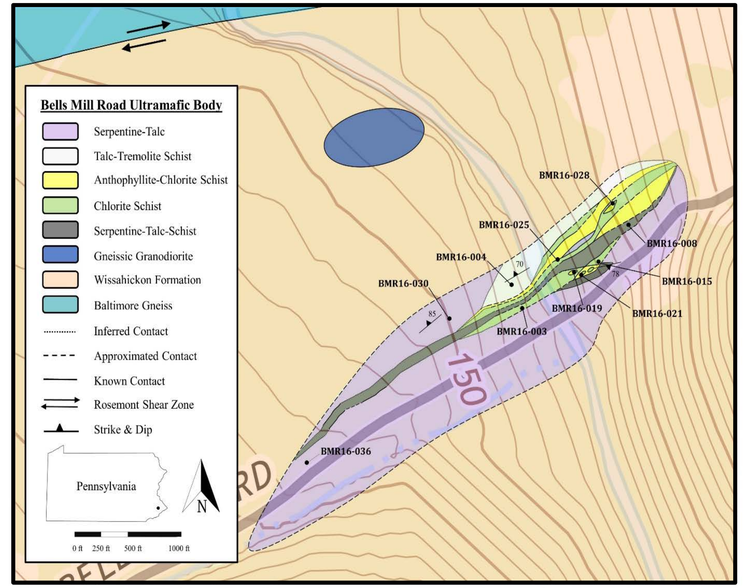


Figure 7. Geologic map of the Bells Mill Road ultramafic pod showing duplication of units (Simboli et al., 2017).

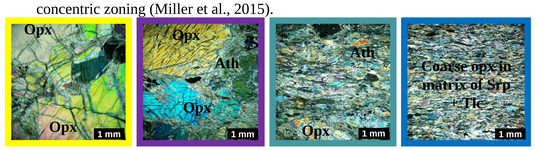
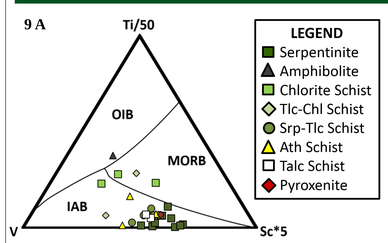


Figure 6. Transition of ultramafic rock from relatively unaltered orthopyroxenite core (map color yellow) grading into anthophyllite-talc schist (map color blue).

Figure 8: Field and laboratory photographs of rock textures: (**a**) serpentine-talc rock (serpentinite pods surrounded by talc-carbonate matrix), (**b**) the contact between chlorite schist and anthophyllite-chlorite schist, (**c**) serpentine-talc-carbonate and (**d**) thin-section of Al-rich phases in chlorite schist indicating intense metasomatism.

Trace Element Geochemistry



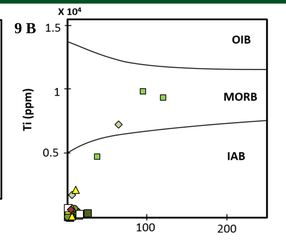


Figure 9. Figure 5: Petrogenetic discrimination diagrams applicable for basaltic systems (**9A -** Shervais, 1981; **9B -** Pearce & Cann, 1971). Geochemical discrimination diagrams identify tectonic origin. Diagrams not specifically designed for ultramafics, however, inferred that protolith originated in an island arc setting.

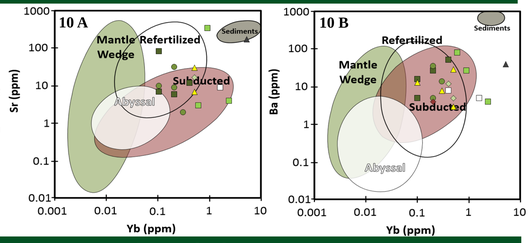


Figure 10: Discrimination diagrams applicable for the serpentinite systems (Deschamps et al., 2013). Plots support a subduction zone setting for refertilization corroborating a subducted island arc setting.

Conclusions

- Some ultramafic bodies represents an ultramafic protolith with zones of increasing hydration toward the country rock, some show duplication/stacking of units, indicating shear, others are completely serpentinized
- The core of the Youngs Ford Road ultramafic body is an orthopyroxenite exhibiting well-defined cumulate textures with minimal alteration/deformation
- The body transitions from a nominally anhydrous orthopyroxenite core to zones of increasingly hydrous mineral phases approaching the country rock
- Several serpentinite pods containing relict olivines are present within the anthophyllite zone perhaps suggesting a different protolith than the core
- Trace element geochemistry supports the hypothesis of an island arc origin for the protolith

Acknowledgements

The present research would not be possible without the generous support of the **University of Pittsburgh at Johnstown Presidential Mentorship Fund** and the **UPJ Natural Sciences Division** and the hard work of many UPJ undergraduates **Kristoffer Miller, Lorin Simboli, Olivia Wolff, Benjamin Shirley,** and **Samuel Louderback.**

We would like to thank Michael Mengason (National Institute of Standards) for free electron beam analyses. Howell Bosbyshell (West Chester University), Paula Callahan (Department of Transportation), and Bill Crawford and Maria Luisa Crawford (Bryn Mawr University) for help finding suitable field sites. Sandy Schenk (Delaware State Survey) and Steve Shank (Pennsylvania State Survey) for helpful conversation at the onset of this project. Also let’s all praise the New England Patriots and hope for another Super Bowl Championship in 2018!

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