Blackwall Alteration and Serpentinization of Ultramafic Bodies in Southeastern Pennsylvania

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Abstract

An examination of ultramafic bodies in southeastern Pennsylvania using field mapping, petrography, and geochemistry has revealed four distinct styles of alteration. The ultramafic bodies are lenticular in shape ranging from 6 km to 0.5 km along their long axis. The bodies are generally adjacent to major shear zones in the region and are considered to have been emplaced during the Taconic Orogeny (470 Ma). Trace elements indicate that the ultramafic protoliths are likely related to the collided island arc rather than ophiolitic or mantle upwelling settings.

Four styles of alteration can be identified: complete serpentinization, blackwall alteration (i.e., a nominally anhydrous cores surrounded by "onion-skin" alteration zones of increasing hydration), sheared blackwall alteration, and siliceous alteration. The westernmost bodies trending west-southwest are encompassed in the Grenvillian (1.0 Ga) mafic Baltimore Gneiss and exhibit complete serpentinization. The serpentine is mainly mesh texture lizardite with relict olivines indicating an olivine-rich protolith. However, the close association with the mafic Baltimore Gneiss may indicate Si-poor fluids reducing the possibility of the anthophyllite-talc alteration seen in the blackwall altered bodies. The remaining three alteration styles are found on the eastern side of the Piedmont within the Taconic (470 Ma) Wissahickon schist trending south-southwest. Two sets of parallel trending bodies closest to northern Philadelphia and adjacent to the Rosemont Shear Zone exhibit blackwall alteration. Counterintuitively, the set closest the Rosemont Shear Zone show little shear deformation and retain their "onion-skin" alteration zones typically with cores of orthopyroxenite. The set slightly further (~1 km) from the Rosemont Shear Zone show significant shear deformation (strain shadows, unit duplication, etc.). The two largest ultramafic bodies show a mix of blackwall alteration, serpentinization, and siliceous alteration. Siliceous alteration is most significant in close proximity with intruding granitic intrusions. The Philadelphia-area ultramafic bodies may represent a dismembered layered mafic complex below an island arc with the olivine-rich stratigraphic bottom to the west and the upper orthopyroxenites to the east.

Paleogeographic Maps

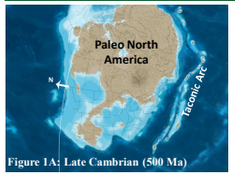


Figure 1A: Late Cambrian (500 Ma)

Figure 1B: Middle Ordovician (470 Ma)

Figure 1. Paleogeographic depictions of the North America based on the geology and tectonics data **(A)** Late Cambrian (500 Ma) the proto-Taconic arc is situated off the east coast **(B)** Middle Ordovician (470 Ma) the Taconic arc begins to collide with North America (Blakey, 2016)

Figure 2. Geologic cross sections of the east coast of North America during the Ordovician (~470 Ma) during the Taconic Orogeny subduction zone producing an island arc (*red*) and North America (*yellow*). Three possible scenarios are depicted which could explain the emplacement of the Piedmont ultramafics.

(A) Scenario I: oceanic lithosphere is obducted on to the continent;

(B) Scenario II: Faulted oceanic lithosphere allows for the diapiric rise of mantle material along weak fault planes;

(C) Scenario III: Collision induced faulting and obduction of lower crustal magmas.

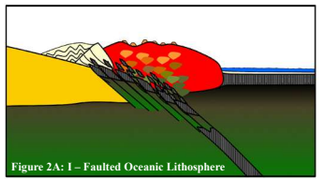


Figure 2A: I – Faulted Oceanic Lithosphere

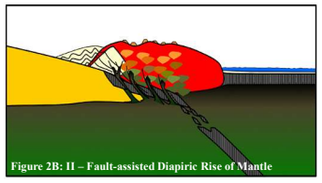


Figure 2B: II – Fault-assisted Diapiric Rise of Mantle

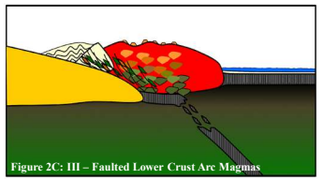


Figure 2C: III – Faulted Lower Crust Arc Magmas

Field Geology and Petrography

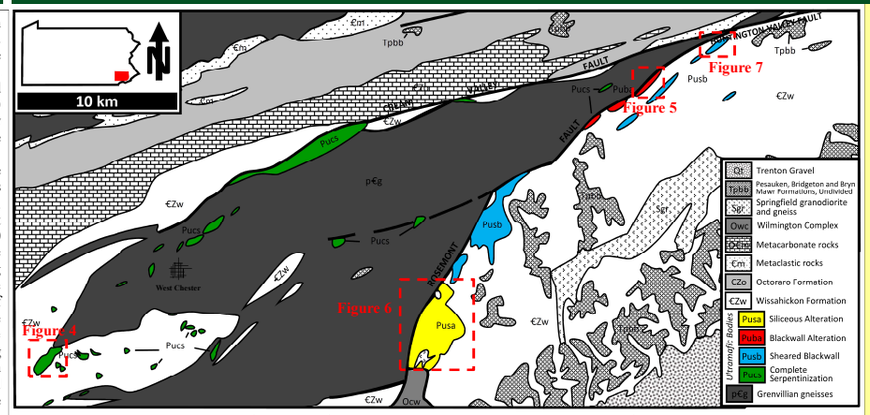


Figure 3. Generalized geologic map of a portion of the central Pennsylvania Piedmont. The ultramafic bodies are depicted as colored units and the other maps presented are outlined in the red boxes. Modified after Bobsyshell (2006).

Complete Serpentinization - Example: *Unionville Serpentine Barrens, Chester County, PA*

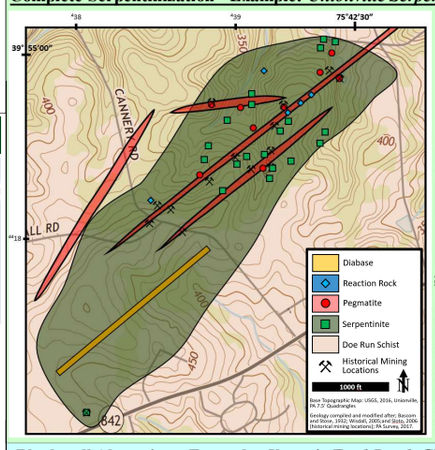


Figure 4. The Unionville Serpentine Barrens ultramafic body is representative of a completely serpentinized ultramafic in the Piedmont. The micro-scale textures present in the serpentinites overwhelming show mesh textures with relict olivine, suggesting an olivine-rich protolith. Additionally, the Unionville body does have later stage intrusions of felsic pegmatite dikes where significant reaction occurs adjacent.

Serpentinite

USB17-014 FOV= 15cm

Reaction Rock

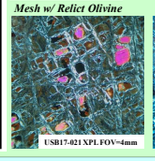
UPG17-009 FOV=8cm

MSREL Pegmatite

UPG17-004 FOV=10cm

Serpentine Textures:

Mesh w/ Relict Olivine

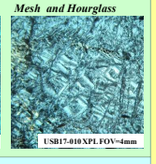


USB17-021 XPL FOV=4mm

Mesh and Hourglass

USB17-004 XPL FOV=4mm

Mesh and Hourglass



USB17-010 XPL FOV=4mm

Blackwall Alteration - Example: *Young's Ford Road, Gladwyne, PA*

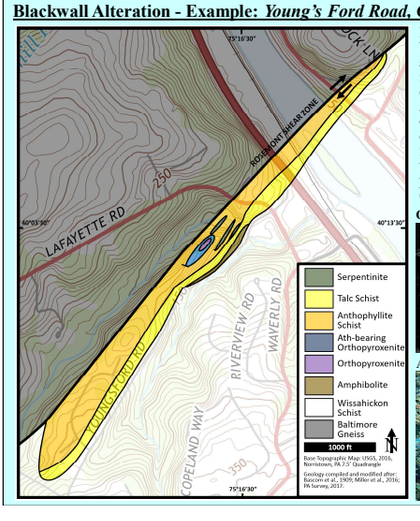
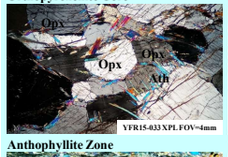


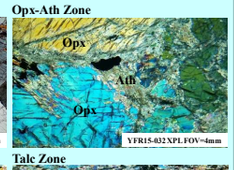
Figure 5. The Youngs Ford Road ultramafic body shows classic blackwall alteration. The geologic map (left) shows the presence of an anhydrous core (*orthopyroxenite*) which transitions to zones of increasing hydration (*anthophyllite to talc*). The cartoon cross-section (*right*) depicts these zone as fluids infiltrated the ultramafic body. The photomicrographs (*below*) show zones.

Orthopyroxenite Core



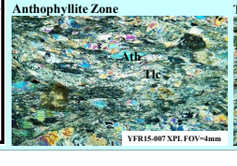
YFR15-033 XPL FOV=4mm

Opx-Ath Zone



YFR15-032 XPL FOV=4mm

Anthophyllite Zone



YFR15-007 XPL FOV=4mm

Talc Zone

YFR15-003 XPL FOV=4mm

Siliceous Alteration – Example: *Lima, Delaware County, PA*

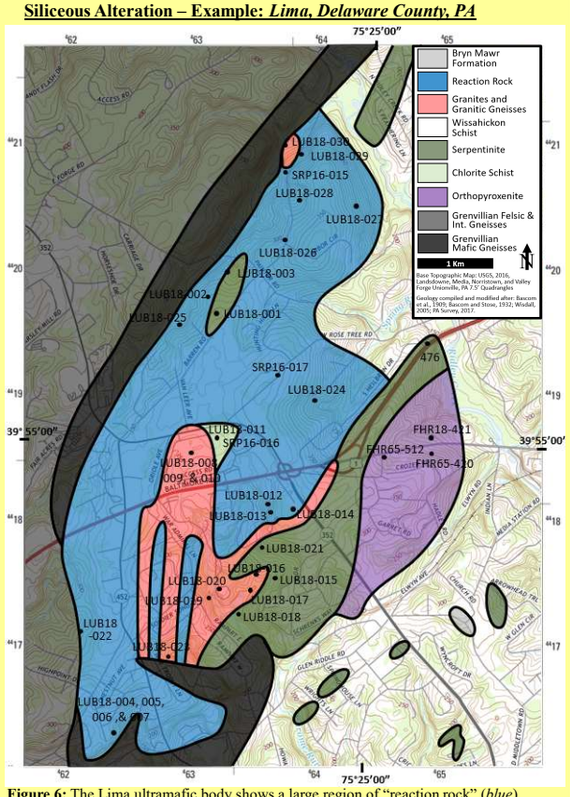
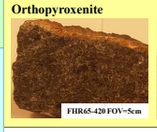


Figure 6: The Lima ultramafic body shows a large region of "reaction rock" (*blue*) where significant siliceous alteration has completely replaced serpentinites and generally produces a honeycomb/veined network. The siliceous alteration is likely due to interactions with the Lima granite (*red*) similar to Unionville (see Figure 4)

Orthopyroxenite



FHR65-420 FOV=5cm

Serpentinite

LUB18-011 FOV=10cm

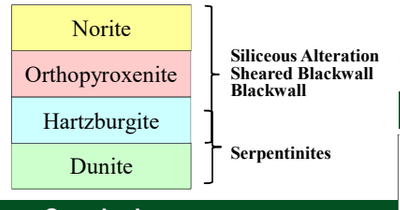
Reaction Rock

LUB18-027 FOV=8cm

Granite

LUB18-008 FOV=6cm

Figure 8: A generalized stratigraphic column for a layer mafic intrusion. The Piedmont ultramafic may represent a dismembered layered mafic intrusion with the stratigraphic bottom located to the west with the serpentine belt and the top to the east with norite/orthopyroxenite bearing blackwall zone bodies.



Sheared Blackwall Alteration - Example: *Bells Mill Road, Philadelphia, PA*

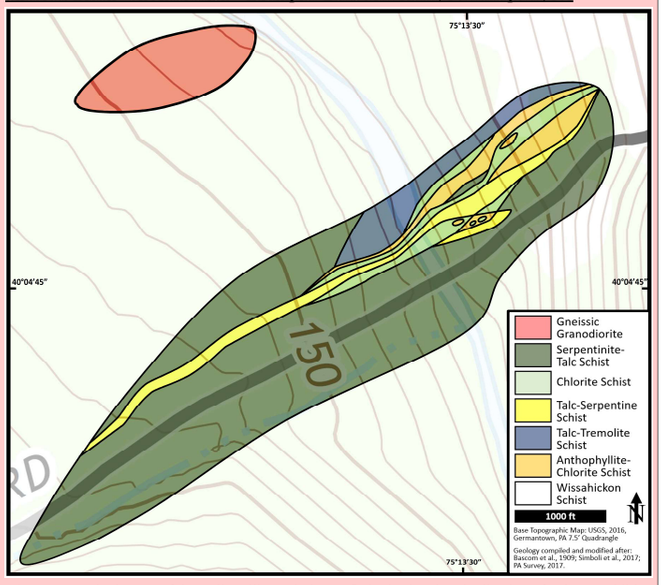


Figure 7. Geologic map of the Bells Mill Road ultramafic body showing duplication of units. In addition to unit duplication, various indications of shear can be seen in the rocks (see below). The stratified nature is from blackwall alteration, however, the shear is due to this ultramafic body's proximity to the Rosemont Shear Zone (Simboli et al., 2017).

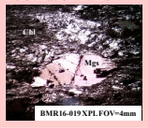
Serpentine-Talc Schist

BMR16-030 FOV=1m

Strain Shadows

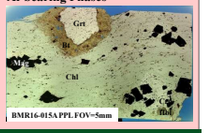
BMR16-003 XPL FOV=4mm

Deformation Twins



BMR16-019 XPL FOV=4mm

Al-bearing Phases



BMR16-015A PPL FOV=5mm

Trace Element Geochemistry

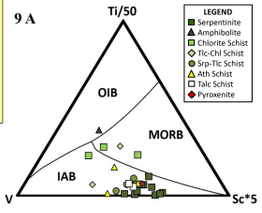
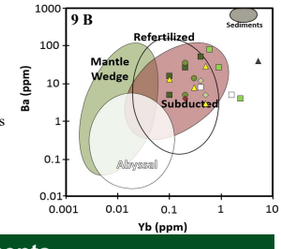


Figure 9: Petrogenetic discrimination diagrams: **9A** for basaltic systems (Shervais, 1981); **9B** for serpentinite systems (Deschamps et al., 2013). Geochemical discrimination diagrams identify tectonic arc origin.



Conclusions

- There is a band of ultramafic bodies in the west that display complete serpentinization. Serpentine textures suggest an olivine-rich protolith.
- The bands of ultramafic bodies located in the east display varying levels of blackwall alteration with the presence of orthopyroxenite and norite protoliths
- Most ultramafic bodies are in the immediate proximity to mapped faults/shear zones and some show clear indications of shear (i.e., duplication/stacking of units, strain shadows, and deformation bands).
- Trace element geochemistry supports an island arc origin for the protolith.
- The series of ultramafic bodies in the Pennsylvanian Piedmont may have a shared origin with a layered mafic intrusion that was subsequently dismembered in orogenesis.

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