Petrographic and Geochemical Evidence for the Tectonic Origin of Bells Mill Road Ultramafic Body of Southeastern, PA

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Abstract

Field work, petrography, and whole-rock geochemistry has been completed to understand the nature of the alteration zones, deformation history, and test origin hypotheses for the Bells Mill Road ultramafic body. The Bells Mill Road ultramafic body is one of several ultramafic bodies of unknown origin within the Piedmont Province of the Central Appalachian Mountain belt. The Piedmont Province 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. The Bells Mill Road ultramafic body is an elongate unit (~0.25 by 1 mile in dimensions) emplaced within the Wissahickon Schist of southeastern PA and is oriented parallel to regional foliations (NE-SW trending).

The geologic history of the Pennsylvanian Piedmont has been thoroughly studied, but the origin of the ultramafic bodies remains a source of contention. There are several competing hypotheses to explain the source of these tectonically emplaced ultramafics, namely: oceanic crust (Desantis, 1978), diapiric mantle (Amenta, 1974), and arc-related magmatic differentiates (Busé and Watson, 1960).

Work in this area is complicated by contradictory data related to contact locations and lithologic relations, so a revised geologic map was created to show the current lithologic zones of alteration within the body. The zones were found to be as follows: serpentine-talc; serpentine- talc-carbonate; talc-anthophyllite-tremolite; chlorite schist; and anthophyllite-chlorite schist. Whole-rock geochemistry was obtained using ICP-MS and XRF, and the geochemistry of individual phases was obtained using EDS. The use of geochemical discrimination diagrams supports an island arc origin; this supports the hypothesis that the ultramafic body is most likely the ultramafic differentiate of an arc-related magma chamber. A small minority of samples show a mid-ocean ridge basalt affinity, but these rocks are rich in Al-phases (Grt, Crn) which may suggest a high level of recrystallization/metasomatism altering inherited signals.

Methods & Materials

- Field samples and structural data were collected from the Bells Mill Road ultramafic body, northwest Philadelphia, PA
- A geologic map was created to show previously undescribed lithologic zones of alteration within the body
- Petrographic thin-sections were point counted to estimate modal mineral abundances and textures were examined
- Whole-rock geochemistry was obtained using ICP-MS and XRF for major and minor trace elements
- Elemental abundances were plotted on petrogenetic discrimination diagrams
- Oxide phases were examined using Energy Dispersive Spectrometry

Mineral Modal Abundances

		Srp	Chl	Tlc	Ath	Tr	Opx	Mgs	Opaques
Serpentine-Talc Schist									
	BMR16-030	70%	0	8%	3%	0	0	12%	7%
	BMR16-036	53%	4%	25%	13%	0	0	4%	1%
Talc-Tremolite									
	BMR16-004	6%	0	49%	15%	27%	3%	0	0
Anthophyllite-Chlorite Schist									
	BMR16-028	0	34%	17%	42%	0	5%	1%	1%
Chlorite Schist									
	BMR16-003	0	90%	0	0	0	0	0	10%
	BMR16-019	0	77%	1%	0	0	0	6%	16%
	BMR16-021	0	75%	1%	13%	0	0	0	11%
Serpentine-Talc-Carbonate									
	BMR16-008	20%	1%	40%	18%	0	0	19%	2%

Field Data

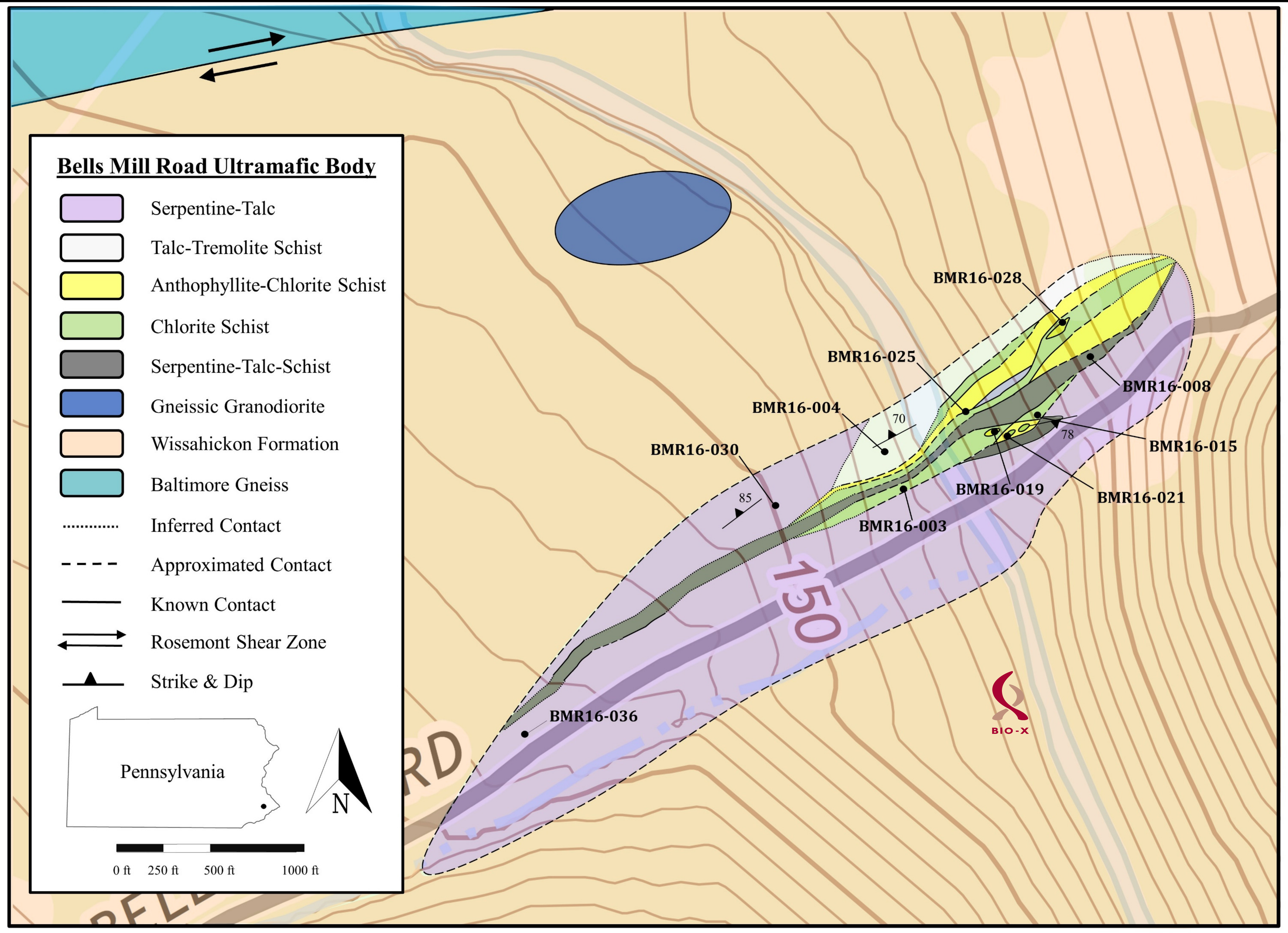

Figure 1: Geologic map of the Bells Mill Road ultramafic body. The lithologic zones of alteration are defined as: serpentine-talc, talc-tremolite, anthophyllite-chlorite schist, chlorite schist, and serpentine-talc-carbonate. The rim of the body is predominantly serpentine-talc, with repeating and interwoven sequences of serpentine-talc-carbonate, chlorite schist, and anthophyllite-chlorite schist towards the core. These repeating sequences may likely be due to shearing within the body.

Spinel Compositions

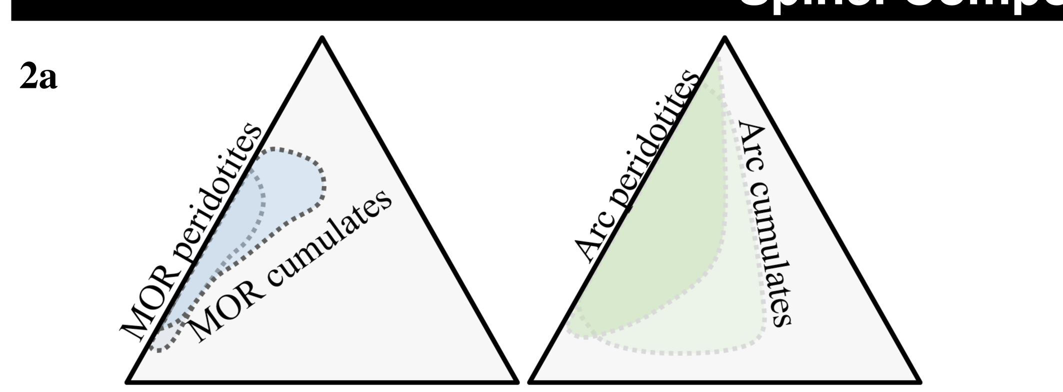

Figure 2a: Fe^{3+}-Cr-Al ternary diagram in atomic % (as below). Fields encapsulate data from Arai et al. (2011)

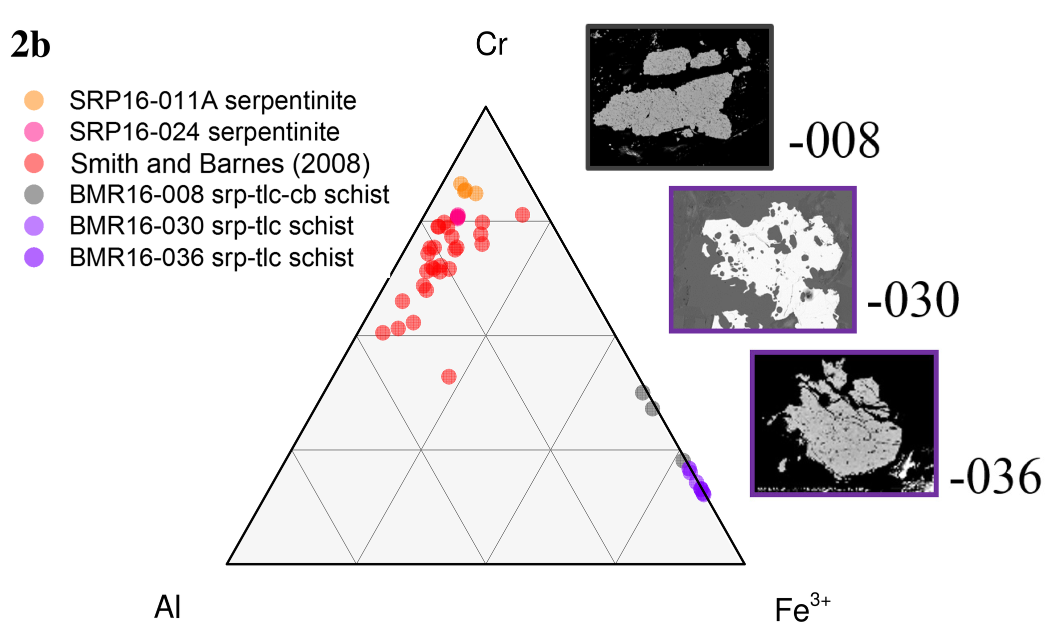

Figure 2b: Core compositions taken from cross-grain transects of Cr-rich spinels. Analysis of these samples performed on SEM with quantitative standards-based EDS using DTSA-II from the National Institute of Standards and Technology (NIST). Fe^{3+} calculated from total Fe assuming charge balance and full site occupancy.

Large Cr-rich spinel from samples showing the least apparent alteration were analyzed for geochemical evidence of tectonic origin. Spinels are more resistant than coexisting silicate minerals to alteration and can retain information through low-grade metamorphism. Spinel from Mid Ocean Ridges (MOR) show a more limited range in Cr:Al ratio compared to those from volcanic arcs (Arc)(fig. 2a).

- The core compositions of spinel from nearby serpentinite units and from Goat Hill serpentine barrens in the Baltimore mafic complex (Smith and Barnes, 2008) plot largely outside of the MOR field and within the Arc field.
- Two core compositions from BMR16-008 are more highly oxidized and depleted in Al by alteration. They can be described as 'ferritchromite' with rim compositions plotting as metamorphic magnetite overgrowth.
- The core compositions from BMR16-030 and -036 are just slightly Cr-enriched compared to their rims and have homogenized with their magnetite overgrowth.
- All of these spinels have undergone significant alteration and no-longer reflect initial compositions. They may be useful in the estimation of metamorphic grade.

Petrography & Geochemistry

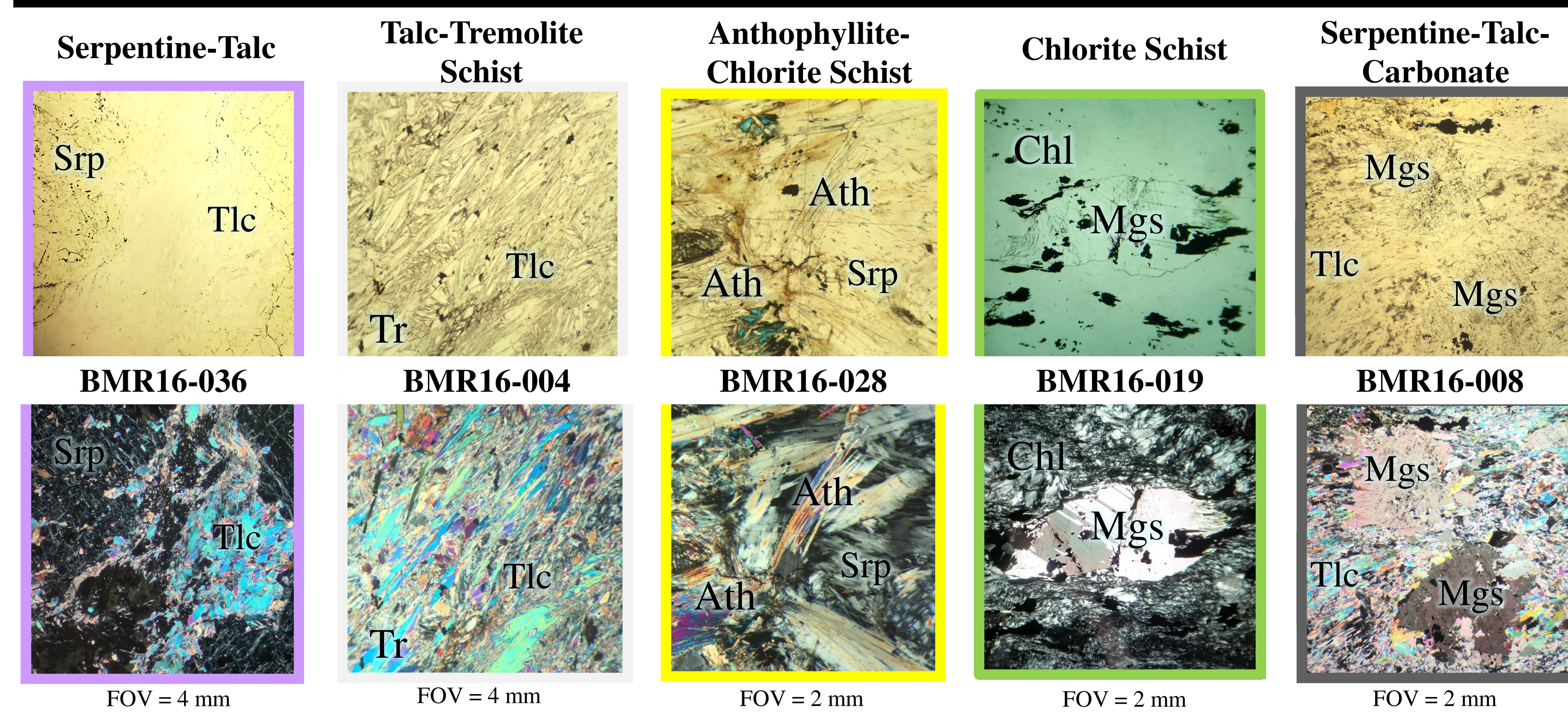

Figure 3: Photomicrographs of thin-sections in plane polarized (top row) and cross polarized light (lower row) for each lithologic zone of alteration. Each photograph is representative of the corresponding zone. Various indication of shear are present in the samples including: strain shadows, deformation twins, cataclastic failure, and planar foliation with shear bands.

Figure 4: Field and laboratory photographs of rock textures: (**a**) serpentine-talc rock (*note:* the serpentinite pods surrounded by a talc-carbonate matrix), (**b**) the contact between chlorite schist (upper green) and anthophyllite-chlorite schist (lower beige), (**c**) serpentine-talc-carbonate (the upper rock show the intense weathering pattern, lower rock shows internal/unweathered habit) and (**d**) thin-section of Al-rich phases in chlorite schist (*note:* this zone of Al-rich phases including garnet and corundum was restricted to a small zone of intense metasomatism).

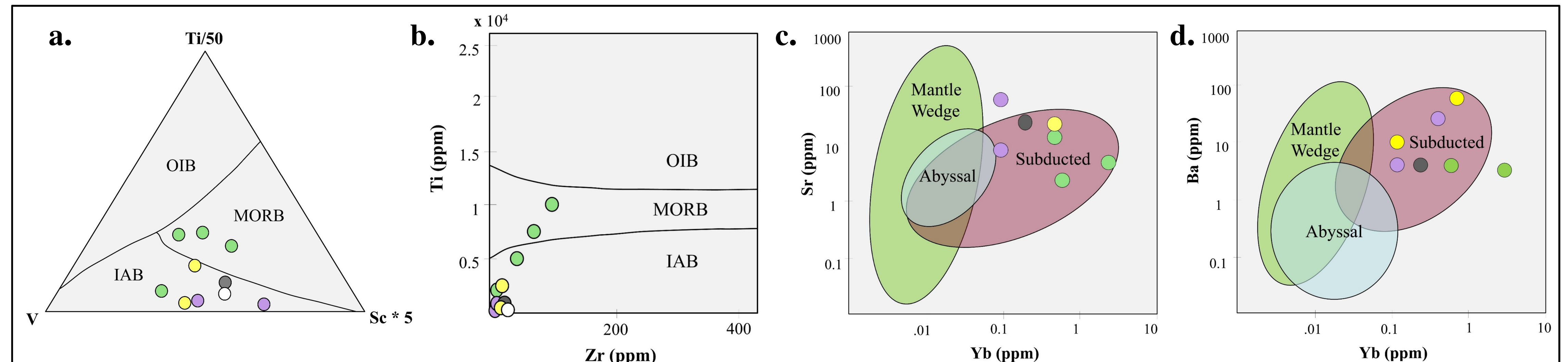

Figure 5: Petrogenetic discrimination diagrams applicable for the following systems: (**a**) basaltic rocks (Shervais, 1981); (**b**) basaltic rocks (Pearce and Cann, 1971); and (**c & d**) serpentinites (Deschamps et al., 2013). Geochemical discrimination diagrams can be used to identify tectonic origin. These diagrams are not specifically designed for ultramafics, however, consistent results are provided. It can be inferred that the source of magma originated from a subducted island arc setting.

Conclusions

- The lithologic zones of alteration that were previously undefined are as follows:
  serpentine-talc; serpentine-talc-carbonate; talc-tremolite; chlorite schist; and anthophyllite-chlorite schist
- Shearing appears present exhibited by duplication of units and shear-induced microstructures (shear banding, pressure shadows, twins, etc.)
- Chromites have undergone significant alteration and no-longer reflect initial compositions
- A small minority of samples show a mid-ocean ridge basalt affinity, but these rocks are rich in Al-phases (garnet and corundum) which may suggest a high level of recrystallization/metasomatism altering inherited signals
- Interpretations of petrogenetic discrimination diagrams suggests that the ultramafic body is most likely a differentiate of an arc-related magma chamber

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Acknowledgements

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