Determining the Origin of Granodiorites in the Pennsylvanian Piedmont using Geochemical and Petrographic Methods

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Abstract

Petrographic and geochemical analyses were used to characterize two granodioritic bodies located in the Piedmont Province of Southeastern Pennsylvania. These small (~300 by 150 m) granodioritic bodies are within 2.25 km of each other, located 15 km north-northwest of downtown Philadelphia, PA. One is referred to here as the Girl Scout Granodiorite (GSG), due to its proximity to a girl scout camp near Manor Road in Lafayette Hill, the other we refer to as the Bells Mill Granodiorite (BMG), due to its location near Bells Mill Road in Philadelphia. At both locations the bodies are surrounded by the Wissahickon Schist. The granodioritic bodies are thought to be contemporaneous with the Taconic orogeny, an island arc collision with the eastern margin of Laurentia approximately 450 Mya. Theories that may explain the origin of the granodioritic bodies include partial melt accumulation during orogenic crustal thickening or magmatism generated within the colliding arc. To the best of our knowledge the origin of these rocks have not previously been characterized.

Petrographic and geochemical analyses were completed. Whole rock geochemical data plotted on discrimination diagrams suggests that the granodiorites have an arc origin. The granodioritic bodies are peraluminous and subalkaline with geochemistry similar to the Springfield Granodiorite located ~7 km south. Outcrop and petrographic thin section analyses reveal deformation in the Bells Mill Granodiorite with foliations parallel to the adjacent Wissahickon Schist while the Girl Scout Granodiorite exhibits a more cumulate texture. The presence of deformation in the Bells Mill Granodiorite can be interpreted to suggest it solidified pre- or syn-tectonically with the regional metamorphosis accompanying the Taconic Orogeny while the Girl Scout Granodiorite may not fully have solidified until after the peak in local stresses and failed to record similar strain.

Background

The geologic history of the central Piedmont Province of the Appalachian Mountain Belt includes several orogenic events which have juxtaposed a wide range of metamorphic and igneous rocks. The crystalline basement formed approximately 900-1100 Ma during the Grenville orogeny which assembled Rodinia. After the breakup of Rodinia, the east coast of North America was subjected to multiple collision events of varying character. The rocks examined in this study are believed to be co-genetic with the Taconic Orogeny. Approximately 500-480 Ma, the Taconic Arc (a volcanic island arc over an eastward dipping subduction zone) formed on the east coast of Laurentia. The Taconic Orogeny culminated with accretion and obduction of the island arc system approximately 450 Ma creating high- to intermediate-grade metamorphic conditions. Arc collision smothered eastward dipping subduction and building stresses initiated a westward dipping subduction zone under eastern Laurentia. **Three prospective magma forming conditions in this setting are as follows: the creation of the Taconic arc during eastward dipping subduction, anorogenic conditions during collision between Laurentia and the arc, and/or westward dipping subduction after arc accretion.**

Several granodioritic bodies throughout the central Appalachian Piedmont including the Springfield, Gunpowder, Ellicott City, and Ellisville were emplaced between 427-458 Ma with pressures of crystallization measured between 600-900 MPa (Bosbyshell, 2005; Becker, 1996). The two granodioritic bodies in this study have similar mineral assemblages and are likely related to the Springfield.

Geologic Map

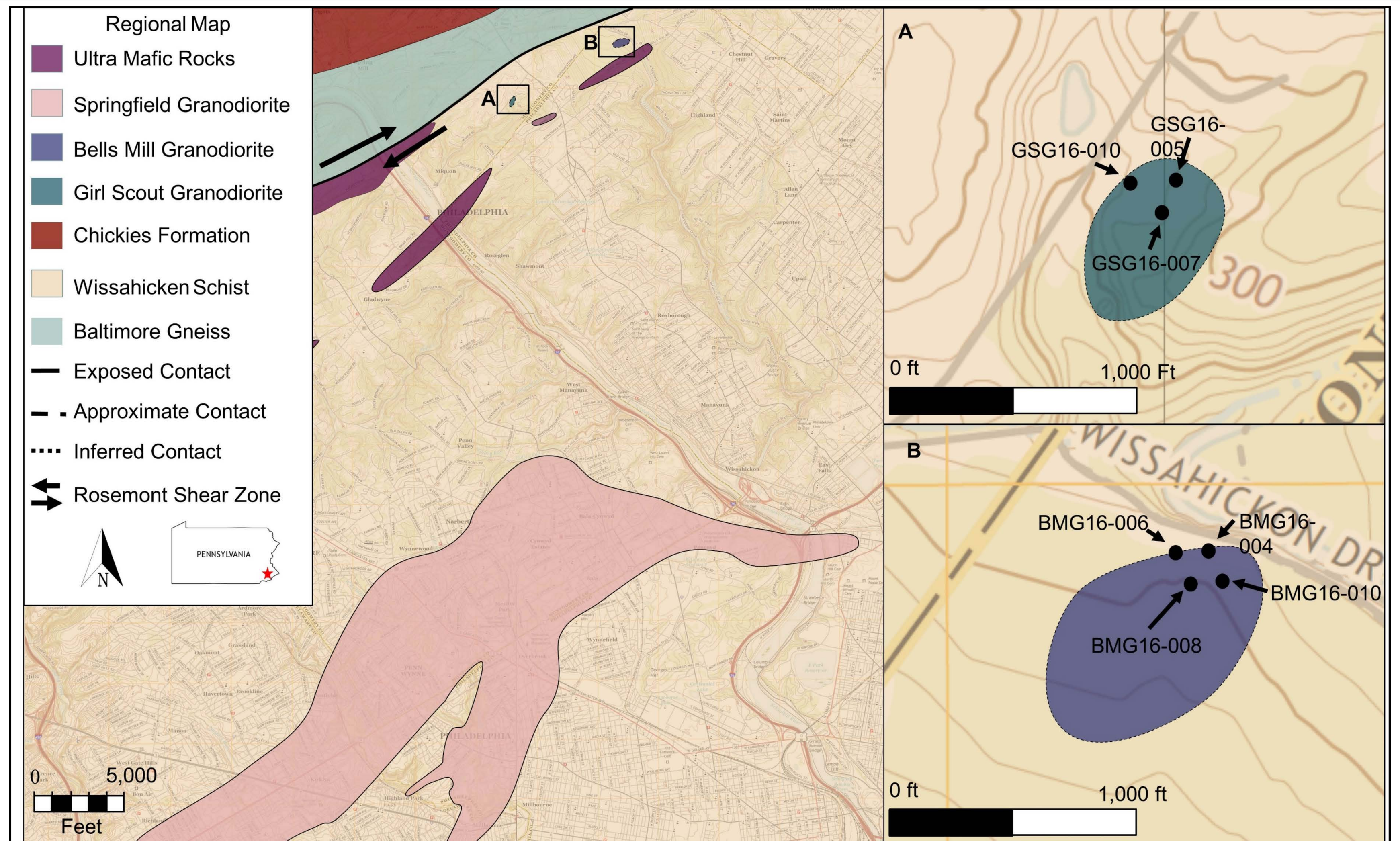


Figure 1: Regional map modified after (Bosbyshell, 2006.) The two insets show Girl Scout and Bells Mill granodiorites sites. The granodioritic bodies are within 2 km of each other and approximately 10 km north of the Springfield granodiorite. Field examination was conducted in defunct building stone quarries.

Methods

Field Geology

- Field relationship data and samples were collected from two granodioritic bodies located northwest of Philadelphia, PA

Petrography

- Thin sections were point counted no less than 600 points per slide to determine model mineral abundances
- Thin sections were examined to determine mineral associations and varying fabrics within the granodiorites

Geochemistry

- Whole-rock geochemical analyses of major and trace elements were obtained using ICP-MS and XRF
- Elemental concentrations were plotted on petrogenetic discrimination diagrams and compared to other igneous bodies in the region

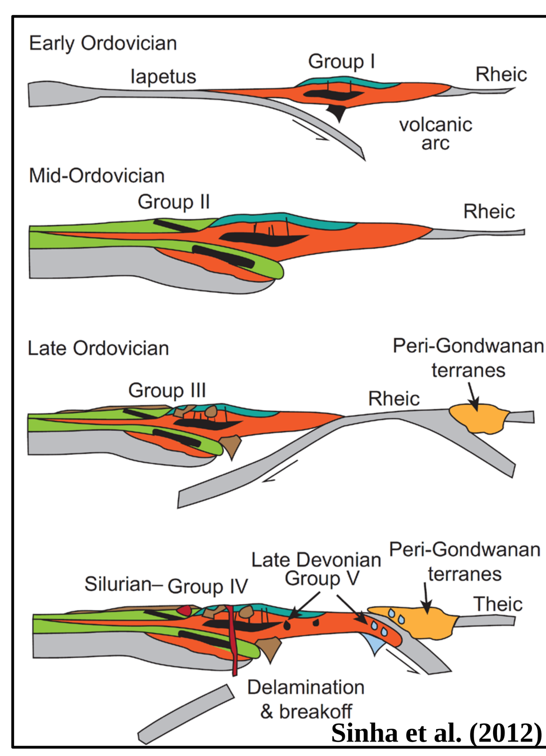


Figure 2: Grouped magmatic rocks of generally Taconic age. Based on reported age of 427 ± (Bosbyshell et al., 2016) and geochemical characteristic reported herein, it appears Group III, IV, or V of Sinha et al. (2012) could account for the GSG and BMG.

Geochemistry

Table 1: Whole compositions of S-I-A-M-type granitoids as well as the Springfield granodiorite, the Bells Mill Road granodiorite (BMG), and the Girl Scout granodiorite (GSG). BMG and GSG are peraluminous and subalkaline, enriched in Al, Ba, and Sr relative to standard granitoids.

	S-type	I-type	A-Type	M-type	Springfield	Bells Mill	Girl Scout
	Chappel and White, 1992		Whalen et al., 1987		Becker, 1996	n = 2	n =3
SiO_2	70.91	69.50	73.41	67.24	69.9	71.93	70.76
TiO_2	0.44	0.41	0.26	0.49	0.6	0.23	0.23
Al_2O_3	14.00	14.21	12.40	15.18	14.5	15.33	15.71
Fe_2O_3	3.11	2.23	2.82	4.29	3.8	1.96	1.89
MnO	0.06	0.07	0.06	0.11	0.1	0.02	0.02
MgO	1.24	1.38	0.20	1.73	1.0	0.42	0.40
CaO	1.88	3.07	0.75	4.27	2.2	1.64	1.96
Na_2O	2.51	3.16	4.07	3.97	3.2	3.72	3.81
K_2O	4.09	3.48	4.65	1.26	4.3	4.38	4.24
P_2O_5	0.15	0.11	0.04	0.09	0.2	0.09	0.07
Major element oxides in reported weight percent							
ASI	1.17	0.98	0.95	0.97	1.04	1.11	1.09
ASI (alumina saturation index) = $Al_2O_3/(CaO+Na_2O+K_2O)$ [Molar]							
Ba	440	519	352	263	-	824	806
Rb	245	164	169	18	144	133	122
Sr	112	235	48	282	142	437	485
Th	19	20	23	1.0	15	14	14
U	5	5	5	0.4	4	3	2
Zr	157	150	528	108	231	148	150
Nb	13	11	37	1.3	11	5	5
Y	32	31	75	22	27	3	3
V	49	57	6	72	54	24	22
Cu	9	9	2	42	6	30	20
Zn	59	48	120	56	53	40	33
Ga	18	16	25	15	17	21	20

Trace elements reported in parts per million

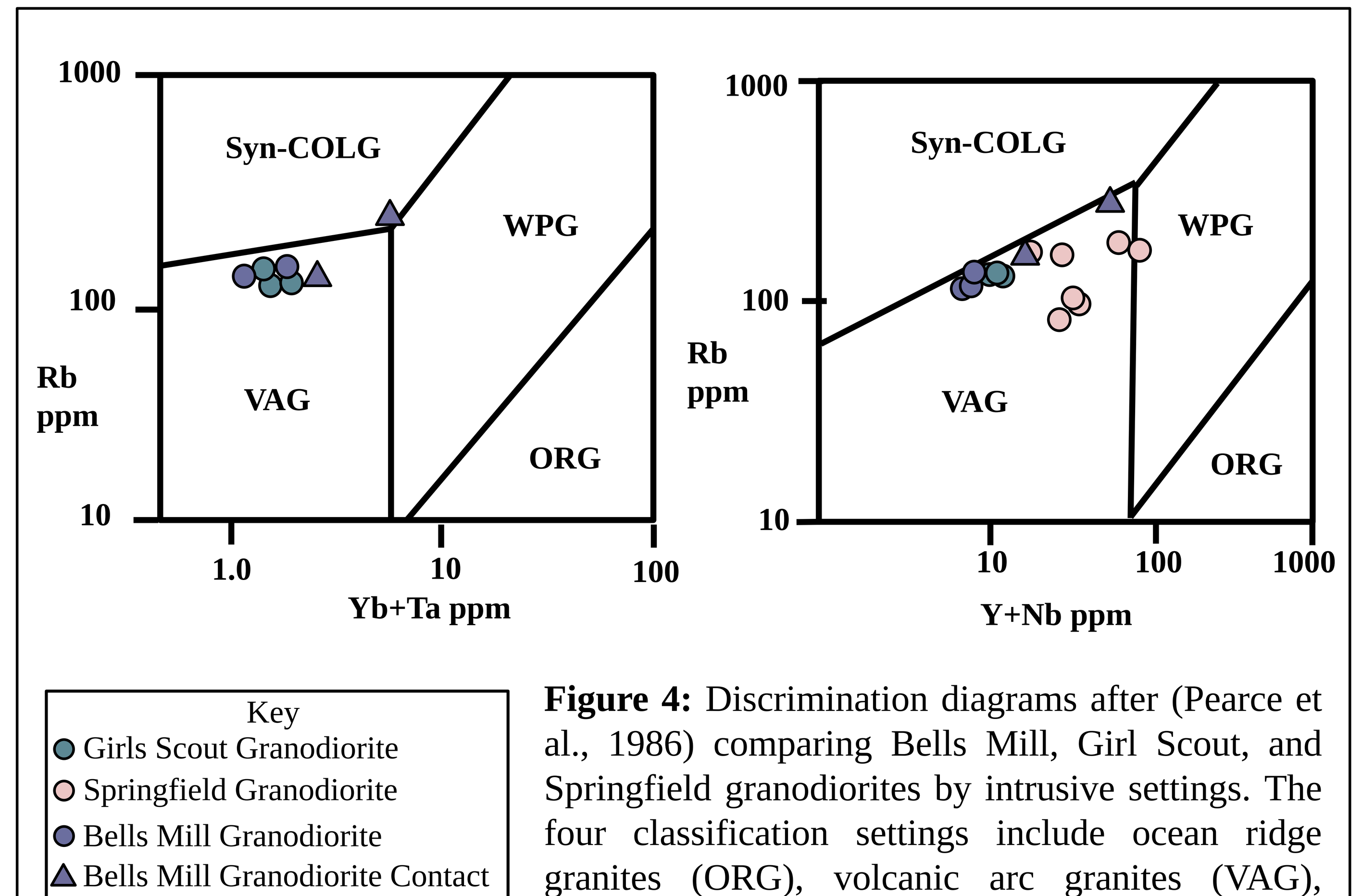


Figure 4: Discrimination diagrams after (Pearce et al., 1986) comparing Bells Mill, Girl Scout, and Springfield granodiorites by intrusive settings. The four classification settings include ocean ridge granites (ORG), volcanic arc granites (VAG), within plate granites (WPG) and collision granites (COLG). Samples analyzed plot within volcanic arc Granitoid field excluding the samples at the contact with the host rock. The sample from the granodiorite/Wissahickon contact follow a trend towards COLG and WPG granitoids. This may represent intermingling with the pelitic Wissahickon schist.

Petrography

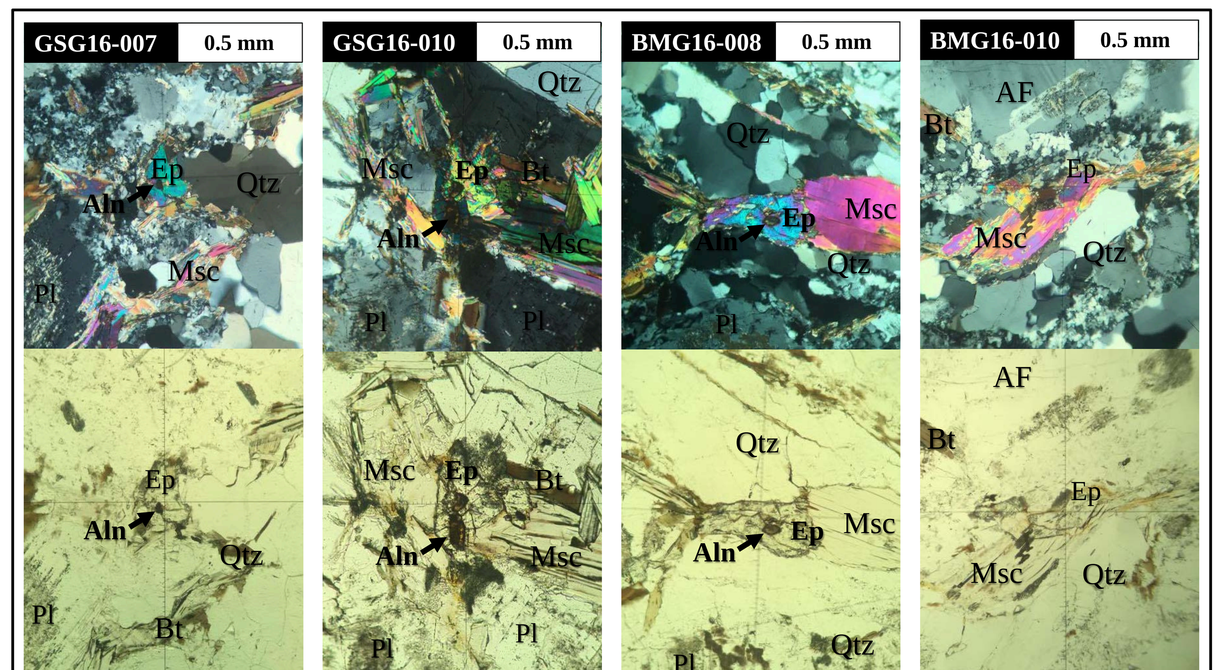


Figure 3: Magmatic epidote present in samples from GSG and BMG often with allanite cores. The presence of epidote and allanite suggest high pressure environment (>600 MPa) (Zen & Hammarstrom, 1984)

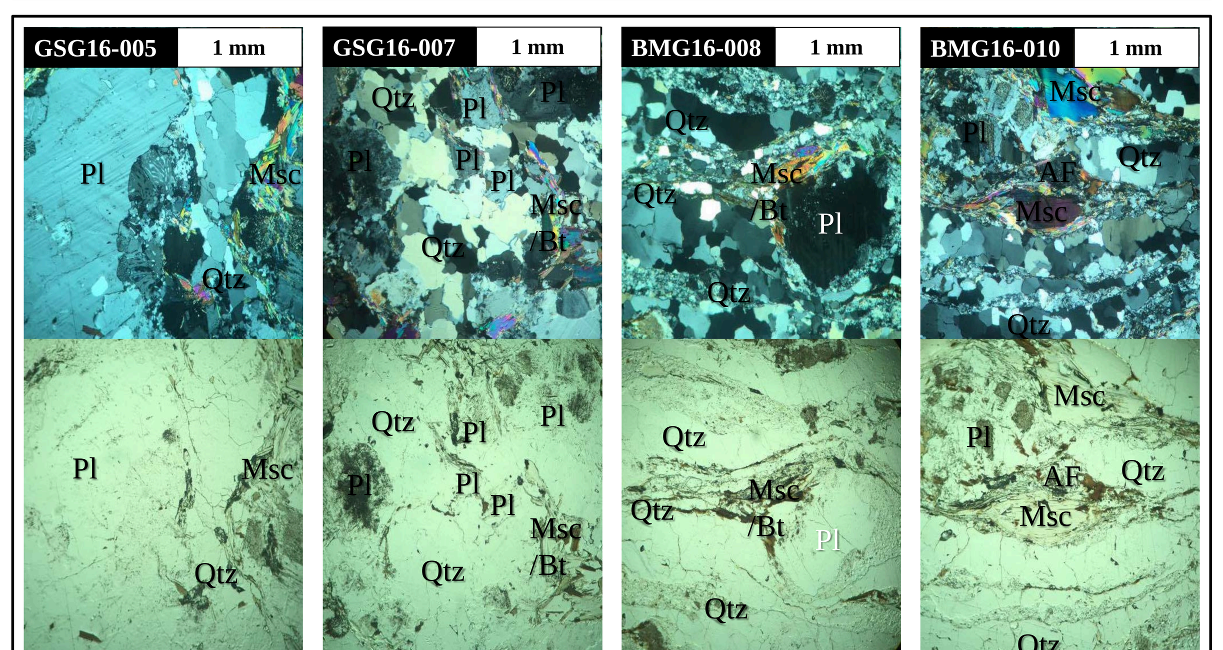
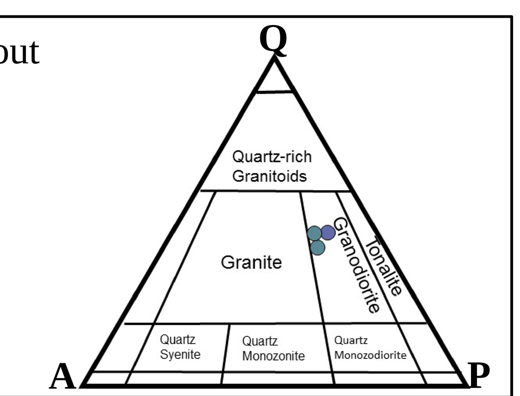


Figure 4: Photomicrographs from GSG show cumulate textures while BMG show foliated textures. This suggests different cooling times at the separate sites, perhaps post-dating and pre-dating metamorphism of the Wissahickon host rock, respectively.

Mineralogy

Table 2: Modal abundance of observed phase in the Springfield (Becker, 1996), Bells Mill, and Gil Scout granodiorites. Modal percents are plotted on a QAP plot placing them all within the granodiorite field.

	Qtz	AF	Pl	Msc	Bt	Ep	Aln	Zrn	Op	Ap
Springfield	34.3	15.7	36.0	0.7	12.4	0.5	tr.	-	tr.	tr.
Bells Mill	38.8	15.5	33.0	7.1	4.8	tr.	tr.	tr.	tr.	tr.
Girl Scout	34.0	8	30.0	5.4	3.6	tr.	tr.	tr.	tr.	tr.



Conclusions

- The presence of magmatic epidote suggests crystallization at high pressures (600-900 MPa) and great depths (20-30 km) in the crust consistent with other granodioritic bodies within the Piedmont including the Springfield (PA) approximately 10 km south of the Bells Mill and Girl Scout granodiorites.
- Mineral modal abundances from the Bell Mill and Girl Scout granodiorites are very similar to the Springfield
- The Bells Mill and Girl Scout granodiorites are peraluminous, subalkaline, and enriched in Al, Ba, and Sr relative to standard granitoids.
- Trace elements plotted on petrogenetic discrimination diagrams plot in the volcanic arc granitoid field. Samples taken in close proximity to the contact with the Wissahickon country rock diverge toward the "within plate granitoid" field showing the influence of assimilation.
- Deformation in the Bells Mill Granodiorite can be interpreted as pre- or syn-tectonic solidification of the granodiorite with respect to peak metamorphism while the Girl Scout Granodiorite may not fully have solidified until after peak metamorphism

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