

## TRIP B1: THE GEOLOGY OF STATEN ISLAND: HARD ROCK GEOLOGY - SELECTED FIELD SITES

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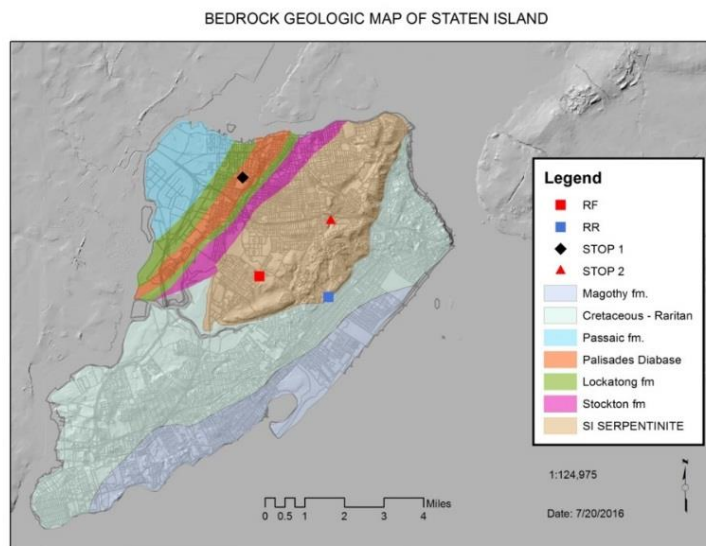
### ABSTRACT

This field trip will visit two localities, namely the Staten Island serpentinite in the I-278 Road Cut and the Palisades Diabase at Graniteville Quarry Park in Staten Island, NY.

### INTRODUCTION

John McPhee(1993) wrote: “ Southeastern Staten Island is a piece of Europe glued onto an ophiolite from the northwest Iapetus floor”.

Staten Island NY, a borough of New York City, approximately 13 miles long axis by 7 miles short axis, has



a very diverse geology (e.g., igneous Rocks, metamorphic rocks, sedimentary rocks, cross bedded sediments, glacial deposits, glacial striations and grooves, kettle holes, beach deposits, streams, bluebelts and coastal features). This field trip will focus on the Diabase of the Palisades Sill at the Graniteville Quarry Park in Staten Island, NY and the Staten Island Serpentine.

Data Sources: FEMA, NYC PLUTO, LION, USGS  
GIS MAP by A. I. Benimoff

Figure 8: Geologic Bedrock map of Staten Island, NY Showing Locations of Field Stops 1 and 2. RF is near Rockland Avenue and Forest Hill Road; RR is at Lincoln Avenue and Richmond Road.

## THE STATEN ISLAND SERPENTINITE

The Staten Island serpentinite (Figure 1) is a lens shaped NE-SW trending body, having a long dimension of 12 km and a width of 4.7 km. The ridge of serpentinite, makes up the bedrock in the northeastern section of Staten Island, and reaches an elevation of approximately 135 meters above sea level. The serpentinite body is part of a string of similar ultramafic bodies, extending throughout the Appalachians, from Alabama to Newfoundland (Figure 1). The serpentinite displays a sheared contact with the Hartland formation along its eastern margin (Lyttle and Epstein, 1987) and is uncomfortably overlain by the Triassic age Stockton formation of the Newark super group at the western margin. In places, the western contact is faulted. The southern and eastern margins of the serpentinite are overlain by the Raritan formation of cretaceous age. Pleistocene glacial deposits overlay most of the serpentinite. In cross section the serpentinite body is a wedge shaped pod, extending downward approximately 1.3 km (Yersak, 1977). The serpentinite is situated on Cameron's Line at the base of the Hartland Formation (Lyttle and Epstein, 1987). Hollick (1909) suggested that the Staten Island Serpentinite is a fault bounded horst block. Crosby (1914) and Miller (1970) share that interpretation.

The Staten Island Serpentinite is part of a discontinuous chain (Figure 2) of ultramafic bodies that extends from Alabama to Québec. The Staten Island body is the largest of four lenticular masses exposed in the New York City area that includes exposures at Hoboken, New Jersey, Western Manhattan, and Easton Bronx. It is a wide lens shape (Figure 1) that trends Northeast – Southwest and comprises the bedrock of northern Staten Island, although the Western boundary is not exposed. There is general agreement that the Staten Island Serpentinite is positioned on Cameron's line which defines the tectonic boundary of the western part of the Appalachian core zone. Lyttle and Epstein (1987) stratigraphically place (Figure 2) the Staten Island meta-peridotite and other related serpentinite bodies on Cameron's line conformably above member C of the Manhattan Schist but suggest that most of the peridotite lies east of Cameron's line at the base of the Hartland terrain.

### Petrology

Germine (1982), Germine and Puffer (1981) and Puffer and Germine (1994) methodically examined samples of the Staten Island Serpentinite from 27 localities. They determined that about 66% of the serpentinite is lizardite and 27% chrysotile. Other predominate minerals are olivine, chromite, and magnetite together with minor talc, anthophyllite, relic pyroxene, chlorite, and magnesite. They concluded that the protoliths of the serpentinite body were harzburgite and dunite. The Staten Island serpentinite has been divided into two zones by Behm, (1954): a highly sheared outer serpentinite characterized by an abundance of talc, anthophyllite, and magnetite, and a relatively massive, under formed inner zone composed largely of partially serpentinite peridotite. Although now largely a serpentinite, the protolith was a peridotite that was serpentinitized before or during Taconic tectonic emplacement. If the protolith was an ophiolite, most hydration to serpentine was probably introduced by heated deep marine water circulation near a spreading center. Most samples of peridotites dredged from the ocean floor are largely hydrated to serpentine and contain over 10% H<sub>2</sub>O. Recent chemical analyses of selected Staten Island Serpentinite are shown in Tables 1 and 2 (Benimoff, 2015).

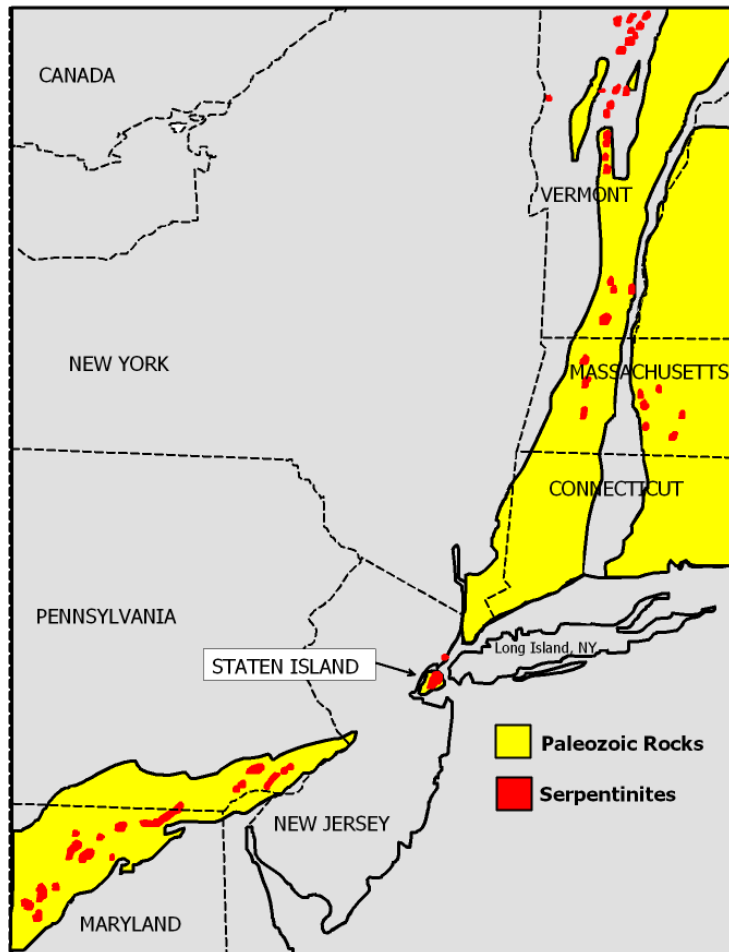


Figure 2: Serpentinite occurrences in the central and northern Appalachians appearing on the USGS "Tectonic map of the United States (modified from Puffer, 1996)

Clues as to the original protolith are found in some of the olivine rich samples, particularly from the North – Central portion of the ultramafic body. Unaltered pyroxene is rarely observed in any of the rock but phenocrysts of pyroxene that have been partially or completely altered to inter growths of chlorite, talc and oxide are common in some of the massive serpentinite. These altered pyroxene phenocrysts make up about 15% of subsamples and indicate that such rock was a harzburgite. Most samples of massive serpentinite where primary igneous textures are preserved, however, do not contain evidence of pyroxene and are probably dunite.

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TABLE 1: Chemical Analyses of Serpentinite (Benimoff, 2015)

	Major Oxides (wt.%)										
	RR01	RR02	RR03	RR04	RR05	27801	27802	27803	27804	103401	103402
SiO <sub>2</sub>	36.40	32.95	37.08	34.27	36.27	37.08	37.77	34.26	37.11	37.33	35.83
TiO <sub>2</sub>	0.002	0.002	0.001	0.002	0.002	0.002	0.001	0.004	0.004	0.005	0.006
Al <sub>2</sub> O <sub>3</sub>	0.31	0.06	0.21	0.07	0.28	0.58	0.45	0.19	0.48	0.56	0.35
FeO*	6.63	5.60	6.23	6.29	6.70	6.52	6.14	6.45	6.22	6.39	6.71
MnO	0.087	0.086	0.094	0.084	0.085	0.101	0.085	0.101	0.087	0.099	0.090
MgO	39.97	42.11	38.79	40.68	39.74	39.12	38.25	39.78	38.02	38.89	39.82
CaO	0.02	0.01	0.04	0.01	0.02	0.06	0.18	0.02	0.22	0.06	0.02
Na <sub>2</sub> O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
K <sub>2</sub> O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
P <sub>2</sub> O <sub>5</sub>	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
LOI %	15.49	17.95	16.10	17.11	15.51	15.56	15.65	17.16	15.84	15.52	15.78
SUM	98.92	98.76	98.56	98.52	98.61	99.02	98.53	97.96	97.98	98.86	98.62
	Trace elements (ppm)										
Ni	2270	2706	2136	2373	2303	2198	2027	2264	2030	2171	2338
Cr	2344	1583	2505	3395	2015	2542	2398	2397	2519	1998	2145
V	21	9	13	12	22	21	22	13	27	23	21
Ga	0	0	1	1	0	2	1	1	1	0	0
Cu	7	5	5	3	6	12	6	6	6	6	6

RR01 – RR05 RR in Figure 1; 103401-103402 RF in figure 1RF; 27801 -27803 Stop 2 in Figure 1

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TABLE 2 : REE Analyses and Other Trace Elements in ppm (ICP-MS) Benimoff, 2015)

Sample ID	RR01	RR02	RR03	RR04	RR05	27801	27802	27803	27804	103401	103402
La	0.090962	0.03474	0.15	0.085	0.076	0.077	0.06	0.141	0.25	0.086	0.034
Ce	0.206854	0.09085	0.304	0.184	0.183	0.174	0.142	0.282	0.451	0.214	0.098
Pr	0.021078	0.00907	0.03	0.016	0.016	0.017	0.014	0.031	0.047	0.024	0.01
Nd	0.08032	0.03696	0.102	0.059	0.061	0.055	0.053	0.122	0.178	0.086	0.05
Sm	0.014897	0.00855	0.008	0.007	0.008	0.008	0.007	0.019	0.032	0.012	0.011
Eu	0.0036	0.00408	0.008	0.002	0.005	0.002	0.003	0.012	0.024	0.003	0.012
Gd	0.013665	0.01071	0.015	0.011	0.014	0.01	0.011	0.027	0.034	0.01	0.01
Tb	0.003096	0.00189	0.003	0.003	0.002	0.003	0.001	0.006	0.009	0.002	0.002
Dy	0.022994	0.01978	0.021	0.019	0.023	0.021	0.018	0.064	0.063	0.016	0.02
Ho	0.005885	0.00589	0.005	0.005	0.008	0.006	0.006	0.018	0.019	0.006	0.006
Er	0.020287	0.02672	0.019	0.017	0.028	0.021	0.024	0.072	0.067	0.021	0.022
Tm	0.003708	0.00431	0.004	0.003	0.006	0.005	0.005	0.015	0.013	0.004	0.004
Yb	0.028288	0.03972	0.026	0.026	0.044	0.044	0.038	0.122	0.107	0.033	0.033
Lu	0.004632	0.00623	0.003	0.004	0.007	0.008	0.007	0.02	0.019	0.006	0.006
Ba	0.889996	0.51446	0.611	0.471	0.997	1.008	0.739	3.476	8.284	0.665	0.561
Th	0.046683	0.0231	0.041	0.037	0.042	0.038	0.035	0.036	0.052	0.046	0.025
Nb	0.032614	0.01118	0.028	0.142	0.027	0.028	0.021	0.05	0.073	0.036	0.008
Y	0.139294	0.17361	0.132	0.134	0.165	0.153	0.131	0.418	0.483	0.144	0.156
Hf	0.021136	0.00973	0.019	0.015	0.017	0.015	0.014	0.02	0.027	0.016	0.01
Ta	0.003095	0.00122	0.002	0.028	0.002	0.003	0.003	0.004	0.009	0.003	0.001
U	0.013377	0.00505	0.014	0.024	0.01	0.013	0.01	0.011	0.014	0.011	0.007
Pb	0.060827	0.06128	0.299	0.212	0.104	0.075	0.062	0.096	0.179	0.059	0.051
Rb	0.141584	0.26724	0.176	0.117	0.172	0.137	0.156	0.872	2.307	0.098	0.216
Cs	0.005796	0.00762	0.083	0.051	0.009	0.016	0.016	0.024	0.03	0.017	0.003
Sr	1.160683	0.28454	0.682	0.507	1.029	0.698	0.73	1.076	2.514	0.64	0.65
Sc	5.87434	1.86186	5.652	2.733	5.552	7.012	6.665	6.834	6.822	5.101	3.772
Zr	0.840324	0.3592	0.574	0.507	0.71	0.603	0.454	0.646	0.793	0.714	0.436

### Ophiolite Emplacement

Most of the original olivine has been altered to serpentine but some samples contain as much as 50% olivine. The average olivine content of the Staten Island serpentinite is about 5% but it is absent from most samples. Where present, olivine typically occurs as relic anhedral micro – islands surrounded by serpentine that has replaced most of the individual grains or as larger grains thing by olivine. Further details of the petrology of the serpentinite are given in Behm (1954), Germine and Puffer (1981) and Puffer (1996). Puffer (1996) compares two mechanisms of serpentinite emplacement: Obduction of an ophiolite-suite member or a metamorphosed olivine cumulate zone in a layered gabbro magma chamber. Puffer (1996) supports the obducted ophiolite member since the serpentinite is associated with the Harland schist. Puffer (1996) concludes that the mode of emplacement of the New York area serpentinites is controversial but most evidence tends to favor Taconic obduction of the base of the lapetus ophiolite sequence. Thus would force the placement of the New York area serpentinites into the

Taconic suture zone (Cameron's line) between the Hartland terrain and Manhattan C terrain. There is general agreement that the chemistry of olivine and spinel reflect the magmatic conditions of origin of highly serpentinized peridotite (Dick and Bullen, 1984; Arai, 1994; Kametesky et al., 2001; Metsger et al., 2002).

Recently Benimoff and Lupulescu (2008) sampled serpentinite samples from an excavation (Figure 2) for a shopping center in the Staten Island Serpentinite (N 40.5813° and W 74.1123°). The average composition of the serpentinite at this location is SiO<sub>2</sub> 34.96, Al<sub>2</sub>O<sub>3</sub> 0.21, CaO 0.04, MgO 41.41, Na<sub>2</sub>O<0.01, K<sub>2</sub>O 0.03, Fe<sub>2</sub>O<sub>3</sub> 7.66, MnO 0.01, TiO<sub>2</sub> 0.02, Cr<sub>2</sub>O<sub>3</sub> 0.44, and LOI 15.57 sum 100.36 wt. %. They reported Cr-spinel grains disseminated in the serpentinite; the grains are fractured and some are zoned with a Cr- rich core and Fe-rich rim. Electron microprobe analyses were used to compute the following empirical formulas for core (Fe<sup>+2</sup> 0.70 Mg 0.28 Mn 0.02) Σ=1.00 (Cr 1.47 Al 0.39 Fe<sup>+3</sup>0.14 ) Σ=2.00 O<sub>4</sub> and rim (Fe<sup>+2</sup>0.88Mg 0.11Mn0.01) Σ=1.00 (Cr 0.7028 Al 0.01 Fe<sup>+3</sup> 1.28) Σ=1.99 O<sub>4</sub> respectively. Cr numbers range from 94-99 in the rim to 79-87 in the core and the Mg numbers from 9-11 in the rim to 25-30 in the core indicating a probable dunite- harzburgite derivation. The core of the spinels analyzed in their study plot at the margin of the fore-arc peridotite region of Coish and Gardner (2004) in the (Cr/Cr+Al)sp vs. (Mg/Mg+Fe)sp diagram.

Recent work by Moores et al. (2000) describe a conflict in many ophiolite complexes that they call the "Ophiolite conundrum". The conflict is between "(1) structural and stratigraphic evidence for sea-floor spreading in a non-island arc environment and (2) geochemical evidence for derivation of magmas from highly depleted mantle similar to that found at present over subduction zones (suprasubduction zone settings)." Furthermore, oceanic paleogeography of the pre-suture ocean basin can be complex because dismembered ophiolitic rocks are associated with both MORB and arc-like igneous rocks (Tankut, et al. 1998). Ophiolite complexes can be divided into either Tethyan or Cordilleran (Moores et al. 2000; Wakabayashi and Dilek, 2003).

Coish and Gardner (2004) studied olivine samples from the meta-peridotite of the Vermont Appalachians in order to evaluate whether they were indeed parts of ophiolites, and if so in what tectonic environment they might have formed. They concluded through remnant olivine and chromite chemistry, that the peridotites probably formed in the fore- arc of an early Ordovician subduction zone. In their study they plotted Fo compositions of olivine against Cr/(Cr+Al)sp. It is clear that their Fo compositions fall mainly within the mantle array. They concluded that this represents conditions before serpentinization and regional deformation. Furthermore, they state that "the small Fo range is typical of residual peridotite, particularly harzburgite and dunite, and unlike cumulate rocks which tend to show lower Fo contents" (Arai, 1994). Their geochemical analyses on olivine and spinel support the hypothesis that their peridotites formed as highly-depleted mantle residues and they probably formed in a fore-arc, suprasubduction zone during the early Paleozoic. The data suggest that this serpentinite body probably formed in the same way as that described by Coish and Gardner (2004) for the serpentinite in the Vermont Appalachians namely in a fore-arc suprasubduction zone (Figure 3).

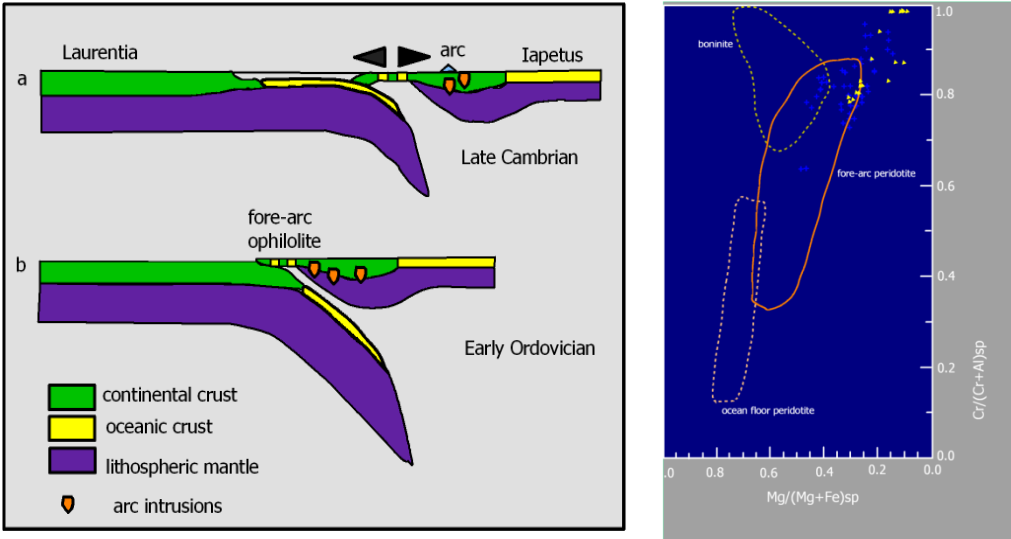


Figure 3 left: Modified from Coish and Gardner (2004). Figure 3 right: modified from Coish and Gardner (2004); Yellow triangles - chromian spinel from Benimoff and Lupulecu (2008). (+) Vermont (Coish and Gardner, 2004); Also shown are fields for ocean floor Peridotite (Dick and Bullen, 1984; Arai 1994b) harzburgite and dunite from hole 779A in the Mariana forearc (Parkinson And Pearce, 1998), and boninites (Arai, 1994a; Barnes and Roeder, 2001). Note that Cr-spinel compositions (Benimoff and Lupulecu, 2008) from the core plot within field of fore-arc peridotite

However, the occurrence of a suprasubduction zone peridotite in the Northern USA Appalachians (Coish and Gardner, 2004) is not clear evidence that the Staten Island serpentinite is a Cordilleran type. Puffer (2013) presents evidence the Staten Island ophiolite resembles the Wakabayashi and Dilek (2003) interpretation of a Tethyan ophiolite more closely than a Cordilleran type. Evidence includes the fact that the Hartland occurs above the Staten Island ophiolite (Figures 2 and 3). If the Hartland is interpreted as an accretionary complex it should instead exist beneath the ophiolite (Figure 4) to fit the Cordilleran description. Puffer (2013) also points out that the petrologic characteristics of undisputed accretionary complexes such as the Franciscan Formation of California are much different than Hartland rock. However, the issue is probably not settled.

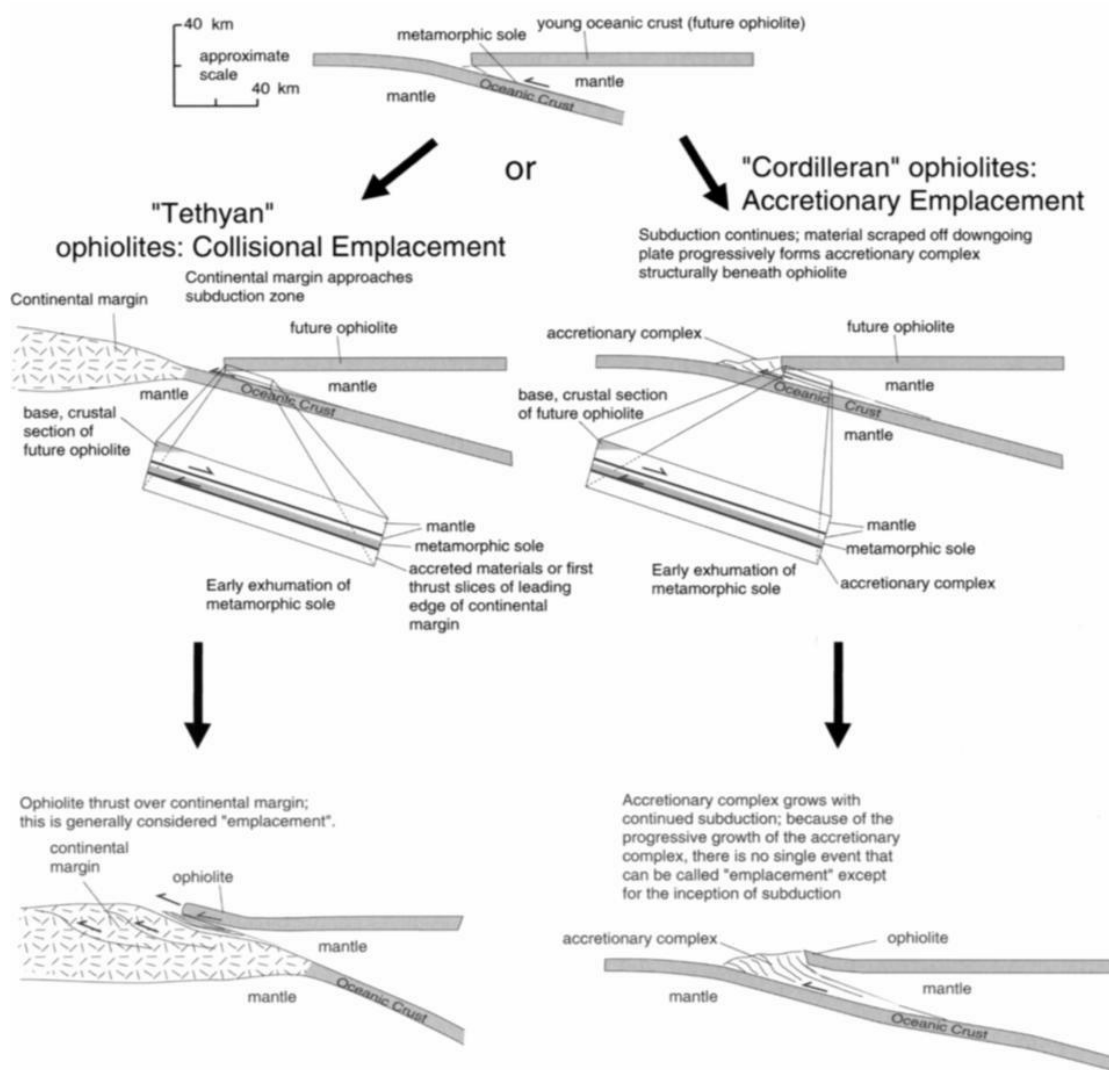


Figure 4. After Wakabashi and Dilek (2003): Emplacement of Tethyan and Cordilleran ophiolites. It should be noted that if a continental margin is attached to the plate subducting beneath a Cordilleran ophiolite, such an ophiolite may eventually be thrust over a continental margin, 'converting' it to a Tethyan-type ophiolite.

#### Further Geochemical Studies

Extended trace element patterns (figure 5) are characterized by a strong enrichment in Pb and a negative anomaly in Nb and Ti.



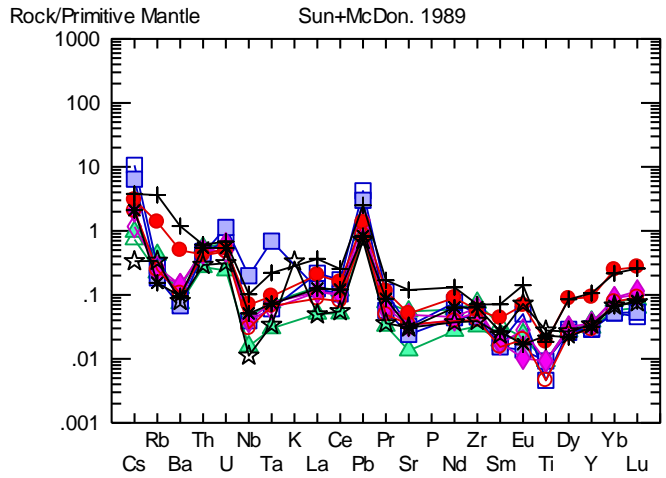


Figure 5. Mantle Normalized spider diagram (Sun and McDonough, 1989) of all samples from Table 2.

Three types of serpentinites are present in subduction zone, namely abyssal serpentinites, mantle wedge serpentinites and subducted serpentinites (Deschamps et al., 2013). Benimoff (2015) reported that most of the specimens of this study plot (La/Yb vs. Yb; U vs. Yb) in the abyssal serpentinite field (figure 6).

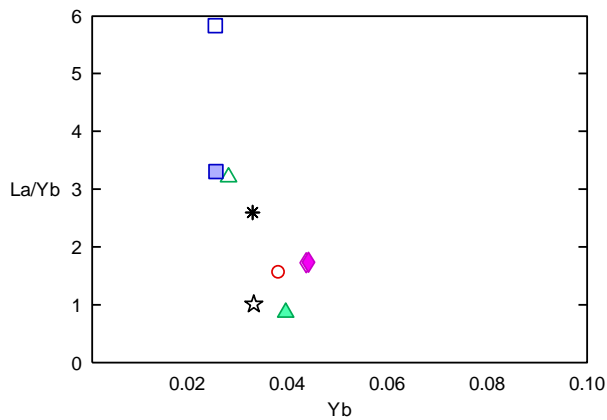


Figure 6 Serpentinites from this study plotted in La/Yb vs. Yb. These samples plot in the abyssal serpentinite field of Deschamps et al. (2013).

## The Palisades Diabase on Staten Island at the Graniteville Quarry Park

Recent details on the Palisades Sill can be found in Puffer et al. (2010) and Puffer (2013). It is an exceptional occurrence wherein one can observe the parent of an igneous rock adjacent to that igneous rock. This is the case at the Graniteville Quarry Park (Stop 1) on this field trip where marginal fusion of a xenolith of sodium-rich Lockatong argillite enclosed in the basaltic magma of the Palisades sill resulted in coexisting silicic and mafic melts. This phenomenon was studied in detail by Benimoff and Sclar (1984) and Sclar and Benimoff (1993), and a summary of these studies is presented below. A xenolith of Lockatong argillite is exposed in the Palisades diabase in the Graniteville Quarry Park in Staten Island.

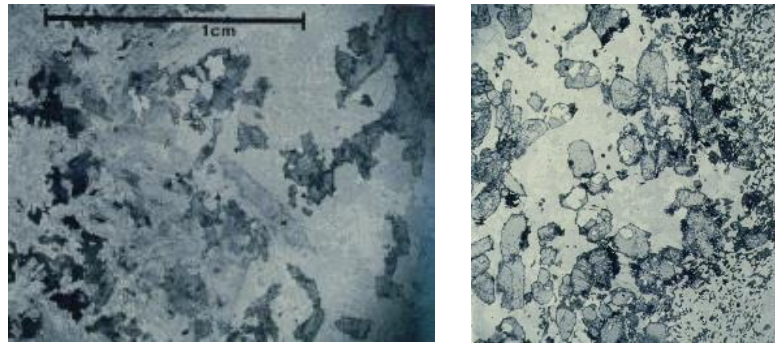


Figure 7: Photomicrographs of the Diabase-Trondhjemite contact (right) and the Trondhjemite – Xenolith contact (left)

The xenolith has been recrystallized to a hornfels. It is a vertically dipping slab, 0.3 to 0.5m wide, and some 30 m long. The xenolith strikes N 30°W. The bottom of the xenolith is not exposed. Benimoff and Sclar (1984) concluded that the xenolith was derived from the Lockatong formation below the sill. Between the diabase and the hornfelsed xenolith is a sharply bounded interface zone of coarse-grained igneous rock (Figure 7). The interface zone ranges from 5 to 12 cm in thickness and completely surrounds the xenolith. They have categorized the coarse-grained rock of the interface zone as a melanocratic pyroxene trondhjemite.

The diabase at Graniteville is composed dominantly of plagioclase ( $An_{61}Ab_{38.8}Or_{0.2}$ ) and augite ( $En_{34-44}Fs_{17-31}Wo_{35-42}$ ) ( Benimoff and Sclar, 1984). The augite contains exsolution lamellae of pigeonite on (001), and typically exhibits simple contact twinning on (100). A granophyric intergrowth of quartz and K-feldspar is present in minor amounts. Grains of titanomagnetite with oxidation lamellae of ilmenite and discrete grains of ilmenite are common.

The trondhjemite is composed dominantly of quartz-albite granophyre in which are enclosed large discrete crystals of albite and Ca-rich clinopyroxene (Benimoff and Sclar, 1984). Minor constituents include interstitial calcite, titanite, ilmenite, optically homogeneous titanomagnetite, nickelian and cobaltian pyrrhotites, apatite, and zinc sulfide (Sclar and Benimoff, 1993). The modal mineral percentages are clinopyroxene 38, albite 38, quartz 18, titanite 2.7, calcite 1.3, and opaques 2.0.

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The xenolith is now a hornfels and exhibits a granoblastic texture. The hornfels is composed dominantly of albite and quartz and subordinantly of calcite, titanite, apatite, ilmenite, and actinolite. The modal mineral percentages are albite 66, quartz 30, titanite 2.3, calcite 0.9, apatite 0.5, and actinolite 0.3. The bulk composition of the xenolith is variable which is not unexpected for a rock of sedimentary origins. Normative albite ranges from 56.4 to 80.2 wt.%, whereas normative quartz ranges from 7.0 to 35.4 wt.%.

A core of the three contiguous rocks was cut into 1mm slabs and each slab was analyzed for major, minor and trace elements (Benimoff and Sclar, 1996). Concentration vs. distance profiles were constructed in order to see the distribution of these elements in the three contiguous rocks. This is the way nature distributed these elements. Further diffusional studies are planned.

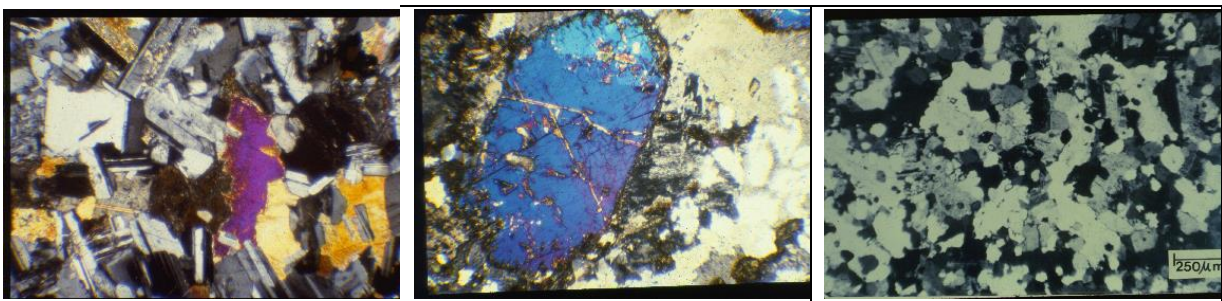


Figure 8. Photomicrographs of diabase, trondhjemite and xenolith

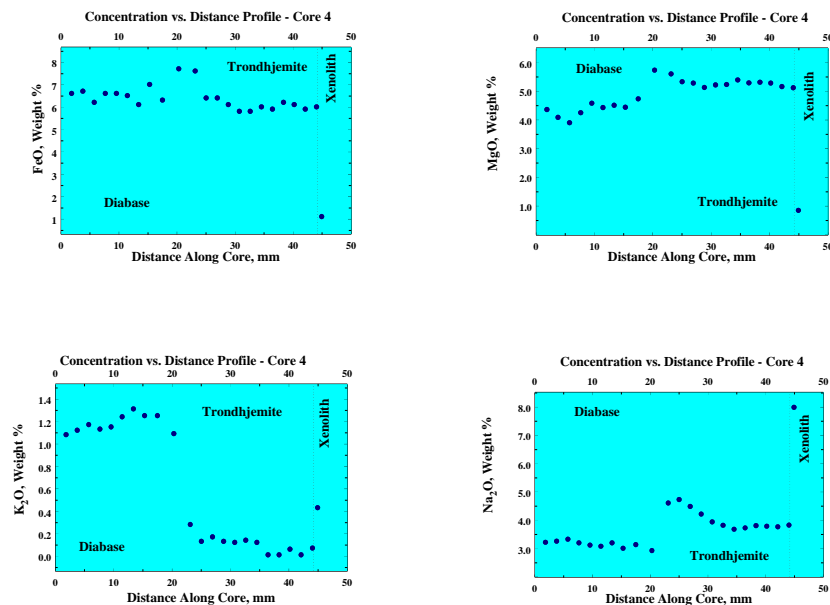


Figure 9 Concentration vs. Distance profiles. The diabase – trondhjemite contact is at 22mm in the core.

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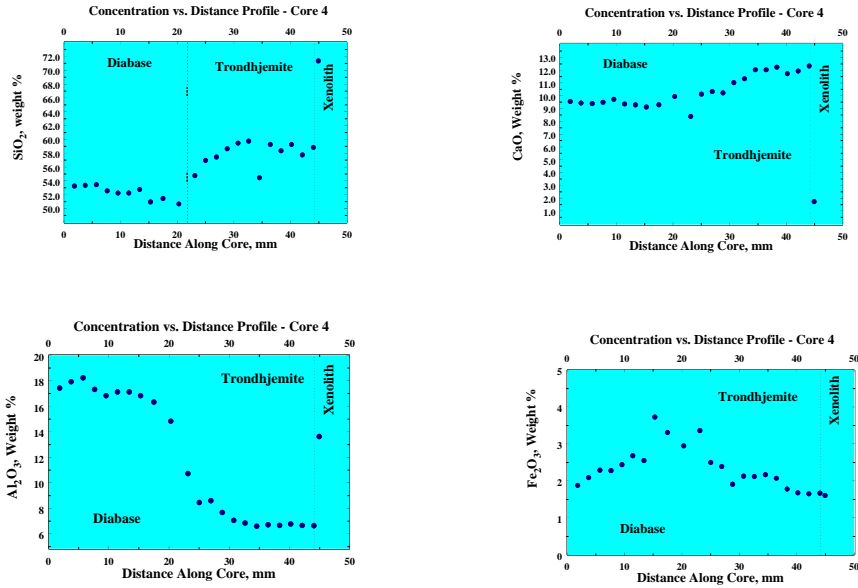


Figure 10 Concentration vs. Distance profiles. The diabase – trondhjemite contact is at 22mm in the core.

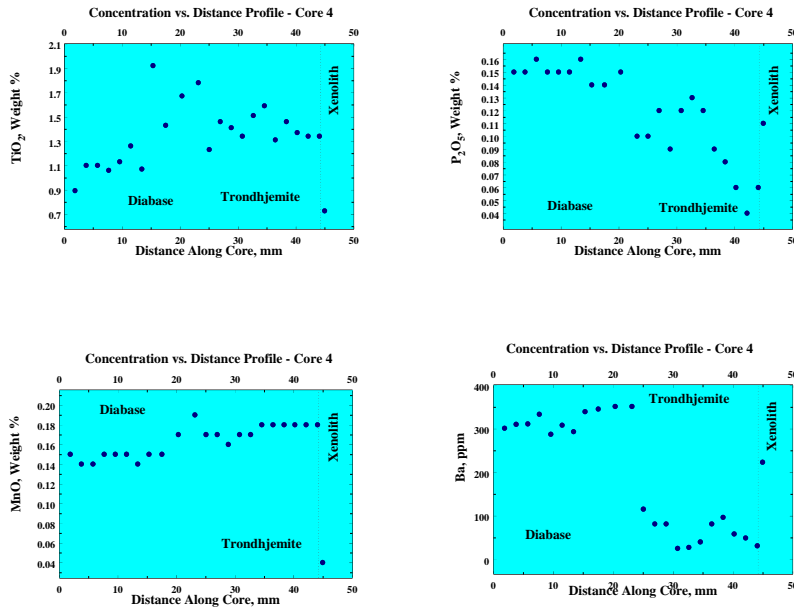


Figure 11 Concentration vs. Distance profiles. The diabase – trondhjemite contact is at 22mm in the core.

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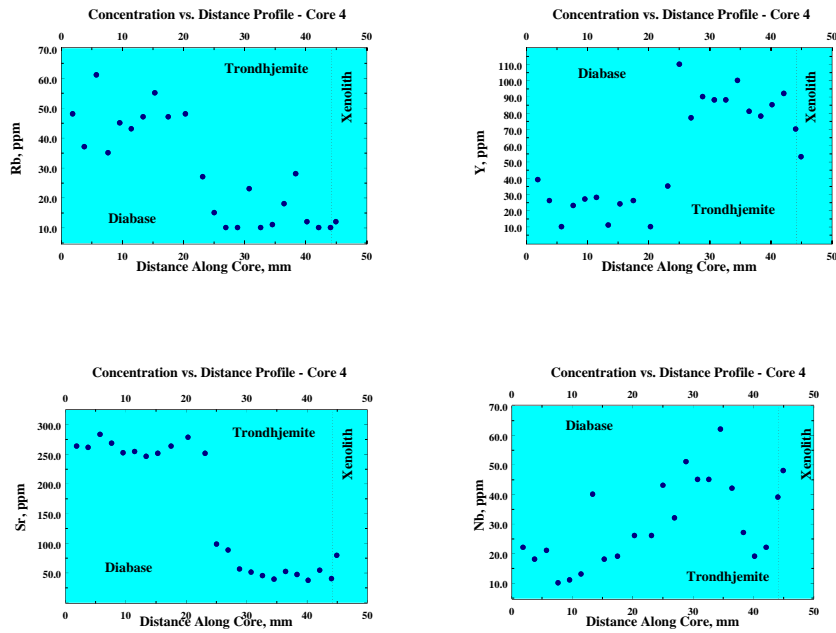


Figure 12 Concentration vs. Distance profiles. The diabase – trondhjemite contact is at 22mm in the core.

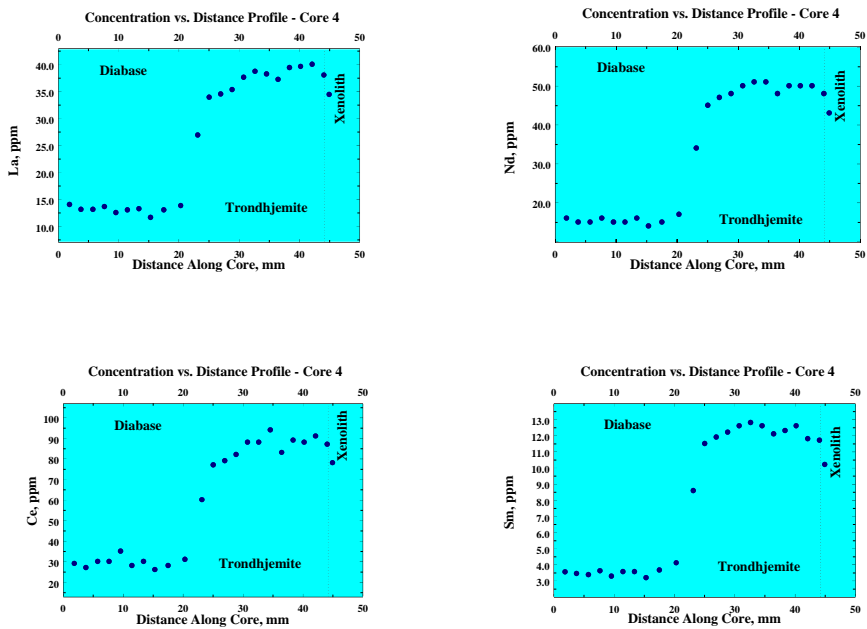


Figure 13 Concentration vs. Distance profiles. The diabase – trondhjemite contact is at 22mm in the core.

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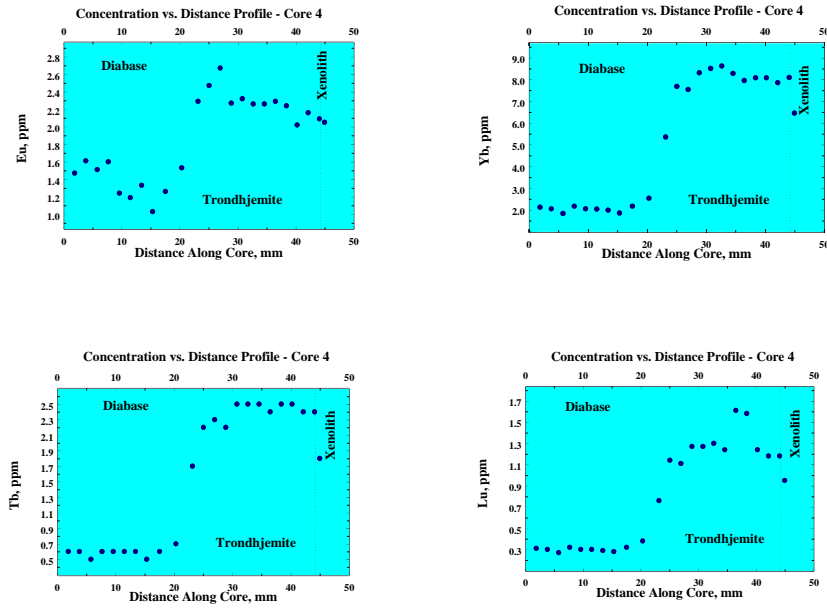


Figure 14 Concentration vs. Distance profiles. The diabase – trondhjemite contact is at 22mm in the core.

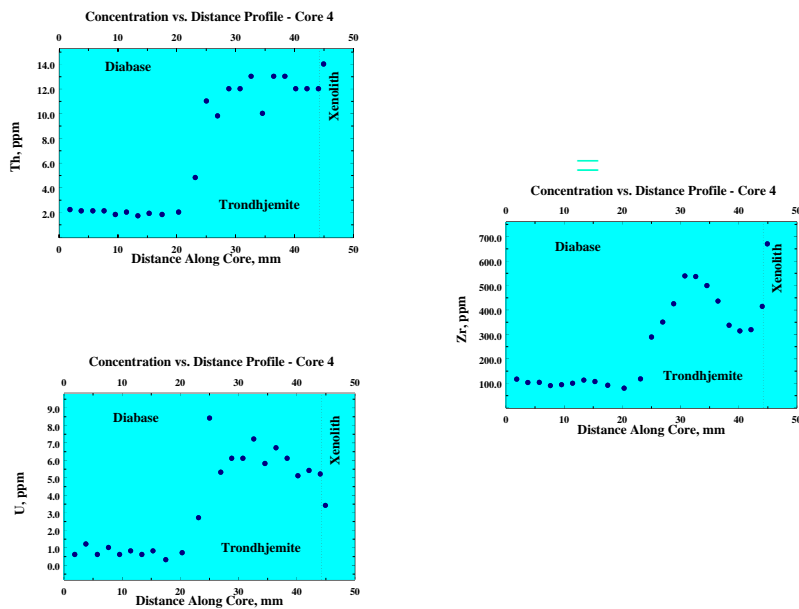


Figure 15 Concentration vs. Distance profiles. The diabase – trondhjemite contact is at 22mm in the core.

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Benimoff and Puffer (2005) in their tri-modal fusion study of meta-argillites in the Palisades sill determined that there is virtually no mixing of the fusion zone melt with the early Jurassic diabase intrusion beyond about 1 mm from the contact and 2) assuming a typical sodic argillite xenolith, the iron, magnesium, and calcium depletion of the unbelted portion of the xenolith is balanced by enrichment of these elements in the fusion zone. The Palisades diabase disk cut 2 mm from the contact with the fusion zone is chemically the same as the disk cut 20 mm from the contact and is the same as a Palisades diabase sample collected 0.5 m from the contact. For example the 10 samples of Palisades diabase sampled within 20 mm of the contact maintain values of 1.3-1.5 percent K<sub>2</sub>O, 291-346 ppm Ba, and 248-269 ppm Sr in distinct contrast to the 0.01-0.08 percent K<sub>2</sub>O, 10-70 ppm Ba, and 31-75 ppm Sr content of the fusion zone.

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## FIELD GUIDE AND ROAD LOG

**DATE: SUNDAY, October 2, 2016**

**MEETING POINT: Graniteville Quarry Park**

From NJ take the Goethals Bridge (I-278 EAST) and exit at Forest Avenue, make left turn onto Forest Avenue; drive 1.4 miles and park on right side south side of Forest Avenue between Van Name and Simonson Avenues meet at sign for Graniteville Quarry Park.

Meeting point Coordinates: Latitude +40.624689° ; Longitude -74.153697

Meeting Time: 9:00 AM

### STOP 1. Xenolith fusion (trondhjemite) at Graniteville Quarry Park , Staten Island, NY

At this stop we will examine a xenolith of argillaceous Lockatong Formation enclosed in Palisades diabase that has undergone partial fusion to yield a pyroxene trondhjemite. The sodium-rich slab-like xenolith of argillite is 30 m long,, 0.5 m thick and strikes N 30° E with a vertical dip. The xenolith was derived from Lockatong located below the sill. One could think of this as ancient divergent plate boundary.

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Distance in Miles			
Cumulative	Point	to	Route Description
	point		
0	0.3		Right turn on willow Road West
0.4	0.1		Enter NY 440 South
1.1	0.7		Bear right onto ramp for I-278 East
1.6	0.9		Enter I-78 east
3.3	1.7		Take Exit 12 Todt Hill Road
3.5	0.2		Right Turn onto Todt Hill road
3.6	0.1		Left Turn onto Lightner Avenue
3.7	0.1		Right Turn onto Melhorn Rd.
3.7	0.0		Park on Melhorn Road. +40.608940°; -74.11433° we will meet here. We will then walk east on Lightner Avenue and take the dead end road on the right. Proceed on trail downhill and take the trail on the left, proceed uphill and proceed north to outcrop. This is a filled in road cut for a now de-mapped road. I-278 is to the north. Do not enter I-278!

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### STOP 2: The Staten Island Serpentinite in the I - 278 Road Cut

This is an outcrop of Staten Island serpentinite that was emplaced during the Taconic Orogeny, during the assembly of Pangaea. The serpentinite was emplaced as an ophiolite along a plate suture between an island arc (Hartland Terrane) and sediments accumulating along the Laurentian continental margin(Manhattan schist). The serpentinite is composed of lizardite, chrysotile, antigorite and Olivine. chromite, magnetite, anthophyllite, magnesite and other accessory minerals. One could think of this as an ancient convergent plate boundary.