THE NYACK SECTION OF THE PALISADES: FACIES, CONTACTS AND LAVA DOMES

Jeffrey C. Steiner
Dept. of Earth and Planetary Sciences
The City College of New York
New York, NY 10031

INTRODUCTION

The Palisades is a large, internally layered tholeiite intrusion which is exposed for approximately fifty miles along the west side of the Hudson River (figure 1). This trip examines pigeonite and augite dolerite sites on an Upper Nyack to Valley Cottage, New York traverse (figure 2).

The data previously collected at these sites will be used to address the issue of identifying the number of magma pulses which produced these and related facies. Peripherally, the relationship of the internal layering to the pulses will also be explored.

The Palisades has widely been considered to have arisen from at least two magma pulses (Walker, 1969). These pulses were defined petrographically by Walker (1969) and may be synchronous with the First Watchung and Ladentown-Union Hill Basalts, respectively (Puffer, et al., 1982, and this volume). Recently, Shirley (1987) identified three to four poorly defined pulses, none of which were characterized petrographically. The pigeonite and augite dolerites of present interest document a pulse distinct from those identified by Shirley (1987), but petrographically similar to Walker's Pulse 1 at Haverstraw Quarry.

INTERNAL STRUCTURE

Walker (1969) defines Pulse 1 as comprised of the chilled dolerite at Kings Bluff, N. J., the early dolerite at Englewood Cliff, N. J., and an early pigeonite dolerite stage at Haverstraw, N. Y. This suite is overlain by the early, middle and late fractionation stages of his Pulse 2. The juncture between these pulses is marked in the southern Palisades by the olivine layer (fractionation stage 2, hyalosiderite) which was considered by Walker (1969) and Walker, F (1940) not to be a separate picritic intrusion, though Husch (1989) provides recent comment to the contrary. Walker (1969) proposed that the hyalosiderite facies is not a cumulus zone (Walker, F., 1940), but rather an unusual facies produced as a contact effect during a quiescent period just subsequent to the second pulse.

The olivine layer occurs 20 to 60 feet above the base of the intrusion in the southern Palisades. It extends to a suggested terminus in Nyack Beach State Park (Walker, 1969). The northern continuation of the inter-pulse boundary was considered to be

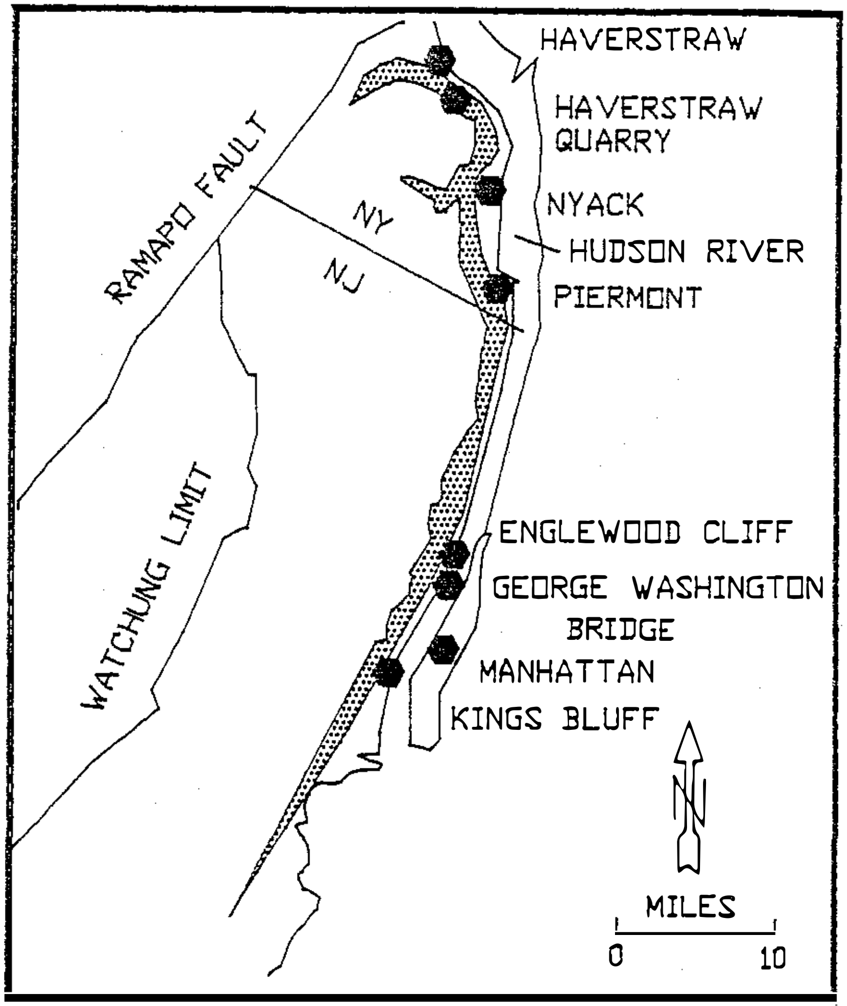

Figure 1. Generalized geologic map after Fisher, et al. (1970) showing the outline of the Palisades.

represented by the (early) pigeonite dolerite of Haverstraw Quarry by virtue of (1) an apparent reversal in pyroxene crystallization, (2) the presence of interstitial glassy mesostasis thought to be otherwise absent in the intrusion and (3) its appropriate location at 105 feet above the base of the intrusion. The early bronzite dolerite encountered by Walker (1969) at the 150 foot level was considered to mark the partially commingled base of the second pulse.

Recent investigations by Steiner, et al. (1989a,b) describe occurrences of pigeonite dolerite south of Nyack Beach State Park and in areas overlooking the Park which are remarkably similar to the early pigeonite facies (Pulse 1, Walker, 1969) at Haverstraw.

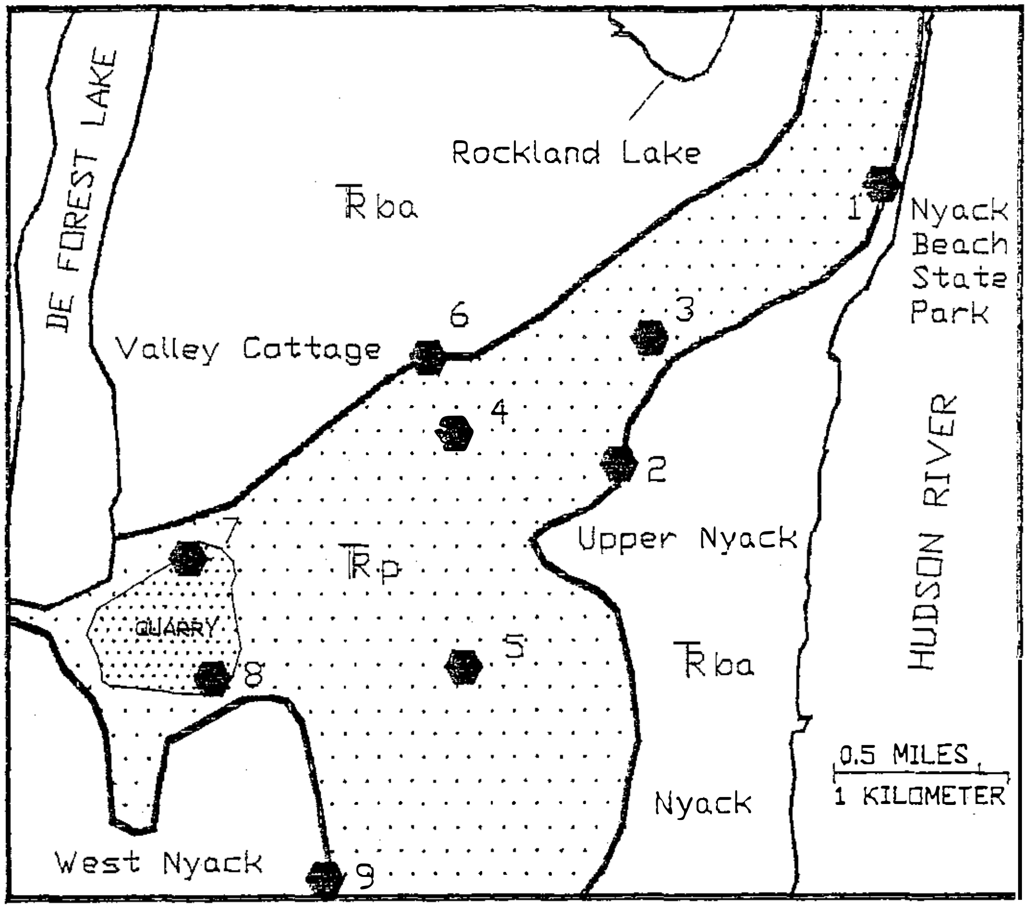

Figure 2. Enlargement showing field trip stop numbers; the Palisades (Trp, stipled) invades mudstone, siltstone and arkose of the Brunswick Formation (Trba, Fisher, et al., 1970).

PIGEONITE DOLERITE

According to Walker (1969), the early pigeonite dolerite and overlying bronzite dolerite are characterized by (1) the absence of reaction rims (presumably on bronzite), (2) scattered oscillatory zoning in minerals of the bronzite dolerite, (3) the presence of augite and a few pigeonite grains on somewhat corroded bronzite microphenocrysts of the bronzite dolerite, (4) numerous patches of glassy mesostasis, (5) independent primary pigeonite crystals, and (6) serpentine after olivine in both dolerites (ibid, p.144). Of these, 4 through 6 apply specifically to the pigeonite dolerite, and the presence of independent pigeonite and "glassy mesostasis" are particularly distinctive and unambiguous.

Walker's (1969) chilled dolerite and early dolerite possess primary pigeonite throughout. In the northern Palisades the texture tends to be intersertal, with pools of dark basaltic glass

Figure 3. Photomicrograph of coarse pigeonite dolerite (stop 3); augite (A) laths with pigeonite (P) cores subophitically intergrown with labradorite (L); accessory titanomagnetite (M); 0.25mm scale.

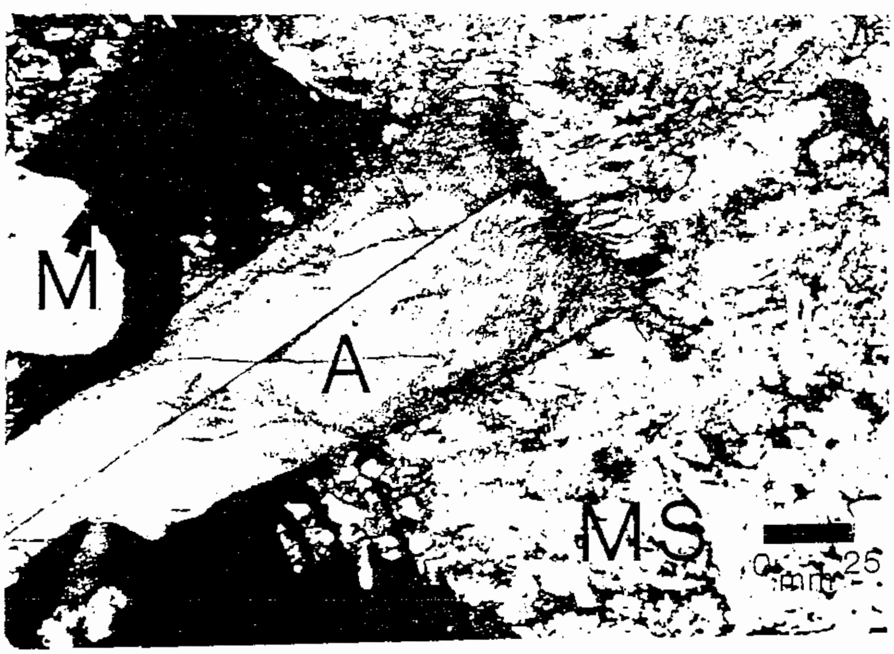

Figure 4. Photomicrograph of augite dolerite (stop 4); augite phenocryst bracketed by dendritic titanomagnetite extending into devitrified mesostasis (MS); 0.25 mm scale.

separating patches of subophitically intergrown pyroxenes and labradorite (Stop 2, figure 7 and 8). Primary pigeonite in the bronzite dolerite (Walker's stage 3i) is absent in bronzite dolerite (Walker's stage 3ii, above 110 feet). Early pigeonite dolerite of the Middle Stages (Walker's stage 5i) contains free pigeonite at the 365 foot level. Pigeonite occurs with augite as principle phases exclusive of orthopyroxene only in Middle Stage 5i and in the first pulse at Haverstraw.

Though there is considerable textural and chemical variation throughout (Steiner, et al., 1989b), the present preliminary survey found that pigeonite occurs as free grains or coarse intergrowths (not restricted to exsolution bands) over the entire traverse exclusive of the augite dolerite (described below). Since these pigeonite facies retain patches of variously recrystallized glassy mesostasis (highly visible in figures 7, 8 and 9), and since intervening orthopyroxene facies have yet to be defined, the pigeonite facies is tentatively assigned petrographically to Walker's Pulse 1 of Haverstraw. This necessitates, at the minimum, a westward revision of the interslab boundary in the northern section.

AUGITE DOLERITE

In the Upper Nyack Section, distinctive iron- and REE-enriched, chromium-poor augite facies with little or no pigeonite is enveloped by pigeonite-bearing facies on the east and a chromium-richer (100 to 250 ppm) pigeonite-poor facies on the west (Stop 6). The facies can be subdivided texturally into pegmatitic and other varieties but is distinctive in (1) in being a facies containing little or no low calcium pyroxene, and (2) retaining the glassy mesostasis patches of the pigeonite dolerite. The texture is locally porphyritic (figure 4), but appears to reflect an increased amount of interstitial mesostasis relative to subophiticly intergrown augite-plagioclase clusters. This gives a mottled appearance to some samples. The tendency for mesostasis to become concentrated away from clusters may produce gabbroic-aphanitic phase separations, as noted by Clay (1988) for a horizon in Haverstraw Quarry.

Even though certain facies of the Palisades become as coarse as plutonic varieties (grain size exceeding 1 mm), the tendency has been to retain the dolerite designation, as in the historical usage of the term pegmatite dolerite.

REE CHEMISTRY

The incompatible elements, inclusive of the rare earth elements, constitute a useful base line comparison technique for magma series. Figure 5 shows that the upper and lower contact facies appear to be derived from essentially identical basaltic magma.

This magma is REE enriched relative to the lower 125 meters of the Palisades at George Washington Bridge (figure 6; GWB data from

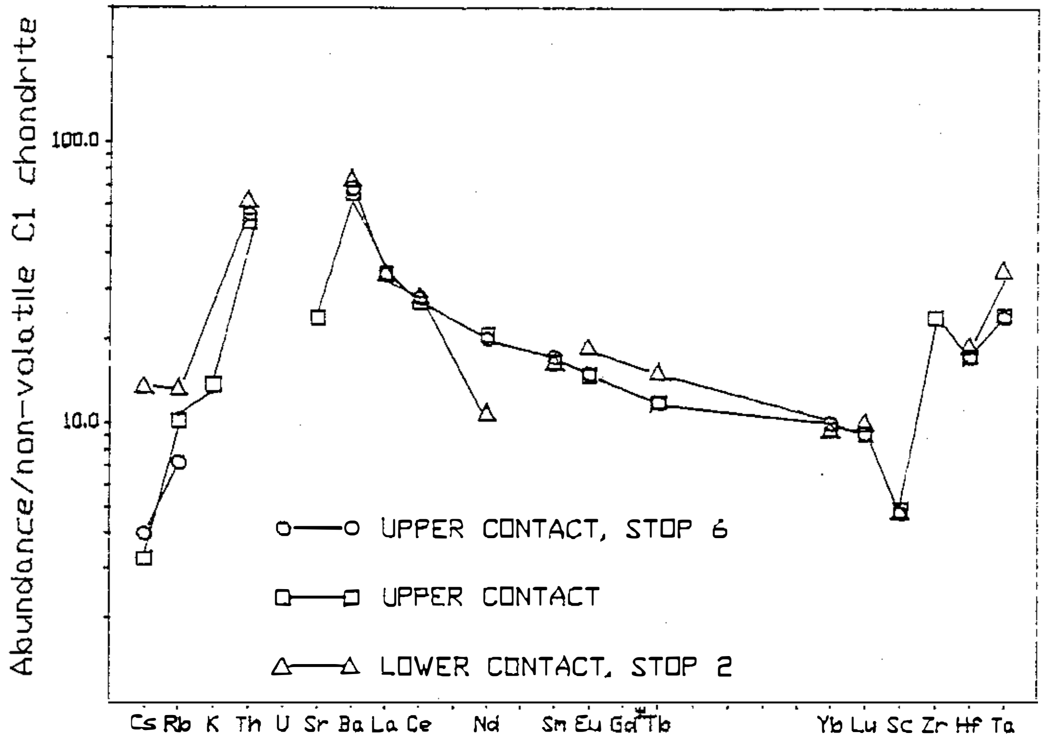

Figure 5. Incompatible element map of quench dolerite facies showing conformable profiles, except for Nd of the lower contact.

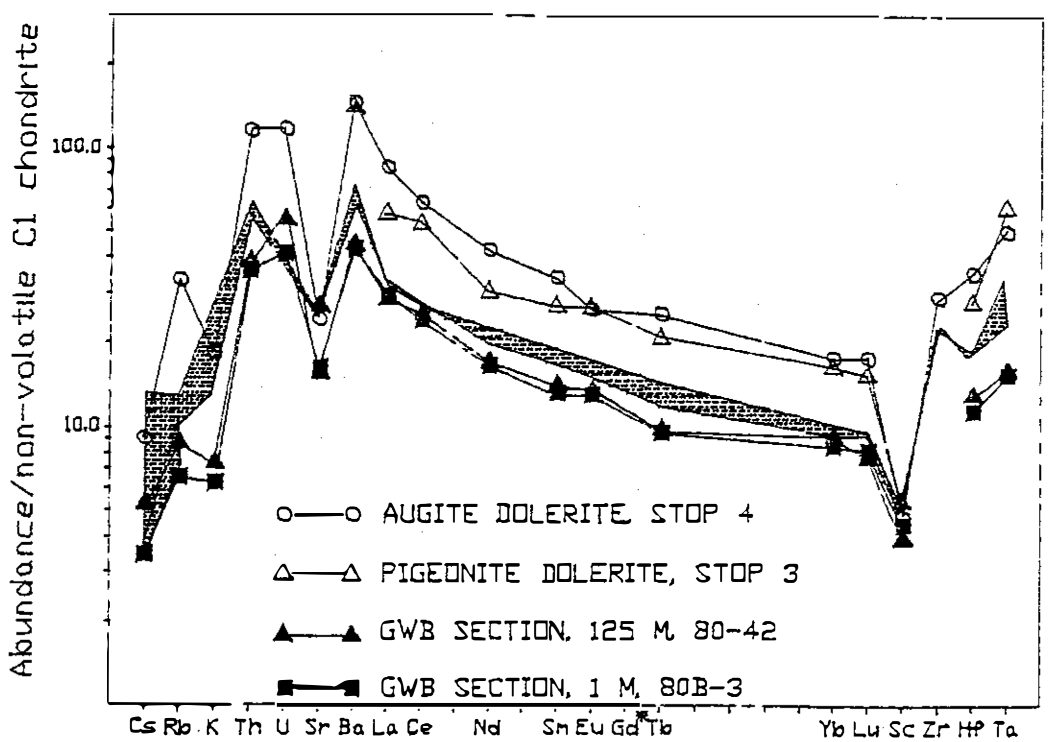

Figure 6. Trends of Nyack quench basalt (shaded) against local dolerites and George Washington Bridge samples at 1 and 125 meters.

Shirley. 1987). Thus, the REE chemistry of the Nyack magma is clearly inconsistent with quench magma of Walker's Pulse 1 or Pulse 2 in the southern Palisades.

The REE patterns of individual rocks in a fractionated suite are systematically offset from one another and comprise an array of non-intersecting curves. The inferred magma is in this sense a possible lateral derivative of magmas at GWB, or a more evolved representative of fractionation processes which gave rise to both varieties. Since both series possess essentially parallel trends, crustal processes are likely to have exerted the dominant control in the latter case (garnet fractionation in the mantle, for example, would generate crossing trend lines).

The Nyack quench basalts also lack the slight positive Eu anomaly of GWB contact lithologies which is suggestive of plagioclase settling at higher levels (Shirley, 1987), or a feature suggestive of pre-emplacement fractionation. The apparent lack of enhancement of the Europium anomaly and the consistency of the pattern over 125 meters indicates that Pulses 1 and 2 of Walker (1969) are indeed very similar chemically at the Bridge, and that additional plagioclase accumulation is not pronounced in the lower levels of Pulse 2 (Shirley, 1987).

ACKNOWLEDGMENTS

The author is indebted to T. Olson, R. Warner and D. Weiss for their constructive comments.

REFERENCES CITED

Fisher, D. W., Isachsen, Y. W., and Rickard, L. V., 1970: Geologic Map of New York, Lower Hudson Sheet, Series No. 15, New York State Museum and Science Service.

Husch, J., 1989, The olivine zone of the Palisades Sill: a reappraisal: Geol. Soc. America, NE Section Ann. Meeting, v. 21, p.24.

Puffer, J. H., Geiger, F. J., and Caamano, E. J., 1982, Mesozoic igneous rocks of Rockland County, New York: Northeastern Geol., v. 3/4, p. 121-130.

Shirley, D. N., 1987, Differentiation and compaction in the Palisades, J. of Petrology, v. 28, 835-866.

Steiner, J. C., Walker, R. J., and Warner, R. D., 1989a, Mineralogy and REE systematics in augite-dolerites of the Palisades Sill, Nyack New York: magma types and petrogenesis, Geol. Soc. America, NE Section. Ann. Meeting, v. 21, p. 68.

Steiner, J. C. and Walker, R., Granophyric porphyries of the Nyack Section: new contacts, old problems: Int. Assoc. of Volc. and Chem. of the Earth's Int. Gen. Assem., Bull. New

Walker, F., 1940, Differentiation of the Palisade diabase, New Jersey: Geol. Soc. America Bull., v. 51, p. 1059-1106.

Walker, K. R., 1969, The Palisades Sill, New Jersey: a reinvestigation: G. S. A. Special Paper 111, 178p.

ROAD LOG FOR FACIES AND CONTACTS OF THE UPPER NYACK SECTION

Cumul. Milage	Miles from Last Point	ROUTE DESCRIPTION
0.0	0.0	Exit left onto Route 59 West from Exit 11 of New York State Thruway (I-287).
0.4	0.4	Turn left at traffic light onto Route 9W North.
2.1	1.7	Turn right at traffic light onto Christian Herald Road (East).
2.4	0.3	Turn left at bottom of hill (no light) onto Old Mountain Road (East).
2.7	0.3	Turn left on Broadway.
3.6	0.9	Enter Nyack Beach State Park, curve around the toll booth and follow the paved incline up the hill to the left. Turn left at the top of the hill approximately 100 yards to the circular turn around and park cars.

STOP 1 NYACK BEACH STATE PARK - OLIVINE LAYER

The escarpment at the eastern edge of Nyack Beach State Park represents the western wall of an infilled stone quarry. On this rock face, at approximately 40 feet above the presently obscured basal contact, a subhorizontal "rotten" zone (first horizontal depression above tree line) can be observed. This zone presumably represents the last vestige of the olivine layer referred to by Walker (1969). It appears to fade northward of the present location.

A closeup view of this structure, which involves a certain risk due to the fractured nature of the rock infrastructure, reveals that the basal part of this horizon is undulose and uneven. It is marked by nodules of basalt enclosed in a weathered granular matrix. Samples of both material show that the composition of the matrix is nearly identical to the composition of early dolerite at thirty feet above the lower contact at Englewood Cliff (Steiner, in preparation). An analysis of one of the olivine bronzite nodules yield 10 percent MgO. This percentage is high for most facies of the Palisades, but substantially less than the 19 percent reported by Walker (1969) for the hyalosiderite facies.

Here, as elsewhere, it appears that cooling cracks are reasonably continuous through the rotten zone. This indicates that the rotten zone belongs to the same cooling unit as the overlying dolerite.

5.1	1.5	Retrace path to intersection of Christian Herald and Route 9W; turn right on Route 9W North.
5.3	0.2	Park in Piccolo Foreign Car Repair lot. Walk about 50 yards North to small escarpment behind trailers.

STOP 2 UPPER NYACK - LOWER CONTACT OF UPPER NYACK SECTION

The basal contact is well exposed along a small escarpment. Here, small, infilled cavities can be observed in the Triassic baked shales indicating that the sediments were not fully lithified at the time of intrusion, and the intrusion was relatively shallow.

A scramble up the escarpment for forty feet reveals small (3 cm) nodule-like protrusions in an otherwise uniform dolerite. These analyze to normal basalt (Steiner, in preparation). An olivine layer has yet to be discovered at this locality.

Backscatter electron imaging of the quench rock (figures 7 and 8) shows subophitic pyroxene and labradorite clusters surrounded partially by pools of interstitial glass. Titanomagnetite and minor plagioclase, sanidine, quartz, and residual glass populate the interstitial spaces (figures 7 and 8).

6.0	0.7	Continue North to top of hill and pull off the road. Be careful of the traffic. Interest and time permitting, drivers will proceed North to Rockland Lake South Lot.

STOP 3 UPPER NYACK - COARSE PIGEONITE DOLERITE

This coarse pigeonite facies is characterized by elongate (1 cm) augite laths with pigeonite cores or attached plates which run parallel to the augite prisms (figure 3). This facies is substantially enriched in REE relative to the contact facies, and shows a slight positive Europium anomaly suggestive of plagioclase accumulation (figure 6).

Time permitting, proceed 25 yards south on Route 9W to intersect a well marked service trail which drops sharply down the east bank. Samples have been taken from approximately 30 yards down the trail to the summit of Hook Mountain. From Hook Mountain, the tabular form of the Palisades is visible against the southern skyline. At Piermont, the topography changes dramatically in apparent response to a stepwise increase in the angle of westerly dip of the Palisades. Haverstraw Quarry is visible to the north. The rolling hills of the Triassic basin are framed by the Hudson Highlands to the east.

6.2	0.2	Proceed north to traffic light at entrance to

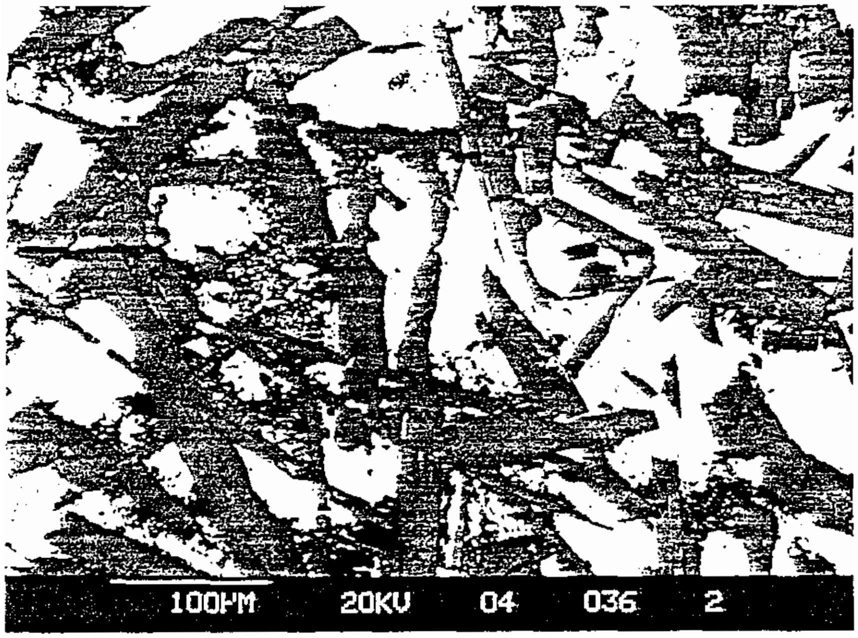

Figure 7. Backscatter electron image of quench dolerite, stop 2. Intersertal texture: subophitic intergrowths of pyroxene (light) and plagioclase (dark); interstitial pools of basaltic glass;

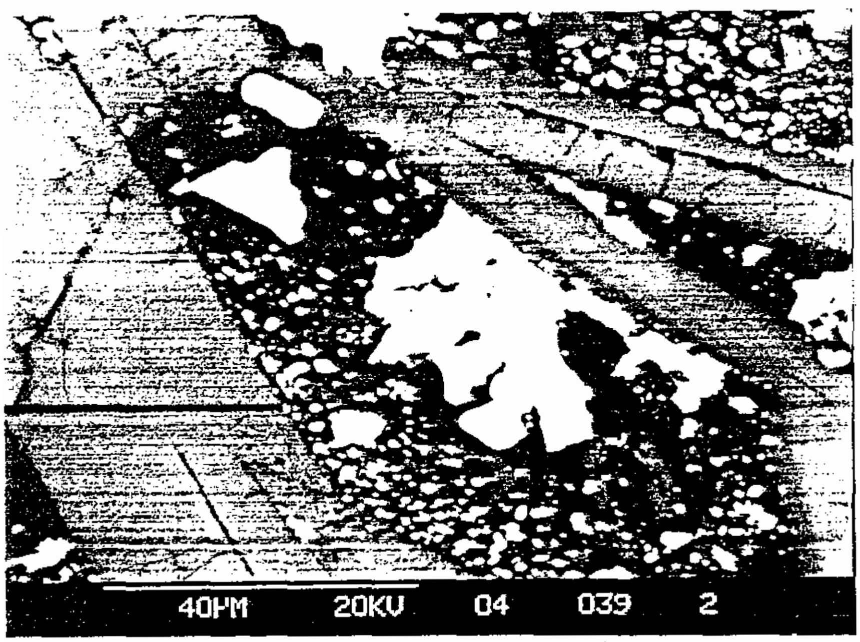

Figure 8. Enlargement showing interstitial area populated with titanomagnetite (white globular), plagioclase, quartz and glass.

		Rockland Lake Park, turn left onto Lake Road.
8.0	1.8	Turn sharply left and uphill onto Christian Herald Road just prior to the traffic light at the intersection with Route 303. Five streets meet at this intersection.
8.4	0.4	Turn left onto Herald Court and pull over to the curb at the first house on the right.

STOP 4 VALLEY COTTAGE - COARSE AUGITE DOLERITE

The best developed porphyritic texture (figure 3) in coarse augite dolerite occurs in the landscaped outcrop at the corner of Christian Herald and Herald Court. Slabs of samples taken prior to landscaping will be shown. PLEASE DO NOT DEFACE THE PROPERTY. DO NOT VISIT WITHOUT THE PERMISSION OF THE OWNER.

The iron-enrichment of the Palisades at this stop is due to abundant titanomagnetite in the groundmass. Titanomagnetite is often dendritic, and is considered to occur as both a primary and a quench feature. There is little indication that the magnetite was emplaced secondarily via an aqueous vapor or solution. Chemically, and to a certain extent petrographically (mesostasis replaces micropegmatite) this facies appears to be equivalent to the late stage ferrodolerite, fayalite granophyre and other facies of Walker (1969), except that the iron enrichment is not accompanied by iron rich ferromagnesian minerals, such as ferroaugite or fayalite. Ferroaugite rims may occur, but the bulk clinopyroxene is clearly augite.

The REE patterns (figure 5 and 6) are consistent with the derivation of this facies from the pigeonite facies through crystal liquid fractionation.

9.1	0.7	Turn left from Herald Court on Christian Herald and turn right onto Mountainview Road.
9.6	0.5	Turn right into asphalt turn around for houses set back from road. Leave cars and walk back to rocks exposed at last curve.

STOP 5 VALLEY COTTAGE - WEATHERED COARSE AUGITE DOLERITE

This is one of the few localities not in someone's yard which shows weathered coarse augite dolerite. Other localities occur sporadically along Mountainview Road.

10.2	1.6	Return to intersection of Lake Road and Route 303. Probably best to park behind the Chemical Bank. Walk across Lake Road to the Convenience Market on the Southeast corner.

STOP 6 VALLEY COTTAGE - UPPER CONTACT RELATIONS

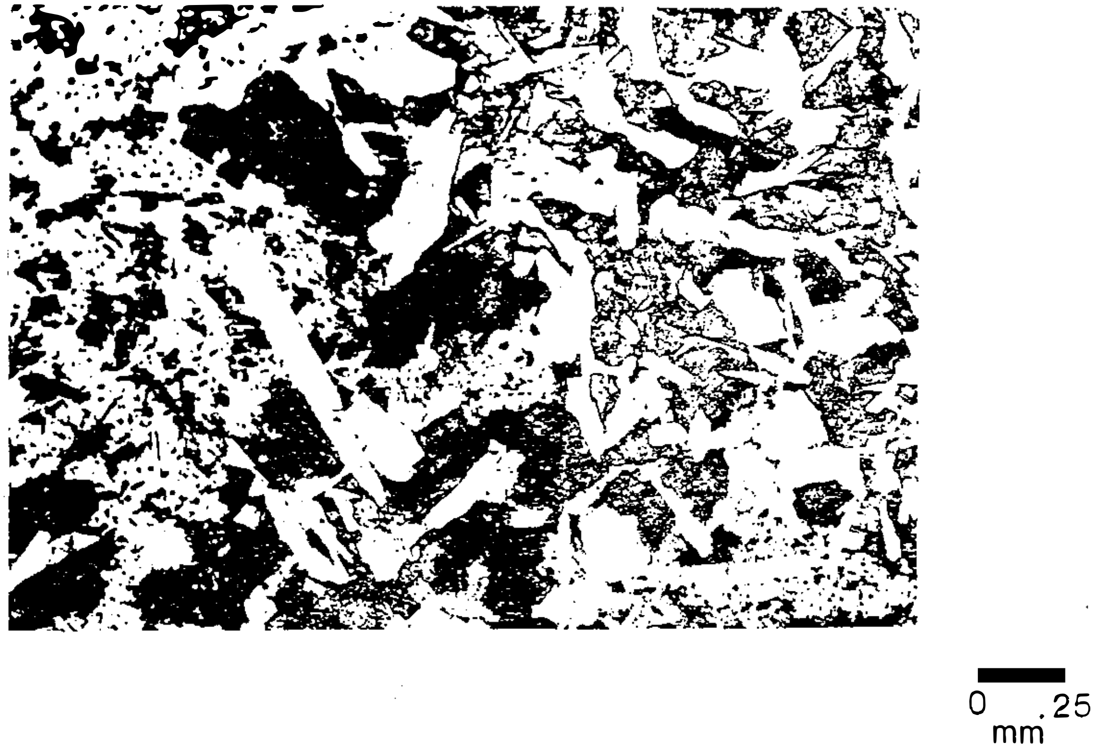

Figure 9. Dolerite at stop 6 showing subophitic texture right of center grading into glassy mesostasis on the far left; 0.25 mm scale.

Figure 10. Photograph of polished slab showing quench texture comprised of plagioclase and augite growing normal to the interface with pigeonite dolerite (lower quarter); 1 cm scale.

From the intersection of Route 303 and Lake Road, walk 20 yards north along the eastern side of Route 303 to examine the contact between diabase and sedimentary rock which dips northerly at about 45 degrees. The contact is very sharp at about 10 feet up from the sidewalk alongside the telephone pole. It is otherwise somewhat hard to observe the trend do to the tendency for the dolerite to reduce the iron in the sedimentary rock producing a black baked sandy shale.

As observed at Stop 2, the intrusive dolerite has vesiculated the sedimentary rock. At this stop the cavities are somewhat sharper and lack infilling. The baked zone buttresses the east-west trending slope which marks the position of the Palisades contact as it extends toward Rockland Lake.

The texture of the contact rocks is microporphyritic with augite microphenocrysts. Within five feet of the contact the texture is ophitic, and beginning perhaps fifteen feet south, occasional recrystallized patches of interstitial mesostasis appear (figure 9).

Proceeding South, the diabase appears to plunge beneath the sedimentary cover. About 0.5 miles north of Lake Road, the contact is rediscovered on the upper potions of the exposed slope which is inset 60 yards east of route 303. The dolerite dips roughly west at about 45 degrees underneath a veneer of backed shales. The intrusive contact is therefore complex, wending in a curvilinear fashion along its margin in the general form of poorly exposed coalesced domes or localized arches.

To see quarried rock of horizon 1 (Steiner, et al. 1989a,b) drive west on Lake Road 0.3 mi to the Valley Cottage Fire Station and park along the West edge of the lot. The large blocks along the stream bank contain pegmatite dolerite clusters with sprays of augite locally reaching 6 cm.

10.6	0.4	Proceed west on Lake Road to traffic light on Kings Highway and turn left.
11.2	0.6	Turn right at stop sign on Crusher Road.
11.7	0.5	Park at company office at base of hill.

STOP 7 WEST NYACK - COARSE PIGEONITE DOLERITE, INTRUSIVE RELATIONS AND LAVA DOME

The suggestion of a domal configuration at many points along the western contact is strongly supported by the lava dome situated southwest of the main quarry buildings. This dome was well exposed in the Fall of 1988, but has since been partially buried by crushed quarry rock.

Several facies are transected when walking or driving to Stop

8. In particular, trondhjemitic and granophyric varieties of the coarse dolerites, ultramafic segregation veins (Steiner, in preparation) and secondary "flowers" of chalcocite against malachite ovals along fracture systems may be visible. Unfortunately, many of these features have been completely removed by the quarrying operation.

STOP 8 WEST NYACK QUARRY - COARSE PIGEONITE DOLERITE WITH PEGMATITIC DOLERITE (COARSE AUGITE DOLERITE) PODS

Along the south end of the westernmost wall at the second level from the top, a coarse intrusive facies (H1, Steiner, et al., 1989a,b) invades diabases comparable to those exposed at Stop 6 along a narrow 12" dike. The dike shows an approximately 1" gap through which the magma welled up into adjacent rocks creating a balloon-like profile. This dike apparently represents an offshoot of the major contact which runs subparallel to the intersecting north wall. Pegmatite dolerite, comparable in many respects to the coarse augite dolerite of Stops 4 and 5 characterizes the general zone separating the two lithologies.

OPTIONAL STOP 9 WEST NYACK - SECOND UPPER CONTACT AND REDUCED ZONE

0.0	0.0	Intersection of Routes 303 and 59.
0.4	0.4	Turn left onto dirt road just past Fesco Fence, over find Greenbush Ave. off Route 59. Park and walk up slope to prominent outcrop.

Here, a dip slope of the Triassic arkose (fossil fish locality) which is visible below abuts the Palisades. Portions of the metamorphosed sedimentary rock form a veneer over and are partially crosscut by offshoots of the dolerite. The tendency for the reduction of iron is again visible in the sedimentary rock.

Return to Route 303 and proceed north to intersection with N.Y.S. Thruway.