THE WATCHUNG BASALTS OF NORTHERN NEW JERSEY

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Introduction

This field trip through the northern end of the Watchung Mountains of New Jersey will include six good exposures of quartz tholeiitic basalt. The Watchung basalt flows of the Mesozoic Newark Basin are exposed as three northeast/southwest trending ridges. The three basalt units dip to the west at about 15 degrees and are known as the Orange Mountain, Preakness, and Hook Mountain Basalts (Fig. 1).

The lower contact of the first flow unit of the Orange Mountain Basalt with the underlying Passaic Formation will be seen at Stop 2. The three flow units of the Orange Mountain Basalt are locally separated from each other by thin layers of sediment and comprise an aggregate thickness averaging 183 m (Faust, 1975). The upper flow is characteristically pillowed and amygdaloidal, whereas the lower two flows typically display well-developed columnar joints (lower colonnade and entablature).

Each of the three flow units of the Preakness Basalt are geochemically distinct, and each will be visited during the fieldtrip. The massive, very coarse grained lower flow of the Preakness will be seen at Stop 3, the second flow together with a thin layer of sediment separating it from the first flow will be seen at Stop 4, and the second and third flows separated by another thin layer of sediment will be seen at Stop 5. The aggregate thickness of the three Preakness flows averages 215 m (Olsen, 1980).

The lower contact of the Hook Mountain Basalt with the underlying Towaco Formation will be seen at Stop 6. The Hook Mountain Basalt extruded about 550,000 years after the extrusion of the Orange Mountain Basalt (Olsen and Fedosh, 1988) and consists of at least two flows with an aggregate thickness of 91 m (Faust, 1975).

The hydrous mineral assemblages that accumulated in the vesicles and vugs between pillows of Watchung Basalt, presumably mixtures of carbonates, clays and alteration products, have responded to low temperature burial metamorphic effects. The resulting zeolite facies assemblage includes some very well developed crystal aggregates of stilbite, heulandite, chabazite, and datolite typically precipitated with calcite, quartz, prehnite, and sulfides (principally chalcopyrite and chalcocite).

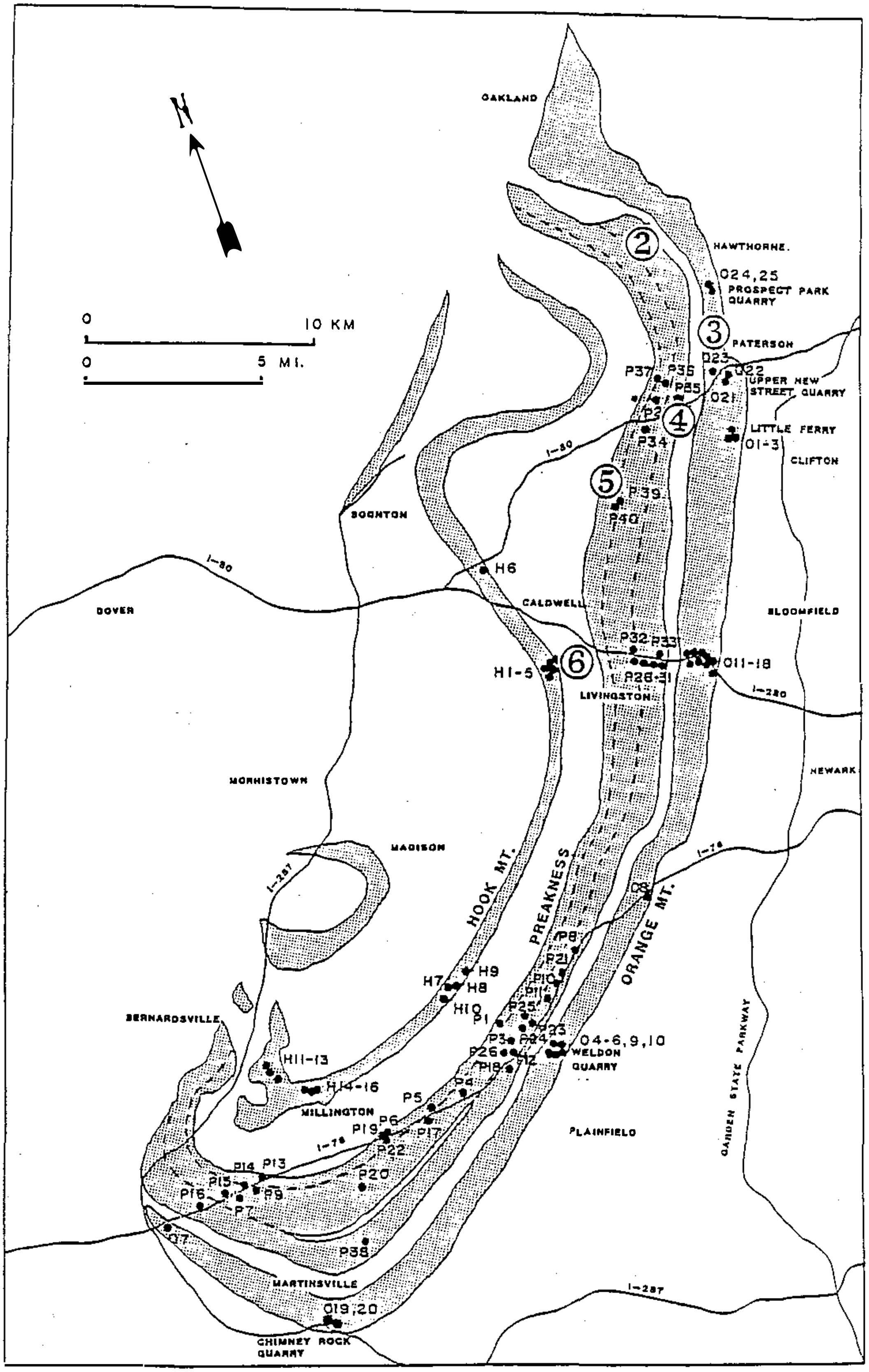

Figure 1. Map of Watchung Basalts with locations of field trip stops, samples chosen for chemical analysis (see Table 1 and Fig. 2), and approximate contacts (dashed lines) of the three Preakness Basalt flows.

The distribution of these secondary minerals has been described by Laskowich and Puffer (1986) but unfortunately the best zeolite and copper collecting localities are found in the active traprock quarries of New Jersey, and entry permission for NYSGA was denied at each quarry. Copper sulfides are particularly abundant in the amygdules and sediments at the base of and between the flow units of the Orange Mountain Basalt.

Discussions held during the field trip will be directed toward reinterpretations of the petrogenesis of the Watchung Basalts that are currently being developed as new data is made available.

Petrography

Orange Mountain Basalt. The Orange Mountain Basalt is a quartz normative tholeiite composed of plagioclase and augite with minor orthopyroxene and altered olivine in a glassy mesostasis containing quench dendrites of Fe-Ti oxides. Augite phenocrysts, glomeroporphyritic aggregates of augite, orthopyroxene, altered olivine, and a few plagioclase phenocrysts are characteristic of the basalt. Typical modes average 35 percent plagioclase (An65), 35 percent pyroxene (augite (Wo34En55Fs10), pigeonite, and minor hypersthene), 28 percent glassy mesostasis, and 3 percent opaque Fe-Ti oxides. Accessory and trace minerals include apatite, biotite, alkali feldspar, and pyrite.

Preakness Basalt. The very coarse-grained appearance of the interior of the first or lowermost of the Preakness, resembling a diabase, may be related to the unusual flow thickness that may have included intrusive pulses similar to those proposed by Philpotts and Burkett (1988). Typical samples from the base of the first flow consist of about 50 percent pyroxene and 43 percent plagioclase as an intergranular mixture with about 3 percent plagioclase phenocrysts and 5 percent dark, fine-grained glassy mesostasis enriched in quench oxides. Typical unaltered coarse grained samples from the interior consist of an intergranular mixture of about 45 percent pyroxene, 50 percent plagioclase, 3 percent opaque oxides, with only about 2 percent brown glass. The plagioclase composition of the least altered samples averages about An57 on the basis of 40 microprobe analyses, with a range from An50 to An60, excluding secondary albite determinations. On the basis of 13 microprobe analyses the augite averages (Wo35En45Fs20). On the basis of 20 microprobe analyses, the magnetite composition averages Usp60, and on the basis of 12 microprobe analyses, the ilmenite is Hem8.

Most samples from the middle flow are medium-grained, intergranular mixtures of 35 percent pyroxene (both pigeonite and augite), 59 percent plagioclase, 4 percent opaque oxides, and 2 percent brown glass. Some samples are aphyric, but large plagioclase phenocrysts make up as much as 10 percent of other middle flow samples.

Table I
Chemical Composition of Watchung Basalts

(typical samples)

	O12 Orange Mt. first flow	O6 Orange Mt. second flow	O9 Orange Mt. third flow	P5b Preakness first flow	P18 Preakness second flow	P6 Preakness third flow	H1 Hook Mt. first flow	H9 Hook Mt. second flow
SiO_2	51.44	51.88	51.31	51.65	51.20	50.83	49.89	49.51
TiO_2	1.19	1.09	1.12	1.05	1.21	0.83	1.44	1.40
Al_2O_3	14.75	14.70	14.31	14.19	15.30	15.65	13.26	13.94
FeO	10.54	10.40	10.60	11.41	12.45	10.15	14.89	14.59
MnO	0.16	0.15	0.17	0.19	0.21	0.17	0.19	0.21
MgO	7.77	7.32	7.61	6.48	5.41	7.60	5.65	5.58
CaO	10.61	9.75	10.15	9.48	9.55	10.31	9.88	10.23
Na_2O	2.35	2.40	2.98	3.05	3.21	2.49	2.53	2.23
K_2O	0.32	0.47	0.52	0.63	0.59	0.36	0.32	0.44
P_2O_5	0.11	0.12	0.12	0.12	0.12	0.08	0.14	0.17
H_2O^+	0.42	0.69	0.91	0.76	0.48	0.61	0.69	1.03
Total	99.66	98.97	99.60	99.01	99.73	99.08	98.88	99.33
Ba	162	165	153	142	135	88	110	119
Co	37	39	39	38	39	38	43	49
Cr	374	330	435	76	53	251	122	72
Cu	120	205	137	78	80	70	167	183
Ni	84	77	69	38	25	55	50	55
Sr	206	191	194	136	151	141	118	128
V	250	250	257	315	340	248	324	351
Zn	72	82	82	84	95	72	115	129
Zr	78	100	97	88	91	56	98	77
La	10.1	10.0	-	9	11	7.4	8.1	-
Ce	22.5	22.0	-	19	26	15	19	-
Nd	13.5	13.0	-	14	16	9	12	-
Sm	3.8	4.0	-	2.8	3.0	2.5	2.9	-
Eu	1.11	1.00	-	1.02	1.25	0.90	1.00	-
Gd	3.6	3.5	-	3.25	3.8	4.0	4.0	-
Dy	3.8	3.9	-	5.0	5.0	4.2	5.5	-
Er	2.3	2.3	-	3.5	3.8	2.5	4.0	-
Yb	2.3	2.35	-	3.1	3.2	2.2	3.1	-

The uppermost flow of the Preakness is exposed best along Interstate 78 (Fig. 1); elsewhere exposures typically are altered. The somewhat vuggy nature of the flow seems to have accelerated alteration. The flow is medium grained and slightly porphyritic, consisting of glomerorphyritic clots of pyroxene (largely augite) and plagioclase in a dark mesostasis enriched in quench oxides. The pyroxene (Wo24En56Fs20) and plagioclase (An73) content of the rock is approximately equal. Large phenocrysts of plagioclase and pyroxene are not uncommon.

Hook Mountain Basalt. The Hook Mountain Basalt consists of at least two amygdaloidal and deeply altered flows. The basalt is composed of plagioclase, clinopyroxene, and Fe-Ti oxides in a fine-grained to glassy and typically vesicular mesostasis. Phenocrysts of plagioclase and pyroxene are common. The plagioclase composition of samples taken at the base of the lower Hook Mountain flow averages An68 and the augite composition from the same samples averages Wo31En51Fs18.

Geochemistry

Orange Mountain Basalt.The Orange Mountain Basalt fits into the HTQ type of ENA tholeiites as proposed by Weigand and Ragland (1970). The chemistry of the basalt is rather uniform throughout (Table 1) and virtually is equivalent in all respects to samples of Palisades chill analysed by Walker (1969), Shirley (1987), and Husch (1988). The REE content of the Orange Mountain Basalt plots close to and parallel with the REE distribution pattern of the lower chill margin of the Palisades sill.

The chemistry, mineralogy, and texture of the Orange Mountain Basalt is equivalent to the first Early Jurassic basalts in the other basins of the Newark Supergroup, such as the Talcott Basalt of the Hartford Basin, Connecticut, and the Mount Zion Church Basalt of the Culpeper Basin, Virginia (Puffer and others, 1981; Puffer, 1984).

Preakness Basalt. The chemical composition of the first flow of the Preakness Basalt (Table 1) is distinctly enriched in most incompatable elements compaired to the Orange Mountain Basalt and is virtually identical to the Holyoke Basalt of Connecticut. The middle flow is even more highly enriched with a TiO_2 content averaging 1.21 (Table 1). Accumulation of plagioclase phenocrysts in some samples of the middle flow is responsible for a slightly positive Eu anomaly. These plagioclase-rich samples plot at the most chemically evolved end of the Preakness field on a TiO_2 versus MgO diagram (Fig. 2).

The chemical composition of the uppermost of the three Preakness flows (Table 1) is characterized by a consistently low TiO_2 content ranging from 0.7 to 0.9 and averages 0.8 percent. The basalt qualifies in all respects as a typical ENA-LTQ basalt as defined by Ragland and Whittington (1983). The occurrence of

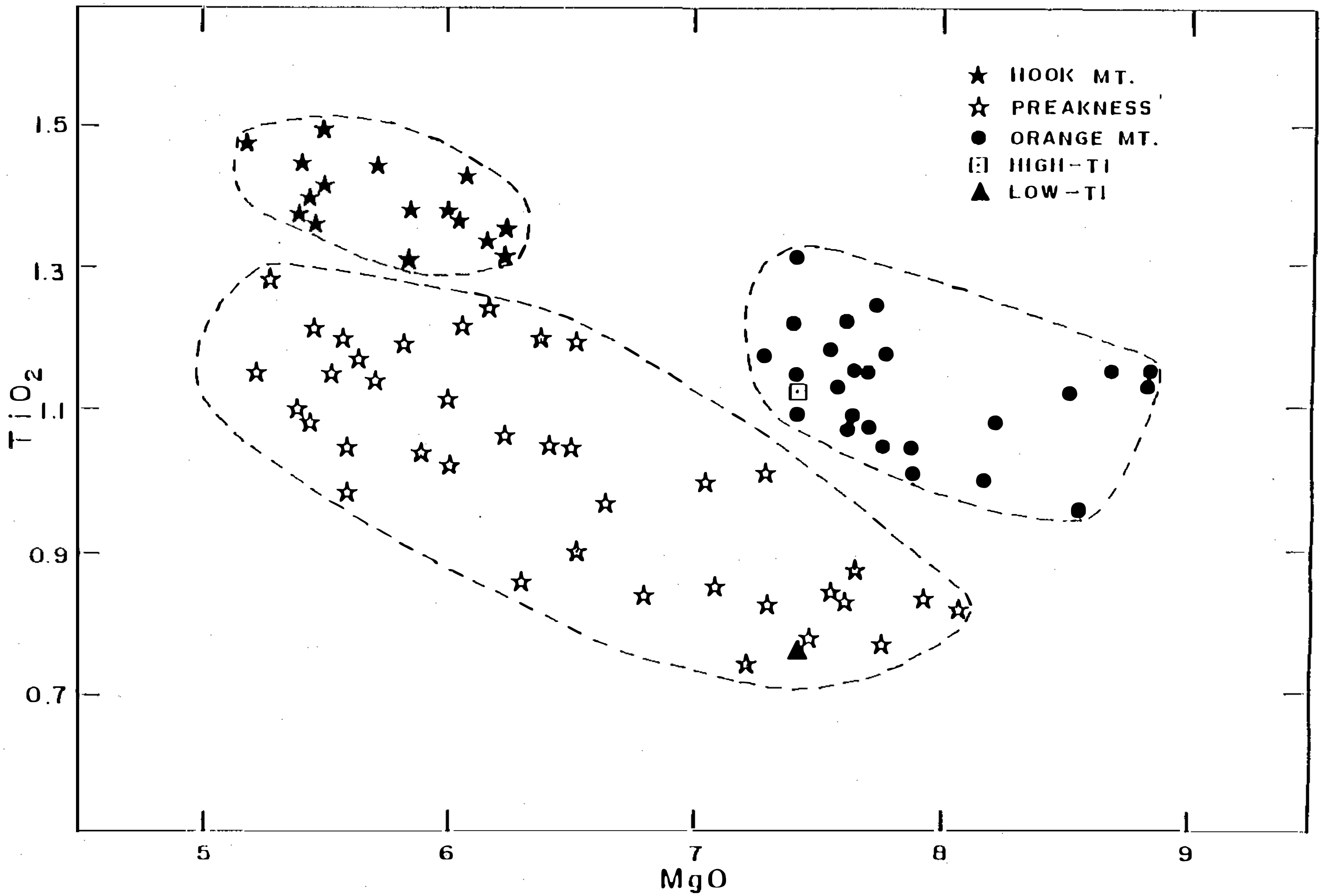

Figure 2. TiO_2 versus MgO diagram showing distribution of Watchung Basalt samples located on Figure 1. High-Ti (HTQ) and Low-Ti (LTQ) values after Weigand and Ragland (1970).

LTQ basalt within the Newark Basin is not surprising in light of its occurrence in the Gettysburg Basin to the south (Smith and others, 1975) and in the Hartford Basin to the north (Philpotts and Martello, 1986).

The overlapping compositions of the three Preakness Basalt flows in Fig. 2 supports interpretations that all three Preakness flows are genetically related to each other

The REE content of the third flow of the Preakness Basalt is within the "low-TI" or LTQ range of Ragland and others (1971), but the first and second flows contain distinctly higher REE concentrations. The distribution patterns (Fig.3), however, are close to each other and reasonably parallel furthur supporting a genetic relationship perhaps controlled by fractionation. The slightly positive Eu anomaly displayed by the second flow (Fig. 3) is consistent with plagioclase enrichment that approximately is balanced by the relatively low plagioclase content of the first Preakness flow.

Hook Mountain Basalt. The SiO_2, Na_2O, Cr, Ni Rb, and Sr contents of the Hook Mountain Basalt (Table 1) are intermediate between those of the Orange Mountain and Preakness Basalts. The REE distribution pattern of the Hook Mountain Basalt (Fig. 3) plots close to that of the Orange Mountain Basalt and is within the "high-Ti" or HTQ range of Ragland and others (1971). The Hook Mountain Basalt, however, contains less light REEs than the Orange Mountain Basalt despite its more highly evolved major element concentrations (including iron and titanium). There is also a distinct cross over in the distribution pattern resulting in a higher heavy REE content for the Hook Mountain Basalt than the Orange Mountain samples.

The composition of the Hook Mountain Basalt particularly the REE content resembles that of the first flow of the Preakness more closely than any of the other Watchung Basalts although a genetic relationship is not clear.

Petrogenesis

Orange Mountain Basalt. Despite the fact that the Orange Mountain Basalt is a quartz normative tholeiite, an interesting although somewhat radical case can be made in support of its assignment as a primary magma. The chief obstacle to a primary magma assignment is the low Mg' value of the Orange Mountain Basalt (0.51) which is considerably lower than the 0.68 to 0.75 range for primary magmas proposed by O'Hara and others (1975) and Frey and others (1978). As they noted, if a magma is primary the forsterite content of its liquidus olivine should be the same as that of olivine in the magma's residual source. Only melts with an Mg' range of 0.68 to 0.75 would be in equilibrium with the Fo90 olivine typically found in harzburgite and lherzolite inclusions interpreted as mantle xenoliths. The currently popular view that only picritic basalts or komatiites qualify as

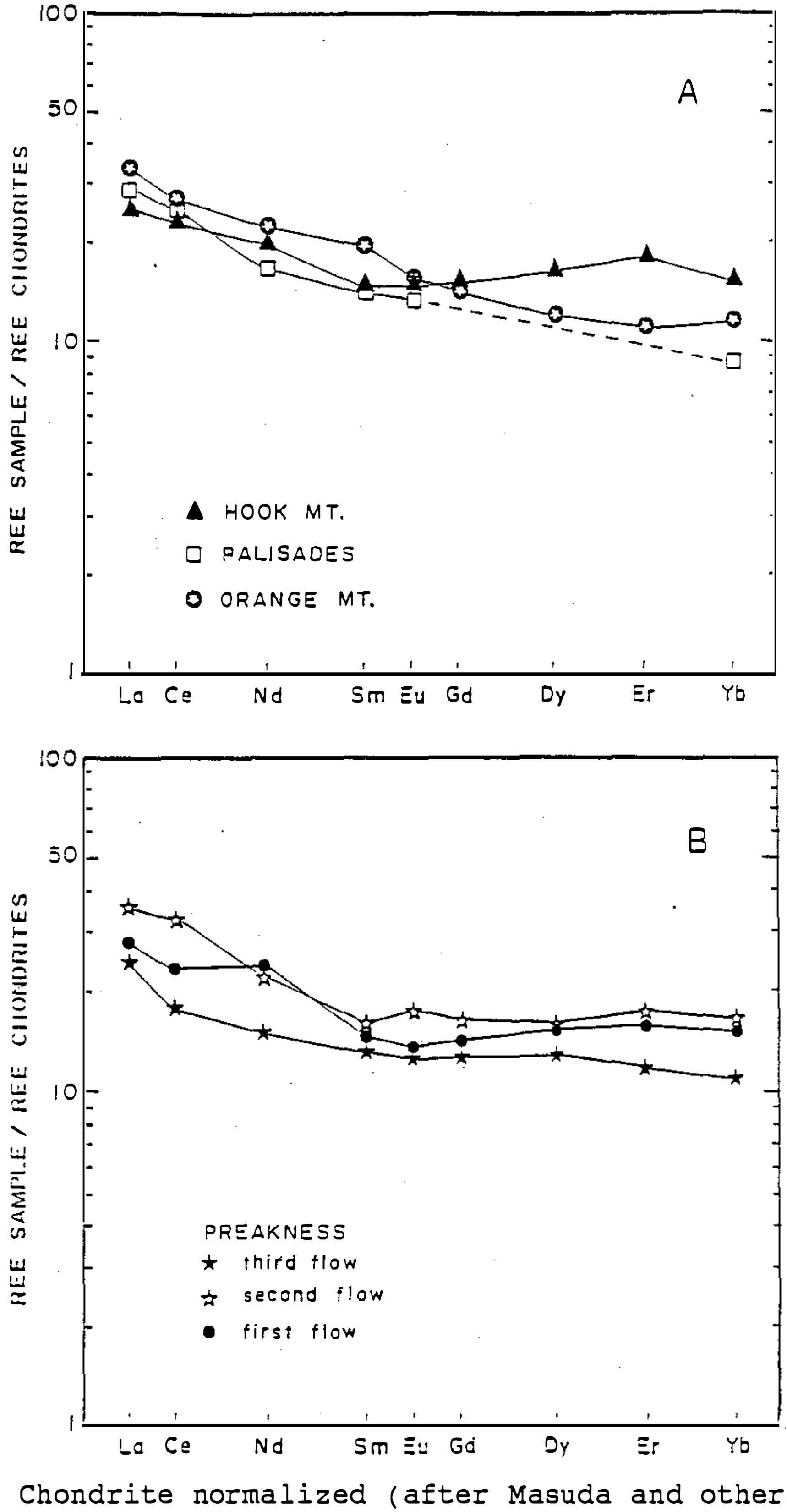

Figure 3. Chondrite normalized (after Masuda and others, 1973) REE distributions of five typical Watchung Basalt samples and the Palisades sill lower chill (sample 80B1 of Shirley (1987)).

primary basaltic magmas supports the interpretation that the ENA quartz tholeiites are derived from the more primative ENA olivine normative magmas (perhaps through fractionation of HLO magma; Fig. 4 after Whittington, 1988).

Mounting evidence, however, suggests that fractionation mechanisms are not useful in genetically relating the various ENA magma types to each other. It now appears that on geochemical grounds none of the Watchung Basalts, for example, can be derived from any other Watchung Basalt or Newark Basin intrusive rocks through fractionation. There is typically some geochemical difference beyond the range of plausable fractionation mechanisms. It might be argued, therefore, that if fractionation has failed as a mechanism capable of genetically relating some closely spaced quartz tholeiites it is even less likely that it will be successful in genetically relating highly diverse magma types such as quartz tholeiite and picrite.

Although a primary magma proposal is clearly highly speculative it is safe to say that not enough is known about all the factors that effect upper mantle partial melting processes to totally reject it. Particularly little is known about the volatile content of upper mantle, subcontinental rocks that may have been the source of the Watchung Basalts. There is also the possibility that the iron content of the source may have been much higher than typically suspected.

Evidence supporting the interpretation of the Orange Mountain Basalt as a primary magma include:

1) Great Magma Volume. Carmichael and others (1974) suggest that great magma volume is one of two principal characteristics of primary magmas. They have observed that "Continental tholeiitic flood basalts and related diabases more than any other class of volcanic rocks satisfy the two criteria postulated for magmas generated directly by fusion - great volume of and compositional homogeneity within each magma province... To derive the magma from picritic basalt of deep-seated origin by low pressure fractionation... requires that again and again each successive draught of magma must rid itself cleanly, while still largely liquid, of the same fraction of crystalline olivine along some identical source of ascent. This seems highly improbable." The same logic also argues against derivatiuon through mantle or crustal assimilation or through filter pressing.

The volume of magma represented by the Orange Mountain Basalt is very greatly extended if each of the ENA high-Ti tholeiites are included together. It was shown that the chemical composition of the Talcott Basalt of the Hartford Basin of Connecticut, and the Mount Zion Church Basalt of the Culpeper Basin, Virginia (Puffer, 1984) are both chemically equilivent to the Orange Mountain Basalt and in each case represent the first of several Mesozoic ENA extrusive events.

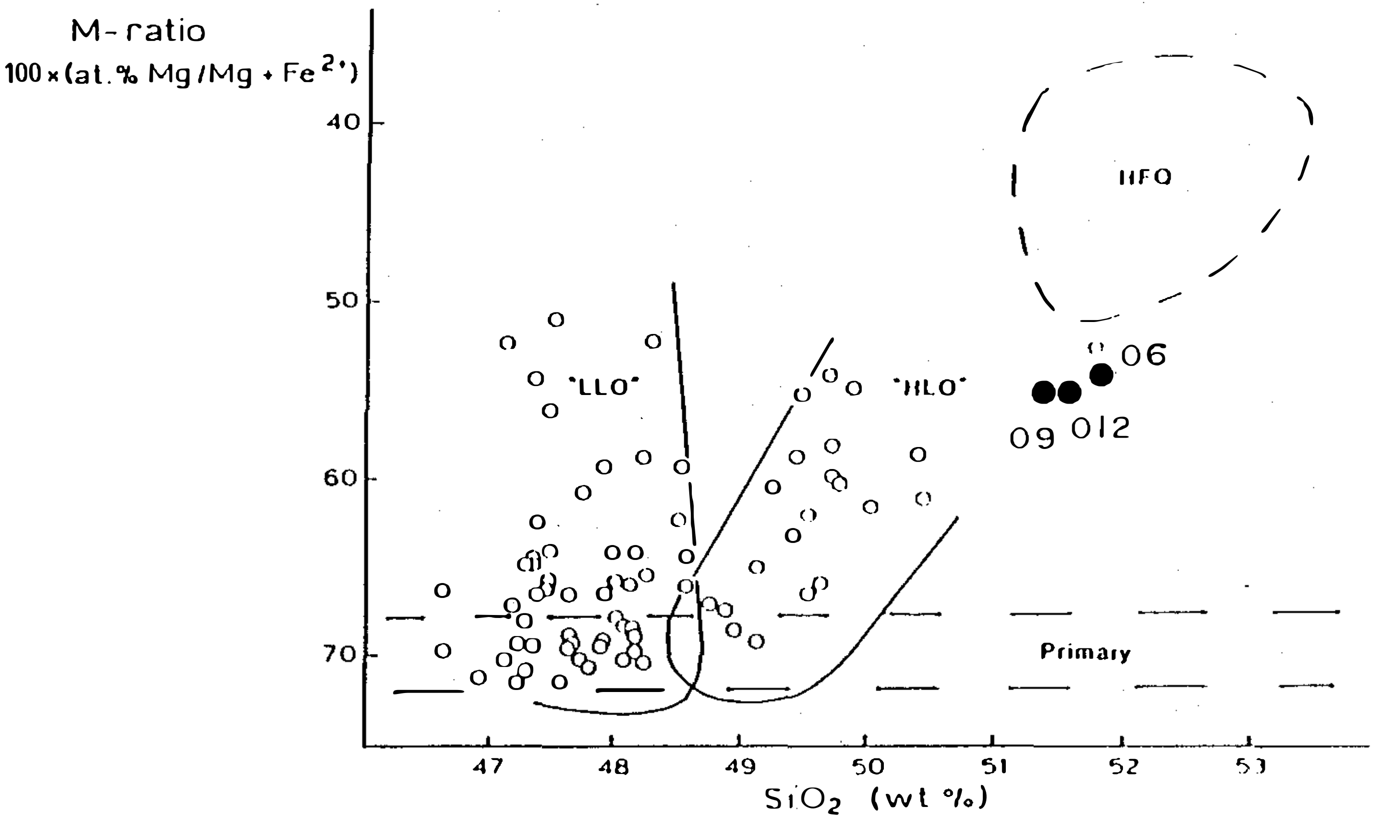

Figure 4. Weight percent SiO_2 vs M-ratio (100 x atomic % Mg/Mg + Fe) for aphyric North Carolina diabase shown with fields for quartz diabase (HFQ) from North Carolina, after Whittington (1988). The vertical trend of no silica enrichment and the inclined trend of silica enrichment correspond to Ragland and Whittington's (1983) LLO and HLO groups, respectively. Orange Mt. samples 06, 09, and 012 (Table 1) are also plotted.

2) Chemical Homogeneity. The second characteristic of primary magmas suggested by Carmichel and others (1974), "compositional homogeneity" is also a characteristic of Orange Mountain Basalt and HTQ basaltic rock in general. Despite the huge volume of magma represented the the entire HTQ population, occurrences of ENA basaltic rock of a composition intermediate between the Orange Mountain and picritic rocks are rare if they exist at all. The entire HTQ population is instead tightly clustered around the original average determined by Weigand and Ragland (1970).

3) Close Resemblance to Other Early Jurassic Basalts of Possible Primary Nature. When the chemistry of the Orange Mountain Basalt is compared with other basalts on a world-wide basis a remarkable coincidence becomes apparent. Of all the known world-wide basalts located beyond the Newark Supergroup the basalts that most closely resemble the Orange Mountain are also Early Jurassic. The close resemblance with the High-Atlas Basalts of Morocco was first reported by Manspeizer and Puffer (1974) and an equally close resemblance with the Lesotho Basalt of South Africa has been recognized (Fig. 5). If the early Jurassic basin containing the High Atlas Basalt was contiguous with the Newark Basin the "great volume and compositional homogeneity" arguments are strengthened and together constitute a kind of igneous super province implying that magma was generated by an early Jurassic tectonic event of major proportions. Melting of the Lesotho may have been triggered by the same event or perhaps by a highly similar event. It has been proposed by Marsh (1987) that the Lesotho magma was a primary type derived from old and enriched subcontinental lithosphere. Sr and Nd isotopic data have been interpreted by Bristow and others (1981) as indicating subcontinental enrichment events beneath southern Africa between approximately 1 and 2 b.y.

4) Extended Insulation of an Old Enriched Subcontinental Lithospheric Source. The isotopic data of Pegram (1983) indicate that the ENA quartz tholeiites are enriched to a degree approximately equivalent to that of the Lesotho. His initial 87Sr/86Sr value of the ENA quartz tholeiites range from 0.7054 to 0.7072 and overlap the 0.7059 average of Lesotho data reported by Compston and others (1968). Pegram (1983) suggests that the ENA quartz tholeiites were derived from a source isotopically distinct from the MORB and reflect a subcontinental mantle with a complex history involving the long term (approximately 1 b.y.) enrichment in Rb/Sr, Nd/Sm, and U/Pb. Pegram (1983) also concludes that his data are inconsistent with crustal contamination.

Elevated temperatures within the upper mantle caused by the prolonged insulation effects of a thick continental cover may have resulted in melting in a shallow, low pressure regime. Elthon and Scarfe (1984) have shown that advanced melting of the mantle at pressures less than 10 kbar would result in primary melts that become increasingly enriched in silica as the pressure decreases. Widespread melting under an attenuated Pangea

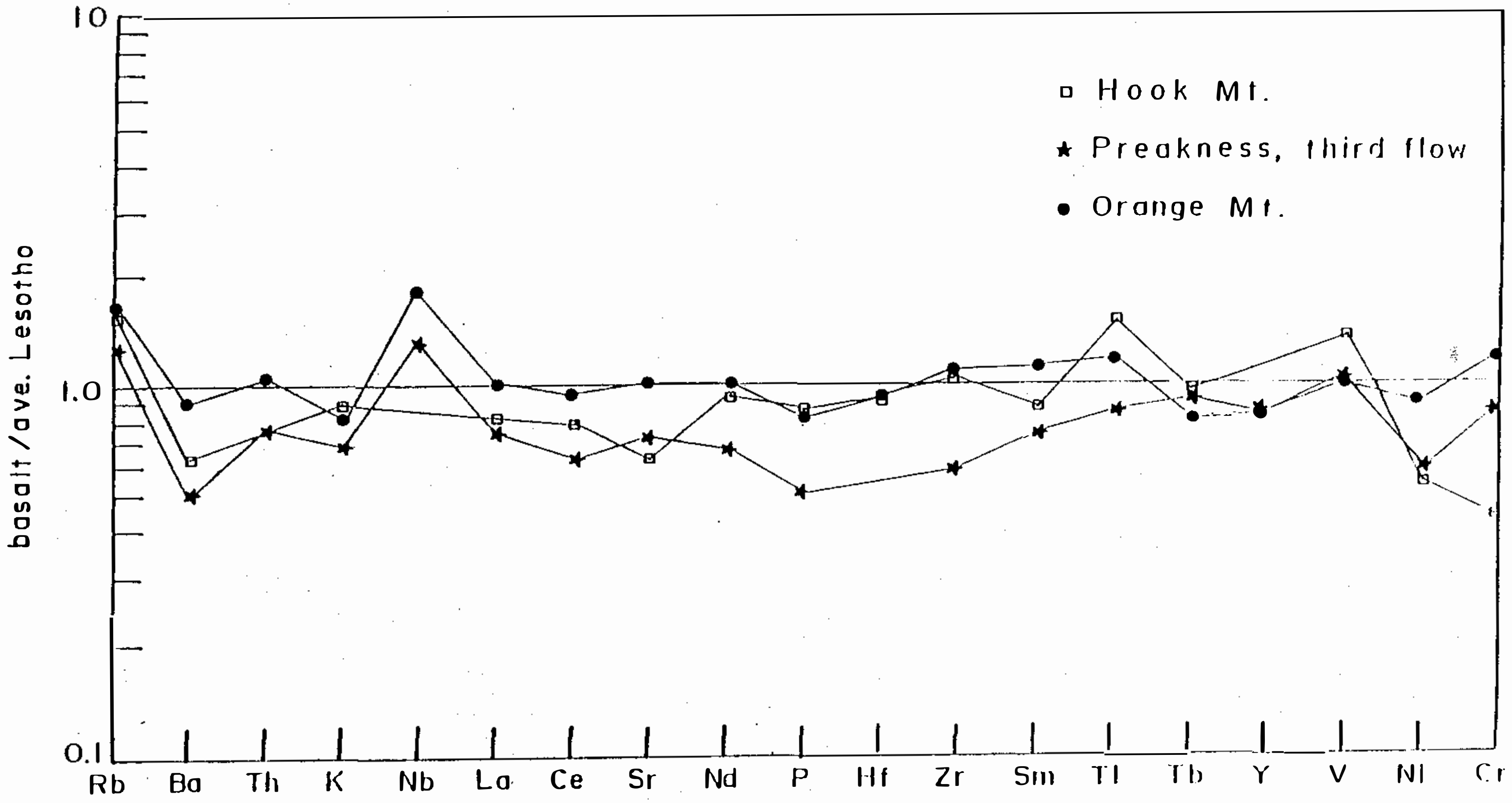

Figure 5. Lesotho normalized diagram comparing average (Karoo) Lesotho basalt (data of Duncan, 1987) with Watchung Basalts, samples 012, P6, and H1 (Table 1)

triggered by Mesozoic rifting, therefore, may have occurred in an enriched, low-pressure environment unlike the environment of oceanic or other basaltic sources.

5) Monovalent Cation Enrichment. Kushiro (1975) and Mysen (1977) have shown that if lherzolite or harzburgite is enriched in monovalent cations such as H_2O, Na_2O, and K_2O, the liquidus boundary shifts towards silica, but if the source rocks are rich in 4 or 5 valent cations such as TiO_2, CO_2, or P_2O_5, the liquidus boundary shifts away from silica (Fig. 6). Compaired with most basalts on a world-wide basis the Orange Mountain contains a distinct high ratio of K_2O + Na_2O/TiO_2 + P_2O_5, clearly much higher than typical oceanic basalt although it is difficult to speculate about water contents. Kushiro (1975) suggests that partial melting of peridotite enriched in water and other monovalent elements would form silica rich magmas such as quartz tholeiite and suggests that such elements may be contained in minerals such as phlogopite with stability fields that extend into the high pressure conditions of the upper mantle. Kaersutitic amphibole (Basu and Murthy, 1977) and beta-Mg_2SiO_4 (Smyth, 1987) have also been proposed as potential sources of water and monovalent cations in the mantle.

Preakness Basalt. The Preakness Basalt is a somewhat less viable candidate for a primary magma designation although it contains even less TiO_2 and P_2O_5 than the Orange Mountain Basalt. Preakness Basalt compositions, unlike Orange Mountain, are spread out over a wide range (Fig. 2) generating a trend that may be derived from a more primative source (Fig. 4). The compositional range, however, overlaps or closely resembles the Sander Basalt of the Culpeper Basin, Virginia (Puffer, 1984), and the Holyoke Basalt of the Hartford Basin (Puffer and others 1981). The composition of the first and second of the three Preakness flows is generally more chemically evolved than the Orange Mountain Basalt to an extent approximately equilivent to the degree the interior of the Palisades Sill differs from the chill-margin of the Palisades Sill. These relationahips were interpreted by Puffer and Lechler (1980) and Walker (1969) as due to fractionation processes. The uppermost of the three Preakness flows, however, has been determined to be a Low-Ti ENA type (Puffer, 1989) unrelated to the underlying high-Ti Orange Mountain Basalt. Analyses of samples from each of the three Preakness flows combine to generate a chemically diverse range that when plotted on MgO variation diagrams (such as Fig. 2) is distinctly depleted in several incompatable elements (Ti, Zr, and light REE) compared to the Orange Mountain Basalt (Table 1).

Although the three Preakness flows are apparently not related to the Orange Mountain Basalt they may be related to each other through fractionation processes that took place in a shallow sill. Philpotts and Asher (1989) present convincing evidence that decompression melting during ascent through the lithosphere has prevented fractionation from effecting some of the igneous rocks of the Hartford Basin, Connecticut. The effects of

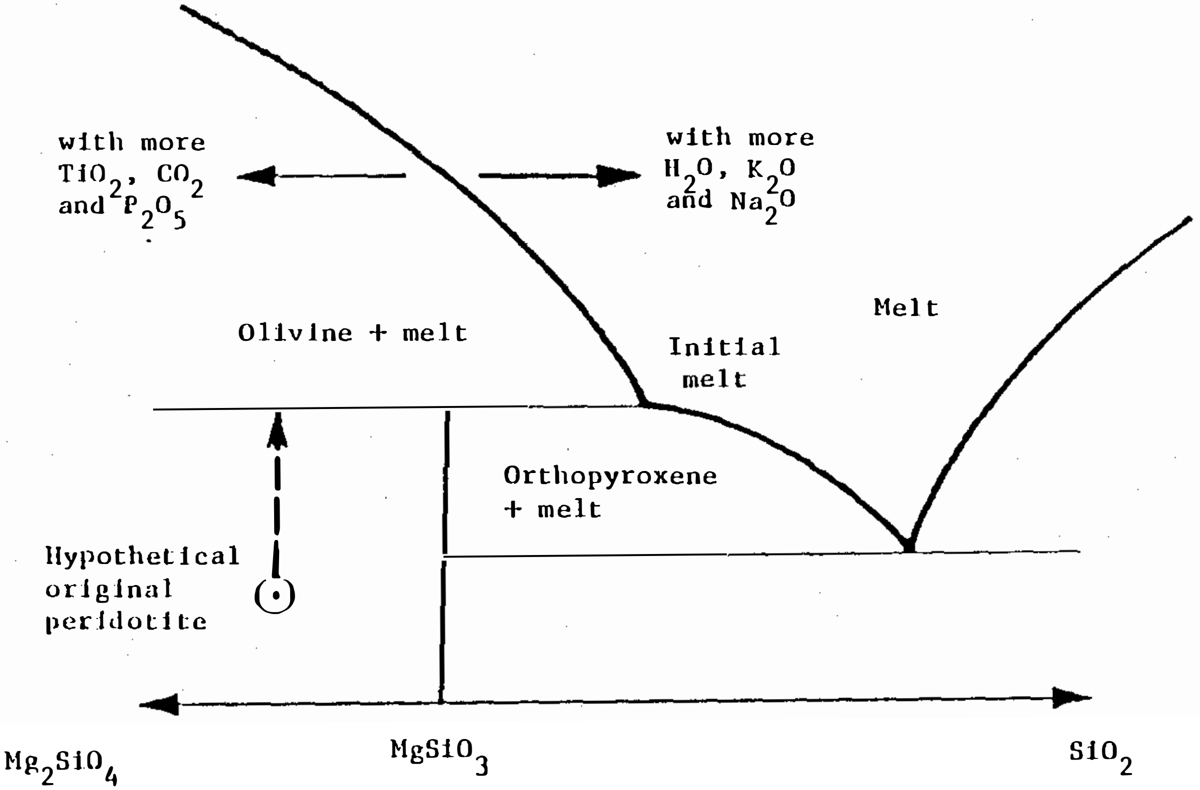

Figure 6. Shift in liquidus boundary with monovalent cations versus 4- or 5-valent cations, after Hyndman (1985). A high ratio of K_2O + Na_2O/TrO_2 + P_2O_5 is a characteristic of Orange Mt. Basalt.

decompression melting, however, are presumably limited to assent. Once shallow sills such as the Palisades are reached, shallow, in-situ pyroxene controlled fractionation may have occurred.

Hook Mountain Basalt. Fractionation processes are also incapable of relating the Hook Mountain Basalt to any of the underlying Watchung Basalts. Puffer and Lechler (1980) have shown that the Hook Mountain Basalt could not have fractionated out of Preakness magma largely because of higher Cr/Mg and Ni/Mg ratios than the Preakness. More recently it has been shown by Gottfried and Tollo (1989) that the Hook Mountain Basalt could not have fractionated out of Orange Mountain Basalt largely because of a lack of expected enrichment in Zr and Nb.

The Hook Mountain Basalt is a relatively minor magma type compaired to the HTQ or LTQ magmas. The Hook Mountain is chemically equivalent to the Hampden Basalt of Connecticut (Puffer and others, 1981), but in both cases the relatively minor magma volume and the upper stratigraphic position makes it more vulernable to a wide range of processes, particularly assimilation, that are capable of affecting magma compositions.

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ROAD LOG FOR EXPOSURES OF WATCHUNG BASALT, NOTHERN NEW JERSEY

CUMULATIVE MILEAGE	MILES FROM LAST POINT	ROUTE DESCRIPTION
0	0	From the intersection of Interstate 84 and Rt. 17 near the Orange County College Campus proceed southeast on Rt. 17 which becomes Rt. 6 near Goshen. Continue

		on Rt. 6 to Exit 131.
18.0	18.0	Proceed south on Rt. 17/32 one traffic light. Make left turn onto Rt 6 and continue toward Bear Mountain.
25.0	7.0	Make second right on circle onto the Palisades Interstate Parkway (south). Continue on parkway to Exit 13.
34.0	9.0	Turn right (west) onto US 202.
36.5	2.5	Park along US 202 opposite the basalt outcrop on the left.

STOP 1. LADENTOWN BASALT

The closely-spaced curved cooling columns displayed by the Ladentown basalt along US 202 contrast with the thick massive columns typical of the Palisades sill that underlied the basalt and was probably its source of magma. The basalt exposed at this locality is fine grained, contains large plagioclase phenocrysts, and is slightly vesicular. Chemical analysis of the Ladentown Basalt (Puffer and others, 1982) compare closely with the fractionated interior (Walker's (1969) second magma pulse of the Palisades sill. The Ladentown Basalt, appears to have extruded onto sediments of the Passaic Formation, perhaps forced to the surface by the injection of a second magma pulse within the Palisades sill. This occurred before the Feltville Formation was deposited, and before the Preakness Basalt was extruded. A physical connection between the Ladentown flow and the western end of the Palisades sill at Mount Ivy is indicated by magnetic and gravity data (Kostsomitis, 1980; Kodama, 1983). However, this connection is not seen at the surface.

Good exposures of coarse boulder conglomerate are located another 0.4 mi. south along US 202. The coarse clast size of the sediment coincides with their close proximity to the western border fault in the valley running parallel to US 202. Note the distinct change in topography on the opposite side of the border fault where Precambrian gneisses are the dominant lithology.

36.8	0.3	Continue south on US 202, observe the coarse-rained fanglomerate exposed on the left and the Precambrian Highlands of the Reading Prong exposed west of the Ramapo fault valley

		on the right.
51.0	14.2	Turn left (southeast onto Rt. 208.
53.8	2.8	Turn right (south) onto Rt. 502 (Ewing Ave.).
55.8	2.0	Turn left onto High Mountain Rd. Bear right at the fork onto Belmont Ave.
57.0	0.2	Park at the base of the jeep trail to the summit of High Mountain.

STOP 2. PREAKNESS BASALT AT HIGH MOUNTAIN, NORTH HALEDON

High Mountain is the highest point (970 ft; 296 m.) in the Preakeness Mountain chain. The upper portion of the hiking or jeep trail to the top of High Mountaom cuts through closely-spaced columnar-jointed basalt typical of the entablature of the Preakness Basalt. At the top of the mountain is a beautiful alpine meadow that on a clear day affords a spectacular view of most of northern New Jersey. The basalt exposed in the meadow is very coarse-grained; it is typical of the interior of the first flow of the Preakness Basalt and resembles diabase.

The view to the southeast includes the New York City skyline in the background behind the ridge formed by the Palisades sill. (A copy of 1981 Paterson 7 1/2-minute Quadrangle is recommended). The city of Paterson is in the foreground where the Passaic River cuts through the First Watchung Mountain ridge formed by the westward dipping Orange Mountain Basalt. The New Street trap-rock quarries and Garret Mountain are clearly visible just north of Paterson. The view directly to the south includes the city of Newark in the distant background on the far side of the First Watchung Mountain, Montclair State College southeast of Paterson, and Paterson State College in the foreground. The view to the southwest includes the Precambrian New Jersey Highlands province west of the Ramapo Fault scarp in the background and the curved "inverted S" shaped Hook Mountain ridge formed by the Hook Mountain Basalt in the foreground.

57.2	0.2	Return to Belmont Ave., turn right.
60.3	3.1	Turn left onto West Broadway.
60.4	0.1	Turn right (west) onto Totowa Ave.
60.7	0.3	Turn left at stadium and park at Passaic Falls.

STOP 3. ORANGE MOUNTAIN BASALT AT PASSAIC FALLS

An excellent exposure of Orange Mountain Basalt is located here in the park above Passaic Falls. Observe the columnar jointing in the basalt and some large convex upward, or half-moon vesicles that typically occur near flow-tops. Carefully climb into the narrow notch in the basalt eroded along the strike-slip fault for a closer inspection of the basalt. Most of the slickensides have been eroded away but a few still remain.

Cross the footbridge, or if blocked, walk down Spruce Street to the statue of Alexander Hamilton. At the exposure along the north edge of the parking lot near the statue of Alexander Hamilton, the lower contact of the Orange Mountain Basalt with the underlying Passaic Formation is seen. Southwest plunging pipe-amygdules and vesicles are exposed in the basalt near the contact. These vesicles occur entirely within the basalt above the basal contact.

From the statue of Alexander Hamilton observe the vertical strike-slip fault planes through the lower flow unit of the Orange Mountain Basalt and the contact between the lower colonnade and the overlying entablature. The "S.U.M." over the door of the historic building near the river at the base of the view area stands for "Society of Useful Manufactures," an organization founded in 1789 to promote local trade.

From the falls, walk south along Spruce Street, cross McBride Avenue and continue one-half block to the Paterson Museum. Some of the best examples of the secondary minerals found in the Paterson area trap-rock quarries are on display at the museum.

63.0	2.3	Continue west on Totowa Ave., turn right onto Green Ave.
63.0	0.0	Turn left onto Claremont Ave.
63.2	0.2	Proceed northwest to a sharp right curve in the road, and park along outcrop.

STOP 4. PREAKNESS PILLOW BASALT, TOTOWA

The lower portion of a Preakness Mountain Basalt flow unit, the second of three, is exposed along the west side of Claremont Avenue. The base of the flow is a subaqueous flow lobe containing ellipsoidal pillows and pahoehoe toes. Secondary mineralization includes calcite, quartz, and minor heulandite in small stretched amygdules. The pillowed base of the flow rests on a thin layer of red silstone exposed (depending on the amount of refuse present) at road level. The flow grades upward into massive columnar basalt. Further north on Claremont Avenue the upper part of the flow, in contrast to the bottom is not pillowed and contains large spherical amygdules mineralized with prehnite and pectolite.

63.4	0.2	Return southeast on Claremont Ave. to Green Ave., and turn right.
63.5	0.1	Turn left on Totowa Road.
63.7	0.2	Turn right (south) onto Union Blvd.
65.5	1.8	Turn right into Walnut St.
65.6	0.1	Turn left onto Montclair Rd.
65.9	0.4	Turn left onto Rt. 23 (Pompton Tpk.).
66.0	0.1	Turn right onto Rt. 527.
67.2	1.2	Turn right onto Greenbrook Rd.
67.7	0.5	Park at intersection of Greenbrook Road with Central Ave. just north of the bridge over Green Brook.

STOP 5. UPPER (LOW-TI) FLOW OF PREAKNESS BASALT, NORTH CALDWELL

The middle and upper flows of the Preakness Basalt are exposed here together with a layer of red siltstone that was deposited between the two flows. The middle flow is well exposed along the banks of Green Pond (sample site P39, Fig. 1) and can be examined by carefully walking down the slope near the bridge. Be careful of the poison ivy. The middle flow is greatly enriched in incompatable elements compaired to the upper high-Ti or HTO flow of the Preakness (Table 1).

The upper flow can be examined along the road-cut just south of the bridge (Sample site P40, Fig 1). It is exposed above the thin red stilstone layer along the road. Good dinosaur footprints were found in this siltstone by Chris Laskovich. Columnar jointing is reasonably well displayed at this stop but both flows are other-wise quite massive with little evidence of secondary mineralization.

69.7	2.0	Proceed south on Central Ave. turn left on Bloomfield Ave.
70.2	0.5	Turn left onto Rt. 527.
72.7	2.5	Turn right (west) onto Interstate 280.
73.9	1.2	Turn left (south) onto Eisenhower Parkway at exit 4A.
74.8	0.9	Turn right into parking lot.

STOP 6. HOOK MOUNTAIN BASALT, ROSELAND

This Hook Mountain exposure displays columnar joints, but a well-defined Tomkeieff (1940) sequence is not apparent. An extensively altered volcano-clastic layer is exposed near the base of the Hook Mountain Basalt. In addition, some bleaching and evidence of low-grade thermal metamorphism is seen at the lower contact.

In contrast to the Orange Mountain (Stop 2) and Preakness (Stop 3) Basalts, the Hook Mountain Basalt is relatively enriched in amygdules and vesicles. Prehnite is abundant at this locality and is easily collected, particularly near the north end of the exposure.

75.7	0.9	Proceed north on Eisenhower Parkway and turn right onto I-280 east.
78.7	3.0	Type section of Preakness Basalt on both sides of highway.
80.2	1.5	Type section of Orange Mountain Basalt on both sides of highway.
83.6	3.4	Exit onto Garden State Parkway north or south.

NOTES