Pre-Ottawan (1.09 Ga) Infrastructure and Tectonics of the Hudson Highlands, New York

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INTRODUCTION

This trip focuses on some of the oldest Mesoproterozic rocks in the Appalachians and the nature of the pre-Ottawan (pre-1.09 Ga) infrastructure of the Hudson Highlands and Manhattan Prong. Zircon geochronology by Aleinikoff (Table 1) is revised from that given in Table 1 of Ratcliffe and Aleinikoff (2008) and is still preliminary. Ongoing geologic mapping east of the Hudson River in the Peekskill, West Point, Lake Carmel, Mohegan Lake, Brewster and Peach Lake quadrangles continues to lead to a reinterpretation and clarification of our former views (Ratcliffe and Aleinikoff, 2001, 2008) as well a new synthesis for the Hudson Highlands east of the Hudson River. After publishing the detailed geology of the Poughquag quadrangle (Ratcliffe and Burton, 1990) and the Oscawana Lake quadrangle (Ratcliffe, 1992), investigations were resumed in 2000 to prepare the previously mapped but unpublished quadrangles for publication.

This trip presents, in preliminary form, much of the recent, (post-2000) information, which helps clarify the age and distribution of Mesoproterozoic basement rocks of the Hudson Highlands and Manhattan Prong and is an abbreviated version of our 2008 NEIGC trip. Please note that stops have been changed and that the route is different.

A remarkable newly recognized aspect of Hudson Highlands geology covered in this trip is the widespread presence of orthogneisses and metavolcanic rocks belonging to the time period between 1400 Ma and 1200 Ma, or during Geochrons 14 and 13 of Rivers (1997). These rocks formed before the Grenville orogeny, defined by Rivers (1997), as ranging from 1.09 Ga to 0.98 Ga, and are coeval with crustal convergence in the Elzevir belt in Ontario and Quebec, at the western margin of the Grenville orogenic belt. We know little about the nature of the deformation that may have affected rocks of the Hudson Highlands during the Elzevirian orogeny except that some were transformed into gneissic rocks prior to about 1230 Ma and multiply deformed after that.

Igneous activity and deformation in the time period of about 1170 to 1145 my ago, at or near the time of the Shawinigan pulse of the Grenville orogeny of Rivers (1997) affected many the rocks of the Hudson Highlands and presumably of the Manhattan Prong although data there are sparse. Penetrative, regionally developed, Y F2 folds of the Hudson Highlands have been mapped in northern New Jersey (Dallmeyer, 1972) and West Point area of the Hudson River (Helenek, 1971; Helenek and Mose, 1984) eastward through the Hudson Highlands (Ratcliffe and Burton, 1990; Ratcliffe, 1992). This deformation resulted in redeformation of older rocks as well as deformation of hornblende granites of the Storm King type, which have an intrusive age of 1174 ± 8 Ma (Table 1). Folds of this generation are folded by the sigmiodal deformation zones associated with the intrusion of the Canopus pluton, and crosscut by mafic dike swarms. Acceptance of an intrusive age of 1143 ± 12 Ma for the Canopus pluton (Table 1) and for the associated mafic dikes, requires that the regional Y F2 dynamothermal event be older than the Ottawan phase of the Grenville orogeny. This is important because many workers think that Ottawan or the terminal phase of the Grenville orogeny was responsible for the major deformational features in Mesoproterozoic rocks of the Appalachians. This view is being revaluated in the Appalachian outliers of the Grenville and in the Adirondacks, as the recognition of rocks and deformational events at about 1230 Ma and 1150-1134 Ma that are older than the Ottawan are discovered (Ratcliffe and others, 1991; Ratcliffe and Aleinikoff, 2001, 2008). In the Adirondack Highlands evidence for Shawingan migmatite in the age range of 1180-1160 Ma is widespread (Heumann and others, 2006; Bickford and others, 2007) Throughout the Hudson Highlands and in northern Appalachians, there is a relative scarcity of Ottawan igneous rocks, although ages of metamorphic overgrowths on zircon and of migmatization of older rocks attest to widespread Ottawan remetamorphism.

Rocks intruded between 1134 ± 8 Ma and 1045 Ma, are foliated, as in adjacent areas, such as the New Milford massif (Walsh and others, 2004) and as seen on this trip. However there are abundant data which suggest that the deformational effects in the Hudson Highlands and elsewhere in the northern Appalachains are the result of multiple orogenic events, some predating the Ottawan. On this trip we will visit and summarize information concerning recently dated rocks that are critical to defining the pre-Ottawan history of the Grenville orogen here and elsewhere in the Appalachians of New York and New England.

In addition newly determined SHRIMP U-Pb zircon data, and Ar^{40} /Ar^{39} hornblende ages support late Ordovician to Silurian Taconian overprinting of the basement and cover rocks between 450 to about 443 my ago and suggest that Acadian effects were minimal by comparison.

MESOPROTEROZOIC ROCKS OF THE GRENVILLE OROGEN OF THE NORTHERN APPALACHIANS

We think that is important to place the setting of this field trip within the context of the broader issue namely, the distribution of pre- Grenville Mesoproterozoic rocks throughout the northern Appalachians which has been developing over the past 10 years with the utilization of SHRIMP- based zircon geochronology.

Figures 1, 2, and 3 are generalized maps of the Green Mountain area in Vermont, the Berkshire massif of Massachusetts and the northern Hudson Highlands and adjacent Manhattan Prong. These show the generalized distribution of Mesoproterozoic igneous rocks based on published and, unpublished geochronology largely by Aleinikoff and mapping from 1961 to the present by Ratcliffe, for the new Bedrock Geologic Map of Vermont (in prep), the Bedrock Geologic Map of Massachusetts (Zen and others, 1983) and in the Hudson Highlands east of the Hudson River included in part, in published reports (Ratcliffe and Burton, 1990; Ratcliffe, 1992). Mapping in the Lake Carmel, Brewster, and Peach Lake quadrangles was conducted from 2002 to the present by Ratcliffe. These diagrams do not portray the many subdivisions of the paragneiss sections or the igneous rocks, but only show generalized distributions of igneous rocks or suites that have been dated by recent U-Pb zircon geochronology studies. The level of understanding among these maps is uneven as geochronolgic data for the Berkshire massif are limited as compared to the other two areas.

Evidence for very old, preGrenville rocks in the Grenvillian orogen of the Appalachains has been growing in recent years but the distribution of these rocks is uneven. In the Green Mountain massif and eastern domes of Vermont, igneous rocks in the age range of 1400 to 1300 Ma (Geon 14) are common and constitute about 25% of the area of the Mesoproterozoic there (Figure 1). Much, but an unknown amount of the paragneiss sequence in the Green Mountains also is older than 1300 Ma so the percentage may be much higher than shown in Figure 1. Ratcliffe and others (1991) and Ratcliffe (1997) showed that plutonic rocks of the College Hill pluton dated at about 1230 Ma cross cut the older 1400 to 1300 Ma gneisses, indicating Elzervirian deformation in the Green Mountains as well as classical Grenvillian events formed between 1200 and 1000 Ma which affected all the Mesoproterozoic rocks.

The Oldest Rocks - Geon 14

Five new U-Pb ages (Table 1) and geochemsitry provide evidence for calcalkaline igneous activity between 1349 and 1328 Ma in the Fordham Gneiss and in the Hudson Highlands east of the Canopus shear zone. Broad areas of biotite-tonalitic, trondhjemitic and biotite granite gneisses (Yrg) extend northward from the main belt of Reservoir Gneiss near Peekskill, into the Poughquag, Lake Carmel and northern part of the Brewster quadrangles (Figure 2). This belt may contain separable types of granitic gneiss but distinguishing them on maps has proven almost impossible thus far. Tonalitic gneisses at Cat Hill (Stop 7) and trondhjemite gneiss (Stop 1) tend to occur in the western areas and more granitic rocks are to the east and to the south. Granodioritic to trondhjemite Reservoir Gneiss at Peekskill (Stop 8) has a U-Pb zircon age of 1338 ± 9 Ma and we think that map continuity suggests that similarly old rocks are present in the Brewster area.

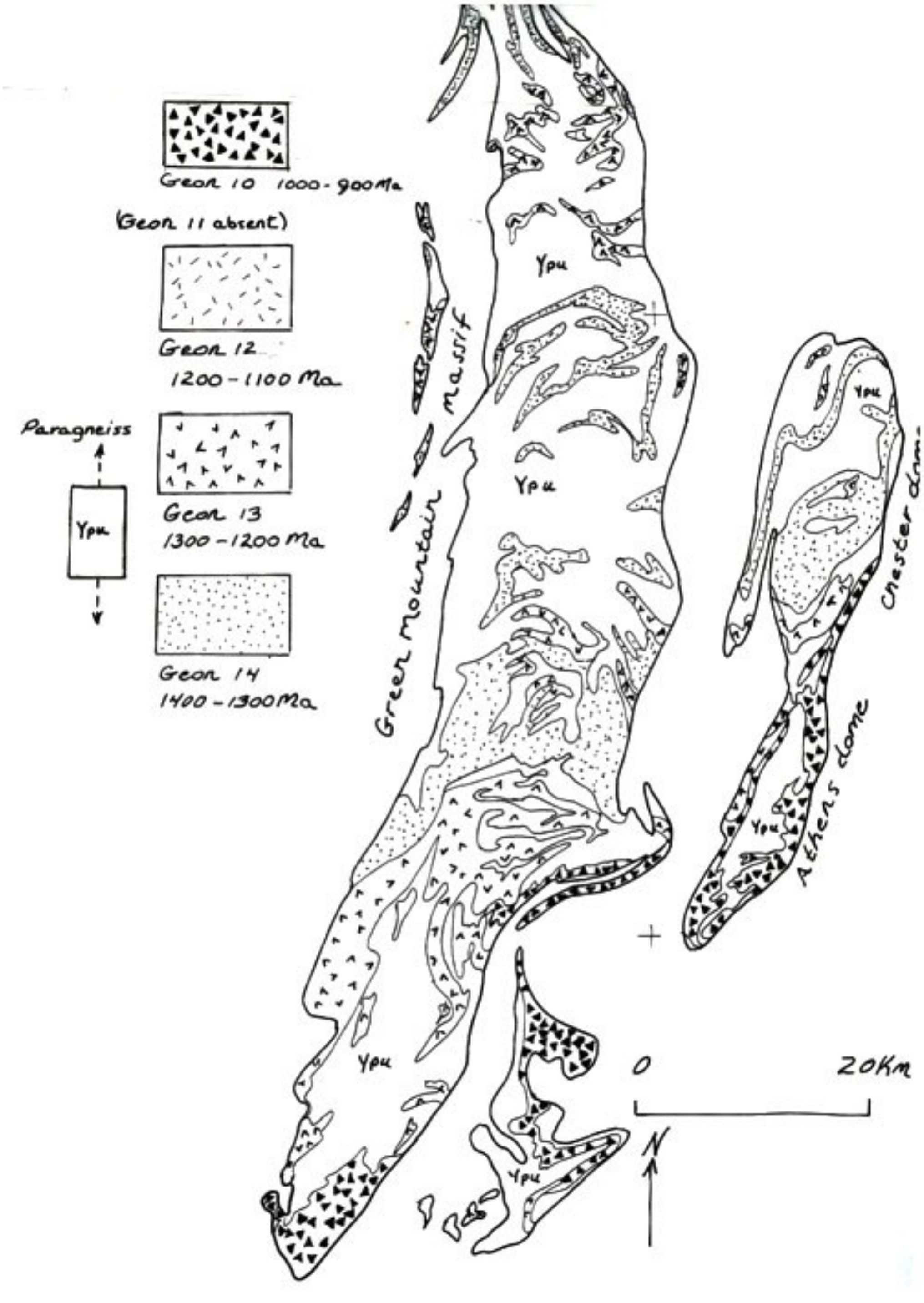

Figure 1. Simplified map of Mesoproterozoic igneous rocks of the Green Mountain massif and eastern domes of Vermont showing broad belts which are characterized by pre-Grenville intrusive rock of Geons 14, and 13, and Grenville intrusive rocks of Geons 12, 11 (minimally represented), and post Ottawan rocks of the Cardinal Brook Intrusive Suite of Geon 10. Paragneiss Ypu contains metasedimentary as well as probable metavocanic rocks that could range from Geon 14 to Geon 13.

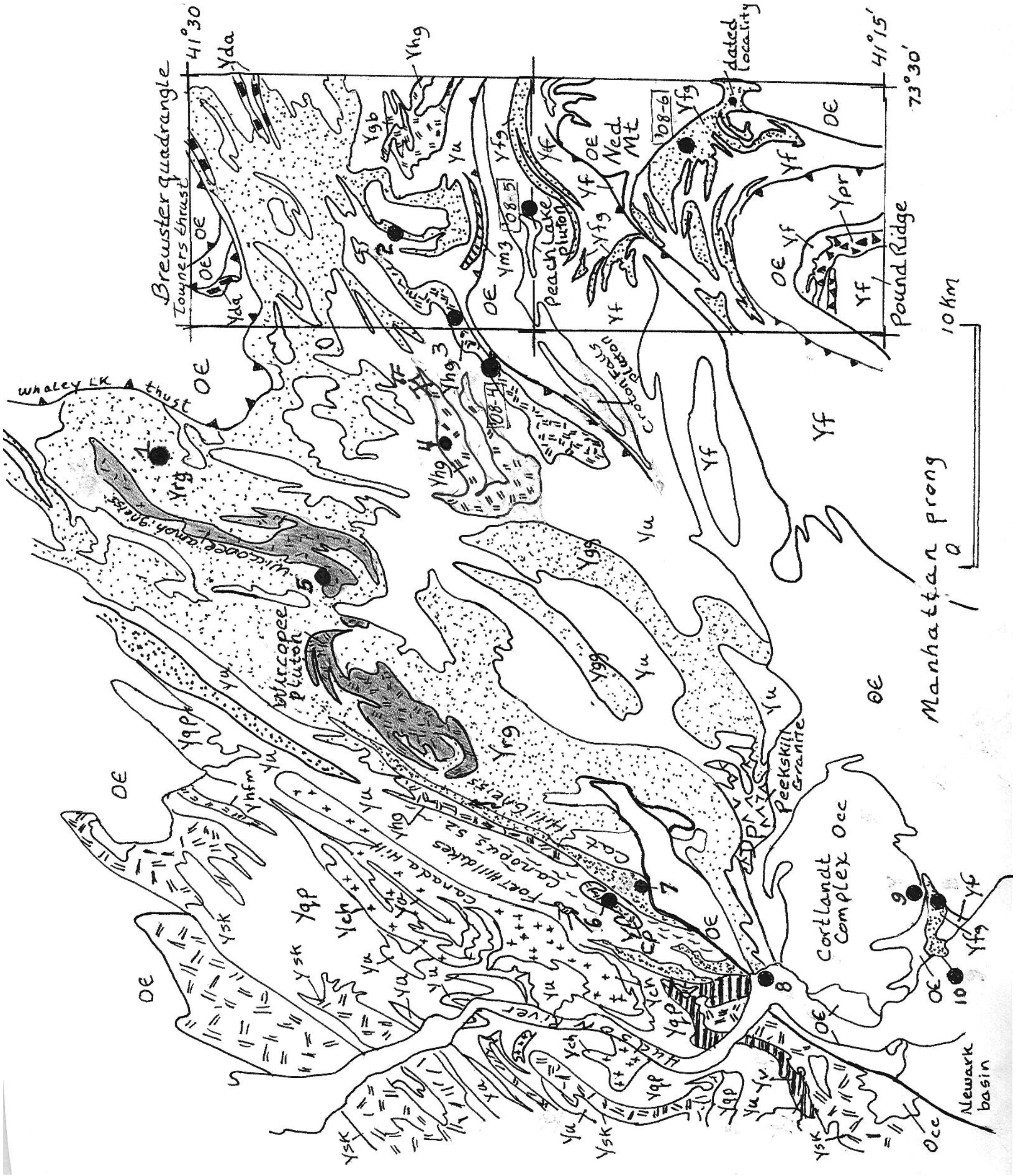

Figure 2. Generalized map of the Hudson Highlands of NY and Connecticut modified from Figure 1 of Ratcliffe and Burton (1990) showing Mesoproterozoic intrusive rocks. Many faults have been eliminated for clarity and new data from the Brewster and Peach Lake quadrangles have been added based on recent mapping by Ratcliffe. Key to unit designators: Geon 14- Yrg Reservoir Gneiss (Stops 1, 2 and 10); Ycth Cat Hill Gneiss; Ygg granitic gneiss undated; Yfg granitic gneiss of the Fordham Gneiss (Stops 6 and 9); Shaded- metapyroxenite, metagabbro, metadiorite and amphibolite gneiss of the Wiccopee pluton and amphibolite belt; Yqp quartz plagioclase gneiss and leucogneiss west of the Canopus shear zone; (continues)

Figure 2. (continued) Geon 13 Ymz monzonite at Joe's Hill, Brewster, NY; Yv metavolcanic and amphibolite Camp Smith; Geon 12-Ysk hornblende granite of the Storm King type; Yhg hornblende granite and diorite at Brewster (Stop 3); Yhfm ferrodoirite and ferromonzonite, Canopus pluton (Stop 12) Fort Hill intrusion and dikes, identified on map; Ygb gabbro and Yhg southeastern part of Brewster quadrangle; Geon 11-Yda Danbury Augen Gneiss; Geon 12 or 11-Ych Canada Hill Granite age uncertain; Geon 10 -Ypd Pound Ridge Granite; Yu paragneiss and undated biotite-quartz-plagioclase gneiss undifferentiated largely Geon 14 and 13 but age uncertain; Yf Fordham Gneiss undifferentiated.

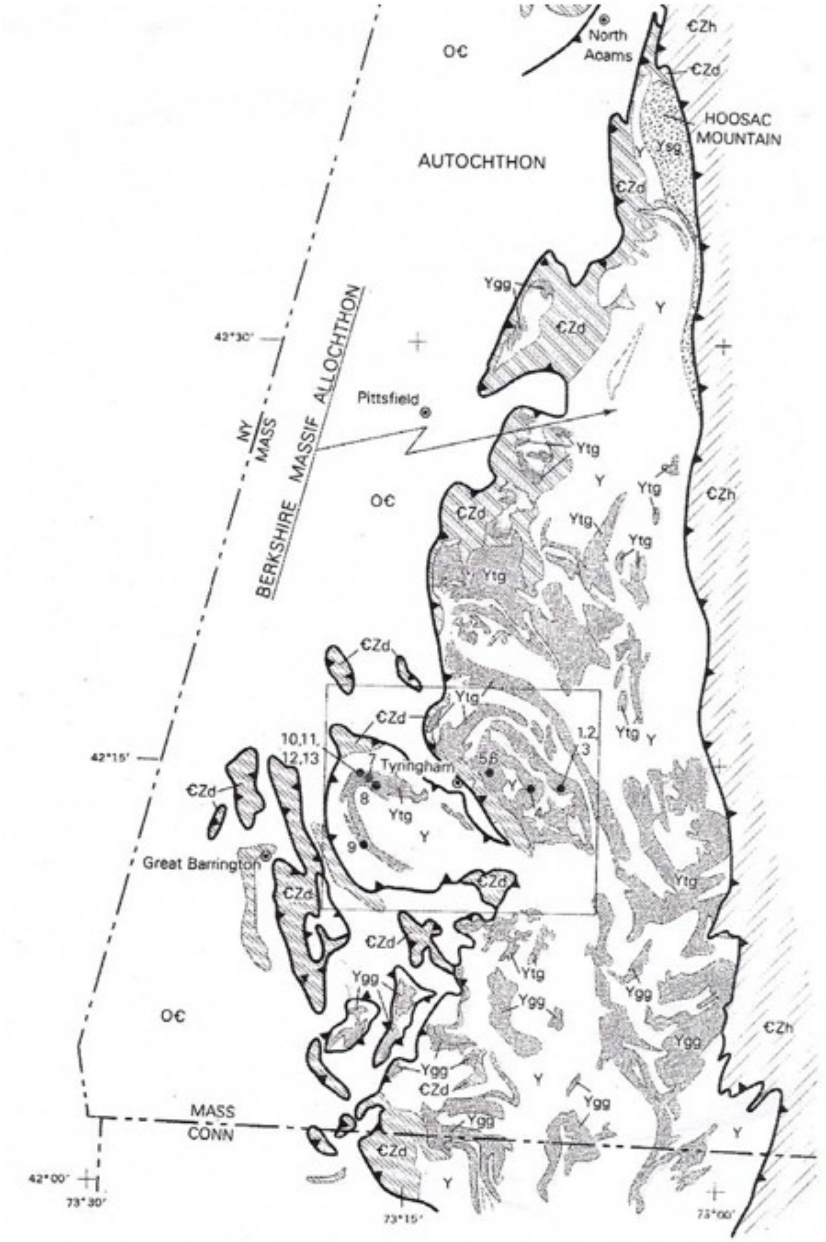

Figure 3. Simplified map, showing the distribution of granitic gneisses of Geon 12 in the Berkshire massif and the post Grenville Stamford Granite of the Cardinal Brook Intrusive Suite, of Geon 10. Ytg Tyringham Gneiss, Ygg other similar unmanned granitic gneisses from Zen and others (1983). Sample locations are those used for Rb/Sr whole rock dating of Mose, reported in Ratcliffe (1975).

Sample No.	**Unit**	**Age-type**	**Overgrowth ages**
		GEON 11	
*NM100	Danbury augen granite	1045 ±7.9 Ma (7/6)	0.965 Ga
*NM772	Layered biotite gneiss	1048 ± 11 Ma (7/6)	0.98 Ga
*NM628	Biotite granite gneiss	1050 ± 14 Ma (7/6)	1.03, 0.98 Ga
*NM576B	Migmatite	1057 ± 10 Ma (7/6)	1.0 Ga
		GEON 12	
Br2549	Hornblende granite (Stop 3)	1134 ± 8 Ma (7/6)	
CP-3	Canopus pluton (Stop 6)	1143 ± 12 Ma (CA)	~1.0 Ga
JA-PK	Storm King granite	1173 ± 7 Ma (CA)	~1.14 Ga
		GEON 13	
Br2215	Quartz monzonite Joe's Hill (Brewster)	1240 ± 7 Ma (7/6)	
PK9-04	YV aplitic gneiss	1238 ± 8 Ma (7/6)	1.22, 0.99 Ga
		GEON 14	
*NM174	Pink granite gneiss	1311 ± 7 Ma (7/6)	1, 0.98 Ga
Br1176	Fordham Gneiss (Stop 6-2008) Scott Ridge (Peach Lake)	1328 ± 8 Ma (CA)	
Br576A	Reservoir Gneiss (Luddingtonville) (Stop 1)	1338 ± 9 Ma (7/6)	1.26, 1.0 Ga
PK11, 876	Cat Hill Gneiss (Peekskill) (Stop 7)	1333 ± 9 Ma (CA)	
PK1-05	Reservoir Gneiss (Stop 8)	1338 ± 6 Ma (CA)	~1.26, 0.98 Ga
PK7A	Fordham Gneiss (Stop 10)	1349 ± 7 Ma (CA)	~1.12, 1.02 Ga

Table 1. U-Pb Zircon ages of Mesoproterozoic rocks of the northern Hudson Highlands, Manhattan Prong, and New Milford massif (NM*) (Walsh and others, 2004), CN = concordant age (7/6)=Pb/Pb age.

Mafic rocks of the Wiccopee pluton (Figure 2) and associated amphibolite gneiss (Stops 5a, b) appear to be intruded by granitic components of the Reservoir Gneiss (Ratcliffe, 1992) and may be the source of some of the xenoliths or enclaves in the granitic gneiss. Biotite granitic gneiss similar to the Reservoir Gneiss but undated occur in a southern zone (labeled Ygg). Granitic gneiss from the New Milford massif in Connecticut has limited areal extent and a U-Pb zircon age of 1313 Ma (Walsh and others, 2002) and closely resembles rocks of the Reservoir Gneiss in the Brewster area. Biotite granite gneiss (Yfg) of the Fordham Gneiss is wide spread in the southern part of the Brewster area and in the core of the belt of Fordham Gneiss in the center of the Peach Lake quadrangle (Stop 6 of Ratcliffe and Aleinikoff, 2008). This rock has a U-Pb zircon age of 1328 ± 8 Ma. Granitic gneiss of the Fordham at stop 10 has a U-Pb zircon age of 1349 ± 7 Ma. In the New Jersey Highlands, Aleinikoff and Volkert (2007) and Volkert and Aleinikoff (2007) report ages of intrusive and volcanic rocks of the Losee Suite as about 1230-1300 Ma.

Areas shown as quartz-plagioclase gneiss (Yqp) in Figure 2 in the West Point and Peekskill quadrangles extend into New Jersey and are Losee-like, although they have not been dated with certainty and probably belong to Geon 14 or 13.

Rocks of Geon 13

The College Hill pluton and other dated but unnamed granite gneisses from the Green Mountains of Vermont have intrusive ages of about 1230 Ma (Ratcliffe and others, 1991) and produce migmatite near there borders and cross cut older folds and gneissosity (Ratcliffe, 1997). Extensive areas of biotite granitic rocks correlated with the dated localities occur through out the central and southern Green Mountains and eastern domes and northern part of the Green Mountain massif are thought to be of the same approximate age based on geologic mapping. In the Hudson Highlands there are only two dated rocks belonging to Geon 13 (Figure 2). One is a small late cross cutting monzonite to granodioritic mass (Ymz on Figure 2) that intrudes across gneissosity in older biotite-hornblende migmatitic gneiss on Joes Hill in the southern part of the Brewster quadrangle. This rock provides evidence for gneissosity of Elzevirian age in the older gneisses. The other rock is aplitic gneiss (Yv in Figure 2) on the east side of the Hudson River and on the north flank of the Dunderberg antiform near Camp Smith. This rock is interlayered either by interbedding or by lit par lit injection with numerous continuous mapped amphibolitic gneisses. The felsic component has a zircon SHRIMP age of 1238 ± 7 Ma.

Rocks of Geon 12

Granitic rocks dated between about 1170 to 1135 Ma are present in Green Mountains, Chester and Athens domes, Berkshire massif Figure 3, and in the Hudson Highlands of New York and New Jersey. Locally these intrusive rocks include gabbro, hypersthene ferrodiorite, ferromonzonite, ferrodiorite dikes. biotite granite augen gneisses, and hornblende granite gneisses of the Storm King Granite type in the Hudson Highlands.

The Tyringham Gneiss in the Berkshire massif and related granitic rocks (Figure 3) make up about 35 per cent of the Berkshire massif, largely in the central and southern area. The age of the Tyringham Gneiss from samples on Beartown Mountain and near Tyringham was determined by whole rock Rb/Sr dating by Doug Mose at about 1170 Ma (Mose in Ratcliffe, 1975). Ratcliffe and Zartman (1976) reported upper intercept ages of approximately 1040 to 1080 for the Tyringham on Beartown Mountain. A more recent SHRIMP zircon age from a sample of Tyringham Gneiss in the East Lee quadrangle of about 1180 Ma (Karabinos and others, 2003) and tends to support the original Rb/ Sr age, as does a SHRIMP zircon age from the Tyringham on Beartown Mountain (Aleinikoff, unpublished data). If the correlations of Ratcliffe are correct as shown on the Bedrock Geologic Map of Massachusetts (Zen, 1983). then most of the granitic rocks of the Berkshire massif belong to Geon 12. Because the Tyringham Gneiss intrudes all mapped units within the Mesoproterozoic of the Berkshire massif it establishes a minimum age for that sequence (Ratcliffe and Zartman, 1976), which is generally consistent with the inferred age of very similar paragneiss sequences in the Vermont and in the Hudson Highlands and Fordham Gneiss.

In the Hudson Highlands, hornblende granite of the Storm King type (Ysk on Figure 2) was intruded at about 1174 ± 8 Ma and was deformed along with country rock before intrusion of the Canopus pluton and attendant mafic dikes (stop 6) and hornblende granite and diorite at Brewster at stop 3 (see below).

In the Hudson Highlands the 1143 ± 12 Ma Canopus pluton (Stop 6) was intruded during significant right slip deformation on vertical faults of the Canopus fault zone. Northeast trending mafic dikes and northwest trending folds document transpressional tectonics at 1143 Ma. Hornblende granite gneiss and aplite near Brewster NY (Stops3 and 4) intrudes aluminous and calcareous paragneiss to produce magnetite- sulphide mineralization of the Brewster magnetite district and crosscuts an older gneissosity.. Hornblende-pyroxene pegmatite and hornblende aplite are common as the border phase of the hornblende granite. The zircon SHRIMP age of the hornblende granite at Brewster is 1134 ± 8 Ma. Associated mafic dikes and diorite – gabbro stocks as well as the hornblende granite cross cut older gneissic structure, older isoclinal folds, and high-grade mylonitic shear zones, as the Canopus pluton and related dikes do. Similar mineralization at Lake Mahopac and at Tilley Foster suggests that this is the age of magnetite and calc silicate mineralization there as well. We think that these two dated rocks (Canopus and hornblende/ diorite at Brewster (stops 3 and 4) are attributable to the same tectonic events of the Shawinagan pulse of the Grenville orogeny, i.e., not the Ottawan phase of the Grenville orogeny.

In the Green Mountains of Vermont (Figure 1) rocks of Geon 12 only are known from the northern most part of the massif where foliated coarse K-feldspar augen gneiss crosscut a gneissosity in older gneisses and has SHRIMP age of about 1172 Ma. Hornblende gabbro and diorite are rocks associated with the augen gneisses in the northern most part of the massif as well.. These observations suggest some high-grade metamorphism and deformation occurred before 1172 Ma.

The data from the Green Mountains and Hudson Highlands support important deformation of the basement rocks after 1230 Ma and prior to 1172 Ma in the Green Mountains and after 1173 Ma but before 1143 Ma in the Hudson Highlands. This is approximately the time of the Shawinigan pulse of the Grenville orogeny, following the usage of Rivers (1997).

Rocks of Geon 11 and 10

Except for widespread pegmatitic muscovite –biotite granites and zircon overgrowth ages there is little evidence for igneous activity in the Green Mountains of Vermont during Geon 11 (Figure 1) and only one of these rocks is well dated. Post Grenvillian rapakivi plutons (Karabinos and Aleinikoff, 1990)of the Cardinal Brook Intrusive Suite (Ratcliffe, 1991) occur in the southeastern Green Mountains, in the core of the Chester and Rayponda domes and at the north end of the Berkshire massif (Ratcliffe and others, 1991). This belt of intrusives lies in a distinct NNE trend, which crosses both the individual mapped units in the Grenville orogen but also east west trending bands of Geon 13 and 14 rocks (Figure 3). In the New Milford area and in the adjacent Hudson Highlands megacrystic Danbury augen gneiss was intruded at 1045 ± 8 Ma roughly coincident with widespread migmatization (Walsh and others, 2004). Biotite granite pegmatite, and migmatization accompanied formation of the Canada Hill pluton formerly thought to be intruded at 1014 Ma. Recent analyses on zircon from the main Canada Hill pluton however, have cast some doubt on this date and the true age of the Canada Hill is uncertain at present (Aleinikoff, 2008, personal communication to Ratcliffe) and may be much older than previously thought.

Mesoproterozic Paragneisses

Abundant quartzite, aluminous metasedimentary rocks, dolomitic and calcitic marbles, calc-silicate rocks are wide spread and interlayered with biotite- quartz-plagioclase paragneiss and amphibolite through out the Green Mountain Mesoproterozoic sequence. Amphibolites of both igneous and metasedimentary origin occur. These biotite- quartz-plagioclase gneisses appear to host metasedimentary rocks of different age. A similar sequence occurs in the Berkshire massif. Because of the uncertainity of origin and the abundant interbedded metasedimentary rock little geochronology has been attempted on these rocks.

Paragneisses in the Hudson Highlands appear to be more localized because of the greater abundance of plutonic rocks and or thicker metavolcanic units, principally massive garnet-plagioclase quartz gneisses. Calc-silicate and sulfidic metapelitic rocks, quartzite and prominent phlogopite -diopside dolomite or calcite diopside marble, white coarse- grained dolomite marble and diopside-scapolite quartzite are distinctive but thin units. Paragneisses are intruded by igneous rocks of Geon 12 and 13, but there are no clear cross cutting examples of the oldest rocks, those of Geon 14, with paragneiss. As we will see, all of the old gneisses always contain mafic bioite-hornblende amphibolite, biotite leptite and dioritic hornblende gneiss inclusions. Some are clearly dikes, although boudinage commonly makes contact relations indistinct. Pyroxene and hornblende form at the contact between mafic masses in the old felsic rock suggesting either intrusive contact reactions or later reaction with younger more felsic sweat outs.

GENERAL GEOLOGY OF THE TRIP AREA

Figure 4 shows the general geology of the northern Hudson Highlands as presented in 1990 following extensive detailed mapping by Ratcliffe, Henry Helenek and William Burton following several years of mapping in the late 1980's. Figure 4 from the Poughquagh Quadangle map (Ratcliffe and Burton, 1990) shows the interpretation of the eastern Hudson Highlands at that time. They recognized that a large area east of the Canopus fault consisted of leucocratic gneisses of the Reservoir Gneiss, ranging from tonalite to granite gneiss in a belt previously identified as the Reservoir Granite by Berkey and Rice (1921).

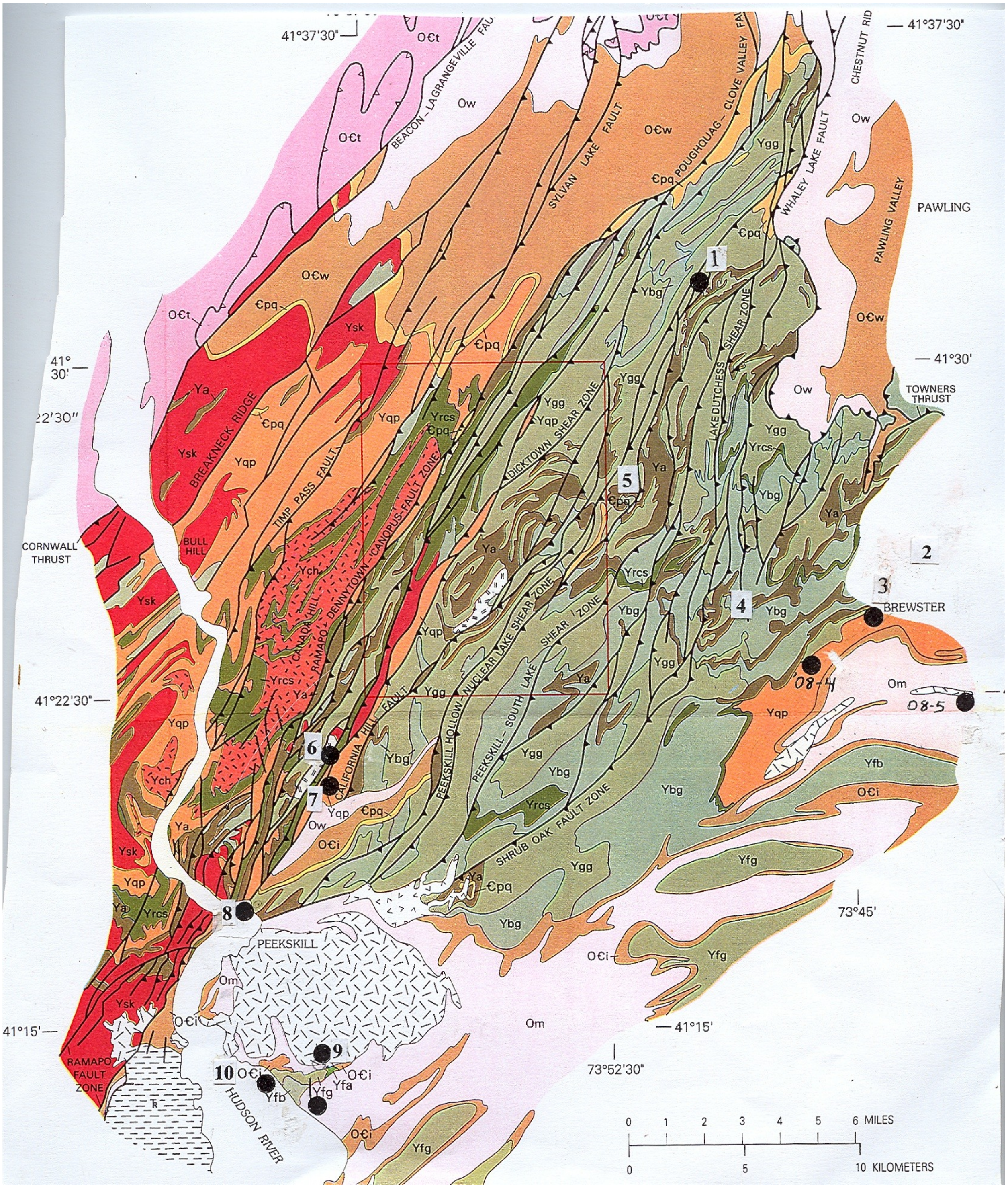

Figure 4. (continues)

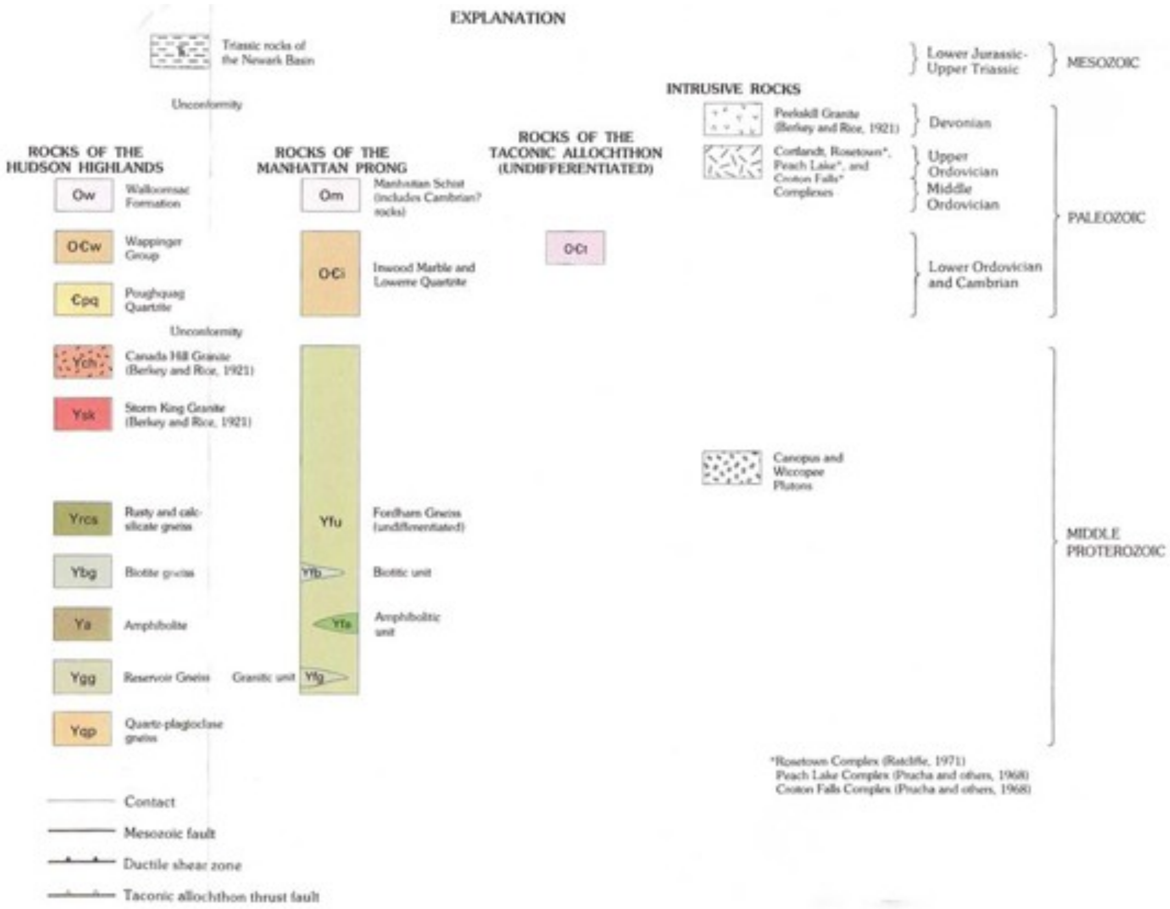

Figure 4. (continued) Geology of field trip area, showing stop locations in the Hudson Highlands from Ratcliffe and Burton (1990). Additional stop locations (see Figure 2).

Rocks of the Hudson Highlands and Manhattan Prong consist of a basement complex of Mesoproterozoic age making up the Highlands gneisses and Fordham Gneiss. These older rocks are now known to range in age from approximately 1350 Ma to about 1000 Ma. In the Hudson Highlands and northwestern part of the Manhattan prong, the Poughquag Quartzite (or Lowerre Quartzite) unconformably overlies the basement. In eastern exposures near Towners and in much of the Manhattan prong, the base of the quartzite becomes increasingly micaceous and feldspathic and contains beds typical of the Dalton Formation which regionally has been interpreted to range down in to the Neoprotoerozoic; for example see a description of the type Dalton in the Pittsfield East quadrangle of Massachusetts (Ratcliffe, 1984). One important aspect of the Dalton Formation as it is mapped throughout Vermont, Massachusetts, New York and Connecticut, is the dominance of quartzofeldspathic schists and granofels and the absence of volcanic rocks (Zen and others, 1983, Rodgers, 1985). At the south end of the Green Mountain massif and on the northern end of the Berkshire massif the Dalton Formation passes laterally into more albitic and aluminous rocks of the Hoosac Formation which contains significance amounts of mafic volcanic rocks having chemical signatures of rift basalts as well as oceanic MORB basalts (Ratcliffe and Armstrong, 1999) In the Hoosac Formation and in the facies of Dalton passing into the Hoosac, quartzites of the Poughquagh and Lowerre types are minor and feather out eastward as the entire sequence becomes older, and more oceanic. This transition between Hoosac and Dalton may be expressed in parts of the Manhattan prong by rocks not marked by quartzite beds like those of the Poughquag and hence rocks mapped as Lowerre Quartzite are now referred to as Dalton Formation in much of the Manhattan prong (Rodgers, 1985) although the rocks by and large are not typical of the Dalton Formation. Regionally rocks of the

Hoosac Formation or correlatives, such as the Cannan Mountain Schist, and or Manhattan schist (units B and C of Hall, 1968) occupy thrust sheets overlying rocks as young as late Ordovician. As a result, rocks resembling the combined Dalton- Hoosac Formation can occur in two structural positions, either resting on the older basement unconformably in which case they are referred to as Dalton or if in thrust sheets as Manhattan Schist. This points to a basic flaw in the use of the term Manhattan Schist to refer only to the allochthonous part of the Manhattan Schist of Hall (1968). This approach produces both a forced stratigraphy and a forced structural solution.

Shelf carbonate rocks of Cambrian through Medial Ordovician age comprise the Wappinger Group of the Hudson River valley and some inliers in the Hudson Highlands and are comparable to carbonate rocks of the Inwood Marble of the Manhattan Prong. Overlying the Inwood or Wappinger are rocks now referred to as the Walloomsac Formation which locally in the Manhattan prong, is referred to as Manhattan A (of Hall, 1968). In the Hudson River valley, Massachusett and Vermont, rocks of the Wallooomsac range from upper Medial Ordovician to Late Ordovician. The depositional age range of the Walloomsac, where controlled by fossils, is about 465 to 445 Ma and marks the pre-Taconian flysch deposits formed just prior to the collisional phase of the Taconian orogeny. The basal Walloomsac Formation contains thin limestones and limestone boulder conglomerate in western exposures but regionally the facies change going eastward. Schistose marbles, phlogopitic feldspathic dolostone, quartzites replace limestone eastward as the formation bites deeper into underlying carbonates and locally rests on Mesoproterozoic rocks. In general the quartzitic, dolomitic and feldspathic rocks are developed regionally in the eastern outcrop belts from western Massachussetts and Connecticut in a line extending from the southwest corner of Massachusettts through the west flank of the Housatonic massif to the west side of the Pawling valley and from there southeastward to the western margin of the Manhattan prong at Crugers, NY, on the Hudson.River near Stop 7.

Distinction Between the Manhattan Prong and Hudson Highlands

These two terms are largely geographic and signify no real differences in the ages of rocks or tectonic history. Conventionally the boundary between the Manhattan Prong and the Hudson Highlands extends from Peekskill to Brewster NY where the contact alternately varies from faulted segments to segments having normal sedimentary contacts from basement up into quartzite or other rocks of the Paleozoic cover sequence (see Figure) and more recent modifications in Figure 4. Semiductile and brittle steeply northwest dipping and strike slip faults characterize segments between Somers and Brewster and eastward.

Deformational History and Structure

This is really not the focus of this trip so this guide is brief on the subject. The area from Brewster lies within either sillimanite- K-spar or sillimanite- muscovite grade of regional metamorphism that is Taconian and the grade decreases westward toward the Hudson River to staurolite grade and to biotite grade near stop 11 and 12. Regional distribution of isograds (Figure 5) coincides with the trend and spacing of a ductile right- oblique thrust and shear zone complex which was responsible for much of the basement response to Taconian deformation (Ratcliffe and Burton, 1990). Igneous rocks of the Cortlandt complex intrude this deformational zone and Barrovian metamorphic field gradient.and cross cut folds and foliations in the country rocks as well. The zircon SHRIMP age from the monzonorite of the Cortlandt complex at Stop 7 of 447 ± 2 Ma is in our judgment the most accurate age obtained for the Cortlandt thus far and we accept this as the age of intrusion. This age is in good agreement with the age of the highest grade sillimanite–K-spar grade metamorphism of 444 - 443 Ma obtained from the New Milford area for formation of migmatite and intrusion of the Candlewood Granite (Walsh and others, 2004), as well as regional Ar/Ar chronometry of the Taconic metamorphism at about 450 Ma as summarized by Hames and others (1991) and by Ratcliffe and others (Trip B4, this volume). Dietsch and Aleinikoff (2006) report U-Pb zircon ages of 437 ± 4 Ma for migmatitization in the core of the Waterbury dome, Connecticut, supporting the concept of extended Taconian metamorphism. Ar/Ar data on hornblende from the region support relict Taconian slow cooling ages from near the Cortland complex and a broad area of Devonian cooling ages in the rest of the Manhattan prong as far east as Long Island Sound (Dietsch and others, 2006). Two muscovite cooling ages, one from the Peekskill granite in garnet zone (Kunk, unpublished data, 2007) and one from a granite dike near Purdys in the sillimanite zone (Diestch and others, 2006), support late Devonian cooling through muscovite blocking temperature of 350 C at about 350 Ma. These data suggest that the dominant metamorphism was Taconian but that elevated temperatures occurred in the Acadian over much of the area east of the sillimanite zone of metamorphism until the Medial to Late Devonian.

Intrusion of the Devonian Peekskill Granite (Ratcliffe and others, 1982) has been confirmed by a concordant SHRIMP age of 380 ± 4 Ma. A slightly younger age of 374 Ma was determined by Douglas Mose (Ratcliffe and others, 1982) using the Rb/Sr whole rock technique. Reexamination of the contact relations of the Peekskill granite and its relation to movement on the Peekskill fault confirms the earlier conclusion of Ratcliffe and others (1982) that the intrusion overlapped movement on the fault and that Devonian activation or reactivation of this fault is probable. The muscovite cooling age above indicates the cooling from granite intrusive temperatures of 650º to 700º C took about 30 million years.

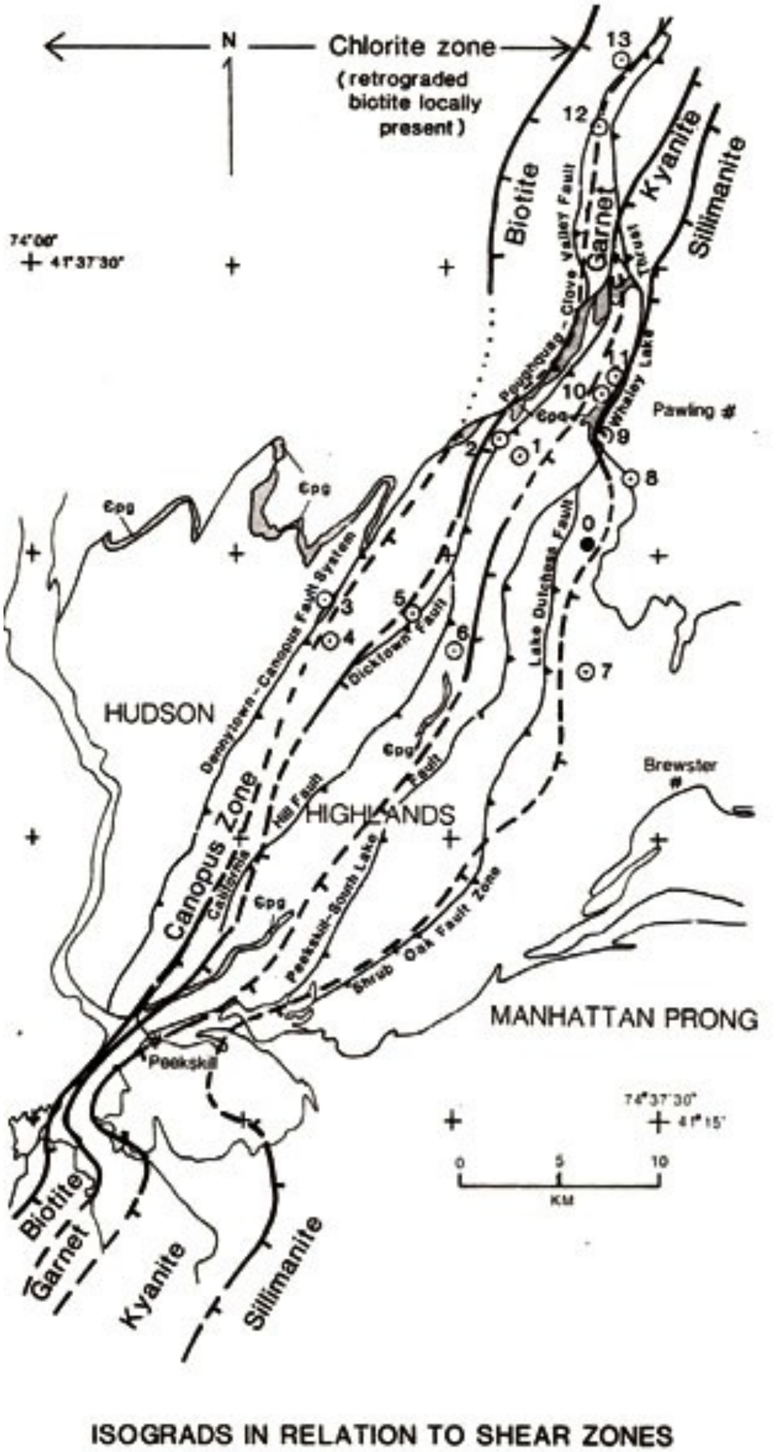

Figure 5. Taconian isograds (Ratcliffe and others, 1985) Stop numbers refer to 1985 field trip.

ROAD LOG

Road log mileages and directions start at Stop 1 driving time from New Paltz about 55 mins. We will leave parking lot at New Paltz at 7:30 and start at Stop 1 at 8:45.

Directions to Stop 1

From parking lot turn N on Manheim Blvd. toward Pond Rd., 0.5 mi turn right on Main St., 0.9 mi. merge onto NY Thruway South. Follow 16 mi. take Exit 17 toward I-84. Take I-84 east to toward Newberg/ Beacon. Cross Hudson Newburgh Bridge. Continue on I-84 to Exit 17 at Luddingtonville Rd. and park opposite the west bound entrance ramp.

General descriptions of the geology we are traversing from stop to stop are shown in italics.

A generalized description of the pertinent geology from the Newburgh Bridge to Stop 1

At the crossing of the Hudson on your right is Storm King Mountain held up by Mesoproterozoic hornblende granite gneiss of the Storm King Granite. Although not dated here at the type locality this rock is identical to that dated (1174 ± 8 Ma) at Dunderberg Mountain to the south. Here it occupies the core of a large isoclinal fold of the regional YF2 generation (Dodd, 1965). These folds are characterized by penetrative high grade mineral fabric and strong northeast plunging fold axes and hornblende lineation. This fold involves hypersthene- quartz- plagioclase leucogneiss that is very similar to the 1337 Ma trondhjemite gneisses at Cat Hill at Stop 7. This old gneiss or its equivalent is similar to some of the Losee Gneiss of New Jersey. Quartz- plagioclase gneiss like this cores YF1 folds through out the Hudson Highlands east of the River and at Bear Mountain.

The Storm King Granite is thrust northwestward over Cambrian and Ordovician cover sequence rocks on the Cornwall thrust that dips at least 45 degrees to the south east at the Hudson River crossing of the Delaware aquaduct (Berkey and Rice, 1921, plate 48). On the east side of the Hudson River from a point just north of the bridge graywackes of the Austin Glen Formation and the upper parts of the Taconic allochthon form the foot wall of a faulted klippe of Storm King and other Mesoproterozoic gneisses and quartzite cover. The klippe is truncated by high angle normal faults (east side down) of probable Mesozoic age on both sides. This complex of faults is termed the Beacon-Lagrangeville fault. (Ratcliffe, 1985). The sole of the klippe likely is the Cornwall thrust and the eastern carbonates part of the normal cover sequence. The Poughquag Quartzite rests unconformably on the basement above the Cornwall thrust in this klippe.

The route of I-84 travels east of the klippe on Wappinger Group carbonate rocks. Several exposures of variegated dolostones of the Pine Plains Formation can be seen along the thruway before the crossing of route 9 at Fishkill. At this point a large fault- controlled valley extends southeastward into the Highlands to the Hudson River north of Cold Spring and crosses the River along the southeast side of Storm King Mountain. I originally placed a southeast dipping thrust fault along this contact in 1980 (Figure). Subsequent studies indicate that the dominate fault structures in this part of the West Point quadrangle are typical of Mesozoic normal and oblique-normal high angle faults. Chlorite and hematite coated, slickensided surfaces are prevalent, as is microbreccia and zeolite mineralization. In addition, the Cambrian Poughquag Quartzite and lamprophyre dikes of the Cortlandt intrusive event are faulted. The mineralization and fractures styles are characteristic of the Ramapo and other fault rocks found in coring of Mesozoic faults (Ratcliffe, 1980). Distinctive mylonitic rocks of high grade associated with Mesoproterozoic faulting or the retrogressive phyllonites typical of the Taconic and or later thrust events as illustrated in Ratcliffe (1985) are lacking or not well developed here. This leads me to conclude that the dominant faulting here is Mesozoic although some Paleozoic thrust faulting may be present as well.

The trend of these faults project southwestward but die out before Lake Tiorati in the southwestern corner of the Popolopen Lake Quadrangle mapped by Dodd (1965) and more recently examined by Gates (1999). Gates places a major ductile shear zone along the western side of Lake Tiorati that he extends northeastward along the contact of the major rock units mapped by Dodd (1965) without any offset of rock units. In support of the age of dextral shear-

ing and the age of this event Gates and others (2004) cite a 1008 ± 4 Ma zircon age from the Lake Tiorati "diorite". The origin of the Tiorati "diorite" has long been in dispute (Lowe 1950; Dodd, 1965). Dodd mapped this rock as his amphibolite II and was uncertain as to its origin.

Mapping in the area of Lake Tiorati and adjacent Thiells quadrangle in 1980 by Bill Burton and myself confirmed the map patterns and fault locations of Dodd, and we do not agree with the mapping of Gates (1999). Instead of being a definable plutonic rock the Lake Tiorati "diorite" occurs as widely separated pods of hornblende- rich rock developed where layered amphibolitic gneiss is intruded by pegmatite. Rather than being a definable intrusive rock the Tiorati "diorite" occurs as inclusions in pegmatite and does not intrude other rocks. Excellent xenoliths in pegmatites show variably changing textures from foliated amphibolite to granite-saturated hornblende gneiss to hornblende pegmatite and pyroxene- hornblende pegmatitic dioritic rock. Tiorati-like coarse pyroxene- hornblende- plagioclase pegmatite occurs as pods and lenses nowhere greater than 50 m wide and commonly less the 10 m and at several localities as xenoliths in pegmatite less than a meter wide and is always in contact with pegmatite, aplite or granite gneiss. This rock occurs at as many as 8 different structural levels west of Lake Tiorati as well as in gneisses east of the proposed Lake Tiorati shear zone in the core of the YF3 synform mapped by Dodd. For these reasons I do not accept Gates and others (2004) interpretation that the zircon age dates the time of dextral strike slip faulting but interpret the1008 ± 4 Ma zircon age as the time of pegmatite generation and regard it as a minimum age for the tectonic fabrics in the gneisses placing this in relatively good agreement with other dated pegmatites of the area. (Volkert, Zartman and Moore, 2005).

East of route 9, I-84 crosses well layered paragneisses that are in contact with Storm King Granite on the slopes above the cuts. The Poughquag Quartzite rests directly on the basement rock with only a thin gritty pebble conglomerate locally developed and a normal succession of Wappinger Group carbonate rocks plunges northward on the noses of basement cored antiforms and broad synforms. It is important to note that throughout all of the Hudson Highlands and immediately adjacent Manhattan prong where the contact beneath the Cambrian quartzite can be located closely, there is no intermediate stratigraphic unit of possible Neoproterozoic age except for some sections that contain feldspathic quartzite attributable to the Dalton Formation. (see Ratcliffe and Burton, 1992 for example).

At the crossing of the Taconic Parkway and from that point northeastward numerous thrust faults marked by low grade phyllonites displace Mesoproterozoic rocks and carbonate rocks along the various splays of the Ordovician-reactivated Canopus and related shear zone (Figure 4). Within this belt evidence of Mesoproterozoic motion synchronous with intrusion of the composite ferrodiorite-monzonite Canopus pluton and dike swarm at about 1143 Ma (note the revision in age as reported by Ratcliffe and Aleinikoff (2001, 2008)) and which corrects the older estimates based on Rb/ Sr and early U/Pb zircon ages reported in Ratcliffe and others (1972) and in Ratcliffe (1992).

The new data Ratcliffe and Aleinikoff (2001, 2008) and this guide book, do not agree in timing of right-lateral deformation proposed for the Reservoir and other faults of about 1008 ±4 Ma and presented in a series of papers (Gates, 1999; Gates and others, 2004). We now regard much of the deformation in the Hudson Highlands as older than the Ottawan and to be Shawinigan. That does not preclude renewed activity in the Ottawan but does urge caution in accepting the Ottawan escape tectonic model of Gates and others (2004). A similar caution is warranted from consideration of the geology of the Green Mountains of Vt and the Berkshires of Massachusetts as shown in Figures 1 and 3, where continuity of structure precludes an extension of the Piseco Lake shear zone and related structures to the east as required by the model of Gates and others (2004). Of some importance is the distribution of the post- Ottawan 955 Ma rapakivi granites of the Cardinal Brook Intrusive Suite. Notable also is E-W tectonic grain of the Berkshire massif that continues southward into the Hudson Highlands. The consistent northeast plunges of the YF3 folds in the Hudson Highlands is attributable to refolding of overturned, but not recumbent, early YF2 folds.

Road log starts at Stop 1 Exit 17 from I-84 Luddingtonville Rd.

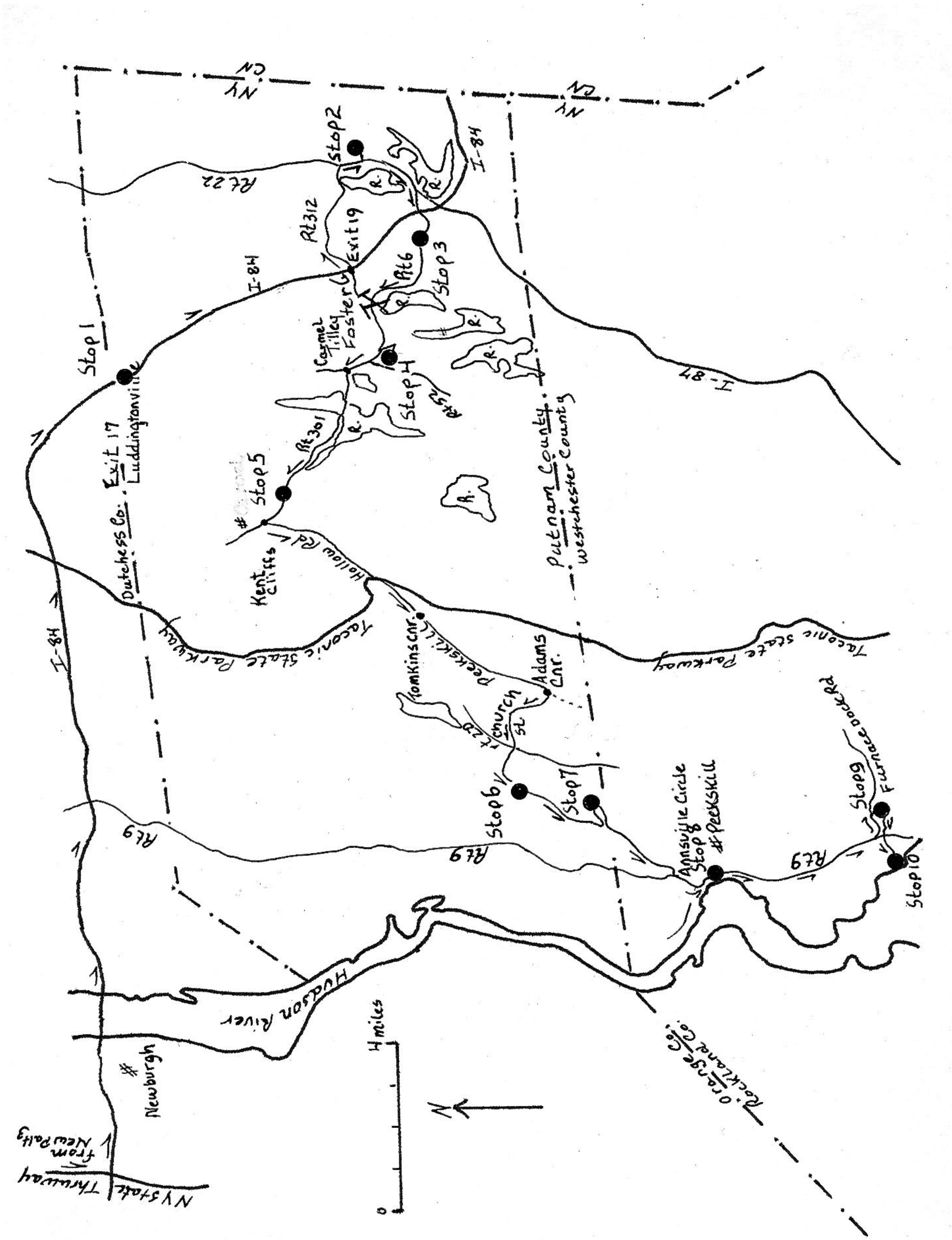

Figure 6. Map showing route and stop locations and major highways.

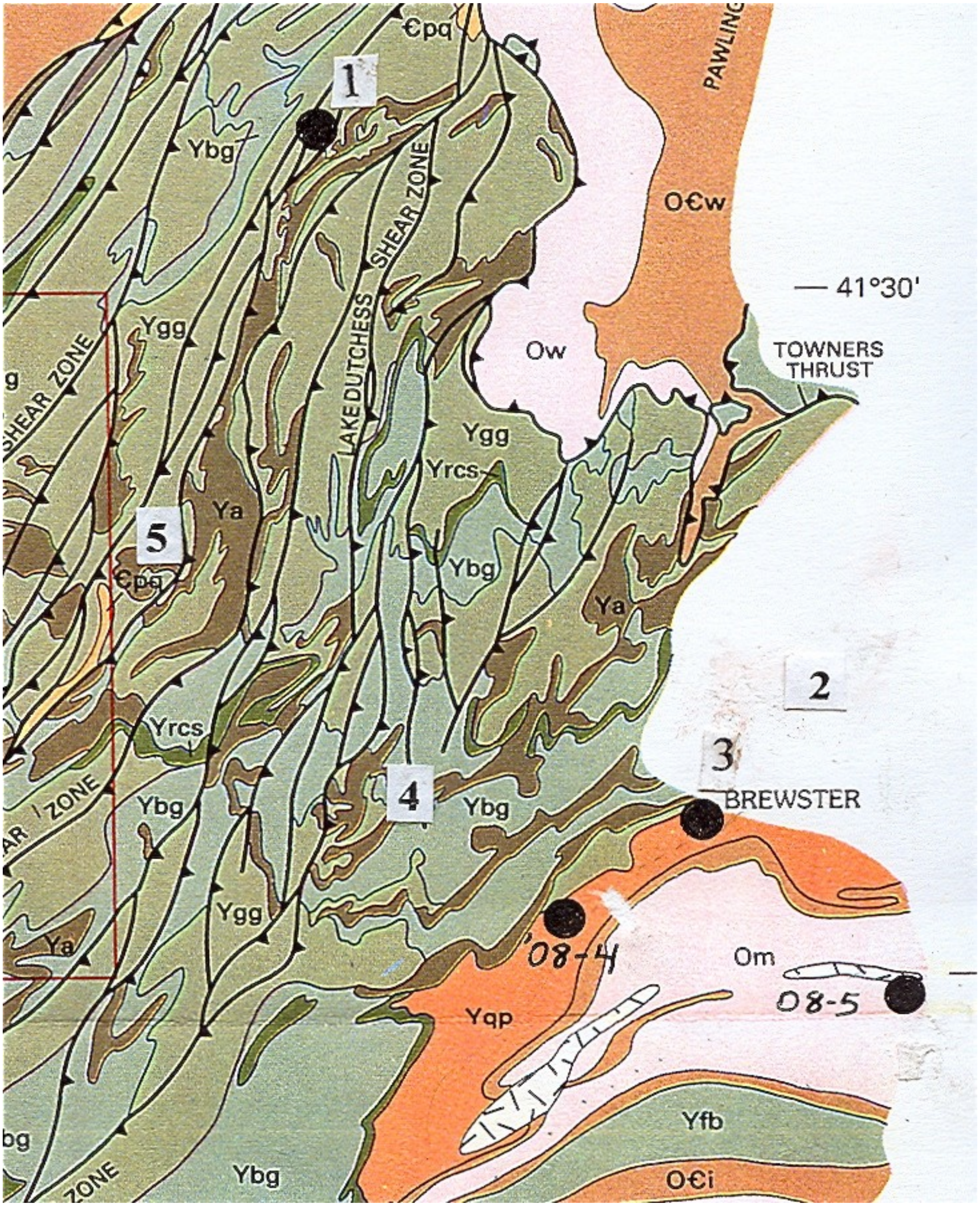

Figure 7. Blow up of the eastern part of Figure 4 showing location of Stops 1, 2, 3, 4 and 5.

Stop 1. Reservoir Gneiss--amphibolite inclusions I-84 Exit 17 Luddingtonville Rd. Poughquag quadrangle
STAY OFF THE INTERSTATE PLEASE. Park by the overpass and walk along west entrance lane.

This belt of trondhjemitic gneiss forms the eastern end of a wide belt of Reservoir Gneiss (of Ratcliffe and Burton, 1990) that extends from near Cat Hill Stop 7 through alternate Stop 5b into the Poughquag quadrangle and the contiguous Brewster quadrangle (Figure). A SHRIMP zircon age of 1333 ± 6 Ma has been obtained from this outcrop. Ages of overgrowths on the zircon are 1.2 and 1.0 Ga indicative of Elzeviran and Ottawan zircon growth. Sweat outs of more granitic composition are common and are shown by coarser grain size in indefinite irregular pockets in which and older gneissosity is overprinted. Abundant mafic inclusions choke this rock in most exposures. Reaction rims around the mafic inclusions contain pyroxene, hornblende, and biotite and are gradational with the host rock. It is likely that these reaction zones and the pegmatitc sweat outs are the result of Ottawa metamorphism.

Normative An- Ab-Or compositions of some the felsic rocks belonging to Geon 14 and those of Geon 13 are plotted in Figure 8 and range from trondhjemite to granite. Fields for the Reservoir Gneiss at Peekskill (stop 9), at Cat Hill (Stop 8), in the Oscawana Lake area (Stop 5b) and here at Luddingtonville (Stop 1) show the range of compositions in the Reservoir Gneiss in the westernmost belt closest to the Canopus deformation zone.

These trondhjemites and granites all have distinctively high La/ Ybcn values, steep middle to light rare earth slopes, and flat, negative to positive HREE slopes comparable to that shown for the Cat Hill Gneiss (Figure 10). The samples of the dated Fordham Gneiss have very similar patterns. Plots of Rb vs Nb+Y (Figure 9) show the similarities among the dated rocks as well. The filled dots are samples of Yrg in the Brewster area that are correlated with the main Reservoir Gneiss belt on the basis of continuity on the ground between the two areas. We can not be certain that all rocks shown as Reservoir Gneiss in the Brewster area are in fact the same as these rocks are not dated.

Mafic inclusions in this outcrop and in all stops in the rocks of Geon 14 may be inclusions and or dikes as will be discuss further at Stop 2. The amphibolites here show no clear indications of having been dikes but that cannot be ruled out. Note the felsic sweat outs and pegmatites near the wall of the "inclusions" as well as the pyroxene- hornblende reaction zones, which grade into the bordering rocks.

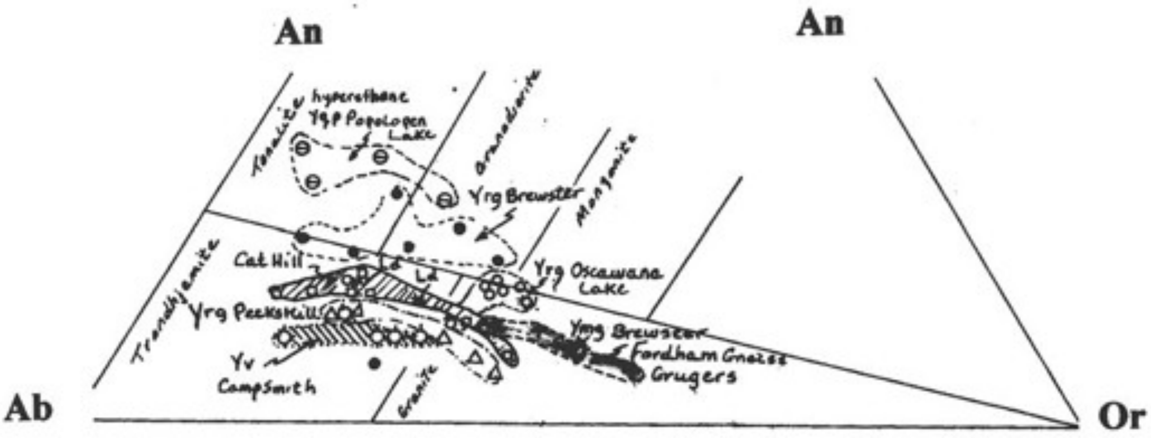

Figure 8. Normative An-Ab-Or plots of dated rocks of Geon 14 and13. Solid dots are samples of Yrg from the Brewster area; squares Cat Hill Gneiss (Stop 7); triangles Reservoir Gneiss Peekskill (Stop 8);stars Reservoir Gneiss (Stop 1);plusses Fordham Gneiss at Stop 10 and from Scott Ridge in the Peach Lake quadrangle; open circles Reservoir Gneiss in Oscawana Lake quadrangle (Stop 5b). Yv – aplitic gneiss at Camp Smith, Peekskill quadrangle zircon SHRIMP age of 1238 ±7 Ma; Ymz- monzonitic dike Joes Hill Brewster Zircon SHRIMP age of 1240 ± 7 Ma and Yqp- hypersthene- quartz-plagioclase gneiss Popolopen Lake quadrangle.

Enter I-84 southbound toward Brewster; turn at exit 19 onto 312 heading east—large road cut in dark gray, biotite-rich quartz plagioclase gneiss and hornblende aplite follow 312 to Rt. 22 about 3.3 mi, turn south (right) on Rt. 22, go 0.7 mi to left, entrance to small professional office complex park by far eastern end of lot. Walk up hill to north 250ft to exposure.

Stop 2. Snake Hill - Granitic gneiss typical of Brewster belt and mafic dikes

Steeply dipping biotite granite gneiss typical of the vast majority of granititic gneiss and associated migmatitic lit par lit contact zone on Joes Hill. Gneissic granite like this is crosscut at the west end of Joe Hill by a monzonite dike that has a zircon Pb207/206 SHRIMP age of 1240 ± 7 Ma. The granite gneiss here is tentatively assigned to the old gneiss belt and is judged to be 1330 Ma or older. Fine -grained foliated mafic dikes cross cut the gneissic structure and are fairly abundant on this hill and in areas to the east. Locally coarser grained diorite to gabbroic masses also cross cut the older gneisses and these rocks pass into finer grained rocks like the dikes seen here.

Figure 12 shows one of a series of meter-wide dikes petrographically like the small ones above. On Joes Hill these dikes cross cut high-grade gneissosity and intrude across mylonite zones.Although apparently straight walled, they are redeformed by isoclinal folding. Both the dikes and the older gneissosity are cut by foliated granitic pegmatite of probable Mesoproterozoic age. Based on these observations, the mafic dikes, like that figured below must be Grenvillian and perhaps older than the Ottawan phase of the Grenville orogeny. In this regard these dikes resemble the dikes of the Canopus pluton (stop 6), which also cross cut an older gneissosity.

Chemically, the dikes in question are somewhat like those of the Canopus pluton as illustrated in Figure 13, and to

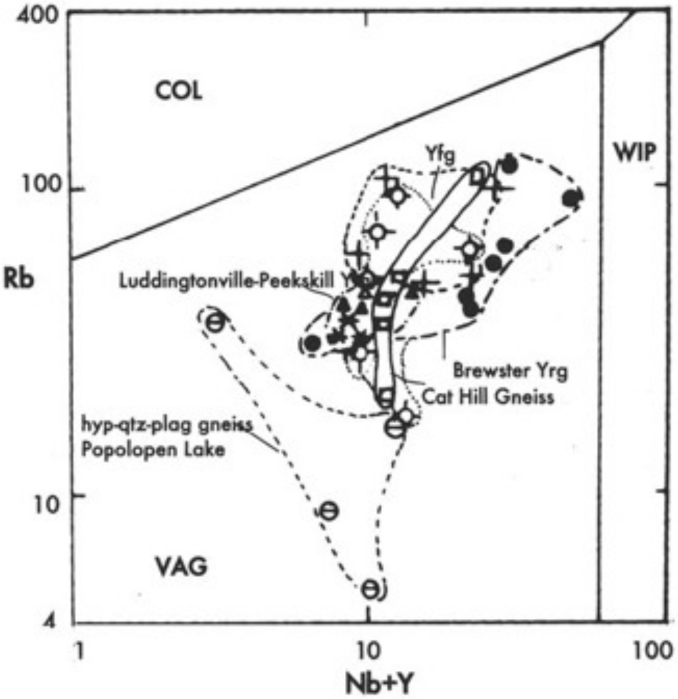

Figure 9. Rb vs Nb+Y plots of rocks of Geon 14 and 13 symbols as in Figure 8.

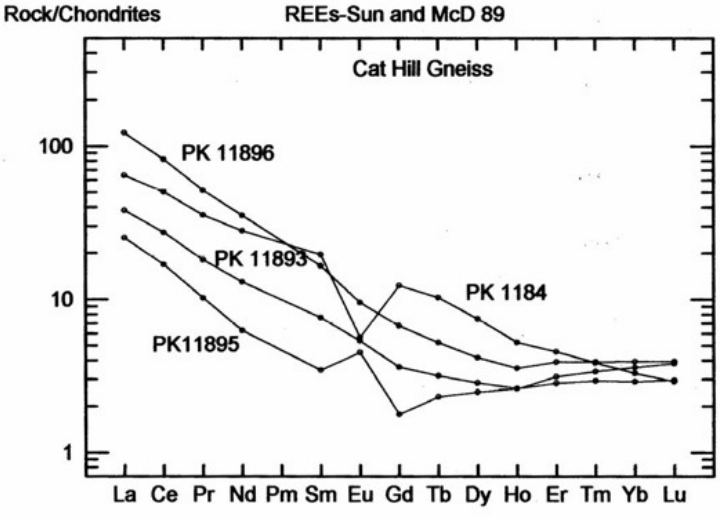

Figure 10. Chondrite- normalized Rare Earth Element patterns of samples of the Cat Hill Gneiss (Stop 7). These are representative of most samples of the Reservoir Gneiss.

dioritic rocks at stop 3. The diagram shows a similarity in chondrite LREE enrichment trends (but not in absolute values) and similar range in Ta -Yb ratios. The plots do not establish identity of the various rocks only suggest that possibility.

Figure 11. Two fine grained mafic dikes cross the coarse ropy gneissosity of granitic gneiss typical of the granitic gneisses in the Brewster quadrangle and judged to be correlative with the Reservoir Gneiss.

The dike in Figure 12 is a typical example. It cross cuts migmatitic gneiss that at this locality is intruded by a monzonitic granite that has a SHRIMP zircon age of 1240 ± 7 Ma (Table 1). The age of these dikes is younger than 1240 Ma. They could be the same age as the diorites associated with the dated hornblende granite (1134 ±8 Ma) at stop 3 and with dikes of the Canopus pluton (Stop 6A, B) that are probably approximated by the Canopus monzonite zircon SHRIMP age of 1143 ±12 Ma. The mafic dikes of the Canopus and elsewhere in the Brewster area cross cut coarse gneissosity in the 1340-1330 Ma rocks; both are intruded by foliated pegmatite.

Alternately these dikes could be Neoproterozoic. However major and trace element characteristic differ from Neoproterozoic dikes found in the Hudson Highlands (Ratcliffe, 1978), which are typical transitional rift basalts.

The clearly cross cutting mafic dikes and mafic and isoclinally folded “ inclusions” in the granitic gneisses of the Brewster area are indistinguishable chemically and petrographically from one another. This observation plus the fact that individual dikes like that in Figure 12, which cross cut a gneissosity can be traced within outcrops into isoclinally and cross foliated zones suggests that many of the inclusions or indefinite dikes like those at stop1 may all be the same age. If so, there is a widespread mafic dike event at about 1143 to 1134 Ma. that post dates an earlier Shawinagan deformation.

Leave parking lot head south, turn left on Rt. 22 toward Brewster, then exit 22 to right for Rt. 202 to Brewster, immediately at “T” intersection bear left following 202. In one mile turn right and cross over East Branch of Croton River, proceed through Brewster parallel to RR tracks. In 0.5 mi turn left on Rt. 6, cross over RR tracks and immediately branch right onto side street go up hill 0.3 mi

Figure 12. Mafic dike cross cutting gneissosity in migmatite gneiss At Joes Hill, Brewster.

and park in parking lot opposite funeral home.

Stop 3. Unnamed 1134 ± 8 Ma hornblende granite gneiss, dioritic gneiss and sulfidic schist screen, Brewster, N.Y.

Hornblende-biotite granite gneiss 140 feet wide, on the southeast end of this NW-SE vertical cut becomes very hornblende rich and passes into a 15-ft-wide pyroxene hornblende pegmatite near the small screen of sulfidic paragneiss. The hornblende granite has a 1134 ± 8 Ma SHRIMP age. North of that dioritic gneiss about 35 ft thick passes northward into a hornblende- rich margin that grades into a second 40 ft-thick zone of granite gneiss. That granite gneiss grades upwards into diorite gneiss at northwest end of the exposure. The felsic and mafic components grade into each other at the margins and appear to be coeval. In this chararacteristic these rocks resemble rocks of the Canopus pluton (Stop 6A, B) and have essentially the same age as the felsic component of the Canopus which has a concordant zircon SHRIMP age of 1143± 12 Ma.

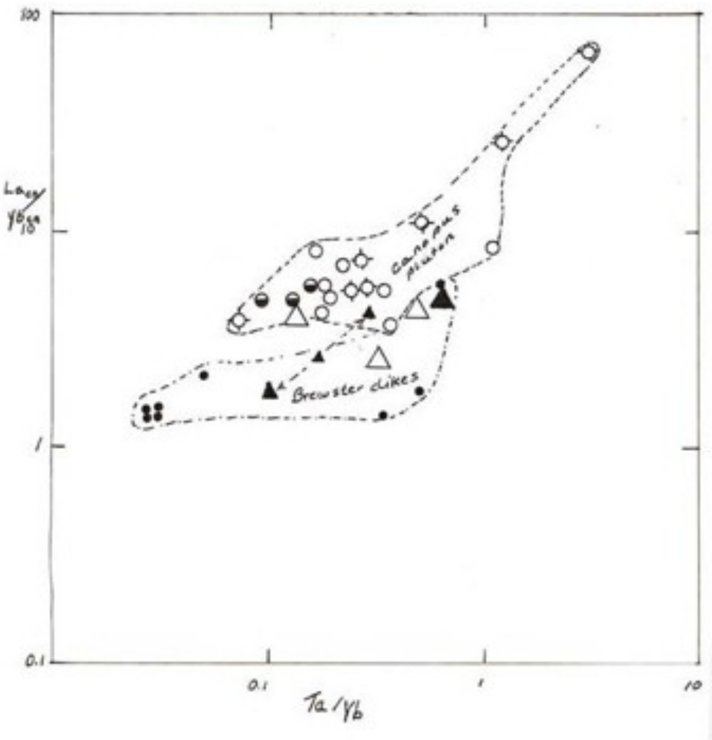

Figure 13. Chondrite normalized La/Yb vs Ta/Yb plot for mafic rocks and dikes of the Canopus pluton compared to mafic dikes at stop 2 and to amphibolite inclusions at stop1 shown by small joined triangles. Large unfilled triangles- gabbro-diorite stocks in Brewster, half filled dots mafic diorites at stop 3 associated with dated hornblende granite.

We regard the felsic and more mafic rocks as part of the same igneous suite. Near contacts with sulfidic schists and calc-silicate rocks hornblende-pyroxene pegmatite and a white hornblende-spotted aplite carrying magnetite is common. This is the common association for the Brewster magnetic deposits, which are developed on strike to the southwest at the borders of xenoliths included in the hornblende granite and along the wall of this intrusion. All the rocks are foliated but tend not to be gneissic like the older rocks. Similar dioritic intrusives occur to the north in Brewster and preserve coarse diabasic texture and relict coarse - plagioclase flow structure. The mafic dikes we have seen may also be the same age.

Return to Route 6, turn right (N), enter Lake Carmel quadrangle, in 2 miles pass Tilley Foster Mines at Rt. 311 intersection.

Calc-silcate rock, marble and magnetite are developed here at the contact with the same hornblende granite gneiss dated at Stop 3.

Continue on Rt. 6 past Tilley Foster 1.4 miles to Intersection of Rt. 35 Stoneleigh Rd Hannerford Market on right. Turn left on Stoneleigh. In 0.1 mile turn right into Retreat Condominiums and proceed 0.9 mi. up hill to left to construction site.

Stop 4. Hornblende Granite gneiss like that at Stop 3

NOTE: on Figure 4 this location does not correctly show the hornblende granite which was discovered after the figure was published. See Figure 2 for a more accurate map. This illustrates an important point namely that telling the old 1340-1300 Ma granite gneisses from the 1134 Ma ones is not easy. I expect to complete mapping in the Lake Carmel quadrangle this Fall and undoubtedly contacts will shift.

Well lineated and foliated hornblende granite gneiss and aplite cuts gneissosity in older well layered biotite and hornblende-quartz-plagioclase gneisses. Both rocks are folded into tight folds containing axial surfaces of N 65 W 45 NE and a strong lineation plunging to the east and northeast. These relationships support the idea that the 1135 Ma hornblende granites cross cut older structure just as the Canopus pluton Stop 6A, B does.

Excellent exposures in the Croton Reservoir (Stop '08-4 of Ratcliffe and Aleinikoff, 2008) are no longer available as the reservoir has now been refilled and the exposures covered. Observations there showed that:

1. The hornblende granite is foliated but does not have the same coarse ropy- textured gneissosity of the older 1340 Ma gneisses seen at Stop 2.
2. Xenoliths of foliated gneisses occur within the younger hornblende granite gneisses and aplite
3. The coarse and fine grained variants of the hornblende granite and hornblende pegmatite occur at contacts with the country rocks and an older gneissosity is truncated by the younger granites.
4. Contacts with rusty sulfidic paragneisses developed abundant magnetite and sulfides just as the wall rocks of the larger bodies of hornblende granite do in the Brewster magnetite district do.

Return to Stoneleigh Rd. turn left to light at at Route 6 and turn left toward Carmel in 08 mi. intersection with Rt. 52 bear right, in 0.3 mi. light and intersection with Rt. 301 turn left and follow across West Brach Reservoir 1.3 mi. Marker west end of Reservoir.

General geology. We are in the center of the Lake Carmel quadrangle headed west across a particularly well developed sequence of Mesoproterozoic paragneiss, calc-silicate rock, marble, thin quartzites and schist. We will cross two of the thickest belts of amphibolite in the Hudson Highlands that are mappable into the Poughquagh quadrangle to the north. These amphibolites are true amphibolites, unlike so many of the rocks mapped as amphibolites by myself and others in the Highlands. These are composed of >70% hornblende rather that the more common type of " dioritic" amphibolites which commonly contain equal amounts of plagioclase and hornblende. This belt of coarse to fine amphibolite is associated with pods of serpentinite, anthophyllite schist and gabbroic to dioritic igneous rocks. The serpentinites are in contact with paragneisses, diopside bearing quartzites, and carbonate containing ovoidal pods of what probably are serpentinized fosterite knots.

In 3.6 mi from the causeway pass Dixon Rd where we pass into the western and thickest of the amphibolites. I mile past Dixon Rd. dam of the Boyds Corner Reservoir and pull off on right.

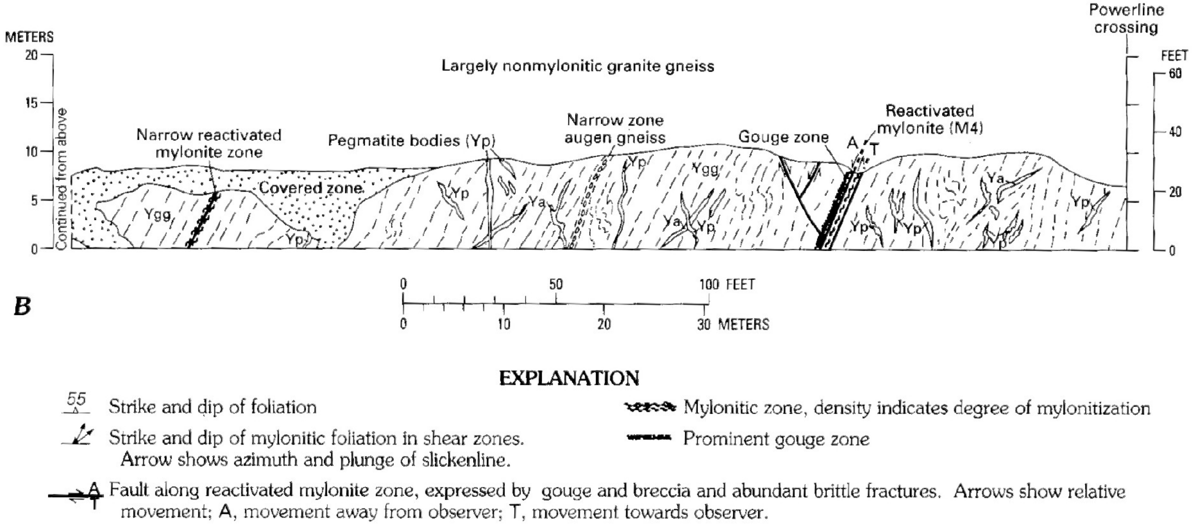

Figure 14. Cross section of the northern end of a long road cut in Reservoir Gneiss along Rt. 301 opposite Boyds Corner Reservoir, Mt Carmel quadrangle, NY. See Ratcliffe (1992) for more complete discussion.

Optional Stop 5A. Coarsest amphibolite perhaps related to the Wiccopee pluton of the Oscawana Lake quadrangle (Ratcliffe, 1992) discussion of amphibolite chemistry

Leave parking area and proceed 0.5 mile to pull off on the right opposite the reservoir.

Optional Stop 5B. Reservoir Gneiss at its type locality discussion of regional tectonic of the Oscawana Lake- right lateral deformation zone (see Stops 1 and 7 for chemistry discussion)

These road cuts in the Reservoir Gneiss represent the type locality of the gneiss and were visited on Stop 6 of Ratcliffe and others (1985) and is in part reproduced from Figure 23 of Ratcliffe (1992). Aside from illustrating the

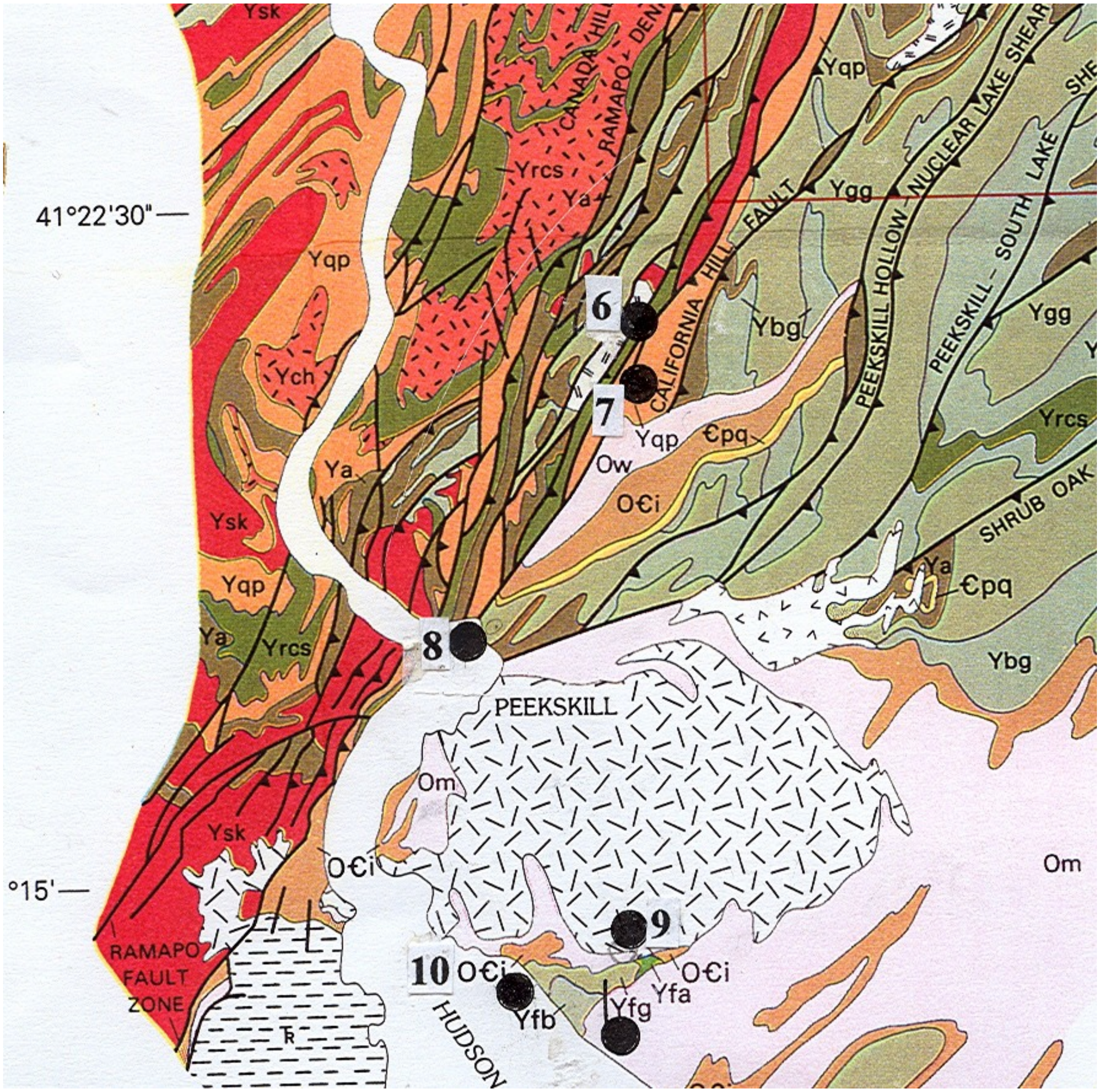

Figure 15. Blow up of a part of figure 4 showing the location of Stops 5, 6, 7, 8, 9 and 10.

type Reservoir Granite of Berkey and Rice (1921), these crops contain mylonite zones typical of the Paleozoic fabrics found to mark the larger shear zones at biotite and higher grades. Here evidence for reactivation as Mesozoic normal faults may be seen. A similar observation will be made at Stop 8.

Continue west on Rt. 301, enter the Oscawana Lake quadrangle.
0.3 mi. intersection Peekskill Hollow Rd on left- turn left, immediately take the right"Y" up hill (not the left) staying on Peekskill Hollow Rd.

We are traveling down the Peekskill Hollow- Nuclear Lake-shear zone that marks the eastern side of the large right-lateral sigmoidal deformation zone in the center of the Oscawana Lake quadrangle. Although the sigmoid is Mesoproterozoic (Ratcliffe, 1992), the California Hill and this shear zone are Paleozoic based on the retrogressive phyllonite there and offsets of Paleozoic rocks along their lengths and from dating of syntectonic biotite in the mylonite of the California Hill shear zone that has a 436 ± 3 Ma Ar/ Ar age (see Figure 0 in Ratcliffe, 1992). The sigmoidal deformation of the gneisses however is Mesoproterozic based on the mapping of non rotated metadiabase dikes that have the chemistry of Neoproterozoic rift basalt. (Ratcliffe, 1992). Based on this reasoning, the California Hill shear zone has both a Mesoproterozoic and a Paleozoic history, as do the faults bordering the Canopus Valley to the west.

In 4 miles cross under the Taconic Parkway and go 5 miles to Adams Corner light and turn right on to Rt. 22 west.

At Adams Corner we will turn west and cross the end of the Annsville syncline which probably has a Mesozoic fault long its northwestern flank. See discussion Stop 7.

Follow County Rt. 22 for 2.2 miles to Crofts Corner and Rt. 20 intersection.

Two miles south on Rt. 20, in front of the Putnam Valley Elementary School, there are superb outcrops of Mesoproterozoic shear zone rocks invaded by aplites that are also highly deformed and crossed by Mesoproterozoic pegmatites supporting intense Mesoproterozoic deformation east of and parallel to the main Canopus shear zones. This is approximately on the California Hill fault zone and supports Mesoproterozoic inheritance here.

Cross over Rt. 20 straight onto Cimmaron Rd..
Continue on Cimmaron Rd.down the hill into the Canopus Valley that is underlain by coarse phlogopitic- felsdspathic- scapolite dolomite marble, quartzite and retrograde diopside calc- silicate rock. This is the thickest belt of Mesoproterozoic marble and calc-silicate rocks in the Hudson Highlands of NY.
2.2 miles from the Rt. 20 intersection on Cimmeron Rd and on the west side of the Canopus Valley is Indian Hill Rd on the west side of the Canopus Valley.

Immediately above and on the south side of Indian Hill Road is an old magnetite mine developed in marble and calc-silcate rock just off the north end of the Canopus pluton. Here aplite and pegmatite that makes the border phase of the Canopus , contain large 1-2 cm clots of magnetite where it intrudes hornblende granite gneiss like the Storm King Granite. This lit par lit border zone will be seen at Stop 6b where it is caught in the retrogressive shear zone along the west side of the Canopus Valley at the east edge of the pluton.

Cimmaron Rd. has now changed name to Sprout Brook Rd.

From the Indian Hill Rd. intersection proceed 0.7 miles south to abandoned asphalt drive on the right opposite mail box 484—pull into the drive and try to get all cars off the road. Limited parking here Aleinikoff, 2008.

Stop 6A. Canopus pluton diorite, dikes and screen of Mesoproterozoic gneiss

At the end of the driveway are excellent new exposures of the dioritic rocks of the pluton on the right and left sides of the cut. Note the well defined areas of monzodiorite in diorite in the block to the left (S), the diorite- a screen of isoclinaly folded country rocks exhibiting the YF2 structure and the flow layered diorite on the right (N). Two mafic dikes cross cut both the gneiss inclusion and the flow layered diorite. The observations here point to composite intrusion of the dioritic phases of the pluton. Dike swarms in the vicinity of the pluton cross cut YF2 structures in the gneisses. Some dikes are as much a 0.5 km long and are present a many as 2 km west of the pluton.These dikes are chemically and petrographically like the dikes in the Brewster area seen at Stop 2.

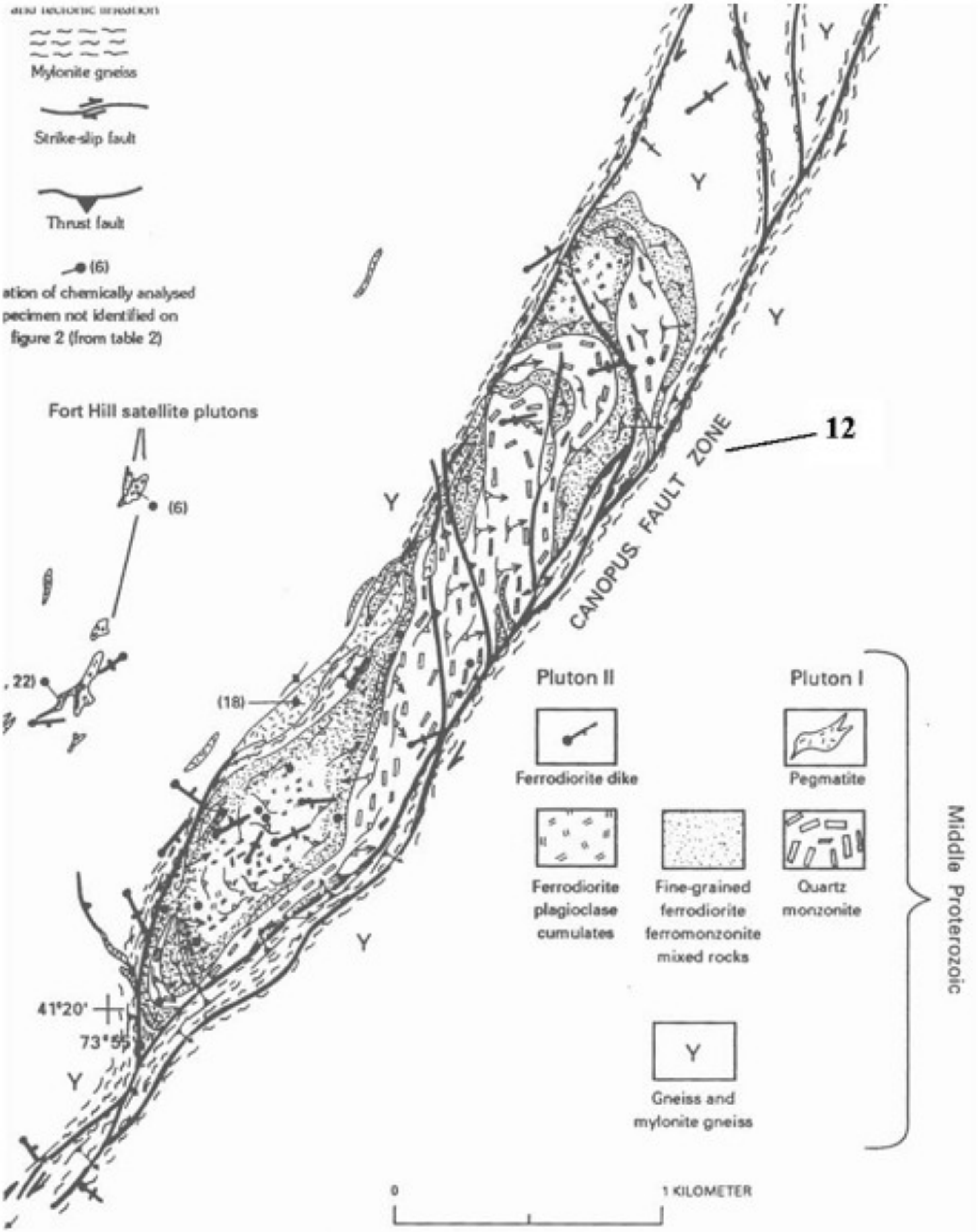

Figure 16. Map of the Canopus pluton after Ratcliffe and others (1972).

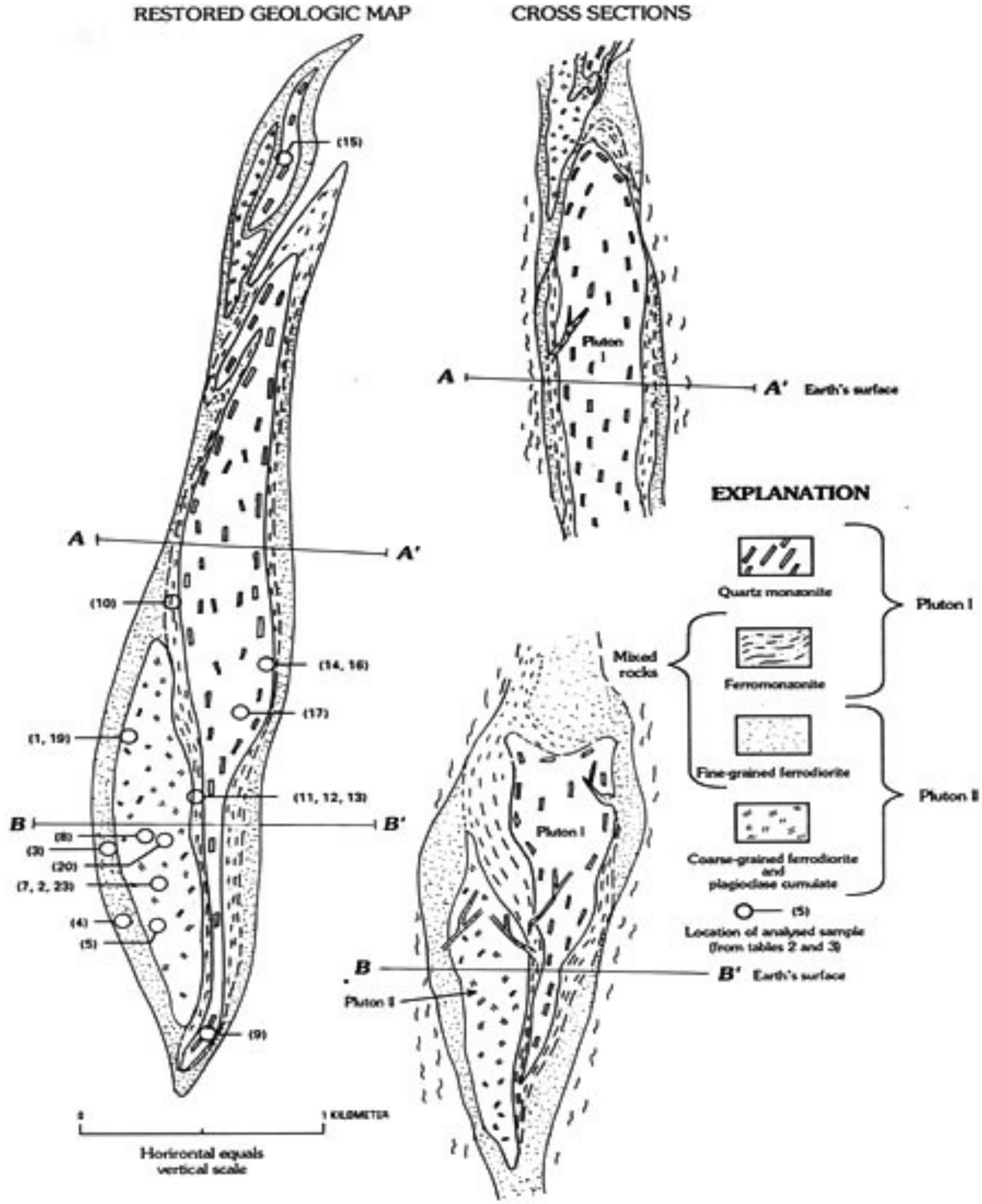

Figure 17. Restored undeformed map on left and sections across the Canopus composite dike showing the intrusive centers of pluton 1 and 2 numbers refer to location of samples for geochemistry dot presented here.

Back down and drive 0.2 mile south to new blasted driveway on right opposite mail box 462. Pull up drive far enough to allow all cars to get off of Canopus Hollow Rd.

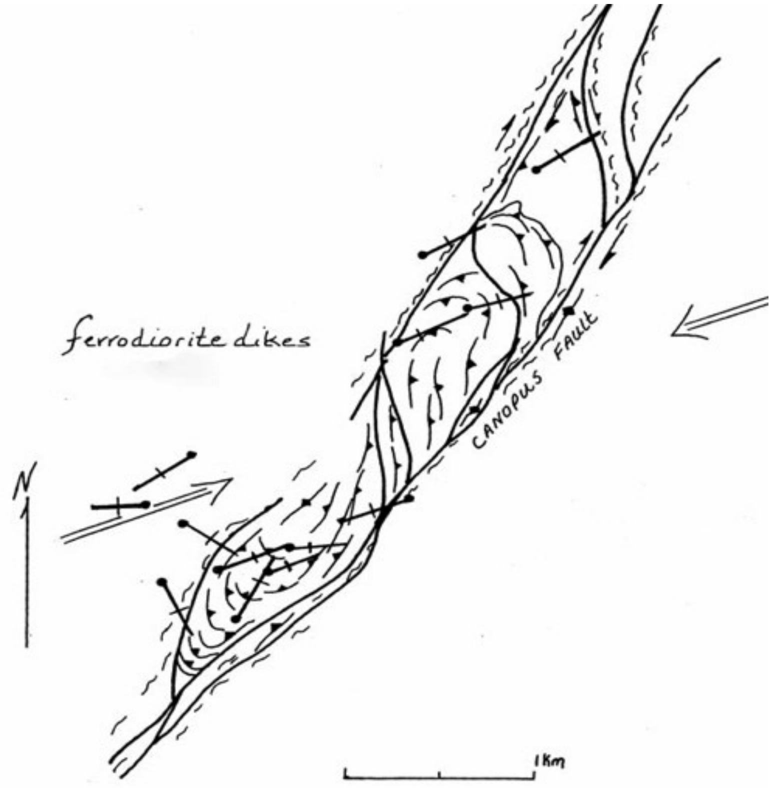

Figure 18. Schematic map showing the orientation of mafic dikes of the Canopus pluton that cross cut the sigmoidal igneous flow structure in the pluton, and the inferred stress field of the 1143 Ma strike slip event.

Stop 6B. Canopus pluton 1143 ± 12 Ma, biotite monzonite and hypersthene biotite diorite composite intrusive

This spectacular and demonstrative new driveway cut exposes the transition from the Canopus shear zone into the Canopus pluton. The Canopus pluton is intruded between two Mesoproterozoic right lateral shear zones. The eastern one has been reactivated at greenschist grade and is exposed here. The western one is not reactivated and contains stringers of monzodiorite- monzonite and cross cutting composite diorite- monzonite dikes of the main pluton and abundant pegmatite, all of which crosscut the mylonitic host rocks, or as much as 2 km north of the pluton. Internal structure in the pluton consists of mutually crystallizing igneous phases and a well developed and folded igneous flow layering that defines right lateral deformation of the pluton during crystallization. At the walls igneous rocks of the pluton cross cut the bordering mylonite zones of the faults and fill internal shears within the pluton. Isoclinal folds in the mylonitic country rocks plunge nearly vertically down the mylonite structure, as do the axes of the internal and folded igneous flow structure in the pluton. This has been interpreted to mean intrusion of the igneous rocks into a subvertical active shear zone in the Mesoproterozoic. Early attempts to date the igneous rocks using Rb/Sr whole rock techniques by Dick Armstrong (Ratcliffe and others, 1972) and using multigrain zircon techniques by Aleinikoff gave ages of about 1.0 Ga and were erroneous. Subsequent SHRIMP zircon dating by Aleinikoff gives a more precise concordant age of 1143± 12 Ma with overgrowth ages of about 1 Ga. That is, during the end stages of the Shawinigan pulse of the Grenville orogeny (Rivers, 1997) as well as Ottawan overgrowths.

Starting from the road level some of the significant features to be seen are:

1. Mylonite, consisting of lit par lit veins of aplite , isoclinal steeply plunging folds in the mylonite.
2. Zones of pegmatite saturating and postdating the mylonite structure
3. The wall of the monzonite with fine grained monzonite in the mylonite
4. Tabular K-spar defining an igneous flow structure cut by aplite dikes and by intermediate diorite dikes
5. A pillowed zone consisting of monzodiorite ellipsoidal segregations in the monzonite and turbulent flow structure in the monzonite around the “pillows”
6. Ductile shear zones in the monzonite which deform the flow layering into lineated tectonites and undeformed granitic segregations which saturate the lineated zones

Some features described above are shown in Figure 19.

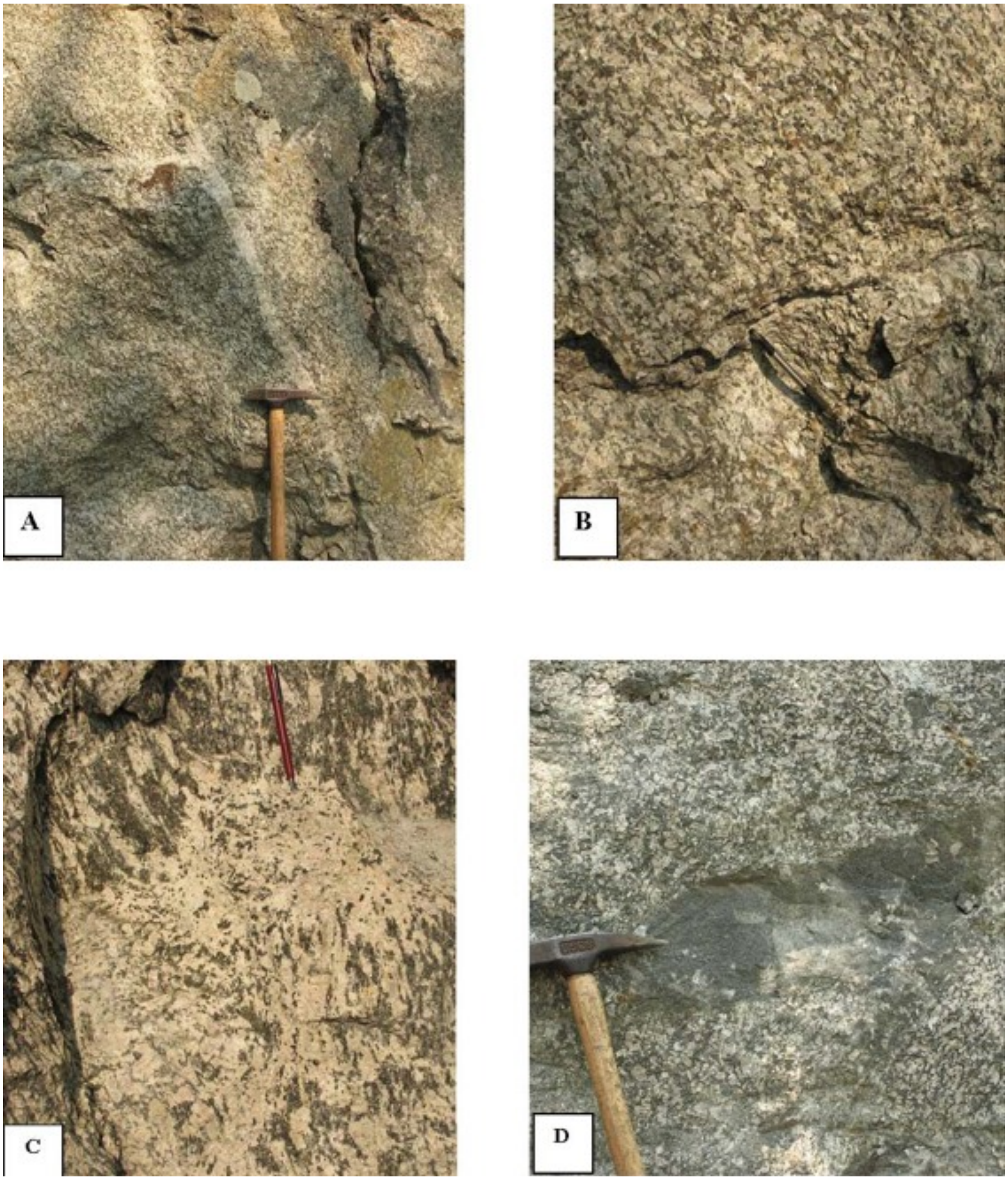

Figure 19. Igneous rocks of the Canopus pluton at Stop6 b. A-Quartz monzonite flow structure cut by unfoliated grantic dkes. B-Close up view of tabular K-feldspar that defines igneous flow structurein the felsic parts of the intrusion. This is like the flow structure that has been mapped in the mafic and felsic parts of the pluton to define the internal geometry of the intrusive components as shown by symbols in figure 16 above.C-Deformed flow structure defined by oriented hornblende (parallel to the pencil) crosscut by pockets of late quartz monzonite showing that tectonic deformation of the pluton accompanied crystallization. D-Ferrodiorite pocket in quartz monzonite in “pillowed zone”. Igneous and deformational features like these are developed through out the pluton and show that the pluton was intruded during the right lateral deformational event during which it was intruded at about 1143 Ma.

These features and other similar observations made during mapping of the shear zones and the igneous rock (Ratcliffe, 1971; Ratcliffe and others, 1972) support the concept of syntectonic intrusion and document right-slip faulting at about 1143 Ma. To the east the right sigmoidal deformation in the area of Wiccopee diorite pluton indicates this type of tectonism in a zone as much as 10 km wide (Ratcliffe, 1992). Mafic dioritic to hornblendic dikes are common within this sheared zone cutting the fault fabrics and folds associated with the strike- slip events. This is very similar to the dikes and igneous rocks associated with stops 2 and 3 today in the Brewster area where a similar age for intrusion of 1134 ± 8 Ma has been established for comagmatic granitic and mafic rocks.

Mafic dikes commonly less than several meters thick, crosscut high grade shear zones on both sides of the Canopus shear zone and have compositions similar to the dioritic and most mafic part of the pluton. Locally ultramafic hornblendite plugs and radiating dikes are found near Fort Hill. Importantly, dioritic dikes and segregations within the pluton crosscut the igneous flow structure (Figure 6), and all rocks of the pluton lack a strong Mesoproterozoic deformational structure that is present in the country rocks. This is also true of the granites and dioritic rocks of the same age at Stops 3 and 4 and of the mafic dikes and gabbro-diorite plutons in the Brewster area. We may speculate that the deformed dikes seen in the tonalite –trondhjemite and at Stop 1 today might also be dikes of the same age.

Back down and continue south on Sprout Brook Rd.
0.5 mile entrance to Continental Village the dated monzonite came from just north of this intersection on the west side of the road.
0.6 mile stop sign at Srout Brook and Gallows Hill Rd.
Proceed up to the left on Gallows Hill Rd.
0.2 mile turn left on Aquaduct Rd 0.4 mile small pond on left and drive pull in and park by first crops by two new houses at north end of pond.

Stop 7. Cat Hill Gneiss 1333 ±7 Ma trondhjemite gneiss and Mesozoic cataclastic structure on the north limb of the Annsville syncline

On the south side of the road are limestone crops of the Cambrian and Ordovician Wappinger Group here barely at biotite grade. North of the road before the Cat Hill Gneiss are crops of the Lower Cambrian Poughquag Quartzite then cataclastic gneiss of the Cat Hill Gneiss. In the 1970's, I mapped an unconformity between Paleozoic rocks of the Annsville syncline and the basement as Walter Bucher had. New cuts and reexamination of the cover rocks along the Annsville syncline to the east now support high angle normal faulting and brecciation of the kind associated with Mesozoic tectonics and the Newark basin.

The Cat Hill Gneiss is less cataclastic in the outcrops behind the house but even these are not typical because of the extensive fracturing. A few hand samples from the dated locality less tan 0.5 miles to the northeast demonstrate the difference. To get to the sample locality follow the directions to Stop 11 in Ratcliffe and Aleinikoff (2008)

The Cat Hill Gneiss is a white-weathering biotite -oligoclase- -quartz gneiss of trondhjemititic and tonalitic composition. It is typical of a series of similar massive biotite poor garnet bearing gneisses that occur in the Reservoir Gneiss of Berkey and Rice (1923) and which closely resemble parts of the Losee gneiss of the New Jersey Highlands. It also is very similar to tonalitic gneisses of the Green Mountains of Vermont, which formed as calc-alkaline intrusives between about 1390 Ma to about 1320 Ma (Ratcliffe and others, 1991). The rock is very massive, contains almost no inclusions. It does pass into a more garnet- rich phase and also hosts abundant white aplitic granites at its contacts with amphibolites and has brown weathering spots suggestive of hypersthene but none has been found here. These bordering aplites produce a spectacular intrusive breccia with inclusions of hornblende gneisses, amphibolites. Because the Cat Hill Gneiss contains migmatitic zones of similar aplite and granite it may be that the breccia is a product of mobilization and intrusion along the walls resulting from secondary mobilization in an event younger than 1337 Ma. The purple brittle fracture zones contain minute riebeckite and are very similar to fracture zones along the Ramapo and other faults along the Newark basin in New Jersey

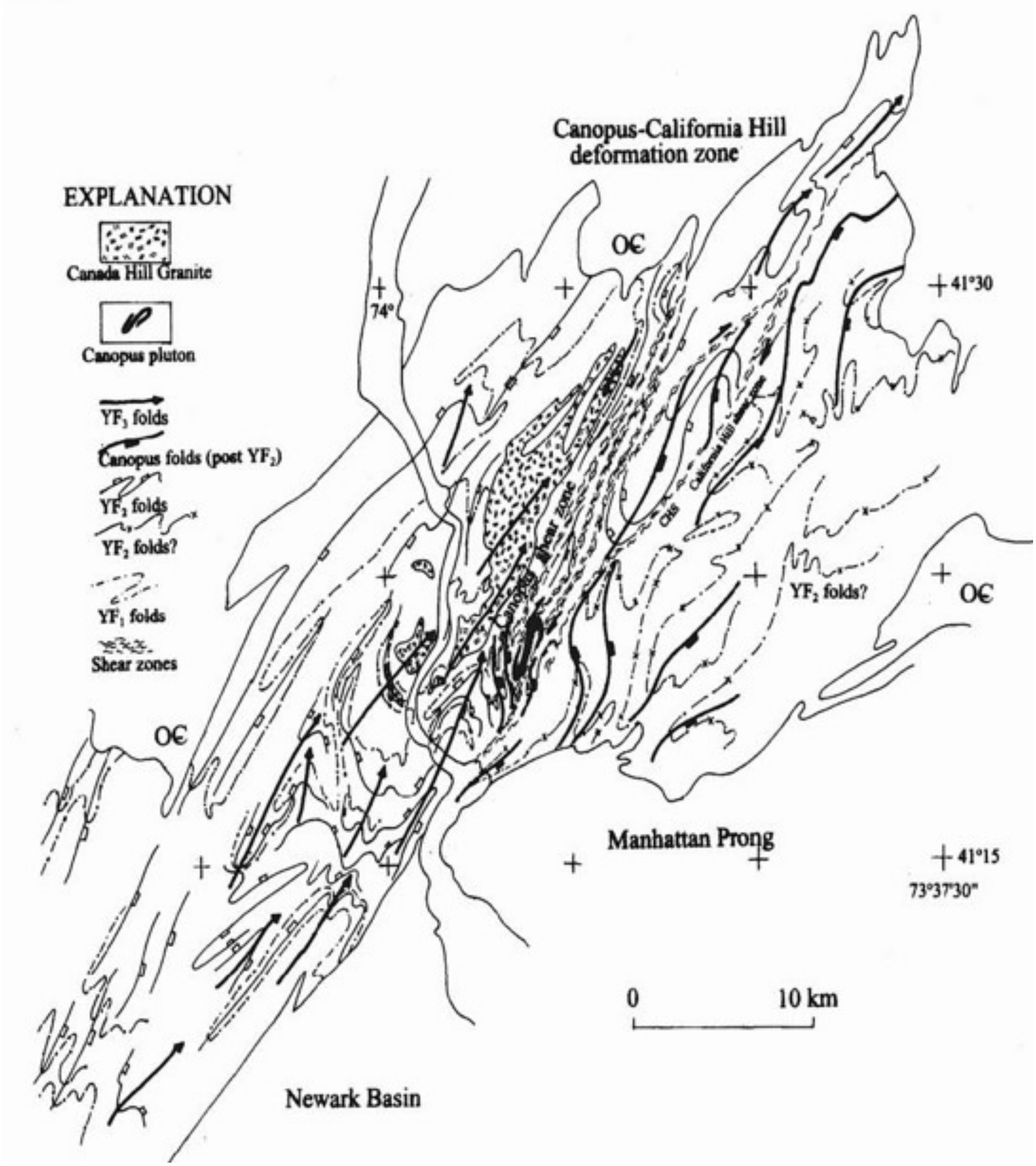

Figure 20. Regional tectonic map showing the distribution of Mesoproterozoic folds of the YF1, YF2 and YF3. Fold events YF1 And YF2 are judged to be Shawinigan and older. The YF2 folds east of the Canopus- California Hill shear zones may be Ottawan.

Figure 20 summarizes the axial traces of Mesoproterozoic folds in the Hudson Highlands of NewYork. Folds related to the Canopus- California hill deformation zone document a wide area of right sigmoidal folding here interpreted to be of Pre-Ottawan at approximately 1142 Ma and contemporaneous with intrusion of the Canopus pluton and its ferrodiorite dikes. Folds west of the shear zone, identified asYf3 folds are Ottawan and folds identified as Yf2? to the east may be also be.In the Brewster quadrangle (Stop 2) and on Joes Hill similar dioritic dikes cross cut the granitic gneisses and intrude along steeply dipping high -grade shear zones. I tentatively correlate the igneous rocks of the Canopus area with the dikes in the Brewster area and with the dated granite-and diorite at stops 3 and 4. If this is correct, there may be evidence for a broad zone of right lateral shearing and igneous activity in the northern Hudson Highlands near the end of the Shawinigan phase of the Grenville orogeny. This raises the possibility that some of the amphibolite inclusions in these older rocks (Stops 1, 8 and 10) could be dikes, masking as xenoliths in the older granitic to tonalitic rocks! The more I learn about these rocks the more that interpretation seems likely to me.

Return to Aquaduct Rd turn left and left again onto Gallows Hill Rd. at the stop sign.
0.7 mi. turn left (S)onto Sprout Brook Rd.

Sprout Brook valley is a continuation of the Canopus Valley that extend south to the Hudson River and which is floored by highly mylonite silimanite containing garnet gneisses, as well as and calc- silicate rocks. Biotite grade phyllites of Ordovician age correlative with the Wallomsac Formation occur along the east side of the valley where they rest on Mesoproterozoic rocks along the east dipping Annsvile fault which I originally interpreted was an Ordovician thrust fault but which I now regard as a Mesozoic normal fault traceable to branches of the main Ramapo fault to the south.

2.1 miles south to Roa Hook Rd, turn right and immediately bear right on to approach road to Rt. 9 D turn left on Rt. 9.

Exposures of Wallomsac Formation in contact with Mesoproterozoic gneiss along the extension of the Annsville fault. At these outcrops Walter Bucher documented a conglomeratic fine grained dolomite with clasts of gneiss which he interpreted as a basal units of the Wappinger Group resting unconformably on the basement. However, the large pebble- to cobble- size inclusions within the dolomite are all fragments of retrograded calc-silicate rock in an ultrafine grained mylonite or foliated dolomitic cataclasite that derived from Mesoproterozoic rock.

Follow Rt. 9 0.5 mi. into traffic circle and take Rt. 6 and 202 south towards Peekskill, cross bridge and at light turn right following Rt. 9.

Crops facing consist of Cambrian Poughquag Quartzite to the left are unconformable on Reservoir Gneiss. Large continuous crops of the Reservoir Gneiss continue for a mile to the south in high road cuts.

1 mile exit Rt. 9 to right and await instructions.

ROAD CONSTRUCTION MAY MAKE IT IMPOSSIBLE TO STOP HERE BUT ACCESS MAY BE POSSIBLE FROM THE PARKING LOT OF THE PEEKSKILL INN. An alternate site is at the Husdon River below the large outcrops.

Stop 8. Reservoir granite of Berkey and Rice (1921) at Peekskill

The exposures sampled for dating of zircon are at the east end of the large road cut on Rt. 9 and 202 below the Peekskill Inn. The exposures extend about 1000 feet to the north in high road cuts. Numerous thin to thick amphibolite gneisses and more biotitic gneisses form septae in the granodioritic gneiss. The rock is remarkably homogeneous and is interpreted as an intrusive rock. At one locality near the middle of the cut a pod of amphibolite is included in the granodiorite. A concordant SHRIMP zircon age of 1338 ± 6 Ma has been determined for the granodiorite. Zircon overgrowth ages are about 1.26 and 0.98 Ga.

Return to Rt. 9 heading south.
0.5 mi south on Rt.9 large new fresh outcrops of south dipping norite of the central basin of the Cortlandt complex here intruding the Walloomsac Formation.

3.5 mi exit Rt. 9 to Rt. 9A turn left at light.
0.5 mi. turn left on Furnace Dock Road.
0.4 mi. turn right into Furnace dock Condominiums and proceed 0.2 mi to the last building on the left pull in behind building.

Stop 9. Cortlandt complex monzonorite and contact with the Walloomsac Formation

We are at the southeastern margin of the Cortlandt complex that consists of igneous norite, diorite, pyroxenite that cross cuts Taconic deformed metasediments of the Manhattan prong as well as the Laurentian basement. It was intruded following Taconic deformation and metamorphism and is one of the key observations in determining the timing of the Taconian orogeny. The igneous rocks are folded and intruded by the Devonian Peekskill Granite. A discussion of the contact relations, chemistry, and petrogenesis of the complex is beyond the scope of the present trip. Several papers and guidebooks provide that information (Bender, 1982; Ratcliffe and others, 1982, 1983) .

The central basin of the complex consists of inward dipping sheets of biotite norite, hornblende and biotite poikilitic norite and locally at the very border a monzodiorite that contains zircon. Pockets of interstial k-feldspar- quartz and radiating biotite define slightly pinkish areas in the norite adjacent to the contact with the Walloomsac Formation. Zircon from this rock yielded a concordant SHRIMP age of 444 ± 3 Ma almost identical to the concordant SHRIMP zircon age from monzodiorite of the Peach Lake pluton (447 ± 5 Ma).

Near the contact igneous rocks and mobilized schist form an intrusive breccia In the breccia are rotated fragments of foliated and folded calc- silicate rock, and calc- schist characteristic of the basal part of the Walloomsac Formation (formerly termed Manhattan A of Hall, 1968). A breccia zone like this was previously recognized along this contact but none of the exposures are as spectacular as this one. Just west of this location and in the cuts for the exit ramp from Rt. 9W dikelets of mobilized schist containing garnet sillimanite-spinel- and corundum back intrude the chill norite and cut across the intrusive flow layering in the igneous rocks (see Stop 6 of Ratcliffe and others, 1983). Evidently the schists of the contact aureole were mobilized not as melts but as volatile-rich pneumatic injections, driven by contact-induced decarbonization and dehydration reactions along the walls.

Thin sections of the contact schist here contain garnet- biotite- staurolite- plagioclase and quartz and lack either kyanite or sillimanite both of which are present in contact rocks not far from here. Schist outside the aureole to the south on Torment Hill also contains abundant staurolite and lacks either kyanite or fibrolite.

Leave the parking lot via Furnace Dock Rd. to Rt.9A and turn left immediately, in 0.1 mi.onto Furnance Dock Rd as it continues across Rt.9A. Follow Furnance Dock 1 mile to the Hudson River and park at the entrance to Oscawana Island Park.

Stop 10 Granitic Fordham Gneiss 1351 ± 6 Ma and amphibolitic gneisses

The first exposures by the RR tracks are dark -gray biotitic gneisses, amphibolite gneisses and some sulphidic schists of the Fordham gneiss, which are in contact with the granite gneiss from the dated locality westward to this point. The biotite- hornblende gneiss resembles the inclusions we will see in the granite gneiss on Oscawana Island. The amphibolitic gneiss is layered and

Figure 21. Amphibolite screens or dikes? In the Fordham Gneiss at Oscawana Island.

grades into schists near the south end ofthe RR exposure. This suggests that the Fordham Gneiss contains paragneisses that are older than 1351 Ma. Hornblende from these exposures yielded a 40 Ar/39Ar cooling age of 450 Ma (Dietsch and others, 2004).

Walk northwest to the island. Take bridge over tracks and follow trail to end of island. Walking south then west along the shore we will see excellent exposures of the dated gneiss and inclusions in it. Some of the tabular to irregular-shaped inclusions are layered, but the gneissosity seems to be shared by the granite. Note this is unlike the relations of the 1134 Ma intrusive rocks at Stops 3 and 4. I have not seen evidence that the 1350-1330 Ma rocks cross cut an older gneissosity.

Here we might consider how the zircon age and intrusive relationships should be interpreted. Does the zircon age date the time of the intrusion of granite, or could the intrusive relations we deduce been produced by migmatization of a pile of felsic and mafic volcanic rocks? This is a difficult question not easily answered, either from the zircon zoning patterns or the field observations. I think we can conclude safely however that the granitic gneiss and the inclusions were present at 1351 Ma, but in what exact form is left undetermined. We have chosen to interpret the zircon age as the emplacement and crystallization age. If this is correct then the biotite hornblende gneisses in the RR cut might be older than the granite and some of the Fordham Gneiss older than 1351 Ma.

Summary diagrams of dike chemistry

Figures 22 and 23 give a summary of some of the chemical characteristics of the mafic dikes and amphibolites we have seen on this trip. The data are consistent with the mysterious dikes of the Brewster area being correlative with 1143 Ma Canopus plutonism rather than Ordovician, as the field observations indicate. The data also allow for some of the amphibolite ”inclusions” in the ~ 1340 Ma granitoids to be deformed dikes, as field observations do indicate for some, perhaps in the same 1143-1134 Ma Shawinigan event. Notable are the coarse amphibolites (Stop 5) of the Nimham belt which are distinct outliers of low TiO_2 mafic rocks. Ta/Yb of the Brewster dikes overlap those of the Canopus dikes although the centroid of the former suggests a more depleted mantle source rather than more MORB- like source for the latter. The quite alkaline nature of the Cortlandt -age dike swarm suggests an enriched mantle source at about 450 Ma., and the high-TiO_2 – low MgO metadiabase dikes of probable Neoproterozoic age (Ratcliffe, 1987) suggest low degrees of partial melting in a rift event at about 570 to 600 Ma, although the age of these dikes has not been determined.

CONCLUSIONS

The recognition of pre- Shawinigan basement as old as 1350 to 1330 Ma in the Hudson Highlands and in the Fordham Gneiss of the Manhattan prong is a new finding that should permit the deciphering of the pre-Ottawan history of the very old basement rocks. Rocks of this age are now known to be widespread in other basement terranes of the Appalachians from New York north to Vermont where detailed mapping has delineated their distribution. Younger intrusive rocks 1174 to 1134 Ma of mafic and felsic composition, cross cut the older rocks and help define a Shawinigan event as well. The possibility of a widespread dike event and strike slip deformation seems likely in the Hudson Highlands but this structural event has not yet been recognized in other massifs to the north and there is uncertainty in the correlation of this event with that proposed by Gates and others (2004) to be Ottawan.. Although the Ottawan deformation and is known from migmatites and from intrusive rocks as young as the 1045 Ma Danbury augen granite (Walsh and Aleinikoff, 2004) and from zircon overgrowth ages (Table 1) the actual structural expression of the Ottawan in the Hudson Highlands is not as yet sorted out. As more and more workers discover the pre-Ottawan events in the Grenville of the Appalachians, the structural complexities become increasingly complex and intriguing. We hope that this trip will provide some food for thought.

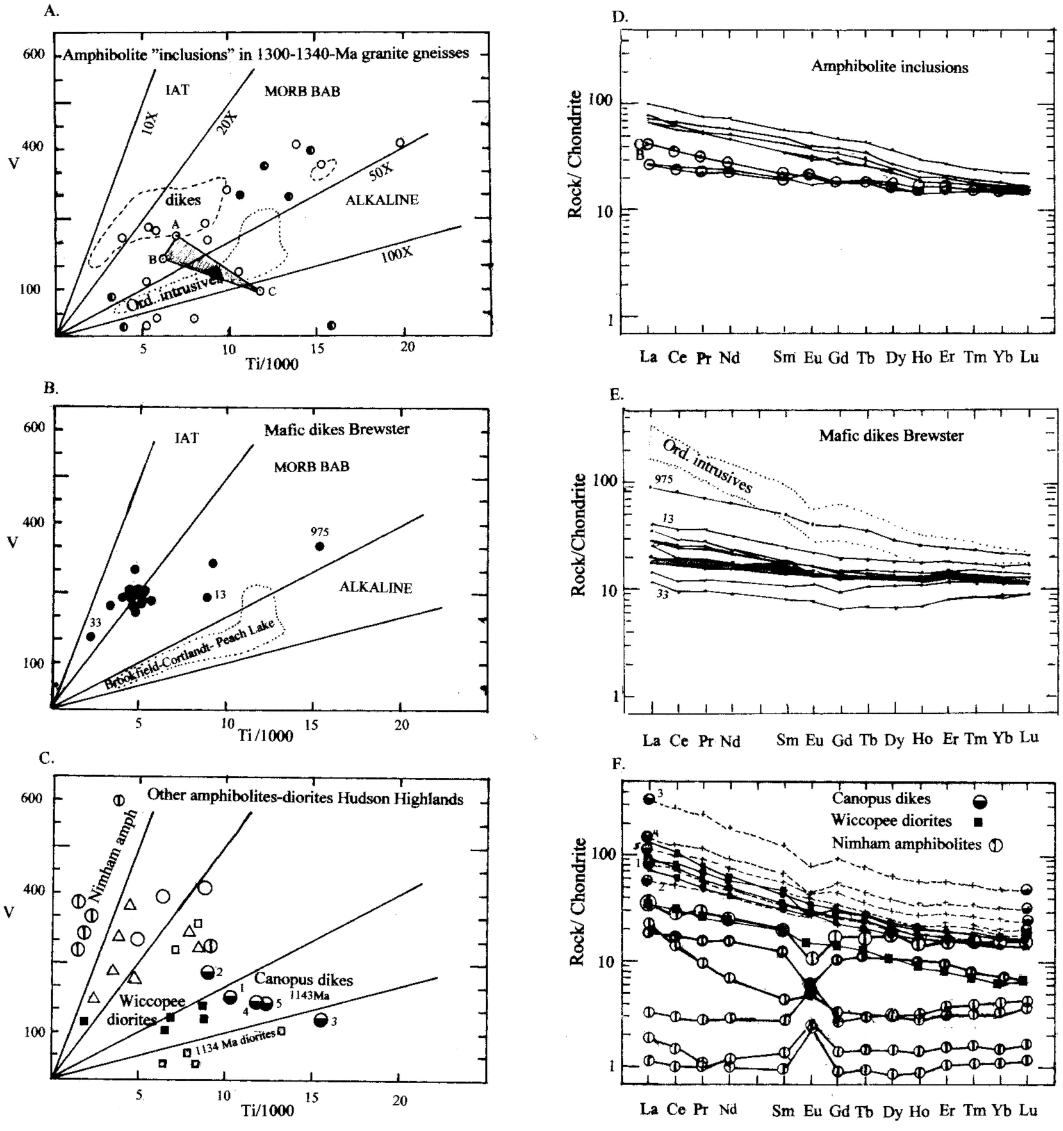

Figure 22. Chemical plots of amphibolites, diorites, and dikes of the Hudson Highlands, NY comparing "inclusions" in 1340-1330 Ma granitoids with 1143-1134 Ma diorites and dikes (Stops 3, 4 and 6) and with undated dikes (Stops 1, and 2). Ordovician dikes of the Cortlandt dike swarm and with probable Neoproterozoic metadiabase dikes (Ratcliffe, 1987).V vs Ti/1000 after Shervais (1982). REE normalization factors (Sun and McDonald, 1989) A. Amphibolite "inclusions" in 1340-1330 Ma granitoids (open circles) and Fordham Gneiss (filled circles). Dashed field shows mafic dikes in B.B. Mafic dikes that crosscut gneissosity in 1340-1330 Ma gneisses C. Other amphibolites of the Hudson Highlands. Circles with vertical line = Nimham belt (Stop5a). Triangles amphibolites Camp Smith interlayered with 1230 Ma felsic gneisses. Half-filled circles = Canopus dikes Stop 6.Open squares diorites of Wiccopee pluton. Filled squares = 1134 Ma diorites and granite Stops 3 and 4. Open circles 3 amphibolites in the Poughquag quadrangle east of Nimham belt.D.Chondrite normalized patterns of representative amphibolite inclusions. Shaded area three amphibolites (A and B) and pyroxenes- hornblende reaction zone (C) with Ottawan pegmatite Stop 1E. Chondrite normalized patterns for mafic dikes in relation to Cortlandt dike swarm F. Chondrite normalized patterns at top Canopus dikes-half filled circles (Stop 6) and dashed field). Middle fields Wiccopee diorites and at bottom amphibolites of Nimham belt (Stop 5).

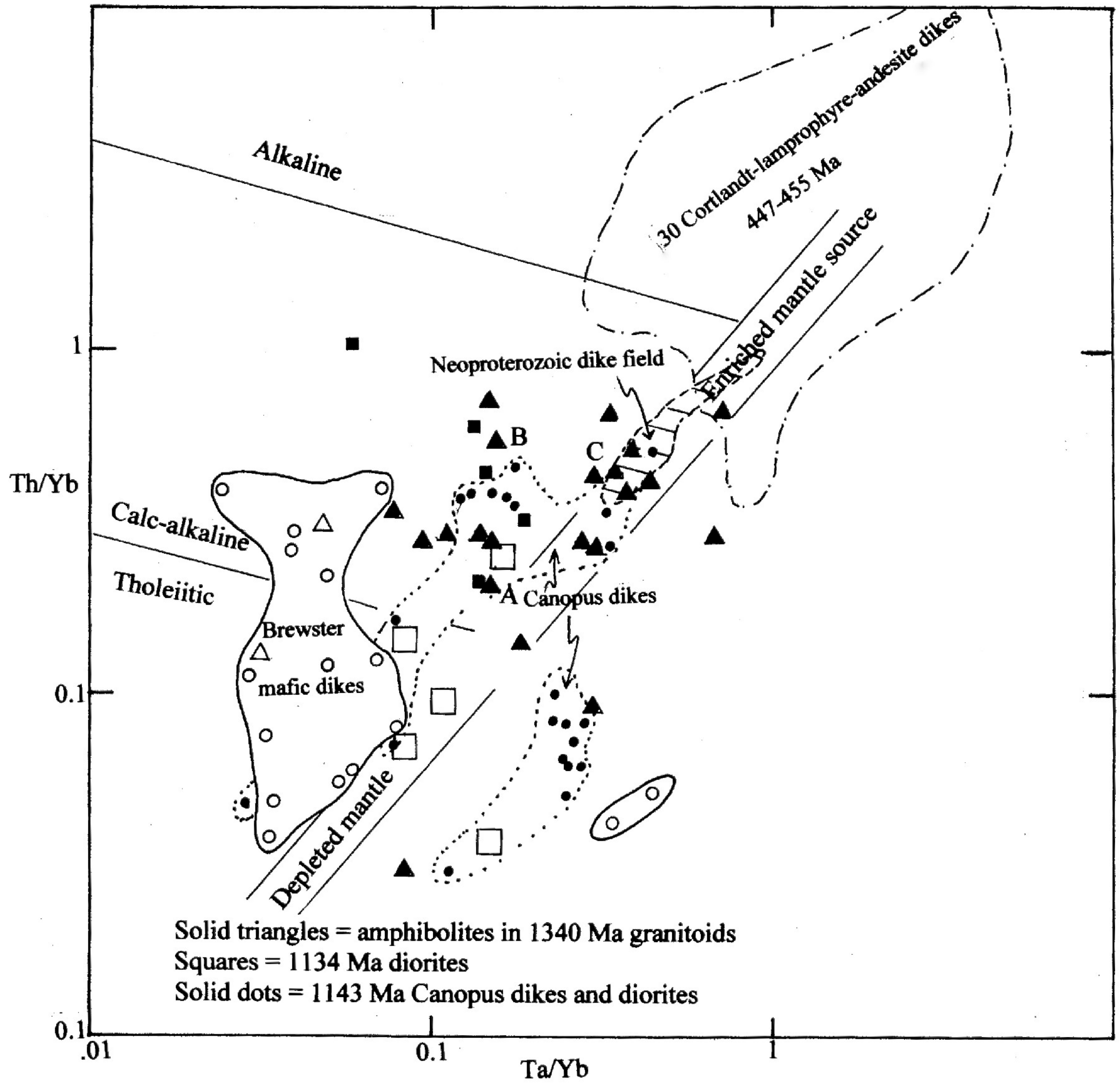

Figure 23. Th/Yb vs Ta/Yb plot (after Pierce, 1983) of mafic dikes in the Brewster area (open circles) compared to amphibolite (triangles) in 1330-1340 Ma granitoids of the Hudson Highlands and Manhattan prong, Samples A, B and C are amphibolites at Stop 1, C is pyroxene hornblende reaction zone with Ottawan pegmatite. Filled circles are mafic dikes and chill ferrodiorites of the 1143 Ma Canopus pluton (Stop 6), and squares are diorites of the Wiccopee pluton (filled squares), and 1134 Ma diorite and hornblende granite (open squares) at Stop 3 and 4. These are shown in comparison to the alkalic dikes of the Cortlandt- Rosetown and Popolopen Lake lamprophyre dike swarm of late Ordovician or early Silurian age and probable Neoproterozoic metadiabase rift basalts of the Hudson Highlands (Ratcliffe, 1987). The diagram suggests that the Brewster dikes are not Neoproterozoic or Ordovician but could be related to 1130-1140 Ma plutonism. It also suggests that many of the “inclusions” in the 1330-1340 Ma tonalitic- trondhjemite and granitic gneisses may be part of an extensive set of Shawinigan ferrogabbro-diorite- ferromonzonite intrusives that include the 1143 Ma Canopus pluton and dikes, the Wiccopee pluton and unnamed 1143 Ma diorite- hornblende granite of the Brewster area.

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