STRUCTURE AND PETROLOGY OF THE PRECAMBRIAN ALLOCHTHON, AUTOCHTHON AND PALEOZOIC SEDIMENTS OF THE MONROE AREA, NEW YORK[1]

HOWARD W. JAFFE
University of Massachusetts
Amherst, Massachusetts

ELIZABETH B. JAFFE
Amherst, Massachusetts

INTRODUCTION

The area covered by this trip lies in the northern part of the Monroe 7.5 minute quadrangle, New York, and consists of a folded and faulted complex of autochthonous Precambrian gneisses, Lower Cambrian through Middle Devonian sediments and allochthonous Precambrian gneisses. Geologic maps covering the trip area have been published by Ries (1897), Fisher, et. al. (1961), and Jaffe and Jaffe (1962 and 1973). Unpublished maps prepared by Colony and by Kothe (Ph.D. thesis, Cornell Univ.) undoubtedly contain valuable information but are not available for study. Recent workers in adjacent areas include Dodd (1965), Helenek (1971) and Frimpter (1967), all in the Precambrian autochthon, and Boucot (1959) and Southard (1960) in the stratigraphy and paleontology of the Paleozoic sediments. The work of Colony (1933), largely unpublished, is impressive.

An attempt to unravel the complex structural history of the region has suggested the following sequence of events:

1) Deposition in the Precambrian of a series of calcareous, siliceous, and pelitic sediments and basic volcanics of the flysch facies in a eugeosynclinal; folding and metamorphism involving complete recrystallization to granulite facies gneiss assemblages which characterize the Precambrian autochthon (Jaffe and Jaffe, 1962; Dodd, 1965). Foliation in the autochthon trends northeast and is generally vertical or dips steeply to the east, with overturning west; fold axes most often plunge gently northeast. The metamorphic foliation appears essentially Precambrian in origin. The present Precambrian allochton was deposited and recrystallized at about the same time as the autochthon; recrystallization took place about 1100 million years ago. The sediments of the allochthon are graphitic, siliceous, calcareous and pelitic and appear to represent a clastic wedge (molasse) deposited in a reducing environment, possibly to the east. Graphitic gneisses are absent from the autochthon of the Monroe quadrangle, although they do occur in the Popolopen Lake quadrangle to the east (Dodd, 1965).

2) After extensive erosion, the Lower Cambrian Poughquag conglomerate, arkose, and quartzite were deposited unconformably on the Precambrian autochthon. As in most of the Hudson Highlands, the Poughquag has been sporadically preserved and here occurs only in the buttressed area northeast of Block 2 (Fig. 2). The Poughquag dips gently to the north.

[1]This article is reproduced (with minor editorial changes) from the New York State Geological Association Guidebooks of 1962 and 1967. The log has been modified to reflect road changes in the last 22 years.

3) Deposition of the Cambro-Ordovician Wappinger Formation, which in this area consists entirely of dolomite. In Block 2 (Fig. 2), it also dips gently to the north. In Block 3 it is moderately to strongly folded along a northeast trend. In Block 5 it outcrops between the Ordovician shales and the Precambrian of the Goose Pond klippe in a northeast striking band that dips west. In about this same attitude it underlies the Precambrian Museum Village klippe in Block 9.

4) Intrusion of lamprophyre dikes into the northwest-trending tension fractures in Precambrian and overlying Cambro-Ordovician rocks (Jaffe and Jaffe, 1962). These dikes have been found only in Blocks 1, 2, and 3.

5) Deposition of the Hudson River shales (Middle? Ordovician) over the entire area. This was followed by either:

   a) gentle folding, followed by erosion, or

   b) upfaulting of the Wappinger dolomite against the shales.

6) Overthrusting of the Precambrian allochton as a nappe from the east, most probably during the Taconic orogeny. Evidence for thrusting is:

   a) GEOMAGNETIC. The Precambrian autochthon everywhere shows a strong positive anomaly, whereas the klippen show none and can therefore be no more than 500 - 600 feet thick (R.W. Bromery, personal communication). The relief of Goose Pond Mountain is of this magnitude. Bull Mine Mountain, which contains magnetite deposits, does show a positive anomaly.

   b) GEOLOGIC. The Precambrian of Bull Mine Mountain is perched on Ordovician shale; the Museum Village klippe can be seen to rest on Wappinger dolomite. At the base of Goose Pond Mountain is a fault breccia; such a zone also exists on Bull Mine Mountain at the contact of the shales and the gneiss.

   Near the klippen, the Ordovician shales are always more strongly folded than elsewhere in the area, and are often overturned.

   c) PETROGRAPHIC. Quartz pebbles and grains, commonly optically continuous except for strain, have length-width ratios up to 17:1. The texture of the klippe gneisses is consistently more deformed and cataclastic than that of the Precambrian autochthon.

7) Folding of the nappe along a northeast axis, followed by erosion, leaving (a) synclinal remnant(s) along the fold axis, extending from Goose Pond Mountain to Snake Hill, near Newburgh, and beyond, to just west of Balmville. The klippen must once have formed such a single line as would be left by an eroded downfold; the alignment from Bull Mine to Snake Hill is too perfect to be a coincidence, and Goose Pond Mountain is on strike with a klippe west of Balmville, a town just north of Newburgh.

8) N 75 W cross-faulting along the Quickway (N.Y. 17) with the north block moving east. This accounts for the present displacement of the Bull Mine - Snake Hill line of klippen from the Goose Pond klippe (The Museum

Village klippe has been rotated from this line by a later fault presumably Triassic.) Apparent displacement is about one mile. The upper calcareous feldspathic quartzite member of the Hudson River shales, which outcrops on Lazy Hill, is essentially absent north of the Quickway fault. If its displacement north of the fault is the same as that of the klippen, its present position north of the fault is somewhere under the western talus slope of Schunemunk Mountain. Except for rotated Blocks 8 and 9, Silurian and younger formations line up on strike across the Quickway fault. The major lateral movement along this fault must therefore have been pre-Silurian.

9) After an erosion interval, the Shawangunk conglomerate and orthoquartzite (Lower to Middle Silurian) were deposited unconformably on the older rocks.

10) Deposition of Lower Devonian sediments.

11) Convincing evidence for the Acadian orogeny in the area is lacking. Such an event might account for pebble-stretching in the Shawangunk conglomerate, and for slight additional east-west movement along the Quickway cross-fault.

12) Deposition of the Cornwall shales and Bellvale graywackes in the Middle Devonian.

13) Appalachian folding. In the course of this folding, the relatively thin and brittle Shawangunk beds broke into detached plates which were thrust over the more yielding shales above and below. This thrusting produced the fluting parallel to the dip of the beds and the marked stretching of the Shawangunk pebbles in both the a and b fabric axes. Pebble beds in the thicker and more massive Bellvale graywackes show far less shattering and stretching of their pebbles.

14) Following the Appalachian revolution, the area was uplifted and has remained positive. During the Triassic orogeny, faulting, partly with and partly across the grain of the country, reactivated old faults and produced a complicated pattern of tilted and rotated, up-faulted and downfaulted blocks (Figs 2 and 2A):

a) Block 1 (Fig. 2) was uplifted along a N 33 E fault to form the Ramapo Mountains.

b) Block 2, which includes Poughquag quartzite and Wappinger dolomite nestled in the curve of the Precambrian massif and dipping gently north, was uplifted. Block 2 is truncated to the north by an eastward continuation of the Quickway fault, as is shown by geomagnetic evidence (R.W. Bromery, personal communication; Henderson, 1962). Block 2 is in fault contact with the younger sediments of Blocks 3 and 4.

c) Block 3 is a graben about 1500 feet wide at the south end of the map, and perhaps one or two miles wide at the north end of Block 2. In this graben, the Wappinger dolomite is moderately to steeply folded on a northeast axis.

d) Block 4 was downfaulted relative to Blocks 2 and 5, and upfaulted relative to Blocks 6, 8, and 9. Anomalous northeast dips at the north end of Block 4 may be the result of drag during faulting.

e) Block 5 was uplifted relative to Block 4, but downthrown relative to the klippen north of the Thruway fault. The Precambrian of Goose Pond Mountain outcrops from an elevation of 480 ft upward; the Museum Village klippe rests on dolomite at about 600 ft. The shale-gneiss contact on Bull Mine Mountain was observed at about 840 ft.

f) The main mass of Schunemunk Mountain, Block 6, is downthrown along northeast-southwest faults on both sides. It must also be considerably downthrown relative to its continuation to the south (Block 4), which has a moderate positive geomagnetic anomaly indicating that the basement is not very far down. The syncline's east limb is truncated to the south.

g) Block 7, in which the Esopus dips about 25° N and under which the basement anomaly is absent, probably was tilted to the north during the uplift of Block 2 and the sinking of Block 6.

h) Block 8, where the synclinal axis of Schunemunk swings to the north-south, has been rotated counterclockwise.

i) The Museum Village klippe and Bull Mine Mountain (Block 9), with the dolomite beneath, have also been rotated counterclockwise as a single block.

j) The Shawangunk sliver, Block 10 between Blocks 8 and 9 has been ground, thrust, rotated and crumpled during the rotation of the blocks.

Interrelations of the faults are highly problematic, partly owing to the masking effects of Pleistocene glaciation.

REFERENCES CITED

Boucot, A.J., 1959, Brachiopods of the Lower Devonian rocks at Highland Mills, New York: Jour. Paleontol., v. 33, p. 727-769.

Colony, R.J., 1933, Structural Geology between New York and Schunemunk Mountain: XVI Intern. Geol. Cong., Guidebook 9: New York Excursions.

Dodd, R.T., Jr., 1965, Precambrian bedrock geology of Popolopen Lake quadrangle, southeastern New York: N.Y. State Mus. and Sci. Serv., Map and Chart Ser. No. 6, 39 p.

Eckelmann, F.D., 1963, Precambrian events recorded in zircon populations of the Storm King granite and Canada Hill gneiss, Bear Mountain, New York, (abs.): Program, 44th Ann. Mtg., Amer. Geophys. Union, p. 120.

Edelman, C.H. and Doeglas, D.J., 1931, Reliktstrukturen detritischer Pyroxenen und Amphibolen: Min. Petrog. Mitt., v. 42, p. 482-490.

Fisher, D.W., Isachsen, Y.W., Richard, L.V., Broughton, J.G., and Offield, T.W., 1962, Geologic Map of New York, 1961: N.Y. State Mus. and Sci. Serv., Geol. Surv., Map and Chart Ser. No. 5.

Frimpter, M.H., 1967, Geology of the Thiells Quadrangle, New York, with emphasis on the igneous and metamorphic rocks: Boston Univ., Ph.D. Thesis, 181 p. (unpublished).

Gordon, C.E., 1911, Geology of the Poughkeepsie quadrangle: N.Y. State Mus. Bull. No. 492, p. 39-48.

Helenek, H.L., 1971, An investigation of the origin, structure and metamorphic evolution of major rock units in the Hudson Highlands (New York): Brown Univ., Ph.D. thesis (unpublished).

Henderson, J.R., Smith, F.C. and others, 1962, Aeromagnetic map of parts of the Monroe and Maybrook quadrangles, Orange County, New York: U.S. Geol. Survey, Geophysical Invest. Map GP-339.

Isachsen, Y.W., 1963, Geochronology of New York State: The Empire State Geogram, 1-9.

Jaffe, H.W. and Jaffe, E.B., 1962, Geology of the Precambrian crystalline rocks and Cambro-Ordovician sediments of the southeastern part of the Monroe quadrangle: N.Y. State Geol. Assn., 34th Ann. Mtg., Field Guidebook, Trip B, p. B 1 - B 10.

-----, and Jaffe, E.B., 1973, Bedrock Geology of the Monroe Quadrangle, Orange County, New York: N.Y. State Mus. and Science Serv., Geol. Surv., Map and Chart Ser. No. 20.

Kay, G.M., 1942, Development of the Northern Allegheny Synclinorium and adjoining regions: Geol. Soc. Amer. Bull., v. 53, p. 1601-1658.

Krynine, P.D., 1948, The megascopic study and field classification of sedimentary rocks: Jour. Geol., v. 56, p. 130-165.

Long, L.E. and Kulp, J.L., 1962, Isotopic age study of the metamorphic history of the Manhattan and Reading Prongs: Geol. Soc. Amer. Bull., v. 73, p. 969-996.

Megathlin, G.R., 1939, Faulting in the Mohawk Valley, N.Y.: N.Y. State Mus. Bull., no. 315, p. 85-122.

Pettijohn, F.J., 1957, <u>Sedimentary Rocks</u>: 2nd Ed., Harper & Bros., N.Y., p. 283-330.

Ratcliffe, N.M., 1967, Paleozoic post-tectonic plutonism at Stony Point, New York (abs.): Program, 2nd Ann. Mtg. Geol. Soc. Amer. NE Sect., Boston, p. 51.

Ries, H., 1897, Geology of Orange County, New York: N.Y. State Mus. Report, No. 49, part 2.

Southard, J.B., 1960, Stratigraphy and structure of the Silurian and Lower Devonian rocks at Highland Mills and Cornwall, New York: Mass. Inst. Tech., B.S. Thesis, 72 p. (unpublished).

Zartman, R.E., Brock, M.R., Heyl, A.V., and Thomas, H.H., 1967, K-Ar and Rb-Sr ages of some alkalic intrusive rocks from central and eastern United States: Amer. Jour. Sci., v. 265, p. 848 - 870.

ROAD LOG FOR STRUCTURE AND PETROLOGY OF THE PRECAMBRIAN ALLOCHTHON AND PALEOZOIC SEDIMENTS OF THE MONROE AREA, NEW YORK

CUMULATIVE MILEAGE	MILES FROM LAST POINT	ROUTE DESCRIPTION
0.0	0.0	This trip starts at intersection (traffic light) of NY 17, 32 and US 6 in Central Valley, NY. Proceed west on Niniger Road.
0.6	0.6	Niniger Road becomes Dunderberg Road.
1.9	1.3	Left at T-intersection with County Route 105
2.4	0.5	Bear right at fork to Spring Street.
3.4	1.0	Bear right onto North Main Street.

4.1	0.7	Bear right onto to Oreco Terrace at the intersection of N.Y. 208, Orange and Rockland Road, and Oreco Terrace. Park on right side of road.

STOP 1. ORECO TERRACE: BELLVALE GRAYWACKE

The outcrop is on the right side of Oreco Terrace just above the intersection of N.Y.208, Orange and Rockland Road, and Oreco Terrace. Here, the Bellvale graywacke of the Hamilton Group (Middle Devonian) is exposed in a section approximately 220 feet thick. It consists of 20 - 40 foot beds of dark blue-gray, green-gray, or gray, fine- to medium-grained (0.08 - 0.25mm average grain size) lithic arenite or graywacke, rhythmically interbedded with thin beds of dark green-gray to blue-gray shale. A representative modal composition of the graywacke follows:

Mode Of Bellvale Graywacke

Detritals:		
	quartz	20%
	oligoclase	2
	shale phyllite	44?
	siltstone chert	15
	greenstone	1
Matrix:		
	clay, sericite, chlorite, Mn oxide	15?
Metamorphic:		
	chlorite	2
	muscovite	1
		100%

Texturally, the rock consists of angular, elongated slivers of detrital quartz and predominantly phyllitic rock fragments (0.08 - 0.25mm) set in a fine matrix of sericitic muscovite, clay, and chlorite. It is often difficult to distinguish smeared-out phyllitic fragments from balled-up micaceous matrix, both of which frequently blend or flow together. Depending upon the uncertainty of the matrix content, or the classification used, the Bellvale is either a low-rank graywacke (Krynine, 1948), a subgraywacke or a lithic graywacke (Pettijohn, 1957) or a graywacke (Folk, 1954). Larger bent grains of chlorite and muscovite in the matrix, are here interpreted to have grown from fine matrix material marking the beginning of the chlorite zone - greenschist facies of regional metamorphism imprinted during the Appalachian orogeny.

In general, the Bellvale graywackes tend to show rhythmic interbedding with shale, with graded bedding low in the section and strong current crossbedding higher in the section. Occasional brachiopods are found low in the section; plant fossils are found higher up. Both features suggest gradation from marine to non-marine depositional environment. The provenance was a low-rank metamorphic or sedimentary terrane.

The shattered outcrop at Oreco Terrace is at the southwest corner of Rotated Block 8 (Fig. 2) and lies near the intersection of four directions of faulting. Attitudes of prominent structures at the outcrop are tabulated:

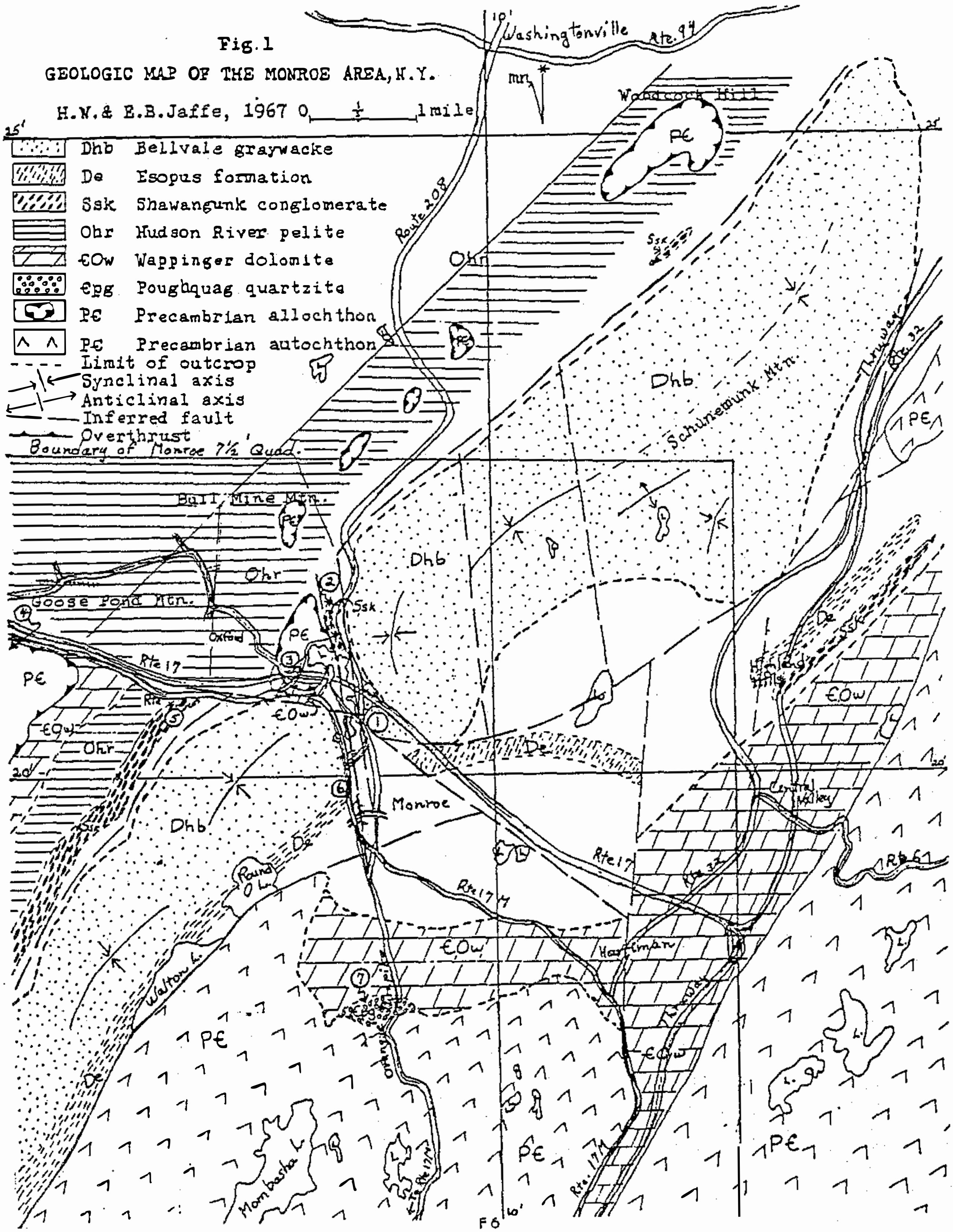
Fig. 1
GEOLOGIC MAP OF THE MONROE AREA, N.Y.
H.W. & E.B. Jaffe, 1967
0 ½ 1 mile
Dhb Bellvale graywacke
De Esopus formation
Ssk Shawangunk conglomerate
Ohr Hudson River pelite
€Ow Wappinger dolomite
€pg Poughquag quartzite
P€ Precambrian allochthon
P€ Precambrian autochthon
Limit of outcrop
Synclinal axis
Anticlinal axis
Inferred fault
Overthrust
Boundary of Monroe 7½ Quad.
Washingtonville
Rte. 94
Woodcock Hill
Route 208
Bull Mine Mtn.
Goose Pond Mtn.
Schunemunk Mtn.
Thruway
Rte. 32
Oxford
Rte 17
Monroe
Rte 17M
Central Valley
Highland Mills
Harriman
Rte 6
Round Lk
Walton L.
Mombasha L.

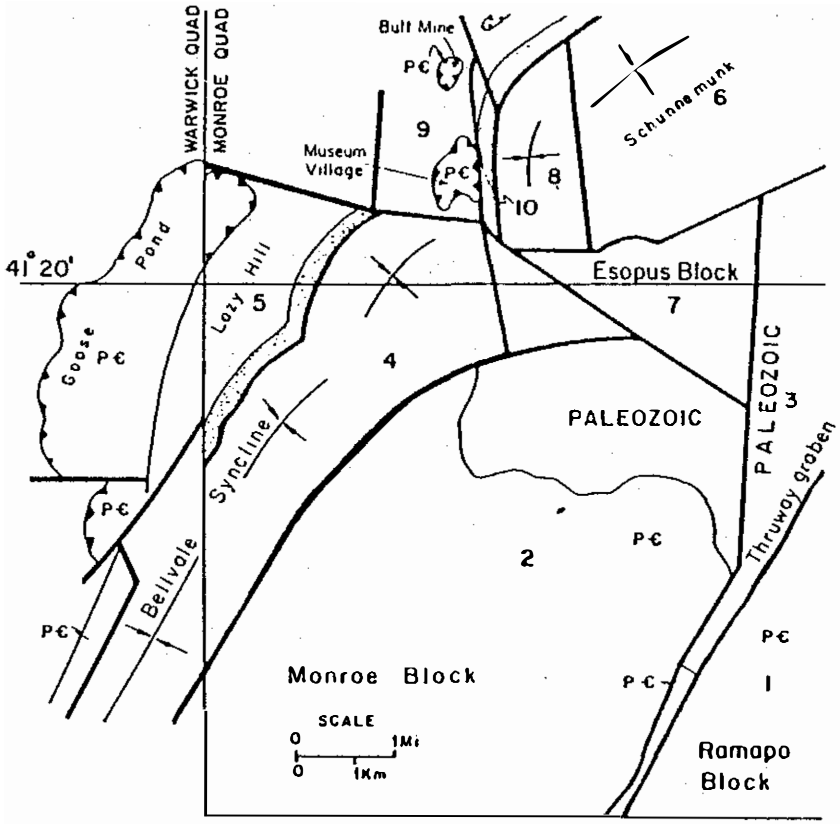

FIGURE 2. Principal fault blocks of the Monroe quadrangle, and their extension in the Warwick quadrangle (geology of the Warwick quadrangle after Offield, 1967). Stippled area is the Shawangunk.

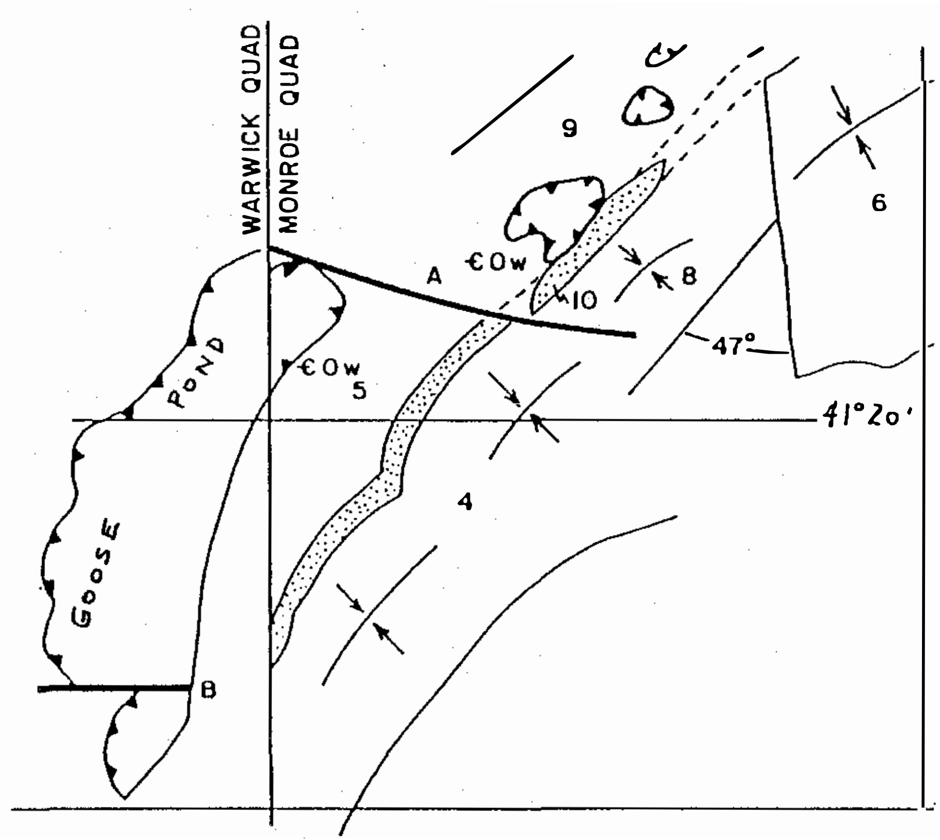

FIGURE 2A. Geologic map of parts of the Monroe and Warwick quadrangles as they may have appeared before the rotation of Blocks 8, 9, and 10 (Warwick quadrangle modified after Offield, 1967).

	Strike	Dip	Plunge
Bedding	N 67 W	30NE	----
Cleavage	N 50 E	37SE	----
Fault	N 13 E	Steep W	
Slickensides			45 N
Fault	N 38 E	Steep W	
Slickensides			60N
Fault	N 30 W	52SW	
Slickensides			39W

5.3 1.2 Drive north about 1.2 mi on N.Y. 208 and turn left at Golf Range sign onto a small road for about 300 feet. Park at the T-intersection and walk 300 feet along dirt road to the left to outcrops on the left side of the road.

STOP 2: GOLF RANGE: SHAWANGUNK CONGLOMERATE

The Shawangunk conglomerate and quartzite (Greenpond conglomerate unit) of Lower to Middle Silurian age occurs in a series of small outcrops extending northeastward along the western edge of Schunemunk Mountain syncline. At this stop the Shawangunk forms a small, relatively inconspicuous topographic knob as contrasted with its occurrence near Stop 5, where the same unit forms the spine of the steep, southeast-facing escarpment of Lazy Hill. At the present stop the Shawangunk consists of about 75% buff pebble conglomerate intercalated with 25% fine-grained green-gray quartzite.

The conglomerate consists of white pebbles of milky vein quartz (averaging 15 - 40mm in length) in a matrix of finer pebbles and grains of rounded quartz, all cemented by secondary silica and buff-orange-red ferric oxides. Occasional pebbles of white orthoclase are present as are black pebbles consisting of green tourmaline and quartz. The color of the weathered surface of the outcrop varies from pink (hematite) to yellow-brown (goethite) or black (manganese oxide dendrites) with some green contributed by lichens.

The pebbles, obviously well-rounded when deposited on the Late Ordovician erosion surface, have taken on a secondary angularity and elongation due to stretching, crowding, rotation, and slippage in the bedding planes produced during Paleozoic orogenies. Most of the pebbles show maximum elongation parallel to the fold axis (b-fabric axis). Many of the pebbles have been corrugated and a large number are cracked and sliced parallel to the b-c fabric plane. Bedding surfaces are slickensided, fluted, and warped parallel to the a-axis (down-dip). The fine-grained, gray-green interbedded quartzite is composed of quartz and minor orthoclase cemented by authigenic quartz, muscovite and chlorite, and Fe-oxides.

The elongation and shattering of the pebbles here at Lazy Hill to the south-west greatly exceeds that observed in pebble beds in Lower and Middle Devonian rocks (Connelly conglomerate of Oriskany age, and Bellvale graywacke, respectively) in this area, suggesting that the Shawangunk was involved in an additional deformation episode of possible pre-Oriskany age.

A pre-Acadian, Silurian deformation period in New York was reported by Megathlin (1939) and discussed by Kay (1942). The sporadic outcrops of Shawangunk quartzite to the north along the western limb of the Schunemunk

Mountain syncline are all heavily silicified and sheared, again much more so than quartzites of Oriskany and Bellvale age.

The conglomerate and quartzite outcrop is S-shaped, with the attitudes of the bedding and a cross-fault as follows:

	STRIKE	DIP
Bedding, Cgl., North end of hill	N 8 E	77E
Bedding, Cgl., North center of hill	N 59 W	70NE
Bedding, Cgl., Center of hill	N 27 W	50NE
Cross-fault	N 77 W	90
Bedding, Qtz., South end of hill	N 2 W	60E

The cross-fault displaces the stratigraphically higher Shawangunk quartzite member to the west, putting it on strike with the lower conglomerate member of the Shawangunk Formation. On first viewing the outcrop, the alternating pebble beds and fine feldspathic quartzites lead one to suspect that the beds are overturned. On close inspection this does not appear to be the case.

5.6	0.3	Return south on N.Y. 208 for 0.3 mi turning right on to Museum Village Road.
6.1	0.5	After 0.5 mi turn right on Old Mansion Road and drive to the far edge of the outcrop.
6.3	0.2	Park near the house on the right.

STOP 3. MUSEUM VILLAGE KLIPPE: ALLOCHTHONOUS PRECAMBRIAN LEUCOGNEISS RESTING ON CAMBRO-ORDOVICIAN WAPPINGER DOLOMITE

From the Old Mansion Road cut in the Precambrian Museum Village klippe, look south across the N 75°W-trending Quickway crossfault. The ridge due south is the Bellvale synclinal extension of Schunemunk Mountain. The next ridge to the west is Lazy Hill, held up by Shawangunk conglomerate, and offset from the Golf Range Shawangunk conglomerate of Stop 2. To the west of Lazy Hill, the next prominent ridge is the Goose Pond Precambrian klippe, formerly continuous with the Museum Village klippe and now offset about 2 miles along the Quickway cross fault.

Museum Village klippe is a thin, synclinal, saucer-shaped slice of gray-white albite-quartz-microperthite leucogneiss that has survived five or six orogenies. The rock of the allochthon were deposited as a clastic wedge (molasse) in a reducing environment, perhaps as long as 1500 million years ago; they were folded and metamorphosed to the sillimanite-almandine-orthoclase metamorphic grade about 1100 million years ago; thrust from the east in Taconic or Late Ordovician time; refolded and faulted in Taconic time; possibly again in Acadian time; refolded and faulted in Appalachian time; and finally shattered by Triassic block faulting and associated block rotation. In outcrop, the leucogneiss is heavily shattered and slickensided with lineations often running in three directions at a given place. Quartz grains and pebbles are stretched into thin corrugated tongues and sheets showing elongations of 15:1 and 20:1 parallel to the b- and a- fabric axes. Over most of the outcrop, biotite and garnet are extensively retrograded to chlorite, and abundant calcite veinlets cross at all angles.

Towards the central and western part of the cut there occur occasional thin layers rich in fresh biotite and uncommonly coarse laths (not needles) of fresh blue-gray sillimanite that have survived the complex orogenic history. As none of the Cambro-Ordovician or younger rocks in the area show any metamorphic grade higher than chlorite zone metamorphism, the sillimanite is assumed Precambrian in age, and its preservation in large fresh grains in an otherwise extensively retrograded outcrop is remarkable.

Modal analyses of samples collected along an east-west traverse across the Museum Village klippe follows:

	Sample Number			
	East Side	Center		West Side
Mineral	36	769-Si	769-N	769-W
Microperthite	49.5%	37.0%	22.5%	68.8%
Albite (An 0-5)	20.2	-	-	3.3
Andesine (An 32)	-	36.0	32.4	-
Quartz	22.2	2.0	35.1	21.5
Chlorite	5.8	-	-	2.5
Biotite	-	8.0	6.0	-
Almandine-pyrope	0.1	2.0	-	-
Graphite	-	3.0	-	-
Sericite	0.7	-	0.3	-
Sillimanite	-	12.0	3.7	-
Tourmaline	-	+	+	-
Calcite	+	-	-	3.4
Apatite	0.7	+	+	+
Zircon	0.1	-	-	+
Ilmenite	0.7	+	+	+
Pyrite	+	+	-	0.5
Sphene	+	-	-	+
	100.0%	100.0%	100.0%	100.0%

The presence of albite in the most retrograded gneisses of this and the other allochthonous Precambrian blocks studied, fairly consistently suggests that it may be a retrograded mineral after an originally more calcic plagioclase. The K-feldspar in all of these rocks is microperthite (usually microcline microperthite) and is indicative of a temperature of Precambrian metamorphism of the order of 600°C. The presence of two plagioclases, one as free grains and the other exsolved in microcline microperthite, is characteristic of many of the granitic gneisses of both the autochthon and the allochthons. In some of the allochthonous leucogneisses, the microperthite and the albite tend to occur in separate bands which may reflect original compositional differences.

Return to the cars and cautiously descend the hill to the left to the Quickway (N.Y. 17-West/U.S. 6). Beware of high speed traffic and stay close to the outcrop which parallels the highway. Walk to the extreme west edge of the roadcut where the Precambrian leucogneiss rests in overthrust contact on the light gray Cambro-Ordovician Wappinger dolomite. Note the occasional flat-lying, slippery fracture planes of the contact.

The metamorphic layering in the allochthon dips to the east whereas the dolomite bedding dips predominantly west.

The average foliation of the leucogneiss is N33°E, 20°SE. The average attitude of the dolomite beds is N22°W, 35°W. Prominent faults in the klippe parallel the metamorphic layering and trend N22°E, 20°SE. The fault contact of the dolomite and the klippe is irregular and has the same general attitude. Both the dolomite and the klippe are cut by vertical faults trending N27°W.

		Drive west along Old Mansion Road observing the flat topography superposed on the Hudson River pelites. These are more gently folded with increasing distance from the Precambrian allochthon.
7.1	0.8	At T-intersection turn right on to Oxford Road (County Route 51).
7.6	0.5	Turn left onto Greycourt Road.
8.5	0.9	Greycourt Road becomes Oxford Road.
9.6	1.1	Bear left to stop sign and turn left onto Greycourt Road.
9.9	0.3	Greycourt Road becomes Leigh Avenue and continues past Hudson River pelites to intersection with NY 17M (stop light).
10.5	0.6	Make hard left turn onto NY 17M east.
11.6	1.1	Pull off N.Y. 17M just west of the ridge of Goose Pond Mountain (Goose Pond west) into parking area on right just beyond entrance to NY 6/17 East.

STOP 4. GREEN POND MOUNTAIN: PRECAMBRIAN ALLOCHTHON OVER OVERTURNED HUDSON RIVER PELITE.

Observe black, fissile Hudson River shales (Middle? Ordovician) in the road cut at the northwest edge of the Precambrian allochthon Careful observation will show that the attitude of the bedding and cleavage is N78°E; the bedding dips 70°S and the cleavage 40°S. This indicates that the outcrop is on the limb of an overturned fold with the synclinal axis north. The shales both here and at Bull Mine Mountain klippe to the north are all wildly folded and overturned close to the overriding Precambrian allochthons.

Many of the Hudson River black shales are calcareous, and consist of fine laminae (0.05 - 0.1mm) of dolomitic silt or mud (marl) intercalated rhythmically (occasionally cross-bedded) with carbonaceous shale. An estimated thin-section mode of a representative Hudson River "shale" follows:

Mineral	Calcareous laminae	Carbonaceous laminae
Detritals and matrix		
dolomite, calcite	30%	5%
quartz	45	25
plagioclase, microcline	10	+
mica, clay, chlorite	15	50
carbonaceous matter, graphite	-	15
pyrite	-	+
Metamorphic:		
chlorite, muscovite, biotite	-	5
	100%	100%

Walk about 100 - 150 feet into the woods southwest of the shale outcrop on N.Y. 17M.

A moss-covered rubble of shale, dolomite, and "limonitized" fault breccia indicate where the covered contact has been crossed. The edge of the Precambrian allochthon of Goose Pond Mountain is found about 130 feet south from the road, and the first rock found in place is a graphitic calcareous quartzite of which sample No. 527 is representative.

12.0 0.4 Return to the cars and drive 0.4 mi east on N.Y. 17M, stopping at a white albite-quartz-microcline microperthite leucogneiss (sample No. 20), in places graphitic, biotitic or rarely, garnetiferous.

Note the extreme elongation and smearing out of quartz pebbles and grains similar to that seen at the Museum Village outcrop of Stop 3. Further to the east, the rocks become increasingly calcareous (sample No. 788). At the extreme eastern edge, prehnitized calc-silicate leucogneiss is interlayered with some amphibolite, the latter of probable basic volcanic origin. Modes of representative rock types of the Goose Pond allochthon follow:

Modes Of Gneisses Of The Goose Pond Mountain Allochthon

	East Side	Center		West Side
Sample No.	529	788	20	527
Mineral				
microperthite	- %	10.0%	42.2%	2.6%
albite (An 0-5)	65.6	-	27.7	-
oligoclase (An 20)	-	49.0	-	-
quartz	16.8	5.0	29.0	81.7
biotite	-	2.5	-	-
chlorite	1.7	-	-	0.3
sericite	7.2	-	0.8	-
graphite	-	-	+	4.2
actinolite	0.2	-	-	3.0
brown hornblende	0.2	33.0	-	-
diopside	1.3	+	-	8.0
sphene	-	-	-	0.2
apatite	+	0.3	0.1	+
ilmenite	-	0.2	0.2	-
prehnite	7.0	-	-	-
zircon	+	+	+	+
	100.0%	100.0%	100.0%	100.0%

Here, as in the Museum Village klippe of Stop 2, the greatest amount of retrograding occurs at the eastern and western margins of the allochthon with some fresh rocks occurring near the center. If the klippen are indeed synclinal saucers the presently exposed centers of the masses would lie at a further distance from the sole of the thrust and would be expected to show less alteration. It should be emphasized that the Precambrian autochthonous gneisses in the southern part of the Monroe quadrangle (Jaffe and Jaffe, 1962) are <u>not</u> comparably retrograded except near Triassic border faults.

13.6	1.6	Continue east on N.Y. 17M about 1.6 mi. and turn right (south) on Bull Mill Road for about 0.2 miles.
13.8	0.2	Turn right at dirt road and park.

STOP 5. LAZY HILL - SHAWANGUNK QUARTZITE

Walk 0.2 miles west crossing buried northeast-trending fault contact between the Shawangunk ridge of Lazy Hill rising steeply ahead and the Bellvale ridge of Durland Hill to the rear. Walk to the north nose of Lazy Hill (permission of the owners, the Durlands, is necessary) where a large outcrop of Shawangunk quartzite is exposed. The rock is a thin-bedded, pink, buff and white orthoquartzite consisting of:

Mode of Shawangunk Orthoquartzite, Durland Property

Quartz	93%
Chert	5
Sericite, Chlorite	2
Zircon	+
Hematite	+
Goethite	+
Pyrite	+
Green tourmaline	+
	100%

The quartz grains are well-rounded, moderately elongated, well-sorted (average diameter, 0.75mm), and the rock is very tightly cemented. Each grain of quartz is cemented to another by authigenic quartz overgrown in optical continuity with the detrital cores. Undulatory extinction due to deformation passes through the core and overgrowth of each grain. The Lazy Hill ridgetop to the south (not visited) is formed of a coarse white pebble conglomerate interbedded with white orthoquartzite (occasionally ripple-marked) and grades eastward to a red arkosic conglomerate below the ridge-top. Quartz pebbles and orthoclase pebbles are strongly elongated (3:1 and 4:1) and heavily shattered and veined in both the red arkosic and the white conglomerate.

14.0	0.2	Return to N.Y. 17M and turn right (south).
15.9	1.9	Drive south to the Monroe Bowl-O-Fun parking lot.

STOP 6. MONROE BOWL-O-FUN: CONNELLY (ORISKANY) - ESOPUS CONTACT)

The outcrop at Monroe Bowl-O-Fun originally was described by Jaffe and Jaffe, (1967) to consist of about 300 feet of the Esopus Formation underlain at the rear of the cut by red and white pebble conglomerate, the Connelly Conglomerate of Oriskany age. Most of the exposure has been covered by a railroad tie retaining wall. Here, a small outcrop of the Connelly is still exposed to the far right near the gasoline service station, and was described by Jaffe and Jaffe (1967) to consist weathered yellow, "limonitic" conglomerate (3 ft or more), succeeded by white to buff, pebble-bearing orthoquartzite (5 ft), which is in turn overlain by bright red hematitic quartzite (10 ft). The pebbles in the Connelly conglomerate are of white, round to slightly elongated quartz, averaging 1-2 mm in maximum dimension. The Connelly is disconformably overlain by a lowermost member of the Esopus Formation, recognized by Southard (1960). A small exposure of the Esopus

Formation is exposed at the far left of the retaining wall. The attitude of both the Connelly and the Esopus at their contact was described to be N68°E, 45°N. A heavily slickensided fault surface, trending N53°, 60°SE cuts across the Connelly beds and presumably also cuts the overlying Esopus Formation.

The lowermost member of the Esopus, at its base, consists of fissile, blue-gray siltstones which weather to brown and orange on cleavage surfaces. Many of the rocks are marked with *Taonurus cauda-galli* on bedding planes. At this outcrop the authors have collected a remarkable fauna including a specimen of the giant trilobite, *Coronura myrmecophorus*, not previously reported from the Esopus Formation. According to D.W. Fisher, New York State paleontologist who identified the specimen, it has previously been reported from the Schoharie and Onondaga Formations. The specimen was donated to the N.Y. State Museum collection.

The lowermost member is also relatively rich in conulariids, none of which have yet been identified. Other fauna include the brachiopods: *Leptocaelia flabellites*, *Schuchertella* sp., *Acrospirifer macrothyris* as well as some chonetid and orbiculoid genera. Platystomid and loxonemid gastropods, rugose corals and a dalmanitid trilobite were also collected by the authors.

The lowermost member grades into the black, poorly fossiliferous Lower Mudstone member which in turn grades into a purple sandstone at the north end of the 350 foot exposure. The sandstone is presumably the lower part of the Highland Mills member of the Esopus Formation. The fauna of the lowermost member at the Bowl-O-Fun appears to differ significantly from that of the Highland Mills member of the Esopus Formation found at Bakertown and Highland Mills (described by Boucot, 1959). The fauna should receive some serious study by specialists before the outcrop is demolished by new construction.

16.6	0.7	Drive south on N.Y. 17M to the second traffic light and turn onto Stage Road.
17.4	0.8	Bear right at stop sign on to the Orange Turnpike
18.0	0.6	Park on the side of the road opposite development.

STOP 7. ORANGE TURNPIKE: POUGHQUAG QUARTZITE (LOWER CAMBRIAN)

Walk 0.16 miles due west over hilltop to the edge of a cliff formed by a 10 foot section of the Poughquag Formation (Lower Cambrian). The section consists of alternating 2 inch to 2 foot thick beds of ferruginous orthoquartzite, conglomerate, and arkose, striking N75°W and dipping 8°N, overlying the vertically dipping Precambrian autochthon with marked angular unconformity. This represents original sedimentary onlap with gentle warping or folding in subsequent geologic time.

Apparently the Precambrian Monroe Massif (Block 2) was sufficiently rigid throughout the Paleozoic to prevent the deformation of the overlapping embayment of Poughquag quartzite and Wappinger dolomite. This is indicated by both the gentle warping observed and also by the relative sphericity of the quartz pebbles in various Poughquag beds.

Several of the beds are feldspathic, a feature uncommon in the Poughquag of the Poughkeepsie Quadrangle (Gordon, 1911). One such bed at the Monroe outcrop is a conglomeratic arkose which is a true high rank arkose in the sense of Krynine (1948). A remarkable textural feature of this rock is the abundance of authigenic feldspar (microcline?) which is the principal cementing medium in sample No. 466. The specimen consists of 1-2m quartz and microcline pebbles (all very round) lying in a matrix of authigenic microcline (?) cement which is clear in appearance. Some sawtooth or hacksaw terminations on the detrital microcline cores (Edelman and Doeglas, 1931) indicate that interstratal solution has taken place after deposition, presumable in situ. The authigenic feldspar overgrowths show only weak twinning when grown around detrital cores showing strongly developed microcline twinning. A mode of such rock is as follows:

Mode Of Lower Cambrian Poughquag Conglomerate Arkose
Specimen No. 466

Microcline	47.4%
Microcline microperthite	+
Quartz	48.6
Albite-oligoclase	+
Muscovite	+
Rutile, Anatase, Tourmaline (green + brown)	0.5
Zircon	0.5
Hematite } Mn oxides }	3.0
	100.0%

The mineralogical composition of the Poughquag at Monroe leaves little doubt that it was derived from erosion of the granitic gneisses it overlies.

On the return walk to the road, stops may be made at exposures of post-Wappinger lamprophyre dikes which the authors believe to be of late Ordovician age (Jaffe and Jaffe, 1962). The authors have studied the dikes in considerable detail and would suggest a possible age of intrusion similar to that of the ultramafic intrusion of the Cortland Complex at Stony Point, New York (Ratcliffe, 1967). The Cortland Complex has been dated by Long and Kulp (1962) at 435 million years by K/A isotopic ratios obtained on biotite from the complex, a date close to the accepted Ordovician-Silurian boundary. An age of 398±17 m.y. was obtained from Ar^{40}/K^{40} ratios on the amphibole (kaersutite) phenocrysts in one of these dikes (Jaffe and Jaffe, 1973). This age may be a bit low because of argon loss during a regional Paleozoic reheating. These ages were run some years before development of more refined Ar^{40}/Ar^{39} methods now in use.

Thus, lamprophyre dikes of deep-seated (mantle-derived?) origin are not restricted to Mesozoic and Tertiary ages. They may range from Precambrian to Recent (Zartman, et al., 1967).

Stops 8, 9, 10, 11, and 12 (Fig. 3) are located in the granulite facies gneisses of the authochthonous block, here called the Monroe crystalline massif of Precambrian (Proterozoic) age. For reemphasis, we note that the gneisses of the authochthon do not show the pervasive retrograde alteration and extensive mineral stretching that characterize the rocks of the allochthon.

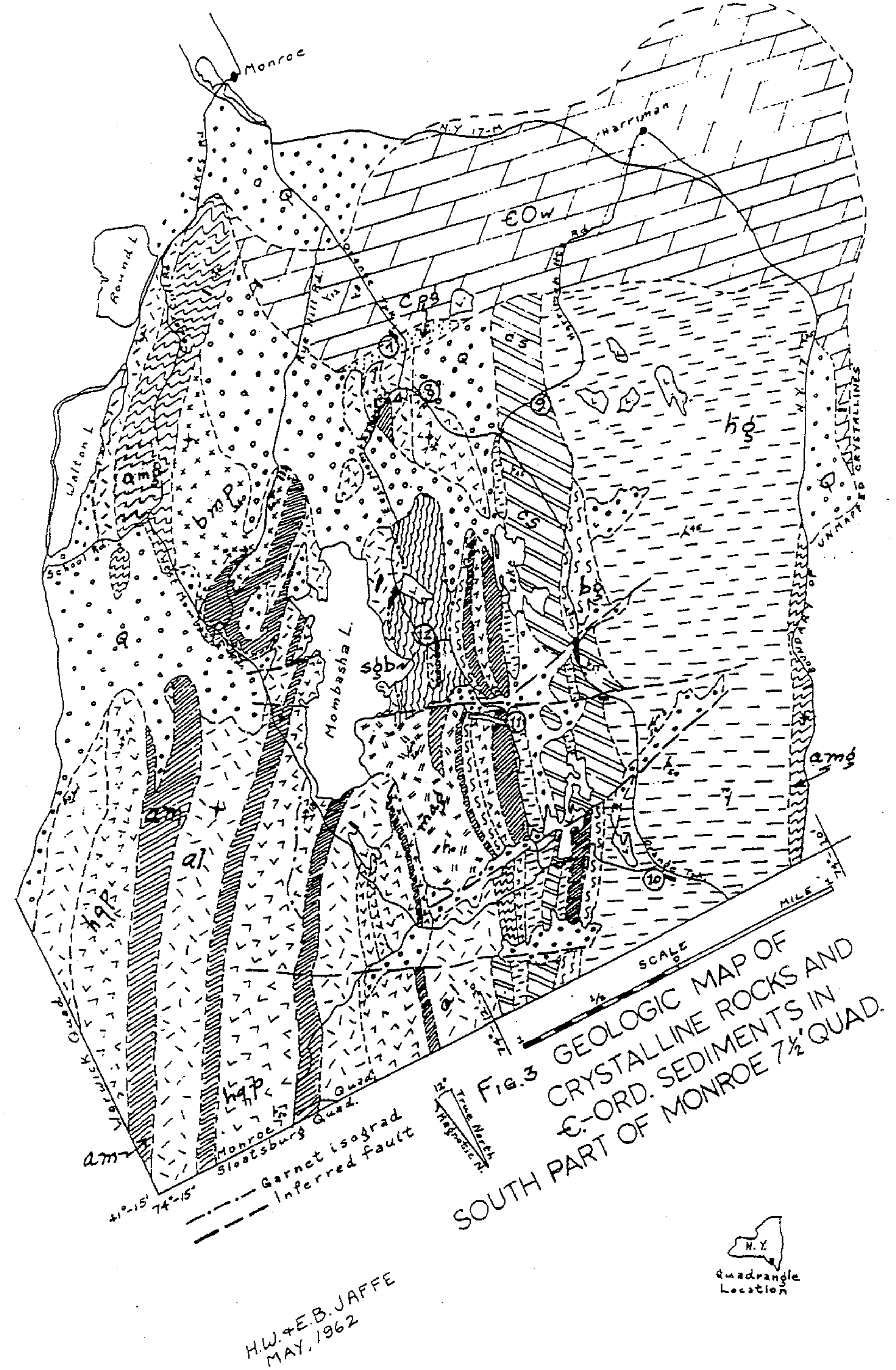

FIG. 3 GEOLOGIC MAP OF CRYSTALLINE ROCKS AND Є-ORD. SEDIMENTS IN SOUTH PART OF MONROE 7½' QUAD.

Quaternary		Q	alluvial and glacial cover
Paleozoic	Cambrian - Ordovician	(dike symbol)	dikes of lamprophyre, leucophyre, diabase.
		€Ow	Wappinger Group, dolostone, minor shale
	Cambrian	€pg	Poughquag Formation : quartzite, arkose, conglomerate

Gneisses of Monroe and Ramapo Blocks

Proterozoic	hg	hornblende (ferrohastingsite) granite gneiss, and pegmatite
	am	amphibolite, pyribolite
	amg	interlayered amphibolite and granodiorite
	cs	calc - silicate gneiss
	hqp	biotite - hypersthene - quartz - plagioclase gneiss
	sgb	sillimanite - cordierite - almandine - biotite - quartz - feldspar gneiss
	bg	biotite gneiss
	bmp	biotite - mesoperthite - gneiss and albite - oligoclase - leucogranite
	hk	biotite - hypersthene - K- feldspar - quartz - plagioclase gneiss
	mag	magnetite - garnet - andesine gneiss
	al	microcline alaskite (leucogranite); contacts with all other Proterozoic units may be intrusive

The prevalence of hypersthene and total absence of muscovite from folded gneisses of the Monroe crystalline massif verify that regional metamorphism took place in the granulite facies. The omnipresent coexistence of hypersthene with augite in mafic rocks; hypersthene-K-feldspar association in granitic gneisses (charnockite); sillimanite-K-feldspar assemblages in pelitic gneisses; Fe-rich cordierite-sillimanite-K-feldspar-almandine-tourmaline assemblages, also in pelitic gneisses; and copious exsolution of pigeonite in host hypersthene collectively indicate that metamorphism occurred at T = 700 - 800°C, at P = 2 - 4 kbars (7-14 km depth) (Jaffe and Jaffe, 1973).

18.4	0.4	Drive southeast on the Orange Turnpike, stopping at the road cut on the west side of the road.

STOP 8. ORANGE TURNPIKE: QUARTZ-OLIGOCLASE GNEISS

Leaving Stop 7, the Orange Turnpike turns southwest and crosses the concealed unconformable Cambrian-Precambrian contact. The quasi-horizontal Poughquag and Wappinger beds overlie vertically dipping Precambrian gneisses, permitting the delineation of a major unconformity, unfortunately not exposed in the area. Beyond the Lipalian interval, the first rock encountered is a fine-grained pink alaskite composed mainly of 1-3 mm microcline-microperthite and quartz, minor sericitized albite-oligoclase and an occasional flake of biotite. Within 100 ft to the south, the pink alaskite grades through a narrow zone of coarse biotite-microperthite-oligoclase granite and granodiorite into a medium-grained (2 mm), gray, essentially massive hypersthene quartz diorite gneiss which forms the bulk of the outcrop. It is variously called quartz oligoclase gneiss or enderbite by other workers. It contains: oligoclase 70%, quartz about 25% and hypersthene, biotite, magnetite and chlorite about 5%. In thin section, quartz is not uniformly distributed but rather forms long tongues which embay adjoining oligoclase grains; these are well-twinned and antiperthitic. On top of the outcrop, observe several lenses of biotite-hornblende-hypersthene-labradorite (An55) pyribolite infolded in the quartz diorite gneiss. Foliation measured on the pyribolite is N35° to 50°E, with a dip close to 90°. Slickensided joint faces strike N24° to 65°W.

About 0.3 mi south (not a scheduled stop) the quartz diorite gneiss darkens in color, the quartz content drops markedly, and the rock grades to an augite diorite gneiss interlayered with hornblende-hypersthene-andesine pyribolite. Where quartz becomes locally abundant, it embays and replaces both plagioclase and the ferromagnesian minerals.

Hypersthene-quartz-oligoclase gneiss (quartz diorite gneiss) is thus formed from the metamorphic reconstitution of pyribolite accompanied by the introduction of silica and small amounts of potash. These constituents could logically be derived from anatectic granitic liquids derived from the fractional melting of sedimentary precursors.

18.9	0.5	Continue south on the Orange Turnpike and take the first left turn onto Harriman Heights Road.
19.3	0.4	Outcrop is on south side of road. Park on north side of road at entrance to Our Lady's Rosary Garden Gift Shop.

STOP 9. HARRIMAN HEIGHTS ROAD: CALC-SILICATE MIGMATITE

A fresh roadcut exposes a dark gray, green, and pink banded migmatite. The gray rock is a calc-silicate paragneiss composed of quartz, microcline, bytownite (An80), augite, green epidote (pistacite), dark brown sphene (titanite), zircon, apatite, and magnetite. The pink bands consist mainly of quartz and microcline or microcline microperthite. Other samples of this migmatite contain almost pure anorthite (An95). Epidote, common throughout the region in calc-silicate units, evidently formed by retrograde metamorphic alteration or exchange of Ca, Al, Si, and Fe in anorthite+augite, in a wet oxygenated environment.

22.4	3.1	Return the 0.4 mi to Orange Turnpike and continue south to the junction with Bramertown Road entering from the west. Park and walk 0.1 mi. south on Orange Turnpike to the outcrop.

STOP 10: ORANGE TURNPIKE: CAMPTONITE DIKE CUTTING HORNBLENDE GRANITE GNEISS

The outcrop on the west side of the road shows a 20-25 ft dike of lamprophyre called camptonite forming the low pavement of the outcrop. It strikes N38°W and dips 86°NE. The dike contains green hornblende phenocrysts up to 1/4 in lying in a matrix of albite laths, 0.2 x 0.4 mm, which, in turn enclose granular epidote. In these rocks, it appears that deuteric alteration of an initially more calcic (intermediate) plagioclase has resulted in the growth of albite+epidote. The camptonite contains: albite - 53.3%, hornblende - 21.5%, epidote - 12.6%, chlorite - 7.3%, and apatite+opaque+calcite+quartz+k-feldspar - 5.3%.

The country rock intruded by the dike is the hornblende granite gneiss that makes up about one-quarter of the volume of the Monroe crystalline massif and is also widespread in the other areas that constitute the Hudson Highlands. In the Monroe block, these granitic gneisses are uncommonly iron-rich and the hornblendes are ferrohastingsites with 100Fe/(Fe+Mg) = 86 that coexist with Ti- and Fe-rich biotites in which 100Fe/(Fe+Mg) = 90, ratios found in minerals at this outcrop. Here, the granite gneiss contains occasional schlieren of very biotite-rich rock.

23.2	0.8	Turn west onto Bramertown Road, and then turn right, north, on first paved road (East Mombasha Road). The road follows the contact of granite gneiss (east) and pyribolite (west).
24.1	0.9	Outcrop is on the west side of the road at a sharp bend to the west.

STOP 11. EAST MOMBASHA ROAD: LEUCOPHYRE DIKE INTRUDING AMPHIBOLITE

Stop 11 shows a 16 ft thick granodiorite leucophyre dike which strikes N48°W, cross-cutting the foliation of the surrounding amphibolite which strikes 57°E and dips 20°S. Note the large wedge of amphibolite in the center of the dike and the occasional pink K-feldspar-quartz bands in the amphibolite. This dike is unique in the Monroe quadrangle, and perhaps in the Highlands. It shows sparse pink phenocrysts of oligoclase, quartz, less microcline and biotite lying in a dark gray matrix, which is again porphyritic on a microscopic scale. The second generation of microphenocrysts is made up of square to rhombic zoned potash feldspar and laths of albite-oligoclase. These lie in a very fine granophyric groundmass made up of feldspar, quartz, mica, chlorite, "limonite" and manganese oxide. The extremely fine-grained oxides form megascopic crenulated black streaks which give the dike a distinct flow layering in parts of the outcrop. A mode was not obtained because of the fine nature of the matrix. X-ray data on a powdered sample indicate that oligoclase>quartz>microcline, hence the dike is of granodioritic composition. East of the road, the dike is not found, and may be cut off by a north-south fault; if so, the dike is very old. An outcrop of the same rock was found 0.25 mi to the west cutting migmatite; it may be an extension of the same dike.

25.1	1.0	Continue north on East Mombasha Road stopping at a dark, mica-rich gneiss just north of Stop Number 12 on the map (Fig. 3).

STOP 12. EAST MOMBASHA ROAD: PELITIC PARAGNEISS

This is a tightly folded, crenulated pelitic paragneiss in the sillimanite-K-feldspar zone of metamorphism. The outcrop consists of thin bands of gray biotite-microcline-labradorite-quartz gneiss intercalated with bands rich in orthoclase cryptoperthite (anorthoclase) and quartz. Abundant garnet (almandine-pyrope), Fe-rich cordierite, dark blue-green tourmaline and prismatic sillimanite are developed along the interfaces of the biotitic and alaskitic layers. Biotite is, under the microscope, intensely pleochroic from "paprika-red" to almost colorless and is undoubtedly rich in Ti as well as Fe. Sillimanite and tourmaline lie in the foliation planes with their long axes parallel to the fold axes. Cordierite, not recognized when the 1962 NYSGA Guidebook was written, is abundant in parts of the outcrop and can be recognized in some places by its characteristic blue or purplish blue color imparted to hand specimens. Under the microscope, it shows both polysynthetic twinning and sector-zoning or twinning; alteration to fibrous pinite plus the twinning make it difficult to identify and it may be mistaken for altered plagioclase; characteristic yellow, bulls-eye halos are virtually absent. Thin sections cut across foliation planes show numerous square cross-sections of sillimanite needles enclosed in cordierite. The relatively Fe-rich nature of this cordierite, $100Fe/(Fe+Mg) = 25$ is useful in limiting the pressure at which the high-temperature regional metamorphism occurred; it is 2-4 kbars with water vapor present but not necessarily saturating the pore spaces. This, plus the hypersthene and sillimanite-K-feldspar parageneses fix the parameters of regional metamorphism in this part of the Hudson Highlands at $T = 700 - 800^{\circ}C$ and $P = 2 - 4$ kbars.

26.4	1.3	Continue north on East Mombasha Road. Turn left onto the Orange Turnpike.
27.2	0.8	Orange Turnpike becomes Still Road.
28.0	0.8	Continue to traffic light at NY 17M. Continuing north past intersection Still Road becomes Freeland Street.
28.6	0.6	Freeland Street becomes County Route 105.
29.0	0.4	Turn right at intersection with Dunderburg Road.
30.9	1.9	Intersection of NY 6, 17, and 32. End of trip.

NOTES