GARNET-PYROXENE GNEISSES AT
BEAR MOUNTAIN, NEW YORK

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Abstract

Iron-rich garnet-pyroxene gneisses occur as layers in hornblende granulite subfacies metasediments at Bear Mountain, New York. Although these gneisses bear a superficial resemblance to both eclogites and skarns, their chemical compositions suggest that they are metamorphosed ferruginous sediments of the chert-carbonate type. Such rocks have not been noted before in the Highlands metamorphic belt.

Introduction

The gneisses described in this paper occur as concordant layers in a sequence of graphitic, iron sulfide-bearing, biotite-quartz-feldspar gneisses in the Precambrian Highlands metamorphic complex at Bear Mountain, New York (Figs. 1, 2). The Bear Mountain sequence also contains small amounts of marble, amphibolite, and skarn. It is thought to represent the hornblende granulite subfacies of regional metamorphism (Dodd, 1962).

The garnet-pyroxene gneisses at Bear Mountain were first described by Lowe, who called them eclogites (Lowe, 1950, p. 142) but did not discuss their mode of origin. Field and petrographic studies by the writer, supplemented by chemical analyses of the garnets and pyroxenes of the gneisses, suggest that the rocks are metamorphosed ferruginous sediments, probably similar to the chert-carbonate rocks of the Lake Superior iron formations (James, 1954). Such metasediments have not been found elsewhere in the Hudson and New Jersey Highlands. They are of interest for this reason and because they permit an assessment of the chemical environment in which the Bear Mountain sediments were deposited.

Field Relations

The principal layer of garnet-pyroxene gneiss is sixteen feet thick. It consists of nine feet of a garnet-quartz-orthopyroxene rock (called hereafter "garnet-orthopyroxene gneiss") overlain, with no apparent gradation, by seven feet of a garnet-magnetite-clinopyroxene gneiss (called hereafter "garnet-clinopyroxene gneiss"). Several thinner layers of the latter rock type occur in the overlying biotite-quartz-feldspar gneisses, through a stratigraphic interval of about eighty feet. The garnet-pyroxene gneisses are exposed for about one-half mile along strike.

Descriptions of the Garnet-Pyroxene Gneisses

Garnet-orthopyroxene gneiss. Garnet-orthopyroxene gneiss is dark green beneath strongly limonitized outcrop surfaces. It consists of an inter-
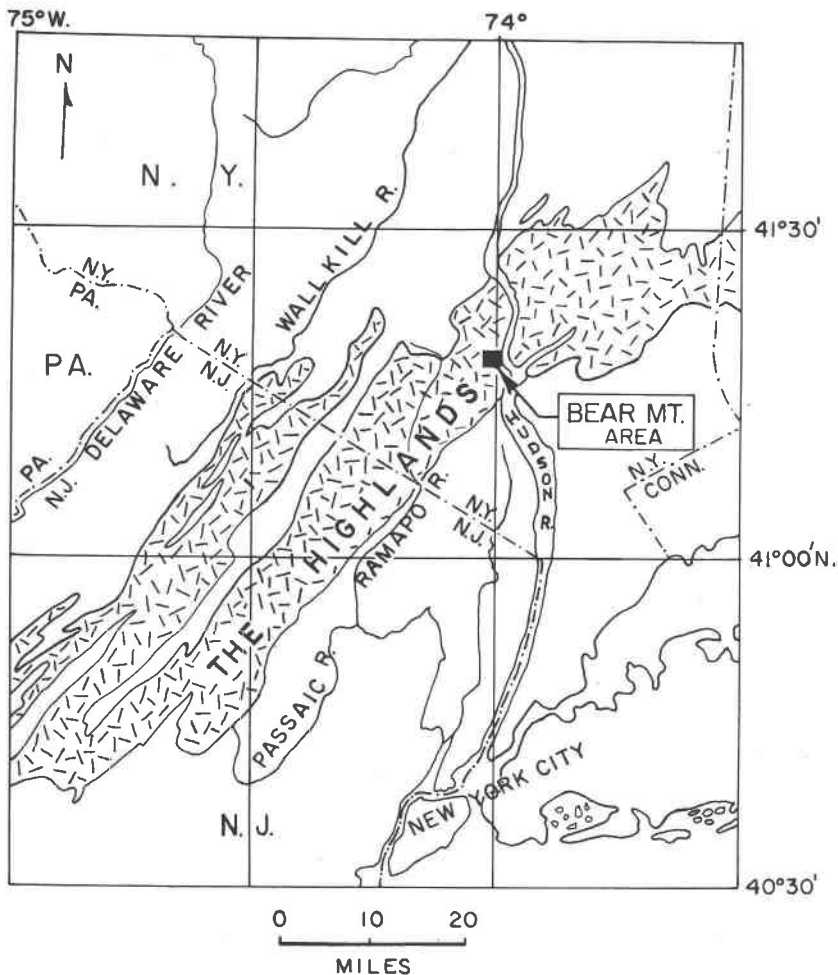
FIG. 1. Index map of the Hudson and New Jersey Highlands.

growth of coarse orthopyroxene crystals (some more than five cm across), within which tiny grains (0.1–0.5 mm in diameter) of dark red garnet and gray quartz are distributed in layers 6 to 12 mm thick. Coarse scales of graphite commonly occupy grain boundaries and cleavages. In addition to the garnet- and quartz-rich layers, the gneiss contains scattered layers of greenish-gray quartzite, which, like the other layers, parallel the foliation of the surrounding gneisses.

The microscopic texture of garnet-orthopyroxene gneiss is shown in Fig. 3. The rock consists chiefly of eulite (En_{17}), garnet (Alm_{55} Sp_{23}
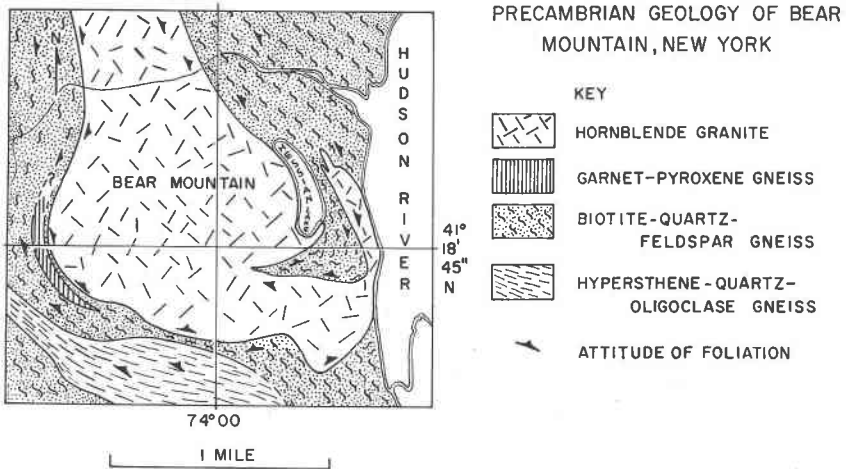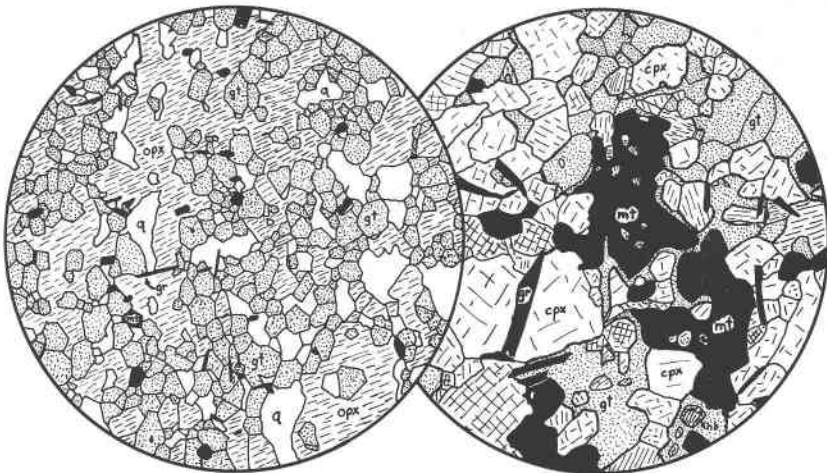
FIG. 2. Precambrian geology of Bear Mountain, New York.

Garnet-Orthopyroxene Gneiss
(No.1167; field = 12 mm.)

Garnet-Clinopyroxene Gneiss
(No.1325; field = 9 mm.)

FIG. 3. Garnet-pyroxene gneisses from Bear Mountain, New York. Drawings were traced from photographs. Literal symbols stand for garnet (gt), quartz (q), orthopyroxene (opx), clinopyroxene (cpx), graphite (gr), and magnetite (mt). A single orthopyroxene crystal fills the field in No. 1167. Note the contrasting habits of garnets in the two rock types.

And$_{13}$ Gr$_5$ Pyr$_4$), and quartz. The proportions of these minerals vary widely, but orthopyroxene (locally with minor clinopyroxene) always makes up more than half of the specimen. Graphite and apatite are present in amounts of about 1%. Minor accessories include biotite, calcite, sphene and magnetite. The last of these occurs both as separate grains and as inclusions in garnet.

The eulite displays complex and puzzling exsolution textures. It contains lamellae and irregular masses of augite, the former parallel to (100). The augite in turn contains sparse, fine lamellae parallel to its (001) plane. These lamellae, of the order of 0.00x mm thick, cannot be identified optically or by x-ray diffraction, but their orientation suggests that they are either pigeonite or orthopyroxene after pigeonite (Poldervaart and Hess, 1951, p. 483). The presence of pigeonite suggests temperatures of exsolution in excess of 900° C. (Bowen and Schairer, 1935). At such temperatures, the surrounding gneisses should have been extensively melted. As field evidence indicates little fusion of the gneisses, there is an evident and unexplained discrepancy between field data and theory.

Chemical and optical data for the eulite and garnet from a sample of garnet-orthopyroxene gneiss are presented in Tables 1 and 3. A modal analysis of the analyzed material is given in Table 4.

TABLE 1. CHEMICAL ANALYSIS AND NORM OF EULITE FROM
GARNET-ORTHOPYROXENE GNEISS (Sample No. 1167/2)

Location: Perkins Memorial Drive, abandoned section, a few hundred feet west of intersection with present Drive, Bear Mountain, Popolopen Lake Quadrangle, New York.

Analysis		Atomic ratios		Fe^{3+}	$2 Fe^{3+}$ Ti	Fe^{3+} Fe^{3+}	Z Y	Cations to Six O	
	Wt. %			Na			W		
SiO$_2$	46.80	Si	780				Z		*Optical data:*
Al$_2$O$_3$	0.01	Al	0				793$\frac{1}{4}$	2.01	$\gamma-\alpha=0.018$
					3	10$\frac{1}{4}$			$\gamma=1.764$
Fe$_2$O$_3$	2.00	Fe^{3+}	25						N$_y$ $\beta=1.757$
				1$\frac{1}{2}$		10$\frac{1}{4}$	WXY		$\alpha=1.746$
FeO	39.63	Fe^{2+}	552						$2V_\alpha=81.2°$
							777$\frac{1}{4}$	1.97	
MgO	5.18	Mg	128$\frac{1}{4}$						Pale green; negligible
CaO	1.31	Ca	23$\frac{1}{4}$						pleochroism
Na$_2$O	0.07	Na	1	1					*Remarks:*
K$_2$O	0.03	K	$\frac{1}{2}$	$\frac{1}{2}$					1. The norm was pre-
H$_2$O$^+$	0.35	Ti	1$\frac{1}{2}$		1$\frac{1}{2}$				pared as outlined
H$_2$O$^-$	0.18	Mn	58$\frac{1}{2}$						by Hess (1949).
TiO$_2$	0.12	O	2364$\frac{1}{4}$						2. Most of the CaO
P$_2$O$_5$	0.24								is thought to re-
MnO	4.15	Analyst: M. Chiba			Ca$_{3.0}$ Mg$_{16.3}$ Fe$_{80.7}$				side in ferroaugite
CO$_2$	—				% Al in Z = 0				lamellae.

TABLE 2. CHEMICAL ANALYSIS AND NORM OF FERROAUGITE FROM
GARNET-CLINOPYROXENE GNEISS (Sample No. 1325)

Location: southwest side of Bear Mountain, Popolopen Lake Quadrangle, New York.

Analysis		Atomic ratios		2 Al / Fe²⁺ / Na	Al / Ti	Z / Fe³⁺	Z / Y / W	Cations to Six O	
	Wt. %								
SiO₂	47.86	Si	798				Z 836	2.01	*Optical data:*
					2	36			$\gamma - \alpha = 0.026$
Al₂O₃	1.94	Al	38						$\gamma = 1.730$
Fe₂O₃	3.31	Fe³⁺	42	5½		36			$2V_\gamma = 58.0°$
FeO	18.24	Fe²⁺	254				WXY 827½	1.99	$Z \wedge c \approx 42°$
MgO	4.99	Mg	124						Pleochroism:
CaO	21.92	Ca	391						X = very pale green
Na₂O	0.15	Na	5	5					Y = Z = medium
K₂O	0.03	K	½	½					green
H₂O⁺	0.30	Ti	1		1				Remarks:
H₂O⁻	0.20	Mn	10½						1. The norm was pre-
TiO₂	0.07	O	2500¼						pared as outlined
P₂O₅	0.19								by Hess (1949).
MnO	0.76	Analyst: M. Chiba			Ca₄₇.₆Mg₁₅.₁Fe₃₇.₃				2. Contains lamellae
CO₂	—				% Al in Z = 4.5				of (?) pigeonite or
									orthopyroxene.

Garnet-clinopyroxene gneiss. Garnet-clinopyroxene gneiss forms granular, vuggy, badly weathered outcrops. Fresh rock is dark green, medium-grained, and indistinctly layered. It consists principally of clinopyroxene, with subordinate but variable amounts of dark red garnet and magnetite and minor graphite. Calcite can be seen in some exposures.

The microscopic texture of the gneiss can be seen in Fig. 3. The principal minerals are ferroaugite ($Fe_{37} Mg_{15} Ca_{48}$), garnet ($Alm_{45} Gr_{31} And_{12} Sp_9 Pyr_4$), and magnetite (with very minor exsolved ilmenite). Accessory minerals include graphite, apatite, zircon, and hornblende, the last occurring as tiny euhedra in magnetite and, less commonly, intergrown with ferroaugite. Calcite was not seen in thin section.

The ferroaugite contains exsolution lamellae, about 0.025 mm thick, which, on the basis of their orientation, are thought to be either pigeonite or orthopyroxene after pigeonite (see discussion in the previous section).

Chemical and optical data for the pyroxene and garnet from a sample of garnet-clinopyroxene gneiss are presented in Tables 2 and 3. A modal analysis of the analyzed sample is given in Table 4.

APPROXIMATE ROCK COMPOSITIONS

Analyses of garnets and pyroxenes from samples of garnet-orthopyroxene gneiss (No. 1167/2) and garnet-clinopyroxene gneiss (No. 1325) were used, with modal analyses, to calculate approximate total rock com-

TABLE 3. ANALYSES, OPTICAL AND X-RAY DATA FOR GARNETS FROM GARNET-
ORTHOPYROXENE GNEISS (1167/2) AND GARNET-CLINOPYROXENE GNEISS (1325)
Analyst: M. Chiba

Oxide		Sample Number	
		1167/2	1325
SiO_2		36.87	37.86
Al_2O_3		19.12	18.91
Fe_2O_3		3.95	3.78
FeO		23.01	19.27
MgO		0.89	1.01
CaO		6.28	14.61
Na_2O		0.13	0.08
K_2O		0.03	0.05
H_2O^+		0.16	0.26
H_2O^-		0.20	0.20
TiO_2		tr.	0.13
P_2O_5		0.42	0.34
MnO		9.47	4.09
CO_2		—	—
Total		100.53	100.59
Molecules:	Andradite	13.02	12.06
	Pyrope	3.64	4.02
	Spessartite	22.92	8.54
	Almandite	55.21	44.72
	Grossularite	5.21	30.65
Cell edge (*a*)		11.614 Å	11.691 Å
Refractive index (±0.001)		1.799	1.799

positions. The modes and rock compositions are given in Table 4. In
view of the layered character of the gneisses, especially No. 1167/2, these
calculated analyses are very imprecise, but they will suffice for a com-
parison of the present rocks with other gneisses and possible parent rocks.

SIMILAR GNEISSES ELSEWHERE

The garnet-pyroxene gneisses of Bear Mountain superficially resemble
eclogites (Lowe, 1950, p. 142) and skarns. However, they lack the om-
phacitic pyroxenes and pyrope-rich garnets which are characteristic of
eclogites, and they lack the andraditic garnet typical of skarns (Table 5).
In addition, garnet-orthopyroxene gneiss is too poor in lime to have had a
calcareous parent.

In mineralogy and chemistry the Bear Mountain gneisses resemble

TABLE 4. MODAL ANALYSES AND CALCULATED CHEMICAL ANALYSES OF GARNET-ORTHOPYROXENE GNEISS (1167/2) AND GARNET-CLINOPYROXENE GNEISS

In calculating analyses, oxides were assumed to be pure magnetite, hornblendes pure hastingsite.

Modes			Calculated Analyses		
Mineral	1167/2	1325	Oxide (Wt. %)	1167/2	1325
Orthopyroxene	52.7	—	SiO_2	55	37
Clinopyroxene	1.9	72.4	TiO_2	tr	tr
Garnet	17.0	13.3	Al_2O_3	4	4
Quartz	25.7	—	Fe_2O_3	3	15
Hornblende	0.2	0.2	FeO	27	20
Oxides	0.7	12.6	MnO	4	1
Apatite	0.7	0.2	MgO	3	3
Graphite	1.1	1.3	CaO	2	17
Total	100.0	100.0	Na_2O	tr	tr
Points Counted	1000	2200	K_2O	tr	tr
			H_2O^+	tr	tr
			H_2O^-	tr	tr
			P_2O_5	1	tr
			C	1	1

ferruginous gneisses described by Tilley from Ross-shire, Scotland (1936) and by Kranck from Labrador (1961). They are chemically similar to some contact metamorphic rocks from the eastern Mesabi Range, but represent a higher metamorphic grade. They differ from the eulysites (see summary by Tilley, 1936) in lacking manganiferous fayalite.

The calculated analyses of the Bear Mountain garnet-pyroxene gneisses

TABLE 5. GARNETS FROM GARNET-ORTHOPYROXENE GNEISS (1167/2) AND GARNET-CLINOPYROXENE GNEISS (1325), COMPARED WITH AVERAGES OF GARNET ANALYSES FROM SEVERAL ROCK TYPES (TRÖGER, 1959)

Molecule	1167/2	1325	A	B	C
Pyrope	3.64	4.02	3 ± 1	$43\frac{1}{2} \pm 7$	$1\frac{1}{2} \pm 2$
Almandine	55.21	44.72	$64\frac{1}{2} \pm 11$	38 ± 7	3 ± 3
Spessartite	22.92	8.54	$16\frac{1}{2} \pm 14$	1 ± 1	1 ± 1
Grossularite	5.21	30.65	11 ± 8	14 ± 6	12 ± 13
Andradite	13.02	12.06	5 ± 4	$3\frac{1}{2} \pm 4$	82 ± 15

A—Average of three garnets from eulysites
B—Average of fourteen garnets from eclogites
C—Average of fifty-five garnets from skarns

TABLE 6. COMPOSITIONS OF GARNET-PYROXENE GNEISSES COMPARED WITH
THOSE OF EULYSITES AND GNEISSES RELATED TO EULYSITES

	Garnet-Pyrox-ene Gneisses		Eulysites				Related Rocks		
	1167/2	1325	A	B	C	D	E	F	G
SiO_2	55	37	32.85	38.12	37.06	39.89	34.80	37.00	51.89
TiO_2	tr	tr	0.20	0.03	0.16	0.05	0.20	0.18	—
Al_2O_3	4	4	3.02	2.01	0.80	2.04	3.82	2.82	7.21
Fe_2O_3	3	15	9.88	1.10	3.01	0.40	18.60	20.61	2.36
FeO	27	20	30.45	24.00	46.36	42.17	19.70	19.44	18.68
MnO	4	1	12.55	20.29	5.01	6.88	7.50	5.93	7.08
MgO	3	3	5.84	5.80	4.37	4.50	4.34	8.79	9.18
CaO	2	17	3.94	7.87	2.47	3.35	10.02	2.55	0.93
Na_2O	tr	tr	tr	0.11	0.37	0.00	tr	tr	0.31
K_2O	tr	tr	tr	0.16	0.30	0.00	tr	tr	0.81
H_2O^+	tr	tr	nil	0.18	0.20	0.00	0.25	1.20	$\Big\{$ 1.33
H_2O^-	tr	tr	0.30	—	—	0.00	0.15	0.30	
P_2O_5	1	tr	0.78	0.44	0.38	0.25	0.09	1.27	—
C	1	1	n.m.	n.m.	n.m.	n.m.	n.m.	n.m.	n.m.
etc.	—	—	—	0.10	0.08	0.09	0.13	—	0.54
Total	—	—	99.81	100.21	100.57	99.62	99.60	100.09	100.32
Total Fe	23	26	30.60	19.44	38.21	33.07	27.44	29.67	16.27
Total Fe+Mn	26	27	40.31	35.14	42.09	38.40	34.24	34.26	21.75

A—Eulysite, Druideig Lodge, Loch Duich, Ross-shire, Scotland. The rock consists of fayalite, hedenbergite, iron-rich hypersthene, magnetite, garnet, and apatite, in order of decreasing abundance. (Tilley, 1936, pp. 333, 335)

B—Eulysite, Stora Utterwicks Hage, Tunaberg, Sweden. (Palmgren, 1916, p. 196)

C—Eulysite, Mansjö Mt., Loos, Sweden. (von Eckermann, 1922, p. 254)

D—Eulysite, Loberget Hill, Loos-Hamra region, Sweden. (von Eckermann, 1936, p. 166). The rock consists of fayalite, quartz, garnet, apatite, and pyrite, in order of decreasing abundance.

E—Hedenbergite-garnet-magnetite rock, Druideig Lodge, Loch Duich, Ross-shire, Scotland. (Tilley, 1936, p. 338)

F—Grunerite-garnet-magnetite rock, Druideig Lodge, Loch Duich, Ross-shire, Scotland. (Tilley, 1936, p. 339)

G—Cummingtonite-garnet schist, 5/12 mile SW of outlet of Loch Bad-na-Sgalaig, between Loch Maree and Gairloch, Scotland. (*Memoir Geol. Surv. Great Britain, N.W. Highlands*, 1907)

are compared with analyses of eulysites and fayalite-free rocks associated with eulysites in Table 6. The Bear Mountain rocks differ from eulysites in containing slightly more alumina and less of both iron and iron plus manganese; they are very similar to the fayalite-free associates of eulysites.

The absence of olivine from the Bear Mountain rocks is probably due to the presence of a high enough ratio of Mg to Fe-plus-Mn to permit orthopyroxene to form instead of the pair fayalite-quartz (Bowen and Schairer, 1935). That it is the total of iron and manganese which controls the stability of pyroxene is suggested by the presence of fayalite in the Tunaberg eulysite (Analysis B, Table 6) despite the low content of iron in that rock. Evidently manganese has the effect of additional iron, as suggested by Kranck (1961).

Sedimentary Parents of Garnet-Pyroxene Gneisses

A sedimentary origin has long been accepted for the eulysites and associated ferruginous gneisses (Tilley, 1936), on the basis of their compositions and observed gradations between such rocks and unmetamorphosed equivalents (James, 1955; Gastil and Knowles, 1960). In the present area, compositional evidence is supplemented by the association of the garnet-pyroxene gneisses with graphitic and pyritic gneisses, skarns, and marbles, all of which can be safely interpreted as metasediments.

The high lime content of garnet-clinopyroxene gneiss suggests a carbonate-rich parent, probably a chert-carbonate sediment such as those described by James (1954, p. 585) and Goodwin (1956, p. 252). The original assemblage was probably chert- Fe, Ca, Mg, Mn carbonate-organic matter. Some primary magnetite may have been present (Huber, 1958, p. 124), but it seems likely that most of the abundant magnetite in the gneiss developed by breakdown of the original carbonates in the absence of enough silica to convert them entirely to silicates (James, 1954, p. 247). The alumina in the gneiss, which is concentrated in garnetiferous layers, probably represents small amounts of clastic material intercalated in the predominantly chemical sediment.

The sediment which produced garnet-orthopyroxene gneiss was probably also essentially a chert-carbonate rock, but one in which the carbonate was a manganiferous siderite and in which silica was plentiful (witness free quartz in the gneiss and the presence of quartzite layers). In this rock, too, clastic intercalations are represented by the garnetiferous layers.

These inferred sedimentary assemblages imply a specific chemical environment. The combination of silica, iron-manganese carbonates, and organic matter is stable in a slightly alkaline ($pH = 7.0-7.8$), slightly reducing environment (Krumbein and Garrels, 1952, p. 26). Primary magnetite is also theoretically possible in this setting (Huber, 1958, p. 124).

These chemical conditions would be satisfied by a basin with restricted circulation. That the Bear Mountain sediments were deposited in such a basin is also suggested by the presence of graphite and iron sulfides in the biotite-quartz-feldspar gneisses.

Summary of Conclusions

The garnet-pyroxene gneisses at Bear Mountain are thought to represent ferruginous chert-carbonate sediments which were part of a series of dominantly argillaceous sediments deposited in a restricted basin under reducing conditions.

Such metasediments have not been reported elsewhere in the High-

lands. The Bear Mountain rocks may be unique, or, perhaps, some of the garnet-pyroxene rocks mapped elsewhere as skarns are of the same type and derivation.

ACKNOWLEDGMENTS

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