GARNET AND BIOTITE COMPOSITIONS AND GEOTHERMOMETRY OF THE HARTLAND AND MANHATTAN SCHIST

Kosinski, J.S., and Puffer, J.H.
Geology Department, Rutgers University, Newark, NJ 07102

INTRODUCTION

The Hartland and Manhattan Schists are each exposed throughout large portions of the greater New York city area. Detailed field mapping, however, has been hindered to some extent by the overlapping physical appearance, mineralogy, metamorphic grade, chemical composition, and structural attitude of the two units. Each of the two rocks typically occur as black, medium grained, garnet bearing biotite schists, chemically resembling pelitic marine sediment, steeply dipping, with foliation striking NE on line with the general Appalachian metamorphic trend, and parallel to Cameron's line. Each of the units are mostly kyanite-sillimanite grade amphibolite facies rocks, although trace mineralogy is not equivalent and large variations in the metamorphic environment, particularly temperature variations, are reflected in the compositions of biotite and garnet. The objective of this project, therefore, is to determine the extent of variations in the equilibrium temperatures of biotite-garnet pairs and to determine whether or not any such variations can be used a criteria for distinguishing between the Hartland Formation and member c of the Manhattan Schist of the New York City area.

GEOLOGIC SETTING

The depositional environment and provenance of the Hartland Formation and member c of the Manhattan Schist, as proposed by Baskerville 1989), Merguerian and Sanders (1991), and others are separate and distinct. The Hartland Formation is interpreted as a eugeosynclinal deep-water shale interlayered with graywacke, and volcaniclastics (Baskerville and Mose (1989; Gates and Martin, 1976) deposited on oceanic crust adjacent to North America during the Early Paleozoic and then accreted to North America during the Taconic Orogeny (Jackson and Hall, 1982). In contrast, the Manhattan Schist is interpreted as miogeoclinal shallow-water shale deposited on the continental shelf (Merguerian, 1983). The provenance of the Hartland Formation was presumably calc-alkaline, island arc, rocks while the provenance of the Manhattan Schist was presumably a complex mix of crystalline Proterozoic granitic rock such as that exposed in the New Jersey Highlands.

METHODS

Samples of Hartland and Manhattan Schist were collected at widely spaced locations throughout the New York City area (Fig. 1). Samples were initially crushed and sieved to obtain a grain size of 0.25 to 0.18 mm. Heavy liquids, (bromoform and thallium malonate formate) were then utilized to isolate the garnet from other minerals in whole rock samples. Garnet was then separated from remaining impurities with a

Franz magnetic separator. Biotite separated during this process was then chemically analyzed (Table 1). Residual biotite contamination, comprising as much as 1 % of the garnet fraction, was then digested and altered or dissolved in boiling concentrated sulfuric acid then separated by recycling through the above steps.

Mineral separates were purposely used as an alternative to microprobe analyses in order to more accurately determine trace element content. Concentrations of trace elements in biotite and garnet may be significantly different among rocks that equilibrated under contrasting metamorphic environments, despite similarity or overlap in mineral content and rock chemistry. Concentrations in the anticipated 5 to 50 PPM range is beyond the resolution of microprobe equipment available to us, including the Phillips superprobe, but is within the range of the Rigaku 3030 XRF unit used for this project.

It was hoped that separation of large garnet porphyroblasts and abundant biotite from the schists would be easily accomplished for rapid XRF analysis. Mineral separation of garnet, however, was complicated by the occurrence of biotite inclusions and to a lesser extent by magnetite inclusions that required multiple cycles of magnetic and heavy liquid treatment to yield high levels of purity. It is, therefore, suggested that for purposes of generating data for garnet-biotite geothermometry, which is particularly dependent on major component determinations (MgO, FeOt), microprobe equipment would be a more convenient choice.

RESULTS

The composition of biotite from both the Hartland Formation and Manhattan Schist is typical of biotite from Amphibolite Facies regional metamorphic terrains, each containing 20 to 22 % FeOt. Biotite from the Hartland Formation, however, contains somewhat higher concentrations of MgO (12 to 12 %) than biotite from the Manhattan Schist (8 to 10 %). Chrome content is about the same in each formation at levels that are slightly higher than typical of such biotite.

The composition of almandine garnet from both the Hartland Formation and the Manhattan Schist is somewhat richer in FeOt (30 to 40 %) and is more depleted in MgO (3 to 5 %) than typical of garnet from Amphibolite Facies terrain. Chrome levels (263 to 426 PPM) are also somewhat higher than typical.

Despite the reasonably narrow compositional range of the biotites and garnets analyzed, a wide range of equilibration temperatures were calculated for the biotite-garnet pairs (Table 1). The garnet-biotite geothermometer as developed by Thompson (1976) and modified by Ferry and Spear (1978), (Fig. 2) is sensitive to minor changes in garnet and biotite compositions and yielded a temperature range of 510 to 670 C^o for the Manhattan Schist and 628 to 719 C^o for the Hartland Formation. (Table 1).

DISCUSSION

Each of the calculated equilibration temperatures pertaining to biotite-garnet pairs presented in Table 1 are within the range of the Amphibolite Facies of regional metamorphic rock as summarized by Hyndman (1985) with the possible exception of the somewhat anomalous upper Greenschist Facies 510 C^o pertaining to Manhattan Schist sample 2-M.

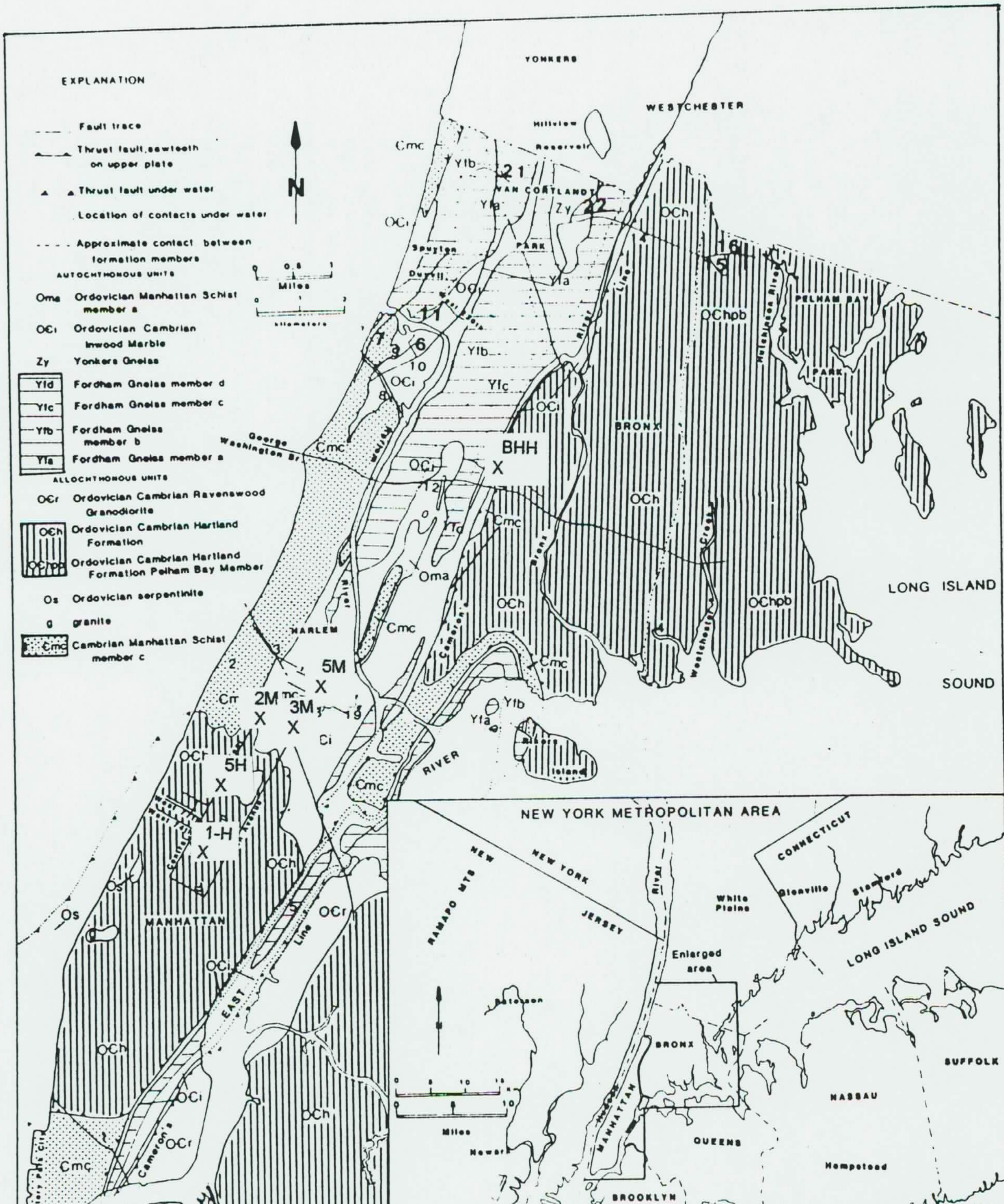

Figure 1. Geologic map of New York City after Baskerville (1989) with locations of samples analyzed for this report.

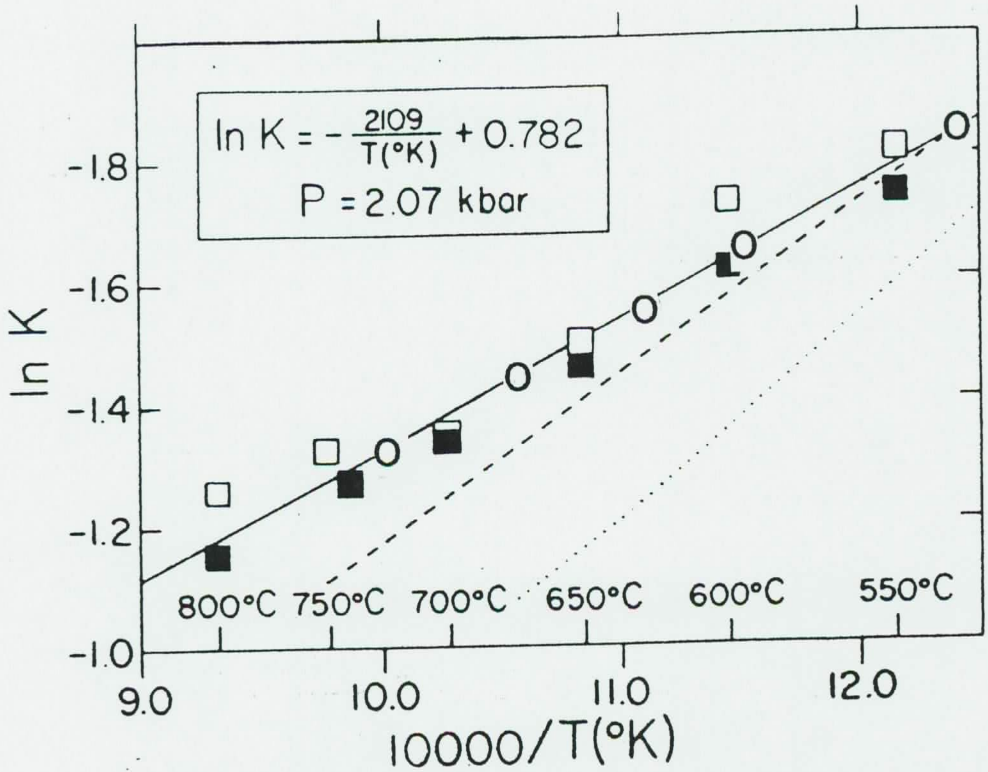

Figure 2. The garnet-biotite geothermometer (solid line) after Ferry and Spear (1978). Dashed line is from Thompson (1975). Boxes are data points establishing the least-squares fit of Ferry and Spear (1978). Circles are data points pertaining to the garnet-biotite pairs of Table 1.

TABLE 1.

Biotite composition

	Manhattan Schist			Hartland Formation	
	Bio 2-M	Bio 3-M	Bio 5M	Bio BHH	Bio 1-H
SiO2	34.65	33.77	35.77	34.48	33.16
TiO2	4.17	3.23	2.95	3.5	2.44
Al2O3	16.09	16.04	16.67	15.14	15.07
FeO	21.22	21.31	20.13	20.2	21.7
MgO	8.03	10.25	9.16	11.02	11.95
MnO	0.15	0.13	0.05	0.22	0.15
CaO	0.22	0.12	0.07	0.26	0.13
Na2O	0.72	0.39	0.4	0.47	0.41
K2O	8.99	9.47	8.89	9.4	9.27
LOI	4.86	4.72	5.31	4.5	5.26
total	99.1	99.43	99.4	99.19	99.54
Cr	214	214	206	332	221
V	571	nd	nd	nd	307
Zr	124	69	95	71	165
Sr	nd	63	65	68	nd

Garnet compositions

	Manhattan Schist			Hartland Formation	
	2M	3M	5M	5H	1-H
SiO2	33.29	32.94	33.68	35.23	37.87
TiO2	0.51	1.67	0.57	0.68	0.87
Al2O3	18.35	15.27	17.31	20.02	21.06
FeO	38.46	39.79	38.4	34.53	30.75
MgO	2.74	3	4.11	3.11	4.38
MnO	4.51	4.84	2.96	2.34	2.3
CaO	2.1	2.22	1.97	2.97	2.5
Na2O	0.03	0.25	0.85	0.95	0.26
K2O	0.01	0.02	0.15	0.17	0.01
total	100	100	100	100	100
Cr	283	395	263	347	426
V	51	123	nd	nd	75
Temp.	592	510	672	628	719

The 719 C° pertaining to Hartland sample 1-H plots close to the boundary of the Amphibolite and Granulite Facies on most facies diagrams. The wide range of temperatures are derived out of rock that is superficially equivalent with respect to texture, mineralogy, and general appearance (Puffer and others, 1994). The sensitivity of the Ferry and Spear (1978) geothermometer to slight variations in MgO/FeO ratios makes it particularly useful as a means for distinguishing between rocks that closely resemble each other. Changes in calculated temperatures across geologic contacts (Fig. 1) are significant. For example the calculated temperatures of Manhattan Schist samples taken from the northern edge of Central Park (510 and 592 C°) contrast with temperatures taken from southern Central Park (628 and 719 C° which are presumably Hartland Formation from south of Cameron's Line.

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