Garnet-Producing Reactions Along the Garnet Isograd in Southeastern Vermont

Aleta Berk Finnila
Pomona College

Pelitic schists from the Pinney Hollow formation in southeastern Vermont have undergone two distinct periods of recrystallization due to the Taconic orogeny and the later Acadian orogeny. Throughout much of southeastern Vermont, the garnet isograd roughly parallels the rock units in a north-south trend. In the Plymouth 7 1/2 minute quadrangle, however, the isograd diagonally crosses the Pinney Hollow formation (Chang, Ern, and Thompson, 1965) and in the northwestern part of the Saxtons River quadrangle the isograd cuts the Lower Paleozoic formations perpendicular to their strike (Fig. 1). This allowed me to study rocks of the same composition on both sides of the garnet isograd. Rocks from the Pinney Hollow formation near the garnet isograd were analyzed both in thin section and by electron microprobe to determine what reaction was responsible for the growth of garnet.

I collected 68 samples (Fig. 1) during a series of traverses which crossed the garnet isograd and paralleled the strike of the formation. This was to ensure that the observed mineralogical changes were a result of changing metamorphic grade and not bulk compositional variation. I collected samples from the most common lithology at an outcrop area as well as from any obviously anomalous lithologies in the vicinity noting mineral content, textures and structures.

I had thirty thin sections made from my samples. I obtained ata on garnet composition using a 5 channel Joel microprobe at the California Institute of Technology, Pasadena, California over the course of two days. The major-mineral assemblage in order of decreasing abundance below the isograd is quartz-muscovite-albite-biotite; just before the isograd it is quartz-muscovite-albite-chlorite-chloritoid; and above the isograd it is muscovite-chlorite-quartz-albite-garnet. Textural evidence indicates that albite and chlorite have been produced in the reaction and that quartz, chloritoid, and muscovite have been consumed. Biotite appears to have been absent from the rock at the time of garnet-production.

The albite in most of the thin sections appears in two distinct habits: as augen-like porphyroblasts in the matrix; and in veins with quartz. The augen formed early because the foliation wraps around them. Some have helicitic texture while others are distinctly zoned. There seems to be a strong relationship between albite and garnet. In the rocks there is an increased amount of albite in the quartz veins with the appearance of garnet, indeed, above the garnet isograd there is often more albite in the quartz veins than quartz. In several instances, albite completely surrounds small garnets. Garnet also seems to always be near a quartz-albite vein.

Chloritoid appears in two thin sections (AF-010, AF-013). In one section, the chloritoid is pervasive if not abundant throughout the matrix immediately below the garnet isograd. The other instance occurs as inclusions in a large garnet. Biotite appears in only one of the thin sections from the Pinney Hollow Formation. It occurs below the garnet isograd in the rock matrix and comprises only about 1% of the rock. Chlorite is notably absent in samples below the garnet isograd in the Pinney Hollow Formation. Just before the garnet isograd, however, some chlorite appears with chloritoid in the matrix. When garnet is present there is usually a significant amount of chlorite in the matrix as well as secondary chlorite which has replaced garnet. Occasionally, chlorite in association with muscovite appears to form veins with larger crystals than appear in the surrounding matrix. Chlorite never

REFERENCES

Cook, S.M., and Karabinos, P., 1988, Polymetamorphism in southeastern Vermont: Geological Society of America Abstracts with Programs, v. 20, p. 13.

Doll, C.G., Cady, W.M., Thompson, J.B., Jr., and Billings, M.P., 1961, Centennial geologic map of Vermont: Vermont Geological Survey, scale, 1:250,000.

Karabinos, P., 1984, Deformation and metamorphism on the east side of the Green Mountain massif in southern Vermont: Geological Society of America Bulletin, v. 95, p. 584-593.

Rosenfeld, J.L., 1968, Garnet rotation due to major Paleozoic deformations in southeastern Vermont: in Studies of Appalachian Geology, Northern and Maritime, E-an Zen et al. (eds.), Interscience, New York, p. 185-202.

Stanley, R.S., and Ratcliffe, N.M., 1985, Tectonic synthesis of the Taconian orogeny in western New England: Geological Society of America Bulletin, v. 96, p. 1227-1250.

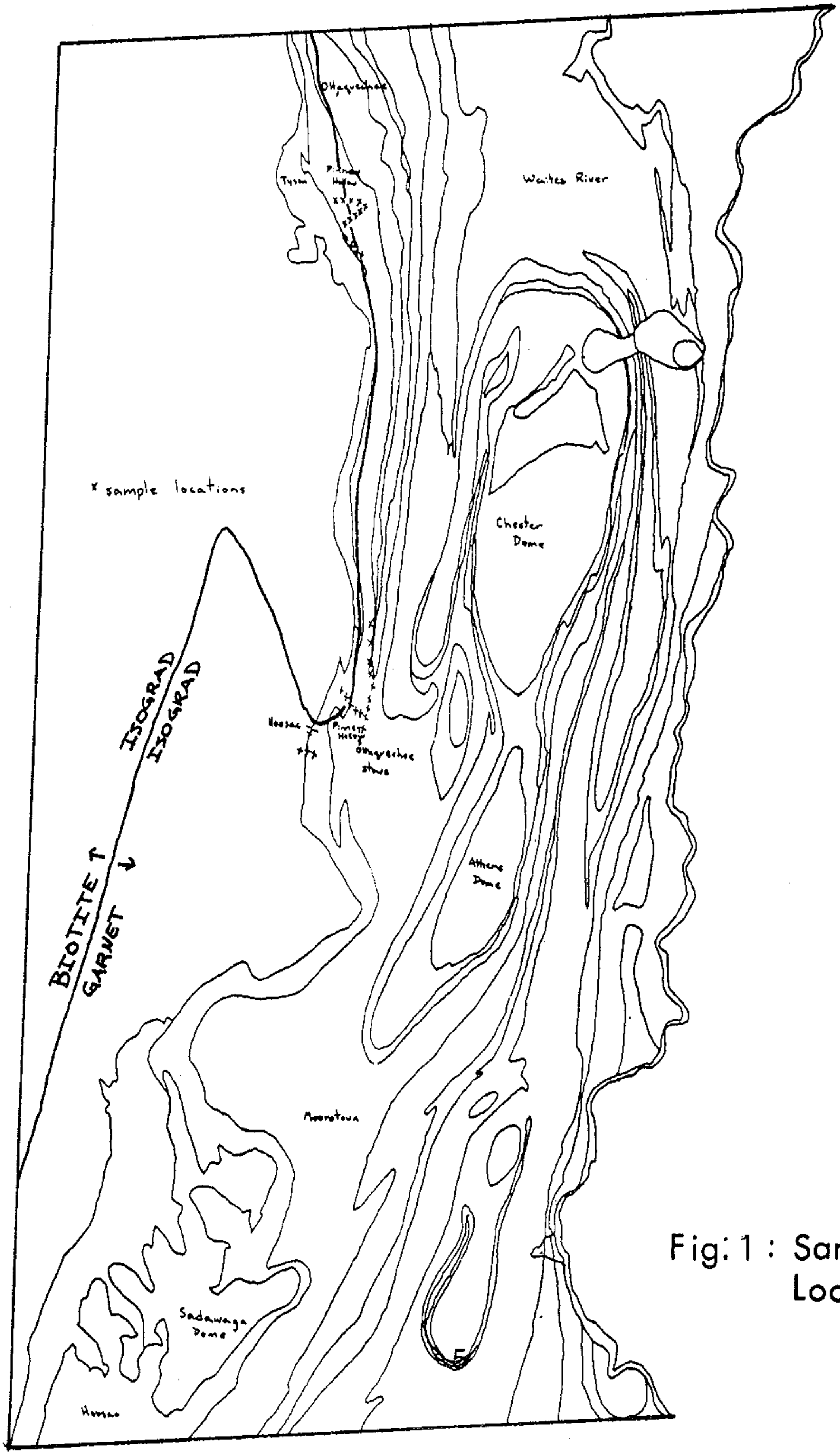

Fig. 1 : Sample Locations

appears in association with biotite. Muscovite is abundant in all the rock samples but diminishes in abundance above the garnet isograd.

Generally, the first garnet to appear in the rock is very small and often has been replaced by chlorite. Shortly beyond the isograd, however, the size increases dramatically and then fluctuates from crystals a fraction of a millimeter in diameter to porphyroblasts up to 2.5 cm in diameter. Usually the garnets are in very poor condition, they are either quite fractured or almost completely replaced by chlorite. There are a few samples with obviously late-formed garnets that have overgrown the most recent fabric, but most of the samples show garnets with primary textures. Some have been "rolled" and have quite spectacular inclusion trails. The inclusions seem to consist of muscovite, quartz, albite, and in at least on sample, chloritoid. Microprobe analysis shows that the garnets have Fe-rich rims and Mn-rich cores. They do not display any zoning with respect to Ca and Mg.

In order to determine what reactions produced garnet in the rock samples, I determined all the simplest reactions that, mathematically, might have occurred between minerals in the rocks. Using a method introduced by J.B. Thompson, I created a list of independent net-transfer reactions. Further combinations of these reactions will yield all the possible reactions but a list of the simplest reactions is most helpful and sufficient to extrapolate from given some additional information. Using textural and modal abundance data from the thin sections I eliminated reactions that contradicted my empirical observations. Because of limited funds, I did not analytically determine the composition of micas and feldspars in the rocks. Therefore I could not determine the extent to which simple exchange reactions occurred between coexisting minerals. Evaluating only net-transfer reactions is a valid approach because only net transfer reactions affect the amount of minerals present and the mineral textures in a rock (Chamberlain, 1986). A partial list of mathematically possible reactions is reproduced in Table I.

After eliminating reactions which did not correspond to the observations, two final reactions remained as being responsible for the growth of garnet:

$$2\text{bio} + 4\text{mus} + 4\text{qtz} = \text{ctd} + \text{chl} + 6\text{ab} + 2\text{tk} \quad (\text{tk} = \text{tschermack substitution})$$

$$4\text{ctd} = \text{gar} + 2\text{chl} + 7\text{tk} + 4\text{qtz}.$$

The first reaction consumes biotite, quartz, and muscovite and produces chlorite, chloritoid, and albite. The second consumes chloritoid and produces garnet, quartz, and more chlorite.

Rocks near the garnet isograd from the Pinney Hollow formation in southeastern Vermont show evidence for two seperate reactions responsible for the growth of garnet. I determined these reactions using the modal abundance and textures of minerals in thin section as a guide.

References

Chamberlain, C. Page (1986) Evidence for Repeated Folding of Isotherms during Regional Metamorphism. Journal of Petrology, Vol. 27, Part I, pp. 63-89.

Chang, P.H., Ern, E.H., Jr., and Thompson, J.B., Jr. (1965) Bedrock geology of the Woodstock quadrangle, Vermont. Vermont Geological Survey Bulletin, v. 29, 65 pp.

Thompson, J.B., Jr. The Tschermak Substitution and Reactions in Pelitic Schists, Harvard University, Cambridge, Massachusetts.

TABLE I

Reactions for the assemblage quartz + muscovite + albite + chlorite + garnet + chloritoid + biotite + water

Number	Reaction	Invariance
(1)	2bio + 3tk + 6qtz = gar + 2mus	<ctd, chl, ab>
(2)	2ctd + tk + 4ab = gar + 4mus	<bio, chl, qtz, wt>
(3)	2chl + 9tk + 8ab + 4qtz = gar + 8mus	<bio, ctd, wt>
(4)	4ctd = gar + 2chl + 7tk + 4qtz	<bio, ab, mus, wt>
(5)	9ctd + 14ab = 4gar + 14mus + chl + 2qtz	<bio, tk, wt>
(6)	ctd + 2mus = 4tk + ab + chl + 2qtz	<bio, gar, wt>
(7)	3bio + 7qtz + mus = chl + 4ab + gar	<ctd, tk, wt>
(8)	6chl + 24ab + 21tk = 4bio + gar + 20mus	<ctd, qtz, wt>
(9)	bio + qtz + 3mus = chl + 4ab + 3tk	<ctd, gar, wt>
(10)	8bio + 20qtz + 3tk = 2chl + 8ab + 3gar	<ctd, mus, wt>
(11)	4bio + 5tk +12qtz = gar + 2ctd + 4ab	<chl, mus, wt>
(12)	3ctd + 4ab = bio + 3gar + 5mus + 3qtz	<chl, tk, wt>
(13)	bio + tk + mus + 3qtz = ctd + 2ab	<chl, gar, wt>
(14)	2chl + 4qtz + 3tk = 3gar + 8wt	<bio, ctd, ab, mus>
(15)	4mus = gar + 4ab +3tk + 4wt	<bio, ctd, chl, qtz>
(16)	ctd = tk + gar + 2wt	<bio, chl, ab, mus, qtz>
(17)	4bio + 3tk + 12qtz = 3gar + 4ab + 4wt	<ctd, chl, mus>
(18)	2bio + 3tk + 6qtz + wt = 2mus + gar	<ctd, chl, ab>
(19)	3chl + 3tk + 2ab = 3gar + 2bio + 11wt	<ctd, mus, qtz>
(20)	6mus = 6ab + chl + 6tk + 2qtz + 2wt	<bio, ctd, gar>
(21)	2chl + 4qtz + 6tk = 3ctd + 2wt	<bio, gar, ab, mus>
(22)	2bio + 4qtz + 2wt = chl + 2ab	<ctd, gar, mus, tk>
(23)	4mus = ctd + 4ab + 2tk + 2wt	<bio, gar, chl, qtz>
(24)	3mus = bio + 2ab + 3tk + 3qtz + 2wt	<ctd, gar, chl>
(25)	4bio + 6tk + 12qtz + 2wt = 3ctd + 4ab	<gar, chl, mus>
(26)	chl + 2mus + 2qtz = 2gar + 2ab + 6wt	<bio, ctd, tk>
(27)	3ctd + 2chl + 4qtz = 6gar + 14wt	<bio, ab, mus, tk>
(28)	3ctd + 4ab = 4mus + 2gar + 2wt	<bio, chl, qtz, tk>
(29)	bio + mus + 3qtz = gar + 2ab + 2wt	<ctd, chl, tk>
(30)	3ctd + 4bio + 12qtz = 6gar + 4ab + 10wt	<chl, mus, tk>

TECTONO-METAMORPHIC EVOLUTION OF THE DEVIL'S DEN AREA, VERMONT

Gerard Greweldinger
Department of Geology
Amherst College
Amherst MA 01002

The Cambrian Hoosac Formation of the Devil's Den area in south-central Vermont (Fig.1) consists of pelitic schists surrounded by Proterozoic basement of the Green Mountain massif. The structure of the Devil's Den area has been interpreted by Slack and Sabin (1983) as a doubly plunging recumbent nappe broken by thrust faults. The rocks considered in this study are correlative with the Hoosac Formation on the eastern flank of the Green Mountains near Jamaica studied by Karabinos (1984), and the Gassetts schist of the Chester Dome studied by Thompson (1977), Downie (1982), and Crowley (1989).

Southern Vermont was subjected to two major Paleozoic deformations, the Ordovician Taconic orogeny and the Devonian Acadian orogeny, that produced multiple generations of mineral growth and fabrics in the Cambro-Ordovician rocks.

The purpose of this study is to use chemical data obtained from the electron microprobe as well as petrographic analysis of textures and fabrics to examine the evolution of the rocks with respect to the Taconic and Acadian orogenies. An understanding of the evolution of rocks from the Devil's Den area will allow comparison with similar rocks to the east that were metamorphosed to similar or higher grade and that contain evidence of polymetamorphic histories.

The Hoosac Formation in the Devil's Den area consists of a high-alumina schist containing the AFM assemblages garnet-chlorite-chloritoid and garnet-chloritoid as well as a low-alumina schist containing the AFM assemblages garnet-biotite-chlorite and garnet-biotite. Additional phases include white mica (muscovite and paragonite), quartz, plagioclase, and ilmenite or rutile, tourmaline, and epidote.

The Hoosac rocks in the Devil's Den area have a prominent schistocity defined by white mica, chlorite, and chloritoid that is folded in tight isoclinal folds. The minerals in the fold noses are bent and sheared. As there is no evidence of a cross cutting axial planar cleavage, the formation of schistocity and folding could have been concurrent. The fabrics are consistent with the westward transport of rocks by tractor-tread folding and may have been produced by prolonged simple shear.

Karabinos (1984) studied Hoosac Formation rocks from Jamaica (Fig.1) with the same assemblage as the high-alumina rocks considered here that contain garnets that have textural unconformities as well as reversals in their chemical zoning that Karabinos (1984) interprets as polymetamorphic growth separated by retrogression. The garnet in the high-alumina rock from the Devil's Den contains no textural unconformity or zoning reversals (Fig.2), suggesting that the high-alumina Hoosac experienced different tectono-metamorphic evolution in the Devil's Den area from Jamaica consistent with the interpretation of fabrics presented here.

The existence of chloritoid as inclusions in garnet that coexists with groundmass chlorite and biotite is consistent with the prograde facing of the reaction biotite + quartz + $H20$ = garnet + chlorite + muscovite proposed by Spear and Cheney (1989). The non-AFM components Mn, Ca, and Na present in these rocks probably stabilize the observed assemblages over a wide range of pressures and temperature.

Additional work will include the analysis of garnet zoning profiles and inclusion compositions to trace the chemical evolution of the rock as well as an analysis of the