Using chemically-zoned garnets to observe metamorphism in the Northern Appalachians: A case study from the Fall Mountain Nappe, New Hampshire

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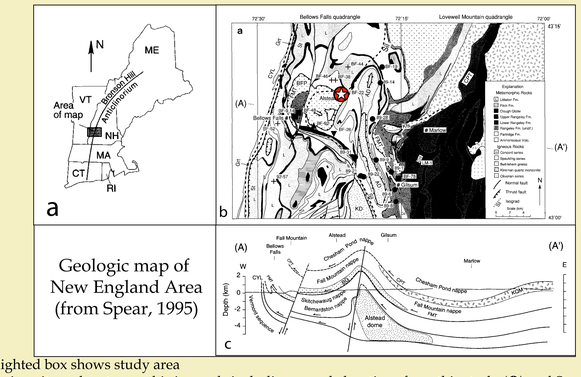
Introduction

A suite of rock samples was collected from the Fall Mountain Nappe in west-central New Hampshire. The rocks in this area have been exposed to metamorphic changes in pressure and temperature due to the collision of Africa with North America approximately 400 million years ago. This collision caused widespread regional metamorphism and resulted in the formation of the northern Appalachian Mountains.

The peak of metamorphism (T=740 ºC, P=3.5 kbar) was near the contact of the two tectonic plates to the east, with a gradient to lower grades of metamorphism traveling west away from the contact. The study site was chosen because the rocks contain the mineral assemblage garnet + biotite + sillimanite + muscovite + quartz + plagioclase, which is typical for higher grades of metamorphism in this area. Garnets from this assemblage were examined in detail because they formed by mineral reaction during metamorphism. Changes in garnet composition during crystal growth reflect changing metamorphic conditions.



Geologic map of New England Area (from Spear, 1995)

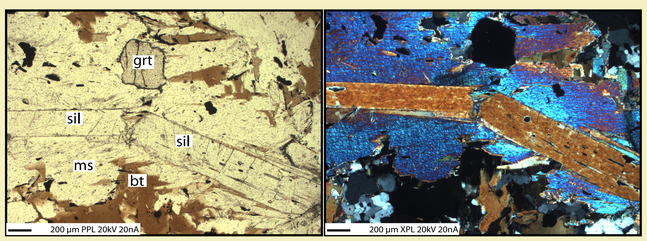
a) Highlighted box shows study area
b) Geologic units and metamorphic isograds including sample locations from this study (✪) and Spear (1995)
c) Cross-section from A–A′ showing structural features.

Petrographic Results

Mineral Name	General Mineral Formula	Mode	Size (mm)	Shape
Biotite	$K(Fe,Mg)_3AlSiO_3O_{10}(OH)_2$	25%	0.5 - 3.0	anhedral
Muscovite	$KAl_2(AlSi_3O_{10})(OH,F,Cl)$	25%	0.5 - 3.0	anhedral
Sillimanite	Al_2SiO_5	20%	0.5 - 5.0	subhedral
Garnet	$(Ca,Mg,Fe^{2+},Mn)_3(Fe^{3+},Al,Cr)_2(SiO_4)_3$	10%	0.25 - 0.5	euhedral
Quartz	SiO_2	7%	< 0.5 - 3.0	anhedral
Plagioclase	$NaAlSi_3O_8$	6%	0.5 - 3.0	anhedral

Note: The remaining 7% contains opaque (ilmenite, rutile, hematite) and accessory (zircon, apatite) minerals ≤ 0.25mm in diameter.

Sample 07FMN01 was analyzed using a petrographic microscope to determine the mineral components, mode, and textures



Photomicrographs of sample 07FMN01. a) Plane-polarized light image
b) Cross-polarized light image (grt=garnet; sil=sillimanite; ms=muscovite, bt=biotite)

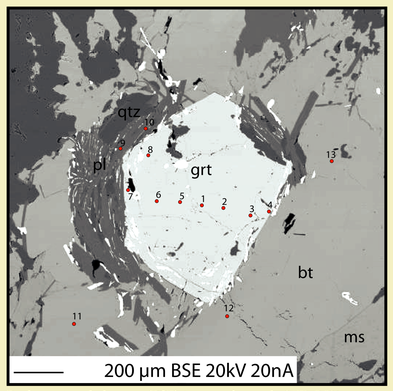
Electron Microprobe Results

The chemical composition of Sample 07FMN01 was determined using an electronmicroprobe (EMP). The EMP bombards the sample with a beam of electrons that generates characteristic X-rays based on the specific elemental composition of the sample. Minerals analyzed include: garnet, biotite, muscovite, ilmenite, and plagioclase. The table to the right shows representative microprobe analyses for these selected minerals.

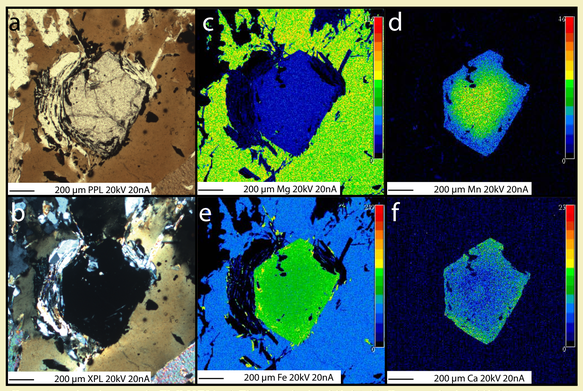
Quantitative spot analyses traversing across a garnet revealed an element zonation from core to rim, and additional X-ray mapping of the garnet verified this zoning. The amount of Fe and Ca increases from core to rim, while the amount of Mn and Mg decrease from core to rim. This type of zoning is commonly observed for garnet growth in regional metamorphic environments.

Representative microprobe analyses

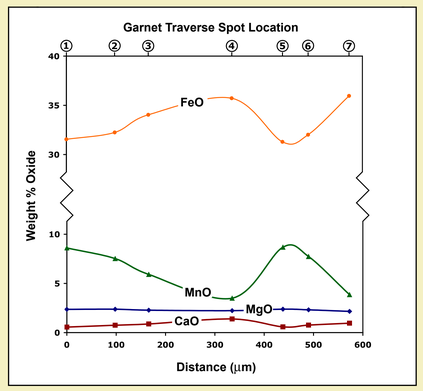
	Garnet Spot 1	Garnet Spot 2	Garnet Spot 3	Garnet Spot 4	Garnet Spot 5	Garnet Spot 6	Garnet Spot 7	Biotite	Muscovite	Plagioclase	Ilmenite
SiO_2	37.234	36.917	37.118	37.000	37.104	37.183	37.295	35.461	45.875	65.499	0.170
TiO_2	0.024	0.016	0.022	0.115	0.000	0.025	0.113	1.791	0.909		51.451
Al_2O_3	20.952	20.868	20.990	20.635	20.791	20.813	20.890	19.397	35.969	22.046	0.054
Cr_2O_3	0.012	0.034	0.030	0.012	0.018	0.017	0.052				0.018
MgO	2.366	2.379	2.285	2.231	2.386	2.316	2.160	9.465	0.492		0.021
CaO	0.562	0.754	0.880	1.390	0.587	0.765	0.960	0.047	0.000	2.721	0.000
MnO	8.608	7.526	5.914	3.499	8.682	7.731	3.862	20.264	1.063		0.776
FeO	31.544	32.242	34.037	35.719	31.288	32.010	35.958	0.285	0.931	0.008	46.293
Na_2O	0.053	0.027	0.001	0.034	0.009	0.027	0.013	8.718	9.519	10.329	0.024
K_2O	0.004	0.004	0.000	0.014	0.008	0.007	0.013	3.948	4.506	0.052	0.074
Σ	101.359	100.767	101.277	100.649	100.873	100.894	101.316	99.376	99.264	100.655	98.881
Oxygen basis	12	12	12	12	12	12	12	22	22	8	12
Si	2.990	2.983	2.985	2.993	2.994	2.998	2.996	5.386	6.105	2.864	0.017
Ti	0.001	0.001	0.001	0.007	0.000	0.001	0.007	0.205	0.091		3.958
Al	1.983	1.987	1.989	1.967	1.977	1.978	1.978	3.472	5.642	1.136	0.007
Cr	0.001	0.002	0.002	0.001	0.001	0.001	0.003				0.001
Mg	0.283	0.287	0.274	0.269	0.287	0.278	0.259	2.143	0.098		0.003
Ca	0.048	0.065	0.076	0.120	0.051	0.066	0.083	0.006	0.000	0.127	0.000
Mn	0.586	0.515	0.403	0.240	0.593	0.528	0.263	2.574	0.118		0.067
Fe	2.119	2.179	2.289	2.416	2.112	2.158	2.416	0.084	0.240	0.000	3.960
Na	0.008	0.004	0.000	0.005	0.001	0.004	0.002	1.689	1.616	0.876	0.005
K	0.000	0.000	0.000	0.001	0.001	0.001	0.001	0.350	0.350	0.003	0.010
Σ	8.019	8.023	8.019	8.019	8.017	8.013	8.008	15.909	14.260	5.006	8.028



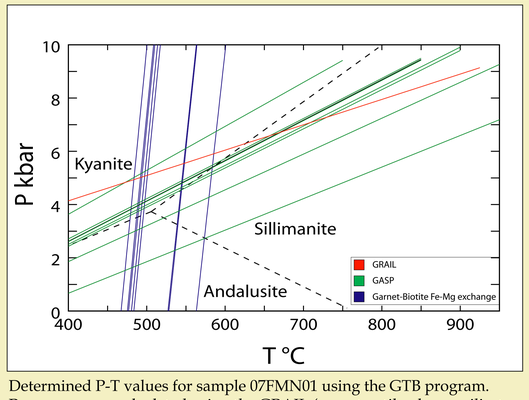
Back-scattered electron (BSE) image of sample 07FMN01. Quantitative spot analyses of various mineral phases have been labeled (grt=garnet; sil=sillimanite; ms=muscovite, bt=biotite, qtz=quartz; pl=plagioclase).



Garnet zoning in sample FMN0701. a) Plane-polarized light; b) Cross-polarized light; c-f) Garnet zoning observed using X-ray maps for various elements.



Elemental zoning profile for sample 07FMN01

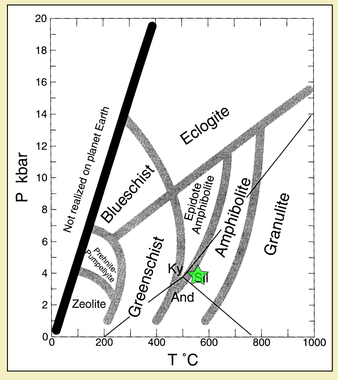


Determined P-T values for sample 07FMN01 using the GTB program. Pressures were calculated using the GRAIL (garnet-rutile-alumnosilicate-ilmenite) and GASP (garnet - alumnosilicate - quartz - plagioclase) geobarometers. Temperatures were calculated using the Garnet-Biotite Fe-Mg exchange geothermometer.

Discussion

Data obtained during EMP analyses were input into the GeoThermoBarometry (GTB) program and used to calculate temperatures and pressures for this sample. The determined values are shown in the left figure, and range from T = 450-550 °C and P = 3.0-3.5 kbar. These values agree with previously determined ranges of pressures and temperatures for this region (Spear, 1995).

Mineral assemblages observed by petrographic analysis, elemental zonation of garnets determined by EMP analysis, and calculations of pressures and temperatures have all provided a consistent picture for the conditions of metamorphism for this region.



General metamorphic facies diagram showing the determined location of sample 07FMN01

REFERENCES: Spear, F.S. (1995) Petrology of the regional sillimanite zone, west-central New Hampshire, U.S.A., with implications for the development of inverted isograds. American Minerologist, 80, 361-376.

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