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OCCURRENCE AND ORIGIN OF GARNETS IN THE SOUTH MOUNTAIN BATHOLITH, NOVA SCOTIA

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ABSTRACT

Garnet occurs as a characteristic mineral in granodiorite, monzogranite and leucocratic monzogranite host rocks near the contact of the South Mountain batholith in Nova Scotia. Three textural groups of garnets are defined on the basis of their crystal size, shape, inclusion content and relationship to biotite. These textural groups also have unique chemical characteristics. Group I garnets are 10–15 mm, anhedral, inclusion-rich and rimmed by biotite, have MnO contents of 1.55–4.62 wt. % and normal zoning, and are considered xenocrysts. Group III garnets are <2 mm, euhedral and inclusion-free, have no reaction relationship with biotite, have MnO contents averaging 6.91 wt. % and reverse zoning, and are considered magmatic. Group II garnets have close affinities with Group III. Projection of coexisting garnet–biotite pairs of magmatic origin into the AFM diagram permits delineation of the liquidus path followed by the South Mountain batholith magma during late stages of differentiation.

Keywords: garnet, textures, chemical analyses, granodiorite, monzogranite, leucocratic monzogranite, phase relations.

SOMMAIRE

Le grenat est un accessoire caractéristique des granodiorite, monzogranite et monzogranite leucocrate dans la zone de contact du batholithe South Mountain (Nouvelle-Ecosse). On distingue trois groupes texturaux de grenats par la taille des cristaux, leur forme, leurs inclusions, leur relation avec la biotite et leur chimisme très particulier. Les grenats du groupe I, de 10 à 15 mm de diamètre, sont xénomorphes, remplis d'inclusions et bordés de biotite; ils tiennent de 1.55 à 4.62% (en poids) de MnO, montrent une zonation normale et seraient des xénocristaux. Les grenats du groupe III sont petits (<2 mm), automorphes, sans inclusions et sans trace de réaction avec la biotite; ils contiennent, en moyenne, 6.91% de MnO, sont inversement zonés et vraisemblablement magmatiques. Les grenats du groupe II montrent une grande affinité à ceux du groupe III. En projection AFM, les couples grenat–biotite magmatiques précisent l'évolution suivant le liquidus du magma granitique aux stades tardifs de sa différenciation.

(Traduit par la Rédaction)

Mots-clés: grenat, texture, analyses chimiques, granodiorite, monzogranite, monzogranite leucocrate, relations de phase.

INTRODUCTION

The South Mountain batholith (SMB) is a post-tectonic, peraluminous granodiorite–monzogranite–leucocratic monzogranite comagmatic complex (McKenzie & Clarke 1975). In general, the biotite granodiorite was intruded first and forms an envelope around later bodies of monzogranite and leucocratic monzogranite (Fig. 1). Rb–Sr age determinations of 372–361 *Ma* (Clarke & Halliday 1980) place the time of intrusion of the SMB on the Devonian–Carboniferous boundary (Armstrong 1978). Gravity surveys show the batholith to be mushroom shaped, with its greatest thickness ($\simeq$ 17 km) in the vicinity of New Ross (Garland 1953).

The SMB has intruded mainly metawackes and metapelites of the Cambro–Ordovician Meguma Group, which had previously undergone regional metamorphism to the greenschist and amphibolite facies (Keppie & Muecke 1979) during the Acadian orogeny. The regional metamorphism has been overprinted by contact metamorphism to the hornblende-hornfels facies in the thermal aureole of the SMB, and xenoliths of this material in the SMB have been raised to pyroxene-hornfels facies (Jamieson 1974).

Garnets are found on both sides of, and close to, the contact between the SMB and Meguma Group rocks. They occur rarely in the thermal aureole, commonly in pelitic xenoliths, occasionally in the granodiorites and rarely in the monzogranites and leucocratic monzogranites. It is the purpose of this paper to determine the origin of the garnets in these various associations.

TEXTURAL CLASSIFICATION OF GARNETS FROM THE SOUTH MOUNTAIN BATHOLITH

Group I

Six of the eight sampling localities shown in Figure 1 (AS, CH, EC, KL, MU and NG) are

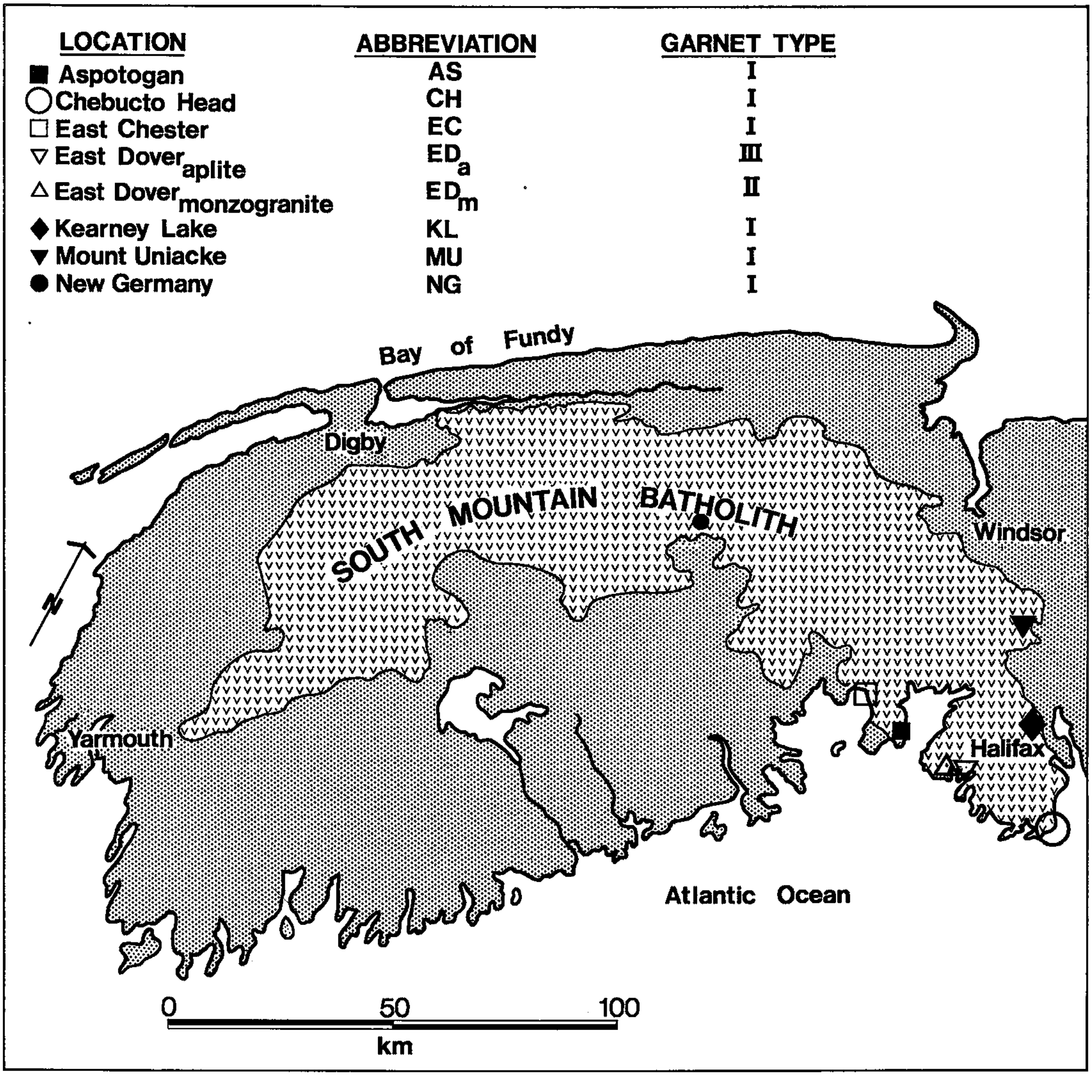

FIG. 1. Geological map of southwestern Nova Scoia showing garnet-collection localities in the South Mountain batholith.

in the granodiorite phase of the batholith. In this association the garnets occur either in xenoliths or in xenolith-rich facies of the granodiorite. The garnets are 10–15 mm in diameter; they have anhedral shapes and extensive reaction rims of biotite.

Group II

At one sampling locality (ED_m), garnets were found in a monzogranite host. In this area no xenoliths are present; the garnets are 5–8 mm in diameter, and the grain shapes are subhedral to euhedral. The textural relationship to biotite is complex in that some garnet grains have biotite cores whereas others have biotite rims.

Group III

An aplite dyke of leucocratic monzogranite composition (ED_a) intrudes the monzogranite (ED_m). In this xenolith-free dyke there are small (2 mm) euhedral garnets showing no reaction relationship with biotite.

CHEMISTRY OF THE GARNETS

Analyses of 92 garnets and 50 coexisting

TABLE 1. AVERAGE ANALYSES

	AS	CH	EC	ED_a	ED_m	KL	MU	NG
GROUP	I	I	I	III	II	I	I	I
Garnet								
SiO_2	36.75±0.26	36.29±0.05	36.60±0.23	35.63±0.20	36.03±0.69	36.34±0.55	37.21±0.33	36.15±0.51
Al_2O_3	20.72±0.19	21.21±0.03	20.75±0.17	20.26±0.13	20.33±0.25	20.87±0.10	21.48±0.05	20.65±0.25
FeO	33.05±0.50	33.71±0.24	35.59±0.97	32.85±0.50	33.12±0.56	33.50±0.41	31.13±0.87	33.97±0.78
MnO	4.62±0.95	2.74±0.40	1.55±0.67	6.91±2.21	6.27±1.72	4.58±1.24	2.68±1.75	2.24±0.91
MgO	3.94±0.55	3.52±0.21	4.01±0.78	2.60±0.71	2.63±0.69	3.64±0.55	5.97±1.09	4.43±0.46
CaO	1.29±0.25	1.22±0.07	1.18±0.19	0.93±0.18	1.02±0.28	1.12±0.09	1.40±0.16	1.05±0.17
Na_2O	0.00	0.00	0.00	0.00	0.00	0.04±0.06	0.00	0.08±0.09
TOTAL:	100.50	98.69	99.88	99.17	99.50	100.24	100.02	98.53
Biotite								
SiO_2	33.55±1.45		34.95±0.57	34.72	35.73±1.68	33.63±0.12	35.06±0.45	37.46±0.93
TiO_2	2.45±0.54		2.86±0.55	4.56	3.33±0.80	2.56±0.50	2.63±0.50	2.33±0.42
Al_2O_3	19.88±0.20		20.34±0.58	19.65	20.04±0.77	20.00±0.16	18.64±0.67	20.45±0.97
FeO	26.13±1.60		24.49±0.73	27.16	26.39±1.99	21.69±0.10	24.49±0.76	20.93±0.65
MnO	0.50±0.20		0.27±0.09	0.35	0.50±0.15	0.38±0.01	0.27±0.07	0.20±0.09
MgO	6.85±0.03		6.42±0.02	3.75	3.86±0.26	7.75±0.10	7.18±0.83	6.95±0.76
Na_2O	0.12±0.02		0.03±0.13	0.17	0.12±0.08	0.13±0.01	0.00	0.03±0.05
K_2O	8.12±1.51		9.29±0.14	9.48	9.51±0.13	9.22±0.66	9.25±0.25	8.95±1.26
TOTAL:	97.60		98.78	99.84	99.66	95.57	97.72	97.50

Garnet: AS avg 5 analyses; CH avg 2 analyses; EC avg 6 analyses; ED_a avg 4 analyses; ED_m avg 20 analyses; KL avg 6 analyses; MU avg 33 analyses; NG avg 16 analyses

Biotite: AS avg 3 analyses; EC avg 3 analyses; ED_a avg 2 analyses; ED_m avg 9 analyses; KL avg 3 analyses; MU avg 10 analyses; NG avg 10 analyses

biotites were done on a Cambridge Microscan 5 electron microprobe using a 149 eV Ortec energy-dispersion system and the EDATAI data-reduction program. Average compositions for each locality are given in Table 1. In general, garnets of the SMB are almandine-rich (67–78 mol. % $Fe_3Al_2Si_3O_{12}$), with subordinate amounts of pyrope (10–23 mol. %), spessartine (3–15 mol. %) and a relatively constant amount of grossular (3–4 mol. %). The garnets from the granodiorite localities contain 1.55–4.62% MnO, whereas those at the monzogranite and leucocratic monzogranite localities have average MnO contents of 6.27 and 6.91 wt. %, respectively.

Compositional profiles across crystals show that Group I garnets are normally zoned (Mn-rich core, Mg–Fe-rich rim), whereas garnets from textural Groups II and III are reversely zoned (Mn-poor core, Mn-rich rim; Fig. 2).

Discussion

The properties of each textural group of garnets are summarized in Table 2, and interpretations of the origins of each group are discussed individually below.

Group I

The following evidence is relevant to interpreting the origin of Group I garnets: (i) Close spatial association with xenoliths. (ii) Anhedral shape. The irregular grain shapes suggest failure to attain chemical equilibrium. (iii) Poikilitic texture. These garnets are full of inclusions of biotite, more characteristic of growth in the

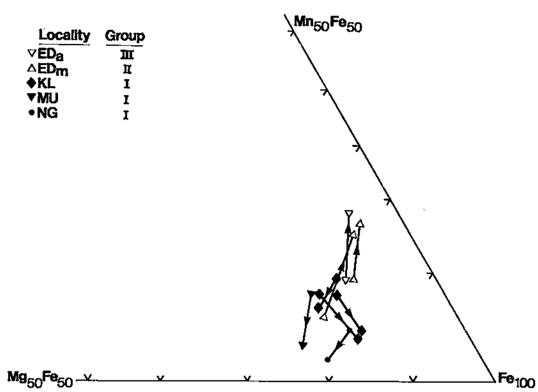

FIG. 2. Analyses of cores and rims of garnets from some of the collection localities. Arrow points from core to rim.

TABLE 2. CHARACTERISTICS OF THE THREE TEXTURAL GROUPS OF GARNETS IN THE SOUTH MOUNTAIN BATHOLITH

	GROUP I	GROUP II	GROUP III
HOST ROCK:	Biotite granodiorite	Monzogranite	Aplitic leucocratic monzogranite
ASSOCIATION:	Xenoliths	---------	---------
TEXTURE:	Garnet core with reaction rim of biotite	Biotite core in euhedral garnet to biotite margin on subhedral garnet	Euhedral garnets
REACTION RELATIONSHIPS:	Liq + Gnt → Bio	Liq + Gnt → Bio Liq + Bio → Gnt Liq → Gnt + Bio	Liq → Bio + Gnt
CHEMISTRY:	Pyrope > Spessartine	Spessartine > Pyrope	Spessartine > Pyrope
ZONATION:	Normal	Reverse	Reverse

solid state than of growth from a silicate melt. (iv) Low MnO contents. Although local concentrations of MnO in pyrophanitic ilmenites (4.4–13.3% MnO; R.M. MacKay, pers. comm.) in the Meguma rocks may have been important in providing Mn for nucleating the garnets, the MnO levels in the garnets (1.55–4.62% MnO) are not characteristic of a magmatic origin (Miller & Stoddard 1978). (v) Normal zoning. This is a feature widely considered characteristic of progressive metamorphism of metasedimentary rocks (Kretz 1973, Green 1977). (vi) Reaction rim of biotite. The extensive reaction rims on many of these garnets in the granodiorites suggest that they were not in chemical equilibrium with the silicate melt at the time of intrusion. (vii) Tielines on AFM projection (Fig. 3). Many of the Group-I garnet–biotite pairs have tielines that are parallel to known metamorphic pairs elsewhere in the Meguma Group (Jamieson 1974, A.C. McKenzie, unpubl. data). Other Group-I garnet–biotite tielines have various orientations that approach or parallel those for Groups II and III.

These lines of evidence suggest that the Group-I garnets formed in the thermal metamorphic aureole and were incorporated into the batholith in xenoliths that then underwent partial assimilation by the silicate melt. During advanced stages of assimilation, some of these garnets developed extensive, protective reaction rims of biotite that ensured their preservation as unequilibrated xenocrysts in the granodiorite magma. Others appear to have equilibrated to different degrees with the biotite of the silicate magma. These garnets, along with occasional mafic schlieren and concentrations of sulfides, are all that remain of some Meguma xenoliths.

Group II

Important observations bearing on the origin of textural Group-II garnets are the following: (i) Absence of xenoliths. If magma–country-rock reaction has been responsible for the nucleation of these garnets, then no other trace of the xenoliths remains. (ii) Variety of grain shapes, from anhedral to euhedral. The euhedral grains, at least, suggest attainment of textural equilibrium with the monzogranitic melt. (iii) Complex textural relations. The relationship between biotite and garnet suggests that any (or all) of the following reactions may have taken place before the solidus temperature was reached: Liq → Bio + Gnt (euhedral garnets); Liq + Bio → Gnt (garnets with biotite cores); Liq + Gnt → Bio (anhedral garnets with biotite rims). (iv) Moderate MnO contents. The spessartine content of Group-II garnets is >10%, and therefore in the range normally considered to be magmatic (Miller & Stoddard 1978). (v) Reverse zoning. Reversely zoned garnets are characteristic of crystal growth under conditions of falling temperature, in a silicate melt or during retrograde metamorphism, whereby the garnet stability field is expanded as the manganese content rises (Green 1977, Vennum & Meyer 1979). (vi) Tielines on AFM projection (Fig. 3). The garnet–biotite tielines in the monzogranite have a different orientation from the majority of granodiorite pairs, suggesting that equilibrium had been attained under different conditions.

Most of these characteristics are consistent with nucleation of the Group-II garnets from the monzogranitic melt. The complex textural relationships with biotite suggest two origins for garnet at this locality, a magmatic type and a highly modified xenolithic type. Further work

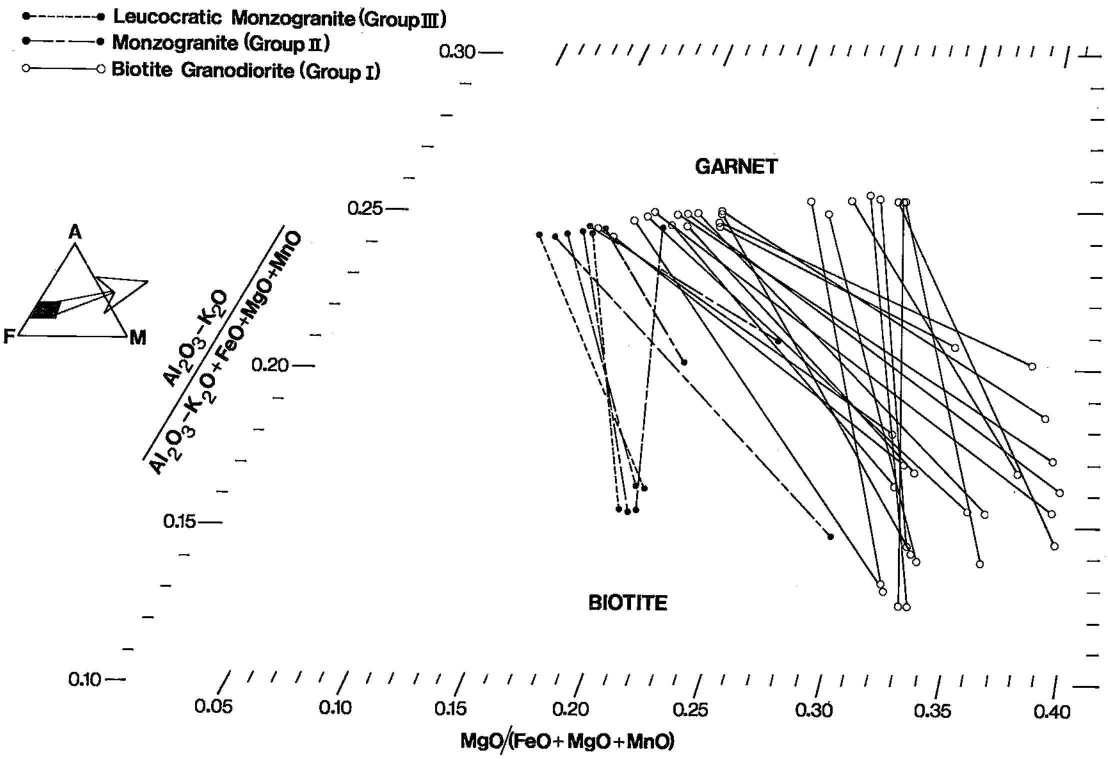

FIG. 3. AFM projection from K-feldspar (Mn included with Fe) of coexisting garnet and biotite pairs from the South Mountain batholith.

on the complex textural relationships of garnet and biotite at this type of locality is deemed necessary.

Group III

The following observations help to define the conditions under which the Group-III garnets grew: (i) Absence of xenoliths. The host rock is a late-stage, sugary-textured, fine grained aplite, a rock type that is invariably free of country-rock xenoliths in the SMB; therefore, a metamorphic origin for the garnets is very unlikely in this case. (ii) Euhedral grain shapes. The well-developed crystal faces on the garnets suggest equilibrium with the silicate melt. (iii) Textural relations. The garnet grain-size is comparable with the sizes of other phases in the aplite; it is therefore unlikely that the garnets formed by some mechanism independent of the pressure quench by which the quartz, feldspars and biotite formed. The lack of a reaction relationship with biotite suggests the following equilibrium: Liq → Bio + Gnt. (iv) Moderate Mn contents. The average Mn content of the aplitic Group-III garnets is slightly higher than that of the monzogranitic Group-II garnets, and both have spessartine contents characteristic of igneous crystallization. (v) Reverse zoning. (As for Group II.) (vi) Tielines on AFM projection (Fig. 3). In general, the Group-III garnets have tielines for garnet–biotite pairs that parallel those of Group-II pairs. The difference is that, as expected from the cross-cutting relations in the field, the Group-III pairs are slightly more evolved in terms of (Fe + Mn)/(Fe + Mn + Mg), suggesting that their compositions have been controlled by normal fractional crystallization processes in a silicate melt.

All lines of evidence clearly point to an igneous origin for the Group-III garnets. They appear to have nucleated as part of a stable assemblage in a melt under conditions of falling temperature.

THE LIQUIDUS MODEL

Abbott & Clarke (1979) considered a number of possible liquidus topologies projected into AFM from quartz and two feldspars. With the

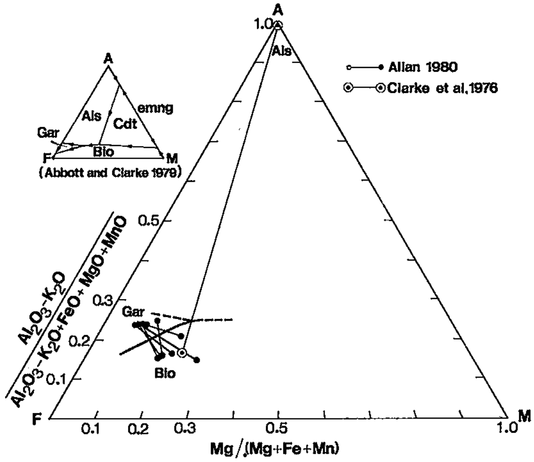

FIG. 4. AFM projection from K-feldspar (Mn included with Fe) showing deduced liquidus topology defined by a coexisting andalusite (Als)–biotite (Bio) pair and the coexisting biotite (Bio) – garnet (Gnt) pairs. This may be compared with the hypothetical liquidus topology (inset) proposed by Abbott & Clarke (1979).

discovery of magmatic garnets (textural Groups II and III), it is now possible to construct an appropriate topology for the middle and late stages of crystallization of the SMB (Fig. 4). The most iron-rich andalusite–biotite pair (Clarke *et al.* 1976) and the most magnesium-rich garnet–biotite pairs (from Groups II and III, this study) have been used to position the invariant point Liq + Als + Bio → Gnt. Thus the sequence of crystallization in middle and late stages of the SMB may have been Liq → Bio + Als, Liq + Als + Bio → Gnt, Liq → Bio + Gnt. The liquidus relationships for the P–T area *emng* of Abbott & Clarke (1979), shown as inset in Figure 4 and representing temperatures of 675–725°C and pressures of 3–6 kbar, may be appropriate to account for the phase relations observed in the SMB.

CONCLUSIONS

(1) Garnets appear to occur in the SMB in areas close to the contact with the Meguma Group country rocks.

(2) All garnets are almandine-rich, with 1.5–6.9% MnO.

(3) Garnets of textural Group I (large, anhedral, many inclusions, reaction rims) are considered of metamorphic origin.

(4) Garnets of textural Groups II and III (small, generally euhedral, inclusion-poor or inclusion-free, variable reaction-relationships) are believed to be generally of igneous origin, probably becoming stable phases as the Mn/(Mn + Mg + Fe) ratio in the silicate melt increased.

(5) The coexisting garnet–biotite pairs of igneous origin permit extension towards the AF join of the phase boundaries on the liquidus appropriate to the South Mountain batholith.

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