The microstructural and metamorphic history preserved within garnet porphyroblasts from southern Vermont and northwestern Massachusetts

VOLUME II

Thesis submitted by

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APPENDICES

APPENDIX 1

Sample Locations

SAMPLE	LONGITUDE	LATITUDE	GEOLOGICAL MAP	FORMATION	ABBREVIATION
BG3	43° 34' 18" N	72° 40' 36" W	Plymouth	Stowe	Csgt
BG4	43° 35' 54" N	72° 40' 18" W	Plymouth	Stowe	Csgt
BG6	43° 32' 06" N	72° 40' 27" W	Plymouth	Stowe	Cs
BG7	43° 31' 18" N	72° 41' 18" W	Plymouth	Ottauquechee	Cob
BG8	43° 35' 30" N	72° 39' 48" W	Plymouth	Moretown	Omwhg
BG9	43° 35' 54" N	72° 40' 48" W	Plymouth	Stowe	Csgt
BG11	43° 37' 06" N	72° 39' 48" W	Plymouth	Moretown	Omwhg
BG13	43° 28' 06" N	72° 40' 06" W	Ludlow/Mt Holly	Stowe	Csgt
BG14	43° 28' 30" N	72° 39' 06" W	Ludlow/Mt Holly	Stowe	Cs
BG15A	43° 23' 30" N	72° 40' 24" W	Ludlow/Mt Holly	Moretown	Omwh
BG17	43° 24' 00" N	72° 41' 30" W	Ludlow/Mt Holly	Pinney Hollow	Czph
BG19	43° 37' 36" N	72° 41' 12" W	Vermont	Stowe	OCs
BG20	43° 34' 18" N	72° 40' 06" W	Plymouth	Moretown	Omwhg
BG21	43° 34' 21" N	72° 40' 12" W	Plymouth	Stowe	Csgt
BG24	43° 12' 54" N	72° 43' 18" W	Vermont	Stowe	OCs
BG30	43° 19' 30" N	72° 42' 12" W	Andover	Stowe	OCs
BG32	43° 20' 12" N	72° 41' 06" W	Andover	Moretown	Omws
BG33	43° 14' 06" N	72° 42' 30" W	Vermont	Moretown	Omm
BG35	43° 21' 36" N	72° 40' 36" W	Andover	Stowe	OCs
BG38	43° 00' 36" N	72° 46' 30" W	Jamaica/Townsend	Rowe	Cr?
BG40	43° 03' 30" N	72° 42' 00" W	Jamaica/Townsend	Moretown	Oms
BG41A	43° 04' 00" N	72° 42' 00" W	Jamaica/Townsend	Moretown	Omr
BG42	43° 06' 24" N	72° 41' 24" W	Vermont	Moretown	Omm
BG43	43° 07' 42" N	72° 42' 18" W	Vermont	Stowe	OCs
BG44	43° 08' 24" N	72° 43' 06" W	Vermont	Stowe	OCs
BG45	43° 08' 36" N	72° 41' 54" W	Vermont	Moretown	Omm
BG46	43° 09' 06" N	72° 43' 18" W	Vermont	Ottauquechee	Co
BG47	43° 01' 06" N	72° 46' 36" W	Jamaica/Townsend	Rowe	Crgt?
BG48	43° 00' 06" N	72° 53' 00" W	Mt Snow/Readsboro	Hoosac	Czhg
BG49	42° 56' 36" N	72° 48' 00" W	West Dover/Jacksonville	Rowe	Cr?
BG50	42° 56' 42" N	72° 45' 06" W	West Dover/Jacksonville	Moretown	Omfp
BG51	42° 58' 12" N	72° 46' 30" W	West Dover/Jacksonville	Rowe	Crgs
BG52	42° 59' 54" N	72° 46' 36" W	West Dover/Jacksonville	Rowe	Crgs
BG53	42° 52' 48" N	72° 56' 54" W	Mt Snow/Readsboro	Hoosac	Czhcgt
BG54	42° 52' 36" N	72° 56' 36" W	Mt Snow/Readsboro	Hoosac	Czhcgt
BG55	42° 52' 18" N	72° 57' 48" W	Mt Snow/Readsboro	Hoosac	Czhbgt
BG56	42° 50' 12" N	72° 59' 30" W	Mt Snow/Readsboro	Hoosac	Czhbgt
BG57B	42° 49' 36" N	72° 59' 06" W	Mt Snow/Readsboro	Hoosac	Czhcgt

BG58B	42° 49' 18" N	72° 58' 48" W	Mt Snow/Readsboro	Hoosac	Czhcgt
BG59	42° 48' 24" N	72° 58' 24" W	Mt Snow/Readsboro	Hoosac	Czhgt
BG60	42° 46' 18" N	72° 56' 48" W	Mt Snow/Readsboro	Hoosac	Czhgt
BG62	42° 45' 54" N	72° 54' 06" W	Mt Snow/Readsboro	Hoosac	Czhgt
BG66B	42° 51' 48" N	72° 45' 36" W	West Dover/Jacksonville	Moretown	Omfp
BG69	42° 55' 00" N	72° 46' 36" W	West Dover/Jacksonville	Rowe	Crgs
BG70	42° 55' 18" N	72° 46' 54" W	West Dover/Jacksonville	Rowe	Crfb
BG71	42° 55' 42" N	72° 47' 06" W	West Dover/Jacksonville	Rowe	Crgs
BG72	42° 56' 30" N	72° 46' 42" W	West Dover/Jacksonville	Rowe	Crs
BG78	42° 47' 48" N	72° 46' 06" W	West Dover/Jacksonville	Moretown	Omgs
BG80	42° 46' 48" N	72° 48' 18" W	West Dover/Jacksonville	Moretown	Omf
BG81	42° 38' 48" N	72° 55' 18" W	Massachusetts	Moretown	Oms
BG83	42° 41' 36" N	72° 52' 06" W	Massachusetts	Moretown	Oms
BG84A	42° 40' 27" N	72° 53' 00" W	Massachusetts	Moretown	Oms
BG85	42° 39' 42" N	72° 54' 06" W	Massachusetts	Moretown	Oms
BG86	42° 42' 36" N	72° 55' 36" W	Massachusetts	Moretown	Om
BG87	42° 43' 54" N	72° 55' 54" W	Massachusetts	Hoosac	Czh
BG88	42° 41' 12" N	72° 58' 42" W	Massachusetts	Rowe	OCr
BG94	42° 39' 48" N	72° 57' 48" W	Massachusetts	Moretown	Om
BG102B	42° 31' 54" N	72° 56' 06" W	Massachusetts	Moretown	Om
BG104	42° 38' 12" N	73° 05' 30" W	Williamstown/Nth Adams	Hoosac	Czhdg
BG105A	43° 19' 42" N	72° 48' 30" W	Weston	Mt Holly Complex	Yrs
BG107A	43° 03' 30" N	72° 46' 18" W	Jamaica/Townsend	Hoosac	Czhg
BG108	43° 03' 12" N	72° 47' 00" W	Jamaica/Townsend	Hoosac	Czhg

Geological Maps:

Plymouth (Walsh & Ratcliffe, 1994)
Ludlow/Mount Holly (Walsh et al., 1994)
Vermont (Doll et al., 1961)
Andover (Ratcliffe, 1996)
Jamaica/Townshend (Ratcliffe, 1997)
Mount Snow/Readsboro (Ratcliffe, 1993)
West Dover/Jacksonsville (Ratcliffe & Armstrong, 1999)
Massachusetts (Zen et al., 1983)
Williamstown/Nth Adams (Ratcliffe et al., 1993)
Weston (Ratcliffe & Burton, 1996)

References:

Doll, C. G., Cady, W. M., Thompson, J. B. & Billings, M. P. 1961. Centennial Geologic Map of Vermont. Vermont Geological Survey, scale 1:250,000.

Ratcliffe, N. M. 1993. Bedrock geologic map of the Mount Snow and Readsboro quadrangles, Bennington and Windham counties, Vermont. U.S. Geological Survey, Miscellaneous Investigations Series Map I-2307. scale 1:24,000.

Ratcliffe, N. M., Potter, D. B. & Stanley, R. S. 1993. Bedrock geologic map of the Williamstown and North Adams quadrangles, Massachusetts and Vermont and part of the Cheshire quadrangle, Massachusetts. U.S. Geological Survey, Miscellaneous Investigations Series Map I-2369. scale 1:24,000.

Ratcliffe, N. M. 1996. Digital Bedrock Geology Map of the Andover Quadrangle, Vermont. U.S. Geological Survey, Open-file Report 96-31-A. scale 1:24,000.

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Ratcliffe, N. M. & Armstrong, T. R. 1999. Bedrock geologic map of the West Dover and Jacksonville quadrangles, Windham County, Vermont. U.S. Geological Survey, Miscellaneous Investigations Series Map I-2552. scale 1:24,000.

Walsh, G. J. & Ratcliffe, N. M. 1994. Digital Bedrock Geologic Map of the Plymouth Quadrangle, Vermont. U.S. Geological Survey, Open-file Report 94-654-A. scale 1:24,000.

Walsh, G. J., Ratcliffe, N. M., Dudley, J. B. & Merrifield, T. 1994. Digital Bedrock Geological Map of the Mount Holly and Ludlow Quadrangles, Vermont and Explanation of the Bedrock Geology Database in the Vermont Geographical Information System. U.S. Geological Survey, Open-file Report 94-229-A. scale 1:24,000.

Zen, E., Goldsmith, R., Ratcliffe, N. M., Robinson, P. & Stanley, R. S. 1983. Bedrock Geologic Map of Massachusetts. U.S. Geological Survey and Commonwealth of Massachusetts Department of Public Works, scale 1:250,000.

APPENDIX 2

Foliation Inflection/Intersection Axis (FIA) Analysis

The method for cutting thin-sections for FIA analysis is shown in Figure X2-1. First, the oriented sample collected in the field was taken back to the laboratory and re-oriented. It was then marked up so a series of horizontal slabs could be made. A north-south trending line was also marked. Each of the horizontal slabs was marked so that they could be cut into radial vertical sections at 10° increments relative to the north arrow. Initially thin sections were prepared for only 6 of these blocks (000°, 030°, 060°, 090°, 120°, 150°). When these sections are viewed from one direction the inclusion trail asymmetry changes from anti-clockwise to clockwise, as shown in Figure X2-2. The axis of curvature must lie between the two sections where this occurs. Thin sections are then made for the 10° blocks between these sections and the location of the axis narrowed down to a 10° range. More than one axis may be found. For example, one axis may be identified from the core of the spiral or staircase shaped trail and one from the rim. In a few cases a third FIA may be preserved between the core and rim. This is referred to as the "median" FIA. The orientation of thin-sections used to determined FIA trend are given in Appendix 3.

To determine the plunge of the FIA in the nine samples discussed in Section A, additional sections were cut striking parallel to the identified spiral axis and dipping by various amounts. Previous workers had found that spiral axes commonly have very shallow plunges (Hayward, 1992; Bell et al., 1995) so initially only four sections were cut, lying 10° and 30° either side of horizontal. The location of the axis was determined by the change in asymmetry in the same way as described above. Additional sections

were then cut to narrow the range of the plunge to 10°. The orientation of thin-sections used to determined FIA plunge are given in Appendix 3.

Errors in FIA Measurements

As discussed by Stallard et al. (2003) the successful application of the FIA method is dependent on FIAs within individual porphyroblasts being non-randomly oriented and having a restricted range in orientation within a sample. In this study, very few samples had thin sections where two asymmetries were present. In cases where one section had two asymmetries present, and the sections either side had a single asymmetry, the FIA was defined as the orientation of the section with two asymmetries. In cases where two sections had two asymmetries present, and the sections either side had a single asymmetry, the FIA was defined as the mid-point between the two sections with two asymmetries. No sample had two asymmetries present in more than two sections (i.e. over more than a 20° range). A more rigorous statistical analysis of the angular range over which the asymmetry switches, such as an asymmetry plot or the Maximum Likelihood Procedure of Stallard et al. (2003), would not produce meaningful results because of the small population of porphyroblasts in each thin-section (~4-6).

The total accumulated error in determining the trend of a FIA from errors made in preparing the oriented thin-sections is estimated as +/- 8° (Bell & Hickey, 1997). Error is introduced at five different stages: precision error in the compass used to mark orientation in the field +/- 1°; repositioning of the compass relative to orientation mark when back in the laboratory +/- 2°; precision error of the compass used to reorient sample in laboratory +/- 1°; error associated with cutting horizontal slabs and marking

north arrow +/- 2°; error in marking up and cutting thin-section blocks +/- 2°. Within a single sample, the possible error associated with orienting thin-sections relative to each other is a function of only the last two stages of sample preparation. Consequently, for samples where more than one FIA was determined, the relative FIA trends are precise to +/- 4°.

References

Bell, T. H., Forde, A. & Wang, J. 1995. A new indicator of movement direction during orogenesis : measurement technique and application to the Alps. Terra Nova 7, 500-508.

Bell, T. H. & Hickey, K. A. 1997. Distribution of pre-folding linear indicators of movement direction around the Spring Hill Synform, Vermont: significance for mechanism of folding in this portion of the Appalachians. Tectonophysics 272, 275-294.

Hayward, N. 1992. Microstructural analysis of the classical spiral garnet porphyroblasts of south-east Vermont: evidence for non-rotation. Journal of Metamorphic Geology 10, 567-587.

Stallard, A., Hickey, K. A. & Upton, G. J. G. 2003. Measurement and correlation of microstructures: the case of foliation intersection axes. Journal of Metamorphic Geology 21, 241-252.

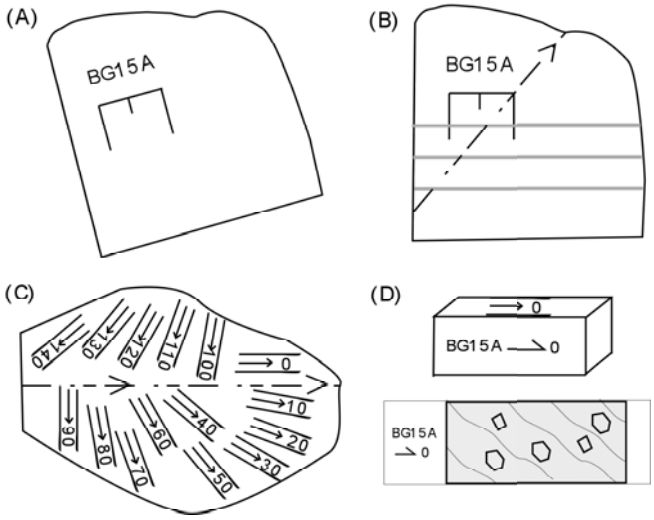


FIGURE X2-1: Diagram showing how oriented vertical thin-sections are prepared for FIA analysis

A: Sample after being collected in the field. Note the orientation marked in indelible pen - the top of the symbol shows the horizontal and the tick mark indicates the dip direction.

B: Sample reoriented in the laboratory using the orientation mark. Horizontal lines (grey lines) are marked in preparation for cutting horizontal slabs and north is also marked (dotted line with arrow).

C: Horizontal slab with north marked across it (dotted line with arrow). Blocks are marked off from north in 10° increments around the compass and cut out.

D: Oriented block. The vertical face is marked with an arrow that shows the strike of the face. The barb of the arrow indicates the top of the block. A vertical thin-section is then prepared from the block and the orientation marks transferred.

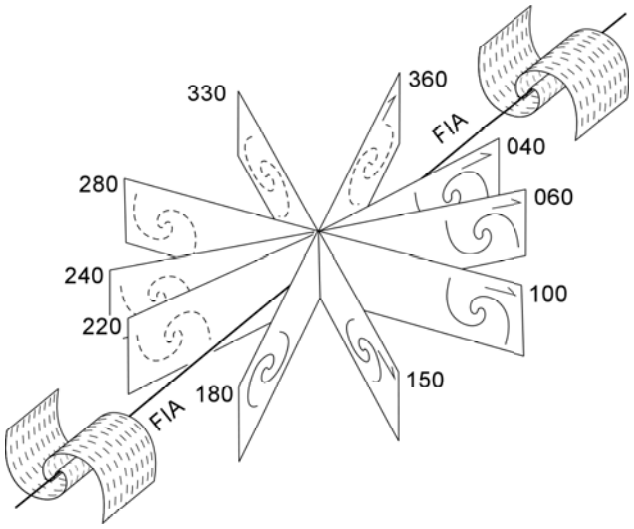


FIGURE X2-2: Sketch showing how a FIA is determined by looking at vertical thin-sections. Note the change from an s-shape to a z-shape inclusion trail geometry (After Bell and Hickey, 1997).

APPENDIX 3

Textural Discontinuity Orientations

Measurements were made from vertical thin-sections. For each sample the trends of the thin-sections are shown in bold. For each thin-section the discontinuity orientations are recorded as the pitch from the horizontal, reading clockwise.

BG11 - 000	**BG11 - 030**	**BG11 - 060**	**BG11 - 090**
13	22	111	355
16	30	18	358
	98	114	345
	6	14	10
	40	19	0
	26	122	2
	355	108	4
	2	19	17
		24	122
		352	98
		348	35
		4	
		10	
BG11 - 120	**BG11 - 150**	**BG11 - 160**	**BG11 - 170**
7	342	20	2
108	353	359	104
99	354	6	105
352	340	345	4
17	342	340	86
106	98		90
97	86		359
10	10		17
7			350
90			332
350			

BG15A - 000	BG15A - 010	BG15A - 020	BG15A - 030	BG15A - 050	BG15A - 060
5	342	20	355	15	2
12	358	359	357	17	90
24	356	75	6	7	30
8	4	9	353	9	54
30	3	2	90	105	15
126	75	353	88		355
350	26		355		
345	6		345		
74	15		97		
12	16		110		
115	7		354		
359	12		4		
	97		80		
BG15A - 090	**BG15A - 120**	**BG15A - 140**	**BG15A - 150**	**BG15A - 160**	**BG15A - 170**
62	55	12	6	78	345
351	15	106	10	352	152
36	1	1	344	352	354
10	72	11	97	74	5
2	63	354	74	65	96
358	335	1	26		65
22	80		52		
15	98				
30	25				
8	82				
351					
351					
104					

BG87 - 000	BG87 - 010	BG87 - 020	BG87 - 030	BG87 - 040	BG87 - 050
339	342	342	355	8	15
351	349	344	341	101	4
90	102	14	352	11	357
94		79	75	98	3
		81	76	339	90
		91	94	330	87
				98	88
				359	
				92	
BG87 - 060	**BG87 - 70**	**BG87 - 80**	**BG87 - 90**	**BG87 - 120**	**BG87 - 150**
7	330	2	13	6	20
6	81	83	345	94	5
105	348	350	9	14	
109	79	94	355	1	
96		7		106	

BG62 - 000	BG62 - 010	BG62 - 020	BG62 - 030	BG62 - 040
12	332	321	355	29
72	336	16	14	358
27	63	16	76	120
100	63	336	345	122
25	5	67	74	8
62	102	333	342	98
4	110	339	4	6
83	5	332	87	99
63	97	68	64	7
53	103		340	110
34	327		13	11
33	62		65	108
29	62		333	32
98	335		65	41
98	323		353	1
25	38		91	350
355			64	40
357			346	327
				62
				342
				38
BG62 - 50	**BG62 - 60**	**BG62 - 90**	**BG62 - 120**	**BG62 - 150**
55	115	352	342	359
51	20	288	75	105
333	20	39	72	13
343	96	326	340	351
55	31		347	19
65	110		8	7
332			116	
20			31	
125			116	
22			10	
110			0	
			106	
			8	
			100	

BG102B - 000	BG102B - 030	BG102B - 060	BG102B - 070	BG102B - 80	BG102B - 090
10	5	6	20	356	350
7	76	12	10	353	2
101	25	98	351	92	3
345	32	10	90	90	93
12	2	9	20	17	1
359		359	28	17	94
109		5		115	358
27		109		20	347
		12		8	
		13		7	
		5			
		6			

BG102B -100	BG102B - 110	BG102B - 120	BG102B - 150	BG102B - 170
11	336	348	80	20
1	83	95	353	105
359	18	70	358	356
342	93	7		89
25	84	345		
15	352			
14	70			
359	18			
	4			
	350			
	80			

BG107A - 000	BG107A - 030	BG107A - 040	BG107A - 050	BG107A - 060	BG107A - 070
95	5	6	10	343	70
348	347	102	75	52	76
0	22	12	140	61	345
7	107	352	344	31	90
357	358	90	340	346	14
24	94	10		12	2
	25	90		85	17
	110	89		359	80
	13	6		5	359
	91	89		18	
		13		20	
		113		93	
		3		120	
		100			
		1			
		98			
		7			

BG107A - 080	BG107A - 090	BG107A - 120	BG107A - 130	BG107A - 150
17	351	356	4	5
27	85	69	78	90
107	5	9	325	68
25	4	351	112	82
114	352	134	8	355
13	90	14	349	340
132	4	4	54	88
42	357	11	19	95
103	350	346	105	76
80	95	86	9	352
346		1		74
87		357		95
344		354		11
17				99
				22
				104
				350
				341
				347
				83
				82
				9
				5

APPENDIX 4

Orientation of thin-sections prepared for this study

Vertical thin-sections

SAMPLE	STANDARD THIN-SECTIONS (strike relative to true north)	POLISHED THIN-SECTIONS
BG3	000,030,060,090,120,150 + 010,020,140,160,170	
BG4	000,030,060,090,120,150 + 010,020	
BG6	000,030,060,090,120,150 + 160,170	
BG7	000,030,060,090,120,150 + 070,080	
BG8	000,030,060,090,120,150 + 160,170	
BG9	000,030,060,090,120,150 + 010,020	
BG11	000,030,060,090,120,150 + 160,170	
BG13	000,030,120,120 + 010, 020,040,070,100,110,130	
BG14	000,030,060,090,120,150 + 040,050,160,170	
BG15A	000,030,060,090,120,150 + 010,020,040,050,160,170	
BG17	000,030,060,090,120,150 + 020,040,070,160,170	
BG19	000,030,060,090,120,150 + 100,110	
BG20	000,030,060,090,120,150 + 010,020,170	
BG21	000,030,060,090,120,150 + 130,140,160,170	
BG24	000,030,060,090,120,150+160,170	
BG30	000,030,060,090,120,150 + 160,170	
BG32	000,030,060,090,120,150 + 070,080	
BG33	000,030,060,090,120,150 + 040,050	
BG35	000,030,060,090,120,150 + 160,170	
BG38	000,030,060,090,120,150 + 10,20	090,100
BG40	000,030,060,090,120,150 + 140,160,170	
BG41A	000,030,060,090,120,150 + 010,020,160,170	
BG42	000,030,060,090,120,150 + 110,100,160	
BG43	000,030,060,090,120,150 + 070, 080	
BG44	000,030,060,090,120,150 + 130,140	
BG45	000,030,060,090,120,150 + 160,170	
BG46	000,030,060,090,120,150 + 040,050	
BG47	000,030,060,090,120,150 + 010,020,170	
BG48	000,030,060,090,120,150 + 160,170	080
BG49	000,030,060,090,120,150 + 160,170	
BG50	000,030,060,090,120,150 + 160,170	
BG51	000,030,060,090,120,150 +160,170	
BG52	000,030,060,090,120,150 + 010,020	
BG53	000,030,060,090,120,150 + 010,020	090
BG54	000,030,060,090,120,150 + 010,170	
BG55	000,030,060,090,120,150 + 040,050,100,110,160	080
BG56	000,030,060,090,120,150 + 040,050	

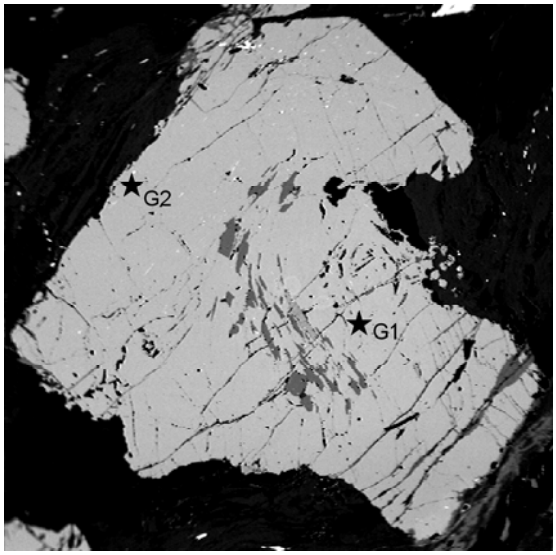
BG57B	000,030,060,090,120,150 + 160,170	
BG58B	000,030,060,090,120,150 + 040,050	110
BG59	000,030,060,090,120,150 + 070,080,160	080
BG60	000,030,060,090,120,150 + 010,020,160,170,040,050	130
BG62	000,030,060,090,120,150 + 010,020,040,050	120,160
BG66B	030,060,090,120,150 + 010,020,070,080,130,140	
BG69	030,060,090,120,150 + 010,170	
BG70	000,030,060,090,120,150 + 070,080	080
BG71	000,030,060,090,120,150 + 010,070	070,100
BG72	000,030,060,090,120,150 + 020,040	
BG78	000,030,060,090,120,150 + 010,020	
BG80	000,030,060,090,120,150 + 160,170	
BG81	000,030,060,090,120,150 + 160,170	
BG83	000,030,060,090,120,150 + 160,170	
BG84A	000,030,060,090,120,150 + 040,050	
BG85	000,030,060,090,120,150 + 160,170	
BG86	000,030,060,090,120,150 + 010,020	
BG87	000,030,060,090,120,150 + 010,020,040,050,070,080	110,140
BG88	000,030,060,090,120,150 + 070,080	170
BG94	000,030,060,090,120,150 + 040,050	
BG102B	000,030,060,090,120,150 + 070,080,100,110,160,170	030,070
BG104	000,030,060,090,120,150 + 070,080,100,130,140,160,170	070
BG105A	000,030,060,090,120,150 + 130,140,160,170	070
BG107A	000,030,060,090,120,150 + 040,050,070,080,130,140	050
BG108	000,030,060,090,120,150 + 080,100,110,140,160,170	010

Inclined thin-sections

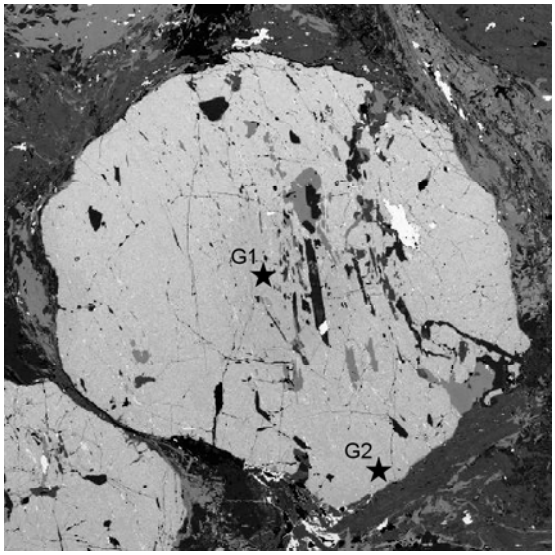
SAMPLE	INCLINED THIN-SECTIONS (dip direction/dip)
BG7	065/10, 065/20, 065/30, 245/10, 245/30
BG19	095/10, 095/20, 095/30, 275/10, 275/30
BG33	045/10, 045/20, 045/30, 225/10, 225/30
BG46	215/10, 215/20, 215/30, 035/10, 035/30
BG48	175/10, 175/20, 175/30, 355/10, 355/30
BG50	160/10, 160/20, 160/30, 340/10, 340/30
BG59	075/10, 075/20, 075/30, 255/10, 255/30
BG94	035/10, 035/20, 035/30, 215/10, 215/30
BG102B	165/10, 165/30, 165/40, 165/50, 345/10, 345/30

APPENDIX 5

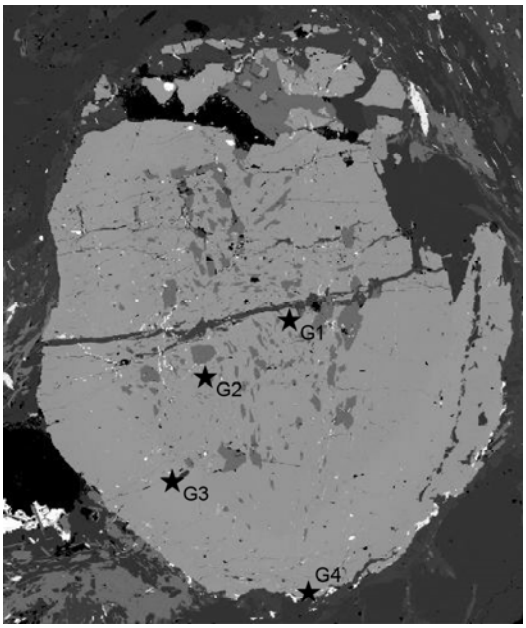
Microprobe Garnet Analyses



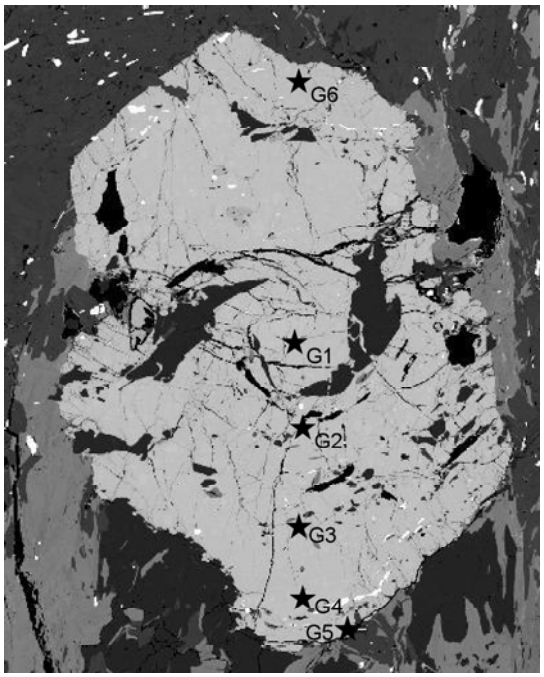
Sample BG53
Vertical polished section 090



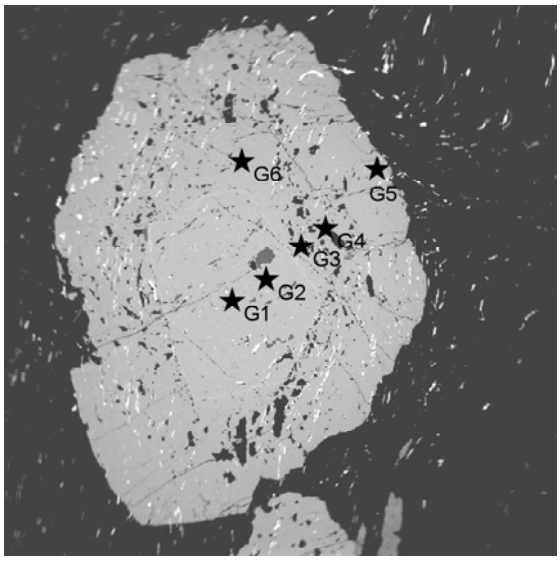
Sample BG58B
Vertical polished section 110



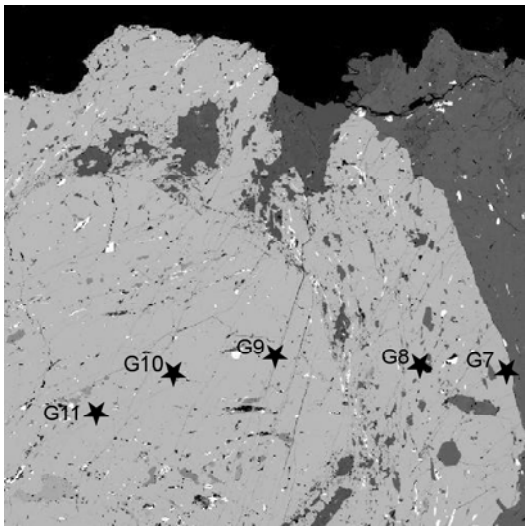
Sample BG59
Vertical polished section 080



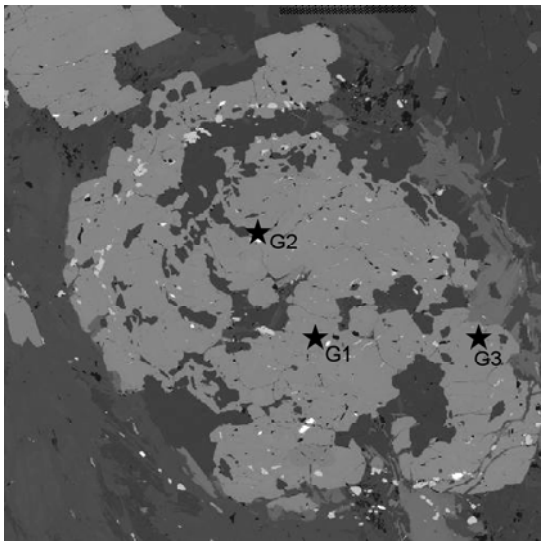
Sample BG62
Vertical polished section 060



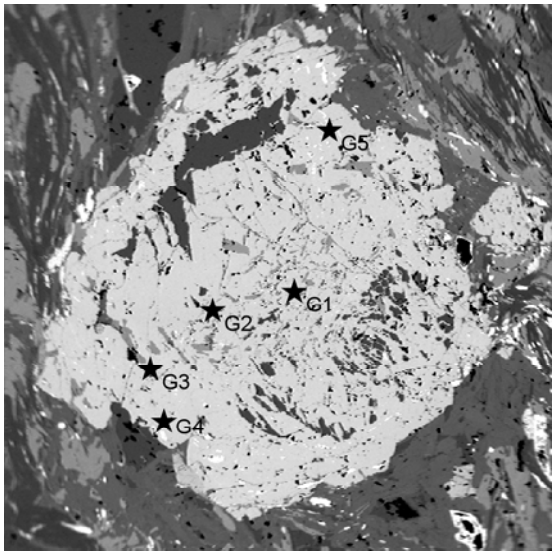
Sample BG87
Vertical polished section 140



Sample BG87
Vertical polished section 110



Sample BG107A
Vertical polished section 050



Sample BG108
Vertical polished section 010

	BG53_G1a	+/- 2 σ	Number of ions on the basis of 24 (O)	BG53_G1b	+/- 2 σ	Number of ions on the basis of 24 (O)
SiO_2	36.88	0.76	6.06	38.10	0.77	6.03
TiO_2	0.09	0.23	0.01	0.26	0.23	0.03
Al_2O_3	20.40	0.66	3.95	21.13	0.66	3.94
FeO	31.60	1.09	4.34	31.65	1.07	4.19
MnO	3.19	0.42	0.44	3.51	0.42	0.47
MgO	0.94	0.48	0.23	1.40	0.47	0.33
CaO	5.23	0.29	0.92	5.54	0.29	0.94
Na_2O	0.00	0.00	0.00	0.17	0.71	0.05
K_2O	0.04	0.16	0.01	0.00	0.00	0.00
Cl	0.09	0.13	0.02	0.10	0.13	0.03
TOTAL	99.44		15.98	100.87		16.02

	BG53_G1c	+/- 2 σ	Number of ions on the basis of 24 (O)	BG53_G1d	+/- 2 σ	Number of ions on the basis of 24 (O)
SiO_2	37.36	0.76	6.07	37.60	0.76	6.14
TiO_2	0.09	0.23	0.01	0.00	0.00	0.00
Al_2O_3	20.65	0.66	3.96	20.53	0.66	3.95
FeO	31.66	1.09	4.30	30.93	1.08	4.22
MnO	3.30	0.42	0.45	3.39	0.42	0.47
MgO	1.02	0.47	0.25	1.13	0.47	0.27
CaO	5.08	0.28	0.88	4.79	0.28	0.84
Na_2O	0.01	0.27	0.00	0.04	0.70	0.01
K_2O	0.04	0.16	0.01	0.00	0.00	0.00
Cl	0.00	0.00	0.00	0.06	0.13	0.02
TOTAL	99.22		15.94	99.46		15.91

	BG53_G2a	+/- 2 σ	Number of ions on the basis of 24 (O)	BG53_G2b	+/- 2 σ	Number of ions on the basis of 24 (O)
SiO_2	38.01	0.78	6.11	36.61	0.77	6.02
TiO_2	0.00	0.00	0.00	0.04	0.27	0.00
Al_2O_3	20.93	0.68	3.96	20.62	0.68	3.99
FeO	33.73	1.10	4.53	33.87	1.10	4.65
MnO	1.06	0.36	0.14	1.02	0.36	0.14
MgO	1.82	0.50	0.44	1.75	0.50	0.43
CaO	4.23	0.29	0.73	3.96	0.28	0.70
Na_2O	0.00	0.00	0.00	0.23	0.72	0.07
K_2O	0.02	0.16	0.00	0.02	0.16	0.00
Cl	0.02	0.13	0.00	0.07	0.13	0.02
TOTAL	99.81		15.92	99.19		16.04

	BG53_G2c	+/- 2 σ	Number of ions on the basis of 24 (O)	BG58B_G1a	+/- 2 σ	Number of ions on the basis of 24 (O)
SiO_2	37.20	0.77	6.02	37.91	0.78	6.09
TiO_2	0.00	0.00	0.00	0.34	0.28	0.04
Al_2O_3	21.11	0.68	4.03	20.46	0.68	3.88
FeO	32.29	1.10	4.37	31.62	1.09	4.25
MnO	1.28	0.36	0.18	1.24	0.37	0.17
MgO	1.91	0.49	0.46	1.23	0.48	0.29
CaO	5.09	0.30	0.88	6.97	0.33	1.20
Na_2O	0.00	0.00	0.00	0.00	0.00	0.00
K_2O	0.17	0.16	0.04	0.02	0.16	0.00
Cl	0.09	0.13	0.02	0.00	0.11	0.00
TOTAL	99.14		16.00	99.78		15.93

	BG58B_G1b	+/- 2 σ	Number of ions on the basis of 24 (O)	BG58B_G1c	+/- 2 σ	Number of ions on the basis of 24 (O)
SiO_2	37.14	0.77	6.07	38.05	0.78	6.06
TiO_2	0.00	0.00	0.00	0.50	0.28	0.06
Al_2O_3	20.46	0.67	3.94	20.87	0.68	3.92
FeO	31.96	1.07	4.37	31.80	1.07	4.24
MnO	1.12	0.35	0.16	1.26	0.35	0.17
MgO	0.96	0.49	0.23	1.10	0.47	0.26
CaO	6.85	0.33	1.20	6.79	0.34	1.16
Na_2O	0.00	0.00	0.00	0.30	0.69	0.09
K_2O	0.00	0.00	0.00	0.02	0.16	0.00
Cl	0.00	0.00	0.00	0.08	0.14	0.02
TOTAL	98.80		15.96	100.77		15.99

	BG58B_G2a	+/- 2 σ	Number of ions on the basis of 24 (O)	BG58B_G2b	+/- 2 σ	Number of ions on the basis of 24 (O)
SiO_2	37.54	0.78	6.03	37.52	0.78	6.02
TiO_2	0.08	0.27	0.01	0.00	0.00	0.00
Al_2O_3	21.76	0.69	4.12	20.73	0.68	3.92
FeO	31.78	1.09	4.26	34.01	1.09	4.56
MnO	0.48	0.32	0.07	0.36	0.33	0.05
MgO	1.85	0.49	0.44	1.73	0.50	0.41
CaO	5.68	0.31	0.98	6.19	0.32	1.06
Na_2O	0.00	0.00	0.00	0.00	0.00	0.00
K_2O	0.07	0.16	0.02	0.00	0.00	0.00
Cl	0.11	0.13	0.03	0.05	0.13	0.01
TOTAL	99.36		15.94	100.58		16.04

	BG58B_G2c	+/- 2 σ	Number of ions on the basis of 24 (O)	BG59_G1a	+/- 2 σ	Number of ions on the basis of 24 (O)
SiO_2	37.52	0.77	5.97	37.85	0.76	6.11
TiO_2	0.09	0.28	0.01	0.00	0.00	0.00
Al_2O_3	21.15	0.68	3.97	19.88	0.65	3.78
FeO	32.88	1.09	4.38	29.90	1.04	4.04
MnO	0.35	0.32	0.05	3.34	0.43	0.46
MgO	2.10	0.48	0.50	1.43	0.47	0.34
CaO	6.64	0.32	1.13	6.87	0.31	1.19
Na_2O	0.14	0.71	0.04	0.53	0.68	0.16
K_2O	0.01	0.14	0.00	0.00	0.00	0.00
Cl	0.10	0.14	0.03	0.00	0.00	0.00
TOTAL	100.98		16.08	99.79		16.08

	BG59_G1b	+/- 2 σ	Number of ions on the basis of 24 (O)	BG59_G1c	+/- 2 σ	Number of ions on the basis of 24 (O)
SiO_2	38.05	0.77	6.11	37.97	0.76	6.14
TiO_2	0.21	0.24	0.03	0.07	0.23	0.01
Al_2O_3	20.16	0.66	3.81	20.33	0.65	3.88
FeO	30.42	1.07	4.08	30.24	1.06	4.09
MnO	3.77	0.43	0.51	3.62	0.43	0.50
MgO	1.51	0.47	0.36	0.71	0.47	0.17
CaO	6.07	0.30	1.04	6.49	0.31	1.12
Na_2O	0.00	0.00	0.00	0.00	0.00	0.00
K_2O	0.05	0.16	0.01	0.00	0.00	0.00
Cl	0.00	0.00	0.00	0.09	0.13	0.03
TOTAL	100.23		15.96	99.52		15.94

	BG59_G1d	+/- 2 σ	Number of ions on the basis of 24 (O)	BG59_G2a	+/- 2 σ	Number of ions on the basis of 24 (O)
SiO_2	38.13	0.76	6.10	37.43	0.76	6.04
TiO_2	0.06	0.24	0.01	0.08	0.23	0.01
Al_2O_3	20.43	0.65	3.85	20.03	0.65	3.81
FeO	30.22	1.06	4.04	29.83	1.06	4.02
MnO	4.21	0.43	0.57	2.31	0.39	0.32
MgO	1.17	0.47	0.28	1.70	0.46	0.41
CaO	6.08	0.31	1.04	8.10	0.34	1.40
Na_2O	0.37	0.70	0.11	0.31	0.70	0.10
K_2O	0.00	0.00	0.00	0.01	0.14	0.00
Cl	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	100.68		16.02	99.79		16.10

	BG59_G2b	+/- 2 σ	Number of ions on the basis of 24 (O)	BG59_G2c	+/- 2 σ	Number of ions on the basis of 24 (O)
SiO_2	37.39	0.76	6.09	37.47	0.77	6.05
TiO_2	0.16	0.23	0.02	0.21	0.23	0.03
Al_2O_3	20.05	0.65	3.85	20.41	0.66	3.88
FeO	30.43	1.05	4.14	30.41	1.06	4.10
MnO	2.70	0.39	0.37	2.32	0.40	0.32
MgO	0.86	0.47	0.21	1.21	0.48	0.29
CaO	7.35	0.32	1.28	7.54	0.33	1.30
Na_2O	0.00	0.00	0.00	0.12	0.73	0.04
K_2O	0.00	0.00	0.00	0.00	0.00	0.00
Cl	0.00	0.10	0.00	0.00	0.00	0.00
TOTAL	98.94		15.97	99.70		16.01

	BG59_G2d	+/- 2 σ	Number of ions on the basis of 24 (O)	BG59_G3a	+/- 2 σ	Number of ions on the basis of 24 (O)
SiO_2	37.53	0.76	6.08	37.75	0.77	6.05
TiO_2	0.00	0.00	0.00	0.25	0.23	0.03
Al_2O_3	20.22	0.65	3.86	20.33	0.66	3.84
FeO	29.88	1.06	4.05	33.99	1.12	4.56
MnO	3.00	0.40	0.41	1.32	0.33	0.18
MgO	1.23	0.47	0.30	1.17	0.48	0.28
CaO	7.47	0.32	1.30	5.66	0.29	0.97
Na_2O	0.00	0.00	0.00	0.46	0.69	0.14
K_2O	0.02	0.16	0.01	0.11	0.16	0.02
Cl	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	99.35		15.99	101.04		16.08

	BG59_G3b	+/- 2 σ	Number of ions on the basis of 24 (O)	BG59_G3c	+/- 2 σ	Number of ions on the basis of 24 (O)
SiO_2	37.43	0.76	6.08	37.36	0.76	6.10
TiO_2	0.24	0.23	0.03	0.06	0.24	0.01
Al_2O_3	19.98	0.66	3.83	20.10	0.65	3.87
FeO	34.49	1.12	4.69	34.21	1.11	4.67
MnO	0.85	0.32	0.12	0.70	0.33	0.10
MgO	1.21	0.48	0.29	0.75	0.48	0.18
CaO	5.37	0.29	0.93	6.00	0.30	1.05
Na_2O	0.00	0.00	0.00	0.00	0.00	0.00
K_2O	0.02	0.16	0.01	0.00	0.00	0.00
Cl	0.00	0.00	0.00	0.04	0.13	0.01
TOTAL	99.59		15.98	99.22		15.97

	BG59_G4a	+/- 2 σ	Number of ions on the basis of 24 (O)	BG59_G4b	+/- 2 σ	Number of ions on the basis of 24 (O)
SiO_2	37.35	0.76	6.08	37.99	0.77	6.07
TiO_2	0.27	0.23	0.03	0.11	0.23	0.01
Al_2O_3	19.97	0.66	3.83	20.62	0.66	3.88
FeO	31.70	1.10	4.31	31.87	1.08	4.25
MnO	0.97	0.33	0.13	0.81	0.32	0.11
MgO	1.51	0.48	0.37	1.65	0.47	0.39
CaO	6.88	0.31	1.20	7.05	0.32	1.21
Na_2O	0.00	0.00	0.00	0.34	0.70	0.10
K_2O	0.10	0.16	0.02	0.04	0.15	0.01
Cl	0.04	0.13	0.01	0.01	0.13	0.00
TOTAL	98.79		15.99	100.49		16.04

	BG59_G4c	+/- 2 σ	Number of ions on the basis of 24 (O)	BG62_G1a	+/- 2 σ	Number of ions on the basis of 24 (O)
SiO_2	37.07	0.76	6.08	37.83	0.76	6.08
TiO_2	0.00	0.00	0.00	0.12	0.23	0.01
Al_2O_3	19.86	0.66	3.84	20.63	0.65	3.91
FeO	33.04	1.10	4.53	29.10	1.05	3.91
MnO	1.35	0.34	0.19	4.03	0.44	0.55
MgO	1.44	0.49	0.35	1.08	0.46	0.26
CaO	5.70	0.30	1.00	6.93	0.31	1.19
Na_2O	0.00	0.00	0.00	0.14	0.68	0.05
K_2O	0.00	0.00	0.00	0.19	0.16	0.04
Cl	0.00	0.10	0.00	0.00	0.00	0.00
TOTAL	99.46		16.00	100.06		16.00

	BG62_G1b	+/- 2 σ	Number of ions on the basis of 24 (O)	BG62_G1c	+/- 2 σ	Number of ions on the basis of 24 (O)
SiO_2	37.16	0.76	6.00	37.86	0.76	6.07
TiO_2	0.06	0.24	0.01	0.12	0.23	0.01
Al_2O_3	20.69	0.66	3.94	20.63	0.65	3.90
FeO	29.07	1.05	3.92	29.71	1.06	3.98
MnO	4.41	0.44	0.60	4.44	0.44	0.60
MgO	1.19	0.46	0.29	0.78	0.46	0.19
CaO	7.17	0.32	1.24	7.03	0.32	1.21
Na_2O	0.13	0.68	0.04	0.00	0.00	0.00
K_2O	0.19	0.16	0.04	0.13	0.16	0.03
Cl	0.00	0.00	0.00	0.04	0.13	0.01
TOTAL	100.05		16.07	100.75		15.99

	BG62_G1d	+/- 2 σ	Number of ions on the basis of 24 (O)	BG62_G2a	+/- 2 σ	Number of ions on the basis of 24 (O)
SiO_2	38.14	0.76	6.15	37.25	0.81	6.12
TiO_2	0.25	0.24	0.03	0.18	0.23	0.02
Al_2O_3	20.47	0.65	3.89	19.97	0.72	3.86
FeO	29.00	1.04	3.91	30.79	1.09	4.23
MnO	4.42	0.45	0.60	2.54	0.40	0.35
MgO	0.49	0.47	0.12	0.62	0.56	0.15
CaO	6.84	0.31	1.18	6.79	0.32	1.19
Na_2O	0.00	0.27	0.00	0.00	0.00	0.00
K_2O	0.00	0.14	0.00	0.00	0.13	0.00
Cl	0.04	0.13	0.01	0.00	0.00	0.00
TOTAL	99.66		15.89	98.15		15.93

	BG62_G2b	+/- 2 σ	Number of ions on the basis of 24 (O)	BG62_G2c	+/- 2 σ	Number of ions on the basis of 24 (O)
SiO_2	37.43	0.81	6.15	34.86	0.78	5.66
TiO_2	0.20	0.24	0.02	6.19	0.40	0.76
Al_2O_3	19.74	0.74	3.82	18.85	0.71	3.61
FeO	30.80	1.09	4.23	29.86	1.06	4.05
MnO	2.63	0.40	0.37	2.78	0.41	0.38
MgO	0.28	0.55	0.07	0.86	0.55	0.21
CaO	7.01	0.33	1.23	6.37	0.32	1.11
Na_2O	0.00	0.00	0.00	0.00	0.00	0.00
K_2O	0.01	0.14	0.00	0.08	0.16	0.02
Cl	0.00	0.00	0.00	0.05	0.13	0.01
TOTAL	98.09		15.91	99.90		15.80

	BG62_G3a	+/- 2 σ	Number of ions on the basis of 24 (O)	BG62_G3b	+/- 2 σ	Number of ions on the basis of 24 (O)
SiO_2	38.21	0.81	6.20	37.38	0.81	6.07
TiO_2	0.00	0.00	0.00	0.00	0.00	0.00
Al_2O_3	20.55	0.73	3.93	20.56	0.74	3.93
FeO	32.51	1.11	4.41	32.71	1.11	4.44
MnO	0.97	0.34	0.13	1.38	0.34	0.19
MgO	0.14	0.57	0.03	0.89	0.57	0.21
CaO	6.46	0.32	1.12	6.51	0.32	1.13
Na_2O	0.00	0.00	0.00	0.00	0.00	0.00
K_2O	0.04	0.15	0.01	0.00	0.00	0.00
Cl	0.09	0.12	0.02	0.00	0.00	0.00
TOTAL	98.96		15.86	99.42		15.97

	BG62_G3c	+/- 2 σ	Number of ions on the basis of 24 (O)	BG62_G4a	+/- 2 σ	Number of ions on the basis of 24 (O)
SiO_2	38.36	0.82	6.15	38.08	0.81	6.16
TiO_2	0.13	0.23	0.02	0.00	0.00	0.00
Al_2O_3	20.20	0.73	3.82	20.75	0.74	3.96
FeO	33.74	1.11	4.52	31.91	1.12	4.32
MnO	1.25	0.34	0.17	1.15	0.34	0.16
MgO	0.92	0.56	0.22	0.89	0.55	0.21
CaO	5.98	0.31	1.03	6.01	0.31	1.04
Na_2O	0.00	0.00	0.00	0.00	0.00	0.00
K_2O	0.08	0.15	0.02	0.00	0.00	0.00
Cl	0.04	0.13	0.01	0.05	0.13	0.01
TOTAL	100.71		15.95	98.85		15.87

	BG62_G4b	+/- 2 σ	Number of ions on the basis of 24 (O)	BG62_G4c	+/- 2 σ	Number of ions on the basis of 24 (O)
SiO_2	37.61	0.81	6.03	37.99	0.81	6.25
TiO_2	0.35	0.23	0.04	0.06	0.24	0.01
Al_2O_3	20.70	0.73	3.91	19.32	0.73	3.74
FeO	34.03	1.12	4.56	33.64	1.12	4.63
MnO	0.69	0.33	0.09	1.07	0.33	0.15
MgO	1.58	0.57	0.38	0.28	0.59	0.07
CaO	5.60	0.30	0.96	5.76	0.31	1.02
Na_2O	0.00	0.00	0.00	0.00	0.00	0.00
K_2O	0.00	0.00	0.00	0.08	0.16	0.02
Cl	0.00	0.00	0.00	0.05	0.13	0.01
TOTAL	100.56		15.97	98.24		15.89

	BG62_G5a	+/- 2 σ	Number of ions on the basis of 24 (O)	BG62_G5b	+/- 2 σ	Number of ions on the basis of 24 (O)
SiO_2	37.63	0.81	6.13	37.81	0.81	6.10
TiO_2	0.10	0.23	0.01	0.04	0.23	0.00
Al_2O_3	20.26	0.73	3.89	20.35	0.73	3.87
FeO	32.60	1.11	4.44	32.97	1.12	4.45
MnO	0.04	0.29	0.01	0.00	0.00	0.00
MgO	1.08	0.59	0.26	1.74	0.57	0.42
CaO	6.70	0.32	1.17	6.46	0.32	1.12
Na_2O	0.00	0.00	0.00	0.00	0.00	0.00
K_2O	0.00	0.00	0.00	0.00	0.00	0.00
Cl	0.08	0.13	0.02	0.00	0.00	0.00
TOTAL	98.48		15.93	99.35		15.96

	BG62_G5c	+/- 2 σ	Number of ions on the basis of 24 (O)	BG62_G6a	+/- 2 σ	Number of ions on the basis of 24 (O)
SiO_2	37.96	0.81	6.14	38.48	0.77	6.13
TiO_2	0.08	0.23	0.01	0.04	0.24	0.01
Al_2O_3	20.41	0.73	3.89	20.60	0.66	3.86
FeO	32.22	1.11	4.35	33.06	1.10	4.40
MnO	0.13	0.29	0.02	0.00	0.00	0.00
MgO	1.44	0.57	0.35	1.76	0.48	0.42
CaO	6.69	0.32	1.16	6.58	0.31	1.12
Na_2O	0.00	0.00	0.00	0.00	0.00	0.00
K_2O	0.05	0.15	0.01	0.00	0.00	0.00
Cl	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	98.99		15.92	100.52		15.94

	BG62_G6b	+/- 2 σ	Number of ions on the basis of 24 (O)	BG62_G6c	+/- 2 σ	Number of ions on the basis of 24 (O)
SiO_2	37.73	0.77	6.04	37.24	0.76	6.01
TiO_2	0.00	0.00	0.00	0.01	0.20	0.00
Al_2O_3	20.55	0.66	3.88	20.45	0.66	3.89
FeO	33.30	1.10	4.45	33.71	1.10	4.55
MnO	0.34	0.30	0.05	0.06	0.29	0.01
MgO	1.72	0.48	0.41	1.83	0.48	0.44
CaO	6.98	0.31	1.20	6.70	0.31	1.16
Na_2O	0.00	0.00	0.00	0.00	0.00	0.00
K_2O	0.05	0.16	0.01	0.01	0.14	0.00
Cl	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	100.67		16.03	100.01		16.05

	BG87_G1a	+/- 2 σ	Number of ions on the basis of 24 (O)	BG87_G1b	+/- 2 σ	Number of ions on the basis of 24 (O)
SiO_2	37.06	0.80	6.10	36.80	0.79	6.07
TiO_2	0.00	0.00	0.00	0.13	0.23	0.02
Al_2O_3	20.02	0.73	3.89	20.26	0.72	3.94
FeO	32.46	1.12	4.47	31.86	1.09	4.39
MnO	2.91	0.41	0.41	3.05	0.40	0.43
MgO	0.94	0.55	0.23	0.28	0.56	0.07
CaO	4.81	0.29	0.85	5.82	0.31	1.03
Na_2O	0.00	0.00	0.00	0.00	0.00	0.00
K_2O	0.08	0.15	0.02	0.00	0.00	0.00
Cl	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	98.29		15.96	98.21		15.94

	BG87_G1c	+/- 2 σ	Number of ions on the basis of 24 (O)	BG87_G2a	+/- 2 σ	Number of ions on the basis of 24 (O)
SiO_2	38.04	0.80	6.06	37.78	0.81	6.17
TiO_2	0.08	0.23	0.01	0.00	0.00	0.00
Al_2O_3	20.76	0.73	3.90	20.19	0.73	3.89
FeO	33.01	1.11	4.40	31.19	1.10	4.26
MnO	3.03	0.40	0.41	2.52	0.39	0.35
MgO	1.12	0.54	0.27	0.82	0.56	0.20
CaO	5.50	0.30	0.94	5.86	0.30	1.02
Na_2O	0.00	0.00	0.00	0.00	0.00	0.00
K_2O	0.04	0.16	0.01	0.00	0.00	0.00
Cl	0.00	0.00	0.00	0.02	0.13	0.01
TOTAL	101.59		15.99	98.39		15.89

	BG87_G2b	+/- 2 σ	Number of ions on the basis of 24 (O)	BG87_G2c	+/- 2 σ	Number of ions on the basis of 24 (O)
SiO_2	38.17	0.81	6.13	37.41	0.81	6.12
TiO_2	0.16	0.23	0.02	0.03	0.23	0.00
Al_2O_3	20.66	0.72	3.91	20.24	0.72	3.90
FeO	31.37	1.09	4.21	31.53	1.10	4.31
MnO	2.54	0.39	0.35	2.54	0.39	0.35
MgO	1.10	0.55	0.26	0.88	0.54	0.21
CaO	5.76	0.31	0.99	5.79	0.31	1.01
Na_2O	0.00	0.00	0.00	0.00	0.00	0.00
K_2O	0.08	0.15	0.02	0.03	0.15	0.01
Cl	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	99.84		15.90	98.43		15.93

	BG87_G3a	+/- 2 σ	Number of ions on the basis of 24 (O)	BG87_G3b	+/- 2 σ	Number of ions on the basis of 24 (O)
SiO_2	37.91	0.81	6.15	37.21	0.80	6.11
TiO_2	0.10	0.23	0.01	0.00	0.20	0.00
Al_2O_3	20.14	0.73	3.85	20.17	0.72	3.90
FeO	32.12	1.10	4.36	32.13	1.10	4.41
MnO	3.10	0.41	0.43	2.97	0.40	0.41
MgO	0.00	0.00	0.00	0.07	0.55	0.02
CaO	6.44	0.32	1.12	6.17	0.31	1.08
Na_2O	0.00	0.00	0.00	0.00	0.00	0.00
K_2O	0.00	0.00	0.00	0.00	0.00	0.00
Cl	0.00	0.00	0.00	0.07	0.12	0.02
TOTAL	99.81		15.91	98.80		15.96

	BG87_G3c	+/- 2 σ	Number of ions on the basis of 24 (O)	BG87_G4a	+/- 2 σ	Number of ions on the basis of 24 (O)
SiO_2	37.97	0.80	6.13	36.32	0.80	5.94
TiO_2	0.08	0.23	0.01	0.18	0.23	0.02
Al_2O_3	20.63	0.72	3.93	20.37	0.73	3.92
FeO	32.03	1.10	4.32	33.11	1.10	4.52
MnO	2.43	0.40	0.33	1.69	0.35	0.23
MgO	0.33	0.54	0.08	0.84	0.54	0.21
CaO	6.20	0.31	1.07	6.98	0.33	1.22
Na_2O	0.00	0.00	0.00	0.00	0.00	0.00
K_2O	0.18	0.15	0.04	0.07	0.15	0.02
Cl	0.05	0.12	0.01	0.03	0.13	0.01
TOTAL	99.90		15.93	99.59		16.09

	BG87_G4b	+/- 2 σ	Number of ions on the basis of 24 (O)	BG87_G4c	+/- 2 σ	Number of ions on the basis of 24 (O)
SiO_2	38.42	0.81	6.17	37.58	0.80	6.11
TiO_2	0.08	0.23	0.01	0.12	0.23	0.01
Al_2O_3	20.69	0.73	3.92	20.43	0.72	3.91
FeO	32.19	1.11	4.32	32.44	1.11	4.41
MnO	1.72	0.36	0.23	1.61	0.35	0.22
MgO	0.05	0.55	0.01	0.09	0.53	0.02
CaO	6.91	0.32	1.19	7.09	0.33	1.23
Na_2O	0.00	0.00	0.00	0.00	0.00	0.00
K_2O	0.10	0.16	0.02	0.04	0.15	0.01
Cl	0.06	0.13	0.02	0.00	0.00	0.00
TOTAL	100.22		15.89	99.40		15.93

	BG87_G5a	+/- 2 σ	Number of ions on the basis of 24 (O)	BG87_G5b	+/- 2 σ	Number of ions on the basis of 24 (O)
SiO_2	36.94	0.81	6.06	**37.64**	0.80	6.13
TiO_2	0.00	0.00	0.00	0.23	0.23	0.03
Al_2O_3	20.62	0.73	3.99	20.49	0.73	3.93
FeO	33.94	1.13	4.66	34.03	1.13	4.63
MnO	0.15	0.29	0.02	0.00	0.00	0.00
MgO	1.44	0.56	0.35	1.29	0.56	0.31
CaO	4.89	0.29	0.86	4.88	0.29	0.85
Na_2O	0.00	0.00	0.00	0.00	0.00	0.00
K_2O	0.01	0.14	0.00	0.00	0.00	0.00
Cl	0.08	0.12	0.02	0.01	0.10	0.00
TOTAL	99.08		15.97	98.57		15.88

	BG87_G5c	+/- 2 σ	Number of ions on the basis of 24 (O)	BG87_G6a	+/- 2 σ	Number of ions on the basis of 24 (O)
SiO_2	38.44	0.81	6.17	38.71	0.81	6.12
TiO_2	0.08	0.23	0.01	0.11	0.24	0.01
Al_2O_3	20.65	0.73	3.91	21.39	0.73	3.98
FeO	35.52	1.14	4.77	31.94	1.10	4.22
MnO	0.14	0.29	0.02	2.55	0.37	0.34
MgO	0.82	0.57	0.20	0.47	0.53	0.11
CaO	4.63	0.29	0.80	6.35	0.32	1.07
Na_2O	0.00	0.00	0.00	0.00	0.00	0.00
K_2O	0.00	0.00	0.00	0.12	0.15	0.02
Cl	0.04	0.12	0.01	0.05	0.13	0.01
TOTAL	100.32		15.88	101.69		15.90

	BG87_G6b	+/- 2 σ	Number of ions on the basis of 24 (O)	BG87_G6c	+/- 2 σ	Number of ions on the basis of 24 (O)
SiO_2	37.33	0.80	6.09	37.77	0.80	6.09
TiO_2	0.18	0.23	0.02	0.00	0.00	0.00
Al_2O_3	20.36	0.73	3.92	20.65	0.73	3.92
FeO	31.89	1.10	4.35	32.53	1.10	4.39
MnO	2.15	0.38	0.30	2.39	0.37	0.33
MgO	0.70	0.54	0.17	0.76	0.54	0.18
CaO	6.11	0.32	1.07	6.01	0.31	1.04
Na_2O	0.00	0.00	0.00	0.00	0.00	0.00
K_2O	0.03	0.15	0.01	0.00	0.00	0.00
Cl	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	98.74		15.93	100.11		15.95

	BG87_G7a	+/- 2 σ	Number of ions on the basis of 24 (O)	BG87_G7b	+/- 2 σ	Number of ions on the basis of 24 (O)
SiO_2	37.37	0.77	6.06	37.23	0.77	6.02
TiO_2	0.00	0.00	0.00	0.14	0.27	0.02
Al_2O_3	20.04	0.67	3.83	20.04	0.67	3.82
FeO	30.08	1.08	4.08	31.42	1.09	4.25
MnO	4.80	0.48	0.66	4.82	0.48	0.66
MgO	0.77	0.48	0.19	0.84	0.49	0.20
CaO	6.80	0.33	1.18	6.10	0.32	1.06
Na_2O	0.04	0.68	0.01	0.00	0.00	0.00
K_2O	0.06	0.16	0.01	0.14	0.16	0.03
Cl	0.00	0.00	0.00	0.11	0.13	0.03
TOTAL	99.96		16.03	100.84		16.09

	BG87_G7c	+/- 2 σ	Number of ions on the basis of 24 (O)	BG87_G8a	+/- 2 σ	Number of ions on the basis of 24 (O)
SiO_2	36.94	0.77	6.08	38.78	0.79	6.14
TiO_2	0.16	0.27	0.02	0.18	0.27	0.02
Al_2O_3	19.47	0.67	3.77	20.75	0.68	3.87
FeO	29.58	1.07	4.07	30.90	1.10	4.09
MnO	4.80	0.47	0.67	4.01	0.46	0.54
MgO	0.63	0.48	0.16	1.15	0.49	0.27
CaO	6.91	0.33	1.22	5.83	0.31	0.99
Na_2O	0.23	0.69	0.07	0.00	0.00	0.00
K_2O	0.02	0.16	0.00	0.00	0.00	0.00
Cl	0.03	0.13	0.01	0.01	0.11	0.00
TOTAL	99.77		16.06	101.60		15.91

	BG87_G8b	+/- 2 σ	Number of ions on the basis of 24 (O)	BG87_G8c	+/- 2 σ	Number of ions on the basis of 24 (O)
SiO_2	37.07	0.77	5.98	37.60	0.77	6.13
TiO_2	0.21	0.27	0.03	0.00	0.00	0.00
Al_2O_3	20.53	0.67	3.90	19.94	0.67	3.83
FeO	30.15	1.08	4.06	29.39	1.07	4.01
MnO	4.25	0.48	0.58	4.61	0.49	0.64
MgO	1.06	0.48	0.26	0.80	0.48	0.19
CaO	7.07	0.33	1.22	6.59	0.33	1.15
Na_2O	0.00	0.00	0.00	0.00	0.00	0.00
K_2O	0.22	0.16	0.05	0.00	0.00	0.00
Cl	0.07	0.13	0.02	0.03	0.14	0.01
TOTAL	100.64		16.09	98.97		15.96

	BG87_G9a	+/- 2 σ	Number of ions on the basis of 24 (O)	BG87_G9b	+/- 2 σ	Number of ions on the basis of 24 (O)
SiO_2	36.65	0.77	6.03	37.22	0.79	6.04
TiO_2	0.18	0.27	0.02	0.02	0.24	0.00
Al_2O_3	20.27	0.68	3.93	20.01	0.69	3.83
FeO	30.53	1.08	4.20	30.27	1.10	4.11
MnO	3.62	0.45	0.50	3.99	0.46	0.55
MgO	0.96	0.50	0.24	1.24	0.48	0.30
CaO	6.00	0.32	1.06	6.89	0.34	1.20
Na_2O	0.00	0.00	0.00	0.00	0.00	0.00
K_2O	0.03	0.16	0.01	0.14	0.16	0.03
Cl	0.05	0.13	0.01	0.04	0.14	0.01
TOTAL	99.29		16.00	99.83		16.07

	BG87_G9c	+/- 2 σ	Number of ions on the basis of 24 (O)	BG87_G10a	+/- 2 σ	Number of ions on the basis of 24 (O)
SiO_2	36.94	0.78	6.02	37.85	0.78	6.08
TiO_2	0.26	0.28	0.03	0.12	0.27	0.01
Al_2O_3	20.09	0.69	3.86	20.85	0.68	3.95
FeO	30.68	1.11	4.18	34.56	1.14	4.64
MnO	4.26	0.47	0.59	0.48	0.32	0.07
MgO	0.65	0.49	0.16	1.25	0.49	0.30
CaO	6.78	0.33	1.18	5.00	0.30	0.86
Na_2O	0.01	0.28	0.00	0.00	0.00	0.00
K_2O	0.02	0.16	0.00	0.13	0.16	0.03
Cl	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	99.69		16.02	100.24		15.94

	BG87_G10b	+/- 2 σ	Number of ions on the basis of 24 (O)	BG87_G10c	+/- 2 σ	Number of ions on the basis of 24 (O)
SiO_2	36.74	0.77	5.99	36.94	0.77	6.04
TiO_2	0.23	0.27	0.03	0.24	0.28	0.03
Al_2O_3	20.64	0.68	3.97	20.02	0.67	3.86
FeO	34.44	1.14	4.70	33.91	1.12	4.63
MnO	0.67	0.33	0.09	0.75	0.35	0.10
MgO	0.98	0.50	0.24	0.99	0.48	0.24
CaO	5.55	0.31	0.97	6.30	0.32	1.10
Na_2O	0.00	0.00	0.00	0.00	0.00	0.00
K_2O	0.00	0.15	0.00	0.08	0.16	0.02
Cl	0.09	0.13	0.02	0.07	0.14	0.02
TOTAL	99.36		16.02	99.29		16.04

	BG87_G11a	+/- 2 σ	Number of ions on the basis of 24 (O)	BG87_G11b	+/- 2 σ	Number of ions on the basis of 24 (O)
SiO_2	37.74	0.78	6.06	37.41	0.78	5.99
TiO_2	0.05	0.27	0.01	0.24	0.27	0.03
Al_2O_3	21.01	0.69	3.97	21.04	0.69	3.97
FeO	34.42	1.14	4.62	34.46	1.13	4.61
MnO	0.09	0.31	0.01	0.00	0.00	0.00
MgO	1.95	0.51	0.47	1.84	0.51	0.44
CaO	4.64	0.29	0.80	5.37	0.31	0.92
Na_2O	0.08	0.74	0.03	0.27	0.70	0.08
K_2O	0.03	0.16	0.01	0.00	0.00	0.00
Cl	0.00	0.00	0.00	0.00	0.11	0.00
TOTAL	100.00		15.96	100.64		16.04

	BG87_G11c	+/- 2 σ	Number of ions on the basis of 24 (O)	BG107A_G1a	+/- 2 σ	Number of ions on the basis of 24 (O)
SiO_2	37.77	0.80	6.04	37.57	0.76	6.12
TiO_2	0.22	0.28	0.03	0.13	0.23	0.02
Al_2O_3	21.01	0.70	3.96	20.17	0.65	3.87
FeO	33.79	1.16	4.52	28.05	1.04	3.82
MnO	0.14	0.31	0.02	3.20	0.42	0.44
MgO	1.76	0.52	0.42	0.83	0.46	0.20
CaO	5.58	0.31	0.96	8.21	0.33	1.43
Na_2O	0.00	0.00	0.00	0.00	0.00	0.00
K_2O	0.11	0.17	0.02	0.08	0.16	0.02
Cl	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	100.38		15.96	99.24		15.93

	BG107A_G1b	+/- 2 σ	Number of ions on the basis of 24 (O)	BG107A_G1c	+/- 2 σ	Number of ions on the basis of 24 (O)
SiO_2	37.53	0.76	6.14	37.53	0.76	6.14
TiO_2	0.03	0.23	0.00	0.03	0.23	0.00
Al_2O_3	19.71	0.65	3.80	19.70	0.65	3.80
FeO	28.70	1.05	3.93	28.71	1.05	3.93
MnO	3.22	0.41	0.45	3.24	0.41	0.45
MgO	0.74	0.46	0.18	0.73	0.46	0.18
CaO	8.07	0.34	1.41	8.08	0.34	1.42
Na_2O	0.15	0.70	0.05	0.14	0.70	0.05
K_2O	0.09	0.16	0.02	0.09	0.16	0.02
Cl	0.06	0.13	0.02	0.06	0.13	0.02
TOTAL	99.31		16.00	99.31		16.00

	BG107A_G1d	+/- 2 σ	Number of ions on the basis of 24 (O)	BG107A_G2a	+/- 2 σ	Number of ions on the basis of 24 (O)
SiO_2	37.62	0.76	6.06	37.95	0.76	6.05
TiO_2	0.22	0.23	0.03	0.24	0.23	0.03
Al_2O_3	20.13	0.66	3.82	20.58	0.65	3.87
FeO	29.77	1.05	4.01	29.97	1.06	3.99
MnO	3.34	0.42	0.46	3.15	0.40	0.42
MgO	0.63	0.46	0.15	0.85	0.45	0.20
CaO	8.13	0.33	1.40	8.34	0.33	1.42
Na_2O	0.54	0.67	0.17	0.00	0.00	0.00
K_2O	0.00	0.00	0.00	0.08	0.16	0.02
Cl	0.00	0.00	0.00	0.03	0.13	0.01
TOTAL	100.37		16.09	101.19		16.01

	BG107A_G2b	+/- 2 σ	Number of ions on the basis of 24 (O)	BG107A_G2c	+/- 2 σ	Number of ions on the basis of 24 (O)
SiO_2	37.54	0.76	6.09	37.30	0.76	6.08
TiO_2	0.00	0.00	0.00	0.11	0.24	0.01
Al_2O_3	20.37	0.65	3.89	20.03	0.65	3.85
FeO	29.39	1.04	3.98	29.54	1.04	4.03
MnO	3.09	0.41	0.42	2.82	0.41	0.39
MgO	0.79	0.46	0.19	0.84	0.45	0.20
CaO	7.95	0.33	1.38	8.06	0.33	1.41
Na_2O	0.00	0.00	0.00	0.01	0.27	0.00
K_2O	0.02	0.16	0.00	0.00	0.00	0.00
Cl	0.02	0.13	0.00	0.00	0.00	0.00
TOTAL	99.17		15.97	98.71		15.98

	BG107A_G3a	+/- 2 σ	Number of ions on the basis of 24 (O)	BG107A_G3b	+/- 2 σ	Number of ions on the basis of 24 (O)
SiO_2	37.86	0.77	6.07	37.65	0.76	6.10
TiO_2	0.06	0.23	0.01	0.00	0.00	0.00
Al_2O_3	20.23	0.66	3.82	20.32	0.66	3.88
FeO	34.41	1.12	4.61	34.00	1.11	4.60
MnO	0.21	0.30	0.03	0.17	0.30	0.02
MgO	2.55	0.50	0.61	2.24	0.49	0.54
CaO	4.95	0.28	0.85	4.58	0.27	0.79
Na_2O	0.00	0.00	0.00	0.12	0.71	0.04
K_2O	0.01	0.14	0.00	0.12	0.16	0.03
Cl	0.01	0.13	0.00	0.01	0.11	0.00
TOTAL	100.29		16.01	99.21		16.00

	BG107A_G3c	+/- 2 σ	Number of ions on the basis of 24 (O)	BG108_G1a	+/- 2 σ	Number of ions on the basis of 24 (O)
SiO_2	37.60	0.77	6.07	38.10	0.78	6.03
TiO_2	0.00	0.20	0.00	0.00	0.00	0.00
Al_2O_3	20.45	0.66	3.89	21.34	0.68	3.98
FeO	34.03	1.10	4.59	28.62	1.06	3.79
MnO	0.50	0.31	0.07	2.86	0.43	0.38
MgO	2.45	0.50	0.59	0.97	0.47	0.23
CaO	4.49	0.27	0.78	9.18	0.37	1.56
Na_2O	0.00	0.00	0.00	0.00	0.00	0.00
K_2O	0.00	0.00	0.00	0.00	0.00	0.00
Cl	0.04	0.13	0.01	0.00	0.00	0.00
TOTAL	99.56		16.00	101.06		15.97

	BG108_G1b	+/- 2 σ	Number of ions on the basis of 24 (O)	BG108_G1c	+/- 2 σ	Number of ions on the basis of 24 (O)
SiO_2	37.18	0.77	6.00	37.38	0.78	5.97
TiO_2	0.00	0.00	0.00	0.32	0.28	0.04
Al_2O_3	20.94	0.68	3.98	20.89	0.68	3.93
FeO	29.12	1.06	3.93	28.52	1.04	3.81
MnO	3.08	0.43	0.42	2.87	0.43	0.39
MgO	1.00	0.48	0.24	0.92	0.48	0.22
CaO	8.33	0.36	1.44	9.60	0.38	1.64
Na_2O	0.00	0.00	0.00	0.28	0.69	0.09
K_2O	0.06	0.16	0.01	0.00	0.00	0.00
Cl	0.05	0.13	0.01	0.07	0.13	0.02
TOTAL	99.77		16.03	100.85		16.09

	BG108_G2a	+/- 2 σ	Number of ions on the basis of 24 (O)	BG108_G2b	+/- 2 σ	Number of ions on the basis of 24 (O)
SiO_2	38.64	0.81	6.15	38.32	0.81	6.14
TiO_2	0.34	0.23	0.04	0.30	0.23	0.04
Al_2O_3	20.59	0.72	3.86	20.49	0.72	3.87
FeO	28.90	1.05	3.85	28.89	1.05	3.87
MnO	2.38	0.38	0.32	2.32	0.39	0.32
MgO	0.41	0.54	0.10	0.40	0.54	0.10
CaO	9.04	0.36	1.54	9.06	0.36	1.56
Na_2O	0.00	0.00	0.00	0.00	0.00	0.00
K_2O	0.09	0.16	0.02	0.00	0.00	0.00
Cl	0.10	0.13	0.03	0.00	0.00	0.00
TOTAL	100.49		15.91	99.79		15.89

	BG108_G2c	+/- 2 σ	Number of ions on the basis of 24 (O)	BG108_G3a	+/- 2 σ	Number of ions on the basis of 24 (O)
SiO_2	37.77	0.81	6.11	37.82	0.80	6.08
TiO_2	0.32	0.23	0.04	0.00	0.00	0.00
Al_2O_3	20.30	0.72	3.87	20.75	0.72	3.93
FeO	28.53	1.04	3.86	31.64	1.08	4.25
MnO	2.20	0.39	0.30	3.18	0.42	0.43
MgO	0.25	0.54	0.06	0.98	0.55	0.24
CaO	9.59	0.37	1.66	5.94	0.31	1.02
Na_2O	0.00	0.00	0.00	0.01	0.36	0.00
K_2O	0.00	0.00	0.00	0.00	0.00	0.00
Cl	0.04	0.12	0.01	0.00	0.00	0.00
TOTAL	99.00		15.92	100.32		15.96

	BG108_G3b	+/- 2 σ	Number of ions on the basis of 24 (O)	BG108_G3c	+/- 2 σ	Number of ions on the basis of 24 (O)
SiO_2	38.06	0.80	6.15	38.13	0.80	6.06
TiO_2	0.22	0.23	0.03	0.21	0.23	0.02
Al_2O_3	20.50	0.71	3.90	21.48	0.73	4.02
FeO	30.60	1.06	4.13	30.96	1.09	4.11
MnO	3.27	0.41	0.45	3.23	0.41	0.44
MgO	0.64	0.54	0.15	0.79	0.56	0.19
CaO	6.13	0.31	1.06	6.22	0.31	1.06
Na_2O	0.00	0.00	0.00	0.00	0.00	0.00
K_2O	0.04	0.16	0.01	0.02	0.15	0.00
Cl	0.01	0.10	0.00	0.03	0.12	0.01
TOTAL	99.45		15.88	101.06		15.91

	BG108_G4a	+/- 2 σ	Number of ions on the basis of 24 (O)	BG108_G4b	+/- 2 σ	Number of ions on the basis of 24 (O)
SiO_2	38.89	0.81	6.17	38.65	0.81	6.10
TiO_2	0.33	0.23	0.04	0.00	0.00	0.00
Al_2O_3	20.60	0.72	3.86	21.35	0.73	3.97
FeO	33.22	1.12	4.41	33.26	1.12	4.39
MnO	1.29	0.34	0.17	1.08	0.34	0.14
MgO	0.84	0.55	0.20	1.28	0.56	0.30
CaO	5.88	0.31	1.00	5.90	0.31	1.00
Na_2O	0.00	0.00	0.00	0.00	0.00	0.00
K_2O	0.06	0.15	0.01	0.10	0.15	0.02
Cl	0.10	0.13	0.03	0.04	0.12	0.01
TOTAL	101.22		15.89	101.67		15.94

	BG108_G4c	+/- 2 σ	Number of ions on the basis of 24 (O)	BG108_G5a	+/- 2 σ	Number of ions on the basis of 24 (O)
SiO_2	37.12	0.80	6.09	38.40	0.81	6.13
TiO_2	0.33	0.23	0.04	0.24	0.23	0.03
Al_2O_3	20.04	0.73	3.87	21.04	0.73	3.96
FeO	32.98	1.10	4.52	32.94	1.11	4.40
MnO	1.13	0.33	0.16	0.96	0.33	0.13
MgO	0.90	0.55	0.22	1.56	0.56	0.37
CaO	5.94	0.31	1.04	4.93	0.29	0.84
Na_2O	0.00	0.00	0.00	0.00	0.00	0.00
K_2O	0.00	0.00	0.00	0.01	0.14	0.00
Cl	0.09	0.13	0.02	0.02	0.12	0.00
TOTAL	98.53		15.96	100.10		15.87

	BG108_G5b	+/- 2 σ	Number of ions on the basis of 24 (O)	BG108_G5c	+/- 2 σ	Number of ions on the basis of 24 (O)
SiO_2	38.53	0.81	6.11	38.08	0.81	6.09
TiO_2	0.00	0.00	0.00	0.29	0.22	0.03
Al_2O_3	21.00	0.72	3.93	21.11	0.73	3.98
FeO	32.87	1.11	4.36	32.46	1.11	4.34
MnO	0.80	0.33	0.11	0.66	0.33	0.09
MgO	2.30	0.57	0.54	1.89	0.57	0.45
CaO	5.11	0.29	0.87	5.16	0.29	0.88
Na_2O	0.00	0.00	0.00	0.00	0.00	0.00
K_2O	0.08	0.15	0.02	0.07	0.16	0.01
Cl	0.03	0.12	0.01	0.00	0.00	0.00
TOTAL	100.71		15.94	99.70		15.89

APPENDIX 6

Calculating the amount of garnet dissolution needed to account for an observed manganese anomaly

Several calculations must be made to determine the amount of garnet that would have had to be dissolved to account for the manganese anomaly observed in given sample. First the amount of manganese in the anomaly, X_a, can be calculated from using the following equation:

$$X_a = \left(\frac{4\pi}{3} r_{a+c}{}^3 - \frac{4\pi}{3} r_c{}^3 \right) Y_a \qquad \text{(Equation 1)}$$

where r_c is the radius of the core, r_{a+c} is the radius of the core plus the width of the anomaly and Y_a is the concentration of manganese in the anomaly. These three variables can be measured.

If X_b is the total amount of manganese in the garnet before is was dissolved then:

$$X_b = X_c + X_a \qquad \text{(Equation 2)}$$

where X_a is the amount of manganese in the anomaly, calculated from Equation 1, and X_c is the amount of manganese in the remaining core. X_c can be calculated from the equation:

$$X_c = \frac{4\pi}{3} r_c{}^3 Y_c \qquad \text{(Equation 3)}$$

where r_c is the radius of the core and Y_c is the concentration of manganese in the core. However, the concentration of manganese is not constant but decreases across the garnet. For simplicity this decrease is assumed to be roughly linear and can therefore be described by the equation:

$$Y_c = mr_c + C \qquad \text{(Equation 4)}$$

where m is slope of the line and C is the y-intercept. Values for m and C can be determined from microprobe analyses at known distances across the porphyroblast. Equation 3 can then be rewritten as:

$$X_c = \left(\frac{4\pi}{3} r_c^{\,3}\right)(mr_c + C) \qquad \text{(Equation 5)}$$

Assuming manganese decreased linearly across the whole porphyroblast a similar equation can be written for X_b, the total amount of manganese in the porphyroblast before dissolution:

$$X_b = \left(\frac{4\pi}{3} r_b^{\,3}\right)(mr_b + C) \qquad \text{(Equation 6)}$$

where r_b is the radius of the garnet before dissolution. This can be expanded to:

$$X_b = \frac{4\pi}{3}\left(mr_b^{\,4} + Cr_b^{\,3}\right) \qquad \text{(Equation 7)}$$

and rewritten in the standard polynomial equation form as:

$$mr_b^{\,4} + Cr_b^{\,3} - \frac{3X_b}{4\pi} = 0 \qquad \text{(Equation 8)}$$

Substituting in the value for X_b from Equation 2 and solving the equation for r_b gives the radius of the garnet prior to dissolution. Subtracting r_b from r_c gives the width of the shell of garnet that must have been dissolved to account for the observed manganese anomaly.

Example 1: Sample BG87

Based on the diameter of the core of the largest garnet sectioned r_c is taken to be 3.5mm. From the compositional maps the width of the anomaly is 0.1mm so r_{a+c} is 3.6mm, and based on microprobe data Y_a is 4.5%. By substituting these values into Equation 1, X_a is found to equal 0.71mm^3.

Based on microprobe measurements made from the core of the porphyroblast is can be seen that the manganese concentration decreases from 4.8% in the centre of the porphyroblast to 2.1% at the core rim boundary. The distance from the centre to the core-rim boundary is r_c, which is equal to 3.5mm. This gives a slope, m, of –0.0077 and a y-intercept, C, of 0.048. By substituting these values into Equation 5, X_c is found to equal 3.78mm^3.

Substituting the calculated values for X_a and X_c into Equation 2 gives a value for X_b of 0.71 + 3.78 = 4.49mm^3. Using this value, and the values for m and C calculated above, Equation 8 can be written as:

$$-0.0077r_b^4 + 0.048r_b^3 - 1.0719 = 0$$

Solving this equation using the polynomial quartic formula gives two "real" values for r_b, 3.92mm and 5.30mm. The smaller of these, 3.92mm, is taken as the actual radius of the garnet before dissolution. This radius is 0.32mm greater than r_c. This indicates that dissolving a shell of garnet approximately 0.32mm wide would have released sufficient manganese to account for the anomaly observed in sample BG87.

Example 2: Sample BG62

Sample BG62 is not as close to a sphere as BG87 but based on the average distance across the core of the largest garnet sectioned r_c is taken to be 2.0mm. From the compositional maps the width of the anomaly is 0.06mm so r_{a+c} is 2.06mm. Based on microprobe data Y_a is 4.4%. By substituting these values into Equation 1, X_a is found to equal 0.14mm^3. This is a minimum because in sample BG62 the anomaly extends along cracks and is therefore not well approximated by a sphere.

Based on microprobe measurements made from the core of the porphyroblast is can be seen that the manganese concentration decreases from 4.3% in the centre of the porphyroblast to 1.8% at the core rim boundary. The distance from the centre to the core-rim boundary is r_c, which is equal to 2.0mm. This gives a slope, *m*, of –0.0125 and

a y-intercept, *C*, of 0.043. By substituting these values into Equation 5, X_c is found to equal 0.60mm^3.

Substituting the calculated values for X_a and X_c into Equation 2 gives a value for X_b of 0.14 + 0.60 = 0.74mm^3. Using this value, and the values for m and C calculated above, Equation 8 can be written as:

$$-0.0125r_b^{\,4} + 0.043r_b^{\,3} - 0.1767 = 0$$

Solving this equation using the polynomial quartic formula gives two "real" values for r_b, 2.35mm and 2.79mm. The smaller of these, 2.35mm, is taken as the actual radius of the garnet before dissolution. This radius is 0.35mm greater than r_c. This indicates that dissolving a shell of garnet approximately 0.35mm wide would have released sufficient manganese to account for the anomaly observed in sample BG62.

APPENDIX 7

Length scale of diffusion calculations

The length scale of diffusion, *h*, depends upon the diffusion coefficient, *D*, and the time scale, *t*, according to the relationship (Spear, 1993):

$$h = \sqrt{Dt} \qquad \text{(Equation 1)}$$

The diffusion coefficient, D, can be calculated from the Ahrenius relationship (Spear, 1993):

$$D = D_o \exp\left(\frac{-\Delta E + \Delta VP}{RT}\right) \qquad \text{(Equation 2)}$$

where D_o is the pre-exponential constant and incorporates the activation entropy of diffusion, ΔE is activation energy for diffusion, ΔV is the activation volume for diffusion, R is the gas constant, P is the pressure and T is the temperature. Based on the experimental work of Chakraborty and Ganguly (1992) values for D_o, ΔE, and ΔV have been estimated for the intracrystalline diffusion of manganese in garnet:

$D_o = 5.1 \times 10^{-8}\ \mathrm{m^2\,s^{-1}}$

$\Delta E = 253420\ \mathrm{J\,mol^{-1}}$

$\Delta V = 6.0 \times 10^{-6}\ \mathrm{m^3\,mol^{-1}}$

The universal gas constant, R, is 8.3144 J mol^{-1} K^{-1}. The exact pressure and temperature conditions experienced by the samples in this study is not known but P-T work by Ratcliffe and Armstrong (1999) suggests peak metamorphic conditions in this area of 7.5 kbar and 530°C (803K). Substituting these values into Equation 2 gives:

$$D = 5.1\times10^{-8} \exp\left(\frac{-253420 + (6.0\times10^{-6}\times 7500)}{8.3144\times 803}\right)$$

$$D = 2.48\times10^{-23}\ \mathrm{m^2 s^{-1}}$$

Substituting this value into Equation 1 gives a length scale of diffusion of 2.8×10^{-5}m over one million years ($\approx 3.15\times10^{13}$ seconds).

References

Chakraborty, S. & Ganguly, J. 1992. Cation diffusion in aluminosilicate garnets: experimental determination in spessartine-almandine diffusion couples, evaluation of effective binary diffusion coefficients, and applications. Contributions to Mineralogy and Petrology 111.

Ratcliffe, N. M. & Armstrong, T. R. 1999. Bedrock geologic map of the West Dover and Jacksonville quadrangles, Windham County, Vermont. U.S. Geological Survey, Miscellaneous Investigations Series Map I-2552. scale 1:24,000.

Spear, F. S. 1993. Metamorphic Phase Equilibria and Pressure-Temperature-Time Paths. Mineralogical Society of America, Washington, D.C.

APPENDIX 8

NCMnKFMASH Datafile

```
%--------------------------------------------------

chl 5     % order-disorder model

      x(chl) 0.6378    % bulk Fe/(Fe+Mg)
      y(chl) 0.6759   % y = 1/2 = clinochlore-amesite
      Q(chl) 0.3240   % order parameter
      M(chl) 0.001410

 % --------------------------------------------------

  p(afchl) 1  1    1  2 -1  y -1  Q

  p(clin)  2  1    0  1  2  Q
              2    0  2 -2/5  x -2/5  M   3  1 -1  y

  p(daph)  1  2    0  1  2/5  x    3  1 -1  y

  p(ames)  1  1    0  2  1  y -1  Q

  p(mnchl) 1  2    0  1  2/5  M    3  1 -1  y

% --------------------------------------------------
  sf

  W(afch,clin)  18   0  0
  W(afchl,daph) 14.5 0  0
  W(afchl,ames) 20   0  0
  W(afchl,mnchl) 0   0  0
  W(clin,daph)   2.5 0  0
  W(clin,ames)  18   0  0
  W(clin,mnchl)  0      0  0
  W(daph,ames)  13.5 0  0
  W(daph,mnchl)  0   0  0
  W(ames,mnchl)  0   0  0

 % --------------------------------------------------
 13

  x(Fe,M23)  1  1    0  1  1  x
  x(Mg,M23)  1  1    1  2 -1  x -1  M
  x(Mn,M23)  1  1    0  1  1  M

  x(Al,M1)   1  1    0  2  1  y -1  Q
  x(Fe,M1)   1  2    0  1  1  x     1  2 -1  y  1  Q
  x(Mg,M1)   1  2    1  2 -1  x -1  M    1  2 -1  y  1  Q
  x(Mn,M1)   1  2    0  1  1  M     1  2 -1  y  1  Q

  x(Al,M4)   1  1    0  2  1  y  1  Q
  x(Fe,M4)   1  2    0  1  1  x     1  2 -1  y -1  Q
  x(Mg,M4)   1  2    1  2 -1  x -1  M    1  2 -1  y -1  Q
  x(Mn,M4)   1  2    0  1  1  M     1  2 -1  y -1  Q

  x(Al,T2)   1  1    0  1  1  y
  x(Si,T2)   1  1    1  1 -1  y
```

```
 % ------------------------------------------------

 afchl  1  4    x(Mg,M23) 4   x(Mg,M1) 1   x(Mg,M4) 1   x(Si,T2) 2
   check 0 0 0 0

 clin   4  5    x(Mg,M23) 4   x(Mg,M1) 1   x(Al,M4) 1   x(Al,T2) 1
x(Si,T2) 1
   check 0 1/2 1/2 0

 daph   4  5    x(Fe,M23) 4   x(Fe,M1) 1   x(Al,M4) 1   x(Al,T2) 1
x(Si,T2) 1
   check 1 1/2 1/2 0

 ames   1  4    x(Mg,M23) 4   x(Al,M1) 1   x(Al,M4) 1   x(Al,T2) 2
   check 0 1 0 0

 mnchl  4  5    x(Mn,M23) 4   x(Mn,M1) 1   x(Al,M4) 1   x(Al,T2) 1
x(Si,T2) 1
            check 0 1/2 1/2 1

% ------------------------------------------------

bi 5      % order-disorder model

 x(bi) 0.7330      % bulk Fe/(Fe + Mg +Mn)
 y(bi) 0.5452     % x(Al,M1)
 Q(bi) 0.1279    % 3(x - x(Fe,M2))
 M(bi) 0.0007511

% ------------------------------------------------

  p(phl)  2 2    1  2 -1  x -1  M   1  1 -1  y
            1    0  1 -2/3   Q

  p(ann)  1 1    0  2  1   x  -1/3  Q

  p(east) 1 1    0  1  1   y

  p(obi)  2 2    0  1 -1   x    0  1  1  y
            1    0  1  1   Q

  p(mnbi) 1 1    0  1  1   M

% ------------------------------------------------

  sf

  W(phl,ann)    9  0  0
  W(phl,east)  10  0  0
  W(phl,obi)    3  0  0
  W(phl,mnbi)   0  0  0
  W(ann,east)  -1  0  0
  W(ann,obi)    6  0  0
  W(ann,mnbi)   0  0  0
  W(east,obi)  10  0  0
  W(east,mnbi)  0  0  0
  W(obi,mnbi)   0  0  0

% ------------------------------------------------
  9     % no of site fractions
```

```
  x(Al,M1)  1 1    0  1  1   y

  x(Fe,M1)  2 2    0  1  1   x    1  1 -1  y
              1    0  1 2/3  Q

  x(Mg,M1)  2 2    1  2 -1   x -1  M   1  1 -1  y
              1    0  1 -2/3 Q

  x(Mn,M1)  1 1    0  1  1  M

  x(Fe,M2)  1 1    0  2  1  x -1/3  Q

  x(Mg,M2)  1 1    1  3 -1  x  1/3  Q -1  M

  x(Mn,M2)  1 1    0  1  1  M

  x(Al,T1)  1 1    1/2 1  1/2  y

  x(Si,T1)  1 1    1/2 1 -1/2  y

% --------------------------------------------------

      phl      4  4    x(Mg,M1) 1   x(Mg,M2) 2   x(Al,T1) 1   x(Si,T1)
1
         check 0 0 0 0

   ann      4  4    x(Fe,M1) 1   x(Fe,M2) 2   x(Al,T1) 1   x(Si,T1) 1
         check 1 0 0 0

   east     1  3    x(Al,M1) 1   x(Mg,M2) 2   x(Al,T1) 2
         check 0 1 0 0

   obi      4  4    x(Fe,M1) 1   x(Mg,M2) 2   x(Al,T1) 1   x(Si,T1) 1

         make       2   phl 2/3 ann 1/3
         DQF      -10.73  0  0
         check 1/3 0 1 0

   mnbi     4  4    x(Mn,M1) 1   x(Mn,M2) 2   x(Al,T1) 1   x(Si,T1) 1
                                    check 0 0 0 1



%--------------------------------------------------

st 3
     x(st) 0.8920
     M(st) 0.0462

  p(mst)   1 1      1  2 -1  x -1  M

  p(fst)   1 1      0  1  1  x

  p(mnst)         1 1                                0  1  1  M


  sf

  w(mst,fst) -8 0 0
  w(mst,mnst) 0 0 0
  w(fst,mnst) 0 0 0
```

```
  3  x(Mg)   1 1      1  2 -1  x -1  M

     x(Fe)   1 1      0  1  1  x

     x(Mn)              1 1                                  0  1  1  M

  mst     1  1      x(Mg)  4

  fst     1  1      x(Fe)  4

  mnst       1     1            x(Mn)  4

%-----------------------------------------------------

ctd 3
      x(ctd) 0.8665
      M(ctd) 0.007935

  p(mctd)   1 1      1  2 -1  x -1 M

  p(fctd)   1 1      0  1  1  x

  p(mnctd)  1 1      0  1  1  M

  sf

  w(mctd,fctd)  1 0 0
  w(mctd,mnctd) 0 0 0
  w(fctd,mnctd) 0 0 0

  3  x(Mg)   1 1      1  2 -1  x -1  M

     x(Fe)   1 1      0  1  1  x

     x(Mn)   1 1      0  1  1  M

  mctd     1  1      x(Mg)  1

  fctd     1  1      x(Fe)  1

  mnctd    1  1      x(Mn)  1

% ------------------------------------------------
% ternary plag: SF: symmetric

pl 3

   ca(pl) 0.1127
   k(pl) 0.01717

% ------------------------------------------------

  p(ab)    1 1    1 2 -1 k -1 ca
  p(an)    1 1    0 1  1 ca
  p(san)   1 1    0 1  1 k

% ------------------------------------------------
  sf

    w(aban)     0   0     0
```

```
    w(sanab) 15.3   0 0.225
    w(sanan)   45   0     0

% -----------------------------------------------
  3

  x(K)     1 1    0 1  1 k
  x(Na)    1 1    1 2 -1 k -1 ca
  x(Ca)    1 1    0 1  1 ca

% -----------------------------------------------

  abh      1 1     x(Na) 1
  an       1 1     x(Ca) 1
           DQF   6.01  -0.0035  0     % C1 plag
  san      1 1     x(K) 1



% Garnet ------------------------------------------

g 4
      F(g)   0.8851    % Fe/Fe+Mg+Ca+Mn
      C(g)   0.01911  % Ca/Fe+Mg+Ca+Mn
      M(g)   0.0139    % Mn/Fe+Mg+Ca+Mn

%-------------------------------------------------------------------
   p(alm)  1  1    0  1  1  F
   p(gr)   1  1    0  1  1  C
   p(spss) 1  1    0  1  1  M
   p(py)   1  1    1  3 -1  C -1  F -1  M

% -----------------------------------------------
   sf

   W(gr,alm)        0  0  0
   W(gr,py)        33  0  0
   W(gr,spss)       0  0  0
   W(alm,py)      2.5  0  0
   W(alm,spss)   0.24  0  0
   W(py,spss)     4.5  0  0

% -----------------------------------------------
   4

   x(Fe,M1)   1  1    0  1  1  F

   x(Ca,M1)   1  1    0  1  1  C

   x(Mn,M1)   1  1    0  1  1  M

    x(Mg,M1)   1  1    1  3 -1  C -1  F -1  M

% -----------------------------------------------

 alm     1  1      x(Fe,M1)  3
 check 1 0 0

 gr      1  1      x(Ca,M1)  3
 check 0 1 0
```

```
 spss    1  1      x(Mn,M1)  3
 check 0 0 1

 py      1  1      x(Mg,M1)  3
 check 0 0 0

% ------------------------------------------------------------
%---mucsovite with (Fe)celadonite, DQF paragonite mixing-------

mu 4
      x(mu) 0.5618 %Fe/Fe+Mg
      y(mu) 0.9645  %Al,T1
      N(mu) 0.1563 %Na/K+Na

% ------------------------------------------------

   p(mu)    1 1      0  2  1  y  -1  N

   p(cel)   1 2      1  1 -1  x       1  1 -1  y

   p(fcel)  1 2      0  1  1  x       1  1 -1  y

   p(pa)          1 1      0  1  1  N


% ------------------------------------------------

sf

W(mu,cel)      0   0   0
W(mu,fcel)     0   0   0
W(mu,pa)       12  0  0.4
W(cel,fcel)    0   0   0
W(cel,pa)      14  0  0.2
W(fcel,pa)     14  0  0.2

% ------------------------------------------------

7
   x(Na,A)        1 1      0  1   1  N

   x(K,A)      1 1      1  1  -1  N

      x(Al,M2A)   1 1      0  1   1  y

   x(Mg,M2A)   1 2      1  1  -1  x       1  1 -1  y

   x(Fe,M2A)   1 2      0  1   1  x       1  1 -1  y

   x(Al,T1)    1 1      0  1   1/2  y

   x(Si,T1)    1 1      1  1  -1/2  y


% ------------------------------------------------

      mu     4  4      x(K,A) 1            x(Al,M2A) 1    x(Al,T1) 1
x(Si,T1)  1
            check 0 1 0
      cel    1  3      x(K,A) 1            x(Mg,M2A) 1    x(Si,T1) 2
                  check 0 0 0
```

```
      fcel   1  3      x(K,A) 1             x(Fe,M2A) 1    x(Si,T1) 2
                  check 1 0 0
      pa     4  4      x(Na,A) 1      x(Al,M2A) 1    x(Al,T1) 1
x(Si,T1)  1
                        DQF 1.42  0  0.4
                        check 0 1 1

%-------------------------------------------------

zo ky sill prl kao and q H2O

*
fluidpresent yes
fluidexcess yes
setexcess q mu

calctatp ask

setdefTwindow yes  450 700
setdefPwindow yes  0.1   18

calcsdnle yes
pseudosection yes
%
% ------------------------------------------------
%           Al2O3 CaO    MgO    FeO   K2O    Na2O   MnO
setbulk yes 0.228 0.0199 0.0490 0.108 0.0465 0.0351 0.00148
% ------------------------------------------------

%dogmin yes
setiso ask
%setmodeiso yes
%zeromodeiso yes

project no

drawpd yes
moreprec yes

*
```

Bulk Rock XRF Analyses

Analyte	SiO2	TiO2	Al2O3	Fe2O3T	MnO	MgO	CaO	Na2O	K2O	P2O5	SO3	LOI	SUM
LINE	KA1,2	KA1,2	KA1,2	KA1,2	KA1,2	KA1,2	KA1,2	KA1,2	KA1,2	KA1,2	KA1,2		
CRYSTAL	InSb	LIF100	PET	LIF100	LIF100	OVO55	LIF100	OVO55	LIF100	GE	GE		
KV	40	50	40	50	50	40	50	30	50	40	40		
mA	60	50	60	50	50	60	50	90	50	60	60		
TIME(SEC)	45	90	65	90	90	40	50	65	25	35	240		
UNITS	%	%	%	%	%	%	%	%	%	%	%	%	%
SAMPLE													
BG53	45.1	1.28	32.5	10.3	0.09	1.55	0.44	2.00	3.49	0.12	bd	3.94	100.8
BG58B	65.2	0.91	17.5	7.12	0.02	1.63	0.68	0.97	3.73	0.16	bd	2.60	100.5
BG59	53.2	1.04	23.2	10.6	0.22	1.91	1.52	1.34	3.58	0.22	0.08	3.57	100.5
BG62	57.9	0.89	21.5	8.95	0.14	2.03	1.27	0.89	3.55	0.25	0.02	3.26	100.6
BG87	55.9	0.97	22.9	9.68	0.14	1.86	1.22	0.80	4.46	0.22	bd	2.58	100.8
BG107A	55.2	1.05	23.3	8.67	0.11	1.98	1.12	1.93	4.37	0.14	bd	2.64	100.5
BG108	60.2	0.77	21.1	8.36	0.15	1.28	0.83	1.30	3.13	0.23	bd	3.01	100.4

APPENDIX 10

Errors in compositional isopleth intersections

There are three main sources of error in calculating compositional isopleths – errors in determining the bulk composition, errors in determining the composition of the garnet porphyroblast core and errors in the calculations performed by THERMOCALC.

Bulk Composition

The bulk composition for each sample was determined by XRF analysis of a crushed fraction of the rock. There are two potential sources of error in these results. Firstly, there are analytical errors associated with the XRF analysis. Secondly, error may be introduced if the crushed fraction is not a representative sample of the bulk rock. This is particularly concerning in rocks where there are large porphyroblasts and/or the rock shows compositional banding. In these cases, a large rock sample (~ 2.5 kg) was crushed and a small fraction of this crushed material used for XRF analysis.

To illustrate the potential impact of errors in bulk composition on determining P-T intersections from garnet compositional isopleths, calculations were carried out for sample BG87 using five slightly different bulk compositions (Table X10-1). These compositions were created by taking the bulk composition for sample BG87, as measured by XRF, and increasing one of the elements used to calculate isopleths. Composition A has 10% more FeO than the measured composition for sample BG87, composition B has 10% more CaO than the measured composition for sample BG87, composition C has 10% more MnO than the measured composition for sample BG87 and composition D has 10% more MgO than the measured composition for sample BG87. Table X10-1 shows the different bulk compositions in mol %, as recalculated by

THERMOCALC to give a sum of 100% for the elements considered. This recalculation means the absolute increase in one element is balanced by a relative decrease in each of the other elements.

Figure X10-1 and Table X10-2 show the P-T values for the garnet isopleth intersections for each of the different bulk compositions. The spread in pressure values is from 4.5 kbar to 4.9 kbar and the spread in temperature values is from 517 °C to 524 °C. These results indicate that a variation in the bulk composition of 10% for one element can lead to an error of +/- 4 °C and +/- 0.2 kbar in the calculated garnet isopleth intersections.

Table X10-1: Bulk rock compositions used to evaluate the impact of variation in bulk composition on garnet isopleth intersections. For each bulk composition the element that has been increased is shown in bold.

	BG87	**A**	**B**	**C**	**D**
Al_2O_3	46.99	45.83	46.78	46.98	46.55
CaO	4.56	4.44	**4.99**	4.55	4.51
MgO	9.66	9.42	9.61	9.65	**10.52**
FeO	25.40	**27.25**	25.29	25.40	25.16
K_2O	9.93	9.68	9.88	9.93	9.83
Na_2O	3.04	2.97	3.03	3.04	3.01
MnO	0.41	0.40	0.41	**0.45**	0.41
TOTAL	100	100	100	100	100

Table X10-2: Garnet compositional isopleth intersections calculated for different bulk compositions.

	M(g),C(g)	C(g),F(g)	F(g),M(g)
BG87	4.8 kbar 520 °C	4.9 kbar 521 °C	4.6 kbar 521 °C
A	4.6 kbar 517 °C	4.7 kbar 517 °C	4.6 kbar 518 °C
B	4.6 kbar 519 °C	4.7 kbar 520 °C	4.5 kbar 520 °C
C	4.8 kbar 520 °C	4.9 kbar 521 °C	4.6 kbar 522 °C
D	4.8 kbar 522 °C	4.9 kbar 524 °C	4.6 kbar 524 °C

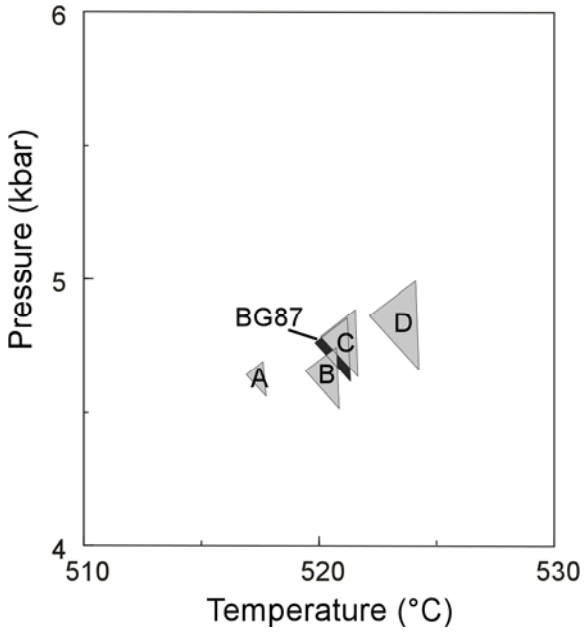


Figure X10-1: Garnet compositional isopleth intersections calculated for different bulk compositions. The original bulk composition (BG87) is shown in black and the four new bulk compositions (A-D) are shown in grey.

Garnet Composition

The garnet core composition for each sample was determined using the electron microprobe. The core of the porphyroblast was identified from manganese compositional maps. The area in the centre of the porphyroblast, showing the highest manganese content, was then probed three times and the results averaged. The 2σ error on each of the probe measurements is shown in Appendix 5.

To illustrate the potential impact of errors in garnet composition on determining P-T intersections from garnet compositional isopleths, calculations were carried out for sample BG87 using five slightly different core compositions. These compositions were created by taking the measured FeO, MnO, MgO and CaO values and increasing each of them, in turn, by the calculated 2σ error (Table X7-3). Composition A has more FeO than the measured garnet core composition for sample BG87, composition B has more CaO than the measured garnet core composition for sample BG87, composition C has more MnO than the measured garnet core composition for sample BG87 and composition D has more MgO than the measured garnet core composition for sample BG87. The created garnet compositions were then converted to molar values and used to calculate new values of F(g), M(g) and C(g) (Table X10-3). Finally, isopleth intersections were calculated from the new F(g), M(g) and C(g) values (Table X10-4 and Figure X10-2). The isopleth intersections show a spread in pressure values from 4.5 kbar to 5.0 kbar and a spread in temperature values from 519 °C to 522 °C. These results indicate that errors in the microprobe analyses of the garnet composition can lead to an error of +/- 2 °C and +/- 0.3 kbar in the calculated garnet isopleth intersections.

Table X10-3: Garnet core compositions used to evaluate the impact of variation in garnet composition on isopleth intersections. For each composition, the element that has been increased is shown in bold.

	BG87	+/- 2σ	A	B	C	D
FeO (wt%)	30.75	1.08	**31.83**	30.75	30.75	30.75
CaO (wt%)	6.45	0.33	6.45	**6.78**	6.45	6.45
MnO (wt%)	4.81	0.48	4.81	4.81	**5.29**	4.81
MgO (wt%)	0.81	0.48	0.81	0.81	0.81	**1.29**
F(g)	0.678		0.686	0.672	0.671	0.666
M(g)	0.107		0.105	0.117	0.105	0.106
C(g)	0.182		0.178	0.181	0.179	0.190

Table X10-4: Isopleth intersections calculated for different garnet compositions.

	M(g),C(g)	C(g),F(g)	F(g),M(g)
BG87	4.8 kbar 520 °C	4.9 kbar 521 °C	4.6 kbar 521 °C
A	4.7 kbar 521 °C	4.8 kbar 522 °C	4.5 kbar 522 °C
B	4.7 kbar 519 °C	4.8 kbar 520 °C	4.5 kbar 520 °C
C	4.7 kbar 520 °C	4.7 kbar 520 °C	4.8 kbar 520 °C
D	4.7 kbar 520 °C	5.0 kbar 520 °C	4.7 kbar 521 °C

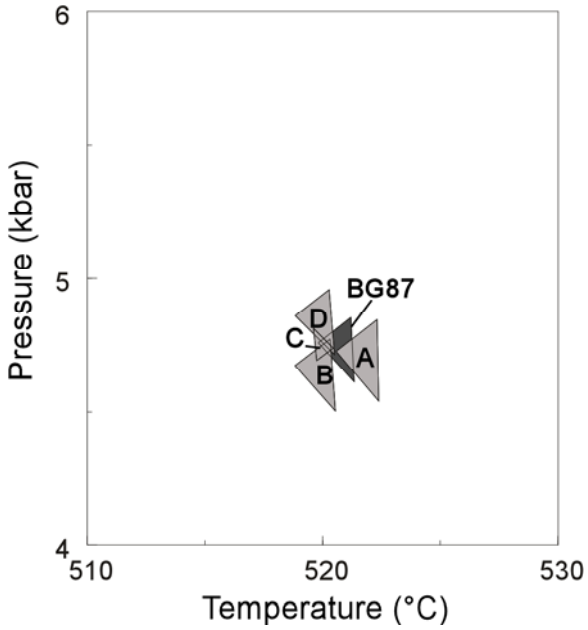


Figure X10-2: Compositional isopleth intersections calculated for different garnet compositions. The original garnet composition (BG87) is shown in black and the four new compositions (A-D) are shown in grey.

THERMOCALC calculations

THERMOCALC performs error propagation on all calculations based on the errors on the activities of the end-members and on the thermodynamic data. For garnet compositional isopleth intersections the 2σ errors reported by THERMOCALC are around +/- 0.5 kbar and +/- 14 °C (Table D-4). For comparative purposes the THERMOCALC 2σ errors for each of the isopleth intersections for sample BG87 are given in Table X10-5 and shown graphically in Figure X10-2.

Table X10-5: Isopleth intersections and errors calculated by THERMOCALC for sample BG87.

	P (kbar)	+/- 2σ	T (°C)	+/- 2σ
M(g),C(g)	4.8	0.6	520	12
C(g),F(g)	4.9	0.6	521	14
F(g),M(g)	4.6	0.4	521	14

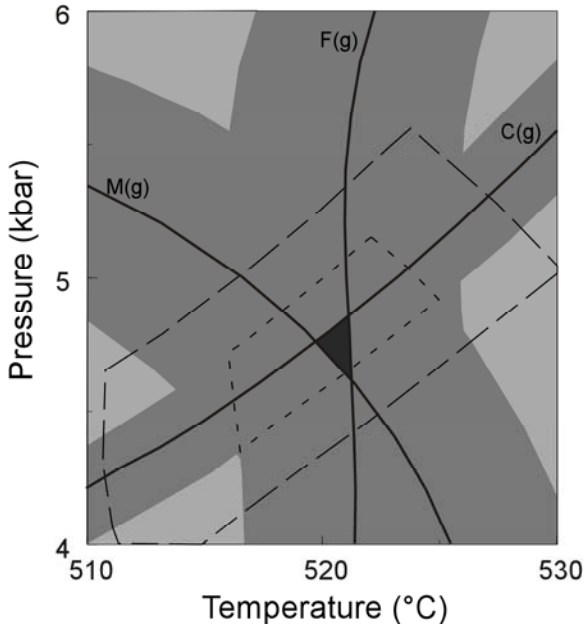


Figure X10-3: Garnet compositional isopleths calculated for sample BG87. The compositional isopleth intersection triangle is shown in black. The dark grey shading indicates the 1σ error on each isopleth, with the area of overlap shown by the dotted line. The light grey shading indicates the 2σ error on each isopleth, with the area of overlap shown by the dashed line.

Conclusions

The largest source of error in calculating compositional isopleths is the error on the activities of the end-members and on the thermodynamic data used by THERMOCALC. When these errors are propagated through THERMOCALC they give a 2σ error on the P-T intersections roughly twice as large as the combined errors associated with variations in the bulk rock composition and the garnet core composition. If all three of the potential sources of error are considered, the error on the P-T intersection points may be as large as +/- 1 kbar and +/- 20 °C.

APPENDIX 11

Specimen Collection List

JCU NUMBER	SAMPLE	LONGITUDE	LATITUDE	STANDARD VERTICAL THIN-SECTIONS	POLISHED VERTICAL THIN-SECTIONS	INCLINED THIN-SECTIONS (dip direction/dip)	BLOCKS
71107	BG3	43° 34' 18" N	72° 40' 36" W	000,030,060,090,120,150 010,020,140,160,170			18
71108	BG4	43° 35' 54" N	72° 40' 18" W	000,030,060,090,120,150 010,020			8
71109	BG6	43° 32' 06" N	72° 40' 27" W	000,030,060,090,120,150 160,170			18
71110	BG7	43° 31' 18" N	72° 41' 18" W	000,030,060,090,120,150 070,080		065/10, 065/20, 065/30, 245/10, 245/30	18
71111	BG8	43° 35' 30" N	72° 39' 48" W	000,030,060,090,120,150 160,170			18
71112	BG9	43° 35' 54" N	72° 40' 48" W	000,030,060,090,120,150 010,020			18
71113	BG11	43° 37' 06" N	72° 39' 48" W	000,030,060,090,120,150 160,170			18
71114	BG13	43° 28' 06" N	72° 40' 06" W	000,030,120,120 010, 020,040,070,100,110,130			18
71115	BG14	43° 28' 30" N	72° 39' 06" W	000,030,060,090,120,150 040,050,160,170			10
71116	BG15A	43° 23' 30" N	72° 40' 24" W	000,030,060,090,120,150 010,020,040,050,160,170			18
71117	BG17	43° 24' 00" N	72° 41' 30" W	000,030,060,090,120,150 020,040,070,160,170			18
71118	BG19	43° 37' 36" N	72° 41' 12" W	000,030,060,090,120,150 100,110		095/10, 095/20, 095/30, 275/10, 275/30	18
71119	BG20	43° 34' 18" N	72° 40' 06" W	000,030,060,090,120,150 010,020,170			18
71120	BG21	43° 34' 21" N	72° 40' 12" W	000,030,060,090,120,150 130,140,160,170			10
71121	BG24	43° 12' 54" N	72° 43' 18" W	000,030,060,090,120,150 160,170			18

71122	BG30	43° 19' 30" N	72° 42' 12" W	000,030,060,090,120,150 160,170			18
71123	BG32	43° 20' 12" N	72° 41' 06" W	000,030,060,090,120,150 070,080			18
71124	BG33	43° 14' 06" N	72° 42' 30" W	000,030,060,090,120,150 040,050		045/10, 045/20, 045/30, 225/10, 225/30	18
71125	BG35	43° 21' 36" N	72° 40' 36" W	000,030,060,090,120,150 160,170			8
71126	BG38	43° 00' 36" N	72° 46' 30" W	000,030,060,090,120,150 010,020	090,100,140		18
71127	BG40	43° 03' 30" N	72° 42' 00" W	000,030,060,090,120,150 140,160,170			18
71128	BG41A	43° 04' 00" N	72° 42' 00" W	000,030,060,090,120,150 010,020,160,170			18
71129	BG42	43° 06' 24" N	72° 41' 24" W	000,030,060,090,120,150 110,100,160			18
71130	BG43	43° 07' 42" N	72° 42' 18" W	000,030,060,090,120,150 070, 080			18
71131	BG44	43° 08' 24" N	72° 43' 06" W	000,030,060,090,120,150 130,140			18
71132	BG45	43° 08' 36" N	72° 41' 54" W	000,030,060,090,120,150 160,170			18
71133	BG46	43° 09' 06" N	72° 43' 18" W	000,030,060,090,120,150 040,050		215/10, 215/20, 215/30, 035/10, 035/30	18
71134	BG47	43° 01' 06" N	72° 46' 36" W	000,030,060,090,120,150 010,020,170			9
71135	BG48	43° 00' 06" N	72° 53' 00" W	000,030,060,090,120,150 160,170	090	175/10, 175/20, 175/30, 355/10, 355/30	18
71136	BG49	42° 56' 36" N	72° 48' 00" W	000,030,060,090,120,150 160,170			18
71137	BG50	42° 56' 42" N	72° 45' 06" W	000,030,060,090,120,150 160,170		160/10, 160/20, 160/30, 340/10, 340/30	18

71138	BG51	42° 58' 12" N	72° 46' 30" W	000,030,060,090,120,150 160,170			8
71139	BG52	42° 59' 54" N	72° 46' 36" W	000,030,060,090,120,150 010,020			18
71140	BG53	42° 52' 48" N	72° 56' 54" W	000,030,060,090,120,150 010,020	090		18
71141	BG54	42° 52' 36" N	72° 56' 36" W	000,030,060,090,120,150 010,170			18
71142	BG55	42° 52' 18" N	72° 57' 48" W	000,030,060,090,120,150 040,050,100,110,160	080		18
71143	BG56	42° 50' 12" N	72° 59' 30" W	000,030,060,090,120,150 040,050			18
71144	BG57B	42° 49' 36" N	72° 59' 06" W	000,030,060,090,120,150 160,170			18
71145	BG58B	42° 49' 18" N	72° 58' 48" W	000,030,060,090,120,150 040,050	110		18
71146	BG59	42° 48' 24" N	72° 58' 24" W	000,030,060,090,120,150 070,080	080	075/10, 075/20, 075/30, 255/10, 255/30	8
71147	BG60	42° 46' 18" N	72° 56' 48" W	000,030,060,090,120,150 010,020,160,170,040,050	130		18
71148	BG62	42° 45' 54" N	72° 54' 06" W	000,030,060,090,120,150 010,020,040,050	120,160		18
71149	BG66B	42° 51' 48" N	72° 45' 36" W	030,060,090,120,150 010,020,070,080,130,140			11
71150	BG69	42° 55' 00" N	72° 46' 36" W	030,060,090,120,150 010,170			18
71151	BG70	42° 55' 18" N	72° 46' 54" W	000,030,060,090,120,150 070,080	080		18
71152	BG71	42° 55' 42" N	72° 47' 06" W	000,030,060,090,120,150 010,070	070,100		18
71153	BG72	42° 56' 30" N	72° 46' 42" W	000,030,060,090,120,150 020,040			8

71154	BG78	42° 47' 48" N	72° 46' 06" W	000,030,060,090,120,150 010,020			18
71155	BG80	42° 46' 48" N	72° 48' 18" W	000,030,060,090,120,150 160,170			18
71156	BG81	42° 38' 48" N	72° 55' 18" W	000,030,060,090,120,150 160,170			18
71157	BG83	42° 41' 36" N	72° 52' 06" W	000,030,060,090,120,150 160,170			8
71158	BG84A	42° 40' 27" N	72° 53' 00" W	000,030,060,090,120,150 040,050			18
71159	BG85	42° 39' 42" N	72° 54' 06" W	000,030,060,090,120,150 160,170			18
71160	BG86	42° 42' 36" N	72° 55' 36" W	000,030,060,090,120,150 010,020			8
71161	BG87	42° 43' 54" N	72° 55' 54" W	000,030,060,090,120,150 010,020,040,050,070,080	110,140		18
71162	BG88	42° 41' 12" N	72° 58' 42" W	000,030,060,090,120,150 070,080	170		18
71163	BG94	42° 39' 48" N	72° 57' 48" W	000,030,060,090,120,150 040,050		035/10, 035/20, 035/30, 215/10, 215/30	18
71164	BG102B	42° 31' 54" N	72° 56' 06" W	000,030,060,090,120,150 070,080,100,110,160,170	030,070	165/10, 165/30, 165/40, 165/50, 345/10, 345/30	12
71165	BG104	42° 38' 12" N	73° 05' 30" W	000,030,060,090,120,150 070,080,100,130,140,160,170	070		13
71166	BG105A	43° 19' 42" N	72° 48' 30" W	000,030,060,090,120,150 130,140,160,170	070		10
71167	BG107A	43° 03' 30" N	72° 46' 18" W	000,030,060,090,120,150 040,050,070,080,130,140	050		18
71168	BG108	43° 03' 12" N	72° 47' 00" W	000,030,060,090,120,150 080,100,110,140,160,170	010		18