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

VOLUME II

Thesis submitted by

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SECTION D

Pressure and temperature conditions during garnet growth in southeastern Vermont

List of Tables and Figures

Table D-1: Mineral assemblages

	Inclusions in garnet porphyroblasts		Matrix
	Core	**Rim**	
BG53	Qtz Pl Ctd Ap Ilm Rt	Qtz Pl Ctd Ap Ilm	Qtz Pl Mu Chl Ctd Bi Ilm Tur St Grt
BG58B	Qtz Pl Mu Chl Ctd Ilm Rt	Qtz Pl Mu Chl Ctd Ilm Rt	Qtz Pl Mu Chl Bi Ilm Tur Grt
BG59	Qtz Pl Mu Ctd Ap Rt	Qtz Pl Mu Ctd Ap Rt	Qtz Pl Mu Chl Ctd Bi Tur Grt
BG62	Qtz Pl Ctd Ilm Rt	Qtz Pl Ctd Ilm Rt	Qtz Pl Mu Chl Ilm Tur Grt
BG87	Qtz Pl Mu Chl Ctd Ilm Rt Ep	Qtz Pl Mu Chl Ilm Ep Tur	Qtz Pl Mu Chl Bi Ilm Ep Tur Grt
BG107A	Qtz Pl Chl Ap Ilm Rt	Qtz Pl Chl Ap Ilm	Qtz Pl Mu Chl Ilm Grt
BG108	Qtz Pl Mu Chl Ctd Ap Ilm Rt	Qtz Pl Mu Chl Ctd Ap Ilm Tur	Qtz Pl Mu Chl Ctd Ap Ilm Tur Gt

Mineral abbreviations are: quartz (Qtz); plagioclase (Pl); muscovite (Mu); chloritoid (Ctd); chlorite (Chl); biotite (Bi); apatite (Ap); ilmenite (Ilm); rutile (Rt); tourmaline (Tur); epidote (Ep); staurolite (St); garnet (Grt)

Table D-2: Bulk rock compositions used to calculate P-T pseudosections.

	BG53	BG58B	BG59	BG62	BG87	BG107A	BG108
Al_2O_3	56.02	46.24	45.45	46.6	46.99	46.73	48.38
CaO	1.38	3.27	5.42	5.00	4.56	4.07	3.46
MgO	6.76	10.9	9.47	11.15	9.66	10.02	7.20
FeO	22.70	24.06	26.55	24.84	25.40	22.20	27.20
K_2O	6.53	10.70	7.61	8.38	9.93	9.51	7.78
Na_2O	6.39	4.75	4.87	3.58	3.04	7.17	5.52
MnO	0.22	0.08	0.62	0.45	0.47	0.30	0.47
MgO/FeO	0.298	0.453	0.357	0.449	0.38	0.451	0.265
Na_2O+K_2O+CaO	14.30	18.72	17.90	16.96	17.53	20.75	16.76

Table D-3: Average garnet core compositions used to calculate isopleths.

	BG53	BG58B	BG59	BG62	BG87	BG107A	BG108
SiO_2	37.45	37.70	38.00	37.75	37.18	37.56	37.55
TiO_2	0.00	0.28	0.09	0.14	0.10	0.10	0.11
Al_2O_3	20.90	20.60	20.20	20.61	19.85	19.93	21.06
FeO	32.08	31.79	30.20	29.22	30.36	28.81	28.75
MnO	2.46	1.21	3.74	4.33	4.81	3.25	2.94
MgO	1.36	1.10	1.21	0.89	0.75	0.73	0.96
CaO	5.26	6.87	6.38	6.99	6.60	8.12	9.04
Total	99.51	99.54	99.80	99.91	99.65	98.51	100.41

Table D-4: Garnet core compositional isopleth intersections

	BG58B (FIA 1)				BG59 (FIA 2)			
	P (kbar)	**+/- 2σ**	**T (°C)**	**+/- 2σ**	**P (kbar)**	**+/- 2σ**	**T (°C)**	**+/- 2σ**
M(g),C(g)	6.4	0.6	532	12	5.7	0.6	524	12
C(g),F(g)	6.5	0.6	533	14	5.7	0.6	524	12
F(g),M(g)	6.4	0.4	532	14	5.7	0.4	524	12
	BG62 (FIA 3.5)				**BG87 (FIA 1)**			
	P (kbar)	**+/- 2σ**	**T (°C)**	**+/- 2σ**	**P (kbar)**	**+/- 2σ**	**T (°C)**	**+/- 2σ**
M(g),C(g)	5.5	0.6	525	12	4.8	0.6	520	12
C(g),F(g)	5.7	0.6	528	12	4.9	0.6	521	14
F(g),M(g)	5.3	0.4	528	14	4.6	0.4	521	14
	BG107A (FIA 3)				**BG108 (FIA 2)**			
	P (kbar)	**+/- 2σ**	**T (°C)**	**+/- 2σ**	**P (kbar)**	**+/- 2σ**	**T (°C)**	**+/- 2σ**
M(g),C(g)	7.3	0.6	519	12	7.0	0.6	508	14
C(g),F(g)	7.7	0.6	521	12	6.9	0.6	508	14
F(g),M(g)	7.2	0.4	522	14	7.0	0.6	507	12

M(g),C(g) = intersection of the manganese isopleth and the calcium isopleth
C(g),F(g) = intersection of the calcium isopleth and the iron isopleth
F(g),M(g) = intersection of the iron isopleth and the manganese isopleth

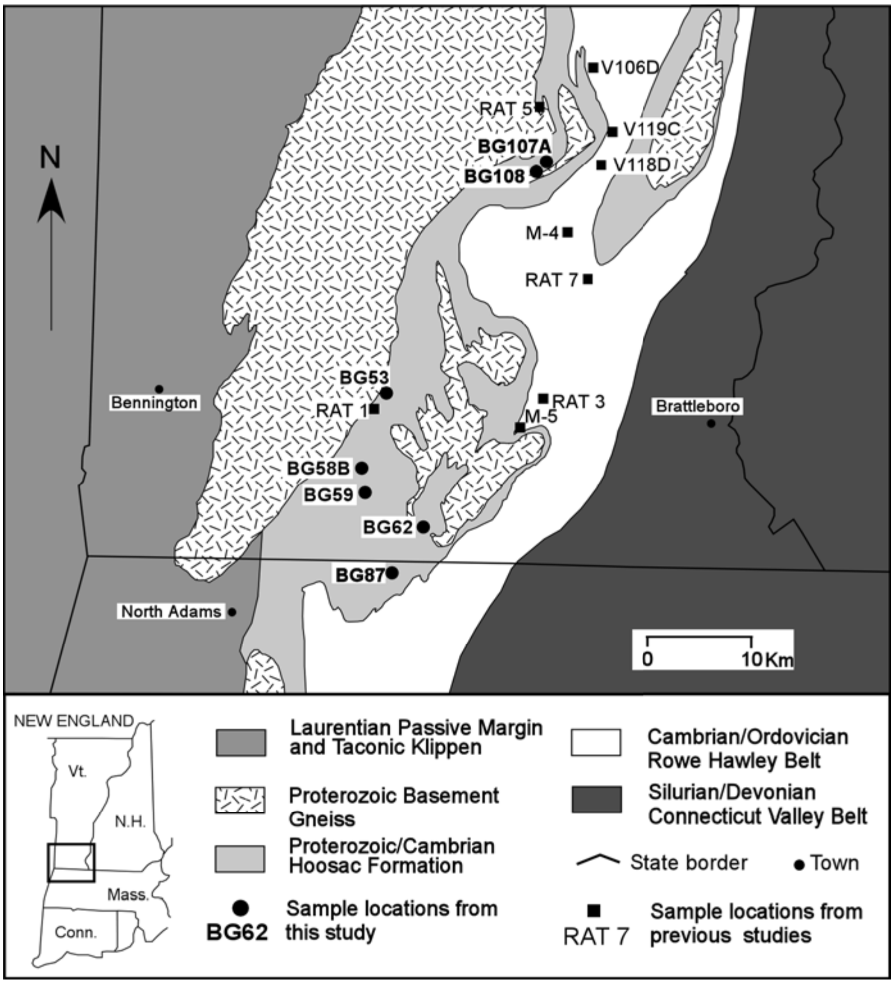
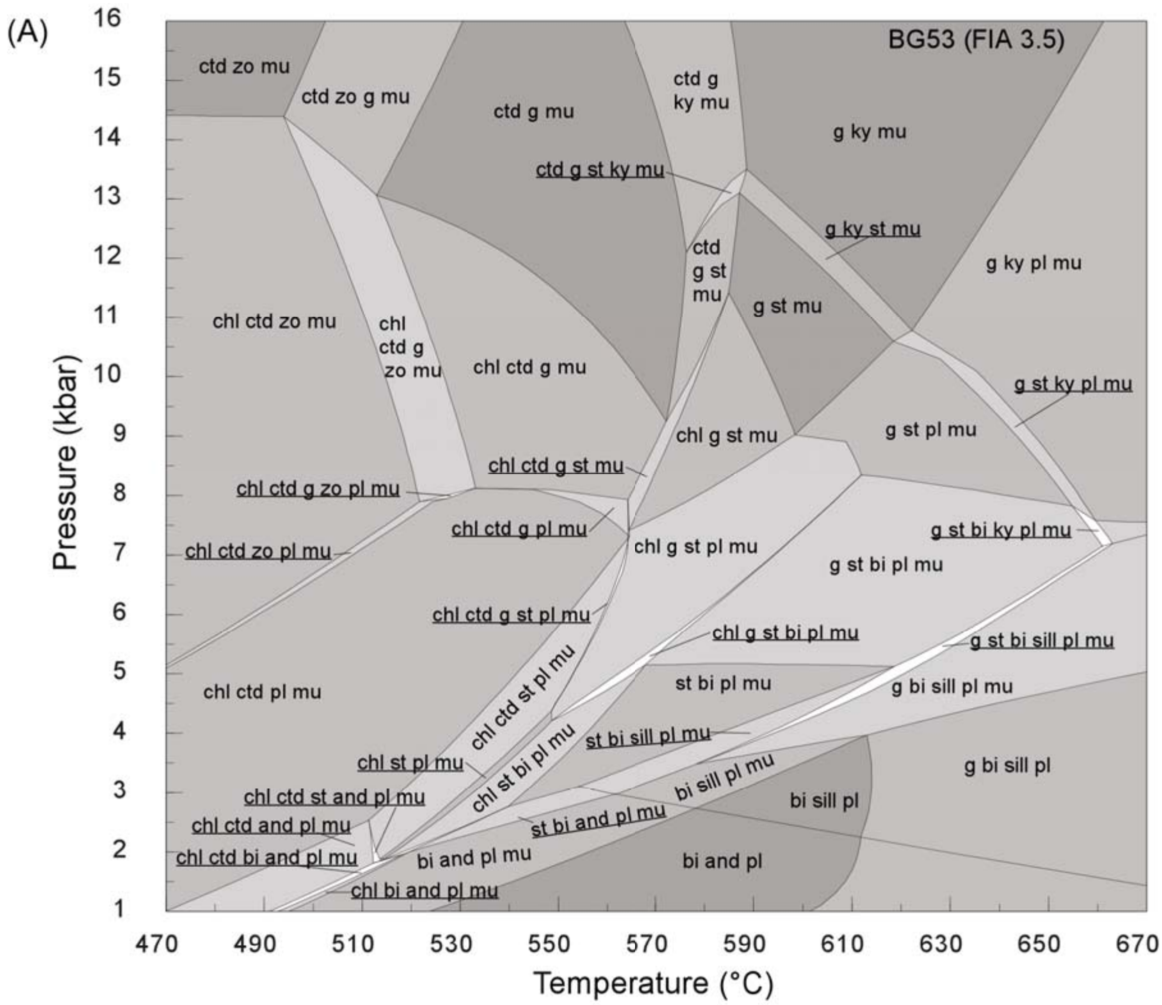


Figure D-1: Map showing the location of samples from this study and of samples from earlier studies mentioned in Figure D-12. Regional geology is based on Doll et al. (1961) and Zen et al. (1983).


(A)
BG53 (FIA 3.5)
ctd zo mu
ctd zo g mu
ctd g mu
ctd g ky mu
g ky mu
ctd g st ky mu
g ky st mu
g ky pl mu
ctd g st mu
g st mu
chl ctd zo mu
chl ctd g zo mu
chl ctd g mu
g st ky pl mu
chl g st mu
g st pl mu
chl ctd g st mu
chl ctd g zo pl mu
chl ctd g pl mu
g st bi ky pl mu
chl ctd zo pl mu
chl g st pl mu
g st bi pl mu
chl ctd g st pl mu
chl g st bi pl mu
g st bi sill pl mu
chl ctd st pl mu
st bi pl mu
g bi sill pl mu
chl ctd pl mu
chl st bi pl mu
st bi sill pl mu
chl st pl mu
g bi sill pl
chl ctd st and pl mu
bi sill pl mu
bi sill pl
chl ctd and pl mu
st bi and pl mu
chl ctd bi and pl mu
bi and pl mu
bi and pl
chl bi and pl mu
Pressure (kbar)
Temperature (°C)

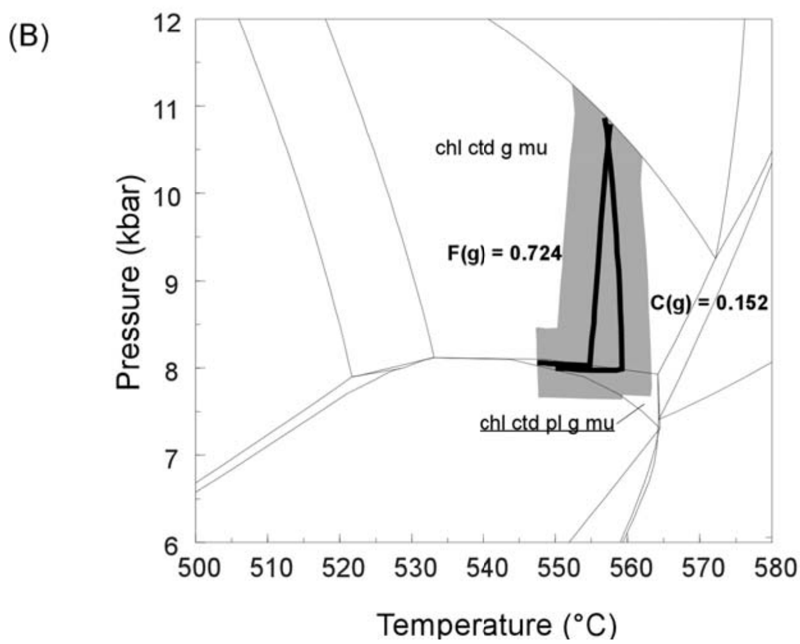
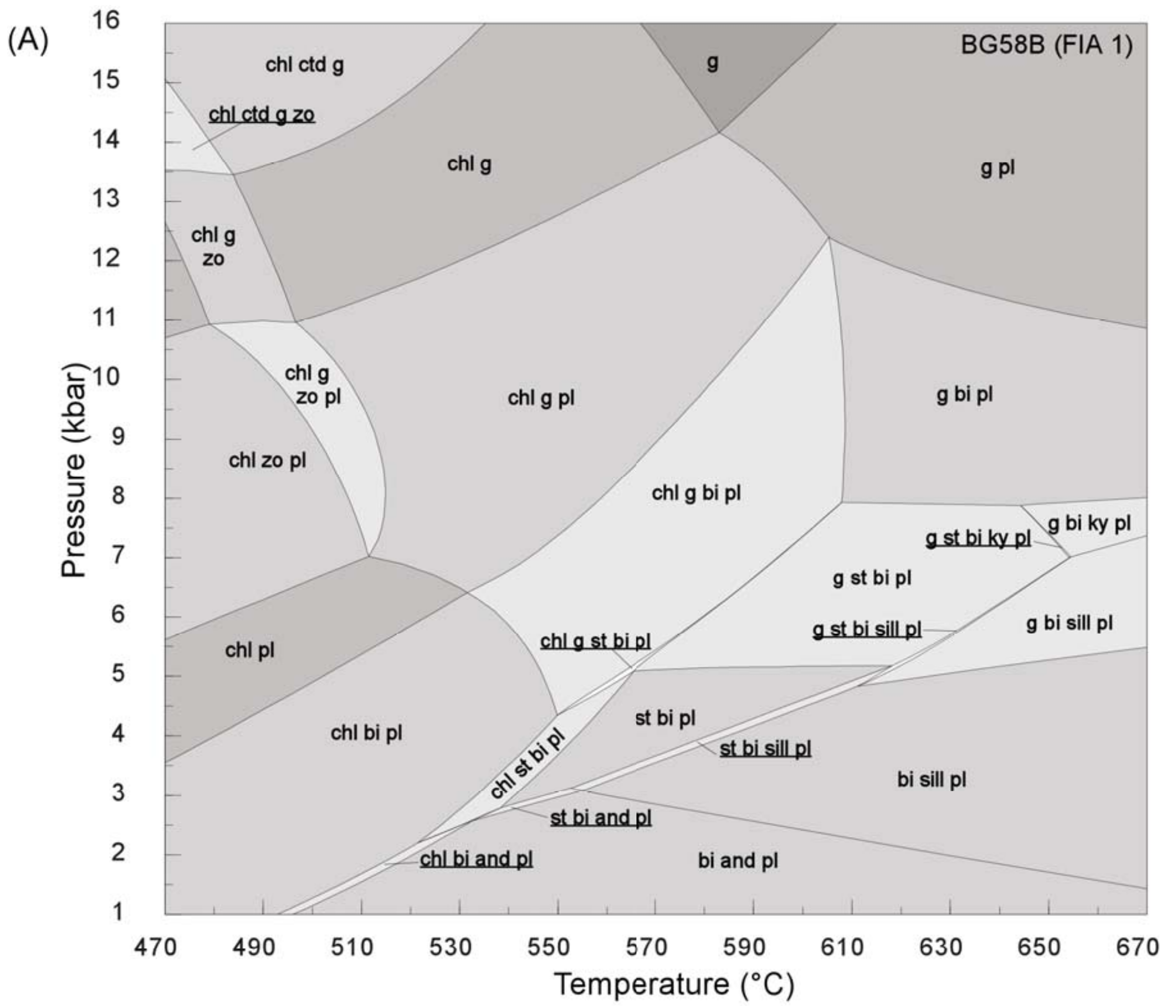

(B)
chl ctd g mu
F(g) = 0.724
C(g) = 0.152
chl ctd pl g mu
Pressure (kbar)
Temperature (°C)

Figure D-2: NCMnKFMASH Pseudosection for sample BG53.
A: Diagram showing the stability of different mineral assemblages. Quartz, and water are in excess. See text for mineral abbreviations. Shading indicates the variance of the different assemblages with the highest variance fields shown in white and the lowest variance fields shown in dark grey.
B: Compositional isopleths for the measured garnet core composition. Light shading around isopleths indicates the magnitude of uncertainty (σ) on the lines, as determined from THERMOCALC uncertainty propagation calculations. The isopleth for M(g) = 0.078 is not shown because this composition is not stable on the pseudosection.


(A)
BG58B (FIA 1)
chl ctd g
chl ctd g zo
g
chl g
g pl
chl g zo
chl g zo pl
chl g pl
g bi pl
chl zo pl
chl g bi pl
g bi ky pl
g st bi ky pl
g st bi pl
chl pl
chl g st bi pl
g st bi sill pl
g bi sill pl
st bi pl
chl bi pl
st bi sill pl
chl st bi pl
bi sill pl
st bi and pl
chl bi and pl
bi and pl
Pressure (kbar)
Temperature (°C)

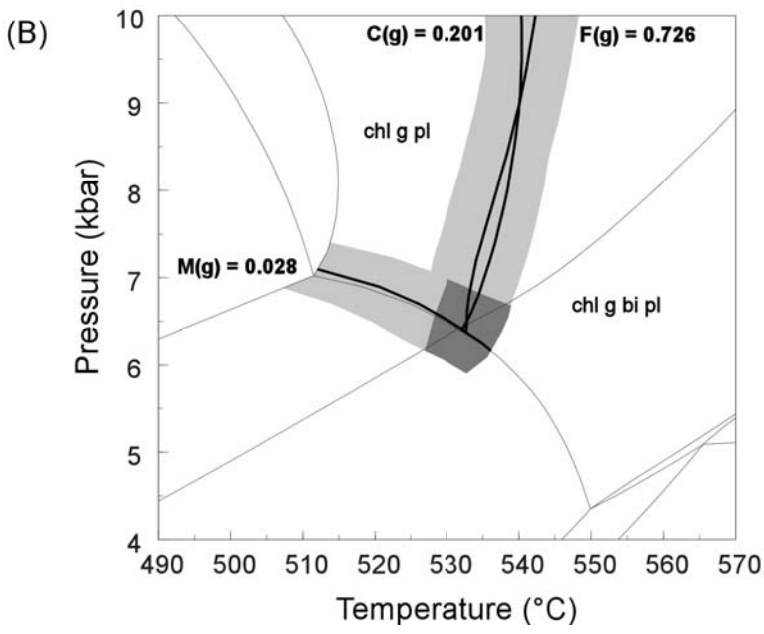

(B)
C(g) = 0.201
F(g) = 0.726
chl g pl
M(g) = 0.028
chl g bi pl
Pressure (kbar)
Temperature (°C)

Figure D-3: NCMnKFMASH Pseudosection for sample BG58B.
A: Diagram showing the stability of different mineral assemblages. Quartz, muscovite and water are in excess. See text for mineral abbreviations. Shading indicates the variance of the different assemblages with the highest variance fields shown in white and the lowest variance fields shown in dark grey.
B: Compositional isopleths for the measured garnet core composition. Light shading around isopleths indicates the magnitude of uncertainty (σ) on the lines, as determined from THERMOCALC uncertainty propagation calculations. Dark shading indicates the area of overlap of all three isopleths.

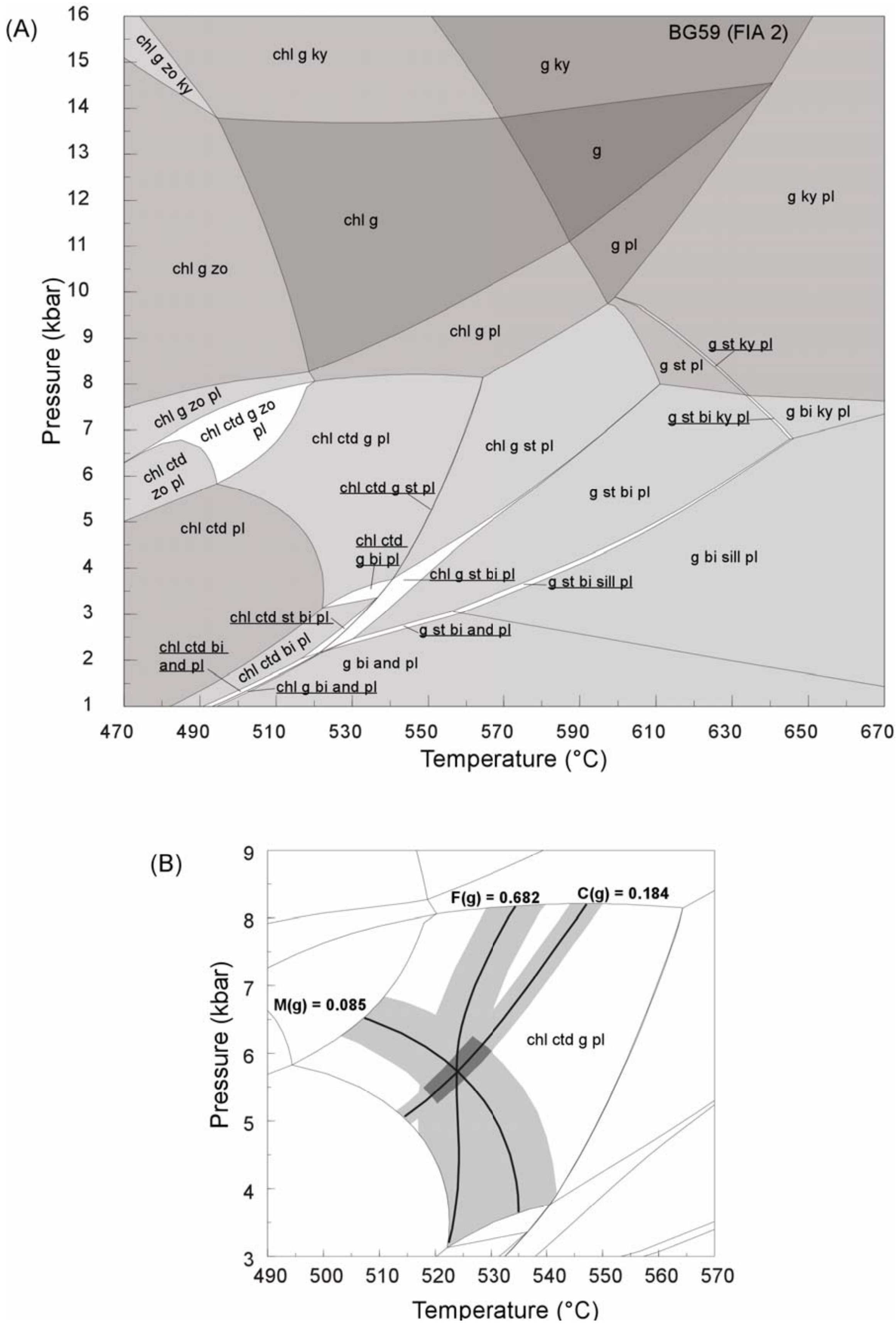
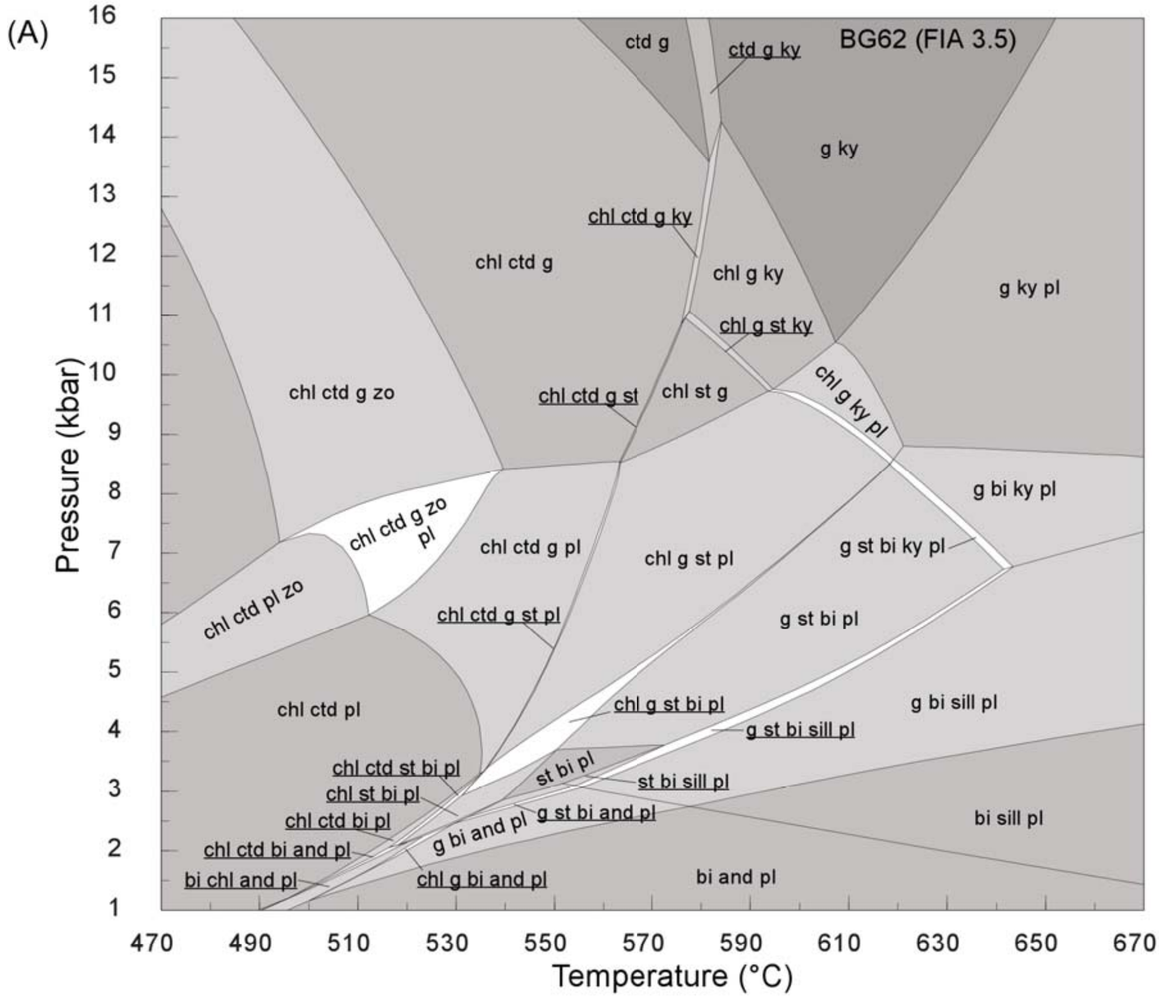

(A)
BG59 (FIA 2)
chl g zo ky
chl g ky
g ky
g
chl g
g ky pl
chl g zo
g pl
chl g pl
g st ky pl
g st pl
chl g zo pl
chl ctd g zo pl
chl ctd g pl
chl g st pl
g st bi ky pl
g bi ky pl
chl ctd zo pl
chl ctd g st pl
g st bi pl
chl ctd pl
chl ctd g bi pl
chl g st bi pl
g st bi sill pl
g bi sill pl
chl ctd st bi pl
g st bi and pl
chl ctd bi and pl
chl ctd bi pl
g bi and pl
chl g bi and pl
Pressure (kbar)
Temperature (°C)
(B)
F(g) = 0.682
C(g) = 0.184
M(g) = 0.085
chl ctd g pl
Pressure (kbar)
Temperature (°C)

Figure D-4: NCMnKFMASH Pseudosection for sample BG59.
A: Diagram showing the stability of different mineral assemblages. Quartz, muscovite and water are in excess. See text for mineral abbreviations. Shading indicates the variance of the different assemblages with the highest variance fields shown in white and the lowest variance fields shown in dark grey.
B: Compositional isopleths for the measured garnet core composition. Light shading around isopleths indicates the magnitude of uncertainty (σ) on the lines, as determined from THERMOCALC uncertainty propagation calculations. Dark shading indicates the area of overlap of all three isopleths.


(A)
BG62 (FIA 3.5)
ctd g
ctd g ky
g ky
chl ctd g ky
chl ctd g
chl g ky
g ky pl
chl g st ky
chl ctd g zo
chl ctd g st
chl st g
chl g ky pl
g bi ky pl
chl ctd g zo pl
chl ctd g pl
chl g st pl
g st bi ky pl
chl ctd pl zo
chl ctd g st pl
g st bi pl
chl ctd pl
chl g st bi pl
g bi sill pl
g st bi sill pl
st bi pl
chl ctd st bi pl
st bi sill pl
chl st bi pl
g st bi and pl
bi sill pl
chl ctd bi pl
g bi and pl
chl ctd bi and pl
bi chl and pl
chl g bi and pl
bi and pl
Pressure (kbar)
Temperature (°C)

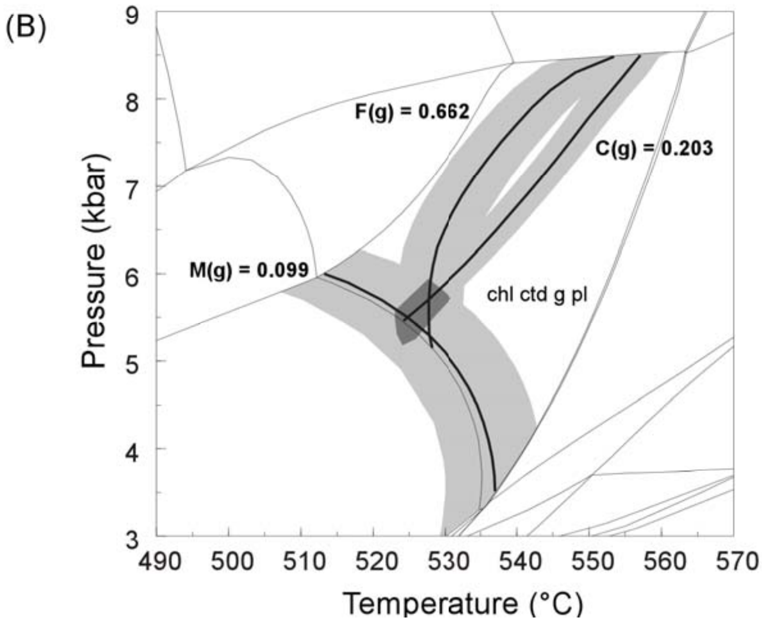
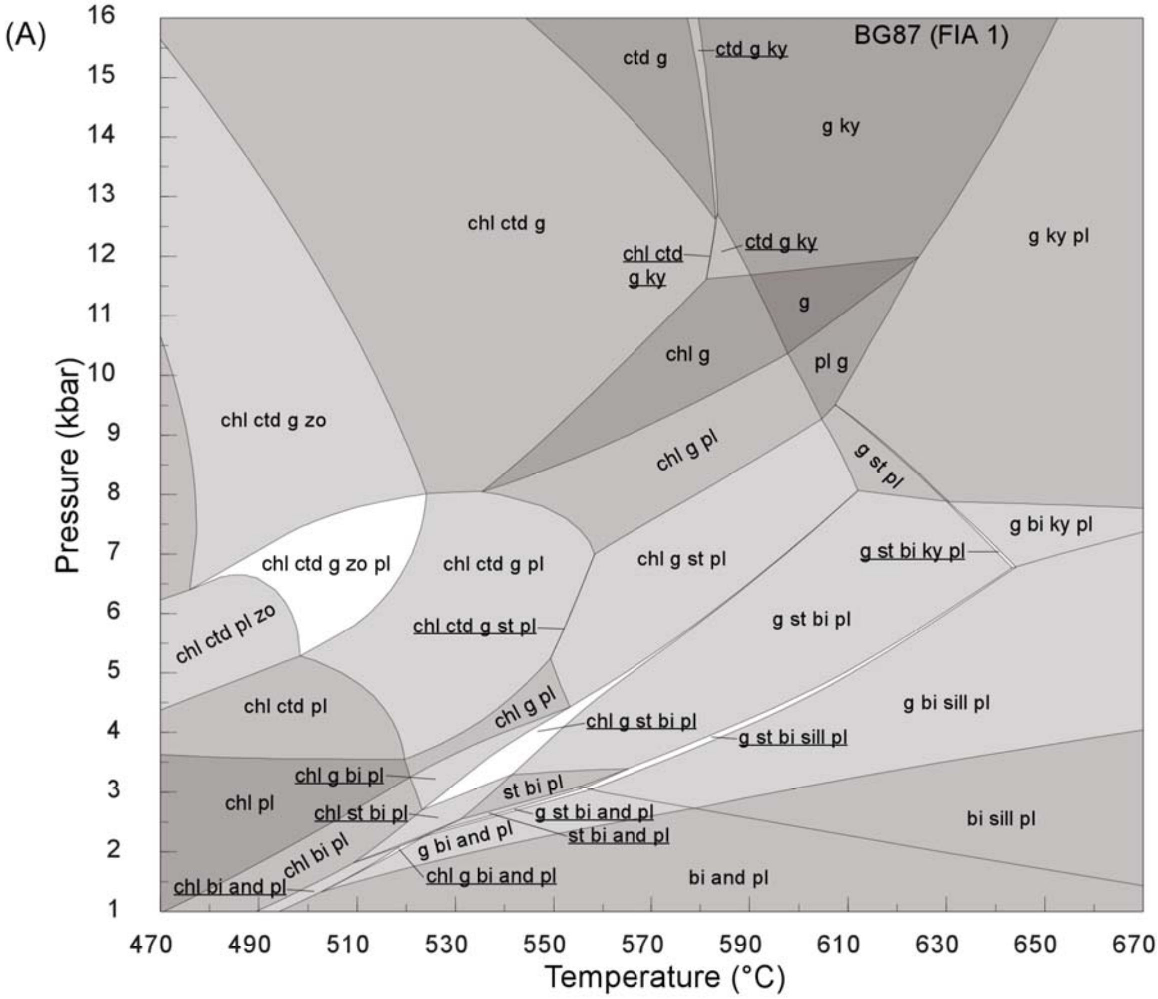

(B)
F(g) = 0.662
C(g) = 0.203
M(g) = 0.099
chl ctd g pl
Pressure (kbar)
Temperature (°C)

Figure D-5: NCMnKFMASH Pseudosection for sample BG62.
A: Diagram showing the stability of different mineral assemblages. Quartz, muscovite and water are in excess. See text for mineral abbreviations. Shading indicates the variance of the different assemblages with the highest variance fields shown in white and the lowest variance fields shown in dark grey.
B: Compositional isopleths for the measured garnet core composition. Light shading around isopleths indicates the magnitude of uncertainty (σ) on the lines, as determined from THERMOCALC uncertainty propagation calculations. Dark shading indicates the area of overlap of all three isopleths.


(A)
BG87 (FIA 1)
ctd g
ctd g ky
g ky
chl ctd g
chl ctd g ky
ctd g ky
g ky pl
g
chl g
pl g
chl ctd g zo
chl g pl
g st pl
g bi ky pl
chl ctd g zo pl
chl ctd g pl
chl g st pl
g st bi ky pl
chl ctd pl zo
chl ctd g st pl
g st bi pl
chl ctd pl
chl g pl
chl g st bi pl
g bi sill pl
g st bi sill pl
chl g bi pl
chl pl
st bi pl
chl st bi pl
g st bi and pl
st bi and pl
bi sill pl
g bi and pl
chl bi pl
chl g bi and pl
chl bi and pl
bi and pl
Pressure (kbar)
Temperature (°C)

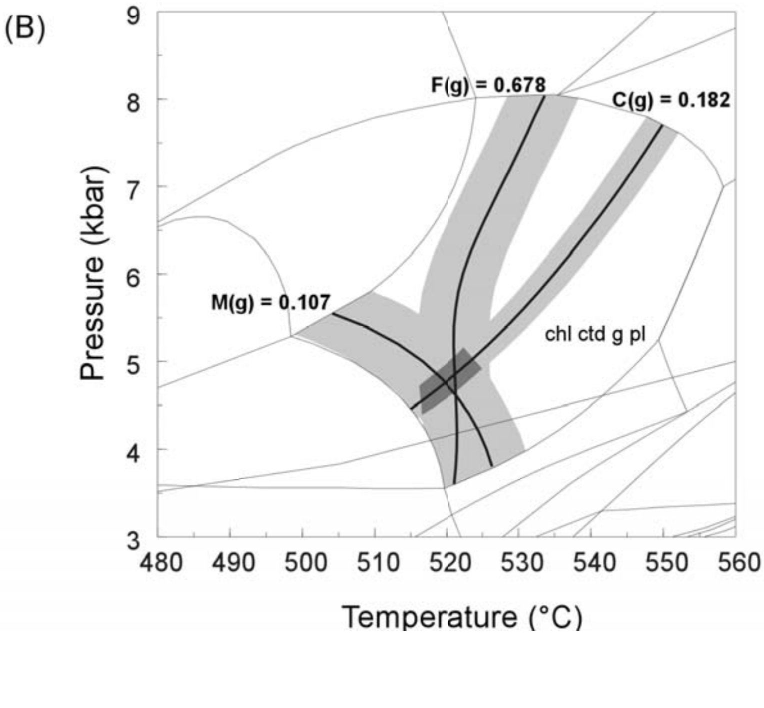
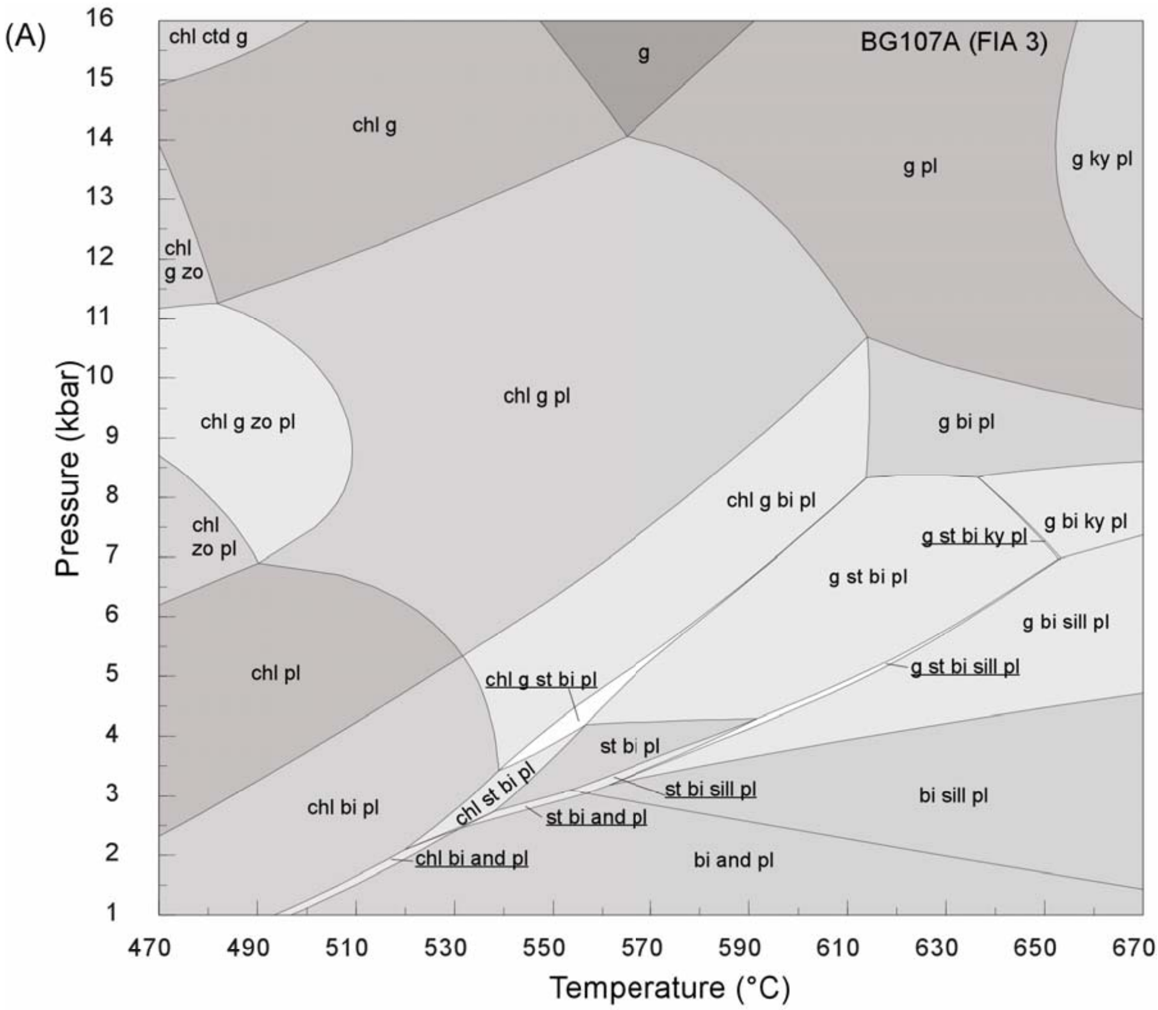

(B)
F(g) = 0.678
C(g) = 0.182
M(g) = 0.107
chl ctd g pl
Pressure (kbar)
Temperature (°C)

Figure D-6: NCMnKFMASH Pseudosection for sample BG87.
A: Diagram showing the stability of different mineral assemblages. Quartz, muscovite and water are in excess. See text for mineral abbreviations. Shading indicates the variance of the different assemblages with the highest variance fields shown in white and the lowest variance fields shown in dark grey.
B: Compositional isopleths for the measured garnet core composition. Light shading around isopleths indicates the magnitude of uncertainty (σ) on the lines, as determined from THERMOCALC uncertainty propagation calculations. Dark shading indicates the area of overlap of all three isopleths.


(A)
BG107A (FIA 3)
chl ctd g
g
chl g
g pl
g ky pl
chl g zo
chl g pl
chl g zo pl
g bi pl
chl g bi pl
chl zo pl
g bi ky pl
g st bi ky pl
g st bi pl
g bi sill pl
chl pl
chl g st bi pl
g st bi sill pl
st bi pl
chl st bi pl
st bi sill pl
bi sill pl
chl bi pl
st bi and pl
chl bi and pl
bi and pl
Pressure (kbar)
Temperature (°C)

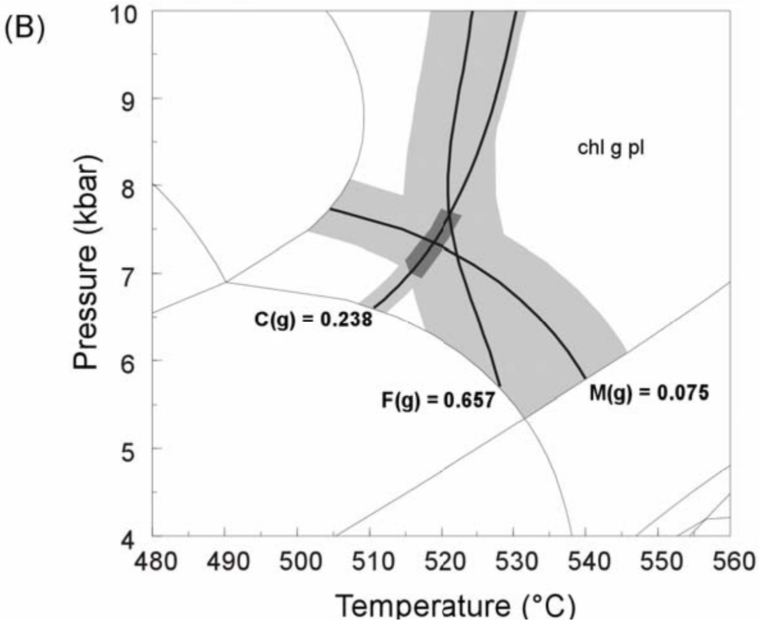
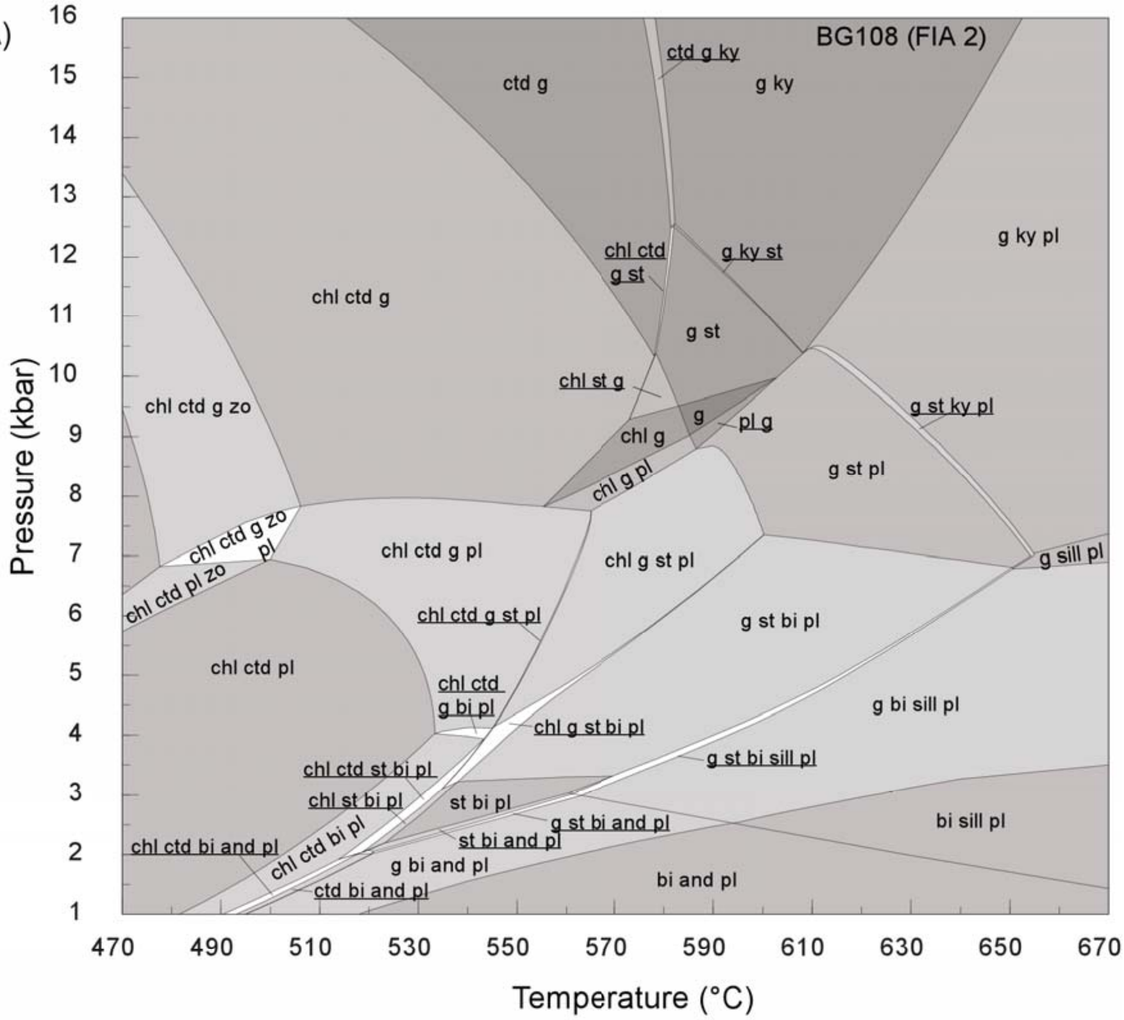

(B)
chl g pl
C(g) = 0.238
F(g) = 0.657
M(g) = 0.075
Pressure (kbar)
Temperature (°C)

Figure D-7: NCMnKFMASH Pseudosection for sample BG107A.
A: Diagram showing the stability of different mineral assemblages. Quartz, muscovite and water are in excess. See text for mineral abbreviations. Shading indicates the variance of the different assemblages with the highest variance fields shown in white and the lowest variance fields shown in dark grey.
B: Compositional isopleths for the measured garnet core composition. Light shading around isopleths indicates the magnitude of uncertainty (σ) on the lines, as determined from THERMOCALC uncertainty propagation calculations. Dark shading indicates the area of overlap of all three isopleths.

(A)


BG108 (FIA 2)
ctd g ky
ctd g
g ky
g ky pl
chl ctd
g st
g ky st
chl ctd g
g st
chl st g
chl ctd g zo
g
pl g
g st ky pl
chl g
chl g pl
g st pl
chl ctd g zo pl
chl ctd g pl
chl g st pl
g sill pl
chl ctd pl zo
chl ctd g st pl
g st bi pl
chl ctd pl
chl ctd
g bi pl
g bi sill pl
chl g st bi pl
g st bi sill pl
chl ctd st bi pl
chl st bi pl
st bi pl
g st bi and pl
bi sill pl
chl ctd bi and pl
st bi and pl
chl ctd bi pl
g bi and pl
bi and pl
ctd bi and pl
Pressure (kbar)
Temperature (°C)

(B)

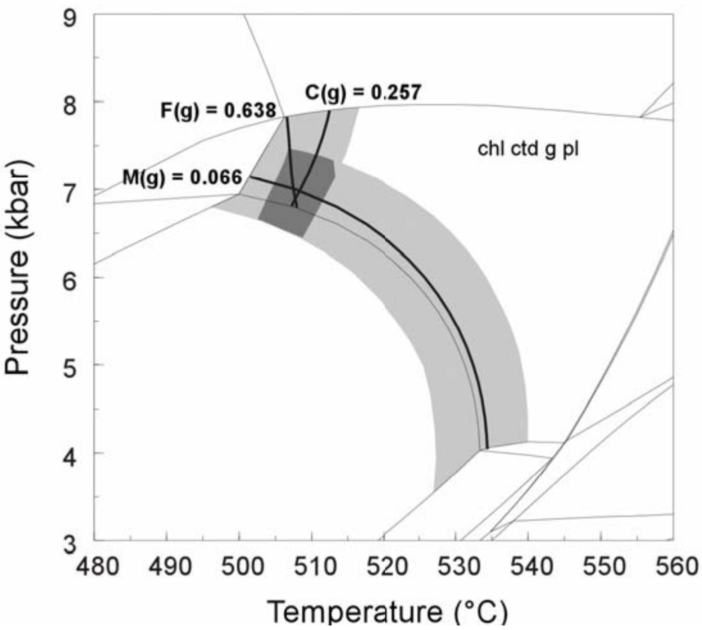

C(g) = 0.257
F(g) = 0.638
chl ctd g pl
M(g) = 0.066
Pressure (kbar)
Temperature (°C)

Figure D-8: NCMnKFMASH Pseudosection for sample BG108.
A: Diagram showing the stability of different mineral assemblages. Quartz, muscovite and water are in excess. See text for mineral abbreviations. Shading indicates the variance of the different assemblages with the highest variance fields shown in white and the lowest variance fields shown in dark grey.
B: Compositional isopleths for the measured garnet core composition. Light shading around isopleths indicates the magnitude of uncertainty (σ) on the lines, as determined from THERMOCALC uncertainty propagation calculations. Dark shading indicates the area of overlap of all three isopleths.

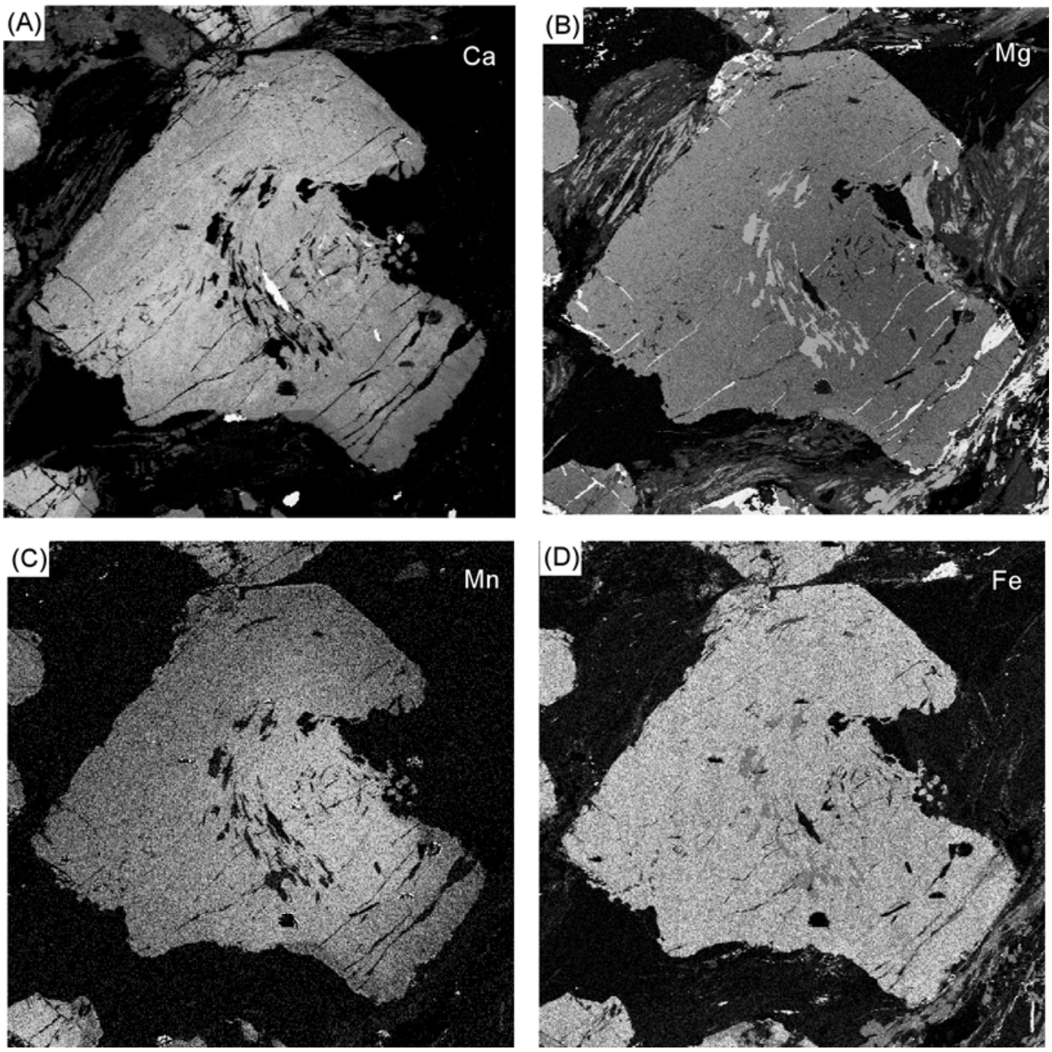


Figure D-9: Electron microprobe compositional maps of a garnet porphyroblast from sample BG53. Images show an area 7mm across. High counts are white, low counts are black. Images have been individually processed to enhance contrast.
A: Calcium compositional map
B: Magnesium compositional map
C: Manganese compositional map
D: Iron compositional map

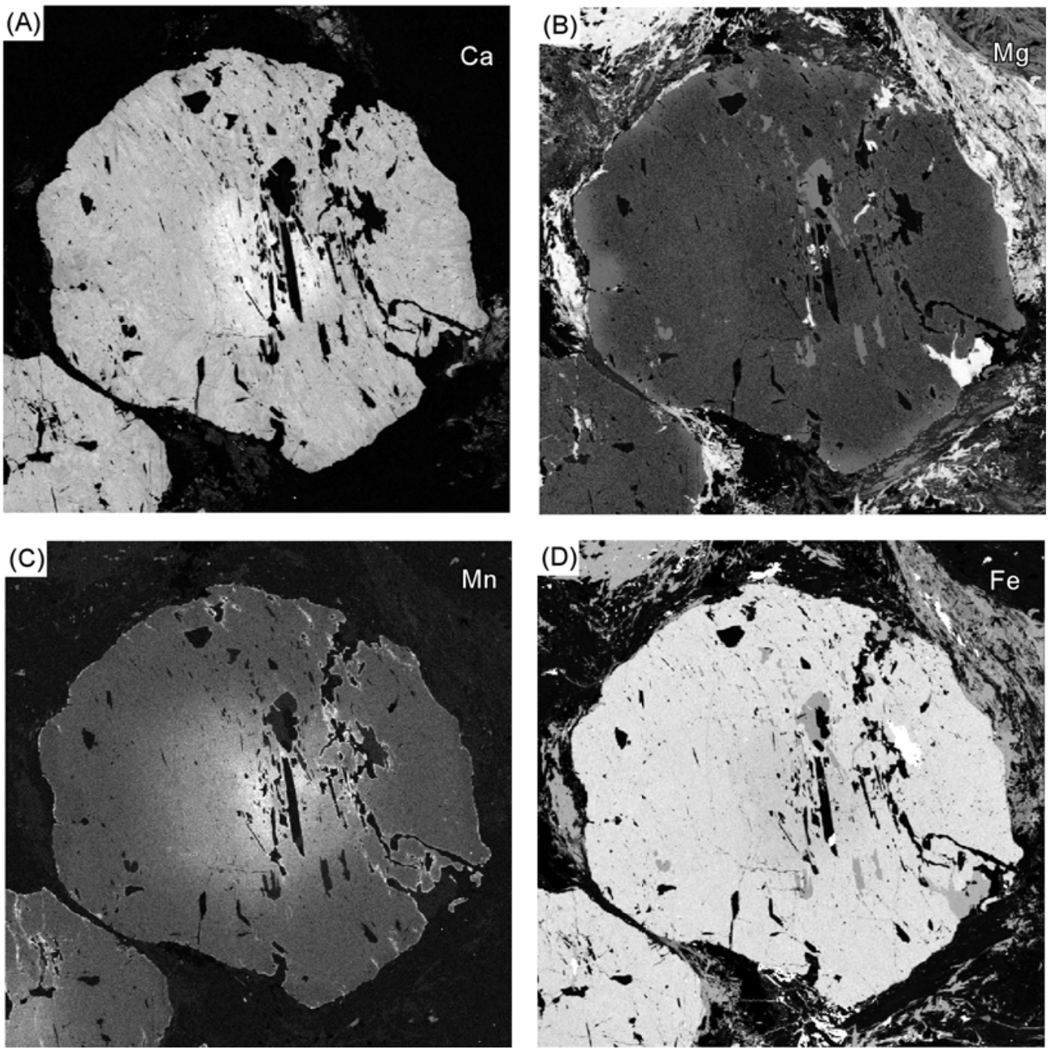


Figure D-10: Electron microprobe compositional maps of a garnet porphyroblast from sample BG58B. Images show an area 7mm across. High counts are white, low counts are black. Images have been individually processed to enhance contrast.
A: Calcium compositional map
B: Magnesium compositional map
C: Manganese compositional map
D: Iron compositional map

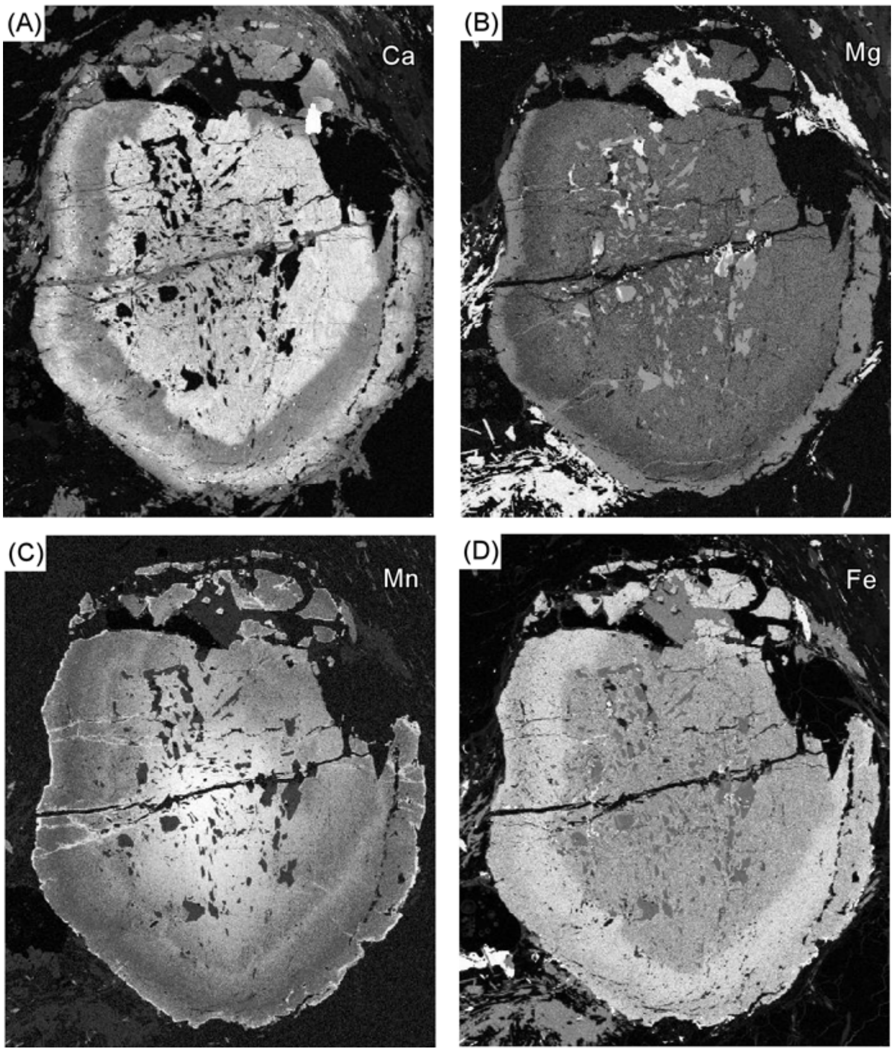
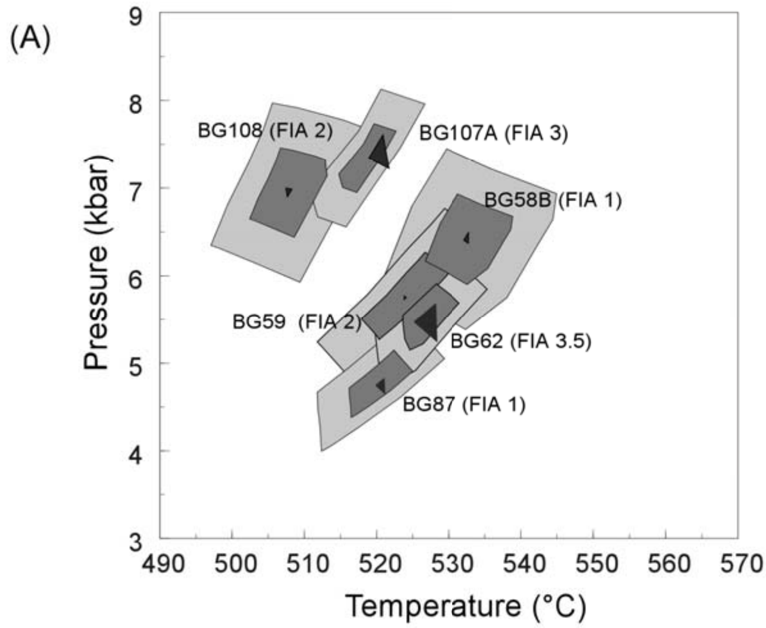


Figure D-11: Electron microprobe compositional maps of a garnet porphyroblast from sample BG59. Images show an area 6mm across. High counts are white, low counts are black. Images have been individually processed to enhance contrast.
A: Calcium compositional map
B: Magnesium compositional map
C: Manganese compositional map
D: Iron compositional map


(A)
BG108 (FIA 2)
BG107A (FIA 3)
BG58B (FIA 1)
BG59 (FIA 2)
BG62 (FIA 3.5)
BG87 (FIA 1)
Pressure (kbar)
Temperature (°C)

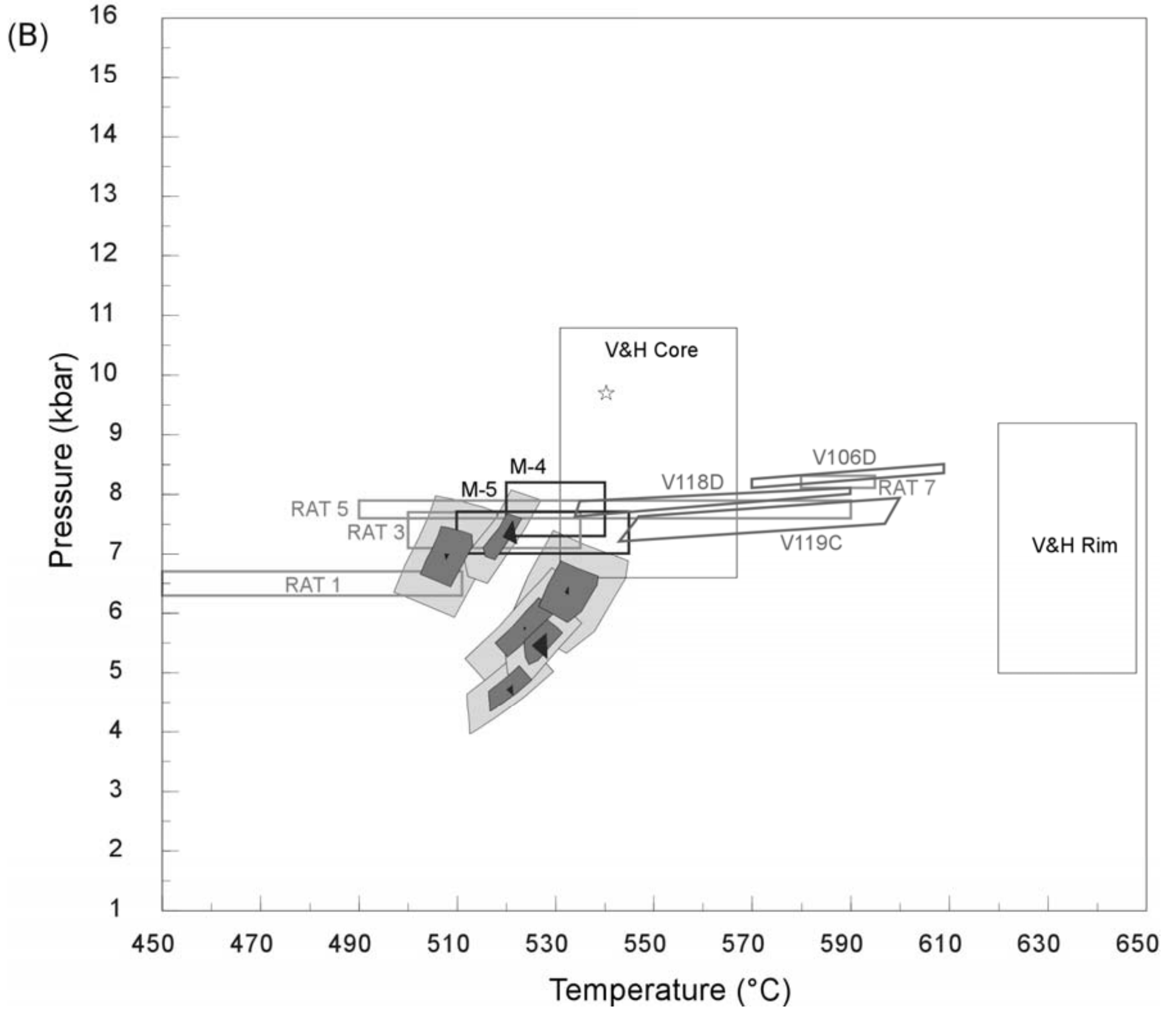

(B)
V&H Core
V&H Rim
M-4
M-5
RAT 5
RAT 3
RAT 1
RAT 7
V118D
V106D
V119C
Pressure (kbar)
Temperature (°C)

Figure D-12: Diagram comparing P-T results.
A: P-T of initial garnet growth in each sample as determined from the compositional isopleth intersections. The black triangle connects the points of intersection of each of the compositional isopleths and the dark grey polygon indicates the area overlap of the 1σ uncertainty of all three compositional isopleths as shown in Figures D-2 to D-8. The light grey polygon indicates the area overlap of the 2σ uncertainty of all three compositional isopleths. The FIA set for each sample is shown in brackets.
B: Peak P-T conditions determined from previous studies. RAT1, RAT3, RAT5 and RAT7 refer to sample locations 1, 3, 5 and 7 from Ratcliffe, Armstrong and Tracy (1992). M-4 and M-5 are from Ratcliffe and Armstrong (1999). V118D, V106D and V119C are samples from Laird and Albee (1981) with the P-T recalculated by Kohn and Spear (1990). V&H core and V&H rim refer to the garnet core and garnet rim values calculated from inclusion mineralogy and the matrix minerals in equilibrium with garnet by Vance and Holland (1993). The star within the V&H core box indicates the P-T determined by Vance and Holland (1993) based on garnet core compositional isopleths.