SECTION -C-

A NEW APPROACH TO THE ESTIMATION OF PRESSURE-TEMPERATURE-DEFORMATION PATHS USING P-T PSEUDOSECTIONS COMBINED WITH FIA DATA IN THE ROBERTSON RIVER METAMORPHICS, NORTHEAST AUSTRALIA

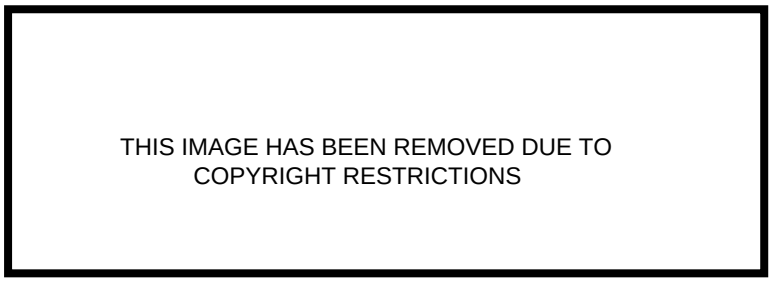


Figure 1. Location map showing major regional geological features and the area in which detailed work done outlined by a box (Compiled from Withnall 1985).

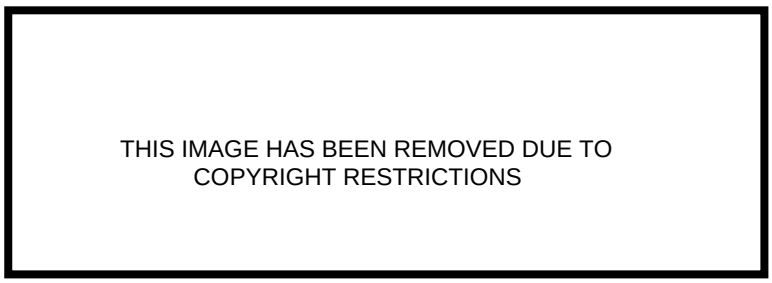
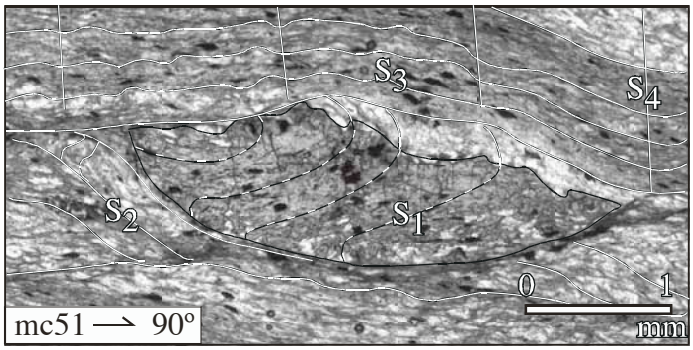


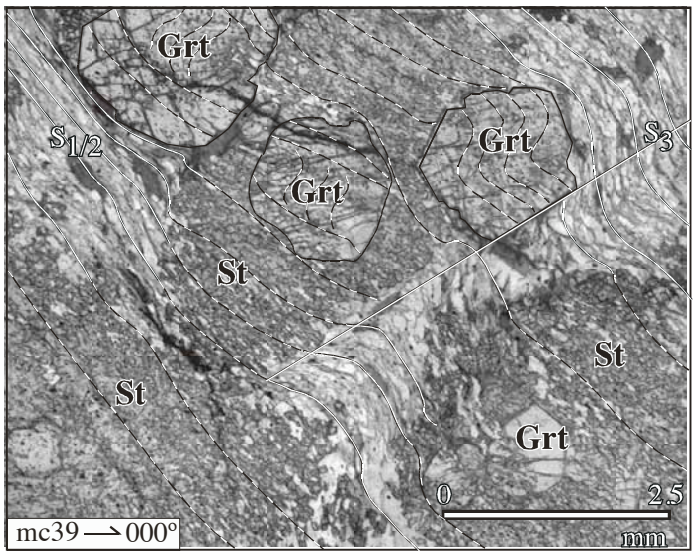
Figure 2. Detailed geological map of the study area outlined in Figure 1 (Modified from Bain et al. 1985). The folded dash lines, which crosscut the area represent the sillimanite (Sill), staurolite-andalusite (St-And) and chlorite-chloritoid (Chl-Cld) isograds.

Figure 3. Photomicrographs showing common textural relationships from the *Chl-Cld*, *St-And* and *Sill* isograd areas a) In the *Chl-Cld* zone, chloritoid (Cld) porphyroblasts seem to dissolve and leave behind quartz (Qtz) rich pseudomorphs. b) In the *St-And* zone, chloritoid disappears and garnet porphyroblasts wrapped by staurolite (St) porphyroblasts as inclusion and c) the inclusion trails within garnet porphyroblasts are discontinuous with the matrix unlike staurolite porphyroblasts. d) In addition, andalusite replaces earlier staurolite generations (overgrew S_1) and e) new staurolite generation (overgrew $S_{1/2}$) following andalusite replacement is also observed. f) In the *Sill* zone, all the earlier porphyroblast generations are overprinted by sillimanite plus biotite. S_1-S_4 represents deformation events observed in the matrix. All these photographs are taken from vertical thin sections cut in different orientations around compass as demonstrated in Fig. 4. These orientations are labelled on the lower left corner of the photographs.

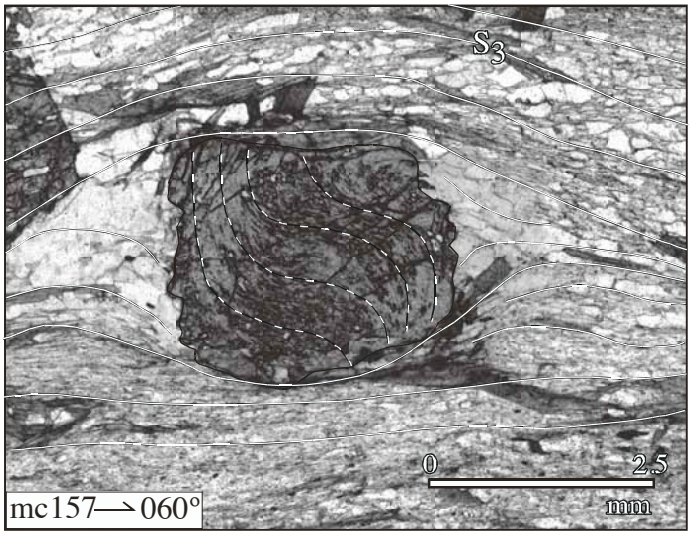
a)


S3
S4
S2
S1
0
1
mm
mc51 ⟶ 90°

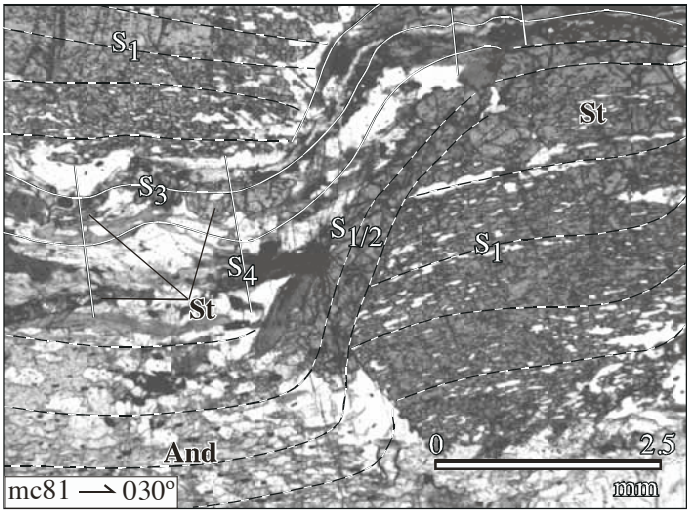
b)


Grt
S1/2
Grt
Grt
S3
St
St
St
Grt
0
2.5
mm
mc39 ⟶ 000°

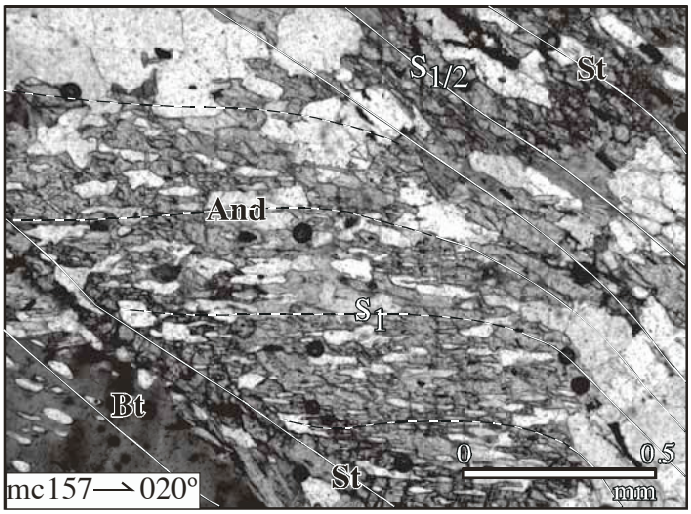
c)


S3
0
2.5
mm
mc157⟶ 060°

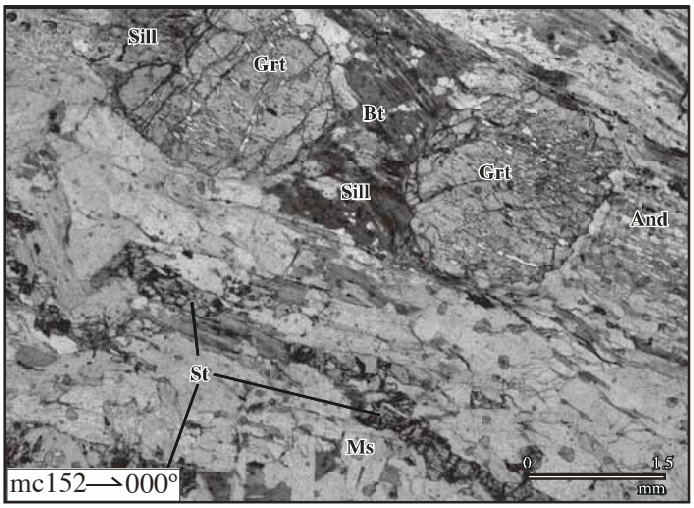
d)


S1
St
S3
S1/2
S1
S4
St
And
0
2.5
mm
mc81 → 030°

e)


S1/2
St
And
S1
Bt
St
0
0.5
mm
mc157→ 020°

f)


Sill
Grt
Bt
Grt
Sill
And
St
Ms
0
1.5
mm
mc152→ 000°

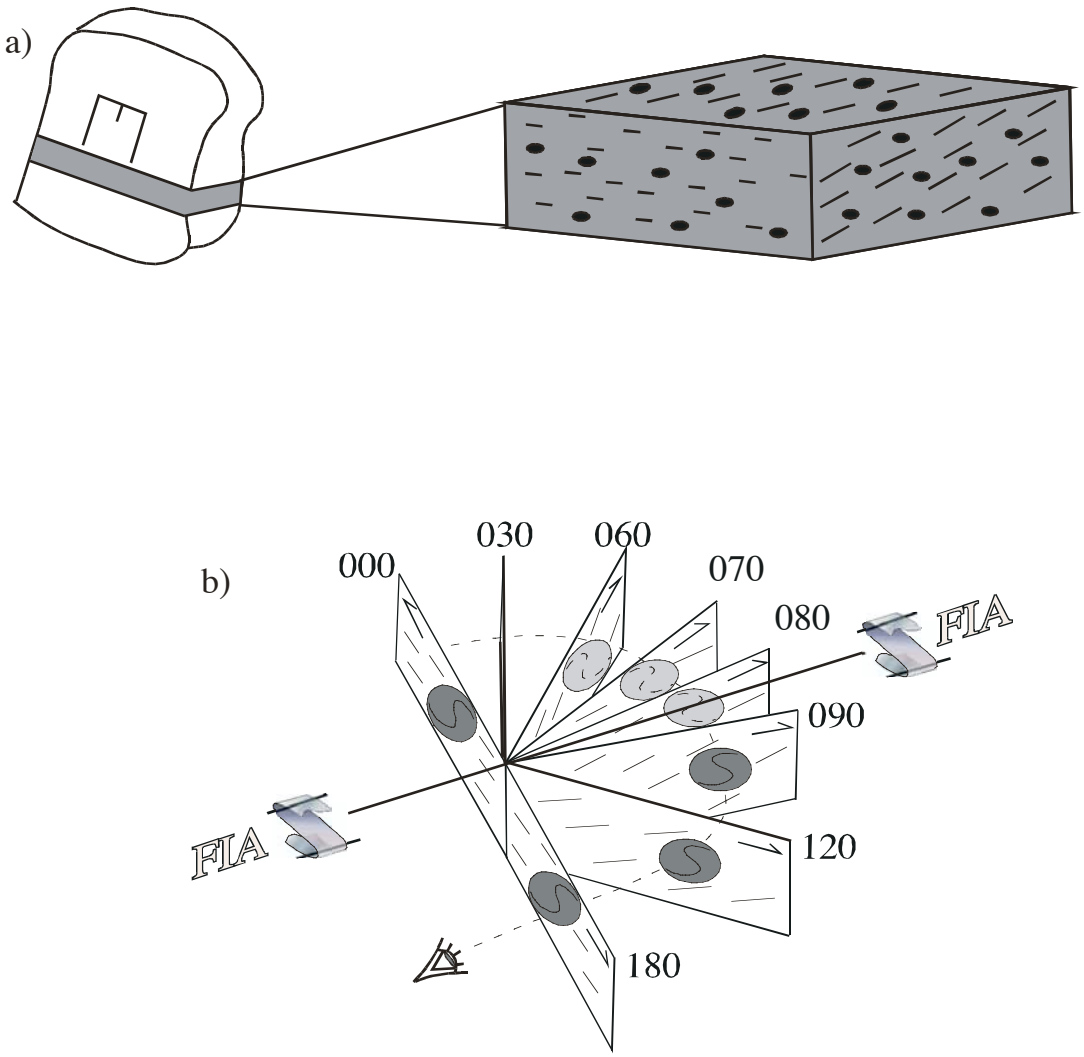


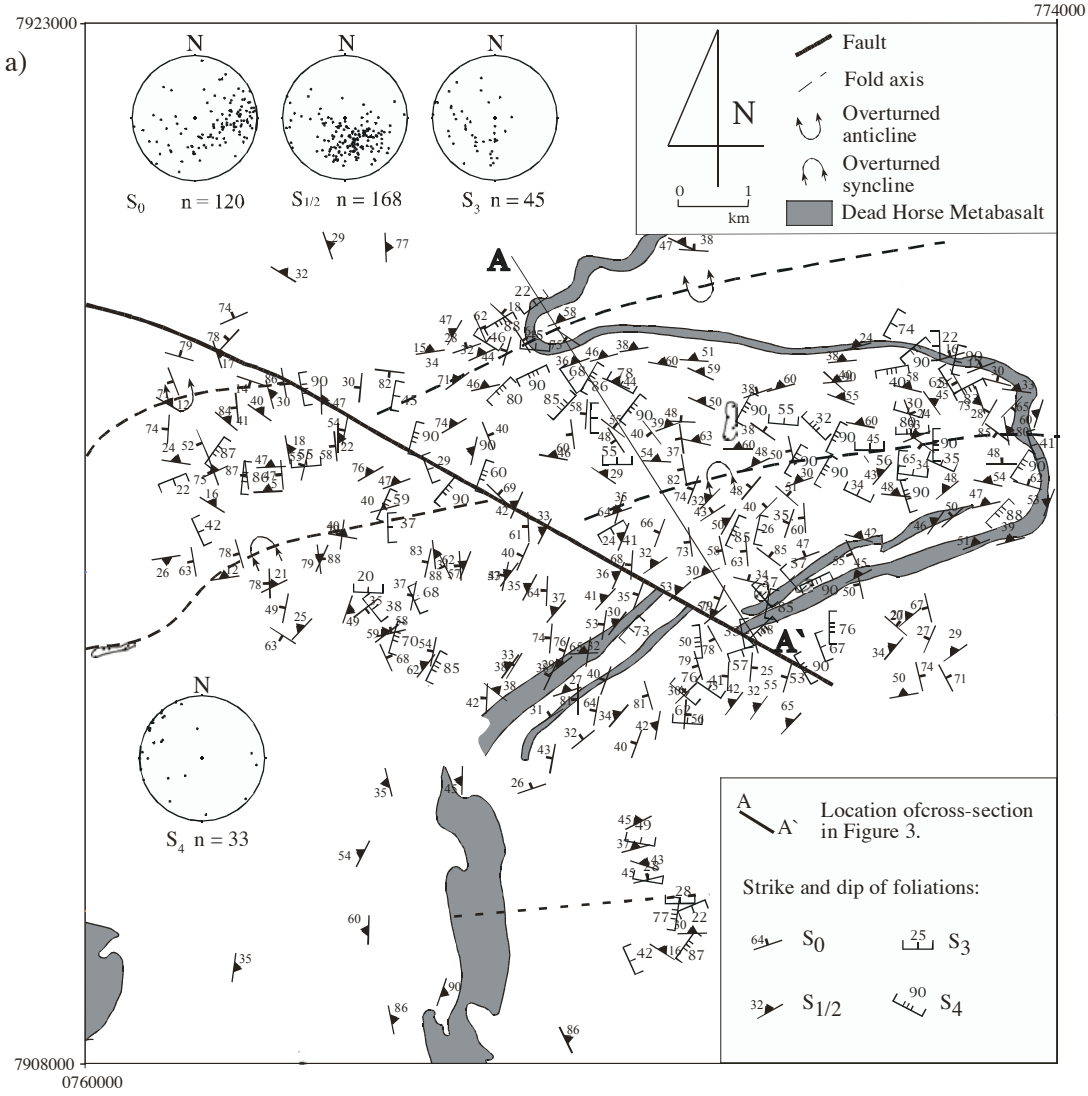
Figure 4. a) Sketches of the oriented rock sample marked and cut into a horizontal slab, and b) multiple-vertical thin sections cut from a horizontal rock slab. FIA is the foliation intersection/inflection axis preserved within porphyroblasts. See appendix for the raw data.

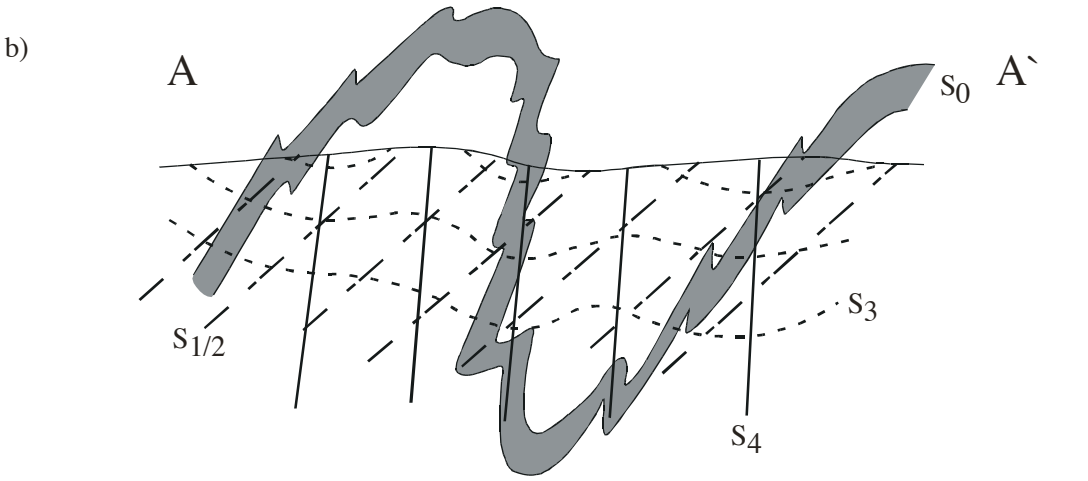
	mc39	**mc55**	**mc81**	**mc157**	**mc137**	**mc23**
SiO2	64.40	61.80	63.40	68.90	66.20	58.40
TiO2	0.75	0.70	0.66	0.75	0.70	0.82
Al2O3	18.70	20.30	17.70	15.10	17.10	21.90
FeO	5.95	5.99	5.73	5.90	5.37	4.53
MnO	0.07	0.12	0.10	0.15	0.10	0.07
MgO	1.73	2.08	2.28	2.20	2.06	2.21
CaO	0.39	0.37	0.36	0.67	0.58	0.57
Na2O	0.31	0.36	0.57	0.68	1.07	1.06
K2O	4.84	3.35	3.35	2.4	2.76	4.21
P2O5	0.22	0.15	0.13	0.12	0.18	0.23
LOI	2.6	3.91	4.87	2.5	3.05	5.01
SUM	99.96	99.13	99.15	99.37	99.17	99.01
A`	0.12	0.37	0.27	0.26	0.29	0.31
Fe/(Fe+Mg)	0.659	0.618	0.585	0.601	0.594	0.535
K/(K+Na)	0.911	0.860	0.795	0.699	0.629	0.723
Mn/(Mn+Mg+Fe)	0.008	0.012	0.010	0.015	0.011	0.008

	mc158	**mc30**	**mc133**	**mc152**	**Avg. Pelite**	**Z93/21**
SiO2	64.10	69.50	59.60	66.20	59.77	67.09
TiO2	0.78	0.76	0.75	0.74		
Al2O3	18.10	14.00	20.70	15.30	16.57	16.64
FeO	5.14	5.48	6.13	6.98	5.88	6.28
MnO	0.13	0.14	0.11	0.10	0.07	0.06
MgO	1.84	2.27	2.67	2.57	2.62	3.38
CaO	0.61	0.84	0.49	0.68	2.17	0.21
Na2O	0.93	0.81	0.76	0.74	1.73	0.37
K2O	3.45	2.06	3.56	2.4	3.53	3.16
P2O5	0.11	0.13	0.18	0.24		
LOI	4.01	3.55	4.98	3.99		
SUM	99.20	99.54	99.93	99.94	92.34	97.19
A`	0.26	0.25	0.31	0.24	-0.13	0.24
Fe/(Fe+Mg)	0.610	0.575	0.563	0.604	0.557	0.510
K/(K+Na)	0.709	0.626	0.755	0.681	0.573	0.849
Mn/(Mn+Mg+Fe)	0.015	0.015	0.010	0.009	0.007	0.005

Table 1. Major element compositions of rock samples (given as weight percent oxide) from the Robertson River Metamorphics in addition to average pelite rock composition of Symmes and Ferry (1991) and a rock sample of Vance and Mahar (1998). The parameters are calculated from mol percent oxides. A`= $\{Al_2O_3\text{-}3K_2O\text{-}CaO\text{-}Na_2O\}/\{Al_2O_3\text{-}3K_2O\text{-}CaO\text{-}Na_2O+FeO+MgO\}$.

Figure 5. a) A structural map shows the distribution of the deformations in the matrix (S_1-S_4). The poles to these structures are plotted on equal area steorenets. b) A cross-section along A-A` shows the relation between macro-scale folds and these matrix deformations.


a)
7923000
774000
7908000
0760000
N
S0 n = 120
S1/2 n = 168
S3 n = 45
S4 n = 33
Fault
Fold axis
Overturned anticline
Overturned syncline
Dead Horse Metabasalt
0 1 km
A
A`
Location ofcross-section in Figure 3.
Strike and dip of foliations:
S0
S3
S1/2
S4


b)
A
A`
S0
S1/2
S3
S4

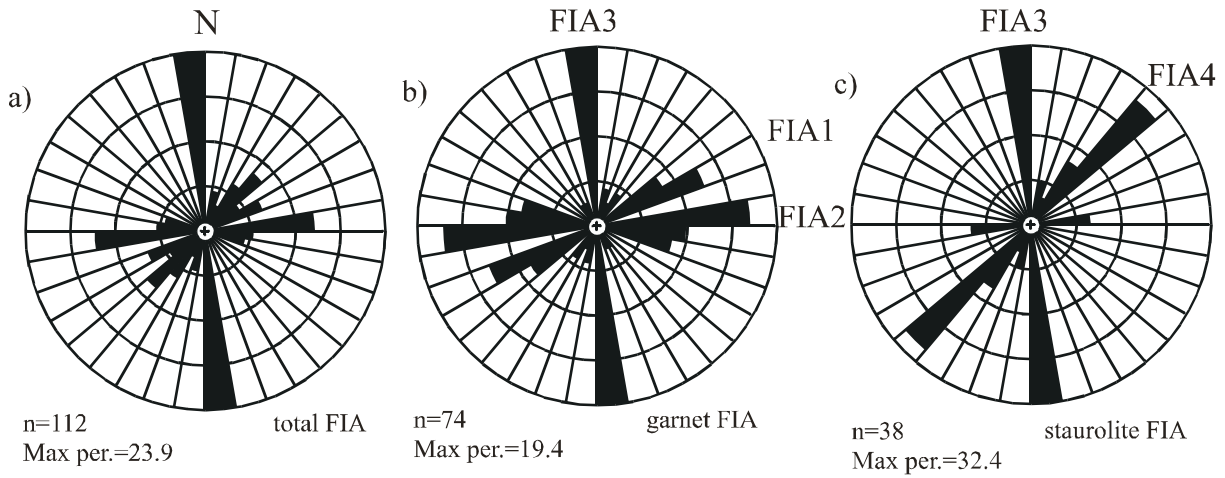
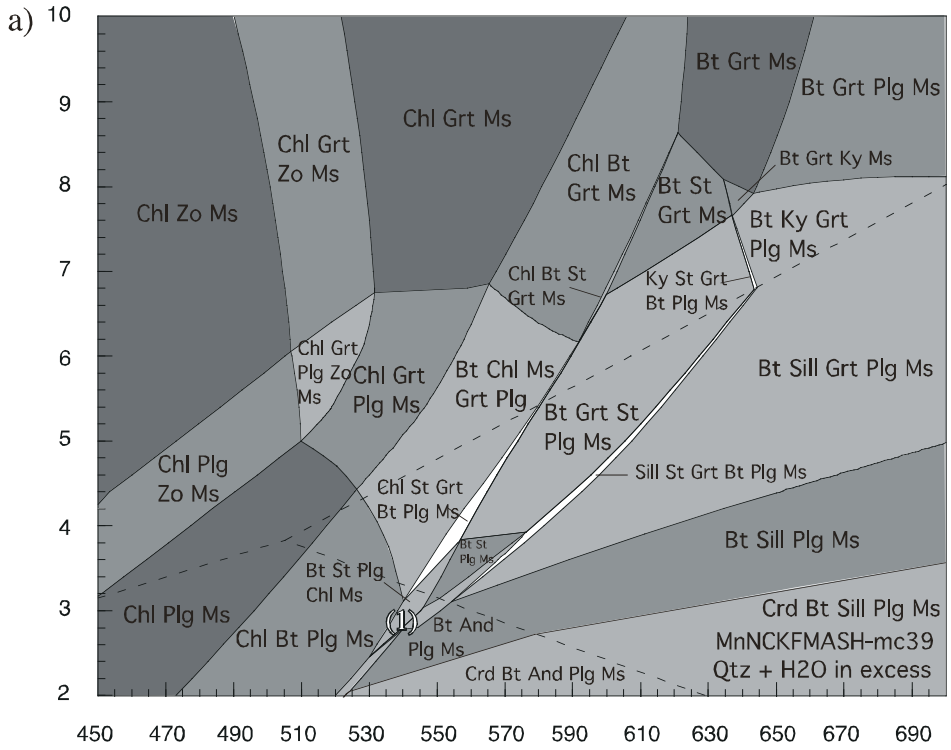
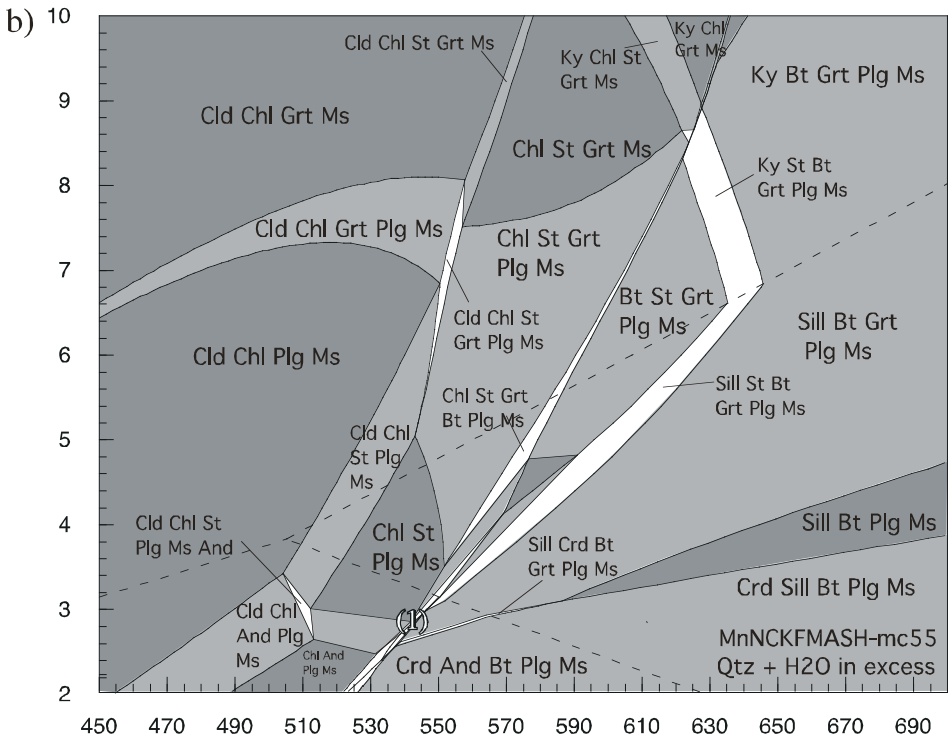


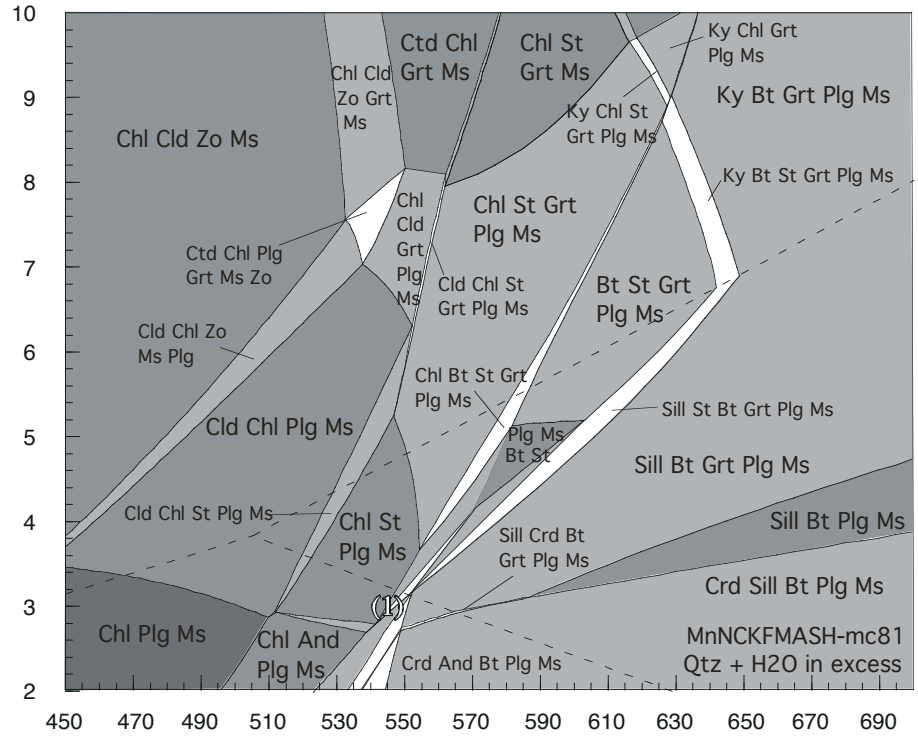
Figure 6. a) Rose diagrams showing the orientations of total FIAs, b) FIA1 (ENE-WSW), FIA2 (E-W) and FIA3 (N-S) in garnet porphyroblasts, and c) FIA2 (E-W), FIA3 (N-S) and FIA4 (NE-SW) in staurolite porphyroblasts across the study area. See Appendix for the FIA data.

Figure 7. Calculated P-T pseudosections for samples mc39 (a), mc55 (b), mc81 (c), mc157 (d). Mineral abbreviations used to indicate fields based on Kretz classification (1983). The small field pointed by (1) refers to a Chl-St-Bt-Plg-Ms-And field. On the pseudosections vertical axis show pressure and horizontal axis temperature.

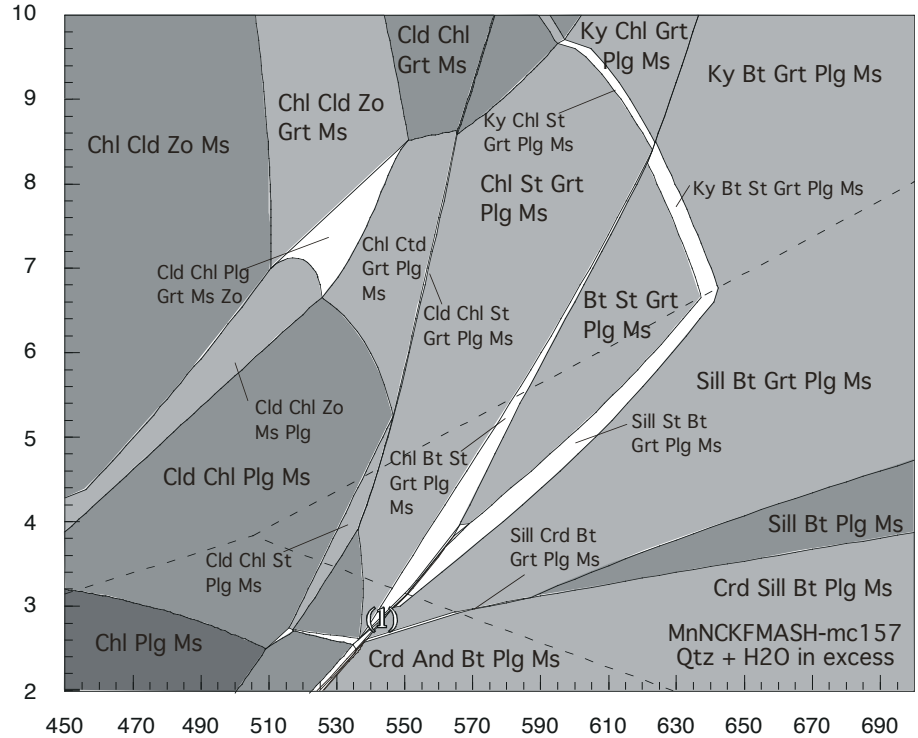

a)
Chl Zo Ms
Chl Grt Zo Ms
Chl Grt Ms
Chl Bt Grt Ms
Bt Grt Ms
Bt Grt Plg Ms
Bt Grt Ky Ms
Bt St Grt Ms
Bt Ky Grt Plg Ms
Chl Bt St Grt Ms
Ky St Grt Bt Plg Ms
Chl Grt Plg Zo Ms
Chl Grt Plg Ms
Bt Chl Ms Grt Plg
Bt Grt St Plg Ms
Bt Sill Grt Plg Ms
Chl Plg Zo Ms
Sill St Grt Bt Plg Ms
Chl St Grt Bt Plg Ms
Bt St Plg Ms
Bt Sill Plg Ms
Bt St Plg Chl Ms
Chl Plg Ms
(1)
Bt And Plg Ms
Crd Bt Sill Plg Ms
MnNCKFMASH-mc39
Qtz + H2O in excess
Chl Bt Plg Ms
Crd Bt And Plg Ms
10
9
8
7
6
5
4
3
2
450 470 490 510 530 550 570 590 610 630 650 670 690


b)
Cld Chl St Grt Ms
Ky Chl St Grt Ms
Ky Chl Grt Ms
Ky Bt Grt Plg Ms
Cld Chl Grt Ms
Chl St Grt Ms
Ky St Bt Grt Plg Ms
Cld Chl Grt Plg Ms
Chl St Grt Plg Ms
Bt St Grt Plg Ms
Cld Chl St Grt Plg Ms
Sill Bt Grt Plg Ms
Cld Chl Plg Ms
Sill St Bt Grt Plg Ms
Chl St Grt Bt Plg Ms
Cld Chl St Plg Ms
Cld Chl St Plg Ms And
Chl St Plg Ms
Sill Bt Plg Ms
Sill Crd Bt Grt Plg Ms
Crd Sill Bt Plg Ms
Cld Chl And Plg Ms
(1)
Chl And Plg Ms
Crd And Bt Plg Ms
MnNCKFMASH-mc55
Qtz + H2O in excess
10
9
8
7
6
5
4
3
2
450 470 490 510 530 550 570 590 610 630 650 670 690

c)


Chl Cld Zo Ms
Chl Cld Zo Grt Ms
Ctd Chl Grt Ms
Chl St Grt Ms
Ky Chl Grt Plg Ms
Ky Bt Grt Plg Ms
Ky Chl St Grt Plg Ms
Ky Bt St Grt Plg Ms
Chl St Grt Plg Ms
Chl Cld Grt Plg Ms
Ctd Chl Plg Grt Ms Zo
Cld Chl St Grt Plg Ms
Bt St Grt Plg Ms
Cld Chl Zo Ms Plg
Chl Bt St Grt Plg Ms
Sill St Bt Grt Plg Ms
Cld Chl Plg Ms
Plg Ms Bt St
Sill Bt Grt Plg Ms
Cld Chl St Plg Ms
Chl St Plg Ms
Sill Bt Plg Ms
Sill Crd Bt Grt Plg Ms
Crd Sill Bt Plg Ms
(1)
Chl Plg Ms
Chl And Plg Ms
MnNCKFMASH-mc81
Qtz + H2O in excess
Crd And Bt Plg Ms
10
9
8
7
6
5
4
3
2
450 470 490 510 530 550 570 590 610 630 650 670 690

d)


Cld Chl Grt Ms
Ky Chl Grt Plg Ms
Ky Bt Grt Plg Ms
Chl Cld Zo Grt Ms
Chl Cld Zo Ms
Ky Chl St Grt Plg Ms
Chl St Grt Plg Ms
Ky Bt St Grt Plg Ms
Chl Ctd Grt Plg Ms
Cld Chl Plg Grt Ms Zo
Cld Chl St Grt Plg Ms
Bt St Grt Plg Ms
Sill Bt Grt Plg Ms
Cld Chl Zo Ms Plg
Sill St Bt Grt Plg Ms
Chl Bt St Grt Plg Ms
Cld Chl Plg Ms
Sill Bt Plg Ms
Sill Crd Bt Grt Plg Ms
Cld Chl St Plg Ms
Crd Sill Bt Plg Ms
(1)
Chl Plg Ms
MnNCKFMASH-mc157
Qtz + H2O in excess
Crd And Bt Plg Ms
10
9
8
7
6
5
4
3
2
450 470 490 510 530 550 570 590 610 630 650 670 690

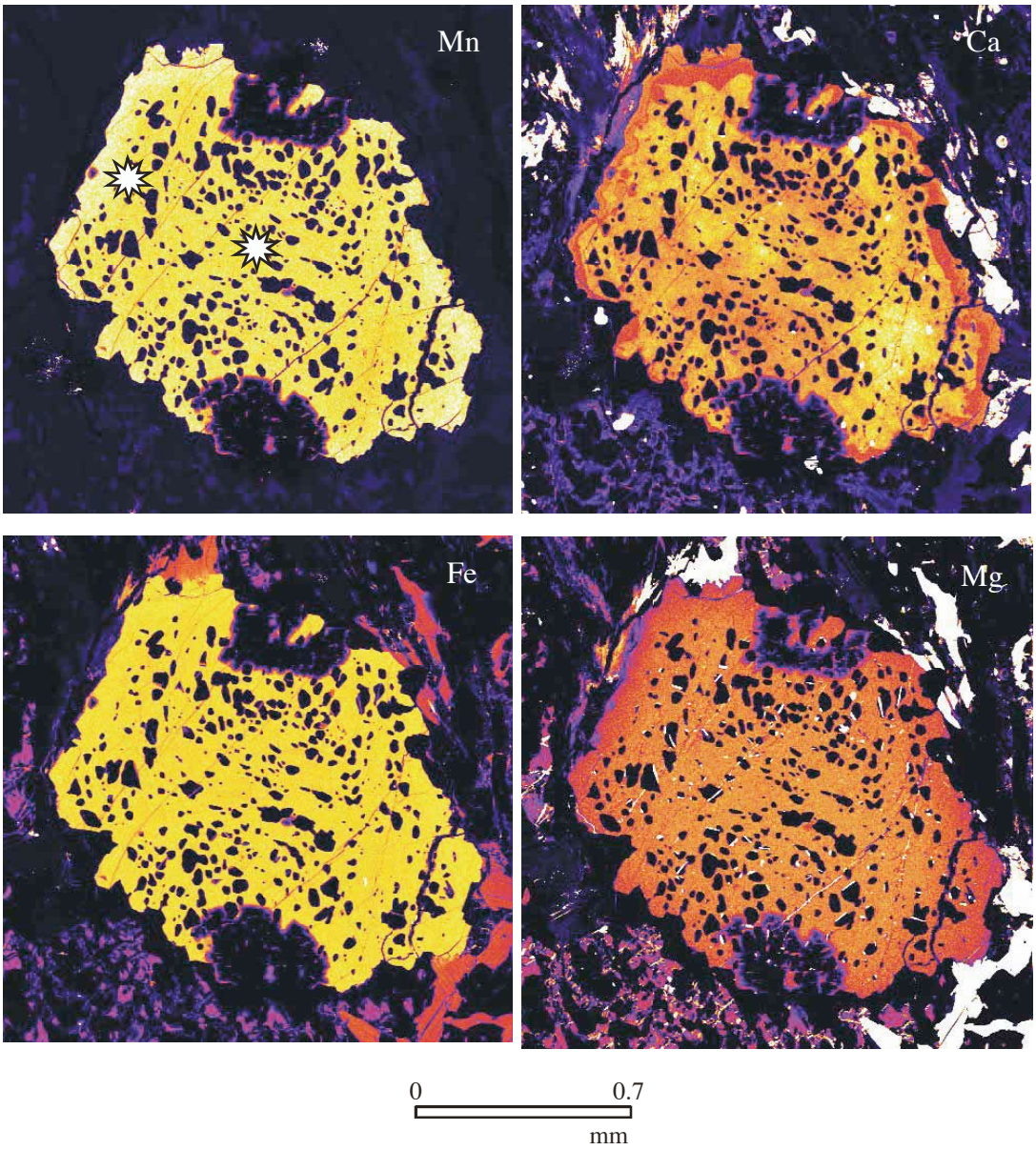


Figure 8. Compositional maps (Mn, Ca, Fe, Mg) of a garnet porphyroblast from a sample mc152. Light colors show higher and dark colors lower concentration. The stars show the positions of the average of at least three analyses from core and rim.

	mc39/core	mc39/med1	mc39/med2	mc39/rim	mc55/core	mc55/med1	mc55/med2	mc55/rim
SiO2	37.3	36.31	36.25	37.03	36.55	37.04	36.82	36.71
Al2O3	21.4	19.62	20.08	21.39	20.67	21.10	20.94	20.67
TiO2	0	0	0	0	0.10	0.00	0	0.00
FeO	29.54	31.44	32.81	34.8	27.88	29.59	30.93	32.98
MnO	5.37	3.61	1.76	1.12	7.06	4.87	2.99	0.86
MgO	1.16	0.72	1.41	1.99	1.27	1.36	1.35	1.87
CaO	6.1	6.48	5.76	2.44	5.12	5.43	5.2	4.31
Total	100.87	98.18	98.07	98.77	98.66	99.81	98.23	97.41
cat Si	2.99	3.01	3.00	3.01	2.99	3.00	3.01	3.02
cat Al	2.02	1.92	1.96	2.05	1.96	2.01	2.02	2.01
cat Ti	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
cat Fe	1.98	2.18	2.27	2.37	1.88	2.01	2.08	2.27
cat Mn	0.36	0.25	0.12	0.08	0.48	0.33	0.20	0.06
cat Mg	0.14	0.09	0.17	0.24	0.15	0.16	0.16	0.23
cat Ca	0.52	0.58	0.51	0.21	0.44	0.47	0.45	0.38
Total cations	8.01	8.03	8.03	7.96	7.97	7.99	7.94	7.97
Almandine	65.85	70.36	73.75	81.68	63.57	67.41	71.89	77.24
Grossular	17.42	18.58	16.59	7.34	14.96	15.84	15.48	12.93
Pyrope	4.61	2.87	5.65	8.33	5.16	5.52	5.59	7.79
Spessartine	12.12	8.18	4.01	2.66	16.30	11.23	7.04	2.04
Fe/(Fe+Mg)	0.93	0.96	0.93	0.91	0.92	0.92	0.93	0.91

	mc81/core	mc81/med1	mc81/med2	mc81/rim	mc157/core	mc157/med1	mc157/med2	mc157/rim
SiO2	37.09	36.36	36.68	37.36	37.64	38.06	37.01	37.64
Al2O3	20.95	20.96	20.37	20.67	21.48	21.39	21.08	21.7
TiO2	0.05	0.01	0	0.05	0.06	0.15	0	0
FeO	28.06	28.98	31.34	33.40	28.31	31.49	32.91	34.23
MnO	6.55	4.9	3.84	1.08	7.82	4.45	2.79	1.25
MgO	1.51	1.8	1.56	2.00	1.37	1.84	1.91	2.6
CaO	4.49	4.51	4.13	2.91	4.28	4.05	3.52	3.42
Total	98.69	97.52	97.92	97.46	100.96	101.42	99.22	100.84
cat Si	3.02	2.99	3.02	3.06	3.01	3.02	3.01	2.99
cat Al	2.01	2.03	1.98	2.00	2.02	2.00	2.02	2.03
cat Ti	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00
cat Fe	1.91	2.00	2.16	2.29	1.89	2.09	2.23	2.28
cat Mn	0.45	0.34	0.27	0.07	0.53	0.30	0.19	0.08
cat Mg	0.18	0.22	0.19	0.24	0.16	0.22	0.23	0.31
cat Ca	0.39	0.40	0.36	0.26	0.37	0.34	0.31	0.29
Total cations	7.97	7.99	7.99	7.93	7.98	7.97	7.99	7.99
Almandine	65.06	67.51	72.38	79.95	64.12	70.85	75.39	76.90
Grossular	13.32	13.46	12.22	8.91	12.43	11.66	10.33	9.84

Pyrope	6.22	7.47	6.42	8.52	5.52	7.36	7.80	10.41
Spessartine	15.39	11.56	8.98	2.61	17.94	10.13	6.47	2.84
Fe/(Fe+Mg)	0.91	0.90	0.92	0.90	0.92	0.91	0.91	0.88

	mc137/rim	mc23/rim	mc158/rim	mc30/rim	mc133/rim	mc152/core	mc152/rim
SiO2	36.66	37.04	37.12	37.69	38.24	37.41	36.87
Al2O3	20.61	21.27	20.38	20.48	21.27	20.68	20.94
TiO2	0.08	0.11	0.00	0.03	0.11	0.14	0
FeO	31.3	31.02	31.83	31.64	31.02	32.7	34.07
MnO	3.98	2.75	3.42	2.23	2.75	5.32	4.99
MgO	1.9	2.24	1.85	2.4	2.24	2.29	1.99
CaO	3.52	3.34	2.79	3.35	3.34	2.74	1.77
Total	98.05	97.77	97.39	97.82	98.96	101.28	100.63
cat Si	3.01	3.02	3.06	3.07	3.07	3.00	2.98
cat Al	2.00	2.05	1.98	1.97	2.01	1.95	2.00
cat Ti	0.00	0.01	0.00	0.00	0.01	0.01	0.00
cat Fe	2.15	2.12	2.19	2.16	2.08	2.19	2.30
cat Mn	0.28	0.19	0.24	0.15	0.19	0.36	0.34
cat Mg	0.23	0.27	0.23	0.29	0.27	0.27	0.24
cat Ca	0.31	0.29	0.25	0.29	0.29	0.24	0.15
Total cations	7.98	7.95	7.95	7.94	7.92	8.02	8.02
Almandine	72.41	73.72	75.48	74.50	73.72	71.58	75.81
Grossular	10.43	9.00	8.47	10.11	10.16	7.68	5.05
Pyrope	7.84	9.49	7.83	10.07	9.50	8.94	7.89
Spessartine	9.33	6.62	8.22	5.32	6.61	11.80	11.25
Fe/(Fe+Mg)	0.90	0.89	0.91	0.88	0.89	0.89	0.91

Table 2. Garnet chemistry data from each sample analysed.

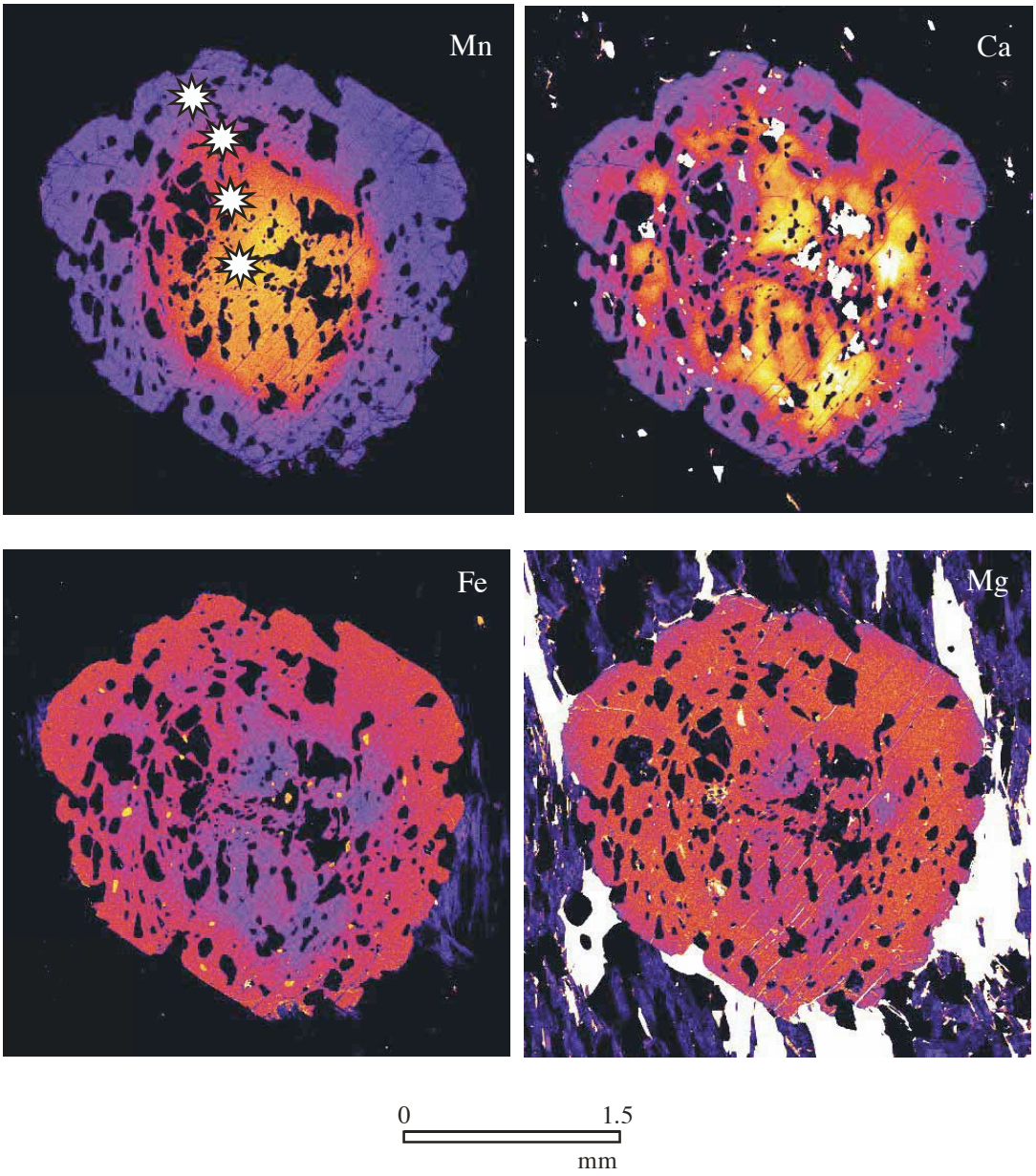


Figure 9. Compositional maps (Mn, Ca, Fe, Mg) of a garnet porphyroblast from a sample sample mc39. Light colors show higher and dark colors lower concentration. The stars show the positions of the average of at least three analyses from core, med1, med2 and rim.

	mc39/St	mc55/St	mc81/St	mc157/St	mc137/St
SiO2	28.01	30.40	28.04	28.54	28.44
Al2O3	52.19	53.84	54.16	51.15	53.42
TiO2	0.45	0.47	0.41	0.39	0.3
FeO	16.06	16.29	14.66	17.55	16.37
MnO	0.00	0.01	0.09	0.13	0.35
MgO	1.24	1.15	1.52	2.00	1.53
CaO	0.00	0.01	0.00	0.00	0.07
ZnO	0.21	0.00	0.00	0.00	0.00
Total	98.16	102.17	98.88	99.76	100.48
cat Si	3.92	4.06	3.86	3.95	3.89
cat Al	8.60	8.48	8.79	8.35	8.61
cat Ti	0.05	0.05	0.04	0.04	0.03
cat Fe	1.88	1.82	1.69	2.03	1.87
cat Mn	0.00	0.00	0.01	0.02	0.04
cat Mg	0.26	0.23	0.31	0.41	0.31
cat Zn	0.02	0.00	0.00	0.04	0.00
cat Ca	0.00	0.00	0.00	0.00	0.01
Total cations	14.73	14.65	14.70	14.84	14.77
Fe/(Fe+Mg)	0.879	0.888	0.844	0.831	0.857

	mc23/St	mc158/St	mc30/St	mc133/St	mc152/St
SiO2	29.29	30.48	30.39	28.89	27.75
Al2O3	53.98	53.45	54.24	54.48	53.29
TiO2	0.39	0.61	0.44	0.48	0.53
FeO	15.81	15.05	14.97	13.22	16.14
MnO	0.24	0.19	0.27	0.36	0.37
MgO	1.17	1.10	1.37	1.37	1.64
CaO	0.05	0.04	0.03	0.01	0.02
ZnO	0.00	0.00	0.00	0.00	0
Total	100.92	100.95	101.88	98.93	99.74
cat Si	3.97	4.10	4.06	3.95	3.83
cat Al	8.62	8.48	8.53	8.77	8.66
cat Ti	0.04	0.06	0.04	0.05	0.05
cat Fe	1.79	1.70	1.67	1.51	1.86
cat Mn	0.03	0.02	0.03	0.04	0.04
cat Mg	0.24	0.22	0.27	0.28	0.34
cat Zn	0.00	0.00	0.02	0.01	0.00
cat Ca	0.01	0.01	0.00	0.00	0.00
Total cations	14.68	14.59	14.63	14.62	14.79
Fe/(Fe+Mg)	0.883	0.884	0.860	0.845	0.847

Table 3. Staurolite chemistry data from each sample analysed.

	mc39/Bt	mc39/Ms	mc55/Bt	mc55/Ms	mc55/Msinc	mc81/Bt	mc81/Btinc	mc81/Ms	mc157/Bt	mc157/Ms
SiO2	34.96	45.36	36.41	45.45	46.33	35.77	33.42	45.61	35.79	43.69
Al2O3	19.49	34.28	19.18	34.46	35.27	19.48	17.49	34.30	19.94	33.70
TiO2	1.37	0.46	1.73	0.42	0.19	1.54	2.23	0.42	1.33	0.67
FeO	21.98	0.99	17.16	0.87	0.81	15.79	18.18	1.19	18.42	4.01
MnO	0.06	0.02	0.00	0.09	0.34	0.07	0.07	0.12	0.00	0.00
MgO	7.71	0.65	8.73	0.59	0.17	10.67	10.84	1.01	9.29	1.02
CaO	0.09	0.09	0.13	0.04	0.34	0.28	0.21	0.16	0.26	0.18
Na2O	0.22	1.26	0.00	0.87	0	0.17	0	1.23	0.45	1.41
K2O	7.77	10.12	9.55	10.20	11.14	6.53	6.67	9.80	8.49	10.18
Cl	0.07	0.05	0.00	0.12	0.08	0.17	0.01	0.05	0.09	0.03
Total	93.72	93.27	92.89	93.11	94.67	90.47	89.12	93.89	94.06	94.89
cat Si	5.43	6.18	5.60	6.19	6.22	5.54	5.37	6.17	5.46	5.97
cat Al	3.57	5.50	3.48	5.53	5.58	3.55	3.31	5.47	3.58	5.43
cat Ti	0.16	0.05	0.20	0.04	0.02	0.18	0.27	0.04	0.15	0.07
cat Fe	2.86	0.11	2.21	0.10	0.09	2.04	2.44	0.13	2.35	0.46
cat Mn	0.01	0.00	0.00	0.01	0.04	0.01	0.01	0.01	0.00	0.00
cat Mg	1.79	0.13	2.00	0.12	0.03	2.46	2.59	0.20	2.11	0.21
cat Ca	0.01	0.01	0.02	0.01	0.05	0.05	0.04	0.02	0.04	0.03
cat Na	0.07	0.33	0.00	0.23	0.00	0.05	0.00	0.32	0.13	0.37
cat K	1.54	1.76	1.88	1.77	1.91	1.29	1.37	1.69	1.65	1.78
Total cations	13.82	11.98	13.52	12.00	12.02	13.83	14.03	12.05	13.70	12.17
Fe/(Fe+Mg)	0.615		0.524			0.454	0.485		0.527	
K/(K+Na)		0.841		0.885	1			0.839		0.826

	mc137/Bt	mc137/Ms	mc23/Bt	mc23/Ms	mc158/Bt	mc158/Ms	mc30/Bt	mc130/Ms	mc133/Bt	mc133/Ms
SiO2	36.00	46.55	36.88	47.16	37.43	47.02	36.88	48.02	35.87	46.72
Al2O3	18.18	34.79	19.67	34.56	19.56	34.70	18.17	33.99	19.61	35.92
TiO2	1.39	0.50	1.63	0.51	1.40	0.56	1.32	0.56	1.74	0.34
FeO	21.50	1.54	18.14	2.01	19.23	2.60	19.66	1.24	18.86	0.96
MnO	0.00	0.15	0.04	0.01	0.05	0.03	0.08	0.00	0.16	0.12
MgO	10.71	0.30	10.27	0.54	9.32	0.55	9.81	0.74	9.55	0.94
CaO	0.03	0.21	0.13	0.07	0.23	0.03	0.36	0.03	0.07	0.10
Na2O	0.09	2.10	0.09	1.40	0.10	0.76	0.00	0.59	0.25	1.44
K2O	8.56	10.06	9.84	9.65	7.81	9.31	5.89	9.84	9.12	10.05
Cl	0.00	0.03	0.04	0.01	0.04	0.11	0.06	0.03	0.00	0.03
Total	96.46	96.23	96.70	95.94	95.17	95.68	92.24	95.04	95.21	96.61
cat Si	5.43	6.17	5.48	6.24	5.61	6.23	5.67	6.36	5.60	6.13
cat Al	3.23	5.44	3.45	5.39	3.45	5.42	3.29	5.31	3.48	5.56
cat Ti	0.16	0.05	0.18	0.05	0.16	0.06	0.15	0.06	0.20	0.03
cat Fe	2.71	0.17	2.25	0.22	2.41	0.29	2.53	0.14	2.21	0.11
cat Mn	0.00	0.02	0.01	0.00	0.01	0.00	0.01	0.00	0.00	0.01
cat Mg	2.41	0.06	2.28	0.11	2.08	0.11	2.25	0.15	2.00	0.18
cat Ca	0.00	0.03	0.02	0.01	0.04	0.00	0.06	0.00	0.02	0.01
cat Na	0.03	0.54	0.03	0.36	0.03	0.20	0.00	0.15	0.00	0.37
cat K	1.65	1.70	1.87	1.63	1.49	1.57	1.15	1.66	1.88	1.68
Total cations	13.95	11.94	13.67	12.02	13.75	12.12	13.96	12.02	13.52	12.03
Fe/(Fe+Mg)	0.530		0.498		0.536		0.529		0.524	
K/(K+Na)		0.759		0.820		0.890		0.916		0.822

	mc152/Bt	mc152/Ms	mc39/Epinc	mc55/Epinc	mc81/Chlinc
SiO2	34.31	45.06	39.15	44.97	27.34
Al2O3	18.36	34.96	28.98	34.39	20.83
TiO2	1.82	0.49	0.1	0.01	0.15
FeO	21.82	0.86	7.52	0.07	25.38
MnO	0.06	0.04	0.13	0.11	0.19
MgO	9.34	0.57	0.2	0	13.37
CaO	0.14	0.06	23.64	19	0.29
Na2O	0.00	1.16	0.27	0.85	0
K2O	7.62	9.75	0.08	0	0
Cl	0.01	0.04	0.03	0	0
Total	93.48	92.99	100.1	99.4	87.55
cat Si	5.35	6.13			
cat Al	3.38	5.61			
cat Ti	0.21	0.05			
cat Fe	2.85	0.10			
cat Mn	0.01	0.00			
cat Mg	2.17	0.12			
cat Ca	0.02	0.01			
cat Na	0.00	0.31			
cat K	1.52	1.69			
Total cations	13.99	12.02			
Fe/(Fe+Mg)	0.567				
K/(K+Na)		0.847			

Table 4. Phyllosilicate chemistry data from each sample analysed.

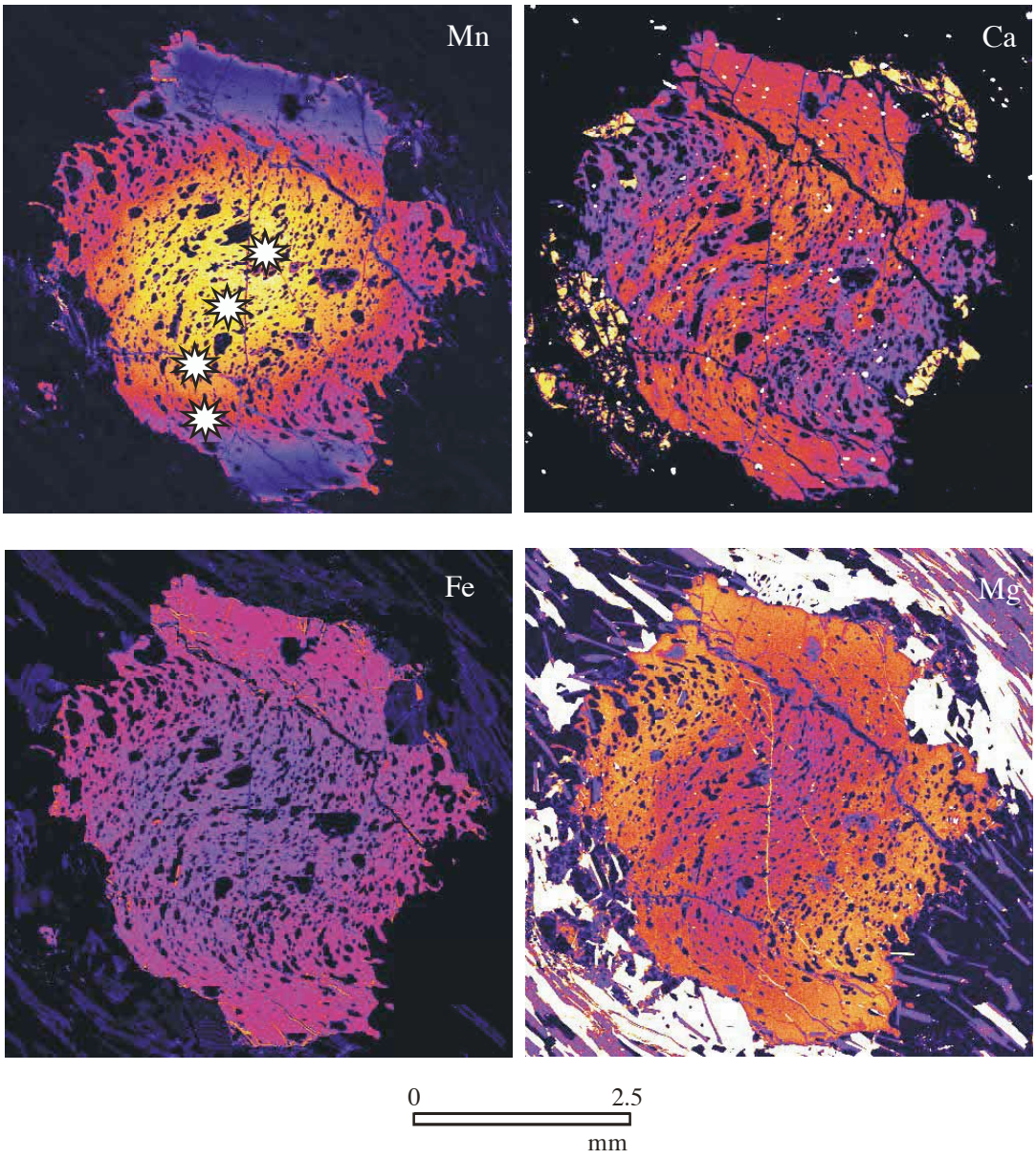


Figure 10. Compositional maps (Mn, Ca, Fe, Mg) of a garnet porphyroblast from a sample mc55. Light colors show higher and dark colors lower concentration. The stars show the positions of the average of at least three analyses from core, med1, med2 and rim.

	mc157/Plg-inclusion within core	mc157/Plg-inclusion within med.	mc157/Plg-matrix	mc55/Plg- matrix core	mc55/Plg- matrix rim	mc81/Plg-inclusion within med.	mc81/Plg- matrix core	mc81/plg- matrix rim
SiO2	59.01	60.61	61.27	57.33	57.14	57.41	57.65	59.24
Al2O3	26.50	25.20	25.43	26.34	26.54	26.13	25.82	24.53
TiO2	0.04	0.09	0	0.00	0.06	0.08	0.00	0.10
FeO	0.07	0.03	0	0.07	0.19	0.06	0.03	0.12
MnO	0.05	0.11	0	0.19	0.00	0	0.00	0.11
MgO	0.04	0.15	0.05	0.13	0.00	0.21	0.06	0.07
Cr2O3	0.00	0.00	0	0	0	0	0	0
CaO	8.14	6.83	6.29	9.70	8.87	8.46	8.66	6.76
Na2O	6.29	6.66	8	5.67	6.78	6.98	6.24	6.69
K2O	0.04	0.00	0.02	0.00	0.02	0	0.00	0.13
Total	100.18	99.68	101.06	99.43	99.60	99.33	98.46	97.75
cat Si	2.61	2.69	2.68	2.58	2.57	2.59	2.61	2.69
cat Al	1.38	1.32	1.31	1.40	1.41	1.39	1.38	1.31
cat Ti	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
cat Fe	0.01	0.02	0.00	0.00	0.01	0.02	0.01	0.00
cat Mn	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00
cat Mg	0.03	0.01	0.03	0.01	0.00	0.01	0.00	0.00
cat Cr	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
cat Ca	0.39	0.32	0.30	0.47	0.43	0.41	0.42	0.33
cat Na	0.54	0.57	0.68	0.50	0.59	0.61	0.55	0.59
cat K	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Total cations	4.97	4.94	5.00	4.96	5.02	5.02	4.97	4.95
XAn	0.42	0.36	0.30	0.49	0.42	0.40	0.43	0.36

	mc152/Plg-matrix	mc137/Plg- matrix	mc133/Plg-matrix	mc158/Plg-matrix	mc30/Plg- matrix	mc23/Plg- matrix
SiO2	61.76	61.1	61.11	64.70	61.47	60.63
Al2O3	23.26	24.76	24.95	23.94	24.85	24.98
TiO2	0.03	0	0.04	0.05	0.05	0.04
FeO	0.03	0.11	0.04	0.19	0.05	0.06
MnO	0	0	0.02	0.05	0.01	0.11
MgO	0.09	0	0.00	0.03	0.04	0.03
Cr2O3	0	0	0.00	0	0	0.00
CaO	5.19	7.36	6.96	5.27	7.47	7.40
Na2O	9.18	8.69	8.20	7.44	6.15	7.90
K2O	0.1	0	0.01	0.36	0.06	0.07
Total	99.64	102.02	101.34	102.01	100.14	101.22
cat Si	2.74	2.68	2.68	2.80	2.72	2.67
cat Al	1.22	1.28	1.29	1.22	1.29	1.30
cat Ti	0.01	0.00	0.00	0.00	0.00	0.00
cat Fe	0.00	0.00	0.01	0.01	0.00	0.01
cat Mn	0.00	0.00	0.00	0.00	0.00	0.00
cat Mg	0.01	0.00	0.00	0.00	0.00	0.02
cat Cr	0.00	0.00	0.00	0.00	0.00	0.00
cat Ca	0.25	0.35	0.33	0.24	0.35	0.35
cat Na	0.79	0.74	0.70	0.62	0.53	0.67
cat K	0.01	0.00	0.00	0.02	0.00	0.00
Total cations	5.04	5.05	5.02	4.91	4.90	5.02
XAn	0.24	0.32	0.32	0.27	0.40	0.34

Table 5. Plagioclase chemistry data from each sample analysed.

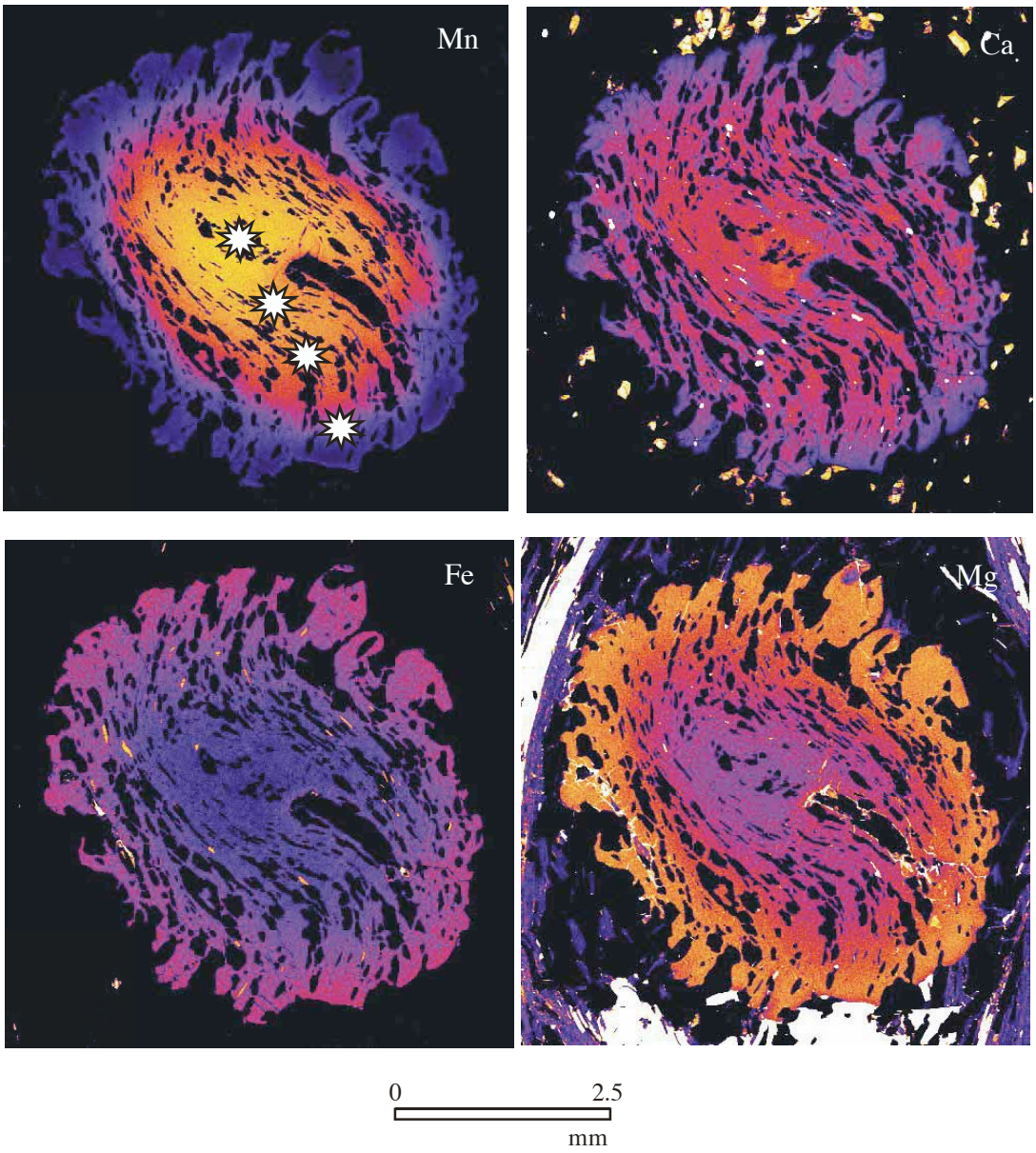


Figure 11. Compositional maps (Mn, Ca, Fe, Mg) of a garnet porphyroblast from a sample mc81. Light colors show higher and dark colors lower concentration. The stars show the positions of the average of at least three analyses from core, med1, med2 and rim.

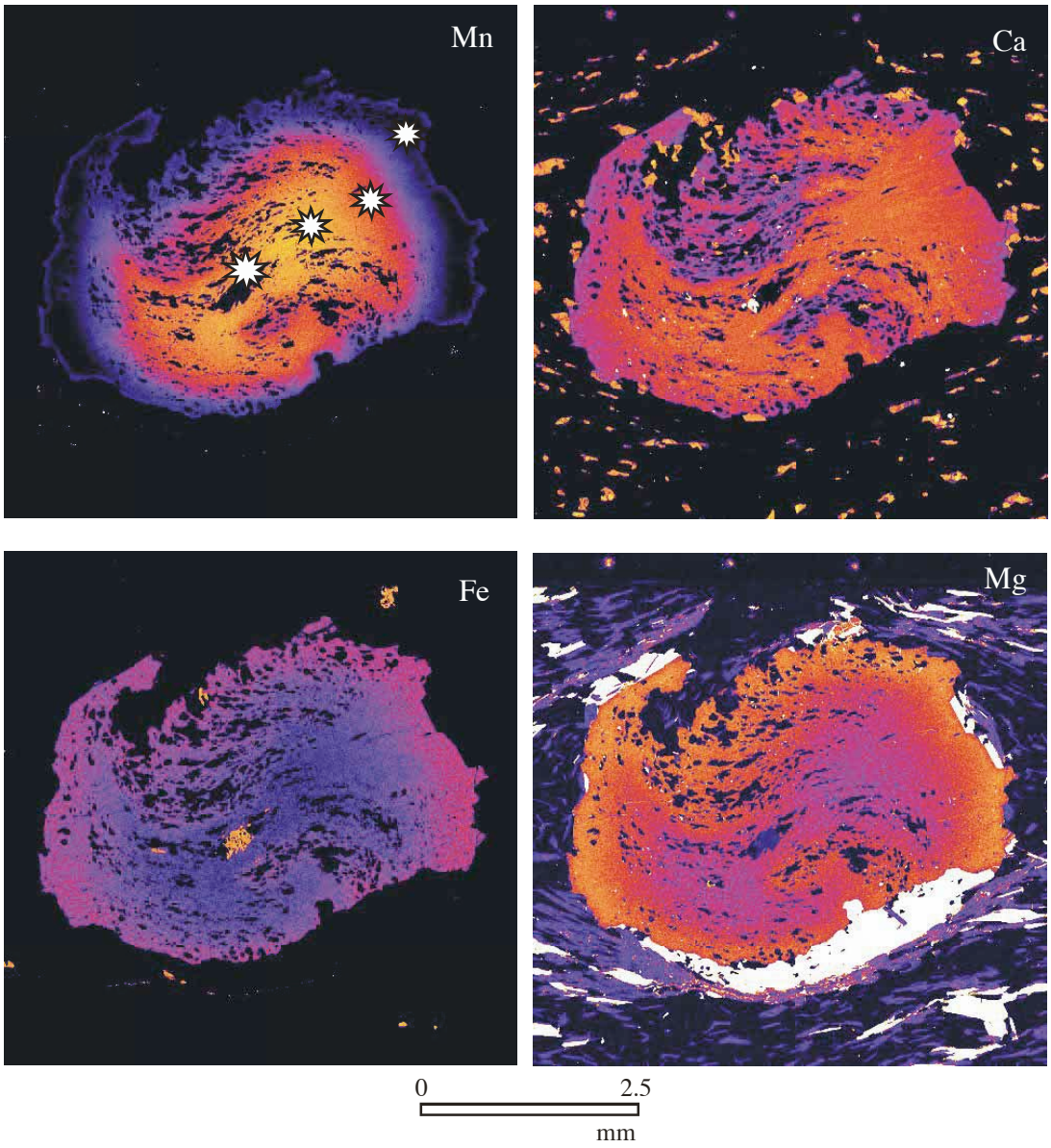


Figure 12. Compositional maps (Mn, Ca, Fe, Mg) of a garnet porphyroblast from a sample mc157. Light colors show higher and dark colors lower concentration. The stars show the positions of the average of at least three analyses from core, med1, med2 and rim.

Figure 13. The representative pseudosections for samples mc39 (a) and mc81 (b) are to show the distribution of X_{Mn}, X_{Ca}, X_{Fe} and X_{An} isopleths. Only shaded areas are contoured for clarity. These are Chl-Grt-Plg-**Bt**-Ms, Chl-Grt-St-Plg-Bt-Ms and Grt-St-Plg-Bt-Ms for sample mc39, and Chl-Grt-Plg-**St**-Ms, Chl-Grt-St-Plg-Bt-Ms and Grt-St-Plg-Bt-Ms for sample mc81 from left to right respectively.

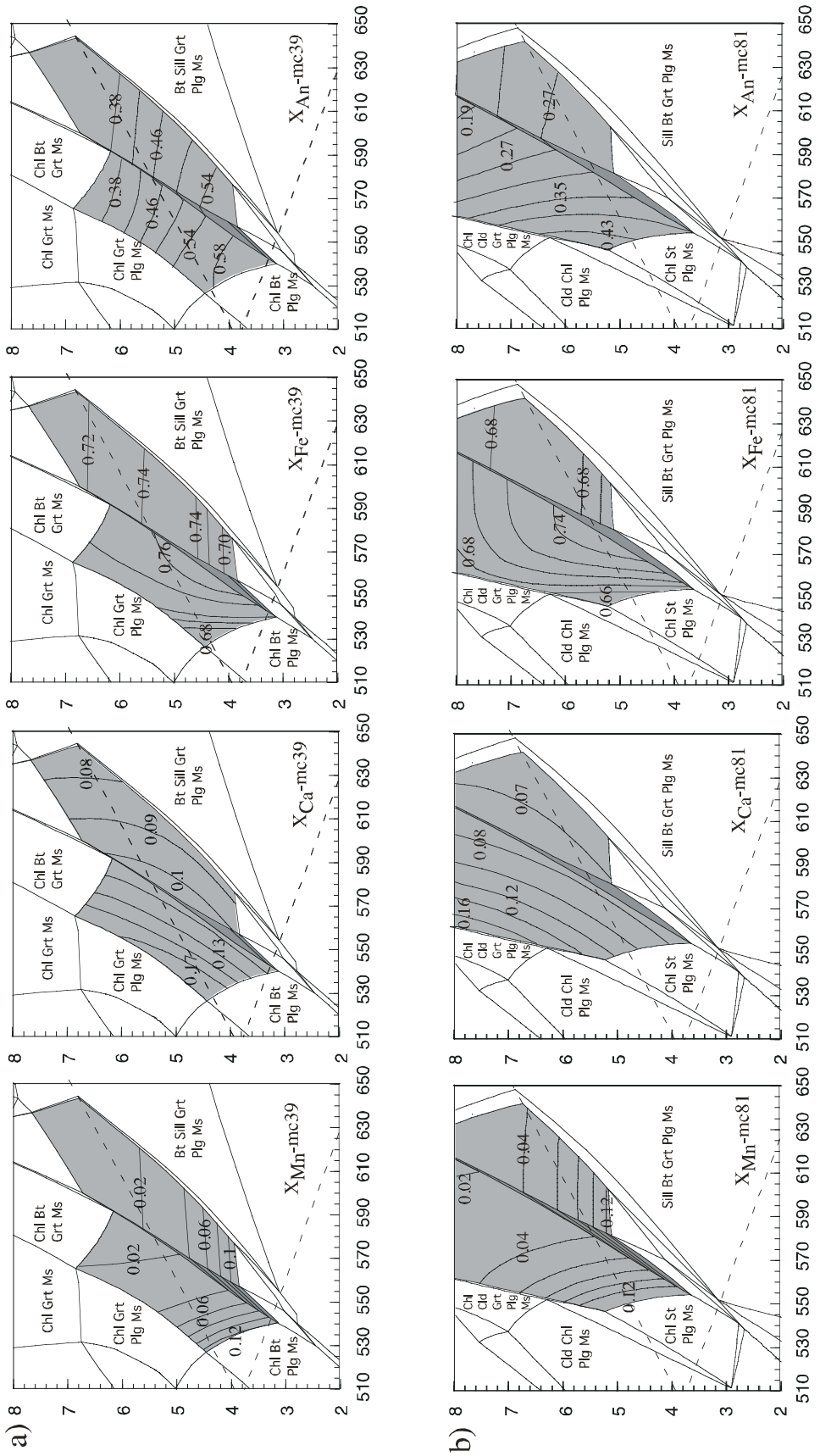

a)
b)
Chl Bt Grt Ms
Chl Grt Ms
Chl Grt Plg Ms
Chl Bt Plg Ms
Bt Sill Grt Plg Ms
Chl Cld Grt Plg Ms
Cld Chl Plg Ms
Chl St Plg Ms
Sill Bt Grt Plg Ms
XMn-mc39
XCa-mc39
XFe-mc39
XAn-mc39
XMn-mc81
XCa-mc81
XFe-mc81
XAn-mc81

Figure 14. The pseudosections showing the P-T estimation of garnet porphyroblast growth by the intersection of three components (X_{Mn}, X_{Ca}, X_{Fe}) for the rock samples mc39 (a), mc55 (b), mc81 (c) and mc157 (d). Grey colours around the individual isopleth lines show their uncertainties, and intersection of these uncertainties point to an uncertainty ellipse of P-T estimation at the time of the core growth. Point analyses from the core of the garnet porphyroblasts within individual rock samples is used for the estimation (See Table 2 and Figs. 8-11).

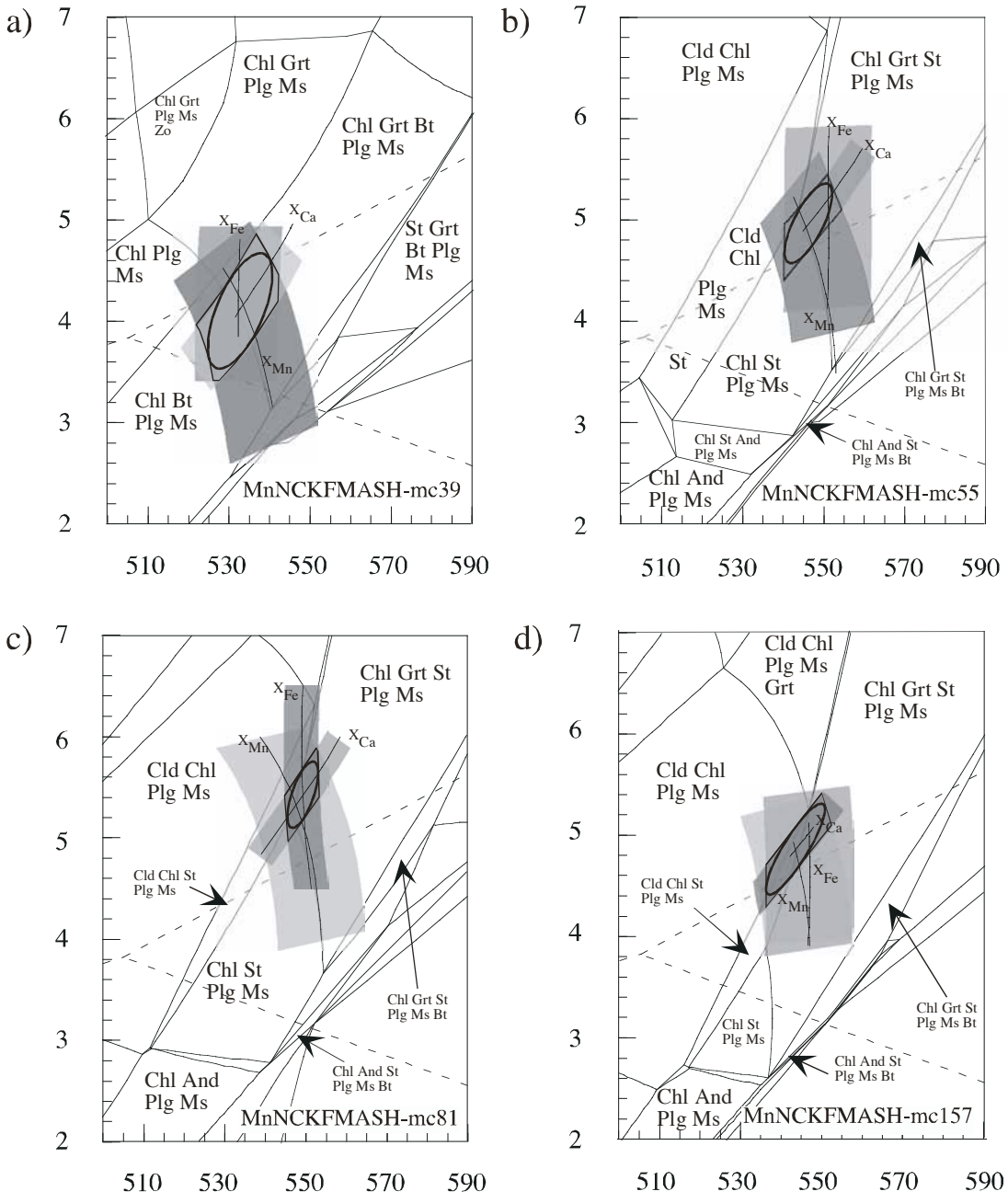
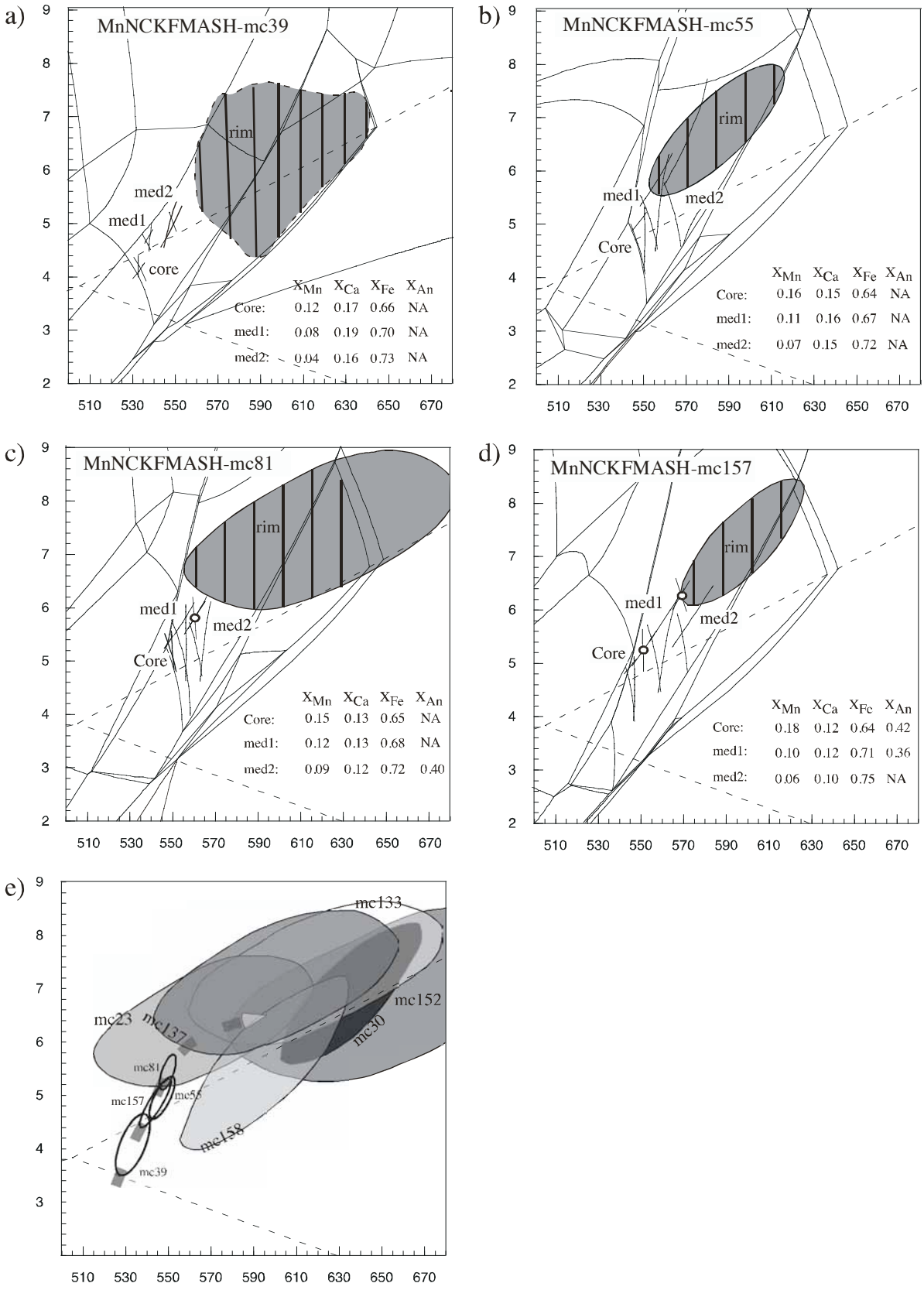

a)
Chl Grt
Plg Ms
Chl Grt
Plg Ms
Zo
Chl Grt Bt
Plg Ms
St Grt
Bt Plg
Ms
Chl Plg
Ms
Chl Bt
Plg Ms
MnNCKFMASH-mc39
b)
Cld Chl
Plg Ms
Chl Grt St
Plg Ms
Cld
Chl
Plg
Ms
St
Chl St
Plg Ms
Chl Grt St
Plg Ms Bt
Chl St And
Plg Ms
Chl And St
Plg Ms Bt
Chl And
Plg Ms
MnNCKFMASH-mc55
c)
Chl Grt St
Plg Ms
Cld Chl
Plg Ms
Cld Chl St
Plg Ms
Chl St
Plg Ms
Chl Grt St
Plg Ms Bt
Chl And St
Plg Ms Bt
Chl And
Plg Ms
MnNCKFMASH-mc81
d)
Cld Chl
Plg Ms
Grt
Chl Grt St
Plg Ms
Cld Chl
Plg Ms
Cld Chl St
Plg Ms
Chl St
Plg Ms
Chl Grt St
Plg Ms Bt
Chl And St
Plg Ms Bt
Chl And
Plg Ms
MnNCKFMASH-mc157
7
6
5
4
3
2
510
530
550
570
590

Figure 15. The pseudosections showing the intersections of X_{Mn}, X_{Ca}, X_{Fe} and X_{Ca}, X_{An} isopleths from core to median of garnet porphyroblasts within the rock samples mc39 (a), mc55 (b), mc81 (c) and mc157 (d). The data for this is displayed on the pseudosections (See also Figs. 8-11 for the positions of point analyses). The average P-T calculations with their uncertainty ellipses (e) for the rim of garnet porphyroblasts are plotted on the pseudosections for the whole rock samples (see Tables 2 and 6). In addition, uncertainty ellipses of P-T estimations for the core growth of successively formed garnets (See Fig. 14) around FIA1 (ENE-WSW), FIA2 (N-S) and FIA3 (E-W) are also plotted (e); thereby P-T is obtained as shown with dashed arrow line. The white centred circular spots refer to the intersection of X_{Ca} and X_{An}. The black stripes in uncertainty ellipses indicate the coincidence of likely places for the rim growth on a P-T space.


a)
MnNCKFMASH-mc39
rim
med2
med1
core
X_{Mn} X_{Ca} X_{Fe} X_{An}
Core: 0.12 0.17 0.66 NA
med1: 0.08 0.19 0.70 NA
med2: 0.04 0.16 0.73 NA
b)
MnNCKFMASH-mc55
rim
med1
med2
Core
X_{Mn} X_{Ca} X_{Fe} X_{An}
Core: 0.16 0.15 0.64 NA
med1: 0.11 0.16 0.67 NA
med2: 0.07 0.15 0.72 NA
c)
MnNCKFMASH-mc81
rim
med1
med2
Core
X_{Mn} X_{Ca} X_{Fe} X_{An}
Core: 0.15 0.13 0.65 NA
med1: 0.12 0.13 0.68 NA
med2: 0.09 0.12 0.72 0.40
d)
MnNCKFMASH-mc157
rim
med1
med2
Core
X_{Mn} X_{Ca} X_{Fe} X_{An}
Core: 0.18 0.12 0.64 0.42
med1: 0.10 0.12 0.71 0.36
med2: 0.06 0.10 0.75 NA
e)
mc133
mc152
mc23
mc137
mc30
mc81
mc157
mc55
mc158
mc39
9 8 7 6 5 4 3 2
510 530 550 570 590 610 630 650 670

Sample	Mineral phases	T(ºC)	Error	P(kb)	Error	Correlation Fit	Sigfit	95% confid. fit
mc39	Grt+St+Bt+Ms	610	80	6.8	2.9	-0.513	1.12	1.73
mc55	Grt+Plg+St+Bt+Ms	585	25	6.8	1.0	0.812	0.60	1.49
mc81	Grt+Plg+St+Bt+Ms	619	51	7.5	1.2	0.576	1.09	1.61
mc157	Grt+Plg+St+Bt+Ms	600	24	7.2	1.0	0.786	0.81	1.49
mc137	Grt+Plg+St+Bt+Ms	601	46	7.1	1.1	0.575	0.94	1.54
mc23	Grt+Plg+St+Bt+Ms	567	41	6.4	1.0	0.58	0.6	1.54
mc158	Grt+Plg+St+Bt+Ms	596	32	5.6	1.3	0.803	1.28	1.54
mc30	Grt+Plg+St+Bt+Ms	636	27	6.9	1.1	0.804	0.79	1.54
mc133	Grt+Plg+St+Bt+Ms	620	48	7.3	1.1	0.582	1.05	1.61
mc152	Grt+Plg+St+Bt+Ms+Sill	655	61	6.9	1.3	0.537	1.16	1.61

Table 6. Average P-T calculations. Correlation fit is a measure of how correlated the pressure and temperature on a scale from ±1-0. 0 = uncorrelated, ±1 = completely correlated. Sigfit is the result of a Chi-squared test at 95% confidence. If it is less than the number presented in the *95% confid fit* column, all the calculated equilibrium overlap the P-T estimate within 95% confidence level.

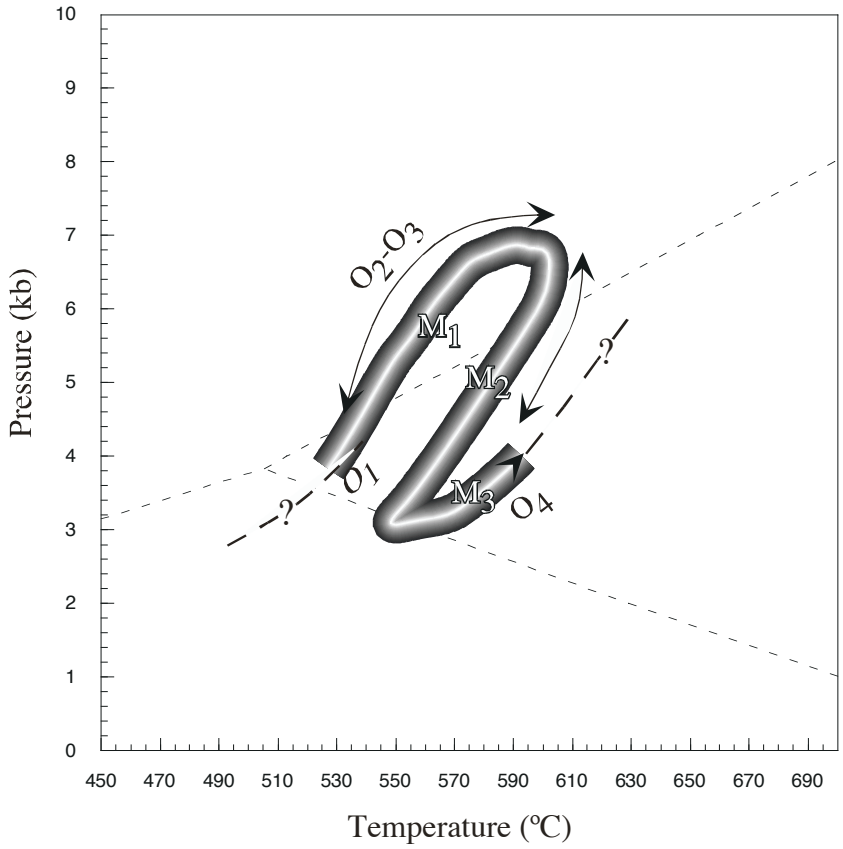


Figure 16. Derivation of complete P-T path based on the methods explained in the text. O_1-O_4 describes the four periods of shortening events accompanied or followed by three metamorphic events, M_1-M_3.