

The chemical composition of garnets from the syenite pegmatites in the Larvik Plutonic Complex

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Introduction

Garnets have previously been regarded as relatively rare minerals in the syenite pegmatites in the Larvik Plutonic Complex. Brøgger (1890) reported garnets from Stokkøya and Arøya in the Langesundsfjord, and at Gusfre in Eidanger. Most of the localities were pegmatites in basalt. During the last decades garnets have been found at several new localities, mainly in the Sandefjord district. Some of these finds were described by Berge & Larsen (1980). The identities of the garnets were determined based on bulk chemical composition. From what we now know most of the garnets are strongly zoned. It is therefore of interest to investigate the minerals using electron microprobe in order to reveal the degree of chemical zonation.

Occurrences

Garnets in the pegmatites in the Larvik plutonic complex are found in three different modes of occurrences:

1. Well-developed garnet crystals in vugs or interstices between large feldspar individuals in pegmatites in larvikite of chill IV by Petersen (1978). Associated minerals typically include albite \pm epidote \pm calcite, rarely vesuvianite. Most of the localities in the Sandefjord district belong to this type of occurrence.
2. Well-developed garnet crystals in vugs or interstices between feldspar individuals or embedded in matrix in pegmatites in basalt. The localities at Stokkøya, Arøya and in Bjørkedalen belong to this type of occurrence.
3. Garnet crystals in vugs associated with, or embedded in, analcime. The occurrences at the Håkestad, the Vevja and the Malerød quarries belong to this type of occurrence.

20 samples with a wide range of colour variations from 16 localities have been selected for the present investigation. The samples are shown in Table 1.

Analysing conditions

The garnets were analysed by a CAMECA SX-100 microprobe using an operating voltage of 15 kV, a beam current of 10 nA, and a defocussed beam spot of 10 μm . The instrument was operating in wave-length dispersive mode. The following standards were used: Wollastonite (SiK α , CaK α), Al₂O₃ (AlK α), Fe₂O₃ (FeK α), MnTiO₃ (MnK α , TiK α) and MgO (MgK α). Backscatter electron imaging was used to investigate the compositional zonation of the crystals. The analytical results showing the typical chemical variation within single crystal individuals are shown in Tables 2-10. The molecular percentages of andradite (AND) and grossular (GRO) have been calculated based on the concentration of Fe³⁺ and Al, respectively.

Results

Andradite: Most of the garnets from the Hotvedt I quarry are andradites. The crystals are strongly zoned. Two examples are shown in Fig. 1 and Fig. 2. Some zones have grossular mol-contents above 50 %. The same applies to the garnet from Kariåsen, which varies from 66 mol-% to 30 mol-% andradite. The garnets from Natholmskjær, Knattholmen, Marøyskjær, Malerød and Slevolden are andradites.

The colours of the andradites from the Larvik plutonic complex are typically dark green to dark brown.

The black garnet from Stokkøya, previously called *yttergranat*, was described already more than 150 years ago. The name *yttergranat* was given to the species because of an erroneously analysed content of 6.66 % *yttrian earth*. Brøgger (1890) and Larsen (1979) re-analysed the mineral. These analyses, however, were done on bulk material. It is therefore of interest to see if the mineral is zoned using electron microprobe. From the results shown in Table 10 it can be concluded that the mineral is rather homogeneous in composition, and the analytical results of this investigation confirms the chemical composition found by Brøgger (1890) and Larsen (1979).

Grossular: The yellowish garnets from the Hotvedt III quarry and Åsm. Berg quarry are grossulars. Pale green garnets from Haga, the Kamfjord quarry, Kariåsen and Gokstad are grossulars. The garnets from Vevja and partly also from the Håkestad quarry are grossulars. The colours of the grossulars from the Larvik plutonic complex are typically yellow, yellowish green to medium green.

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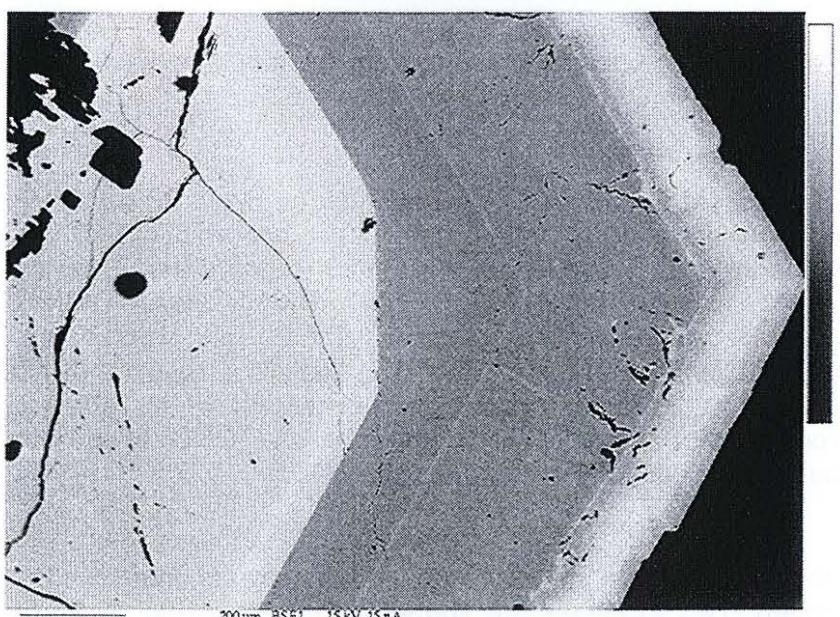


Fig. 1. SEM backscatter image of a part of a garnet crystal from Hotvedt I quarry. The width of field is appr. 1.4 mm.

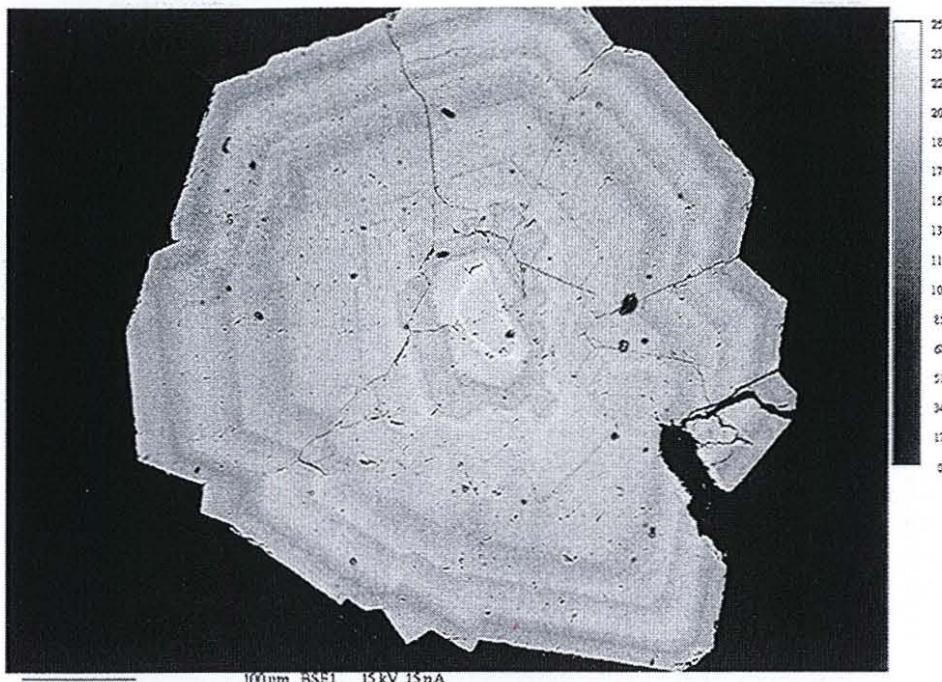


Fig. 2. SEM backscatter image of a garnet crystal (appr. 0.6 mm across) from Torp, Sandefjord showing multiple zones.

Table 1. The samples and the corresponding colour of the garnets.

Sample name	Locality	Colour
H1A	Hotvedt I quarry, Sandefjord	Dark green
H1B	Hotvedt I quarry, Sandefjord	Very dark green
H1C	Hotvedt I quarry, Sandefjord	Brown
H3A	Hotvedt III quarry, Sandefjord	Yellow
BERG	Åsm. Berg quarry (middle), Hotvedt, Sandefjord	Greenish yellow
TORP	Torp, Sandefjord	Green
HAGA	Haga, Vindal, Vesterøya, Sandefjord	Pale green
KAM1	Kamfjord quarry, Vesterøya, Sandefjord	Pale green
KAM2	Kamfjord quarry, Vesterøya, Sandefjord	Green
KARI	Kariåsen, Sandefjord	Green
GOK	Gokstad, Sandefjord	Pale green
NAT1	Natholmskjær, Lahellefjorden, Sandefjord	Brown
NAT2	Natholmskjær, Lahellefjorden, Sandefjord	Green
KNAT	Knattholmen, Lahellefjorden, Sandefjord	Dark brown
MAR	Marøyskjær, Lahellefjorden, Sandefjord	Dark green
HAK	Håkestad quarry, Tjølling, Larvik	Green
VEV	Vevja quarry, Tvedalen, Larvik	Green
MAL	Malerød quarry, Larvik	Green
SLE	Slevolden, Eidanger	Dark green
STOKKØYA	Stokkøya, Langesundsfjorden	Black

Table 2. Chemical composition (in wt.% oxides, *apfu* based on 12 O, and mol-% of andradite (AND) and grossular (GRO)) on garnets from the Hotvedt I quarry (H1A, H1B), Sandefjord.

	H1A			H1B		
	a	b	c	a	b	c
SiO ₂	36.32	35.74	35.55	36.52	36.17	34.79
TiO ₂	0.75	1.93	1.26	0.95	0.73	0.27
Al ₂ O ₃	10.97	3.58	6.59	7.98	10.32	12.77
Fe ₂ O ₃	15.36	24.80	21.03	19.69	16.67	13.92
MnO	0.32	0.36	0.25	0.83	0.29	0.22
MgO	0.00	0.00	0.00	0.02	0.00	0.00
CaO	35.84	33.90	34.64	34.21	35.69	36.33
Total	99.56	100.31	99.32	100.20	99.87	98.30
Si	2.922	2.951	2.928	2.957	2.913	2.833
Ti	0.045	0.120	0.078	0.058	0.044	0.017
Al	1.040	0.348	0.640	0.762	0.980	1.225
Fe ³⁺	0.930	1.541	1.303	1.200	1.010	0.853
Mn	0.022	0.025	0.017	0.057	0.020	0.015
Mg	0.000	0.000	0.000	0.002	0.000	0.000
Ca	3.089	2.999	3.057	2.968	3.080	3.169
AND	47	82	67	61	51	41
GRO	52	18	32	39	49	59

Table 3. Chemical composition (in wt.% oxides, *apfu* based on 12 O, and mol-% of andradite (AND) and grossular (GRO)) on garnets from the Hotvedt I (H1C) and the Hotvedt III (H3A) quarries, Sandefjord.

	H1C			H3A	
	a	b	c	a	b
SiO ₂	37.89	36.47	34.96	37.69	35.39
TiO ₂	0.21	0.05	0.60	0.01	0.06
Al ₂ O ₃	14.86	8.15	10.43	16.00	13.64
Fe ₂ O ₃	12.37	20.34	16.36	9.53	12.40
MnO	1.79	0.67	0.32	0.82	0.20
MgO	0.00	0.00	0.00	0.00	0.00
CaO	33.43	34.70	35.91	36.08	36.96
Total	100.55	100.38	98.58	100.13	98.65
Si	2.959	2.954	2.865	2.941	2.855
Ti	0.012	0.003	0.037	0.001	0.004
Al	1.370	0.778	1.007	1.471	1.297
Fe ³⁺	0.727	1.240	1.008	0.560	0.753
Mn	0.118	0.046	0.022	0.054	0.014
Mg	0.000	0.000	0.000	0.000	0.000
Ca	2.794	3.012	3.151	3.016	3.195
AND	35	61	50	28	37
GRO	65	39	50	72	63

Table 4. Chemical composition (in wt.% oxides, *apfu* based on 12 O, and mol-% of andradite (AND) and grossular (GRO)) on garnets from the Åsm. Berg quarry (BERG) and Torp, Sandefjord.

	BERG		TORP			
	a	b	a	b	c	d
SiO ₂	37.53	37.02	36.17	35.37	36.12	35.91
TiO ₂	0.00	0.00	0.00	0.26	0.99	0.76
Al ₂ O ₃	15.63	13.98	4.82	0.44	7.62	9.29
Fe ₂ O ₃	10.05	12.76	24.43	30.50	20.06	17.69
MnO	0.88	1.57	0.16	0.17	0.70	0.49
MgO	0.01	0.01	0.00	0.00	0.00	0.00
CaO	36.45	34.56	34.72	33.65	34.47	35.21
Total	100.55	99.90	100.30	100.39	99.96	99.35
Si	2.927	2.932	2.978	2.978	2.943	2.923
Ti	0.000	0.000	0.000	0.016	0.061	0.046
Al	1.437	1.305	0.468	0.043	0.732	0.891
Fe ³⁺	0.590	0.760	1.513	1.932	1.230	1.083
Mn	0.058	0.105	0.011	0.012	0.048	0.034
Mg	0.001	0.001	0.000	0.000	0.000	0.000
Ca	3.046	2.932	3.062	3.035	3.001	3.069
AND	29	37	76	98	63	55
GRO	71	63	24	2	37	45

Table 5 Chemical composition (in wt.% oxides, *apfu* based on 12 O, and mol-% of andradite (AND) and grossular (GRO)) on garnets from Haga (HAGA) and the Kamfjord quarry (KAM1, KAM2), Sandefjord.

	HAGA	KAM1		KAM2
	a	a	b	a
SiO ₂	36.52	36.45	35.31	35.69
TiO ₂	0.68	1.73	0.72	1.10
Al ₂ O ₃	21.22	15.79	12.52	16.71
Fe ₂ O ₃	4.58	7.89	13.11	7.24
MnO	0.98	0.48	0.25	0.69
MgO	0.01	0.00	0.00	0.00
CaO	36.80	36.58	36.18	36.68
Total	100.79	98.92	98.09	98.11
Si	2.791	2.879	2.871	2.843
Ti	0.039	0.103	0.044	0.066
Al	1.911	1.469	1.200	1.569
Fe ³⁺	0.263	0.469	0.802	0.434
Mn	0.063	0.032	0.017	0.046
Mg	0.001	0.000	0.000	0.000
Ca	3.013	3.096	3.151	3.131
AND	12	24	40	22
GRO	88	76	60	78

Table 6. Chemical composition (in wt.% oxides, *apfu* based on 12 O, and mol-% of andradite (AND) and grossular (GRO)) on garnets from Kariåsen (KARI) and Gokstad (GOK), Sandefjord.

	KARI				GOK	
	a	b	c	d	a	b
SiO ₂	36.06	35.17	35.42	33.60	37.03	35.67
TiO ₂	1.17	0.87	0.63	0.93	0.00	0.75
Al ₂ O ₃	14.52	13.14	10.64	6.78	19.24	13.94
Fe ₂ O ₃	9.62	12.39	16.27	20.96	5.39	11.47
MnO	1.47	0.95	0.71	0.29	0.61	0.48
MgO	0.02	0.00	0.00	0.02	0.00	0.00
CaO	35.20	35.74	35.13	35.10	37.09	36.27
Total	98.06	98.26	98.80	97.68	99.36	98.58
Si	2.896	2.852	2.887	2.837	2.878	2.866
Ti	0.071	0.053	0.039	0.059	0.000	0.045
Al	1.375	1.256	1.022	0.675	1.762	1.320
Fe ³⁺	0.581	0.756	0.998	1.332	0.315	0.694
Mn	0.100	0.065	0.049	0.021	0.040	0.033
Mg	0.002	0.000	0.000	0.003	0.000	0.000
Ca	3.029	3.106	3.068	3.175	3.088	3.123
AND	30	38	49	66	15	34
GRO	70	62	51	34	85	65

Table 7. Chemical composition (in wt.% oxides, *apfu* based on 12 O, and mol-% of andradite (AND) and grossular (GRO)) on garnets from Natholmskjær (NAT1, NAT2) and Knattholmen (KNAT), Sandefjord.

	NAT1			NAT2			KNAT
	a	b	c	a	b	c	a
SiO ₂	35.51	35.65	36.34	35.32	35.81	36.50	35.72
TiO ₂	0.00	1.11	0.23	0.02	0.00	0.01	0.14
Al ₂ O ₃	1.59	5.81	9.34	0.39	5.29	7.19	3.45
Fe ₂ O ₃	28.71	22.25	18.28	30.03	24.47	21.35	27.25
MnO	0.34	0.88	0.61	0.39	0.63	0.69	0.79
MgO	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CaO	33.84	34.17	35.28	33.60	33.93	34.37	33.54
Total	99.99	99.87	100.08	99.75	100.13	100.11	100.89
Si	2.984	2.936	2.937	2.994	2.954	2.975	2.954
Ti	0.000	0.069	0.001	0.001	0.000	0.001	0.009
Al	0.157	0.564	0.890	0.038	0.514	0.691	0.336
Fe ³⁺	1.816	1.379	1.112	1.915	1.519	1.309	1.696
Mn	0.024	0.061	0.042	0.028	0.044	0.048	0.055
Mg	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Ca	3.047	3.015	3.055	3.051	2.999	3.001	2.972
AND	92	71	56	98	75	65	83
GRO	8	29	44	2	25	35	17

Table 8. Chemical composition (in wt.% oxides, *apfu* based on 12 O, and mol-% of andradite (AND) and grossular (GRO)) on garnets from Marøyskjær (MAR), Sandefjord and the Håkestad quarry (HAK), Larvik.

	MAR			HAK		
	a	b	c	a	b	c
SiO ₂	35.89	38.25	35.63	36.26	33.81	35.37
TiO ₂	1.39	0.70	0.00	0.79	1.10	0.84
Al ₂ O ₃	7.53	17.43	2.14	10.51	6.53	11.93
Fe ₂ O ₃	18.12	8.39	25.46	16.80	21.47	14.12
MnO	0.75	0.18	0.44	0.55	0.24	0.57
MgO	0.08	0.25	0.00	0.00	0.01	0.00
CaO	34.73	36.14	33.68	35.63	35.14	35.68
Total	98.49	101.34	97.35	100.54	98.30	98.51
Si	2.958	2.922	3.049	2.903	2.839	2.872
Ti	0.086	0.040	0.000	0.048	0.069	0.051
Al	0.731	1.569	0.216	0.993	0.646	1.142
Fe ³⁺	1.124	0.482	1.639	1.012	1.357	0.863
Mn	0.052	0.012	0.032	0.037	0.017	0.039
Mg	0.010	0.028	0.000	0.000	0.001	0.000
Ca	3.067	2.958	3.088	3.056	3.161	3.105
AND	61	24	88	51	68	43
GRO	39	76	12	49	32	57

Table 9. Chemical composition (in wt.% oxides, *apfu* based on 12 O, and mol-% of andradite (AND) and grossular (GRO)) on garnets from the Vevja quarry (VEV) and the Malerød quarry (MAL) in Larvik, and Slevolden (SLE), Porsgrunn.

	VEV	MAL		SLE
	a	a	b	a
SiO ₂	34.19	34.06	32.80	36.08
TiO ₂	0.61	1.40	0.73	0.31
Al ₂ O ₃	12.81	5.86	8.91	5.15
Fe ₂ O ₃	12.89	21.46	18.09	23.64
MnO	0.49	0.27	0.54	0.86
MgO	0.00	0.00	0.03	0.02
CaO	36.04	34.36	35.14	33.99
Total	97.03	97.41	96.24	100.05
Si	2.819	2.881	2.791	2.974
Ti	0.038	0.089	0.047	0.019
Al	1.245	0.584	0.894	0.500
Fe ³⁺	0.800	1.366	1.158	1.466
Mn	0.034	0.019	0.039	0.060
Mg	0.000	0.000	0.004	0.002
Ca	3.184	3.114	3.204	3.002
AND	39	70	56	75
GRO	61	30	44	25

Table 10. Chemical composition (in wt.% oxides, *apfu* based on 12 O, and mol-% of andradite (AND) and grossular (GRO)) on garnet from the southern part of Stokkøya in the Langesundsfjord.

	STOKKØYA (this study)		STOKKØYA (Larsen 1979)	STOKKØYA (Brøgger 1890)
	mean (n = 10)	range		
SiO ₂	32.89	32.14 - 33.60	32.97	31.53
TiO ₂	2.33	1.57 - 2.98	2.14	3.52
ZrO ₂	0.44	0.23 - 0.58	0.36	n.a.
Al ₂ O ₃	1.46	1.36 - 1.58	2.34	2.01
Fe ₂ O ₃	27.78	27.09 - 28.67	25.71	26.68
Y ₂ O ₃	1.61	0.95 - 2.40	0.90	0.38
MnO	1.81	1.73 - 1.94	1.15	1.93
MgO	0.34	0.16 - 0.50	1.75	0.38
CaO	30.16	29.37 - 31.13	29.83	30.78
Na ₂ O	0.20	0.17 - 0.25	1.05	0.79
Total	99.02		98.20	98.00
Si	2.830			
Ti	0.151			
Zr	0.018			
Al	0.148			
Fe ³⁺	1.798			
Y	0.074			
Mn	0.132			
Mg	0.044			
Ca	2.780			
Na	0.033			
AND	92			
GRO	8			