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Title of article New coesite-bearing eclogites in western Norway: The nature of an ultrahigh-pressure province in the western gneiss region

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Contents

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Garnet chemisrty *used in Garnet-Cpx-Phengite thermobarometry

		*	*	*	*	*			*		*		*
	sample	aw428b	hn127a	Nd30	aw377	aw389b	awd13	awd13	MWD187	MWD187	Hn142	Hn142	HN133a
	Location	Flatraket	Risnakken	Drage	Totland	Rundheim	S Nordfjord	S Nordfjord	N Nordfjord	N Nordfjord	N Nordfjord	N Nordfjord	N Nordfjord
	Lithology	Coesite Ec	Coesite Ec	Coesite Ec	RPQ Ec	RPQ Ec	Qtz ec	Qtz ec	Qtz ec	Qtz ec	Qtz ec	Qtz ec	Qtz ec
	Grt	average	average	average	average	average	av rims	core	av rims	core	av rims	core	av rims
	No	18	51	10	14	16	8	1	36	1	14	1	20
Microprobe analyses													
	SiO2	40.20	40.35	40.72	39.07	40.12	39.76	38.80	38.98	38.43	40.70	40.10	39.28
	TiO2	0.02	0.04	0.04	0.04	0.04	0.03	0.11	0.07	0.14	0.03	0.04	0.03
	Al2O3	21.90	22.35	22.12	21.41	22.21	22.12	21.53	21.53	21.25	22.33	22.01	22.16
	Fe2O3												
	FeO	18.14	17.28	16.49	23.40	16.78	22.98	23.40	23.98	23.45	20.06	21.63	21.53
	MnO	0.35	0.34	0.28	0.47	0.52	0.38	2.42	0.51	3.75	0.25	0.48	0.41
	MgO	11.44	10.09	10.08	5.76	9.74	7.93	4.17	5.30	3.84	10.86	9.38	8.64
	CaO	7.47	10.14	10.62	9.90	10.53	7.59	10.26	10.17	9.60	6.67	6.82	8.59
	Na2O	0.02	0.03	0.03	0.03	0.02	0.02	0.00	0.03	0.04	0.03	0.02	0.03
	K2O	0.00	0.04	0.00	0.06	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.04
	Total	99.54	100.67	100.38	100.09	99.95	100.79	100.69	100.56	100.50	100.91	100.48	100.71
	Oxygens	12	12	12	12	12	12	12	12	12	12	12	12
Divalent Fe only	Si	3.02	3.01	3.03	3.02	3.01	3.02	3.01	3.01	3.01	3.03	3.03	2.98
	Ti	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.00
	Al	1.94	1.96	1.94	1.95	1.97	1.98	1.97	1.96	1.96	1.96	1.96	1.98
	Fe3+	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Fe2+	1.14	1.08	1.03	1.51	1.05	1.46	1.52	1.55	1.53	1.25	1.37	1.36
	Mn	0.02	0.02	0.02	0.03	0.03	0.02	0.16	0.03	0.25	0.02	0.03	0.03
	Mg	1.28	1.12	1.12	0.66	1.09	0.90	0.48	0.61	0.45	1.20	1.06	0.98
	Ca	0.60	0.81	0.85	0.82	0.85	0.62	0.85	0.84	0.80	0.53	0.55	0.70
	Na	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
	K	0.00	0.00	7.99	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sum	8.01	8.01	7.99	8.01	8.00	7.99	8.00	8.01	8.01	7.99	7.99	8.03
	Xmg	0.53	0.51	0.52	0.30	0.51	0.38	0.24	0.28	0.23	0.49	0.44	0.42
Fe3+ recalculated (Droop 1987)	Si	3.02	3.00		3.02	3.01			3.00				2.97
	Ti	0.00	0.00		0.00	0.00			0.00				0.00
	Al	1.94	1.96		1.95	1.96			1.96				1.97
	Fe3+	0.03	0.04		0.03	0.01			0.04				0.10
	Fe2+	1.11	1.04		1.49	1.04			1.51				1.26
	Mn	0.02	0.02		0.03	0.03			0.03				0.03
	Mg	1.28	1.12		0.66	1.09			0.61				0.97
	Ca	0.60	0.81		0.82	0.85			0.84				0.70
	Na	0.00	0.00		0.01	0.00			0.01				0.01
	K	0.00	0.00		0.01	0.00			0.00				0.00
	Sum	8.00	8.00		8.00	8.00			8.00				8.00
	Xmg	0.54	0.52		0.31	0.51			0.29				0.44

Fe3+ recalc where possible in samples used in thermobarometry

HN133a	aw431	aw431	aw36	aw408b	aw408b	aw485a	aw485a	aw412	aw412
N Nordfjord	Straumen	Straumen	Flatraket	Nordpollen	Nordpollen	N Nordfjord	N Nordfjord	Nordpollen	Nordpollen
Qtz ec	Qtz ec	Qtz ec	Qtz ec	Qtz ec	Qtz ec	Qtz ec	Qtz ec	Qtz ec	Qtz ec
core	av rims	core	av rims	av rims	core	rim	core	core	rim
1	10	1	21	17	1	1	1	1	20
38.82	39.74	39.19	39.30	40.26	39.88	39.11	38.48	38.50	39.35
0.05	0.04	0.11	0.03	0.07	0.13	0.00	0.00	0.09	0.02
22.02	22.07	21.76	21.67	22.36	22.17	22.18	21.56	20.67	21.76
21.84	21.44	24.26	25.62	20.26	19.86	22.04	23.33	25.62	22.65
0.21	0.21	0.71	0.52	0.45	1.14	0.28	0.80	1.82	0.38
7.76	9.24	6.16	6.81	10.65	9.24	8.59	4.82	4.84	7.92
9.16	7.46	8.72	6.94	6.89	8.62	8.05	10.85	8.13	7.81
0.04	0.02	0.06	0.02	0.03	0.02	0.00	0.00	0.00	0.02
0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
99.95	100.23	100.97	100.91	100.95	101.06	100.25	99.84	99.67	99.89
12	12	12	12	12	12	12	12	12	12
2.98	3.01	3.01	3.02	3.01	3.00	2.98	3.00	3.03	3.01
0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.01	0.00
1.99	1.97	1.97	1.96	1.97	1.96	1.99	1.98	1.92	1.96
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.40	1.36	1.56	1.64	1.26	1.25	1.40	1.52	1.69	1.45
0.01	0.01	0.05	0.03	0.03	0.07	0.02	0.05	0.12	0.02
0.89	1.04	0.70	0.80	1.19	1.03	0.98	0.56	0.57	0.90
0.75	0.61	0.72	0.57	0.55	0.69	0.66	0.91	0.69	0.64
0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8.03	8.00	8.01	8.01	8.01	8.02	8.03	8.01	8.01	8.00
0.39	0.43	0.31	0.32	0.48	0.45	0.41	0.27	0.25	0.38
	3.01		3.01	3.00					3.01
	0.00		0.00	0.00					0.00
	1.97		1.96	1.97					1.96
	0.01		0.02	0.03					0.01
	1.34		1.63	1.24					1.44
	0.01		0.03	0.03					0.03
	1.04		0.78	1.18					0.90
	0.61		0.57	0.55					0.64
	0.00		0.00	0.00					0.00
	0.00		0.00	0.00					0.00
	8.00		8.00	8.00					8.00
	0.44		0.32	0.49					0.38

Phengite Mineral Chemistry
All analyses used in Garnet-Cpx-Phengite thermobarometry

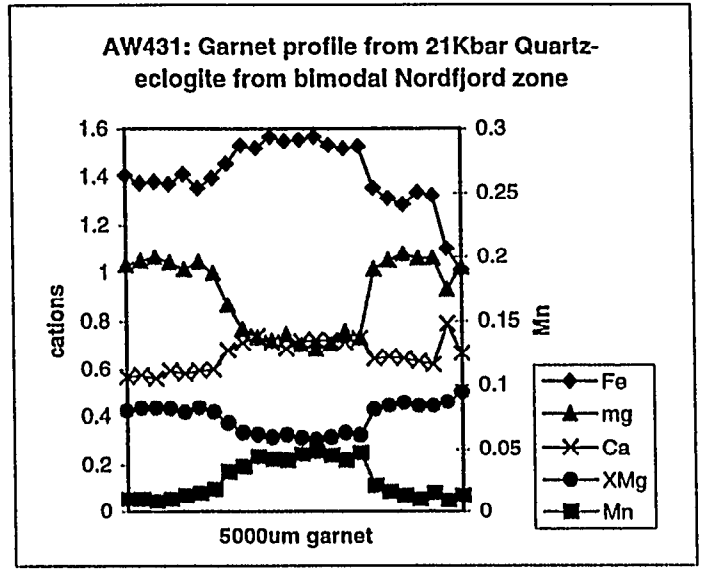
	sample	aw428b	hn127a	ND30	AW377	aw389b	MWD187	Hn142	HN133a	aw431c	AW36	aw408b	aw412
	Location	Flatraket	Risnakken	Drage	Totland	Rundheim	N Nordfjord	N Nordfjord	N Nordfjord	Straumen	Flatraket	Nordpollen	Nordpollen
	Lithology	Coesite ec	Coesite ec	Coesite ec	Pseu ec	Pseu ec	Qtz eclogite	Qtz eclogite	Qtz eclogite	Qtz eclogite	Qtz eclogite	Qtz eclogite	Qtz eclogite
	Phengite	Highest Si	Highest Si	Highest Si	Highest Si	Highest Si	Highest Si	Highest Si	Highest Si	Highest Si	Highest Si	Highest Si	Highest Si
Microprobe analyses	SiO2	53.48	52.12	52.16	51.92	52.55	52.33	52.84	51.97	52.63	52.86	52.22	50.65
	TiO2	0.39	0.43	0.39	0.30	0.47	0.41	0.30	0.41	0.30	0.52	0.58	0.30
	Al2O3	24.71	25.97	25.34	23.85	26.34	25.80	25.80	26.21	25.83	23.88	26.68	26.92
	Fe2O3												
	FeO	1.28	0.94	0.95	2.01	0.95	2.10	1.20	1.50	1.37	2.23	1.40	1.93
	MnO	0.01	0.01	0.00	0.01	0.03	0.03	0.01	0.00	0.01	0.00	0.00	0.00
	MgO	4.40	4.07	4.17	4.07	4.08	3.66	4.40	3.74	4.02	4.15	3.96	3.71
	CaO	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.06
	Na2O	0.40	0.41	0.34	0.27	0.34	0.56	0.57	0.41	0.45	0.27	0.69	0.60
	K2O	9.10	11.18	11.27	10.60	10.25	10.37	10.74	10.63	10.52	10.85	10.11	10.16
	BaO	0.33	0.30	0.08		0.33	0.25	0.66	0.37	0.11	0.17	0.41	
	Total	94.08	95.43	94.70	93.03	95.34	95.51	96.53	95.24	95.24	94.93	96.05	94.33
	Oxygens	22	22	22	22	22	22	22	22	22	22	22	22
Divalent Fe only	Si	7.12	6.94	6.99	7.08	6.95	6.96	6.96	6.93	6.99	7.09	6.89	6.81
	Ti	0.04	0.04	0.04	0.03	0.05	0.04	0.03	0.04	0.03	0.05	0.06	0.03
	Al	3.88	4.07	4.00	3.84	4.11	4.05	4.01	4.12	4.04	3.78	4.15	4.27
	Fe3+	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Fe2+	0.14	0.11	0.11	0.23	0.11	0.23	0.13	0.17	0.15	0.25	0.15	0.22
	Mn	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Mg	0.87	0.81	0.83	0.83	0.80	0.73	0.86	0.74	0.80	0.83	0.78	0.74
	Ca	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
	Na	0.10	0.11	0.09	0.07	0.09	0.14	0.15	0.11	0.12	0.07	0.18	0.16
	K	1.54	1.90	1.93	1.85	1.73	1.76	1.81	1.81	1.78	1.86	1.70	1.74
	Ba	0.02	0.02	0.00	0.00	0.02	0.01	0.03	0.02	0.01	0.01	0.02	0.00
	Sum	13.72	13.99	13.98	13.93	13.86	13.93	13.98	13.93	13.91	13.93	13.92	13.98
	Xmg	0.86	0.89	0.89	0.78	0.88	0.76	0.87	0.82	0.84	0.77	0.83	0.77

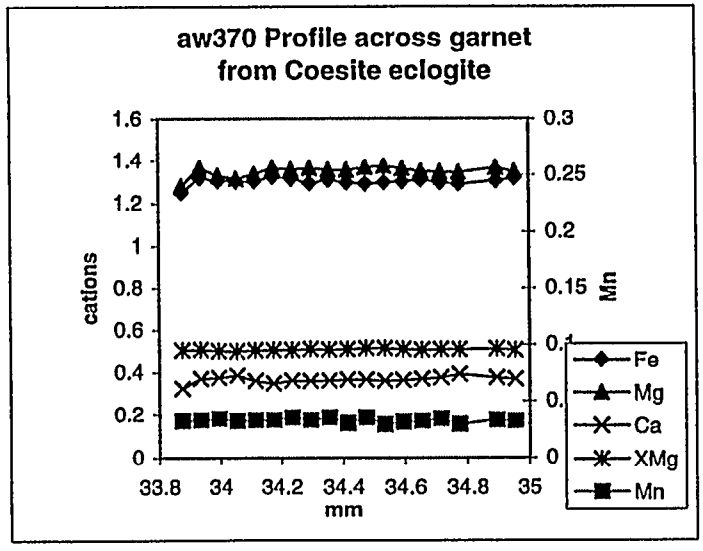
Clinopyroxene Mineral Chemistry:
all used in garnet-clinopyroxene-phengite thermobarometry

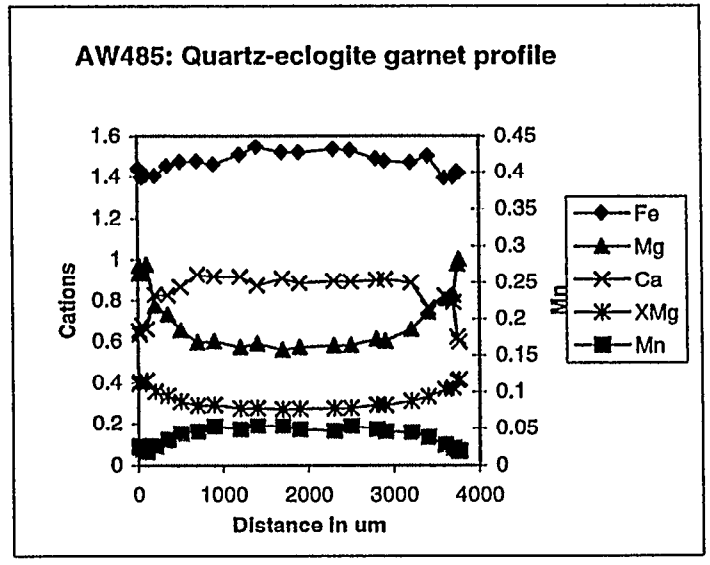
	sample	aw428b	hn127a	nd30	AW377	aw389	MWD187	Hn142	H133	aw431c	AW36	aw408b	aw412
	Location	Flatraket	Risnakken	Drage	Totland	Rundheim	N Nordfjord	N Nordfjord	N Nordfjord	Straumen	Flatraket	Nordpollen	Nordpollen
	Lithology	Coesite ec	Coesite ec	Coesite ec	Pseu ec	Pseu ec	Qtz eclogite	Qtz eclogite	Qtz eclogite	Qtz eclogite	Qtz eclogite	Qtz eclogite	Qtz eclogite
	Cpx	average	average	average	average	average	average	average	average	average	average	average	average
	No	41	30	5	16	8	32	12	18	13	20	34	26
Microprobe analyses													
	SiO2	56.08	55.34	55.54	56.21	55.58	55.96	56.68	56.17	55.53	55.78	56.62	56.22
	TiO2	0.08	0.14	0.13	0.08	0.08	0.08	0.06	0.08	0.08	0.07	0.13	0.06
	Al2O3	10.79	10.53	9.30	10.70	10.12	10.41	11.12	11.42	10.04	10.49	11.10	11.39
	Fe2O3												
	FeO	2.71	2.66	2.74	4.59	2.42	4.22	2.95	3.06	3.81	5.42	3.09	3.87
	MnO	0.03	0.03	0.02	0.03	0.03	0.03	0.03	0.02	0.03	0.00	0.02	0.01
	MgO	8.94	9.63	10.44	7.93	9.67	8.47	8.65	8.44	8.94	7.76	8.70	7.98
	CaO	14.04	15.62	16.58	12.94	15.51	13.84	13.25	13.02	14.77	12.43	13.38	12.15
	Na2O	6.67	5.08	5.01	7.38	5.89	6.52	6.88	7.17	6.22	7.22	6.98	7.50
	K2O	0.04	0.07	0.21	0.04	0.04	0.04	0.04	0.06	0.03	0.00	0.04	0.04
	Total	99.38	99.07	99.97	99.87	99.33	99.57	99.68	99.45	99.45	99.17	100.06	99.22
	Oxygens	6	6	6	6	6	6	6	6	6	6	6	6
Divalent Fe only	Si	2.00	1.98	1.98	2.01	1.98	2.00	2.01	2.00	1.99	2.01	2.00	2.01
	Ti	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00
	Al	0.45	0.44	0.39	0.45	0.43	0.44	0.46	0.48	0.42	0.45	0.46	0.48
	Fe3+	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Fe2+	0.08	0.08	0.08	0.14	0.06	0.13	0.09	0.09	0.11	0.16	0.09	0.12
	Mn	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Mg	0.47	0.51	0.56	0.42	0.51	0.45	0.46	0.45	0.48	0.42	0.46	0.42
	Ca	0.54	0.60	0.63	0.49	0.59	0.53	0.50	0.50	0.57	0.48	0.51	0.46
	Na	0.46	0.35	0.35	0.51	0.41	0.45	0.47	0.50	0.43	0.50	0.48	0.52
	K	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sum	4.01	3.97	4.00	4.02	4.00	4.00	4.00	4.01	4.01	4.02	4.00	4.01
	Xmg	0.85	0.87	0.87	0.75	0.90	0.78	0.84	0.83	0.81	0.72	0.83	0.79
Fe3+ recalculated (Droop 1987)	Si	1.99			1.99	1.99	2.00		1.99	1.99	2.00	2.00	2.00
	Ti	0.00			0.00	0.00	0.00		0.00	0.00	0.00	0.00	0.00
	Al	0.45			0.45	0.43	0.44		0.48	0.42	0.44	0.46	0.48
	Fe3+	0.02			0.07	0.00	0.01		0.03	0.04	0.06	0.01	0.04
	Fe2+	0.06			0.07	0.07	0.11		0.06	0.08	0.11	0.08	0.08
	Mn	0.00			0.00	0.00	0.00		0.00	0.00	0.00	0.00	0.00
	Mg	0.47			0.42	0.51	0.45		0.45	0.48	0.41	0.46	0.42
	Ca	0.54			0.49	0.59	0.53		0.50	0.57	0.48	0.51	0.46
	Na	0.46			0.51	0.41	0.45		0.49	0.43	0.50	0.48	0.52
	K	0.00			0.00	0.00	0.00		0.00	0.00	0.00	0.00	0.00
	Sum	4.00			4.00	4.00	4.00		4.00	4.00	4.00	4.00	4.00
	Xmg	0.88			0.87	0.88	0.80		0.88	0.86	0.80	0.85	0.85

Fe3+ recalc where possible

Garnet zoning profiles for UHP and HP eclogites







Garnet-Climopyroxene-Phengite Thermobarometry: Wain 1997

sample	Loclality	Eclogite type	Fe treatment in Cpx and Grt	Grt-Cpx Powell 1985 T/C	Grt-Cpx-Phengite Waters and Martin 1996 P/Kbars
aw428	Flatraket	Coesite	Divalent only	817	28.5
h127	Risnakken	Coesite	Divalent only	854	29.6
nd30	Drage	Coesite-pseudomorph	Divalent only	838	29.2
aw377	Totland	Coesite-pseudomorph	Divalent only	791	27.9
aw389	Rundheim	Coesite-pseudomorph	Divalent only	830	28.2
m187	N. Nordfjord	Quartz prograde	Divalent only	712	23.0
h142	N. Nordfjord	Quartz prograde	Divalent only	774	24.1
h133	N. Nordfjord	Quartz prograde	Divalent only	752	24.3
aw431	Straumen	Quartz prograde	Divalent only	792	22.7
aw36	Flatraket	Quartz prograde	Divalent only	787	24.0
aw408	Nordpollen	Quartz prograde	Divalent only	773	22.0
aw412	Nordpollen	Quartz prograde	Divalent only	771	21.4
aw428	Flatraket	Coesite	Charge balance (Droop 1987)	751	27.3
h127	Risnakken	Coesite	Charge balance (Droop 1987)	855	29.4
aw377	Drage	Coesite-pseudomorph	Charge balance (Droop 1987)	612	24.8
aw389	Totland	Coesite-pseudomorph	Charge balance (Droop 1987)	789	27.7
m187	N. Nordfjord	Quartz prograde	Charge balance (Droop 1987)	693	22.4
h142	N. Nordfjord	Quartz prograde	Charge balance (Droop 1987)	706	23.9
h133	N. Nordfjord	Quartz prograde	Charge balance (Droop 1987)	673	23.3
aw431	Straumen	Quartz prograde	Charge balance (Droop 1987)	684	22.1
aw36	Flatraket	Quartz prograde	Charge balance (Droop 1987)	668	22.2
aw408	Nordpollen	Quartz prograde	Charge balance (Droop 1987)	736	21.6
aw412	Nordpollen	Quartz prograde	Charge balance (Droop 1987)	663	20.3

Locality (Fig. 1)	Rock type	Evidence for Coesite				Host
		C	PRQ	PPQ	MQ	
Flatraket	B	2	6	7	3	G
Nordpollen	B	1	5	9	18	Cpx, G
Risnakken	B	5	2	1	4	Cpx, K, G
Liberholmen	B	4	2			Cpx
Otnheim	B	4	2	2	1	G
Otnheim	F		6	4	10	G, Z
Totland	B		2	7	1	Cpx, G
Totland	F		1			Z
Totland 2	F			1		G
Flister	B		5	5	3	G, Cpx
Rundheim	B		5	9	1	Cpx, G
Barmsund	B		6	3	2	Cpx, G
Salt	B		5	14	6	G, Cpx
Barmen	B		1	3	3	Cpx
Krokereid	B		1	1		Cpx
Selje Kloster	B			4	1	G
Rekvik	B		8	9	5	G
Otnes	B		1	2	6	G, Cpx
(S1)	B		1	4		G
(S2)	B		1		1	G
Drage	F		2	1	2	G, Z
Drage*	B		*			Cpx, G
Liset*	B		*			G
Aarsheim*	B		*		*	G
Grytting*	B	*	*		*	Cpx, G
Straumen*	B	*	*		*	G, Cpx, K
Usltein*	B		*		*	G
Hessdalen*	B				*	Cpx

<u>Table showing evidence for coesite in eclogites from western Norway:</u>

all Data of Alice Wain, except that marked by *, which is David Smith's data.

C Coesite
PRQ Polycrystalline radial, palisade texture quartz inclusions
PPQ Polycrystalline polygonal texture quartz inclusions
MQ Multi-crystalline polygonal quartz inclusions (<10 per inclusion, Smith 1988)

Cpx Clinopyroxene
G Garnet
K Kyanite
Z Zoisite or clinozoisite

Geobarometry in eclogites

A geobarometer is a chemical equilibrium written among minerals which, because of a large volume difference between reactants and products, is sensitive to changes in pressure. Good geobarometers have low slopes (dP/dT) on a P-T diagram, and can be calibrated by precise phase equilibrium experiments or reliable thermochemical data. The defining assemblage should occur in common rock types, over a wide range of pressure and temperature. Many successful barometers depend on the large molar volume contrast between feldspar (anorthite or albite) and end members of denser phases such as garnet or pyroxene:

grossular (in garnet) + 2 kyanite + quartz = 3 anorthite (in plagioclase)

jadeite (in clinopyroxene) + quartz = albite (in plagioclase)

However, feldspars do not occur in true eclogites, and equilibria such as these can give only a lower limit to the actual pressures experienced during eclogite-facies metamorphism. Many of the published pressure estimates for eclogites are minima of this kind, and it would clearly be valuable to search for more relevant geobarometers.

Eclogite-facies rocks commonly contain other minerals in addition to the essential metabasic eclogite association garnet + omphacitic clinopyroxene. White micas (paragonite, phengitic muscovite) are of particular interest. The potential of paragonite-bearing assemblages for barometry was explored by Koons (1986). Of even more widespread applicability are equilibria involving phengite, whose composition can vary, in response to pressure, along the Tschermak exchange vector Al2Mg-1Si-1 between muscovite and celadonite (see Massonne and Schreyer 1987, 1989).

Another problem with high-pressure metamorphic rocks is that it can be difficult to demonstrate chemical equilibrium among minerals, because of compositional zoning in the minerals, or partial overprinting by retrograde mineral assemblages. In such cases the most useful equilibria involve a small number of phases, which have a good probability of being found in mutual contact or with unambiguous paragenetic relationships.

The equilibrium which most nearly answers the criteria for reliable barometry is

pyrope + 2grossular + 3celadonite = 6diopside + 3muscovite

which can also be written

pyrope + 2grossular = 6diopside + 3Al2Mg-1Si-1

It involves only three phases, garnet, clinopyroxene and phengite. It is independent of water activity and of silica saturation. No Fe end members are involved, so that the uncertainty related to formula recalculation for Fe3+ in clinopyroxene or phengite is minimal.

A preliminary calibration was offered by Waters and Martin (1993). For the current recommended calibration, with discussion of activity models and uncertainties, follow the link!

References

Koons PO (1986) Relative geobarometry from high-pressure rocks of quartzofeldspathic composition from the Sesia Zone, Western Alps, Italy. Contributions to Mineralogy and Petrology 93: 322-334.
Massonne HJ, Schreyer W (1987) Phengite geobarometry based on the limiting assemblage with K-feldspar, phlogopite, and quartz. Contributions to Mineralogy and Petrology 96: 212-224.

+ phengite and two new phengite barometers. European Journal of Mineralogy 1: 391-410.
Waters DJ, Martin HN (1993) Terra Abstracts 5 (1): 410-411.

The Garnet-Cpx-Phengite Barometer

Recommended calibration and calculation method, updated 1 March 1996

The barometer uses the equilibrium

pyrope + 2grossular = 6diopside + 3Al2Mg-1Si-1

The calibration is based on the self-consistent thermodynamic dataset of Holland and Powell (1990, J Metamorphic Geol. 8, 89-124). We have fitted a linear expression to the isopleths of lnK such that the linearised isopleths deviate by less than 100 bars from those calculated from the full dataset in the applicable part of the P-T range 6 - 40 kbar, 400 - 900°C:

$$P(kbar) = 28.05 + 0.02044T - 0.002995T.\ln K$$

where T is in Kelvin and the lnK term is calculated as follows:

$$\ln K = 6 \ln adi - \ln aprp - 2 \ln agrs + 3 \ln \left[\frac{X\,Al,M1.(4-Si)}{X\,Mg,M1.(Si-2)} \right]$$

In the phengite (right-hand) term, Si cations are per formula unit of 12(O,OH), and M1 are the dioctahedral cation sites. Ideal mixing on sites was used for data extraction in mica end members by Holland and Powell (1990) and so must also be used in the application. Cancellation of the site terms held in common between the muscovite and celadonite end members leads to the formulation above.

Activity models for garnet and clinopyroxene are a major source of uncertainty in applying the barometer. An independent test of its accuracy is provided by the experiments of Schmidt MW (1993, Am. J. Sci. 293, 1011-1060). The barometer calibration above overestimates the experimental pressures by a little over 3 kbar when the acitivity models outlined below are used. Until such time as there is better characterisation of the a-X relations in all three phases, and better thermochemical data on the Tschermak exchange in phengite, we recommend the following:

(Note that, because of the limitations of HTML, I have had to use y in place of the small greek letter gamma to represent an activity coefficient)

make an empirical correction of -0.000543 to the T.lnK term coefficient (on the assumption that the discrepancy with the Schmidt experiments, and with certain other natural data sets, lies mainly in the inadequacy of the activity models), so that

$$P(kbar) = 28.05 + 0.02044T - 0.003539T.\ln K$$

use simple Mg-Ca mixing in garnet.
Normalise the analysis to 12 oxygens, 8 cations.
Then, XMg = Mg/3, XCa = Ca/3, XAl = Al/2, where Mg etc. represents the number of Mg cations per formula unit.
$\ln a(prp) = 3\ln(XMg) + 3\ln(yMg) + 2\ln(XAl)$
$\ln a(grs) = 3\ln(XCa) + 3\ln(yCa) + 2\ln(XAl)$

From Newton and Haselton (1981), with units converted to J/mol:
$\ln(yMg) = [(13807 - 6.276T).XCa.(1-XMg)]/RT$

$\ln(yCa) = [(13807 - 6.276T).XMg.(1-XCa)]/RT$

use the reciprocal salt-solution model of Holland (1990, CMP 105, 446-453) for Cpx.
Normalise the analysis to 6 oxygens, 4 cations. Then XCa, M2 = Ca cations, XMg,M1 = Mg cations.
For long-range-disordered or Fe3+-bearing pyroxene:
$\ln a(di) = \ln(XCa,M2.XMg,M1) + \ln yCaMg$
From Holland (1990),
$\ln(yCaMg) = \{XNa,M2[WA(XAl,M1+XFe3+,M1)+(WA-WB)XFe2+,M1]\}/RT$
where WA = 26000 J, WB = 25000 J.
For ordered omphacite near the di-jd join, an additional activity coefficient y ord,di appears, arising from the Landau ordering model. Its value can be calculated from equation (12b) of Holland (1990).

use ideal mixing on sites for phengite.
Using the activity expressions in Holland and Powell (1990)
$a(Al2Mg\text{-}1Si\text{-}1) = XAl,M2.XAl,T2/(XMg,M2.XSi,T2)$
For a microprobe analysis normalised to 11 oxygens (without H2O) this can be expressed in terms of cations as
$(Al+Si-4).(4-Si)/[Mg.(Si-2)]$

This calibration can be found at :

http://www.earth.ox.ac.uk/davewa/ecbar.html