DEPARTMENT OF THE INTERIOR

U.S. GEOLOGICAL SURVEY

Garnet xenocryst analyses: Potential for diamonds in the Williams kimberlite, north-central Montana and the Lake Ellen kimberlite, northern Michigan

by

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Open-File Report 87-418

1987

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Abstract

Electron microprobe analyses of deep purple, 0.5-1 mm garnet xenocrysts from panned concentrates from the Williams and Lake Ellen kimberlites show that the majority of the garnets are Cr-bearing pyropes and are within the range typical of garnet lherzolites. Four garnets from the Williams kimberlite and three garnets from the Lake Ellen kimberlite are slightly subcalcic and are similar to the subcalcic garnet compositions associated with diamond; thus, they suggest a potential for diamonds in the Williams and Lake Ellen kimberlites.

Introduction

Purple, Cr-rich pyropic garnet that occurs in peridotite xenoliths and as a xenocryst phase in kimberlites is resistant to weathering and thus is commonly used as an indicator mineral to locate the presence of kimberlite. Most peridotitic garnets are Mg-rich and show a positive correlation between CaO and Cr_2O_3 contents (Sobolev et al., 1973), but peridotitic garnets associated with diamond have subcalcic and chrome-rich compositions compared to those typical of lherzolitic garnets (Gurney and Switzer, 1973; Gurney, 1984). Gurney (1984) has shown that the presence of subcalcic high chromium pyrope xenocrysts from southern Africa kimberlites correlates with the presence of diamond. The low calcium, high chromium pyropes are similar in composition to the garnets found as inclusions in diamonds and to the garnets in diamond-bearing peridotite xenoliths. Using the CaO and Cr_2O_3 compositions of garnet inclusions in diamond, Gurney (1984) outlined a field that includes approximately 85% of garnets associated with diamond. He has found that barren kimberlite pipes have no garnets that plot within this field, and for kimberlites in southern Africa, the presence of subcalcic garnets and the presence of diamond seems to correlate well (Gurney, 1984). As part of a study to determine whether diamonds might be present at two U.S. kimberlites, nearly 300 electron microprobe analyses have been made of garnet xenocrysts from panned concentrates.

The Williams kimberlite in north-central Montana and the Lake Ellen kimberlite in northern Michigan contain upper mantle xenoliths derived from depths where diamonds might be present (Hearn and McGee, 1984; McGee and Hearn, 1984). Cr-rich garnets and clinopyroxenes, Mg-rich ilmenites, and Cr-rich spinels have been found at both localities. Pyroxene compositions from xenoliths and from composite xenocrysts give temperatures and pressures of equilibration that are in the diamond stability field. Thus, although to date no diamonds have been found at either site, the indications for diamonds have been encouraging.

Selection of garnets and analytical techniques

Xenocryst garnets from the Williams and Lake Ellen kimberlites have Cr-rich compositions typical of peridotitic garnets and Cr-poor compositions typical of granulitic, amphibolitic, or eclogitic garnets (Hearn and McGee, 1983; McGee and Hearn, 1984). At both localities, deep purple color seems to correlate with Cr-rich peridotitic compositions (Hearn and McGee, 1983; McGee and Hearn, 1984). To look for the subcalcic, Cr-rich garnets that are associated with diamond elsewhere, purple garnets were preferentially selected from panned concentrates obtained from bag samples collected on the outcrops at each locality. In order to increase the chance of finding the desired compositions among the garnet xenocrysts, more than 100 deep purple garnets with grain diameters between 0.5 - 1 mm, were selected from each locality. Thus, 137 garnets from the Williams kimberlite and 178 garnets from the Lake Ellen kimberlite were selected using an incandescent light source. One microprobe analysis was made on each grain, but if a grain differed significantly in CaO and Cr_2O_3 content from the majority, one or two additional analyses were made on the grain.

Analyses were made using an ARL-SEMQ electron microprobe operating at 15 KV and 0.1 μa beam current, with counting times of 20 seconds. Data were reduced on-line using Bence and Albee (1968) correction procedures with modifications from Albee and Ray (1970). All samples were analyzed for SiO_2, TiO_2, Al_2O_3, Cr_2O_3, FeO, MnO, MgO, CaO, and Na_2O. Detection limits for TiO_2, MnO, and Na_2O that have low concentration in these garnets were respectively: 0.03, .04, and .02 weight percent. Natural standards were used for all elements analyzed and a garnet from Kakanui, New Zealand (USNM #143968) was always analyzed as a check of the standardization prior to analyzing the garnet xenocrysts. Oxide totals between 98.00 and 102.00 were accepted, cation stoichiometry was checked, and CaO vs Cr_2O_3 contents were plotted on-line before the next grain was analyzed.

Data and results

Analyses of the Williams and Lake Ellen garnet xenocrysts are shown respectively in Tables 1 and 2. The number of analyses made for each locality provides a good statistical representation of the compositions of the purple garnet xenocrysts at each site.

The garnets are pyropic (average MgO, Williams: 19.74 wt. %; average MgO, Lake Ellen: 18.98 wt. %) and are chrome rich (range, Williams: 0.04-12.96 wt. %; range, Lake Ellen: 5.09-12.86 wt. %). Most are within the compositional range typical for garnets from garnet lherzolites (Figs. 1, 2). Four garnets from the Williams kimberlite (L-4-6, L-12-2, L-12-15, L-14-12) and three garnets from the Lake Ellen kimberlite (M-2-9, M-5-8, M-6-19) are slightly subcalcic and suggest a potential for diamonds. However, the relative scarcity and only slightly subcalcic compositions of these garnets suggest that diamonds, if present, may be sparse. The evidence for diamonds at the Williams and Lake Ellen kimberlites, based on garnet xenocryst compositions, agrees with the evidence obtained in previous work (Hearn and McGee, 1984, McGee and Hearn, 1984). Until diamonds are actually found and reported from these localities there will be no certainty about diamond presence, but the indications from several lines of evidence are encouraging. Further discussion and interpretation of these garnet xenocryst analyses is in preparation.

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Table 1. Analyses of small purple garnet xenocrysts, Williams kimberlite[1]

	L-1-1	L-1-2	L-1-3	L-1-4	L-1-5	L-1-6	L-1-7	L-1-8	L-2-1
SiO_2	41.45	41.07	41.20	42.17	41.66	41.60	41.06	40.92	41.68
TiO_2	.31	.25	.08	.23	.08	.32	.98	0.00	.27
Al_2O_3	19.32	19.05	21.44	20.20	21.34	21.62	16.74	19.64	18.94
Cr_2O_3	4.85	5.02	2.83	3.07	2.61	2.27	6.99	5.46	6.21
FeO	6.63	6.52	7.03	6.66	7.07	7.08	6.99	6.83	6.20
MnO	.32	.30	.37	.29	.38	.29	.34	.45	.30
MgO	20.42	20.43	20.99	20.96	20.91	21.01	20.35	19.68	20.41
CaO	5.78	5.81	4.69	5.03	4.74	4.80	5.44	5.75	5.82
Na_2O	.02	.04	.02	.18	.02	.05	.10	.01	.01
Total	99.09	98.49	98.66	98.81	98.82	99.05	98.99	98.75	99.85

	L-2-2	L-2-3	L-2-4	L-2-5	L-2-6	L-2-7	L-2-8	L-2-9	L-3-1
SiO_2	41.33	42.09	41.06	41.09	41.17	41.04	40.87	41.28	41.40
TiO_2	.31	.12	.03	.16	.25	.27	2.29	.07	.43
Al_2O_3	20.27	22.12	21.49	19.05	20.66	17.16	21.01	19.72	20.65
Cr_2O_3	4.17	2.72	2.95	5.49	3.57	8.11	.16	5.67	3.30
FeO	6.90	7.27	9.34	6.58	6.68	6.55	13.10	7.72	7.17
MnO	.31	.41	.59	.30	.29	.33	.43	.51	.30
MgO	20.78	20.71	18.29	20.24	20.88	19.41	18.98	19.02	20.90
CaO	5.28	4.67	6.12	5.99	5.22	6.62	3.40	6.04	5.07
Na_2O	.04	.02	.01	.02	.02	.02	.09	.03	.04
Total	99.38	100.10	99.87	98.92	98.74	99.52	100.30	100.10	99.25

	L-3-2	L-3-3	L-3-4	L-3-5	L-3-6	L-3-7	L-4-1	L-4-2	L-4-3
SiO_2	41.82	41.21	41.64	41.96	41.73	41.28	41.70	41.56	41.90
TiO_2	.19	.03	.08	0.00	.32	.42	.46	.28	.23
Al_2O_3	19.92	21.01	18.98	21.89	19.37	17.61	18.59	18.83	20.60
Cr_2O_3	5.01	4.27	6.25	2.21	5.40	7.14	5.86	6.30	3.60
FeO	6.65	8.65	6.68	10.06	6.59	6.74	6.95	6.59	6.91
MnO	.31	.54	.33	.55	.29	.37	.32	.32	.26
MgO	20.22	18.70	20.05	18.44	20.15	19.90	19.65	19.81	20.73
CaO	5.78	5.84	6.03	5.38	5.89	6.32	6.01	6.02	5.31
Na_2O	0.00	.01	.01	0.00	.01	.01	.02	0.00	.02
Total	99.90	100.30	100.00	100.50	99.75	99.79	99.57	99.71	99.58

	L-4-4	L-4-5	L-4-6	L-4-7	L-4-8	L-4-9	L-4-10	L-5-1	L-5-2
SiO_2	38.13	41.50	41.29	41.19	40.72	41.13	40.97	41.26	41.33
TiO_2	.15	.08	.19	.28	.51	.01	.42	.06	.39
Al_2O_3	21.19	21.45	16.97	19.52	20.38	20.65	19.20	19.09	19.33
Cr_2O_3	.04	3.02	8.62	5.73	2.95	4.01	5.16	5.78	5.09
FeO	26.52	8.82	6.72	5.79	10.43	8.89	6.56	8.12	6.52
MnO	.74	.50	.35	.29	.42	.67	.32	.50	.31
MgO	7.06	19.30	19.74	20.48	18.92	17.79	20.54	18.93	20.49
CaO	6.37	4.84	5.56	5.65	4.77	6.50	5.72	6.10	5.72
Na_2O	.03	.02	.03	.04	.08	0.00	.04	.03	.01
Total	100.20	99.53	99.47	98.98	99.18	99.64	98.94	99.88	99.19

Table 1. con't.

	L-5-3	L-5-4	L-5-5	L-5-6	L-5-7	L-5-8	L-5-9	L-5-10	L-6-1
SiO_2	40.86	41.10	41.82	40.53	41.51	41.13	40.77	41.26	41.68
TiO_2	.15	.45	.51	.21	.05	.28	.20	.11	.38
Al_2O_3	17.70	20.67	18.68	19.52	19.22	20.80	18.40	19.17	21.29
Cr_2O_3	6.90	2.92	5.85	5.15	5.56	3.19	6.62	5.77	2.68
FeO	6.66	7.04	6.60	6.74	6.39	7.00	6.67	8.45	7.22
MnO	.31	.31	.30	.32	.31	.29	.33	.47	.33
MgO	19.95	21.16	20.39	20.32	20.26	20.95	19.77	18.62	21.04
CaO	6.47	4.80	5.57	5.75	6.07	5.07	6.16	6.15	5.06
Na_2O	.01	.04	.05	.02	0.00	.03	0.00	.02	.03
Total	99.02	98.50	99.77	98.56	99.36	98.72	98.93	100.00	99.71

	L-6-2	L-6-3	L-6-4	L-6-5	L-6-6	L-6-7	L-6-8	L-6-9	L-6-10
SiO_2	41.90	41.79	41.94	41.87	42.43	42.07	41.30	41.85	41.13
TiO_2	.40	.27	.07	.24	.02	.17	.53	.22	.13
Al_2O_3	21.43	18.37	22.30	20.24	22.11	18.70	20.93	19.51	18.66
Cr_2O_3	2.30	6.77	1.95	3.89	2.99	6.71	3.47	6.41	6.31
FeO	7.28	6.50	9.96	6.64	7.36	6.49	10.56	6.50	6.54
MnO	.26	.31	.65	.29	.50	.32	.45	.31	.30
MgO	21.10	20.02	18.39	20.94	19.86	19.79	18.45	19.99	20.24
CaO	4.77	6.05	5.58	5.52	5.58	6.30	5.10	6.06	5.97
Na_2O	.03	.02	0.00	0.00	.01	.01	.07	0.00	.01
Total	99.47	100.10	100.90	99.64	100.90	100.60	100.90	100.90	99.29

	L-7-1	L-7-2	L-7-3	L-7-4	L-7-5	L-7-6	L-7-7	L-7-8	L-7-9
SiO_2	41.68	42.13	41.38	41.01	41.75	41.60	41.43	42.37	42.00
TiO_2	.32	2.17	.32	.14	.22	.04	.06	.03	.01
Al_2O_3	19.49	21.62	21.68	18.69	19.36	19.82	18.39	21.94	21.32
Cr_2O_3	5.64	.27	1.17	6.87	5.60	5.91	7.61	3.06	3.40
FeO	6.73	10.98	13.29	6.65	6.81	6.72	6.52	7.93	7.76
MnO	.32	.34	.46	.35	.35	.46	.27	.52	.58
MgO	19.87	20.92	17.61	19.72	20.06	19.49	19.35	19.72	19.22
CaO	5.83	2.46	4.35	6.47	5.96	5.95	6.64	4.61	5.91
Na_2O	.01	.05	.05	.01	.01	.04	.01	0.00	.02
Total	99.89	100.90	100.30	99.92	100.10	100.00	100.30	100.20	100.20

	L-7-10	L-8-1	L-8-2	L-8-3	L-8-4	L-8-5	L-8-6	L-8-7	L-8-8
SiO_2	41.28	40.61	41.51	40.88	42.24	41.38	41.78	41.97	41.53
TiO_2	.64	.86	.05	.07	0.00	0.00	0.00	.20	2.30
Al_2O_3	18.94	17.36	21.83	20.11	21.93	19.51	19.40	20.98	20.90
Cr_2O_3	5.74	7.84	3.37	4.67	3.34	6.25	6.31	4.06	.04
FeO	6.76	8.15	8.10	8.99	8.12	7.65	7.43	6.95	11.37
MnO	.32	.36	.47	.57	.46	.46	.45	.31	.32
MgO	19.96	18.38	19.64	17.68	19.77	18.84	19.40	20.52	21.02
CaO	6.18	6.83	5.38	6.77	4.93	6.04	5.87	5.49	2.89
Na_2O	.02	.07	0.00	.03	.01	.03	.01	.02	.07
Total	99.85	100.50	100.40	99.78	100.80	100.20	100.70	100.50	100.40

Table 1. con't.

	L-8-9	L-8-10	L-8-11	L-9-1	L-9-2	L-9-4	L-9-5	L-9-6	L-9-7
SiO_2	41.98	42.01	41.89	42.53	41.87	42.25	41.82	41.54	41.93
TiO_2	.01	.30	.09	.11	.12	.02	.02	.04	.20
Al_2O_3	19.78	19.61	21.75	19.65	22.37	21.19	22.10	19.94	21.53
Cr_2O_3	6.51	4.89	3.00	5.72	3.19	4.60	3.24	6.02	3.40
FeO	7.11	6.94	8.20	6.50	7.86	7.79	8.35	8.13	6.89
MnO	.48	.31	.56	.30	.47	.47	.54	.52	.31
MgO	19.10	20.32	19.29	20.38	19.91	19.28	19.04	18.83	20.99
CaO	6.19	5.72	5.48	5.94	4.97	5.68	6.20	6.13	5.36
Na_2O	.03	.02	.01	.01	.05	.04	.03	.03	.03
Total	101.20	100.10	100.30	101.10	100.80	101.30	101.30	101.20	100.60

	L-9-8	L-9-9	L-9-10	L-10-1	L-10-2	L-10-3	L-10-4	L-10-5	L-10-6
SiO_2	42.51	42.06	41.96	41.12	42.10	42.46	41.41	41.54	41.22
TiO_2	.48	.12	.06	.10	.44	.39	0.00	.03	.05
Al_2O_3	21.19	20.22	20.20	20.73	22.05	20.90	19.96	20.29	20.10
Cr_2O_3	3.14	5.46	5.39	5.05	2.04	3.74	6.10	5.38	6.04
FeO	7.23	6.53	7.80	7.86	7.02	6.87	7.30	7.66	7.22
MnO	.30	.31	.54	.52	.29	.29	.47	.51	.47
MgO	20.95	20.25	19.02	19.86	21.32	20.87	19.29	19.92	19.58
CaO	5.09	6.05	6.10	5.32	4.74	5.38	5.92	5.19	5.93
Na_2O	.05	.02	.03	.05	.05	.03	.04	.03	.04
Total	100.90	101.00	101.10	100.60	100.10	100.90	100.50	100.60	100.70

	L-10-7	L-11-1	L-11-2	L-11-4	L-11-5	L-11-7	L-11-8	L-11-9	L-11-10
SiO_2	41.94	42.10	41.66	41.18	42.09	41.80	41.90	41.54	41.59
TiO_2	.02	.37	.25	.44	.32	.30	.20	.16	.45
Al_2O_3	20.59	21.10	19.58	20.14	20.14	19.19	20.45	19.36	22.75
Cr_2O_3	5.56	4.10	5.95	4.85	5.07	6.32	5.16	6.51	1.44
FeO	7.40	6.78	7.54	6.72	6.62	6.37	8.39	6.65	13.12
MnO	.48	.31	.54	.29	.33	.33	.47	.36	.43
MgO	19.48	20.84	19.84	20.58	20.33	20.13	18.89	19.89	17.39
CaO	5.55	5.32	5.20	5.81	5.86	6.02	5.89	6.26	4.55
Na_2O	.02	.04	.07	.03	.01	.03	.05	.02	.06
Total	101.00	101.00	100.60	100.10	100.80	100.50	101.40	100.80	101.80

	L-12-1	L-12-2-1	L-12-2-2	L-12-2-3	L-12-3	L-12-4-1	L-12-4-2	L-12-5	L-12-6-1
SiO_2	41.50	41.66	41.56	41.69	41.34	42.56	42.03	42.36	39.48
TiO_2	.56	.07	.03	0.00	.05	.50	.26	.26	.52
Al_2O_3	20.00	21.83	21.51	21.68	21.74	22.15	21.50	20.24	14.07
Cr_2O_3	5.42	4.49	4.49	3.89	3.75	2.50	3.69	5.55	12.76
FeO	7.01	8.06	7.79	7.82	8.10	7.28	6.91	6.71	6.64
MnO	.30	.49	.52	.52	.56	.30	.29	.32	.30
MgO	20.69	20.88	20.73	20.45	19.28	21.06	20.74	20.20	18.20
CaO	5.40	3.65	4.07	4.24	5.76	4.93	5.43	5.79	7.29
Na_2O	.07	.03	.01	.02	.01	.04	.02	.04	.06
Total	100.90	101.20	100.70	100.30	100.60	101.30	100.90	101.50	99.31

Table 1. con't.

	L-12-6-2	L-12-7	L-12-9	L-12-10	L-12-11	L-12-13	L-12-14	L-12-15	L-12-16
SiO_2	40.60	41.83	41.98	42.11	42.13	41.82	40.98	42.73	41.64
TiO_2	.45	.71	.02	.13	.08	0.00	.01	.03	.31
Al_2O_3	14.18	19.56	21.01	21.73	21.97	21.53	20.51	20.54	20.06
Cr_2O_3	12.96	5.28	5.11	4.03	3.58	4.73	5.27	5.89	5.76
FeO	6.78	6.86	7.37	8.16	7.97	7.45	6.72	6.96	6.82
MnO	.37	.32	.42	.50	.49	.40	.39	.40	.33
MgO	18.02	20.25	19.63	18.89	19.00	19.56	19.46	20.54	20.08
CaO	7.30	6.11	5.95	5.83	6.34	5.61	5.35	4.74	5.85
Na_2O	.06	.03	.04	.03	.01	.05	.04	.06	.03
Total	100.70	101.00	101.50	101.40	101.60	101.10	98.75	101.90	100.90

	L-12-17	L-13-1	L-13-2	L-13-3	L-13-4	L-13-5	L-14-1	L-14-2	L-14-3
SiO_2	42.26	41.73	41.94	41.13	41.96	42.03	38.07	41.20	41.38
TiO_2	.34	.06	.06	.08	.01	.16	.10	.36	.57
Al_2O_3	22.02	21.34	22.72	20.19	20.97	19.60	21.72	20.50	20.29
Cr_2O_3	3.23	3.89	2.85	5.66	5.01	5.36	.07	5.15	4.76
FeO	6.64	7.84	7.84	7.25	7.98	6.02	28.06	6.82	6.94
MnO	.29	.51	.44	.49	.55	.29	.87	.33	.32
MgO	21.21	19.61	19.55	19.55	19.24	20.01	6.35	20.36	19.99
CaO	5.01	5.59	5.37	5.82	5.73	5.78	6.20	5.78	5.73
Na_2O	.05	.03	.02	.04	.02	.01	.01	.04	.04
Total	101.10	100.60	100.80	100.20	101.50	99.27	101.40	100.50	100.00

	L-14-4	L-14-5	L-14-6	L-14-7	L-14-8	L-14-9	L-14-10	L-14-11	L-14-12-1
SiO_2	41.97	41.93	41.01	41.68	41.53	41.79	41.78	42.09	40.72
TiO_2	.23	.11	.37	.75	.25	.20	.62	.06	.11
Al_2O_3	21.83	20.00	19.38	19.33	19.93	19.82	22.39	19.50	15.65
Cr_2O_3	2.22	6.06	5.77	5.75	5.76	5.15	1.20	5.68	11.17
FeO	7.52	6.50	6.64	6.11	6.67	6.81	9.35	6.52	6.80
MnO	.30	.32	.36	.30	.32	.33	.32	.30	.40
MgO	21.04	20.22	20.20	21.17	19.82	20.35	20.32	20.22	20.37
CaO	4.64	6.34	5.90	5.27	6.08	5.93	4.48	6.34	5.04
Na_2O	.04	.03	.04	.09	.03	.02	.08	.02	.05
Total	99.79	101.50	99.67	100.40	100.40	100.40	100.50	100.70	100.30

	L-14-12-2	L-14-12-3	L-15-1	L-15-2	L-15-4	L-15-5	L-15-6	L-15-7
SiO_2	41.31	40.49	41.87	41.28	40.83	41.68	42.23	41.60
TiO_2	.16	.13	.31	.18	0.00	.62	.65	.52
Al_2O_3	15.49	15.71	21.01	19.33	19.55	22.70	22.80	21.89
Cr_2O_3	11.36	11.19	3.61	6.31	6.18	1.43	1.08	2.93
FeO	6.56	6.55	7.07	6.54	7.09	8.72	8.61	7.30
MnO	.35	.35	.30	.29	.55	.31	.26	.34
MgO	20.33	20.21	20.96	20.27	19.33	20.39	20.24	20.75
CaO	5.24	5.23	5.08	5.90	6.30	4.51	4.53	5.01
Na_2O	.05	.05	.04	.02	.03	.08	.08	.05
Total	100.90	99.91	100.20	100.10	99.86	100.40	100.50	100.40

[1] All analyses are single points on individual grains; duplicate analyses on a grain are indicated by an additional digit in the sample label (eg. L-12-2-1).

Table 2. Analyses of small purple garnet xenocrysts, Lake Ellen kimberlite[1]

	M-1-1	M-1-2	M-1-3	M-1-4	M-1-5	M-1-6	M-1-7	M-1-8	M-1-9
SiO_2	40.76	41.75	41.97	41.14	42.11	41.53	42.31	41.28	41.94
TiO_2	.57	.14	.09	.03	0.00	.20	.09	.06	.11
Al_2O_3	15.56	16.62	16.29	17.25	19.62	17.64	19.57	16.91	17.77
Cr_2O_3	9.91	8.91	9.53	8.70	5.93	7.51	5.81	9.01	8.06
FeO	6.91	6.80	6.36	6.37	7.51	6.83	7.01	6.74	5.97
MnO	.34	.33	.29	.35	.44	.32	.47	.32	.30
MgO	17.71	19.01	18.95	18.63	20.09	19.45	20.62	18.55	19.43
CaO	8.05	7.22	7.09	7.09	5.09	6.38	5.13	7.02	5.94
Na_2O	.02	.01	0.00	0.00	.02	.01	.02	0.00	.01
Total	99.83	100.80	100.60	99.58	100.80	99.85	101.00	99.89	99.53

	M-2-1	M-2-2	M-2-3	M-2-4	M-2-5	M-2-6	M-2-7	M-2-8	M-2-9
SiO_2	41.54	42.33	42.21	40.50	41.59	40.69	41.69	41.80	40.41
TiO_2	.11	.08	.04	.21	.05	.27	.23	.24	.16
Al_2O_3	17.87	19.71	20.09	15.74	19.06	16.40	18.83	16.70	14.21
Cr_2O_3	8.31	5.78	5.78	10.27	6.46	10.00	6.86	9.16	12.38
FeO	6.64	7.51	7.29	6.65	6.64	6.81	7.00	6.43	6.95
MnO	.34	.44	.45	.34	.30	.34	.44	.33	.35
MgO	18.94	19.56	19.41	18.23	18.96	18.05	19.72	19.04	18.48
CaO	6.79	5.58	4.97	7.38	6.35	7.49	5.73	6.77	6.68
Na_2O	0.00	.03	.02	.03	.02	.01	.04	.03	0.00
Total	100.50	101.00	100.30	99.35	99.43	100.10	100.50	100.50	99.62

	M-2-10	M-2-11	M-3-1	M-3-2	M-3-3	M-3-4	M-3-5	M-3-6	M-3-7
SiO_2	41.47	41.57	40.80	41.57	41.52	42.09	41.17	41.51	40.76
TiO_2	.14	.06	.05	.13	.49	.11	.09	.09	.61
Al_2O_3	16.67	18.01	16.39	15.72	16.16	16.85	15.77	16.65	15.69
Cr_2O_3	9.23	7.97	9.98	10.62	9.47	9.15	10.24	9.87	9.65
FeO	6.74	6.48	6.27	6.62	6.88	6.65	7.09	6.95	6.78
MnO	.36	.28	.38	.36	.33	.32	.34	.36	.29
MgO	18.37	18.88	18.45	18.64	18.38	18.62	18.18	17.34	18.15
CaO	7.56	6.77	7.10	7.46	6.98	7.24	7.58	7.40	7.73
Na_2O	.01	0.00	0.00	.01	.03	0.00	0.00	0.00	.03
Total	100.50	100.00	99.41	101.10	100.20	101.00	100.50	100.20	99.68

	M-3-8	M-3-9	M-3-10	M-4-1	M-4-2	M-4-3	M-4-4	M-4-5	M-4-6
SiO_2	42.64	41.01	41.59	41.45	42.48	40.86	42.11	41.90	41.74
TiO_2	.08	.12	.11	.10	.20	.37	.08	.06	.17
Al_2O_3	19.04	16.73	16.78	17.58	17.80	16.13	18.85	17.89	15.49
Cr_2O_3	6.77	9.62	9.37	8.23	7.98	9.56	6.45	7.76	10.54
FeO	7.11	6.24	6.55	6.94	6.58	7.10	6.73	6.45	6.48
MnO	.43	.33	.30	.35	.32	.34	.36	.33	.32
MgO	19.76	18.69	18.53	19.00	19.20	17.66	20.30	19.68	18.84
CaO	5.69	7.33	7.28	6.87	6.56	7.98	6.12	6.34	6.94
Na_2O	.02	.01	0.00	.01	.01	.03	0.00	.01	.01
Total	101.50	100.10	100.50	100.50	101.10	100.00	101.00	100.40	100.50

Table 2. con't.

	M-4-7	M-4-8	M-4-9	M-4-10	M-5-1	M-5-2	M-5-3	M-5-4	M-5-5
SiO_2	41.64	41.14	41.49	41.79	41.59	41.86	42.08	41.75	41.78
TiO_2	.37	.27	.04	.09	.23	.05	.09	.04	.66
Al_2O_3	16.31	16.35	16.13	18.32	16.73	19.81	17.00	17.47	15.20
Cr_2O_3	9.37	9.60	9.95	7.21	9.15	5.54	8.54	8.51	10.14
FeO	6.44	7.50	6.73	6.61	6.43	7.76	6.37	6.93	7.19
MnO	.31	.34	.30	.32	.33	.49	.32	.34	.34
MgO	19.18	17.50	18.27	19.66	19.55	19.29	19.30	18.44	19.55
CaO	6.92	7.92	7.79	6.28	7.16	6.01	6.81	7.26	6.65
Na_2O	.01	.01	0.00	.01	.01	0.00	0.00	0.00	.04
Total	100.60	100.60	100.70	100.30	101.20	100.80	100.50	100.70	101.60

	M-5-6	M-5-7	M-5-8	M-5-9	M-5-10	M-5-11	M-5-12	M-5-13	M-5-14
SiO_2	41.70	41.78	41.13	41.94	41.84	42.14	41.89	41.55	41.44
TiO_2	.09	.09	.03	.08	.10	.13	.14	.10	.35
Al_2O_3	17.13	17.84	15.19	17.27	17.03	19.73	16.19	17.30	14.63
Cr_2O_3	8.84	7.99	11.73	8.81	8.68	5.99	10.01	8.63	11.99
FeO	6.53	6.70	6.91	6.21	6.73	7.06	6.39	6.82	6.60
MnO	.33	.35	.32	.32	.29	.46	.37	.34	.36
MgO	18.82	19.69	19.20	18.84	18.95	20.00	18.62	18.73	17.94
CaO	6.91	6.38	6.09	7.17	7.19	5.21	7.52	7.04	8.04
Na_2O	.01	.02	.01	0.00	0.00	.04	0.00	.03	.03
Total	100.40	100.80	100.60	100.60	100.80	100.80	101.10	100.50	101.40

	M-5-15	M-5-16	M-5-17	M-5-18	M-5-19	M-6-1	M-6-2	M-6-3	M-6-4-1
SiO_2	41.43	41.38	40.67	40.70	40.83	41.70	40.56	40.64	41.07
TiO_2	0.00	.12	.18	.26	.10	.07	.77	.31	.18
Al_2O_3	19.31	17.07	14.61	16.06	16.47	19.43	14.21	14.79	17.76
Cr_2O_3	6.54	8.59	11.98	9.39	9.82	6.27	11.52	11.98	7.96
FeO	7.19	6.66	6.83	6.43	7.00	7.35	7.15	6.57	6.90
MnO	.47	.33	.37	.35	.34	.51	.35	.38	.30
MgO	20.16	19.91	18.73	19.36	18.80	20.45	18.64	18.34	19.61
CaO	5.27	6.75	7.47	7.08	7.15	5.08	7.19	7.82	6.39
Na_2O	.02	.01	.02	.01	.02	.04	.06	.02	.01
Total	100.40	100.80	100.90	99.66	100.50	100.90	100.50	100.90	100.20

	M-6-4-2	M-6-5-1	M-6-5-2	M-6-6-1	M-6-6-2	M-6-7	M-6-8	M-6-9	M-6-10
SiO_2	41.34	41.70	41.84	41.38	41.02	41.21	41.62	41.22	40.56
TiO_2	.21	.07	.08	.08	.16	.15	.14	.19	.05
Al_2O_3	17.20	19.52	19.24	17.46	16.88	14.79	19.04	14.94	14.74
Cr_2O_3	8.22	6.06	6.47	8.29	8.50	11.33	6.88	11.72	12.34
FeO	7.08	7.07	7.20	6.83	6.81	6.91	7.19	6.81	6.57
MnO	.33	.47	.48	.37	.35	.37	.45	.37	.39
MgO	20.01	20.26	20.55	19.28	19.83	19.04	19.41	18.83	17.79
CaO	6.43	5.10	5.05	6.74	6.71	6.84	5.61	7.59	8.46
Na_2O	.04	.03	.04	.02	.02	0.00	.04	.02	.02
Total	100.90	100.30	100.90	100.40	100.30	100.60	100.40	101.70	100.90

Table 2. con't.

	M-6-11	M-6-12	M-6-13	M-6-14	M-6-15	M-6-16	M-6-17	M-6-18	M-6-19
SiO_2	40.77	41.37	41.86	40.93	40.94	41.14	40.31	41.43	41.05
TiO_2	.72	.12	.09	.08	.17	.21	.42	.35	.27
Al_2O_3	15.38	17.14	17.77	16.72	15.72	14.44	14.29	17.10	15.64
Cr_2O_3	10.11	9.25	7.84	9.36	11.26	12.86	12.36	8.76	10.36
FeO	7.42	6.46	6.60	6.91	6.63	6.88	6.56	6.99	7.73
MnO	.37	.35	.33	.34	.38	.37	.37	.40	.37
MgO	18.49	19.89	19.76	18.57	18.33	18.29	18.25	19.25	19.59
CaO	7.10	6.51	6.55	7.45	7.58	7.48	8.31	6.72	5.96
Na_2O	.07	.02	.01	.01	.03	.03	.04	.04	.02
Total	100.40	101.10	100.80	100.40	101.00	101.70	100.90	101.00	101.00

	M-6-20	M-6-21	M-7-1	M-7-2	M-7-3	M-7-4	M-7-5	M-7-6	M-7-7
SiO_2	41.46	41.00	41.81	40.24	40.97	41.68	40.74	40.06	42.12
TiO_2	.05	.28	.04	.94	.06	.05	.03	.15	0.00
Al_2O_3	16.99	14.90	19.47	14.19	14.90	16.73	15.00	15.59	17.32
Cr_2O_3	8.42	10.65	5.88	10.70	11.14	8.97	10.77	10.27	7.99
FeO	6.54	6.90	7.12	6.66	6.77	7.04	6.59	6.60	6.46
MnO	.28	.36	.44	.35	.36	.35	.36	.34	.32
MgO	19.57	18.27	20.17	18.69	18.84	18.38	18.40	17.83	19.26
CaO	7.14	7.74	4.89	7.49	6.85	7.12	7.67	8.00	6.97
Na_2O	.02	.04	.05	.09	.04	.04	.05	.04	.03
Total	100.50	100.10	99.87	99.34	99.94	100.40	99.60	98.89	100.50

	M-7-8	M-7-9	M-7-10	M-7-11	M-7-12	M-7-13	M-7-14	M-7-15	M-7-16
SiO_2	41.32	41.22	41.12	40.43	40.74	41.04	41.84	41.82	41.46
TiO_2	.05	.11	.09	.76	.27	.26	.17	.16	.09
Al_2O_3	17.39	17.36	16.79	14.17	14.80	17.09	17.59	18.03	17.84
Cr_2O_3	7.90	8.30	8.17	10.56	10.43	8.40	7.72	7.48	7.95
FeO	6.62	6.38	6.69	7.06	6.96	6.65	7.01	6.37	6.82
MnO	.31	.31	.31	.37	.34	.31	.34	.34	.34
MgO	19.35	19.00	19.43	18.62	18.37	18.68	19.32	19.94	18.56
CaO	6.68	6.83	6.67	7.27	7.57	6.99	6.68	6.33	6.68
Na_2O	.03	.03	.03	.06	.04	.03	.05	.06	.03
Total	99.65	99.55	99.29	99.30	99.51	99.46	100.70	100.50	99.77

	M-7-17	M-7-18	M-7-19	M-7-20	M-8-1	M-8-2	M-8-3	M-8-4	M-8-5
SiO_2	40.40	41.80	41.56	40.93	40.70	41.28	41.35	41.21	41.06
TiO_2	.95	.10	.02	.76	.22	.08	.07	.07	.05
Al_2O_3	14.46	17.48	16.42	14.81	17.55	16.66	17.12	17.79	17.96
Cr_2O_3	10.51	8.22	9.18	10.41	7.92	8.91	8.29	7.39	7.41
FeO	6.99	7.08	6.84	7.25	6.83	6.37	6.96	6.64	6.65
MnO	.35	.34	.37	.37	.32	.34	.36	.34	.31
MgO	18.39	18.86	18.66	18.69	19.38	18.92	18.46	19.52	19.06
CaO	7.21	6.92	7.44	7.06	6.65	7.48	7.16	6.45	6.40
Na_2O	.07	.03	.03	.08	.06	.04	.05	.04	.04
Total	99.34	100.80	100.50	100.40	99.63	100.10	99.83	99.44	98.95

Table 2. con't.

	M-8-6	M-8-7	M-8-8	M-9-1	M-9-2	M-9-3	M-9-4	M-9-5	M-9-6
SiO_2	40.79	40.77	41.19	41.37	41.86	41.61	41.08	40.84	40.61
TiO_2	.06	.36	.27	.18	.10	.06	.24	.12	.11
Al_2O_3	17.38	15.80	16.58	16.24	17.11	16.35	15.46	15.14	16.28
Cr_2O_3	8.51	9.68	9.12	9.62	8.42	9.56	10.29	10.75	9.61
FeO	7.10	7.14	7.08	6.40	6.52	6.60	6.70	6.83	6.40
MnO	.36	.36	.38	.34	.32	.34	.36	.32	.35
MgO	18.41	18.85	18.68	18.58	19.43	17.84	18.62	18.14	18.84
CaO	7.12	6.91	6.80	7.25	6.98	7.65	6.97	8.02	7.27
Na_2O	.03	.06	.05	.04	.03	.03	.04	.03	.03
Total	99.75	99.94	100.20	100.00	100.80	100.00	99.75	100.20	99.51

	M-9-7	M-9-8	M-10-1	M-10-2	M-10-3	M-10-4	M-10-5	M-10-6	M-10-7
SiO_2	41.41	41.43	40.69	41.54	41.40	42.14	40.94	41.59	41.17
TiO_2	.17	.12	.27	.24	.06	.08	.34	.09	.22
Al_2O_3	14.39	17.15	16.17	16.83	17.57	18.00	17.03	17.93	17.10
Cr_2O_3	11.58	8.72	9.60	8.35	7.47	7.17	8.07	7.36	8.28
FeO	6.72	6.48	6.72	6.34	6.71	6.35	6.75	6.75	6.83
MnO	.34	.30	.34	.30	.31	.27	.30	.31	.34
MgO	18.55	19.24	18.73	19.26	19.51	19.65	19.31	18.96	19.07
CaO	7.02	6.64	7.20	7.00	6.69	6.38	6.68	6.62	6.80
Na_2O	.04	.04	.05	.05	.03	.03	.05	.04	.05
Total	100.20	100.10	99.77	99.92	99.75	100.10	99.47	99.65	99.86

	M-10-8	M-11-1	M-11-2	M-11-3	M-11-4	M-11-5	M-11-6	M-11-7	M-11-8
SiO_2	40.51	40.79	41.03	41.05	41.13	41.25	40.09	41.48	41.21
TiO_2	.23	.10	.07	.40	.06	.24	.08	.13	.18
Al_2O_3	16.37	15.77	16.95	16.54	19.18	17.89	13.69	16.05	17.45
Cr_2O_3	9.61	9.27	8.55	8.33	6.27	7.64	12.47	9.76	8.04
FeO	6.40	6.77	6.64	7.11	7.10	7.15	6.89	6.47	6.64
MnO	.32	.33	.32	.30	.48	.35	.38	.33	.32
MgO	18.47	18.95	19.41	19.33	19.79	19.50	17.21	18.98	19.48
CaO	7.24	7.33	6.89	6.53	5.21	6.32	8.69	6.97	6.61
Na_2O	.05	.03	.03	.06	.05	.05	.03	.02	.05
Total	99.20	99.34	99.89	99.65	99.26	100.40	99.53	100.20	99.98

	M-11-9	M-11-10	M-11-11	M-12-1	M-12-2	M-12-3	M-12-4	M-12-5	M-12-6
SiO_2	41.57	41.36	40.90	40.96	41.70	41.27	41.76	42.38	41.55
TiO_2	.08	.10	.05	.17	.30	.42	0.00	.06	.35
Al_2O_3	19.25	16.23	16.87	16.10	16.67	16.30	20.25	19.68	19.30
Cr_2O_3	6.37	9.04	8.24	9.74	8.27	8.05	5.09	5.60	5.35
FeO	7.16	6.50	6.68	7.10	6.77	7.12	8.22	7.18	6.93
MnO	.45	.31	.34	.37	.32	.29	.49	.43	.30
MgO	19.97	18.93	18.92	18.46	18.98	19.42	18.34	20.25	19.89
CaO	5.19	7.17	7.03	6.97	7.14	6.87	6.25	4.97	5.65
Na_2O	.06	.03	.04	.04	.04	.05	.03	.06	.06
Total	100.10	99.67	99.07	99.92	100.20	99.78	100.40	100.60	99.38

Table 2. con't.

	M-12-7	M-12-8	M-12-9	M-12-10	M-13-1	M-13-2	M-13-3	M-13-4	M-13-5
SiO_2	41.86	41.33	41.65	41.47	41.28	41.23	40.49	41.83	41.45
TiO_2	.04	.25	.23	.09	.10	.06	.09	.15	.07
Al_2O_3	18.72	16.51	17.00	18.98	18.75	16.13	16.40	17.57	17.14
Cr_2O_3	6.16	8.63	8.61	6.22	6.81	9.36	9.00	7.97	8.30
FeO	6.97	7.41	6.40	7.26	6.96	6.50	6.67	6.83	7.11
MnO	.34	.33	.33	.45	.47	.30	.32	.32	.38
MgO	19.17	18.64	18.68	19.90	19.89	18.59	19.02	18.80	18.82
CaO	6.63	7.03	7.22	5.59	5.70	7.16	7.24	6.79	6.87
Na_2O	.02	.05	.02	.06	.06	.03	.04	.02	.04
Total	99.91	100.20	100.10	100.00	100.00	99.35	99.25	100.30	100.20

	M-13-6	M-13-7	M-13-8	M-13-9	M-13-10	M-14-1	M-14-2	M-14-3	M-14-4
SiO_2	41.02	41.39	40.74	41.02	40.92	40.85	40.93	41.15	41.29
TiO_2	.21	.28	.19	.91	1.06	.16	.39	.10	.41
Al_2O_3	15.92	16.25	16.89	17.37	13.78	16.14	17.26	16.93	17.77
Cr_2O_3	9.58	9.59	8.62	7.32	11.24	9.35	7.94	8.76	7.49
FeO	6.90	6.83	6.51	6.85	7.17	6.72	6.98	6.80	6.46
MnO	.32	.33	.35	.31	.37	.34	.36	.36	.34
MgO	18.41	19.26	18.77	19.98	18.61	18.69	18.69	19.28	19.55
CaO	7.19	6.65	6.99	5.59	7.59	7.46	6.98	6.91	6.33
Na_2O	.05	.05	.02	.13	.10	.05	.06	.04	.06
Total	99.60	100.60	99.08	99.47	100.80	99.77	99.60	100.30	99.70

	M-14-5	M-14-6	M-14-7	M-14-8	M-14-9	M-14-10	M-14-11	M-15-1	M-15-2
SiO_2	41.22	41.49	41.83	40.82	40.06	41.05	40.41	41.10	40.41
TiO_2	.15	.16	.01	.49	.12	.19	.15	.18	.22
Al_2O_3	17.32	17.83	19.74	17.41	16.27	17.93	15.69	16.79	14.96
Cr_2O_3	7.74	7.76	5.70	8.05	10.08	7.59	10.25	8.79	10.88
FeO	6.86	6.57	7.58	7.25	6.63	6.72	6.67	6.61	7.12
MnO	.34	.30	.47	.34	.34	.31	.33	.32	.37
MgO	19.17	19.02	19.92	18.35	18.59	19.32	17.89	19.20	16.70
CaO	6.88	6.68	5.14	6.40	6.77	6.46	7.89	6.52	9.30
Na_2O	.03	.03	.04	.07	.05	.05	.04	.04	.05
Total	99.71	99.84	100.40	99.18	98.93	99.62	99.31	99.55	100.00

	M-15-3	M-15-4	M-15-5	M-15-6	M-15-7	M-15-8	M-15-9	M-15-10	M-15-11
SiO_2	41.12	41.08	40.77	41.29	40.84	41.64	40.94	41.15	41.41
TiO_2	.11	.05	.11	.08	.12	.16	.11	.04	.13
Al_2O_3	17.62	17.07	17.66	15.91	17.50	17.50	17.48	16.95	19.67
Cr_2O_3	7.57	8.54	7.57	9.88	8.21	7.89	8.08	8.83	5.66
FeO	6.65	6.65	6.70	6.27	6.98	6.67	6.49	6.76	7.10
MnO	.33	.36	.32	.32	.37	.34	.31	.33	.44
MgO	19.22	19.04	20.00	18.95	18.35	19.04	18.96	18.21	19.93
CaO	6.72	6.85	6.40	7.22	6.77	6.57	6.83	7.23	4.99
Na_2O	.02	.04	.04	.04	.04	.04	.03	.03	.06
Total	99.37	99.68	99.58	99.96	99.18	99.85	99.22	99.53	99.39

Table 2. con't.

	M-15-12
SiO_2	41.20
TiO_2	.11
Al_2O_3	16.87
Cr_2O_3	8.87
FeO	7.00
MnO	.34
MgO	18.19
CaO	7.17
Na_2O	.05
Total	99.80

[1] All analyses are single points on individual grains; duplicate analyses on a grain are indicated by an additional digit in the sample label (eg. M-6-4-1).

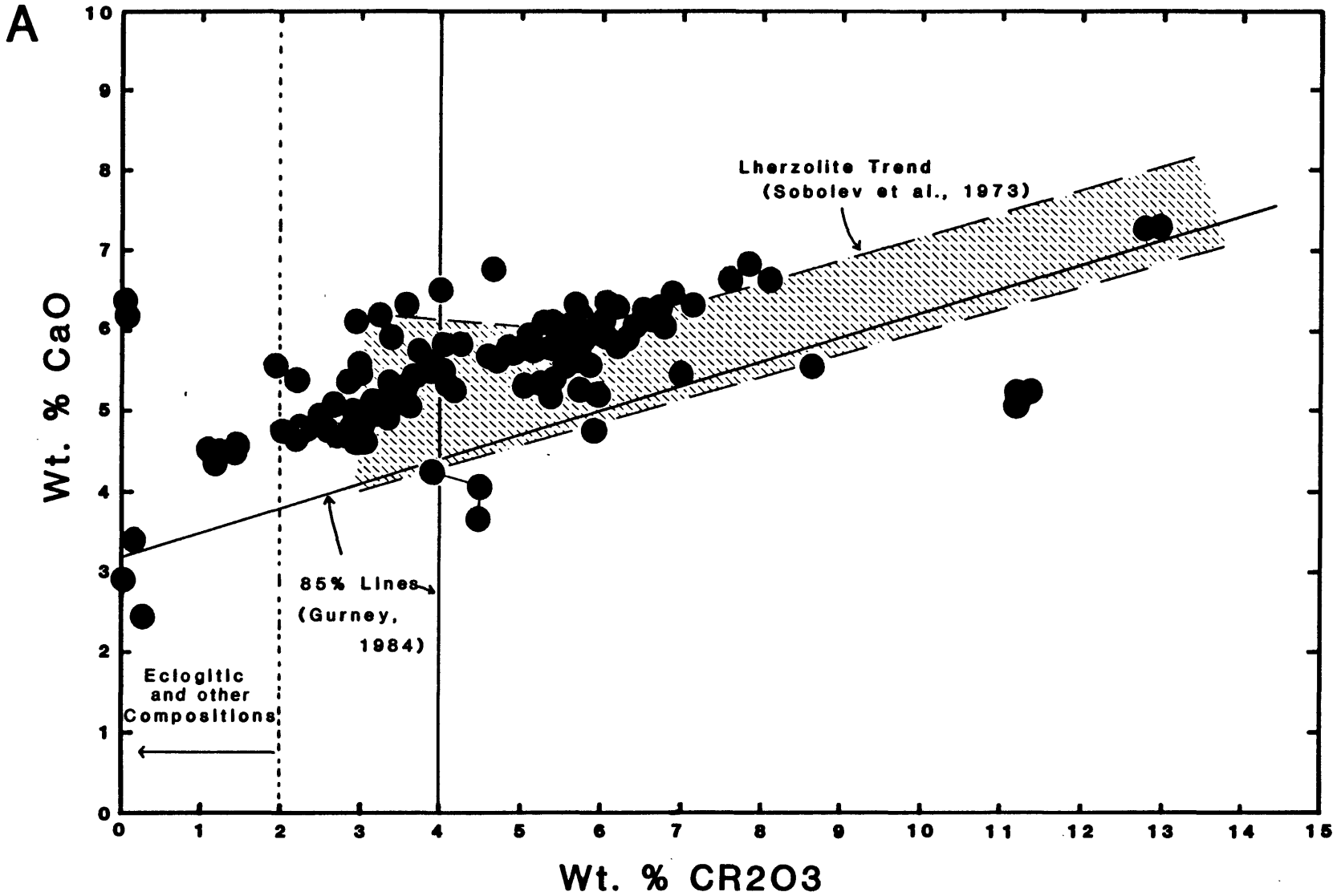

Figure 1. Wt. % CaO vs wt. % Cr_2O_3 diagram for Williams garnet xenocrysts. Compositions below and to the right of the solid line fall in Gurney's (1984) field for 85% of peridotitic garnets associated with diamond. The dashed line is Gurney's (1984) boundary between eclogitic and peridotitic compositions, but Williams garnets with less than 2% Cr_2O_3 are from peridotites and crustal metamorphic rocks.

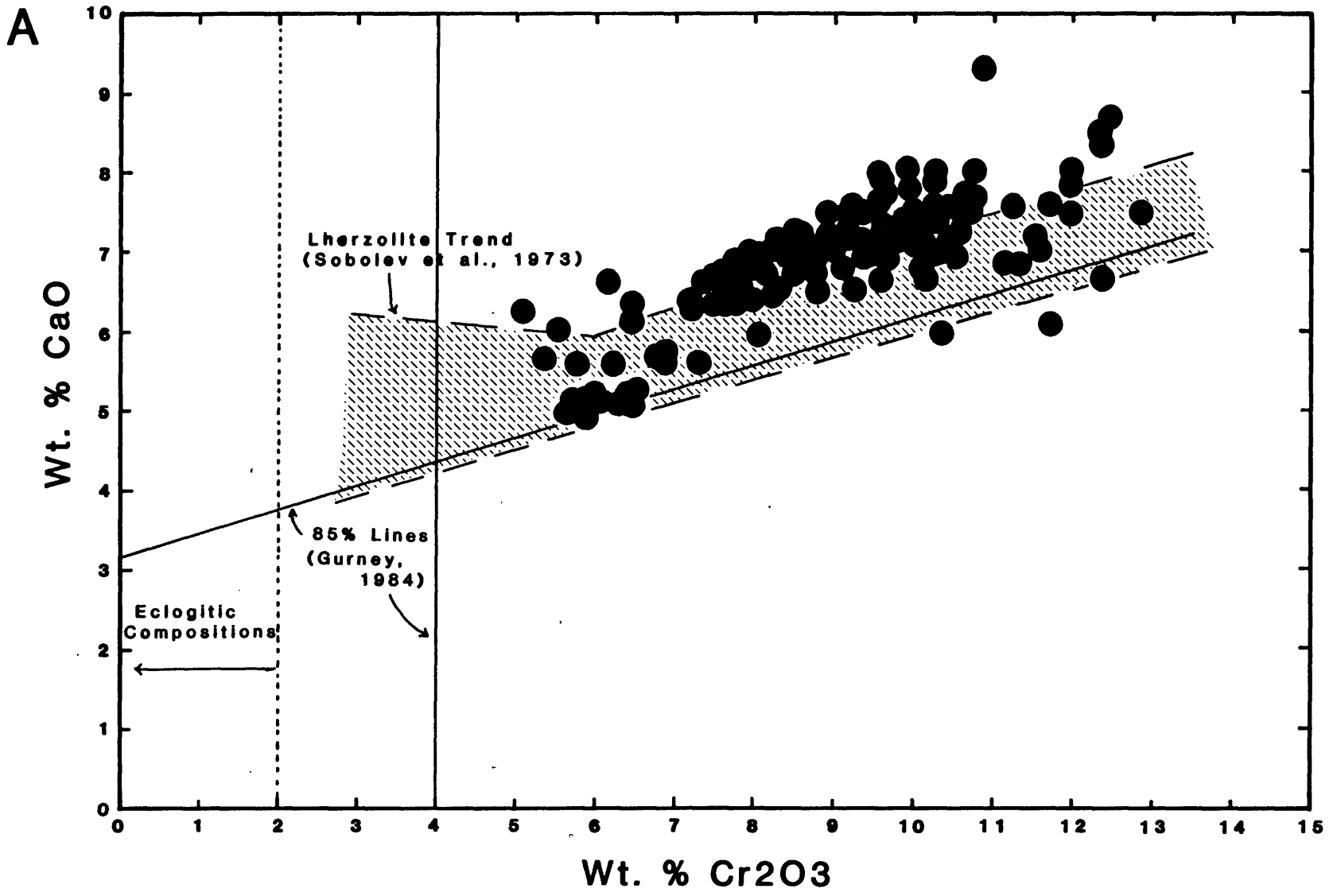

Figure 2. Wt. % CaO vs wt. % Cr_2O_3 diagram for Lake Ellen garnet xenocrysts. Compositions below and to the right of the solid line fall in Gurney's (1984) field for 85% of peridotitic garnets associated with diamond. The dashed line is Gurney's (1984) boundary between eclogitic and peridotitc compositions.