INCLUSIONS IN DIAMONDS: GARNET LHERZOLITE AND ECLOGITE ASSEMBLAGES.

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Thirty inclusion-bearing diamonds have been studied in order to determine the mineral assemblages and chemical compositions of the inclusions. Inclusions were exposed either by cracking or burning the diamond or studied _in situ_ within cut gems. They were analyzed with an electron microprobe, and supplemental data were obtained by optical goniometry and x-ray techniques. Inclusions range in size from $<10\ \mu m$ to about 1 mm, but are mostly 50-200 μm. Inclusions which are syngenetic with the formation of the diamond have good crystal faces, but they generally appear to have the morphology of negative crystals of diamond, rather than of their own crystal structure. Thus, garnets, pyroxenes, olivines, and other minerals are dominated by octahedral faces. Sobolev et al.(1972) has reported a similar finding. These crystals which have foreign faces, are termed xenohedral.

Inclusion assemblages fall into two suites, garnet lherzolite (or peridotite) and eclogite. Sobolev(1972) and Meyer and Boyd (1972) have found a similar grouping. Each has compositionally distinct mineralogy and therefore an assemblage can be assigned to one of the suites even when one mineral is present. Thus, the compositional range of assemblages reported here represents portions of assemblages from different diamonds.

Twelve diamonds contained portions of the garnet lherzolite assemblage which consists of garnet, diopside, enstatite, olivine, and chromite. Garnet is burgundy-colored, is pyrope-knorringite-rich, with 0.7-9.2% Cr_2O_3 (Table 1). Diopside has 0.11-1.56% Cr_2O_3 and 2.8-4.4% Al_2O_3. Diopside, in two diamonds, appears to have exsolved enstatite into wholly separate portions of a single crystal. Enstatite (En_{86-94}) has 0.06-0.28% Cr_2O_3 and 0.09-1.32% Al_2O_3 (Table 2). Olivine (Fo_{92-93}), commonly present as elongated crystals, has 0.03-0.15 Cr_2O_3; the Cr may possibly be present as Cr^{+2}. Chromite has about 66% Cr_2O_3, 6% Al_2O_3, and 10% MgO (Table 3).

Eighteen diamonds contained portions of the eclogite assemblage. The essential minerals are garnet and omphacitic pyroxene. Garnets are honey-brown in color and rich in pyrope, grossular, and almandine molecules (Table 1); they contain about 0.2% Na_2O. Omphacitic pyroxenes have 2.7-10.7% Al_2O_3, 1.4-5.8% Na_2O, and 0.04-0.87% K_2O (Table 2). K_2O contents of 0.62-0.87% were found in numerous crystals within 4 diamonds and are considerably higher than any previously recorded in omphacite; the K_2O is homogeneously distributed and x-ray data shows that no other phase is intergrown. Other primary minerals present in the eclogite assemblage are kyanite(Table 3;reported for the first time in a diamond), olivine (in a rare olivine eclogite assemblage), rutile (Table 3), phlogopite, and magnetite. The phlogopite is in a polymineralic inclusion, with omphacite and rutile, is low in MgO and high in FeO and TiO_2 (Table 3), and is the first recorded occurrence within a diamond. Magnetite is found in 6 eclogite assemblage diamonds and is a very pure phase (Table 3), except for some inhomogeneously distributed Ni and Co. Crystals are highly porous, and the origin of the porosity is not yet known. Its common occurrence in eclogite assemblage minerals suggests that it is syngenetic, although the oxygen fugacities necessary for its stability remain unknown. Sanidine, a polymorph of silica (possibly coesite), and a membranous material rich in SiO_2, Al_2O_3 and K_2O are also present in diamonds with eclogite assemblage, but it is not yet clear if they are syngenetic or epigenetic with the origin of the diamond.

Epigenetic minerals found in diamonds are muscovite, amphibole (hornblende, actinolite), sulfide (pentlandite, chalcopyite), and an altered SiO_2-Al_2O_3-FeO phase which may have originally been kyanite.

The following results and conclusions are drawn from this study: (1) Diamonds appear to be a unique window into the upper mantle and provide unaltered samples of a wide compositional range of several rock suites. (2) No mixing of suites has been found within a single diamond. (3) Temperatures of formation of the pyroxenes in garnet lherzolite assemblages are between 1000°C and 1400°C, depending upon whether the present compositions are used or the presumed compositions of the original homogeneous pyroxenes, assuming exsolution. The pressures of formation for the garnet lherzolite assemblages are at least 40 kb, but cannot yet be estimated with existing experimental data. (4) The presence of high (0.6-0.8%) K_2O in omphacitic pyroxene may be highly significant in terms of partial melting models and heat sources in the upper mantle and should be studied experimentally. (5) Some kyanite eclogites are now known to be stable at temperatures and pressures at which diamond is stable. (6) The abundance and variety of inclusions, both monomineralic and polymineralic, within single diamond crystals suggests that a complex history has preceded the formation of the host diamond. This history would appear to precede the formation and emplacement of kimberlite and further study of inclusions in diamonds will reveal some of its details.

References:

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Sobolev, N.V. (1972). Aust. Nat. Univ. Publ. No. 210, 38 p.

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Table 1. Electron microprobe analyses of garnet inclusions in some diamonds (in weight percent).

	Garnet Lherzolite Assemblage			Eclogite Assemblage		
Diamond No.	9	14	1	38	42	27
SiO_2	41.9	41.8	41.7	40.1	39.3	39.0
TiO_2	.04	*	.39	.49	.81	1.03
Al_2O_3	17.3	16.3	23.0	22.4	22.1	21.9
Cr_2O_3	9.2	8.3	.70	.06	.18	.03
V_2O_3	.02	.03	.02	.03	.04	.04
$^{+}Fe_2O_3$	.60	.50	1.00	--	.50	.70
FeO	5.0	8.1	8.3	17.6	18.8	14.9
MnO	.31	.34	.46	.55	.49	.32
MgO	24.3	20.7	20.8	12.1	8.7	6.0
CaO	1.29	3.2	4.2	5.6	9.1	16.2
Na_2O	*	.05	.03	.22	.40	.28
K_2O	.01	.03	*	.13	.11	.02
Total	99.97	99.35	100.60	99.28	100.53	100.42

$^{+}Fe_2O_3$ Calculated to balance garnet formula.

Molecular End Members						
Knorringite	26.0	25.2	2.0	.3	.7	.2
Pyrope	60.2	53.4	71.7	45.1	31.9	22.4
Grossular	1.7	7.6	8.2	16.6	25.4	43.3
Almandine	9.8	11.6	14.5	36.8	39.5	31.5
Andradite	1.6	1.4	2.7	--	1.4	2.0
Spessartite	.6	.7	.9	1.2	1.0	.7

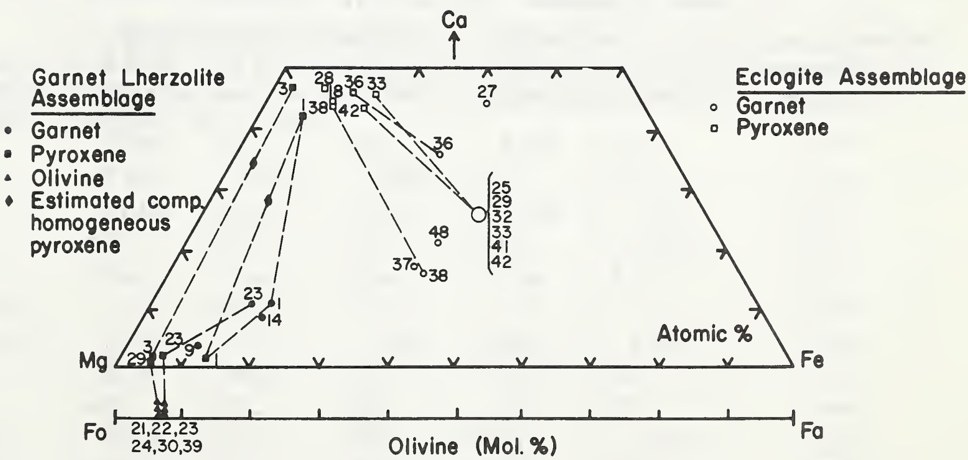

Fig. 1. Ca-Mg-Fe plot of garnet and pyroxene data, and Forsterite-Fayalite (Fo-Fa) plot of olivine data from garnet lherzolite and eclogite inclusion assemblages in diamonds. Dashed lines connect coexisting minerals within a single diamond. Numbers refer to individual diamonds.

Table 2. Electron microprobe analyses of pyroxene inclusions in some diamonds (in weight percent).

	Garnet Lherzolite Assemblage				Eclogite Assemblage	
Diamond No.	3(Cpx)	3(Opx)	1(Cpx)	1(Opx)	38	42
SiO_2	55.6	58.1	55.5	57.3	55.8	54.7
TiO_2	.23	.07	.14	.04	.19	.25
Al_2O_3	2.78	.09	4.4	1.32	10.7	7.6
Cr_2O_3	1.56	.11	.28	.06	.13	.13
V_2O_3	.05	.01	.03	*	.09	.05
FeO	1.61	3.9	3.8	8.5	4.1	6.4
NiO	.03	.03	.02	.01	*	*
MnO	.07	.06	.18	.21	.05	.11
MgO	15.6	35.7	15.6	31.4	9.8	10.4
CaO	19.5	.29	17.9	.63	13.3	15.6
Na_2O	2.23	.08	1.82	.13	5.8	3.8
K_2O	.11	*	.16	.02	.15	.87
Total	99.37	98.44	99.83	99.62	100.11	99.91
Kushiro (1962)	End Members					
$NaAlSi_2O_6$	16.3	.4	13.1	.9	40.9	30.9
$CaAl_2SiO_6$	.2	.4	3.1	2.3	1.8	.4
$CaTiAl_2O_6$	.6	--	.4	.1	.5	.7
$MgSiO_3$	42.5	88.7	43.2	83.7	26.1	28.2
$FeSiO_3$	2.6	9.9	6.2	13.0	6.3	9.9
$CaSiO_3$	37.8	.6	34.0	--	24.4	29.9

Table 3. Electron microprobe analyses of selected minerals in some diamonds (in weight percent).

Garnet Lherzolite Assemblage		Eclogite Assemblage				
Diamond No.	4b	51	30	18	18	33
Mineral	Chromite	Kyanite	Rutile	Rutile	Phlogopite	Magnetite
SiO_2	.11	36.6	.08	.24	36.6	.04
TiO_2	.32	.13	90.0	96.7	10.8	*
Al_2O_3	5.9	62.1	1.91	1.35	11.8	*
Cr_2O_3	66.2	.02	.17	.34	.35	.09
V_2O_3	.33	n.d.	.20	n.d.	n.d.	.01
Fe_2O_3	--	--	7.2	1.14	--	68.4
FeO	16.1	.30	--	--	12.1	30.8
NiO	.14	n.d.	.21	n.d.	n.d.	.30**
MnO	.22	*	.11	.05	.04	.01
MgO	10.0	.04	.07	.01	12.6	*
CaO	.03	.01	.42	.26	.09	.04
Na_2O	n.d.	.03	n.d.	n.d.	.10	n.d.
K_2O	n.d.	*	n.d.	n.d.	9.6	n.d.
Total	99.35	99.24	100.37	100.09	94.08	99.92

** CoO, 0.23%. Ni and Co variable within crystals.