34. PETROLOGY OF BASALTS FROM SITE 487, DEEP SEA DRILLING PROJECT LEG 66, MIDDLE AMERICA TRENCH AREA OFF MEXICO[1]

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ABSTRACT

Basaltic rocks recovered at the Middle America Trench area off Mexico are typical plagioclase–olivine phyric abyssal tholeiites containing less than 0.2 wt.% K_2O. Phenocrysts of plagioclase and olivine usually make up the aggregate. Plagioclase phenocrysts are Ca-rich and up to An_{90}. Olivine phenocrysts, which are always attached to plagioclase phenocrysts, are magnesian, Fo_{88} to Fo_{89}, and contain 0.2 to 0.3 wt.% of NiO. Plagioclase phenocrysts contain numerous glass inclusions with the Mg/Mg + Fe atomic ratio of 0.70 to 0.73, which is distinctly higher than the same ratio of the bulk rock (0.62–0.63). Olivine of Fo_{88} to Fo_{89} is equilibrated with the liquid with an Mg/Mg + Fe atomic ratio of about 0.7, assuming the K_D^{Mg-Fe} between liquid and olivine of 0.3. Small droplets of glass within glass inclusions in plagioclase are more enriched in K_2O and volatiles than the host glass. This enrichment may have been caused by the extraction of Al_2O_3 as plagioclase from the trapped liquid and implies its immiscibility.

Aggregates of plagioclase with small amounts of olivine may have been floated from more primitive magma with an Mg/Mg + Fe atomic ratio of about 0.7, judging from the chemical characteristics mentioned above. Flotation must have occurred at relatively high pressure. Large crystals of plagioclase and smaller crystals of olivine are xenocryst rather than phenocryst. Parental magma of Leg 66 basalt was high-MgO olivine tholeiite.

INTRODUCTION

Basaltic rocks were recovered at Site 487 of DSDP Leg 66. Site 487 is located at about 10 km seaward of the axis of the Middle America Trench off Mexico. Basaltic rocks are covered by brown pelagic clay and may occur as a lava flow with a thickness of 2 to 10 meters. The foraminiferal age of the overlying sediments is early late Miocene.

In this study, three samples of basaltic rocks, 487-9-11, 487-93-95, and 487-118-120 (Fig. 1) were petrographically, chemically and mineralogically examined to investigate the petrological nature of the rocks.

PETROGRAPHIC DESCRIPTION

Basalt is typically intersertal and contains phenocrysts of plagioclase and olivine. Olivine is less frequent and smaller than plagioclase and is usually attached to a plagioclase phenocryst (Fig. 2A–D). Plagioclase phenocrysts are usually agglutinated to make a large aggregate (Fig. 1; Fig. 2A and 2B). Plagioclase phenocrysts have numerous glass inclusions of variable size and shape (Fig. 2I–P). Small globular ones tend to be located in the central part of the phenocryst (Fig. 2A–D). Large inclusions with a convex-inward wall are sometimes observed (Fig. 5). Rectangular or slender glass inclusions occasionally form a line along the composition plane of plagioclase phenocrysts (Fig. 2M–P).

Glass inclusions do not contain any crystals. Glass is more or less devitrified and has weak birefringence. It is light brown (under microscope) and characteristically contains almost colorless globules of another glass (Fig. 2I–L; Figs. 4 and 5). These small globules are less devitrified and have weaker birefringence than the surrounding light brown glass.

Olivine phenocrysts are smaller and less frequent than plagioclase. They are free from chromian spinel inclusions and rarely contain glass (Fig. 2H). Olivine is usually somewhat altered to make carbonate and clay.

Chromian spinel is euhedral and brown in thin section and completely or partly enclosed in plagioclase phenocrysts (Fig. 2E and 2F). Chromian spinel is rare in the groundmass as discrete crystals (Fig. 2G).

The groundmass is composed of plagioclase, clinopyroxene, olivine, and magnetite. Plagioclase is partly hollow and sometimes forms a long needle (Fig. 2F). Olivine is anhedral to subhedral. Clinopyroxene is finer grained than plagioclase (Fig. 2F). It is sometimes feathery and sometimes dendritic (Fig. 2F and 2M). Magnetite makes a minute idiomorph. Aggregates of clay minerals are common in the groundmass (Fig. 2G and 2R). Clay minerals are very fine grained and yellow in thin section. They are not pleochroic and have weak birefringence. They often contain needles of plagioclase and euhedral crystals of clinopyroxene of microphenocrystal size (Fig. 2Q and 2R).

Samples 487-9-11, which was derived from the top of the flow, contains larger amounts of phenocrysts than Samples 487-93-95 and 487-118-120 (Fig. 1). The volume of phenocrysts in Sample 487-9-11 is about 10%, whereas that of Samples 487-93-95 and 487-118-120 is less than 5%. Furthermore, the groundmass of Sample 487-118-120 is coarser grained than Samples 487-9-11 and 487-93-95, which were recovered from a higher part than Sample 487-118-120 (Fig. 2F and 2G).

BULK CHEMICAL COMPOSITION

Two samples (487-93-95 and 487-118-120) were chemically analyzed by the conventional wet chemical method (Table 1). They are low in K_2O (Table 1) and

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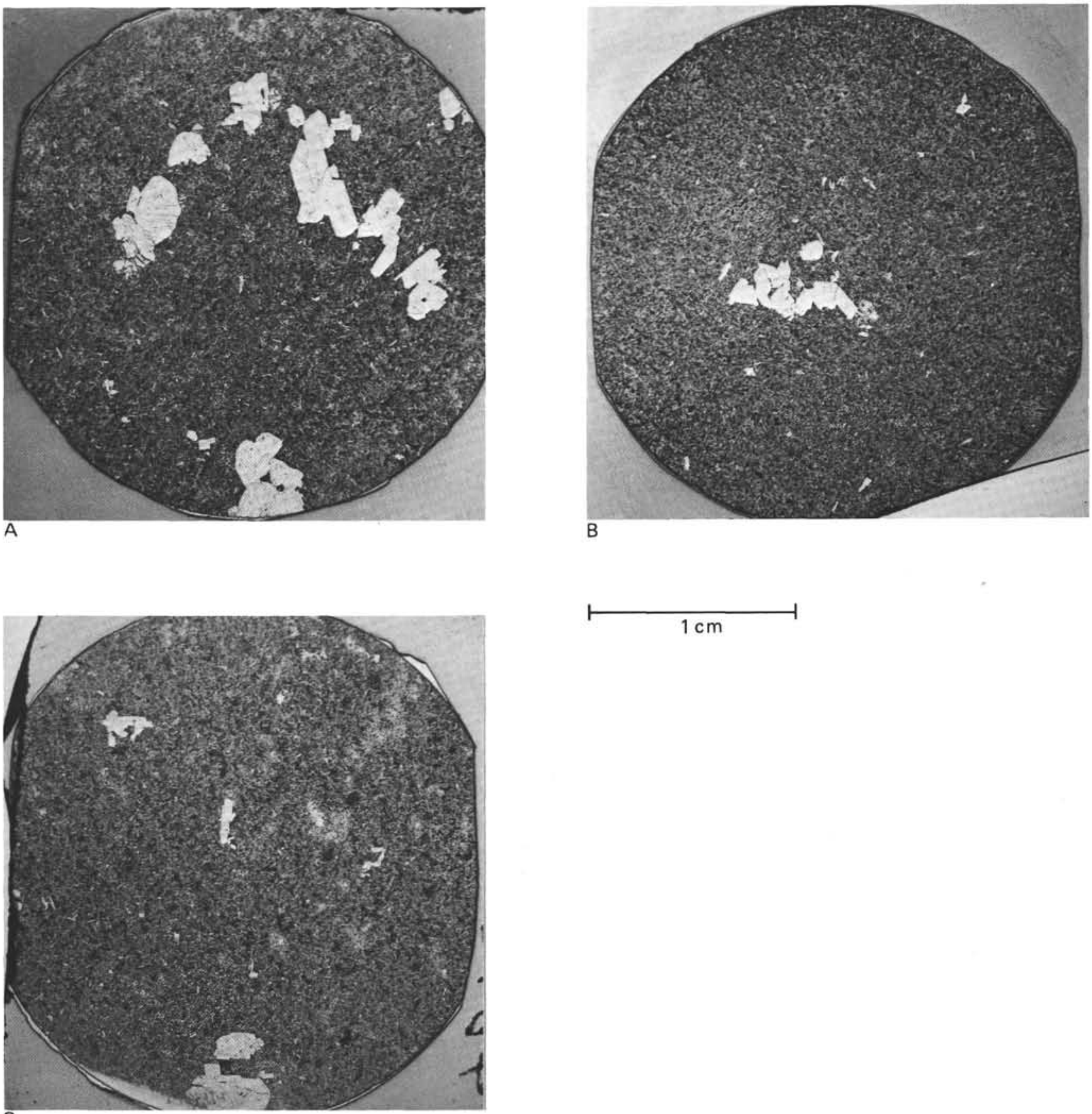

Figure 1. Thin sections, Leg 66 basalts. A. Sample 487-9-11; B. Sample 487-93-95; C. Sample 487-118-120. Note plagioclase aggregates in A.

show the chemical character of typical abyssal tholeiite (Shido et al., 1971). FeO* (total iron)/MgO ratios of Samples 487-93-95 and 487-118-120 by weight are 1.08 and 1.03, respectively. Judging from the high contents of water and ferric iron, the rocks (especially in Sample 487-118-120) suffered from relatively extensive alteration or weathering. Basalt from Leg 66 is PL-tholeiite after the definition of Shido et al. (1971) (Fig. 9). Sample 487-118-120 is almost free from normative olivine and is distant from the "cotectic line" between olivine and plagioclase of Shido et al. (1971) (Fig. 9) resulting from the high content of Fe_2O_3 (Table 1). Samples 487-93-95 and 487-118-120 are not so enriched in phenocrysts (less than 5% in volume) (Fig. 1), and bulk chemical compositions may be almost identical to those of liquids.

CHEMICAL COMPOSITIONS OF MINERALS

Chemical compositions of constituent minerals and glass inclusions were determined with JEOL electron probe X-ray microanalyzer (EPMA) Model JXA-5 at the University of Tokyo. Correction procedures are the same as those described by Nakamura and Kushiro (1970).

Plagioclase phenocrysts are simply zoned in the normal way (Fig. 6). It has a Ca-rich core (Table 2; Fig. 3), with An_{90} or so in composition. Na content increases first very slightly in the direction of the rim and rapidly near the rim (Fig. 6). The most sodic marginal part may reach An_{65} in composition, judging from the scanning profile, though it is too thin to be quantitatively analyzed. In the agglutinated plagioclase grains, Na content decreases gradually inward along the margin and the contact plane (Fig. 3). It is noteworthy that Na content also rises abruptly near the glass inclusions (Figs. 3 to 6). Groundmass plagioclase is nearly identical to the marginal part of phenocryst in chemical composition and is more sodic than An_{80} (Table 2; Figs. 3, 4, and 6). K_2O content is almost nil (Table 2).

Olivine is very magnesian (Table 3). The core of the olivine phenocryst is always up to Fo_{89} (Table 3). Olivine phenocrysts are slightly zoned and the composition of the rim sometimes attains Fo_{87}. Groundmass or microphenocryst olivine is slightly less magnesian and is Fo_{87} to Fo_{88}. NiO content is 0.2 to 0.3 wt. % (Table 3). CaO content is constant and slightly lower than 0.4 wt.% (Table 3). Olivine usually contains 0.1 wt.% of Al_2O_3 and up to 0.06 wt.% Cr_2O_3 (Table 3).

Clinopyroxene. Because feathery clinopyroxene in the groundmass is too minute to analyze by electron beam, the microphenocrysts, especially euhedral ones in clay (altered glass), were mainly analyzed (Table 4). Clinopyroxene is titaniferous augite containing up to 2.4 wt.% TiO_2 (Table 4; Fig. 7). Clinopyroxene is normally zoned as regards the Mg/Fe ratio, though the zoning pattern is not so simple. Al and Cr decrease from the core toward the rim (Table 4). Ti and Al contents are also positively correlated (Table 4).

Chromian spinel is homogeneous and shows a prominent grain-by-grain uniformity of chemical composition (Table 5; Fig. 8). Mg/Mg + Fe^{2+} atomic ratio varies from 0.72 to 0.73. Cr/Cr + Al atomic ratio is about 0.415 (Table 5; Fig. 8), which is in the wide range of the ratio given by the spinels from oceanic basalts and peridotites (Fig. 8).

Titanomagnetite contains 11 to 13 wt.% TiO_2 (Table 5), and the ulvöspinel molecule is calculated to be 31 to 35% (Table 5).

Glass. Chemical compositions and C.I.P.W. norms of glass inclusions in plagioclase are listed in Table 6. Glass in plagioclase is more enriched in normative pyroxene and more depleted in normative plagioclase than the bulk rock (Fig. 9). Brown glass is slightly more enriched in normative olivine than the bulk rock (Fig. 9) and has the chemistry of a kind of picritic basalt except for the low content of Al_2O_3. Colorless glass globules in brown glass have considerably low totals on EPMA analysis (Table 6), which may be partly due to the high volatile content. Comparing with the surrounding brown glass, it is more enriched in K and more depleted in Ti, total Fe, Mn, Ca and Na (Table 6; Table 7). Two of the three analyses of colorless glass globules give normative quartz (Table 6).

Clay. A clot of clay mineral, which may be altered glass, was analyzed with the EPMA (Table 8). The clay is characterized by a low Al_2O_3 content. Mg/Mg + Fe* atomic ratio is high—from 0.74 to 0.88. It may be equivalent to the interstratified mineral of smectite-chlorite.

DISCUSSION

Glass inclusions in plagioclase were derived from the liquid trapped in the course of enlargement of plagioclase crystal. Plagioclase may have been enlarged by the agglutination of crystals or by normal crystal growth.

Mg/Mg + Fe* atomic ratio of brown glass enclosed in plagioclase varies from 0.70 to 0.73, which is distinctly higher than the same ratio of the bulk rock (0.62–0.63). Because the Mg/Mg + Fe* ratio of trapped liquid in plagioclase may not have been altered so much by the element redistribution between liquid and host plagioclase as by the precipitation of plagioclase, the formation and agglutination of plagioclase occurred in a more primitive liquid with the Mg/Mg + Fe* atomic ratio of 0.70 to 0.73. Furthermore, if the partition coefficient $K_D^{Mg\text{-}Fe}$ between liquid and olivine is about 0.3 (Roeder and Emslie, 1970), the core of the olivine phenocryst, of which the composition is Fo_{88} to Fo_{89}, was equilibrated with the liquid with the Mg/Mg + Fe* atomic ratio of 0.69 to 0.71. This ratio is just consistent with that of glass inclusion in plagioclase phenocrysts (Table 6). These chemical characteristics and the mode of occurrence of olivine, which is always attached to plagioclase phenocrysts, may indicate that the aggregates of phenocrysts were segregated from more primitive magma by flotation or sinking. In other words, the aggregates of large plagioclase and smaller olivine are xenocrystal, although the rim may have been equilibrated with the surrounding liquid, which had been consolidated to form the groundmass of the Leg 66 basalts.

Fo content of large crystals of olivine (88–89) is almost equivalent to the mantle olivine (e.g., Aoki and Shiba, 1974). NiO content, however, varies from 0.2 to 0.3 wt.% (Table 3) and is lower than that of the ordinary mantle olivine (Sato, 1977). An content of plagioclase (about 90) is as high as that of plagioclase from some mantle-derived plagioclase peridotites of alpine type (e.g., Takasawa, 1976; Arai and Uchida, 1979). High An and Fo molecule content in plagioclase and olivine is almost comparable to those from mantle-derived peridotites and implies the primitive nature of the parent liquid of plagioclase and olivine "phenocrysts" of Leg 66 basalts.

Glass in plagioclase is characterized by the extreme impoverishment of Al_2O_3 (Table 6), which may have resulted from the extraction of plagioclase to make the lining of relatively sodic plagioclase around the inclusions (Figs. 3 and 5) and have caused the liquid unmixing (Fig. 10). The initial composition of the trapped liquid can be calculated, assuming that it was modified only by the removal of a plagioclase halo, An_{90} to An_{65} in composition, around the glass inclusions (Figs. 3 and 5). The volume and the mean chemical composition of halo of relatively sodic plagioclase around the glass inclusions (Figs. 3 and 5) are estimated to be 40% of the

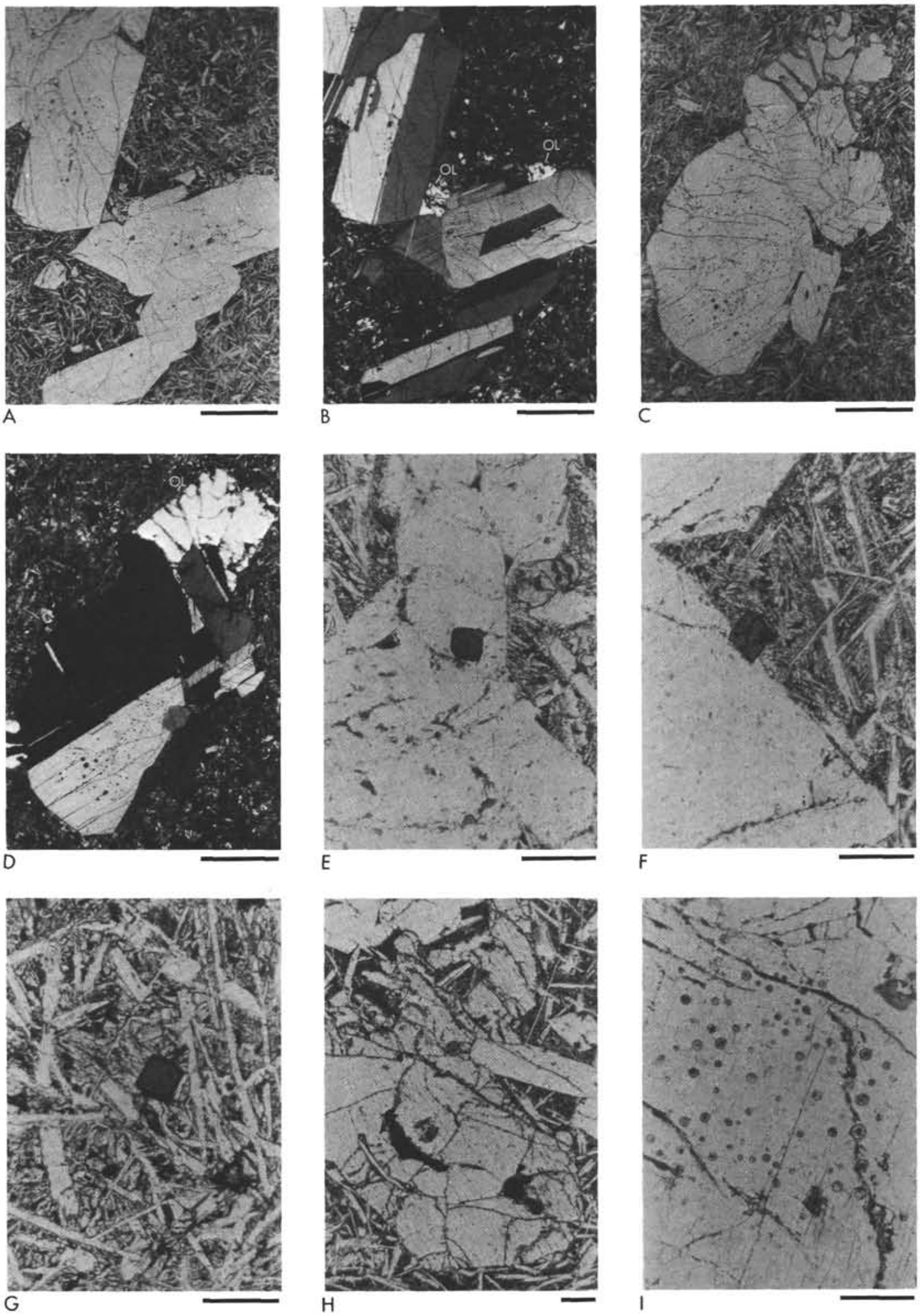

Figure 2. Photomicrographs of Leg 66 basalts. Scale bar = 0.1 mm except for A to D. A–D. Aggregate of large crystals of plagioclase. Note the mode of occurrence of olivine (OL). Sample 487-9-11. B and D, crossed nicols. E. Euhedral chromian spinel enclosed in plagioclase. Sample 487-118-120. F. Euhedral chromian spinel partly enclosed in plagioclase phenocryst. Sample 487-93-95. G. Euhedral chromian spinel in the groundmass. Sample 487-118-120. H. Relatively fresh olivine phenocryst with dark glass inclusions. Sample 487-118-120. I. Small glass globules enclosed in the core of a huge plagioclase phenocryst. Sample 487-93-95. J. Angular devitrified inclusion in plagioclase. Note the glass globule in the inclusion. Sample 487-118-120. K. Brown glass inclusion with colorless (now dirty) glass globule in plagioclase. Sample 487-93-95. L. Brown glass inclusion with colorless glass globule in plagioclase. Sample 487-118-120. M, N. Glass inclusions arranged along the composition plane of plagioclase phenocryst. Sample 487-118-120. N, crossed nicols. O, P. Slender glass inclusions along composition plane of plagioclase. Sample 487-118-120. P, crossed nicols. Q, R. Euhedral clinopyroxene microphenocrysts in clot of clay. Sample 487-118-120. R, crossed nicols.

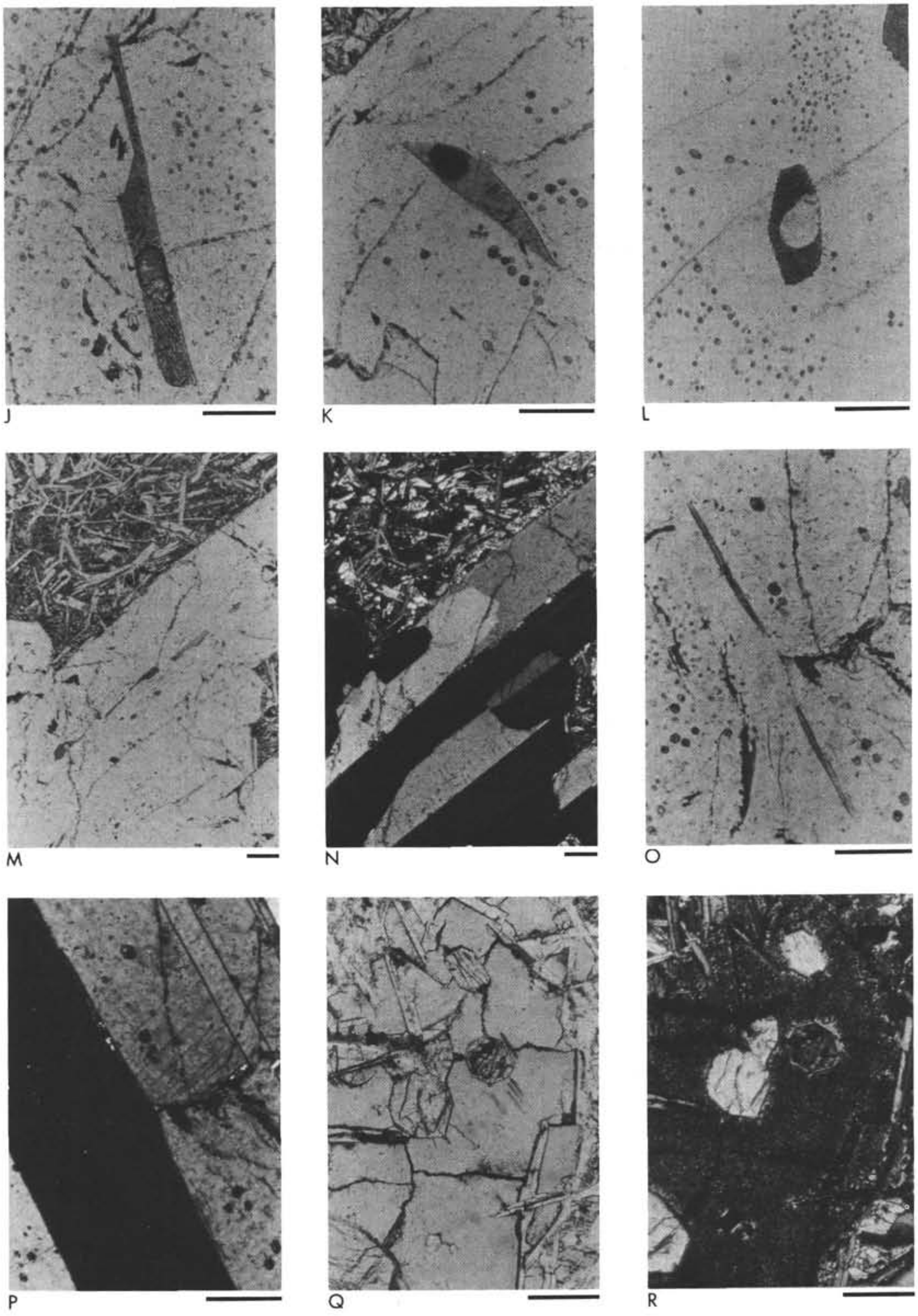

Figure 2. (Continued).

Table 1. Bulk chemical compositions of basalts.

Sample	487-93-95	487-118-120
No.	1	2
SiO_2	47.58	48.08
TiO_2	0.82	0.84
Al_2O_3	17.45	16.59
Fe_2O_3	3.30	4.25
FeO	5.83	4.30
MnO	0.15	0.13
MgO	8.13	7.89
CaO	13.55	13.07
Na_2O	2.01	2.22
K_2O	0.14	0.17
H_2O (−)	0.57	1.30
H_2O (+)	0.72	1.36
P_2O_5	0.08	0.06
Cr_2O_3	0.04	0.03
Total	100.33	100.26
C.I.P.W. Norms		
Or	0.83	1.00
Ab	16.99	18.77
An	38.19	34.80
Di	22.81	23.48
Hy	7.25	11.48
Ol	6.41	0.12
Mt	4.79	6.16
Cm	0.07	0.04
Il	1.56	1.59
Ap	0.20	0.13

Note: Analyst, H. Haramura.

total volume of glass inclusions and An_{77}, respectively (Figs. 3 and 5). It is also estimated that colorless glass globules occupy 5% in volume of the total glass inclusions. The result is shown in Table 8. The liquid is characterized by relatively high MgO content and is nearly identical to the high-MgO tholeiite from Leg 3 of DSDP (Frey et al., 1974) (Table 7).

Initial liquid trapped by plagioclase had plagioclase, olivine, and chromian spinel as liquidus phases. However, the trapped liquid precipitated only plagioclase in disequilibrium upon quenching as the Na-rich halo around inclusions, and fractionation may have been very effective in making precipitated plagioclase and residual liquid rapidly Na-rich and Al-poor, respectively. Liquid immiscibility may have occurred because of the removal of Al_2O_3 as plagioclase (Fig. 10).

Fujii et al. (1978) claim that the plagioclase-phyric oceanic tholeiite may derive from more primitive olivine tholeiite by flotation of plagioclase. This hypothesis seems to be applicable to the genesis of the Leg 66 basalt, and No. 3 of Table 7 is the candidate for such a parent magma, which is a kind of magnesian olivine tholeiite. Plagioclase sinks or floats in basaltic liquids, depending on the compositions of liquid and plagioclase and on the pressure (Fujii and Kushiro, 1977). Flotation of plagioclase is apparently indicated in the Leg 66 basalt flow by the fact that large crystals of plagioclase are more concentrated in Sample 487-9-11, which was derived near the top of the flow (Fig. 1), though plagioclase of An_{90} cannot float in the Leg 66 basalt magma at

Figure 3. Distribution of An content in plagioclase phenocryst. Note the low An content around the glass inclusion (dotted portion). Sample 487-93-95.

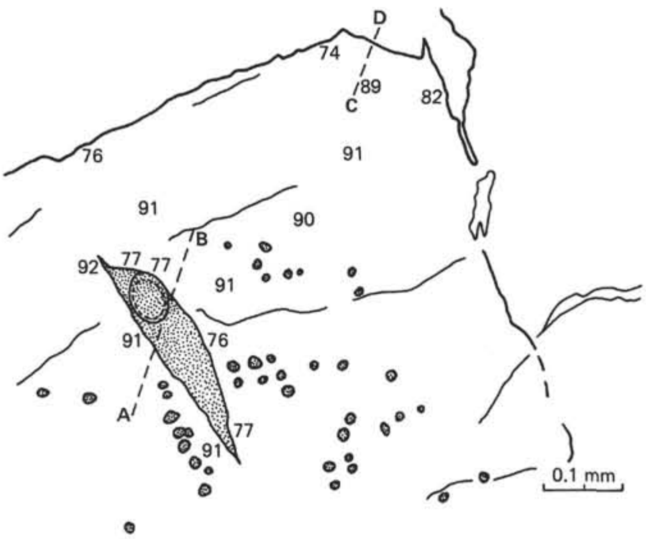

Figure 4. Distribution of An content in plagioclase phenocryst. Note the low An content around the glass inclusion (dotted portion). Sample 487-93-95. Scanning profiles along A-B and C-D are shown in Figure 6.

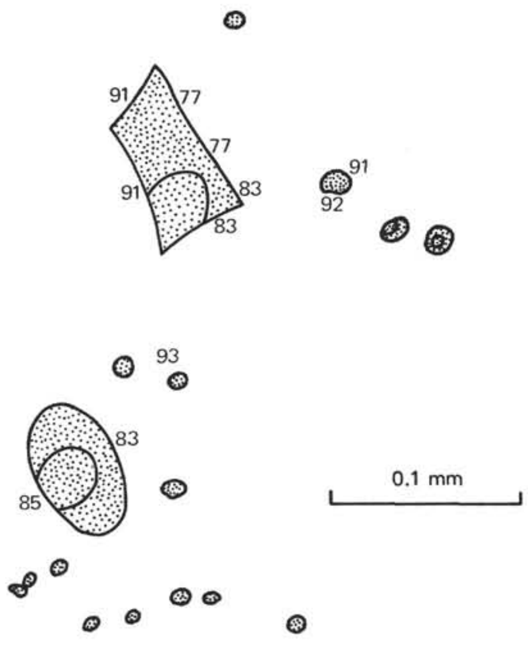

Figure 5. Distribution of An content of plagioclase around glass inclusions. Note the variation of shape and size of the inclusion. Sample 487-93-95.

low pressure according to the experiment of Fujii and Kushiro (1977). Olivine phenocrysts, which are usually small and attached to plagioclase, may have been floated with a plagioclase aggregate from more primitive liquid, though olivine itself is denser than basaltic liquid. Flotation of the aggregate of calcic plagioclase (An_{90}) and small amounts of magnesian olivine (Fo_{89}) may occur only at the high pressures of more than 6 kbar (Fujii and Kushiro, 1977).

In summary, Leg 66 basalt originated from the upper part of fractionated olivine tholeiite magma with floated Cr-rich plagioclase in the magma reservoir from a relatively deep section of Hole 487 (more than 20 km).

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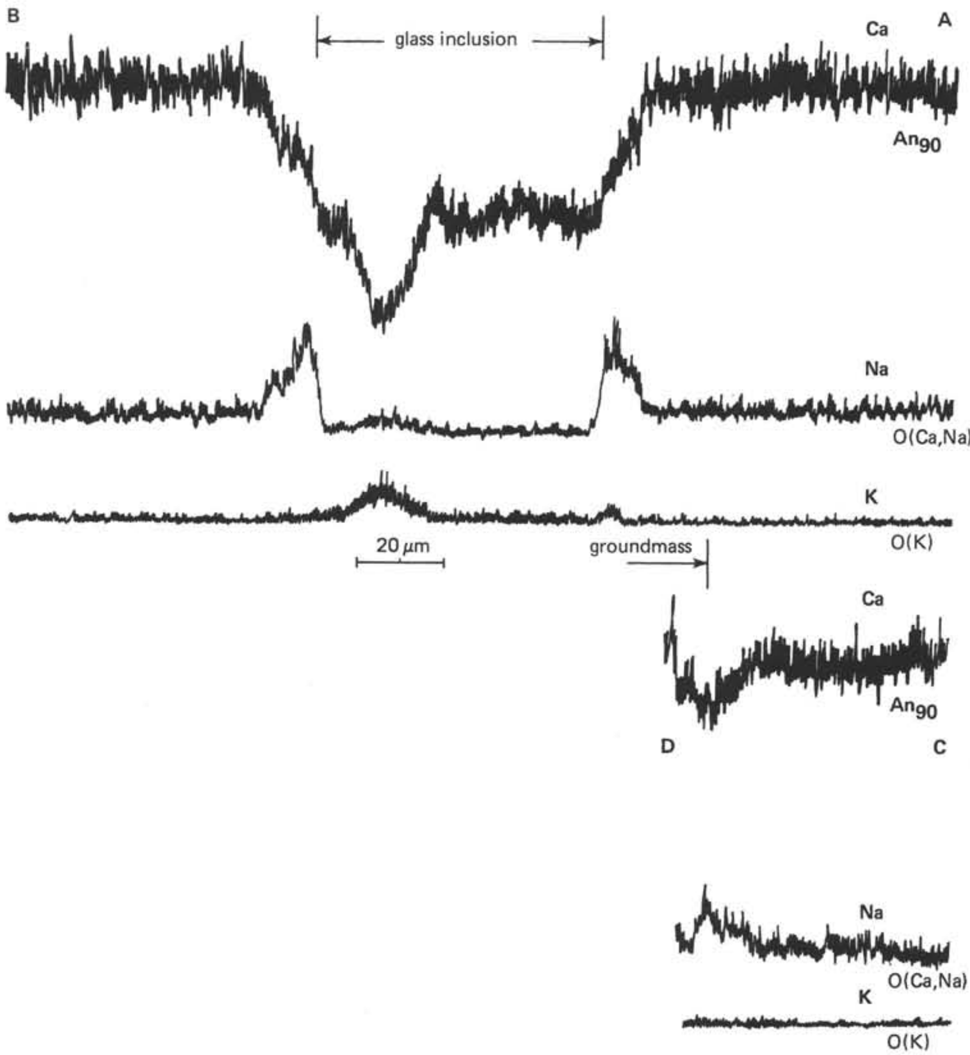

Figure 6. Distribution patterns of Ca, Na, and K in plagioclase phenocryst across glass inclusion (A–B) and grain boundary (C–D). (See Figure 4.) Sample 487-93-95.

Table 2. Selected EPMA analyses of plagioclase.

Sample	487-9-11			487-118-120			
No.	1[a]	2[b]	3[c]	4[a]	5[b]	6[d]	7[d]
SiO_2	45.1	47.0	49.8	44.3	51.3	49.4	48.0
TiO_2	0.02	0.04	0.04	0.02	0.05	0.06	0.04
Al_2O_3	34.0	32.0	30.4	33.2	28.5	30.6	31.5
FeO*	0.33	0.40	0.51	0.31	0.53	0.61	0.40
MnO	0.01	0.00	0.00	0.00	0.00	0.00	0.01
MgO	0.23	0.28	0.40	0.24	0.41	0.44	0.34
CaO	18.6	17.0	15.5	18.6	15.9	15.3	16.5
Na_2O	1.06	2.15	2.85	1.08	2.79	2.99	2.32
K_2O	0.00	0.01	0.01	0.01	0.01	0.03	0.01
Total	99.4	98.9	99.5	97.8	99.5	99.4	99.1
Ca	0.906	0.813	0.749	0.905	0.758	0.738	0.796
Na	0.094	0.187	0.250	0.095	0.242	0.261	0.203
K	0.000	0.000	0.001	0.000	0.001	0.002	0.001

Note: FeO* = total iron as FeO.
[a] Core (phenocryst).
[b] Rim (phenocryst).
[c] Groundmass.
[d] Groundmass (in clay).

Table 3. Selected EPMA analyses of olivine.

Sample		487-9-11			487-93-95		487-118-120	
No.	1[a]	2[b]	3[c]	4[a]	5[b]	6[c]	7[a]	8[c]
SiO_2	39.7	39.3	n.d.	39.4	39.4	39.4	38.1	38.1
TiO_2	0.01	0.00	0.01	0.00	0.01	0.01	0.00	0.01
Al_2O_3	0.09	0.10	0.10	0.09	0.11	0.09	0.11	0.11
Cr_2O_3	0.02	0.02	0.05	0.03	0.06	0.05	0.06	0.05
FeO*	11.1	11.3	11.9	11.0	12.5	11.3	11.3	12.9
MnO	0.15	0.16	0.15	0.17	0.24	0.17	0.15	0.19
MgO	48.4	48.3	47.1	48.5	46.6	48.1	47.9	47.2
CaO	0.35	0.36	0.35	0.32	0.39	0.35	0.37	0.37
Na_2O	0.00	0.00	0.02	0.00	0.02	0.00	0.00	0.01
NiO	0.17	0.30	0.18	0.21	0.25	0.26	0.15	0.19
Total	100.0	99.8	—	99.7	99.6	99.7	98.1	99.1
Mg	0.881	0.880	0.872	0.884	0.865	0.880	0.879	0.863
Ca	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005
Fe*	0.114	0.115	0.123	0.112	0.130	0.116	0.116	0.132
Fo	88.6	88.4	87.6	88.7	86.9	88.4	88.4	86.8

Note: FeO* and Fe* = total iron as FeO and Fe, respectively.
[a] Core (phenocryst).
[b] Rim (phenocryst).
[c] Groundmass (or microphenocryst).

Table 4. Selected EPMA analyses of clinopyroxene.

Sample	487-9-11		587-93-95			987-118-120		
No.	1[a]	2[b]	3[c]	4[c]	5[d]	6[e]	7[d]	8[e]
SiO_2	47.0	48.7	48.1	50.5	48.7	47.9	47.3	45.4
TiO_2	0.93	0.84	1.57	0.50	1.20	2.05	1.54	2.35
Al_2O_3	5.51	3.96	3.79	2.46	5.44	4.02	6.36	5.75
Cr_2O_3	0.28	0.12	0.09	0.10	0.14	0.02	0.36	0.01
FeO*	8.02	8.70	9.86	7.53	7.67	10.1	7.45	9.38
MnO	0.21	0.17	0.19	0.15	0.08	0.10	0.08	0.13
MgO	13.9	15.1	14.3	14.9	13.6	12.7	14.3	12.8
CaO	21.5	21.1	19.9	21.8	21.9	21.2	21.1	21.6
Na_2O	0.34	0.28	0.41	0.20	0.39	0.66	0.49	0.68
Total	97.7	99.0	98.2	98.1	99.1	98.8	99.0	98.1
Number of atoms for O = 6								
Si	1.803	1.843	1.843	1.913	1.833	1.833	1.770	1.753
Al	0.249	0.177	0.171	0.110	0.241	0.181	0.281	0.262
Ti	0.027	0.024	0.045	0.014	0.034	0.059	0.043	0.068
Cr	0.009	0.004	0.003	0.003	0.004	0.001	0.011	0.000
Fe*	0.257	0.275	0.316	0.238	0.241	0.322	0.233	0.303
Mn	0.007	0.005	0.006	0.005	0.003	0.003	0.003	0.004
Mg	0.795	0.849	0.813	0.886	0.883	0.868	0.887	0.893
Ca	0.884	0.855	0.814	0.886	0.883	0.868	0.887	0.893
Na	0.025	0.020	0.031	0.015	0.028	0.049	0.036	0.051
Mg	0.411	0.429	0.419	0.428	0.403	0.378	0.415	0.382
Ca	0.456	0.432	0.419	0.451	0.469	0.453	0.463	0.462
Fe*	0.133	0.139	0.162	0.121	0.128	0.168	0.122	0.156
Mg*	0.756	0.755	0.721	0.779	0.759	0.692	0.773	0.709

Note: Mg* = Mg/Mg + Fe* atomic ratio.
[a] Core (microphenocryst).
[b] Rim (microphenocryst).
[c] Groundmass.
[d] Core (microphenocryst in clay).
[e] Rim (microphenocryst in clay).

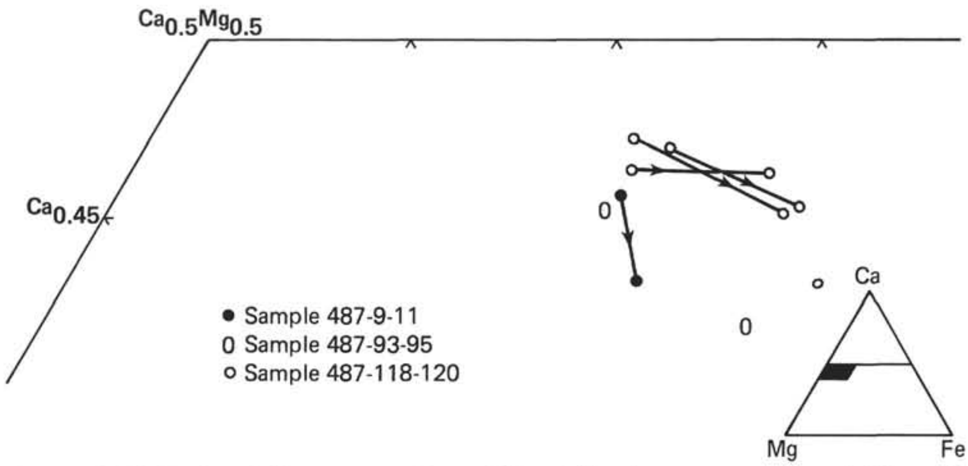

Figure 7. Ca-Mg-Fe plots of clinopyroxenes. Core and rim of microphenocryst are connected with a solid line with an arrow (from core to rim).

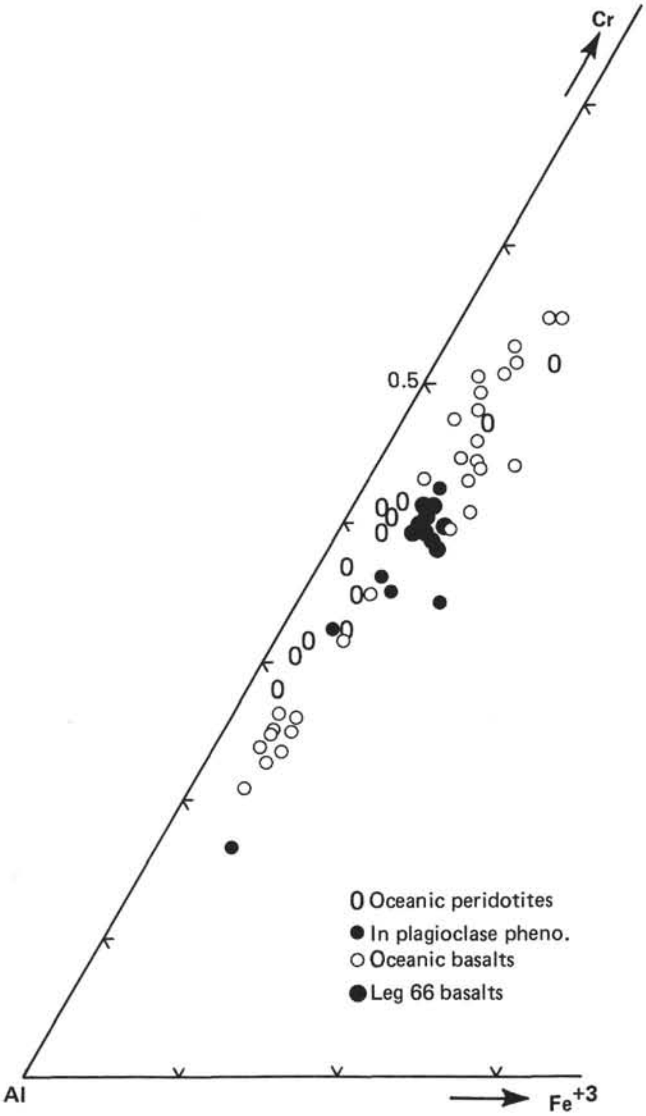

Figure 8. Cr-Al-Fe^{3+} plots of chromian spinels from Leg 66 basalts and other oceanic rocks. Data from Arai and Fujii (1978), Frey et al. (1974), Ridley et al. (1974), Sigurdsson (1977), and Sigurdsson and Schilling (1976).

Table 5. Selected EMPA analyses of chromian spinel and titanomagnetite.

Sample	487-9-11	487-93-98	487-118-120		487-93-95		487-118-120	
No.	1[a]	2[a]	3[b]		4[c]	5[c]	6[c]	7[c]
SiO_2	0.11	0.11	0.07		0.21	0.32	0.19	0.14
TiO_2	0.40	0.40	0.40		13.2	11.8	11.8	10.7
Al_2O_3	32.1	32.0	32.5		3.20	1.80	1.26	2.64
Cr_2O_3	33.9	34.0	34.6		0.04	0.14	0.05	0.02
FeO*	16.9	16.0	16.3		75.2	75.7	79.1	75.4
MnO	0.25	0.46	0.48		0.31	0.31	0.31	0.21
MgO	16.5	16.8	16.8		1.92	1.21	1.12	3.14
CaO	0.10	0.08	0.06		0.14	0.41	0.13	0.08
Na_2O	0.01	0.00	0.00		0.00	0.02	0.02	0.04
Total	100.3	99.9	101.2		94.2	91.7	94.0	92.4
Mg*	0.715	0.729	0.719	Ulv	0.390	0.358	0.344	0.309
Cr	0.389	0.392	0.393	Sp	0.073	0.043	0.029	0.059
Al	0.549	0.549	0.551	Mt	0.537	0.599	0.627	0.632
Fe^{3+}	0.063	0.059	0.055					
Cr*	0.415	0.416	0.416					

Note: Mg* = Mg/Mg + Fe^{2+} atomic ratio. Cr* = Cr/Cr + Al atomic ratio. Fe^{2+} and Fe^{3+} are determined, assuming the spinel stoichiometry. Ulv = ulvospinel molecule (Mg, Fe^{2+}) TiO_4. Sp = spinel molecule (Mg, Fe^{2+}) $(Al, Cr)_2O_4$. Mt = magnetite molecule (Mg, Fe^{2+}) $Fe^{3+}_2O_4$.

[a] Chromian spinel in plagioclase.
[b] Chromian spinel in groundmass.
[c] Titanomagnetite in groundmass.

Table 6. EPMA analyses and C.I.P.W. norms of glass inclusions in plagioclase.

Sample	487-9-11			487-118-120						
No.	1[a]	2[a]	3[a]	4[a]	5[b]	6[a]	7[b]	8[a]	9[b]	10[a]
SiO_2	48.2	49.0	48.0	48.9	49.2	44.9	47.3	47.4	46.7	47.1
TiO_2	0.81	0.64	0.79	0.01	1.15	0.36	0.90	0.21	1.07	0.73
Al_2O_3	13.0	5.98	7.49	3.49	8.67	5.96	5.66	5.53	5.81	6.37
FeO*	10.4	13.2	12.8	8.62	10.6	8.66	13.2	9.75	12.3	12.0
MnO	0.19	0.22	0.22	0.01	0.20	0.05	0.26	0.00	0.25	0.23
MgO	15.0	18.1	16.9	20.5	15.3	17.2	17.2	10.7	17.5	18.0
CaO	12.0	11.5	11.3	1.15	11.5	2.05	11.8	1.90	12.3	11.4
Na_2O	1.56	0.29	0.98	0.18	1.32	0.70	0.29	0.74	0.31	0.27
K_2O	0.02	0.17	0.13	0.75	0.07	1.09	0.06	1.50	0.01	0.07
Cr_2O_3	0.03	0.07	0.07	0.00	0.00	0.02	0.08	0.00	0.10	0.08
NiO	n.d.	n.d.	n.d.	0.08	0.07	n.d.	n.d.	n.d.	n.d.	n.d.
Total	101.2	99.2	98.7	83.7	98.1	81.0	96.8	77.7	96.4	96.3
C.I.P.W. Norms										
Q				4.6				9.9		
C				0.4						
or	0.1	1.0	0.8	4.5		6.5	0.4	8.9		0.5
ab	13.2	2.5	8.3	1.6	11.2	5.9	2.4	6.2	2.6	2.3
an	28.3	14.5	15.6	5.7	17.7	9.9	14.0	7.4	14.5	16.0
di	25.2	34.3	32.6		31.7	0.3	36.1	1.7	37.5	33.0
hy	5.3	28.6	15.6	67.0	20.8	57.2	25.9	43.3	20.5	24.8
ol	27.4	16.9	24.1		14.8	0.9	16.5		19.3	18.4
il	1.5	1.2	1.5		2.2	0.7	1.7	0.4	2.0	1.4
Mg*	0.720	0.709	0.703	0.809	0.720	0.779	0.698	0.661	0.717	0.727

Note: FeO* = total Fe as FeO. Mg* = Mg/Mg + Fe* atomic ratio.
[a] Brown glass.
[b] Colorless glass globule in brown glass (Nos. 5, 7, 9, included in 4, 6, 8, respectively).

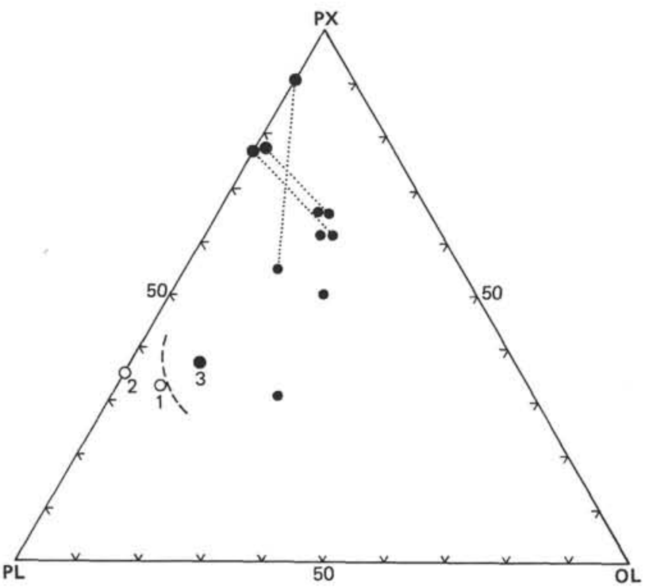

Figure 9. Normative Px(hy + di)-PL(ab + an)-OL(fo + fa) plots of bulk rocks and glass inclusions in plagioclase. (Open circle = bulk rock. 1, 2, and 3, Nos. 1 and 2 of Table 1 and No. 3 of Table 8, respectively. Small solid circle = brown glass in plagioclase. Large solid circle = colorless glass in brown glass connected with dotted line. Broken line = cotectic curve between olivine and plagioclase of Shido et al. [1971].)

Table 7. Inferred chemical compositions of liquids.

No.	1[a]	2[b]	3[c]	4[d]
SiO_2	47.9	47.1	48.2	50.3
TiO_2	0.88	0.19	0.51	0.73
Al_2O_3	6.66	4.99	17.2	16.6
FeO*	12.4	9.01	7.38	7.99
MnO	0.23	0.02	0.13	0.12
MgO	17.2	16.1	10.3	10.2
CaO	11.6	1.70	12.9	13.2
Na_2O	0.58	0.54	1.39	2.00
K_2O	0.09	1.11	0.08	0.01
Total	97.5	80.8	98.1	101.2
Mg*	0.712	0.761	0.713	0.695

Note: Mg* = Mg/Mg + Fe* atomic ratio.
[a] Mean chemical composition of brown glass of Nos. 2, 3, 5, 7, 9, 10 (Table 6).
[b] Mean chemical composition of colorless glass of Nos. 4, 6, 8, (Table 6).
[c] Inferred parental magma of Leg 66 basalt (see text).
[d] High-MgO oceanic tholeiite from Leg 3 (Frey et al., 1974).

Table 8. EMPA analyses of clay and related mineral.

Sample	487-9-11	487-118-120			
No.	1[a]	2[a]	3[a]	4[a]	5[b]
SiO_2	52.2	51.4	53.3	48.8	48.2
TiO_2	0.00	0.00	0.00	0.00	0.00
Al_2O_3	2.24	1.81	2.40	1.86	0.47
Cr_2O_3	0.00	0.00	0.00	0.00	0.00
FeO*	6.11	13.3	9.61	11.5	29.5
MnO	0.00	0.03	0.03	0.01	0.04
MgO	24.2	21.4	22.5	21.7	4.33
CaO	1.03	0.36	0.50	0.38	0.47
Na_2O	0.18	0.40	0.41	0.48	0.10
K_2O	0.45	1.00	0.89	0.81	3.27
Total	86.2	89.7	89.6	85.5	86.4
Number of atoms					
O	22.0	22.0	22.0	22.0	—
Si	7.593	7.514	7.614	7.438	8.0
Al	0.386	0.312	0.405	0.334	0.918
Fe*	0.746	1.612	1.149	1.469	4.093
Mn	0.000	0.003	0.003	0.000	0.005
Mg	5.261	4.674	4.798	4.943	1.071
Ca	0.162	0.057	0.076	0.062	0.083
Na	0.050	0.114	0.115	0.143	0.032
K	0.085	0.186	0.162	0.157	0.693
Mg*	0.876	0.742	0.807	0.771	0.207

Note: Mg* = Mg/Mg + Fe* atomic ratio.
[a] Yellow clay mineral in groundmass.
[b] Stilpromelane-like mineral included in No. 2.

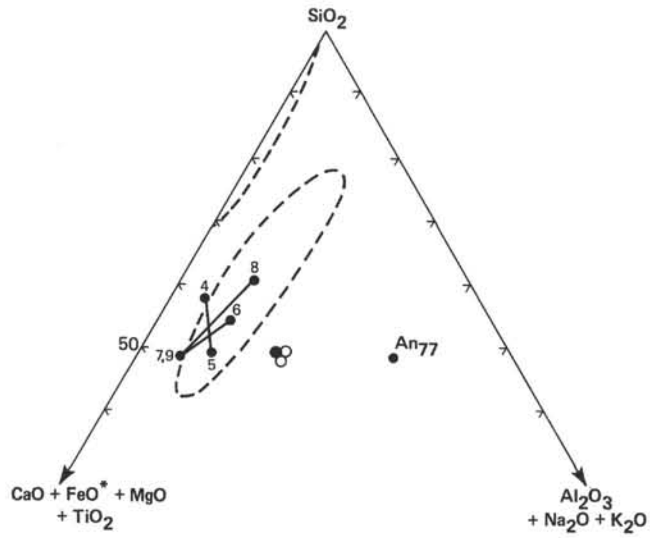

Figure 10. Plot of the compositions of glass inclusions in plagioclase (small solid circle with number), Leg 66 basalts (open circle), plagioclase of An_{77}, and inferred parental magma of Leg 66 basalt (large solid circle) (see text). Nos. 4 to 9 are the same as in Table 6. Two immiscibility fields in the system fayalite-leucite-silica (Roedder, 1951) are indicated by dashed lines. FeO* = total Fe as FeO.