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PETROCHEMISTRY OF THE HILO 7 1/2' QUADRANGLE, ISLAND OF HAWAII

by

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PETROCHEMISTRY OF THE HILO 7 1/2' QUADRANGLE, ISLAND OF HAWAII

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INTRODUCTION

The Hilo 7 1/2' quadrangle is located along the east-central coast of the Island of Hawaii (fig. 1). During geologic mapping of the quadrangle, at least one sample from each lava flow was collected for chemical analysis. A few samples were collected from radiocarbon-dated lava flows in the Piihonua and Mountain View quadrangles, which border the west and south sides of the Hilo quadrangle, respectively (fig. 1).

Stratigraphic Framework

The stratigraphic framework for volcanic rocks defined by Langenheim and Clague (1987) is followed in this report, and a more complete discussion is given in Buchanan-Banks (in press). Four main eruptive stages are recognized in Hawaii volcanism (Clague and Dalrymple, 1987; Peterson and Moore, 1987). Rocks of two of these stages, shield and postshield, are exposed within the map area. No preshield stage rocks are exposed and no rejuvenated stage rocks have yet been erupted. The map area is surfaced by basalt flows from three of the five volcanoes that form the Island of Hawaii (figs. 1 and 2). Most of the flows are from Mauna Loa, the others from Mauna Kea and Kilauea.

The only postshield stage lava flows within the map area are derived from Mauna Kea; these are the alkalic Pleistocene-age Hamakua Volcanics. No shield stage tholeiitic lavas of Mauna Kea occur in the map area. Rift zones on Mauna Kea are less well defined than those on Mauna Loa or Kilauea and are mainly suggested by westward, southward, and eastward alignments of cinder cones (fig. 1).

All exposed lava flows of Mauna Loa are shield-stage tholeiitic lava erupted from the northeast rift zone (fig. 1); these belong to the Kahuku Basalt of Pleistocene age, and the Ka'u Basalt of Pleistocene and Holocene age. The Kahuku and Ka'u generally are separated by a Pahalatype ash of Pleistocene age (between about 10 to 30 ka) (Easton, 1987). The Ka'u Basalt consists of a historic member (19th century) and prehistoric members (0.6 to 14 ka).

All exposed lava flows from Kilauea within the map area, like those of Mauna Loa, are shield-stage tholeiitic lava erupted from the east rift zone. These belong to the Puna Basalt of Pleistocene and Holocene age.

Ages of Lava Flows

Chemical analyses presented in tables 1 and 2 are arranged in order of flow age from youngest to oldest. Ages are well established for historical flows and flows dated by radiocarbon methods (Buchanan-Banks, Lockwood, and Rubin, 1989). Twenty-six samples of carbonized roots and other plant material were collected from beneath 15 prehistoric Mauna Loa flows and analyzed by Meyer Rubin, USGS, Reston (Buchanan-Banks, in press, map sheet and table 1). Ages of most other flows and ash deposits are constrained by stratigraphic relations with the dated flows.

Directions of remanent magnetization were used to correlate isolated outcrops and to establish the approximate ages of some flows not dated by radiocarbon techniques (Buchanan-Banks, in press, map sheet and table 3).

Distribution of Lava Flows

Mauna Kea - The ash-covered alkalic basalt flows of the Hamakua Volcanics crop out in the northwest corner of the map area. South of the Wailuku River, the older ash and lava flows of Mauna Kea are locally covered by tholeiitic basalt flows from Mauna Loa. No interfingering of Mauna Kea and Mauna Loa lava flows was found in the map area. The Mauna Kea flows are weathered more severely than flows of Mauna Loa known to be at least 24 ka, implying that the Mauna Kea flows are substantially older. Because of limited lateral extent of flows, difficult access, and small likelihood of correlating flows from stream to stream, rock samples for chemical analyses were collected from only a few mappable flows of the Hamakua Volcanics.

Mauna Loa - Tholeiitic lava of the Ka'u and Kahuku Basalts erupted from vents southwest of the Hilo quadrangle on the northeast rift zone (fig. 1) are the predominant surface flows south of the Wailuku River. The oldest lava flows are exposed in the beds of ephemeral streams where the normal overburden of "Pahala-like" ash has been stripped away.

Kilauea - A lava flow of the Puna Basalt (table 1, plot symbols o and O) forms a thin veneer over Mauna Loa flows in the southeast corner of the quadrangle. More than one flow may be present, but possible contacts are obscured by a cane-waste slurry of mud and rocks deposited on the flows.

METHODS OF STUDY

At least one rock sample was collected from each lava flow identified within the Hilo 7 1/2' quadrangle; a few samples were collected in the Piihonua and Mountain View quadrangles usually from lava flows from under which carbonaceous material was collected for radiocarbon dating. Samples were of the freshest material available but in the older Mauna Loa flows and all Mauna Kea flows weathered samples could not be avoided. Rock samples were cut into slabs and representative material was submitted for chemical analyses and thin section preparation (for details of thin-section examination see Buchanan-Banks, in press, Discussion of Map Units).

Computer Reduction of Chemical Data

A set of interactive computer programs has been used in working with the chemical data (T. C. Wright, written commun., 1986).

1. Chemical data have been tabulated and normalized using a program called CHEMTAB (tables 1 and 2).
2. Mineral control lines for suites of related analyses have been computed using a program called SLOPE, which computes linear regressions for the equation of the form $y = ax + b$, where y is the major oxide or element, x is the MgO content, a is the slope, and b is the y intercept value at MgO=0 weight percent (table 3). The program available at the Cascades Volcano Observatory was based on "BmDo5R Polynomial Regression" by Dixon (1968) modified by D.B. Johnson to increase its 'friendliness'.

3. Chemical data are plotted on magnesia (MgO) variation diagrams (figs. 3-6) using a computer-directed plotter and a computer program called OXVAR. This program is titled "B844: Chemical Plot" and is described more fully in Wright (1971, p. 6).

CHEMISTRY AND PETROGRAPHY

All lava flows from Mauna Kea are chemically typical of the basalts erupted during the postshield stage (Clague and Dalrymple, 1987, p. 25). The lava flows are fairly homogenous in their mineral compositions but show chemical diversity (table 1 and fig. 3). The silica content (in weight percent) of the flows averages about 44 percent and ranges from nearly 41 percent in the more olivine-rich alkalic basalt (table 1, plot sympbol 8) to slightly more than 47 percent (table 1, plot symbol 2). Most flows are slightly porphyritic, have an aphanitic groundmass, and are light gray; some are aphyric. A few flows contain narrow bands of darker material that probably resulted from chemical weathering along hairline fractures. In thin section, the most common phenocrysts and microphenocrysts are lath-shaped plagioclases, which composes less than 0.5 to as much as 6 percent of some flows; one flow contains 12 percent plagioclase. Most flows contain as much as 3 percent olivine as phenocrysts and microphenocrysts, and one picritic basalt contains nearly 48 percent olivine. Phenocrysts and microphenocrysts of opaque minerals and pyroxene are generally less abundant. Stellate cumulocrysts of microphenocrystic plagioclase commonly are found with pyroxene and olivine microphenocrysts. Phenocrysts and microphenocrysts in several flows show slight flow alignment of the plagioclase laths; a few flows have trachytic texture. The most common groundmass mineral is plagioclase, whose laths are slightly oriented parallel to flow direction; olivine and other mafic and opaque minerals fill the interstices between the groundmass plagioclase laths, and apatite is commonly present as an accessory mineral.

All lava flows from Kilauea and Mauna Loa volcanoes are of basaltic composition but can be chemically distinguished from the flows of Mauna Kea by their higher silica and consistently lower alkali content (tables 1 and 2). The silica content of these flows averages almost 50 percent and ranges from nearly 47 percent silica in picritic tholeiitic basalt to more than 52 percent in tholeiitic basalt. Most flows are porphyritic, have a microcrystalline to aphanitic groundmass, and are medium to dark gray. The most common phenocrysts are olivine and plagioclase; phenocrystic pyroxene is more rare. Microphenocrysts of hypersthene are present in a few flows. Most flows contain 1 to 5 percent olivine as euhedral to subhedral phenocrysts and microphenocrysts, but some contain 10 to 30 percent; a few picritic basalts contain as much as 42 percent olivine. Phenocrysts and microphenocrysts of plagioclase, usually lath shaped, constitute 1 to 5 percent of a flow, but a few flows contain about 10 percent plagioclase, and one flow contains as much as 21 percent. Cumulocrystic intergrowths of olivine and plagioclase are found in about half of the flows; pyroxene is locally present. In the groundmass, small grains of olivine, mafic and opaque minerals, and devitrified glass heavily dusted with opaque minerals, fill interstices between plagioclase laths. Moderately to heavily porphyritic basalt flows are present in both the Ka'u and Kahuku Basalts of Mauna Loa.

Major-element Chemistry

Chemical analyses are given for Kilauea and Mauna Kea volcanoes (table 1), and for Mauna Loa volcano (table 2); ratios for K_2O:P_2O5 are also given in the tables to aid in evaluating the processes by which the lavas of each volcano have evolved (Anderson and Greenland, 1969). The 0.01 percent K_2O

for sample number H84-33 (table 2, map no. C49) is extremely low and may represent an error in analysis. K_2O values lower than about 0.3 percent may reflect deep weathering of the samples.

The analyses are depicted as a series of MgO variation diagrams after normalization to 100 percent dry weight and conversion of Fe_2O_3 to "FeO" (figs. 3 and 4); analyses for Mauna Loa flows are further divided by age into five groups (figs. 5A-E). The wide range in olivine content for the flows permitted precise calculation of olivine-control lines by linear least-squares regression. Coefficients for the computation of equation of the form $y = ax + b$ are given in table 3. Most oxides correlate negatively with MgO (figs. 3, 4, and 5A-E) reflecting the diluting effect of increasing olivine content on elements that do not enter the olivine crystal structure.

Lava Flows from all Volcanoes

Chemical analyses of lava flows from Mauna Kea, and those of Kilauea and Mauna Loa form two distinct fields (fig. 3). Most analyzed samples from Mauna Kea fit the definition of differentiated lavas (MgO is less than 6.8 percent); the single exception is plotting symbol 8 (table 1), which has an MgO content of 10.7 percent. Although lava flows of Mauna Kea show variability, they can be clearly distinguished from flows of Mauna Loa and Kilauea by their lower SiO_2, higher Al_2O_3 and "FeO", lower CaO, higher Na_2O, K_2O, TiO_2, P_2O_5, and MnO. Mineral control lines for the two data sets cross each other only in the plot for Na_2O. Slope of olivine control lines (dotted and dashed line for Mauna Kea) is negative except for plots of "FeO", P_2O_5, and MnO.

Flows from Kilauea and Mauna Loa are mostly olivine-controlled lavas. Chemical analyses for flows from these volcanoes were combined to compute the slope of the dashed mineral control lines because 1) lava flows from both volcanoes are shield-stage tholeiitic basalt, and 2) only two samples from Kilauea flows were analysed because few flows entered the Hilo quadrangle. Analyses of Kilauea rocks are similar to those of Mauna Loa, except for slightly higher CaO, lower K_2O (symbol O only), and higher TiO_2 contents. Solid line represents olivine control line for analysis of rock samples from Mauna Loa.

Lava Flows from Mauna Loa

Chemical analyses of lava flows from Mauna Loa are plotted using a letter symbol to represent each of the 34 flows identified during mapping; some flows have more than one analysis (fig. 4; note scale change from fig. 3). Major element composition of Mauna Loa lava flows are broadly similar forming a linear trend. Only two lava flows represented by plot symbols f and j (fig. 4 and table 2) fit the definition of differentiated lavas. The analyses show a concentration of flows with an MgO content between 6 and 8 percent; these flows represent all age groups except those having radiocarbon ages between about 9.0-10.0 ka (fig. 5C) and those greater than 14.0 ka (fig. 5E). Plots of "FeO", K_2O, and P_2O_5 show some scatter. Slopes of lines are negative, except for "FeO".

Ages of lava flows range from the historical flow of 1880-81 to about 25.0 ka; a few flows may be older than 25.0 ka. The flows are plotted according to age based mainly on breaks in the radiocarbon-dating record (figs. 5A-E). Age groupings are assigned somewhat arbitrarily; for example, although a break in the radiocarbon dating record occurs at about 5,000 years B.P., several undated flows, one known to be older than 5,000 years and others known to be younger than 9,000 years, occur within this gap; thus one group comprises flows from about 3.0 to less than 9.0 ka.

Eighteen analyses of 7 flows (table 2, plot symbols * and a-j) having ages between about 100 years (the 1880-81 flow) to radiocarbon ages of about 2.0 ka are given in figure 5A. The analyses have MgO content between 6 and 14 percent. Plot symbols c, d, e, and f (table 2) represent a single large eruption that has been divided into four flow units based mainly on morphology and mineral abundances (see Buchanan-Banks, in press, Discussion of Map Units). One analysis for flow unit represented by plot symbol d (table 2, map no. C12) shows unusually high SiO_2, and low CaO and P_2O_5 content, while an analysis for flow unit represented by plot symbol f (table 2, map no. C16) shows higher CaO and lower P_2O_5 than typical for this lava flow. Slope of olivine control lines (solid line for analyses from this age group; dashed line for analyses of all Mauna Loa lava flows) are negative for all oxides, including "FeO".

Eleven analyses for 8 flows (table 2, plot symbols k through s) having radiocarbon ages between about 3.0 and 9.0 ka are given in figure 5B. Most flows have an MgO content between 7 and 10 percent, except for flow represented by plot symbol n (table 2), which has an MgO content in excess of 18 percent. In addition to the expected scatter in the data for "FeO", K_2O, and P_2O_5, some scatter also occurs in the data for TiO_2.

Ten analyses for 2 flows (table 2, plot symbols t through x) having radiocarbon ages between 9.0 and 10.0 ka are given in figure 5C. Plot symbols t, u, v, and w (table 2) represent a single lava flow divided into four flow units mainly on basis of topographic expression (see Buchanan-Banks, in press, Discussion of Map Units); these flow units have an MgO content between about 11 and 18 percent. The single other flow represented by plot symbol x (table 2, map nos. C40 and C41) has an MgO content of nearly 7 percent; the two analyses from this flow display significantly different amounts of K_2O. Olivine control line for this age group and line for all Mauna Loa flows coincides in plot of MnO.

Fourteen analyses for 6 flows (table 2, plot symbols y, z,), \, [, and ~) having radiocarbon ages between about 10.0 and 15.0 ka are given in figure 5D. The analyses define two fields based on MgO content; one field has between 17 to nearly 25 percent MgO, and the other between 7 to 10 percent MgO. The group of flows having lower MgO content, with the exception of flow represented by plot symbol \ with MgO content of nearly 12 percent (table 2, map no. C49), has an average radiocarbon age of about 10.5 ka. For the group of flows having higher MgO content, no maximum age has been determined, although a minimum age of about 9.8 ka has been established through stratigraphic relations with overlying lava flows dated through radiocarbon techniques. One group lies generally to either side of the flows plotted in figure 5C. Olivine control line for this age group and line for all Mauna Loa flows coincide for plots of P_2O_5 and MnO.

The Kahuku Basalt is represented by six analyses for five flows (table 2, plot symbols =, <, +, >, and /) having radiocarbon ages greater than 14.0 ka (fig. 5E). The analyses define two fields based on MgO content; plot symbol < composes one field representing analyses of rock samples from spatter cone (table 2, map no. C57, about 14 percent MgO) and lava flow (table 2, map no. C58, about 18 percent MgO) from Halai hill having between 14 and 18 percent MgO. This field plus flow represented by plot symbol = (table 2) are known to be older than about 14.0 ka because of stratigraphic relations with overlying lava flows dated by radiocarbon techniques; no maximum age has been determined. The second field occupies a narrow range of between 7 to 9 percent MgO. Two of the four flows of this second group are about 24.0 ka based on radiocarbon dating (table 2, plot symbols + and /). Flow represented by plot symbol > is overlain by flow represented by plot symbol +, thus it is older than 24.0 ka; no minimum age has been determined for this flow.

Mauna Loa lava flows are plotted in figure 6 with respect to age using a letter symbol to represent each of the five age groups of figures 5A-E (see figure 5 for explanation of age parameters). It is likely that the trends shown in figure 6 will be modified when chemical analyses from more than one quadrangle are included.

ACKNOWLEDGEMENT

Daniel Dzurisin lent invaluable assistance to the author in learning computer programs, methods of data entry, and techniques of scaling plots.

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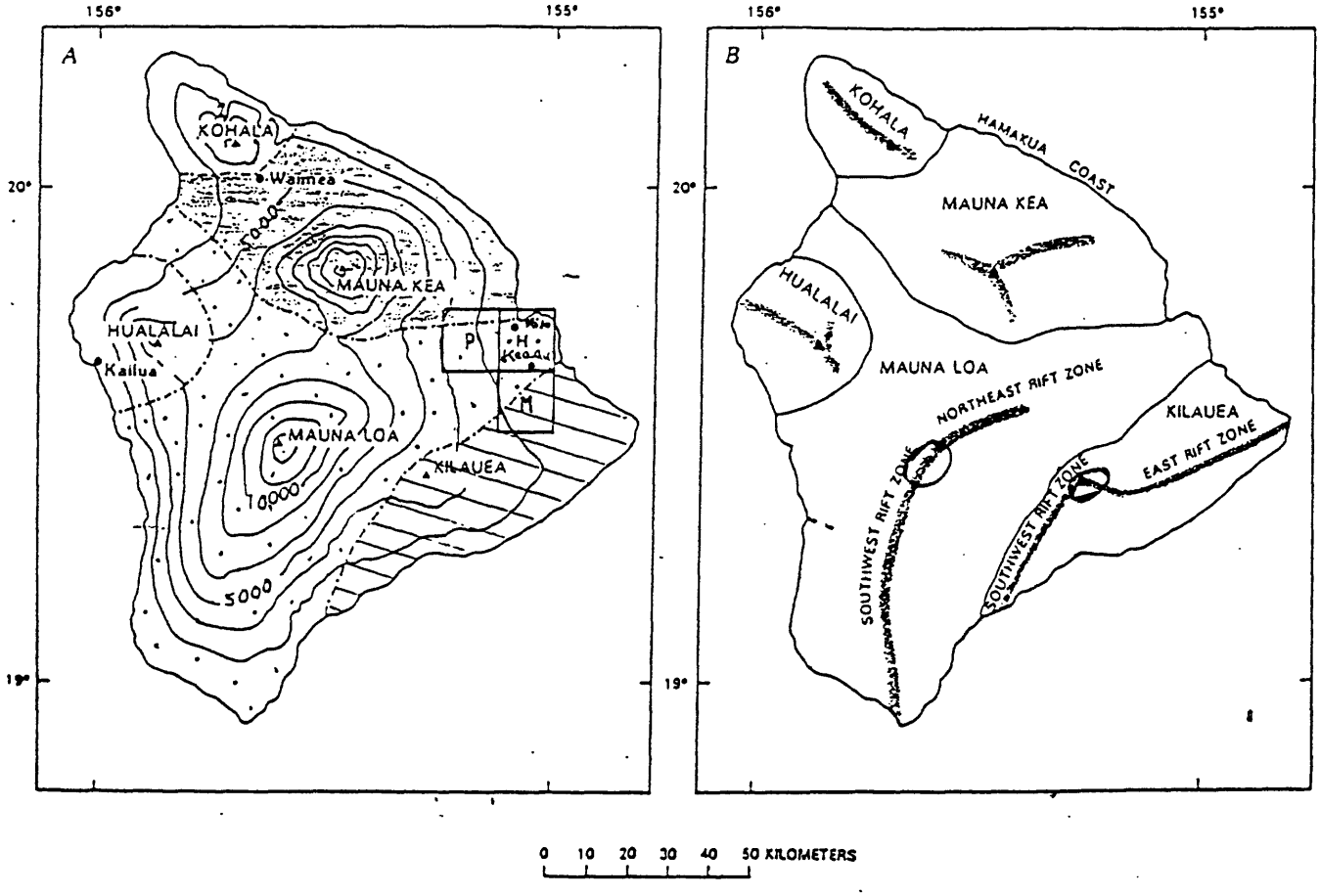


Figure 1. Island of Hawaii showing selected geographic and geologic features. A, Generalized topography and boundaries of five volcanoes; stippled area, lava flows chiefly from Mauna Loa; hatched area, lava flows chiefly from Kilauea; shaded area, lava flows chiefly from Mauna Kea; unpatterned area, lava chiefly from Hualalai and Kohala. Three 7 1/2' quadrangles shown are P, Piihonua, H, Hilo, and M, Mountain View. Contours in feet. B, Major rift zones; rift zones on Kilauea and Mauna Loa are named and calderas are shown.

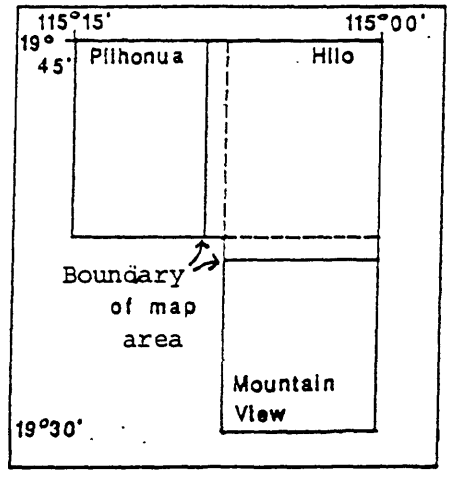


Figure 2. LOCATIONS OF 7 1/2' QUADRANGLES AND BOUNDARY OF MAP AREA

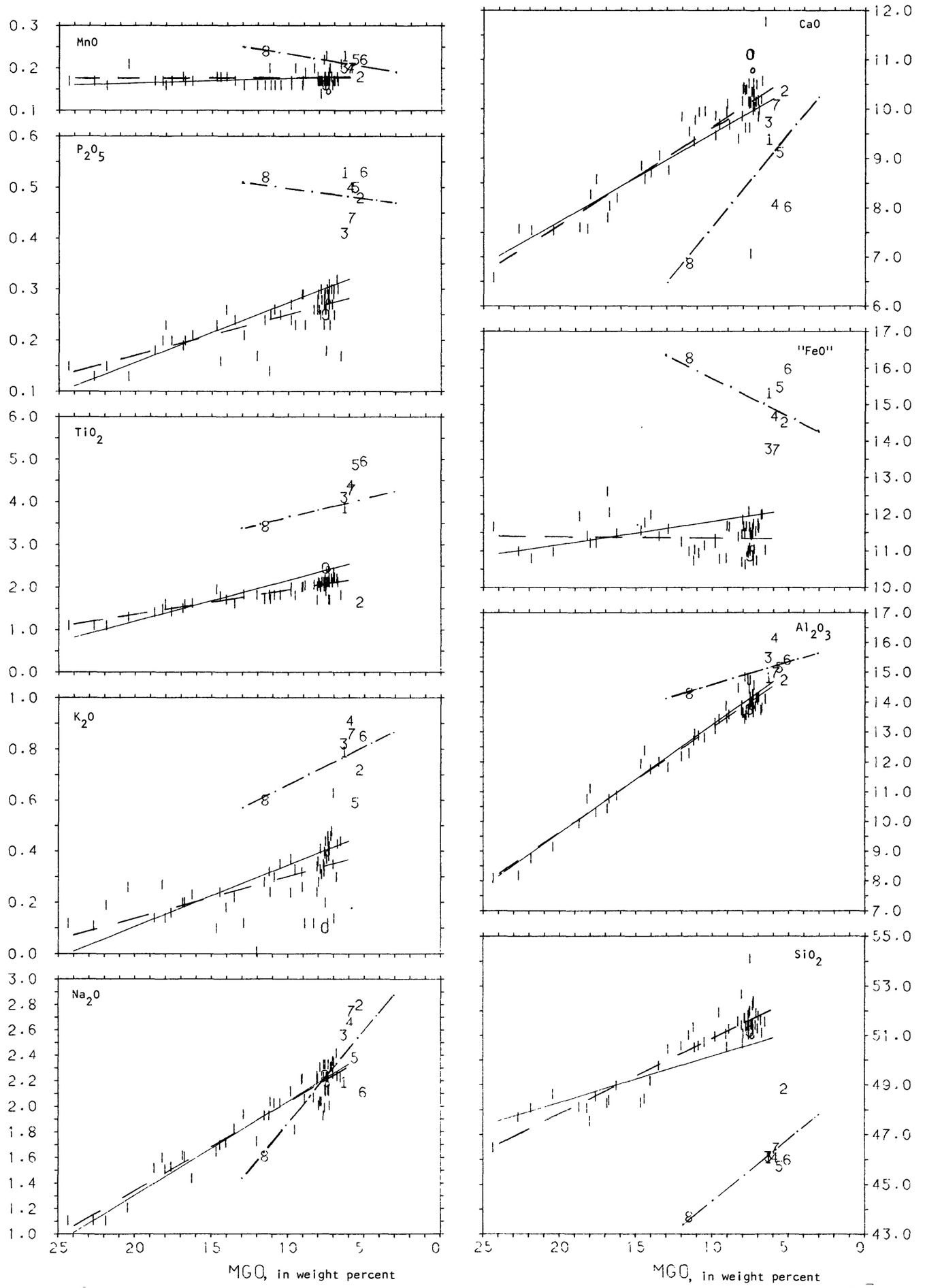


Figure 3. MgO variation diagrams showing Mauna Kea, Kilauea, and Mauna Loa lava flows and olivine control lines. Analyses are given in table 1 for Kilauea and Mauna Kea, and in table 2 for Mauna Loa. Solid line, lava flows from Mauna Loa; dashed line, lava flows from Kilauea and Mauna Loa; dotted and dashed line, lava flows from Mauna Kea. Plot symbols: 1 through 8, Mauna Kea; o, O, Kilauea; and I, Mauna Loa.

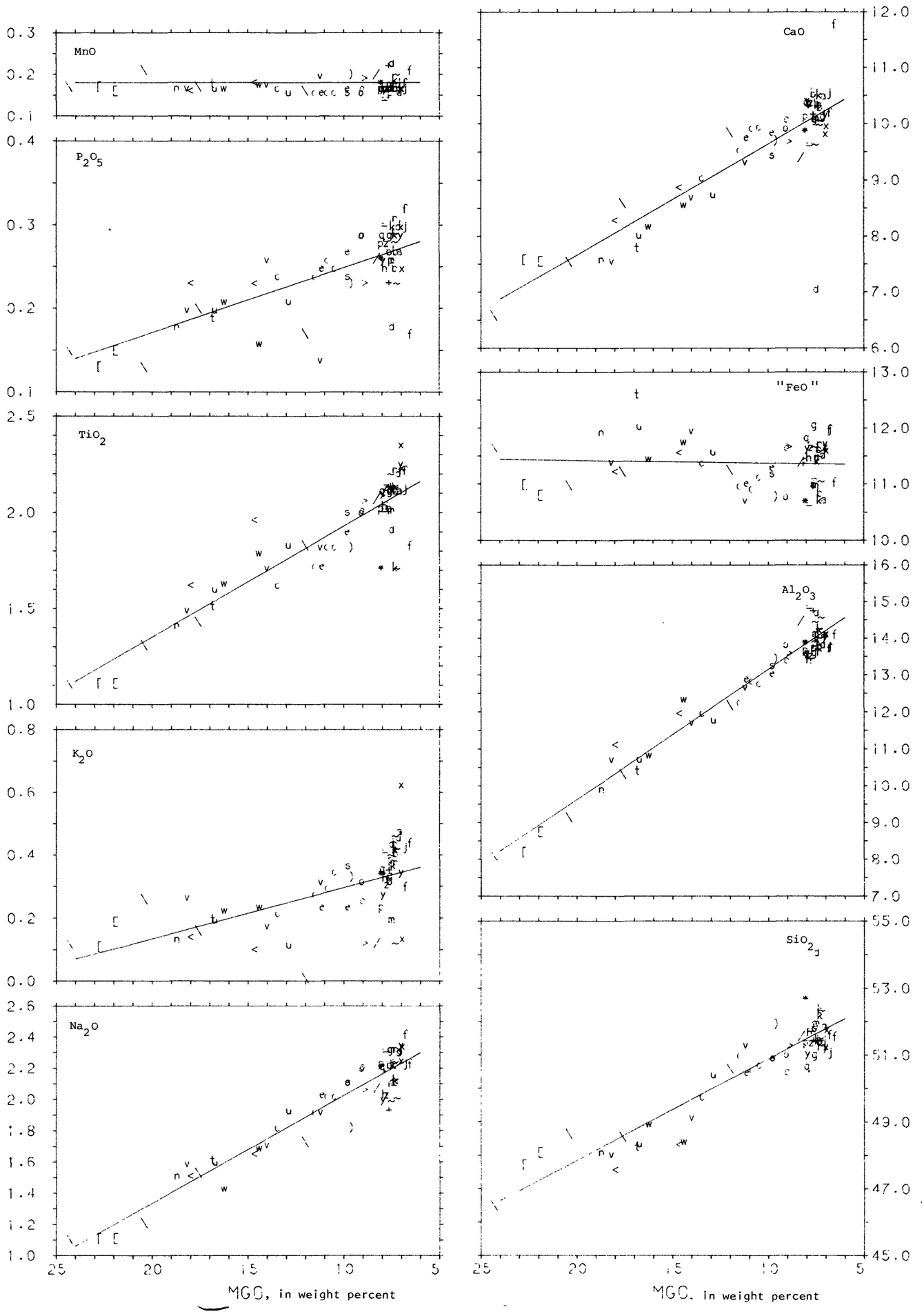


Figure 4. MgO variation diagrams showing Mauna Loa lava flows and olivine control lines. Letter symbols refer to analyses given in table 2. Note change in scale from figure 3.

Figures 5A - 5E. MgO variation diagrams and olivine control lines for Mauna Loa lava flows plotted in age groups. Letter symbols and analyses given in table 2. Solid line, olivine control line for data from selected age group; dashed line, olivine control line for data from all Mauna Loa lava flows. Flows having radiocarbon ages from: A, about 0.1 to 3.0 ka; B, about 3.0 to 9.0 ka; C, about 9.0 to 10.0 ka; D, about 10.0 to 15.0 ka; E, greater than about 15.0 ka.

(See figures on following sheets)

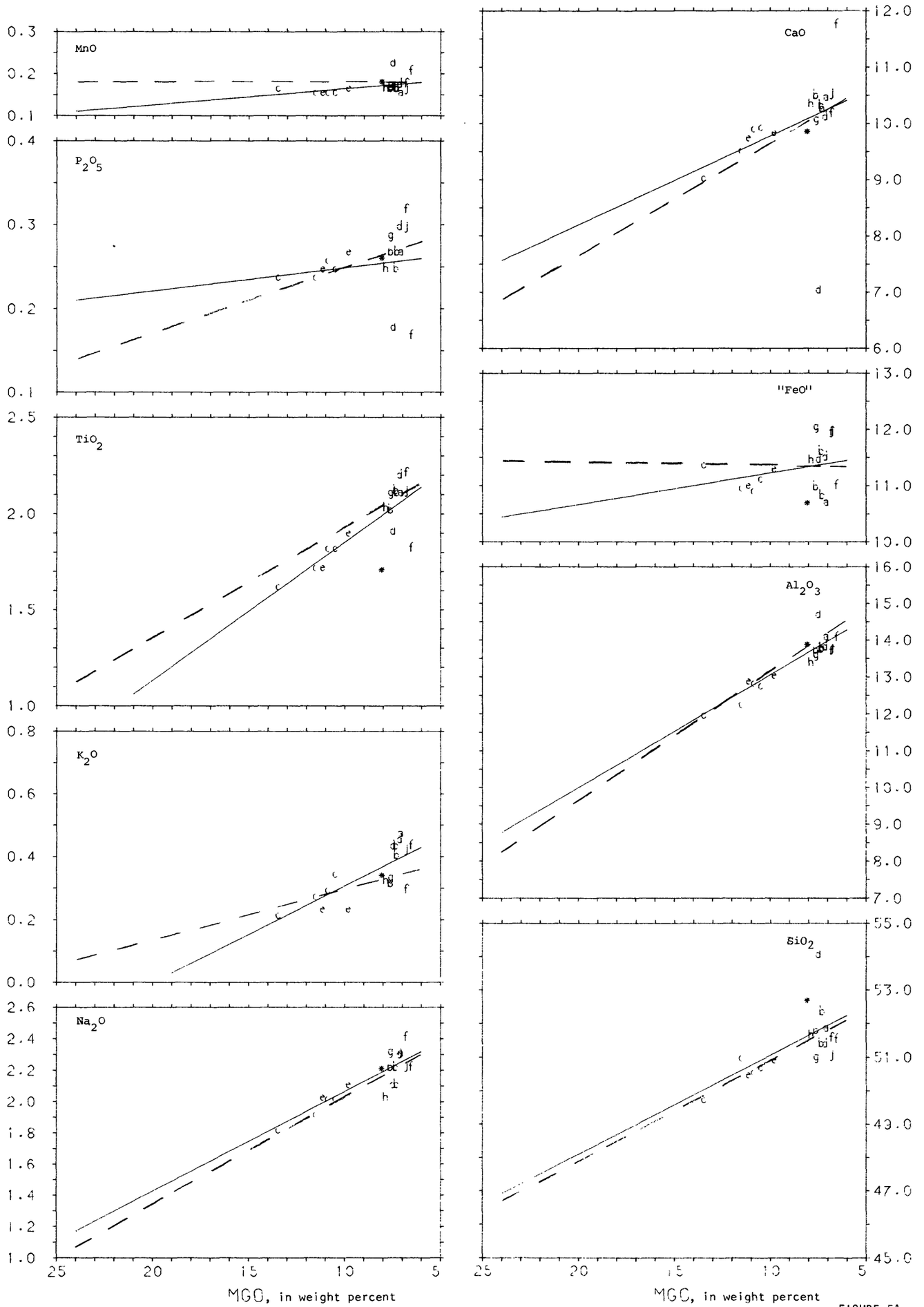

MnO
P_2O_5
TiO_2
K_2O
Na_2O
CaO
"FeO"
Al_2O_3
SiO_2
MGO, in weight percent
MGO, in weight percent

FIGURE 5A.

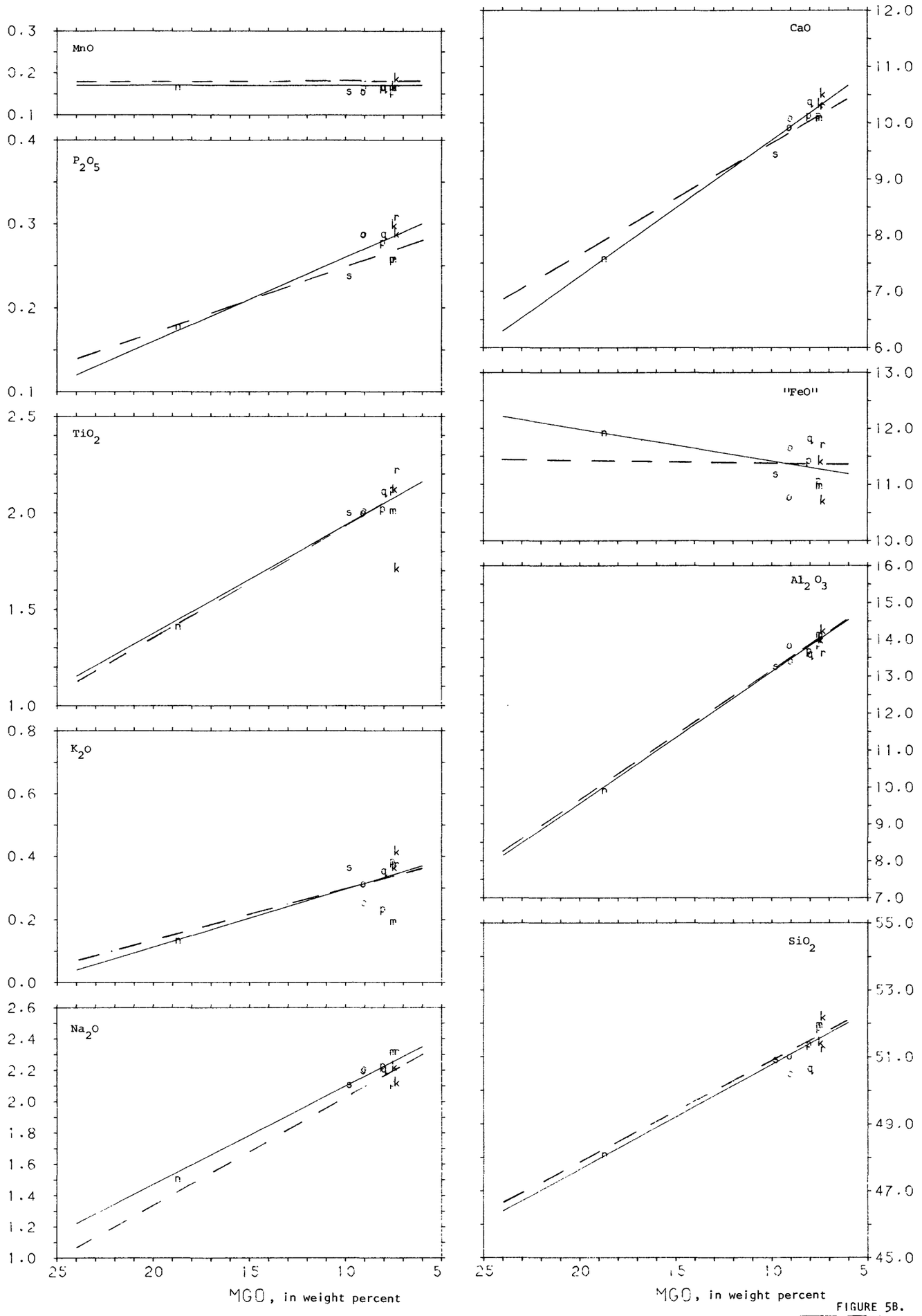

MnO
P_2O_5
TiO_2
K_2O
Na_2O
CaO
"FeO"
Al_2O_3
SiO_2
MGO, in weight percent
MGO, in weight percent

FIGURE 5B.

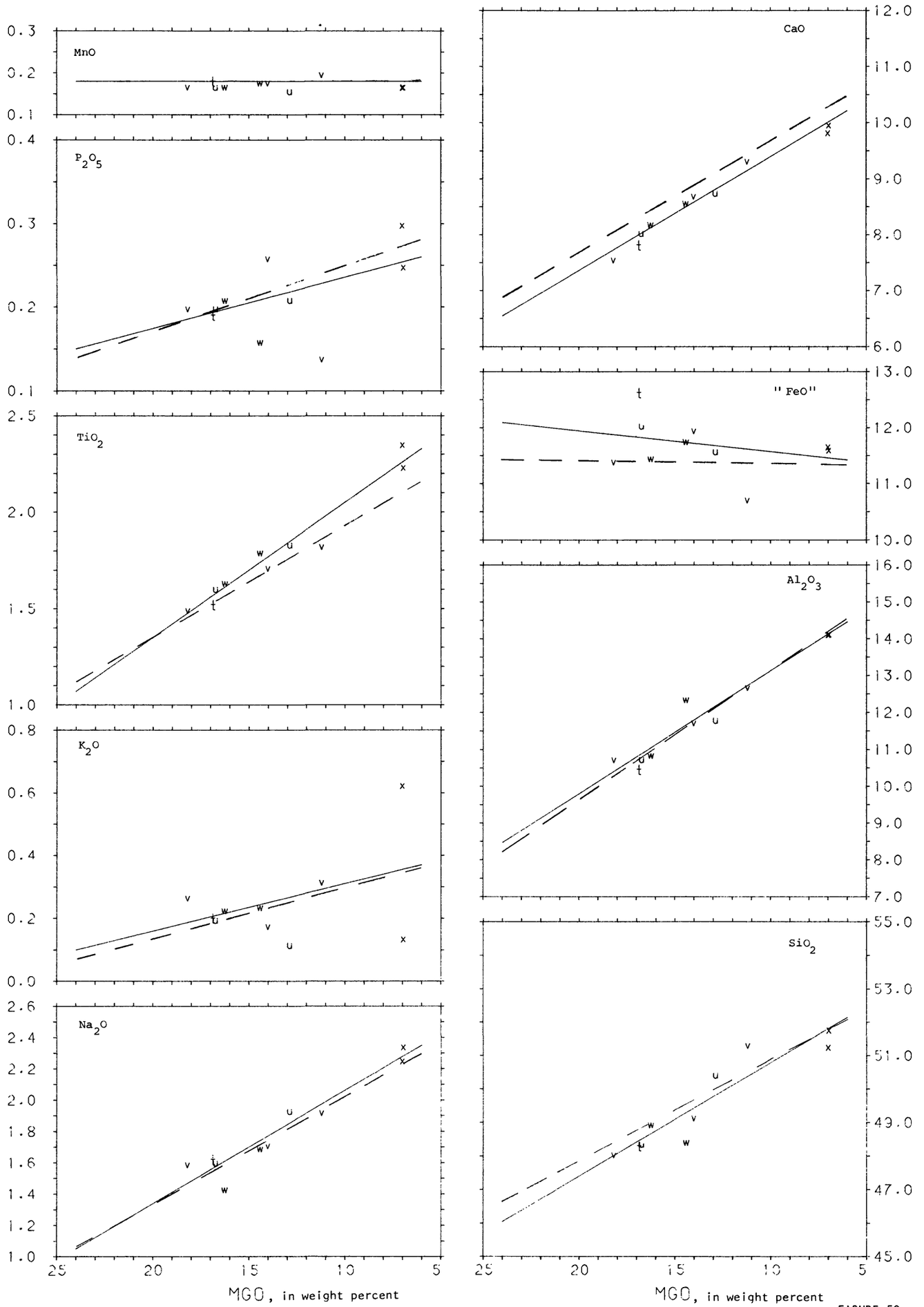

MnO
P_2O_5
TiO_2
K_2O
Na_2O
CaO
"FeO"
Al_2O_3
SiO_2
MGO, in weight percent
MGO, in weight percent

FIGURE 5C.

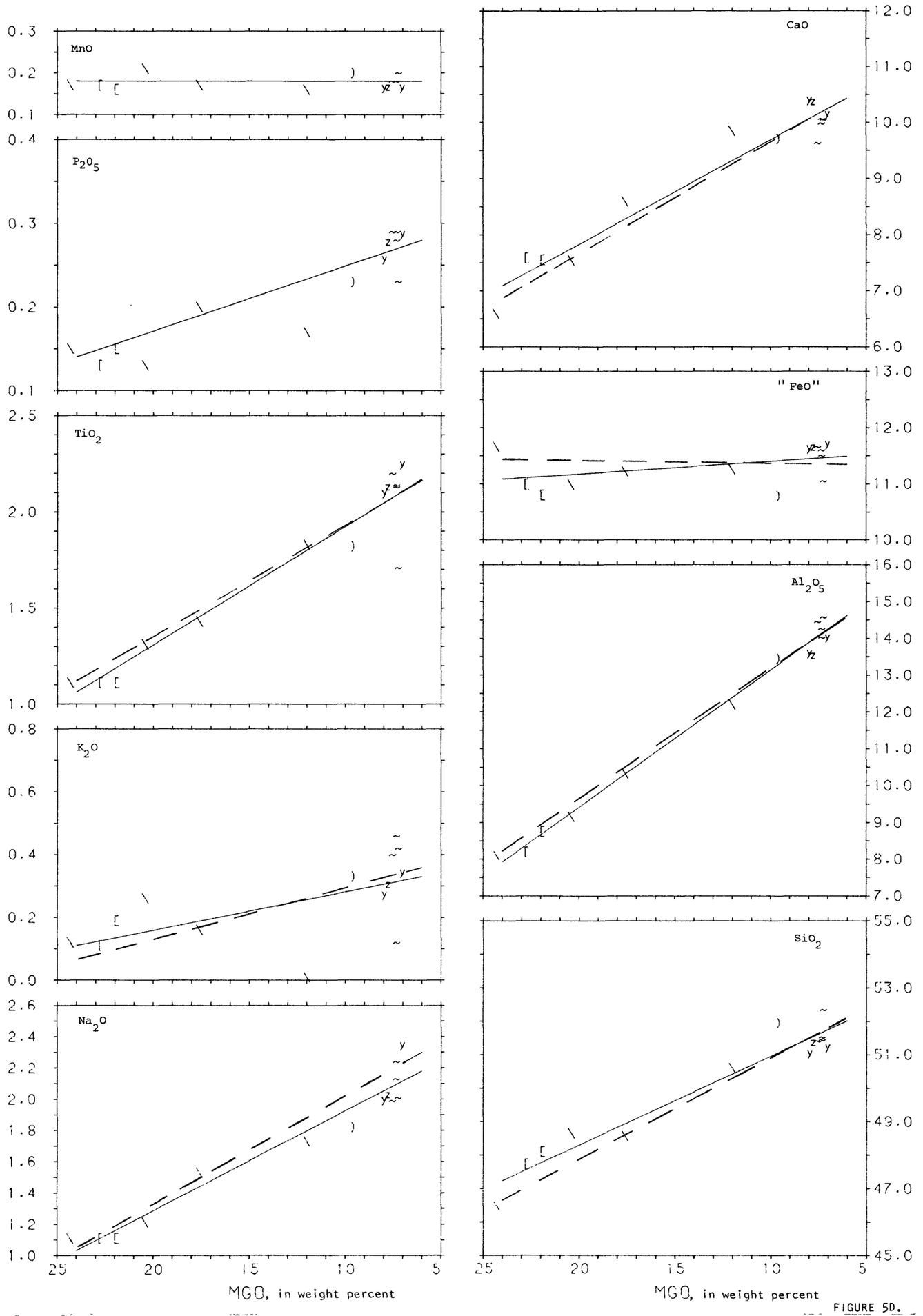
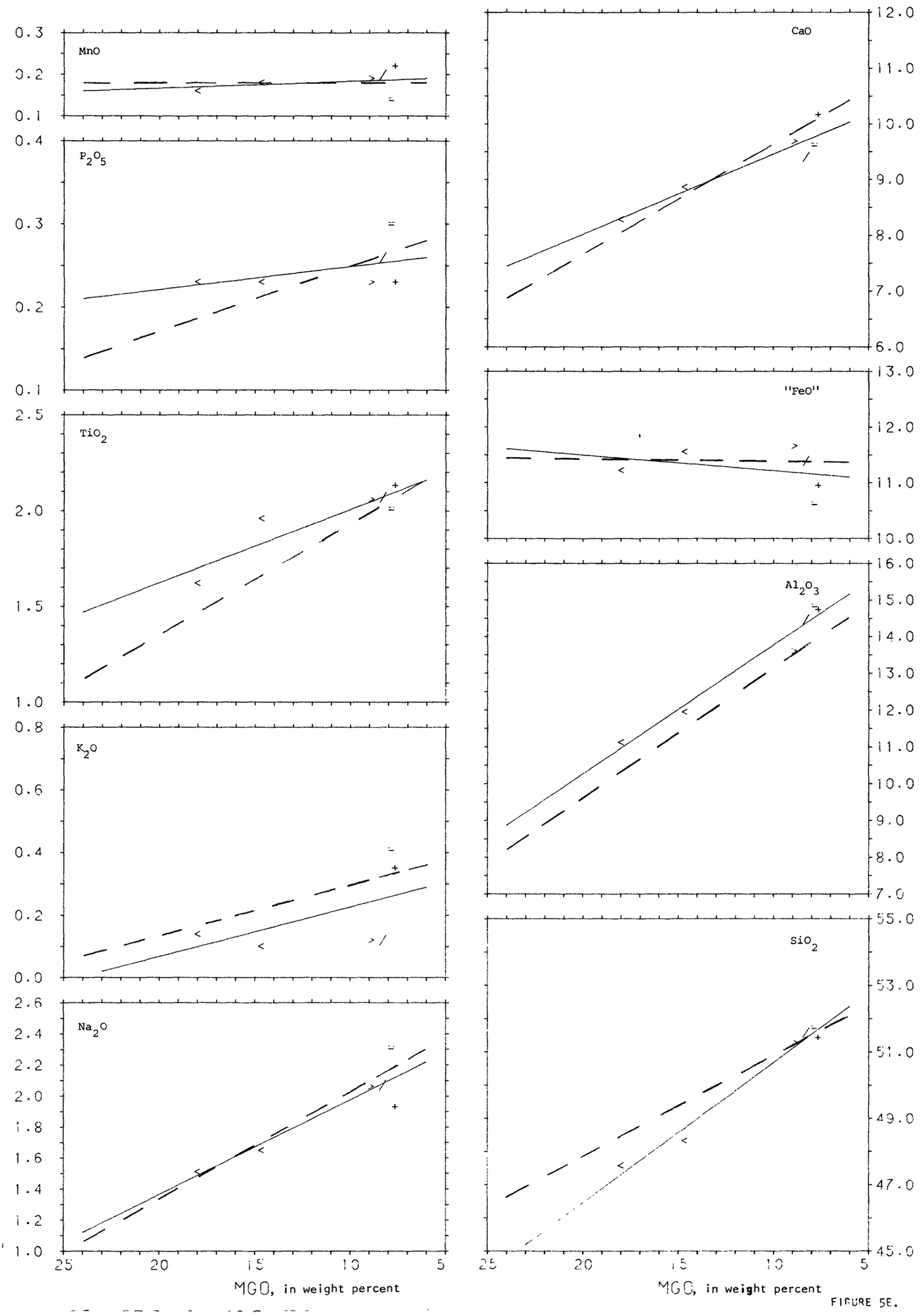

MnO
P_2O_5
TiO_2
K_2O
Na_2O
CaO
"FeO"
Al_2O_5
SiO_2
MGO, in weight percent
MGO, in weight percent

FIGURE 5D.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TiO_2
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CaO
"FeO"
Al_2O_3
SiO_2
MGO, in weight percent
MGO, in weight percent

FIGURE 5E.

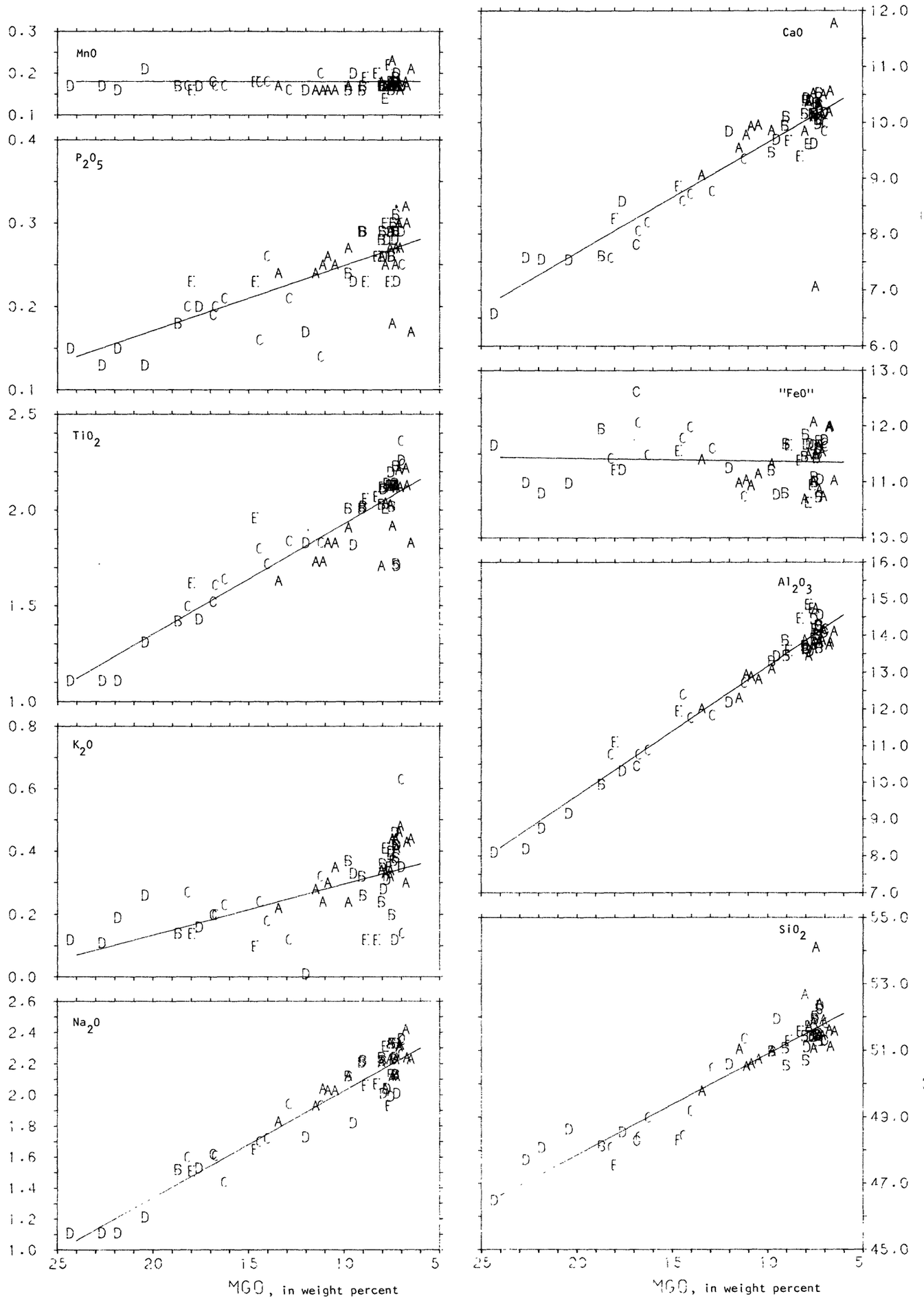

Figure 6. MgO variation diagrams and olivine control lines for Mauna Loa lava flows plotted with respect to age. Letter symbol refers to age groups defined in figure 5. Solid line, olivine control line for data from all Mauna Loa lava flows.

Table 1. Chemical analyses of lavas of prehistoric age from Kilauea and Mauna Kea volcanoes, Island of Hawaii

[Analyses performed at U.S.G.S., Reston, Va.; for analysts see Buchanan-Banks, in press, table 2]

Volcano	KILAUEA		MAUNA KEA							
Formation	Puna Basalt		Hamakua Volcanics							
Plot Symbol	o	0	1	2	3	4	5	6	7	8
Map No.[1]	C1	C2	C62	C63	C64	C65	C66	C67	C68	C69
Map Unit[2]	kipvt	kipvt	khpi	kh14	kh28	khkg	KH32	kh30	kh29	kh22
Sample No.[3]	M82-136	M82-136a	P79-100	W83-14	W81-28	W81-27	W81-32	W81-30	W81-29	H81-22
SiO2.....	51.40	50.20	44.20	47.10	45.00	45.10	44.10	43.60	45.60	40.70
Al2O3.....	14.00	13.50	14.20	14.20	15.10	15.80	14.60	14.60	14.70	13.30
Fe2O3.....	2.00	3.50	5.20	4.00	4.50	4.30	3.80	8.60	3.90	9.30
FeO.....	9.40	7.50	10.00	10.40	9.40	10.50	11.50	7.40	10.00	6.80
MgO.....	7.40	7.40	6.00	5.10	6.20	5.80	5.40	4.80	5.70	10.70
CaO.....	10.90	10.90	9.00	10.00	9.50	7.90	8.80	7.60	9.90	6.40
Na2O.....	2.20	2.20	2.10	2.70	2.50	2.60	2.30	2.00	2.70	1.50
K2O.....	0.40	0.10	0.76	0.69	0.80	0.89	0.57	0.81	0.84	0.56
H2O+.....	0.38	0.26	2.60	1.50	1.10	1.00	1.50	2.30	0.51	3.50
H2O-.....	0.27	0.10	0.25	0.95	0.67	0.53	1.00	2.20	0.26	2.00
TiO2.....	2.50	2.40	3.70	1.60	4.00	4.30	4.70	4.70	4.20	3.20
P2O5.....	0.28	0.25	0.51	0.46	0.40	0.49	0.48	0.50	0.43	0.48
MnO.....	0.15	0.16	0.22	0.17	0.20	0.20	0.21	0.21	0.20	0.22
CO2.....	0.02	0.01	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.03
Total	101.30	98.48	98.76	98.89	99.39	99.42	98.97	99.33	98.95	98.69
K2O:P2O5	1.43	0.40	1.49	1.50	2.00	1.82	1.19	1.62	1.95	1.17
Normalized Data:										
SiO2.....	51.08	51.17	46.09	48.85	46.11	46.08	45.72	45.98	46.45	43.69
Al2O3.....	13.91	13.76	14.81	14.73	15.47	16.14	15.14	15.40	14.97	14.28
'FeO'.....	11.13	10.86	15.31	14.52	13.78	14.68	15.47	15.97	13.76	16.28
MgO.....	7.35	7.54	6.26	5.29	6.35	5.93	5.60	5.06	5.81	11.49
CaO.....	10.83	11.11	9.39	10.37	9.73	8.07	9.12	8.02	10.08	6.87
Na2O.....	2.19	2.24	2.19	2.80	2.56	2.66	2.38	2.11	2.75	1.61
K2O.....	0.40	0.10	0.79	0.72	0.82	0.91	0.59	0.85	0.86	0.60
TiO2.....	2.48	2.45	3.86	1.66	4.10	4.39	4.87	4.96	4.28	3.43
P2O5.....	0.28	0.25	0.53	0.48	0.41	0.50	0.50	0.53	0.44	0.52
MnO.....	0.15	0.16	0.23	0.18	0.20	0.20	0.22	0.22	0.20	0.24
Total	99.80	99.64	99.46	99.60	99.53	99.56	99.61	99.10	99.60	99.01

[1] See Buchanan-Banks, in press, map sheet, for location of sample site.

[2] See Buchanan-Banks, in press, Description of Map Units for map-unit explanation.

[3] M, collected in Mountain View quadrangle; P, collected in Piihonua quadrangle; W, collected in Wailuku River, Hilo quadrangle.

Table 2. Chemical analyses of lavas from northeast rift zone of Mauna Loa volcano, Island of Hawaii

[Analyses performed at U.S.G.S., Reston, Va.; for analysts see Buchanan-Banks, in press, table 2]

Formation	Kau Basalt														
Symbol	*	a	b	b	b	c	c	c	c	d	d	e	e	f	f
Map No.[1]	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17
Map Unit[2]	lk21881	lk2ku	lk2kk	lk2kk	lk2kk	lk2pf4	lk2pf4	lk2pf4	lk2pf4	lk2pf3	lk2pf3	lk2pf2	lk2pf2	lk2pf1	lk2pf1
Sample No.[3]	H78-8	P84-30	H79-39	H79-125	H84-37	H82-116	H84-22	H84-22a	H84-22b	H81-37	H84-8	H80-46	H83-25	H79-76M	H84-24
SiO2.....	52.40	51.40	51.20	51.90	50.70	48.90	49.90	49.90	50.20	53.60	51.20	49.60	50.60	50.80	51.10
Al2O3.....	13.80	14.00	13.60	13.70	13.60	11.80	12.60	12.70	12.10	14.60	13.80	12.70	13.00	13.90	13.60
Fe2O3.....	1.70	2.70	2.30	2.40	2.30	2.00	2.30	2.10	2.90	2.10	4.10	1.60	2.50	1.30	2.40
FeO.....	9.10	8.20	8.80	8.60	9.40	9.40	8.90	8.90	8.20	9.50	7.80	9.40	9.00	9.70	9.70
MgO.....	8.00	7.00	7.50	7.20	7.20	13.20	10.30	10.70	11.30	7.40	7.10	10.90	9.70	6.40	6.70
CaO.....	9.80	10.40	10.40	10.20	10.20	8.90	9.80	9.80	9.40	7.00	10.10	9.60	9.80	11.60	10.10
Na2O.....	2.20	2.30	2.20	2.10	2.20	1.80	2.00	2.00	1.90	2.10	2.30	2.00	2.10	2.20	2.40
K2O.....	0.34	0.48	0.32	0.41	0.43	0.22	0.34	0.30	0.28	0.44	0.46	0.24	0.24	0.43	0.30
H2O+.....	0.26	0.20	0.11	0.37	0.53	0.39	0.35	0.52	0.50	0.40	0.11	0.28	0.24	0.43	0.47
H2O-.....	0.10	0.04	0.06	0.11	0.28	0.07	0.04	0.01	0.06	0.03	0.04	0.08	0.07	0.05	0.03
TiO2.....	1.70	2.10	2.00	2.10	2.10	1.60	1.80	1.80	1.70	1.90	2.20	1.70	1.90	1.80	2.20
P2O5.....	0.26	0.27	0.27	0.27	0.25	0.24	0.25	0.26	0.24	0.18	0.30	0.25	0.27	0.17	0.32
MnO.....	0.18	0.16	0.17	0.17	0.17	0.17	0.16	0.16	0.16	0.23	0.18	0.16	0.17	0.21	0.18
CO2.....	0.01	0.01	0.03	0.01	0.01	0.07	0.05	0.07	0.08	0.05	0.01	0.07	0.06	0.01	0.08
Total	99.84	99.26	98.96	99.54	99.37	98.76	98.79	99.22	99.02	99.53	99.70	98.58	99.65	98.99	99.58
K2O:P2O5	1.31	1.78	1.19	1.52	1.72	0.92	1.36	1.15	1.17	2.44	1.53	0.96	0.89	2.53	0.94
Normalized Data:															
SiO2.....	52.67	51.91	51.84	52.40	51.45	49.78	50.74	50.60	51.03	54.11	51.44	50.53	50.97	51.57	51.62
Al2O3.....	13.87	14.14	13.77	13.83	13.80	12.01	12.81	12.88	12.30	14.74	13.86	12.94	13.09	14.11	13.74
'FeO'.....	10.69	10.74	11.01	10.86	11.64	11.40	11.15	10.94	10.99	11.50	11.54	11.04	11.33	11.03	11.98
MgO.....	8.04	7.07	7.59	7.27	7.31	13.44	10.47	10.85	11.49	7.47	7.13	11.11	9.77	6.50	6.77
CaO.....	9.85	10.50	10.53	10.30	10.35	9.06	9.96	9.94	9.55	7.07	10.15	9.78	9.87	11.78	10.20
Na2O.....	2.21	2.32	2.23	2.12	2.23	1.83	2.03	2.03	1.93	2.12	2.31	2.04	2.12	2.23	2.42
K2O.....	0.34	0.48	0.32	0.41	0.44	0.22	0.35	0.30	0.28	0.44	0.46	0.24	0.24	0.44	0.30
TiO2.....	1.71	2.12	2.03	2.12	2.13	1.63	1.83	1.83	1.73	1.92	2.21	1.73	1.91	1.83	2.22
P2O5.....	0.26	0.27	0.27	0.27	0.25	0.24	0.25	0.26	0.24	0.18	0.30	0.25	0.27	0.17	0.32
MnO.....	0.18	0.16	0.17	0.17	0.17	0.17	0.16	0.16	0.16	0.23	0.18	0.16	0.17	0.21	0.18
Total	99.82	99.71	99.76	99.75	99.77	99.78	99.75	99.79	99.70	99.78	99.58	99.82	99.74	99.87	99.75

Table 2. Chemical analyses of lavas from northeast rift zone of Mauna Loa volcano, Island of Hawaii (continued)

Formation	Ka'u Basalt													
Symbol	g	h	j	k	k	m	n	o	o	p	p	q	r	s
Map no.[1]	C18	C19	C20	C21	C22	C23	C24	C25	C26	C27	C28	C29	C30	C31
Map Unit[2]	lk2mv	lk2ws	lk2ho	lk2pu	lk2pu	lk2wi	lk2ps	lk2ol	lk2ol	lk2ks	lk2ks	lk2wr	lk2ai	lk2ar
Sample No.[3]	M82-118a	H83-15	H79-124	H79-19	H79-55	H81-45	H82-132b	H82-128	H82-132c	H81-19a	H82-93	P82-65	P80-45	P80-106
SiO2.....	50.50	50.80	50.30	50.70	51.60	51.40	47.40	50.80	50.00	51.10	50.60	50.20	50.70	50.60
Al2O3.....	13.50	13.20	13.60	13.80	14.10	14.00	9.80	13.80	13.30	13.70	13.50	13.50	13.50	13.20
Fe2O3.....	2.50	3.10	4.90	1.40	2.00	2.30	2.30	2.60	2.50	2.90	2.30	2.70	2.90	3.70
FeO.....	9.70	8.50	7.40	10.00	8.80	8.80	9.70	8.40	9.30	8.30	9.20	9.30	9.00	7.80
MgO.....	7.50	7.70	6.60	7.30	7.20	7.40	18.40	9.00	8.90	7.40	7.90	7.90	7.20	9.70
CaO.....	10.00	10.20	10.40	10.20	10.40	10.00	7.50	9.90	10.00	10.00	10.00	10.30	10.20	9.40
Na2O.....	2.30	2.00	2.20	2.20	2.10	2.30	1.50	2.20	2.20	2.10	2.20	2.20	2.30	2.10
K2O.....	0.34	0.32	0.42	0.36	0.41	0.20	0.14	0.32	0.26	0.38	0.24	0.36	0.38	0.37
H2O+.....	0.43	0.46	0.39	0.70	0.48	0.53	0.46	0.66	0.37	0.40	0.37	0.18	0.21	0.39
H2O-.....	0.03	0.25	0.01	0.40	0.10	0.15	0.28	0.35	0.17	0.33	0.19	0.30	0.24	0.25
TiO2.....	2.10	2.00	2.10	2.10	1.70	2.00	1.40	2.00	2.00	2.10	2.00	2.10	2.20	2.00
P2O5.....	0.29	0.25	0.30	0.30	0.29	0.26	0.18	0.29	0.29	0.26	0.28	0.29	0.31	0.24
MnO.....	0.18	0.17	0.17	0.17	0.19	0.17	0.17	0.16	0.17	0.16	0.17	0.17	0.17	0.16
CO2.....	0.06	0.09	0.02	0.04	0.01	0.02	0.03	0.04	0.07	0.01	0.08	0.09	0.03	0.01
Total	99.43	99.04	98.81	99.67	99.37	99.53	99.26	100.52	99.53	99.14	99.03	99.59	99.34	99.92
K2O:P2O5	1.17	1.28	1.40	1.20	1.41	0.77	0.78	1.10	0.90	1.46	0.86	1.24	1.23	1.54
Normalized Data:														
SiO2.....	51.06	51.71	51.12	51.46	52.23	52.01	48.13	51.07	50.55	51.93	51.43	50.70	51.28	50.97
Al2O3.....	13.65	13.44	13.82	14.01	14.27	14.17	9.95	13.87	13.45	13.92	13.72	13.63	13.66	13.30
'FeO'.....	12.08	11.49	12.00	11.43	10.73	11.00	11.95	10.80	11.68	11.09	11.45	11.85	11.74	11.21
MgO.....	7.58	7.84	6.71	7.41	7.29	7.49	18.68	9.05	9.00	7.52	8.03	7.98	7.28	9.77
CaO.....	10.11	10.38	10.57	10.35	10.53	10.12	7.61	9.95	10.11	10.16	10.16	10.40	10.32	9.47
Na2O.....	2.33	2.04	2.24	2.23	2.13	2.33	1.52	2.21	2.22	2.13	2.24	2.22	2.33	2.12
K2O.....	0.34	0.33	0.43	0.37	0.42	0.20	0.14	0.32	0.26	0.39	0.24	0.36	0.38	0.37
TiO2.....	2.12	2.04	2.13	2.13	1.72	2.02	1.42	2.01	2.02	2.13	2.03	2.12	2.23	2.01
P2O5.....	0.29	0.25	0.30	0.30	0.29	0.26	0.18	0.29	0.29	0.26	0.28	0.29	0.31	0.24
MnO.....	0.18	0.17	0.17	0.17	0.19	0.17	0.17	0.16	0.17	0.16	0.17	0.17	0.17	0.16
Total	99.74	99.69	99.49	99.86	99.80	99.77	99.75	99.73	99.75	99.69	99.75	99.72	99.70	99.62

Table 2. Chemical analyses of lavas from northeast rift zone of Mauna Loa volcano, Island of Hawaii (continued)

Formation	Ka'u Basalt														
Symbol	t	u	u	v	v	v	w	w	x	x	y	y	z	)	\
Map No.[1]	C32	C33	C34	C35	C36	C37	C38	C39	C40	C41	C42	C43	C44	C45	C46
Map Unit[2]	lk2ad4	lk2ad3	lk2ad3	lk2ad2	lk2ad2	lk2ad2	lk2ad1	lk2ad1	lk2wh	lk2wh	lk2my	lk2my	lk2mo	lk2rf	lk2lr
Sample No.[3]	H79-133	H82-94	H82-92	H81-38	H79-16	H87-12	H82-44	H84-56	H80-13	H80-27a	P81-40	H82-78	H84-21	H80-6M	H80-28
SiO2.....	47.60	49.50	48.10	50.50	48.50	48.20	47.70	48.50	50.80	50.00	49.90	50.90	50.40	51.40	45.90
Al2O3.....	10.30	11.60	10.70	12.50	11.60	10.80	10.60	12.40	13.90	13.80	13.70	13.60	13.30	13.30	8.00
Fe2O3.....	2.60	2.20	2.20	2.40	2.90	2.50	5.20	3.10	3.00	3.10	2.70	3.80	2.50	2.30	1.90
FeO.....	10.10	9.40	10.00	8.40	9.20	9.20	6.50	9.00	8.70	8.60	9.00	8.20	9.20	8.60	9.80
MgO.....	16.60	12.60	16.60	11.00	13.80	18.20	15.80	14.40	6.80	6.80	6.80	7.90	7.60	9.40	24.00
CaO.....	7.70	8.60	8.00	9.20	8.60	7.60	8.00	8.60	9.80	9.60	9.90	10.40	10.20	9.60	6.50
Na2O.....	1.60	1.90	1.60	1.90	1.70	1.60	1.40	1.70	2.30	2.20	2.30	2.00	2.00	1.80	1.10
K2O.....	0.20	0.12	0.20	0.31	0.18	0.27	0.22	0.24	0.14	0.61	0.34	0.28	0.30	0.33	0.12
H2O+.....	0.25	0.74	0.41	0.53	0.20	0.38	0.66	0.59	0.65	0.83	0.51	0.59	0.48	0.48	0.61
H2O-.....	0.14	0.27	0.16	0.27	0.14	0.17	0.74	0.33	0.34	0.57	0.79	0.31	0.20	0.12	0.59
TiO2.....	1.50	1.80	1.60	1.80	1.70	1.50	1.60	1.80	2.20	2.30	2.20	2.10	2.10	1.80	1.10
P2O5.....	0.19	0.21	0.20	0.14	0.26	0.20	0.20	0.16	0.25	0.29	0.28	0.26	0.27	0.23	0.15
MnO.....	0.18	0.16	0.17	0.20	0.18	0.17	0.17	0.18	0.17	0.17	0.17	0.17	0.17	0.20	0.17
CO2.....	0.07	0.05	0.06	0.01	0.03	0.01	0.01	0.01	0.06	0.02	0.02	0.08	0.09	0.01	0.06
Total	99.03	99.15	100.00	99.15	98.99	101.01	98.80	101.01	99.11	98.89	98.61	100.59	98.81	99.56	100.00
K2O:P2O5	1.05	0.57	1.00	2.21	0.69	1.35	1.10	1.50	0.56	2.10	1.21	1.08	1.11	1.43	0.80
Normalized Data:															
SiO2.....	48.29	50.46	48.40	51.35	49.18	48.08	48.98	48.46	51.81	51.30	51.29	51.10	51.41	51.94	46.49
Al2O3.....	10.45	11.83	10.77	12.71	11.76	10.77	10.88	12.39	14.17	14.16	14.08	13.65	13.57	13.44	8.10
'FeO'.....	12.62	11.60	12.06	10.74	11.98	11.42	11.48	11.78	11.63	11.69	11.75	11.67	11.68	10.78	11.66
MgO.....	16.84	12.85	16.71	11.18	13.99	18.16	16.22	14.39	6.93	6.98	6.99	7.93	7.75	9.50	24.31
CaO.....	7.81	8.77	8.05	9.35	8.72	7.58	8.21	8.59	9.99	9.85	10.18	10.44	10.40	9.70	6.58
Na2O.....	1.62	1.94	1.61	1.93	1.72	1.60	1.44	1.70	2.35	2.26	2.36	2.01	2.04	1.82	1.11
K2O.....	0.20	0.12	0.20	0.32	0.18	0.27	0.23	0.24	0.14	0.63	0.35	0.28	0.31	0.33	0.12
TiO2.....	1.52	1.84	1.61	1.83	1.72	1.50	1.64	1.80	2.24	2.36	2.26	2.11	2.14	1.82	1.11
P2O5.....	0.19	0.21	0.20	0.14	0.26	0.20	0.21	0.16	0.25	0.30	0.29	0.26	0.28	0.23	0.15
MnO.....	0.18	0.16	0.17	0.20	0.18	0.17	0.17	0.18	0.17	0.17	0.17	0.17	0.17	0.20	0.17
Total	99.72	99.78	99.78	99.75	99.69	99.75	99.46	99.69	99.68	99.70	99.72	99.62	99.75	99.76	99.80

Table 2. Chemical analyses of lavas from northeast rift zone of Mauna Loa volcano, Island of Hawaii (continued)

Formation	Ka'u Basalt										Kahuku Basalt				
Symbol	\	\	\	[	[	~	~	~	~	=	<	<	+	>	/
Map No.[1]	C47	C48	C49	C50	C51	C52	C53	C54	C55	C56	C57	C58	C59	C60	C61
Map Unit[2]	lk2lr	lk2lr	lk2lr	lk2ka	lk2ka	lk2wa	lk2wa	lk2wa	lk2wa	lk1mp	lk1hc	lk1hf	lk1wy	lk1wo	lk1hr
Sample No.[3]	H80-30	H80-82	H84-33	H82-55a	H84-53	H80-37	H80-17	H81-12	H81-19	H80-40	H85-9	H81-19b	H80-100	H81-42	P81-41
SiO2.....	47.50	48.40	49.80	47.80	47.20	50.70	52.10	50.50	49.10	51.60	46.90	47.10	50.60	49.80	49.90
Al2O3.....	10.10	9.10	12.00	8.70	8.10	13.80	14.50	14.00	13.80	14.80	11.60	11.00	14.50	13.20	14.00
Fe2O3.....	2.20	1.70	2.30	2.60	2.30	3.80	2.00	4.10	2.60	2.00	5.80	1.90	2.30	2.80	1.80
FeO.....	9.00	9.40	9.00	8.40	8.80	7.90	9.20	7.70	8.80	8.80	6.00	9.40	8.70	8.80	9.40
MgO.....	17.20	20.30	11.80	21.70	22.40	7.20	7.20	7.20	7.20	7.80	14.20	17.80	7.50	8.60	8.00
CaO.....	8.40	7.50	9.70	7.50	7.50	9.90	10.00	9.80	9.20	9.60	8.60	8.20	10.00	9.40	9.10
Na2O.....	1.50	1.20	1.70	1.10	1.10	2.10	2.00	2.20	1.90	2.30	1.60	1.50	1.90	2.00	2.00
K2O.....	0.16	0.26	0.01	0.19	0.11	0.45	0.42	0.12	0.38	0.41	0.10	0.14	0.34	0.12	0.12
H2O+.....	0.53	0.28	0.63	0.35	0.57	0.97	0.94	0.57	1.70	1.00	1.10	0.60	1.30	1.30	1.60
H2O-.....	0.41	0.16	0.47	0.15	0.23	0.58	0.55	0.43	1.50	0.66	0.44	0.39	0.73	0.64	0.87
TiO2.....	1.40	1.30	1.80	1.10	1.10	2.10	1.70	2.10	2.10	2.00	1.90	1.60	2.10	2.00	2.00
P2O5.....	0.20	0.13	0.17	0.15	0.13	0.29	0.23	0.27	0.28	0.30	0.22	0.23	0.23	0.22	0.25
MnO.....	0.17	0.21	0.16	0.16	0.17	0.18	0.20	0.18	0.17	0.14	0.17	0.16	0.22	0.18	0.19
CO2.....	0.08	0.08	0.01	0.01	0.01	0.01	0.04	0.04	0.03	0.06	0.01	0.01	0.02	0.06	0.03
Total	98.85	100.02	99.55	99.91	99.72	99.98	101.08	99.21	98.76	101.47	98.64	100.03	100.44	99.12	99.26
K2O:P2O5	0.80	2.00	0.06	1.27	0.85	1.55	1.83	0.44	1.36	1.37	0.45	0.61	1.48	0.55	0.48
Normalized Data:															
SiO2.....	48.55	48.64	50.59	48.09	47.72	51.51	52.34	51.44	51.40	51.73	48.31	47.56	51.43	51.28	51.57
Al2O3.....	10.32	9.15	12.19	8.75	8.19	14.02	14.57	14.26	14.45	14.84	11.95	11.11	14.74	13.59	14.47
'FeO'.....	11.22	10.98	11.25	10.80	10.99	11.50	11.05	11.60	11.66	10.63	11.56	11.22	10.95	11.66	11.39
MgO.....	17.58	20.40	11.99	21.83	22.65	7.32	7.23	7.33	7.54	7.82	14.63	17.97	7.62	8.86	8.27
CaO.....	8.59	7.54	9.85	7.55	7.58	10.06	10.05	9.98	9.63	9.62	8.86	8.28	10.16	9.68	9.40
Na2O.....	1.53	1.21	1.73	1.11	1.11	2.13	2.01	2.24	1.99	2.31	1.65	1.51	1.93	2.06	2.07
K2O.....	0.16	0.26	0.01	0.19	0.11	0.46	0.42	0.12	0.40	0.41	0.10	0.14	0.35	0.12	0.12
TiO2.....	1.43	1.31	1.83	1.11	1.11	2.13	1.71	2.14	2.20	2.01	1.96	1.62	2.13	2.06	2.07
P2O5.....	0.20	0.13	0.17	0.15	0.13	0.29	0.23	0.28	0.29	0.30	0.23	0.23	0.23	0.23	0.26
MnO.....	0.17	0.21	0.16	0.16	0.17	0.18	0.20	0.18	0.18	0.14	0.18	0.16	0.22	0.19	0.20
Total	99.75	99.83	99.77	99.74	99.76	99.60	99.81	99.57	99.74	99.81	99.43	99.80	99.76	99.73	99.82

Table 2. Chemical analyses of lavas from northeast rift zone of Mauna Loa volcano, Island of Hawaii (continued)

1
See Buchanan-Banks, in press, map sheet, for location of sample site.
2
See Buchanan-Banks, in press, Description of Map Units for map-unit explanation.
3
H, collected in Hilo quadrangle; P, collected in Piihonua quadrangle; M, collected in Mountian View quadrangle.

Table 3.--Coefficient for computation of olivine control lines

[Coefficients for equation of form y = ax + b, where y is major oxide or element, x is MgO content, a is slope, and b is y intercept value at MgO=0 weight percent; uncertainty is one standard deviation either side of mean slope]

	x (MgO mean, and range in parentheses)	y Element	a	b
Mauna Kea flows	7.75 (4.8-10.7)	SiO2	-0.500 +/-0.026	49.358
		Al2O3	- .153 +/- .130	16.106
		FeO	.209 +/- .234	13.620
		CaO	- .379 +/- .253	11.408
		Na2O	- .145 +/- .074	3.319
		K2O	- .030 +/- .029	.960
		TiO2	- .086 +/- .288	4.500
		P2O5	.004 +/- .012	.462
		MnO	.006 +/- .004	.174
Mauna Loa and Kilauea flows	15.2 (6.4-24.0)	SiO2	-0.303 +/-0.024	53.916
		Al2O3	- .352 +/- .014	16.669
		FeO	.005 +/- .017	11.323
		CaO	- .198 +/- .021	11.622
		Na2O	- .069 +/- .004	2.713
		K2O	- .016 +/- .004	.458
		TiO2	- .058 +/- .005	2.507
		P2O5	- .008 +/- .001	.328
		MnO	.0 +/- .001	.180
Mauna Loa flows	15.2 (6.4-24.0)	SiO2	-0.303 +/-0.024	53.916
		Al2O4	- .352 +/- .014	16.669
		FeO	- .005 +/- .017	11.323
		CaO	- .198 +/- .021	11.622
		Na2O	- .069 +/- .004	2.713
		K2O	- .016 +/- .004	.458
		TiO2	- .058 +/- .005	2.507
		P2O5	- .008 +/- .001	.328
		MnO	- .0 +/- .001	.180
Mauna Loa flows 0.1 to about 2.0 Ka	9.8 (6.4-13.2)	SiO2	-0.296 +/-0.127	54.015
		Al2O3	- .306 +/- .048	16.117
		FeO	- .056 +/- .072	11.781
		CaO	- .158 +/- .147	11.356
		Na2O	- .064 +/- .014	2.702
		K2O	- .031 +/- .009	.616
		TiO2	- .072 +/- .021	2.571
		P2O5	- .003 +/- .006	.282
		MnO	- .004 +/- .003	.208
Mauna Loa flows from about 3.0 to 8.0 Ka	12.8 (7.2-18.4)	SiO2	-0.313 +/-0.058	53.901
		Al2O3	- .356 +/- .032	16.670
		FeO	.057 +/- .054	10.840
		CaO	- .243 +/- .022	12.122
		Na2O	- .063 +/- .010	2.727
		K2O	- .018 +/- .010	.474
		TiO2	- .056 +/- .019	2.491
		P2O5	- .010 +/- .003	.358
		MnO	.0 +/- .001	.171
Mauna Loa flows from about 9.0 to 10.0 Ka	12.5 (6.8-18.2)	SiO2	-0.339 +/-0.066	54.175
		Al2O3	- .333 +/- .041	16.453
		FeO	.037 +/- .058	11.178
		CaO	- .204 +/- .017	11.436
		Na2O	- .072 +/- .011	2.778
		K2O	- .015 +/- .017	.456
		TiO2	- .070 +/- .008	2.749
		P2O5	- .006 +/- .005	.292
		MnO	.0 +/- .001	.176
Mauna Loa flows from about 10.0 to 14.0 Ka	15.4 (6.8-24.0)	SiO2	-0.266 +/-0.027	53.609
		Al2O3	- .372 +/- .015	16.848
		FeO	- .023 +/- .019	11.628
		CaO	- .186 +/- .019	11.547
		Na2O	- .064 +/- .006	2.564
		K2O	- .012 +/- .007	.402
		TiO2	- .062 +/- .008	2.546
		P2O5	- .008 +/- .002	.329
		MnO	.0 +/- .001	.182
Mauna Loa flows greater than 14.0 Ka	12.65 (7.5-17.8)	SiO2	-0.423 +/-0.043	54.904
		Al2O3	- .353 +/- .052	17.285
		FeO	.028 +/- .060	10.935
		CaO	- .144 +/- .037	10.895
		Na2O	- .061 +/- .020	2.586
		K2O	- .016 +/- .019	.385
		TiO2	.038 +/- .013	2.386
		P2O5	- .003 +/- .004	.280
		MnO	- .002 +/- .004	.207