THE ORIGIN OF THE TICHKA PLUTONIC MASSIF, MOROCCO

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by

John Kantz Preston

Abstract

The Tichka Massif is a small (23 by 13 km) shallowly emplaced, domal intrusion which has produced a thermal aureole in the surrounding rocks. Steep walled drainages in the interior of the massif expose a series of relatively small (maximum length 400 m) tear-drop shaped granitic pods surrounded by a well-foliated, heterogeneous assemblage of primarily dioritic rocks, ranging in composition from gabbro to granodiorite. The pods have a strong vertical component to their orientation. At the margin of the massif, abundant granitic occurs at the contact with the metasediments. Field observations indicate that the dioritic and granitic rocks had overlapping crystallization histories and that the granitic magmas coexisted with the dioritic magmas.

In this study, two models for the origin of the Tichka Massif are evaluated: 1) The rock types in the massif are related by differentiation to a common parental material, or; 2) the granitic and dioritic magmas have an independent origin. On the basis of the field relationships, major element geochemistry and mineralogic data, and using Chayes (1968) least squares approximation test, a differentiation model is rejected.

A model is proposed that involves the intrusion of a differentiation, mantle-derived magma into the lower crust which produces a granitic magma by fractional fusion. Subsequently, the granitic magma is incorporated by the intruding dioritic magma in the form of pods. Mixing is prevented by the viscosity differences between the granitic and dioritic liquids, the low diffusion rates in granitic magmas, and flowage of the dioritic magma around the granitic pods. During emplacement, assimilation of andesitic volcanics by the dioritic magma, and differentiation during flowage, produces the varying dioritic compositions.

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INTRODUCTION

The Tichka Massif is one of a series of Late-Paleozoic (Hercynian) plutonic massifs occurring throughout northwestern Africa (Figure 1). Typically, these massifs are small (generally less than 200 km^2), shallowly emplaced, and composed of composite igneous rocks. All possess a thermal aureole and range in age from 240 - 320 m.y. (Morin, 1971; Choubert, et al., 1965; Vandeven, 1969; Termier and Termier, 1971a; Termier and Termier, 1971b; Termier, et al., 1972). With the exception of the Tichka Massif, the massifs are very poorly exposed.

Located approximately 100 km south of Marrakech, Morocco, the Tichka Massif forms a domal intrusion which has uplifted and thermally metamorphosed the overlying Paleozoic sedments. It has an oval shaped outcrop approximately 23 km long and 13 km wide, with a total relief of about 2 km. Steep walled drainages dissect the massif, affording a spectacular three-dimensional view of the lithologic relationships.

In the center of the massif, these drainages expose a series of granitic pods surrounded by a heterogeneous assemblage of more mafic rocks; predominately dioritic in composition. Abundant granite occurs along the margins of the massif, underlying the uplifted sediments. At the top of

Figure 1 Generalized geologic map of the southern two-thirds of Morocco showing the location of the Late-Paleozoic igneous massifs. Massif Number 8 (and inset) is the Tichka Massif.

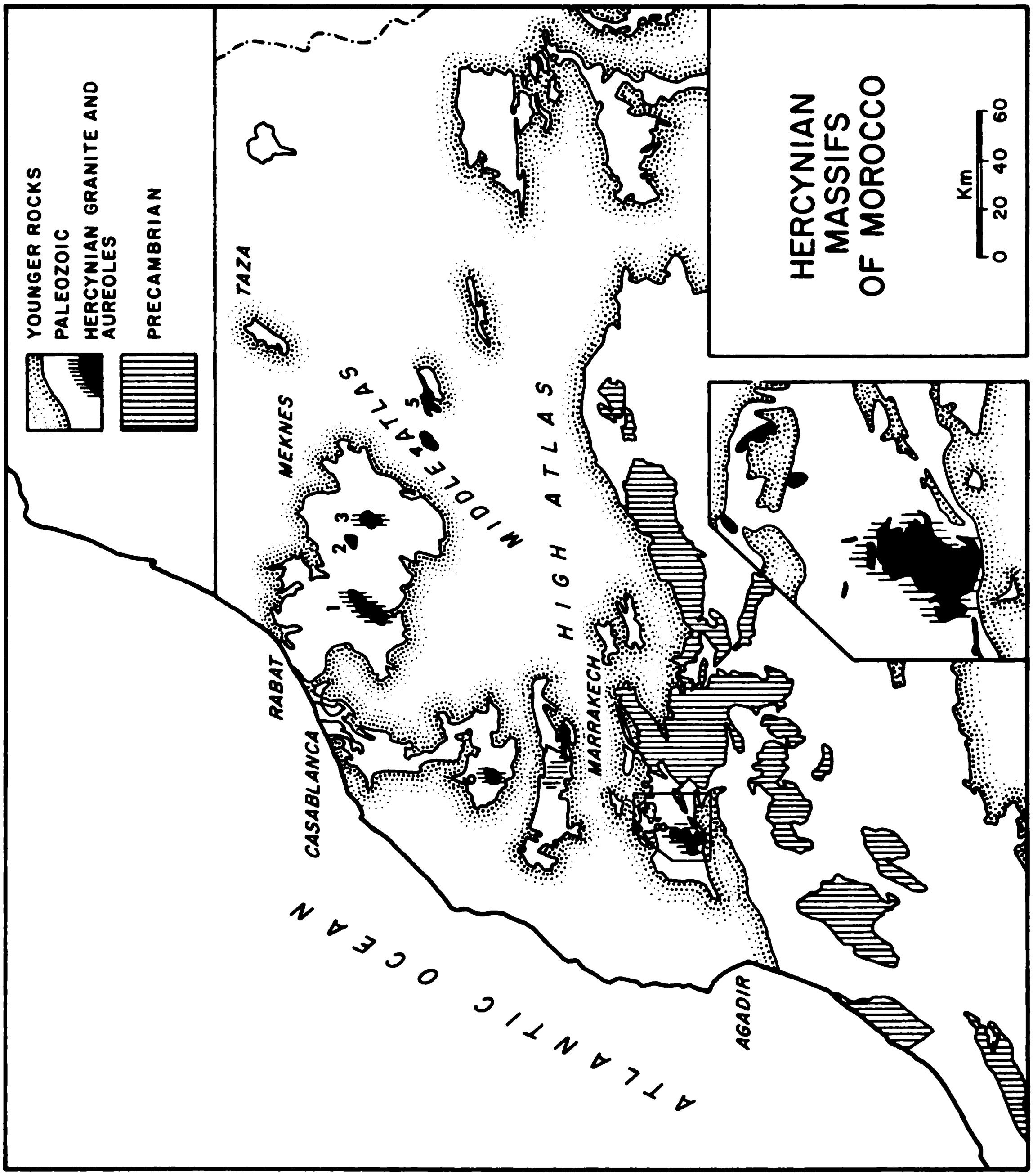

HERCYNIAN MASSIFS OF MOROCCO
Km
0 20 40 60
YOUNGER ROCKS
PALEOZOIC
HERCYNIAN GRANITE AND AUREOLES
PRECAMBRIAN
TAZA
MEKNES
MIDDLE ATLAS
HIGH ATLAS
RABAT
CASABLANCA
MARRAKECH
AGADIR
ATLANTIC OCEAN
1
2
3
4
5

Figure 1

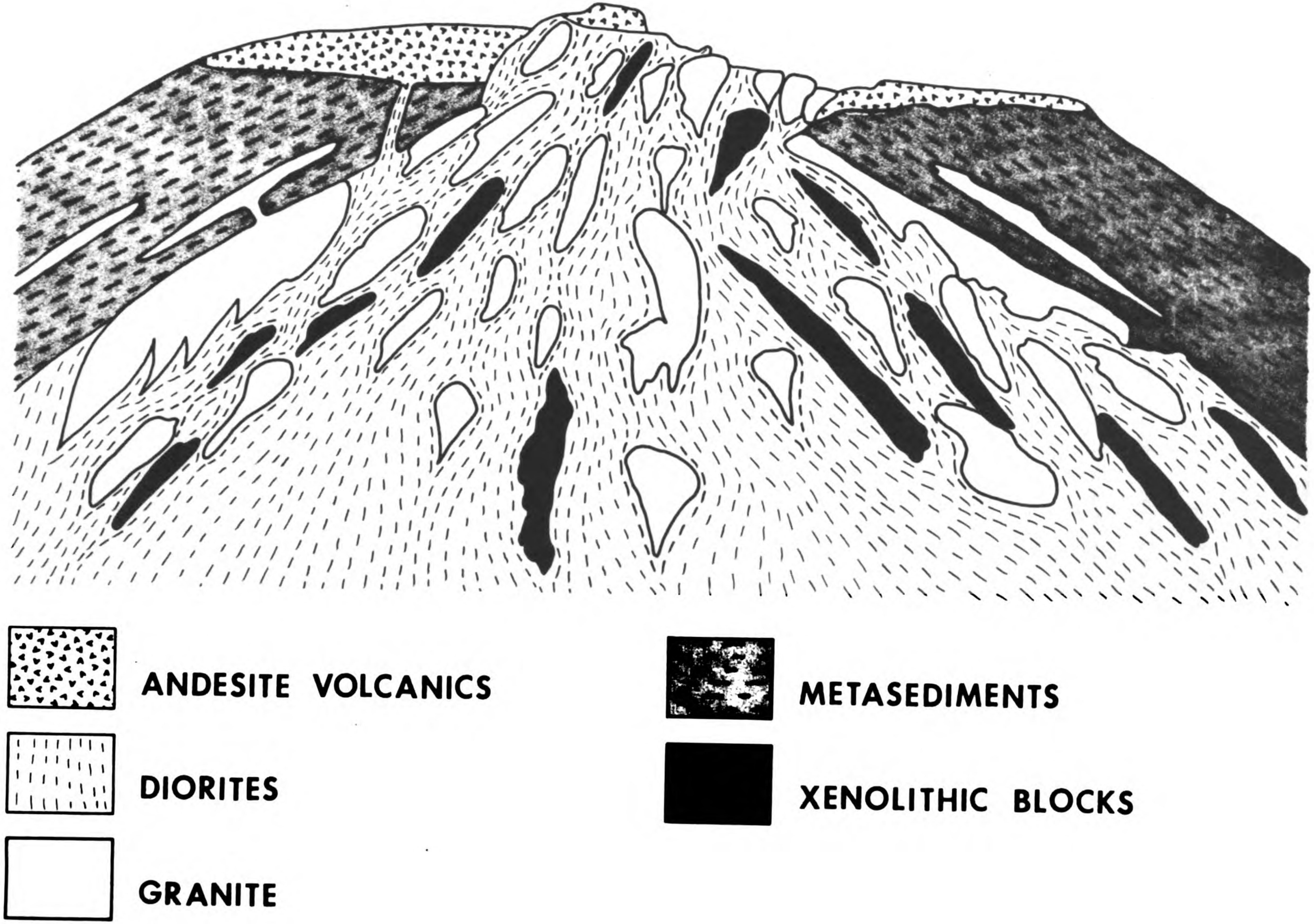
the massif, vesicular andesitic volcanics occur.

Field relationships of the Tichka Massif have been studied in detail by Vogel and Walker (1975). On the basis of these relationships they concluded that the granitic and dioritic magmas coexisted simultaneously. In their emplacement model, the viscous granite pods moved upwards through a heterogeneous assemblage of dioritic material. Near the roof of the massif, larger masses of granite coalesced and were entrapped by supercrustal sediments. Figure 2 is a general sketch of a cross-section at the Tichka Massif based on Vogel and Walker's (1975) study.

The purpose of this study is to evaluate models for the origin of the rock types found in the Tichka Massif. Based on the field relationship, two basic models can be proposed: 1) The rock types of the massif are related to a common parent by fractional melting and/or fractional crystallization, or by imiscible liquid relationship, or; 2) the dioritic and granitic rocks represent independent magma types.

In order to test the validity of these models, it is necessary to determine the mineralogical and chemical variations within the Tichka Massif and to relate these variations to the observed field relationships. Chayes (1968) has developed a least squares approximation method to test

Figure 2   Generalized cross-section of the Tichka Massif.


ANDESITE VOLCANICS
DIORITES
GRANITE
METASEDIMENTS
XENOLITHIC BLOCKS

various petrogenetic hypotheses. The advantage of this method is that all available chemical data are used to test these models in an unambiguous manner.

The work by Presnall (1968) and Presnall and Bateman (1973) can be used to evaluate partial fusion models for the generation of the rock types found in the Tichka Massif.

LITHOLOGIC RELATIONSHIPS

Granitic Pods

The single most important feature of the massif is the ubiquitious occurrence of the granitic pods, which range in composition from leuco-granite to biotite quartz monzonite. These pods are characterized by a tear-drop shape and typically have a strong vertical component to their orientation. Length of the pods varies from 10 m up to 400 m, with the width 1/3 to 1/2 the length. Frequently, the pods are grouped together and appear to be aligned along zones in the massif (see Vogel and Walker, 1975, Figure 1).

Surrounding the granitic pods is a heterogeneous assemblage of rocks that range in composition from olivine gabbro to granodiorite, with the dioritic rocks dominating. In all cases, the contact relationships between these surrounding rocks and the granitic pods are sharply defined. Occasionally, where the quartz diorites are in contact with the granitic pods, they are penetrated by apophyses of granite.

Massif Margins

Granite also occurs extensively along the margins of the massif, forming an envelope of granite around the massif and under the uplifted Paleozoic sediments (primarily metasandstones and carbonates) (Figure 2). This granite at the massif margin is interpreted to be pods which have coalesced during emplacement of the massif.

Dioritic Rocks

The two most abundant rock types that surround the granitic pods are; a mafic hornblende diorite (an average of 55 % plagioclase, 44 % mafics, and 1 % quartz) and a quartz diorite (an average of 59 % plagioclase, 27 % mafics, 7 % microcline, and 7 % quartz). Although both of these rocks are diorites, they are quite distinctive in the field. The mafic diorite is a very dark rock, while the quartz diorite is much lighter in color due to lesser amount of mafics it contains. Also included in this heterogeneous igneous assemblage are small amounts of granodiorite and olivine gabbro.

Extreme heterogeneity, which occurs on a hand sample scale, is the most characteristic feature of the quartz diorites. These rocks have a well-developed flow foliation produced by compositional layering of biotite and hornblende. The foliation is, without exception, parallel to the granitic pods (Vogel and Walker, 1975). In contrast, foliation in the pods is generally absent or is at best not obvious.

Part of the compositional heterogeneity in the quartz diorites is the result of the partial assimilation of pre-existing rocks primarily andesitic volcanics and metasediments. Part is due to differentiation during flow. This results in a layered appearance, with fine-grained layers set in a coarser-grained quartz dioritic matrix. The net effect in these quartz dioritic rocks is to yield a complex, well-foliated rock; some of the heterogeneity is due to interaction with pre-existing rocks and some due to differentiation during flowage.

The heterogeneity and well-developed flow foliation in the quartz diorites is also found in the granodiorites. These rocks are lighter colored and coarser-grained than the quartz diorites. It is possible that the granodiorites are marginal phases of the pods, but contact relationships between the two are generally sharply defined (Vogel and Walker, 1975), except at the distal end of the tails of the pods.

The mafic diorite is a much darker, finer-grained, and more homogeneous rock than the quartz diorites or the granodiorites. It is always highly veined by intersecting quartz--albite stringers (Vogel and Walker, 1975). Crystal lined vugs are common in these veins, which are confined to the mafic diorite.

Summary of Lithologic Relationships

Vogel and Walker (1975) summarized the most important lithologic relations in the Tichka Massif as follows:

1. The ubiquitous occurrance of tear-drop shaped granitic pods surrounded by dioritic rocks, indicating that the granitic pods were emplaced diapirically.
2. Apophyses from the granitic pods locally interfingering with the surrounding dioritic rocks, indicating that the granite-diorite contact in these places was a liquid-solid relationshp.
3. The mafic diorite-quartz contact relations, indicating that they had overlapping crystallization histories.
4. Flow foliation in the diorite parallel to the granite pods and lack of foliation in the granite pods, indicating that most of the penetrative deformation (flowage) occurred in the dioritic material.
5. Andesite dikes crosscutting the granite pods and emanating from the diorite, demonstrating that in these occurrences the diorite was liquid.

6. The occurrance of quartz-albite veins confined to the more mafic diorite suggests that the mafic diorite magma was saturated with water.

EMPLACEMENT MODEL

The following emplacement model is summarized from Vogel and Walker (1975). The Tichka Massif provides clear-cut evidence of the simultaneous existance of granitic and dioritic magmas. As is demonstrated by the sharply defined granite-diorite boundaries, mixing of these two magmas did not occur. This is attributed to viscosity differences between the magmas as well as the relatively low diffusion rates in granitic magmas.

Field evidence indicates that the overall motion of the magmas with respect to the wall rocks was vertical. However, the relative motion of the dioritic magma with respect to the granitic magma was downward. The granitic pods were rising through the dioritic magma as "tear-drop shaped" diaperic pods similar to Ramberg's (1970) laboratory models. Ramberg (1970, p. 262 and p. 276) has shown that diaperic emplacement can only occur when the viscosity difference between the two materials is within a few orders of magnitude (i.e., solid-solid or liquid-liquid; not solid-liquid).

The shapes of the granitic pods are further indications of liquid-liquid relationships.

The viscous granite pods moved upward, surrounded by a heterogeneous assemblage of lower viscosity dioritic rocks in which most of the relative motion occurred. The granite mass at the margin of the massif are interpreted to be granite pods that coalesced near the roof of the massif. Diaperic emplacement of the pods ceased when the diorites crystallized, freezing the shpaes of the granitic pods.

PETROGRAPHY OF ROCK TYPES

Granitic Pods

The granitic pods can be devided into two populations; light pink leucogranites and darker, more mafic, biotite quartz monzonites. No systematic study has been done on the relationship between pod composition to location or size of pod.

The modes for the leucogranites are shown in Table 1. Plagiocalse is subhedral, well twinned or zoned, and slightly altered to sericite. Phenocrysts are rare and well-zoned. The quartz is interstitial and occasionally contains small apatite needles and magnetite. Microcline is interstitial and often contains plagioclase crystals. Myrmekites are ubiquitous. The small amount of biotite present is brown to green, and is often slightly altered to chlorite, magnetite, and hematite.

In comparison to the leucogranites, the quartz monzonites are compositionally (Table 1) and texturally heterogeneous. In the quartz monzonites the plagioclase is subhedral, well twinned, moderately sericitized, and occasionally contains apatite needles and biotite. Well-zoned phenocrysts are abundant. Quartz is interstitial and often

TABLE I

Modes - Pods and Margins

	(1)	(2)	(3)	(4)
AV. Pl %	26.0	43.0	34.5	22.5
s.e.	1.4	2.9	3.3	3.5
AV. An %	26.8	32.0	29.4	25.0
s.e.	2.9	1.8	1.8	1.1
AV. Q %	38.6	26.7	32.7	37.7
s.e.	1.6	3.4	2.8	0.9
AV. Kf %	33.7	18.8	26.3	36.2
s.e.	1.1	3.8	2.9	3.1
AV. Hbl %	TR	1.2	0.6	TR
s.e.	--	0.4	0.4	--
AV. Biot %	0.9	9.3	5.1	2.8
s.e.	0.3	1.8	1.5	0.6
AV. Chl %	TR	0.4	0.2	0.8
s.e.	--	0.3	0.2	0.3
AV. Mag %	TR	0.6	0.3	TR
s.e.	--	0.5	0.2	--

(1) Leucogranite pods, 4 samples

(2) Biotite Quartz Monzanite pods, 4 samples

(3) Total pods, 8 samples

(4) Granite Margins, 7 samples (Williams, in prep.)

s.e. = standard error

contain apatite needles and magnetite. Microcline is interstitial and frequently contains plagioclase crystals. Myrmekites are slightly less abundant than in the leucogranits. The biotite is light brown to green, and tends to form clusters with very faint alignment. Small amounts of epidote and highly corroded green hornblende are also present. Chlorite, magnetite, and hemitite are common alteration products of biotite and hornblende.

Dioritic Rocks

The heterogeneity present in the granodiorites and quartz diorites in the field is further reflected on a microscopic scale. Large compositional and textural variations can be observed between thin sections cut from the same hand sample and, even within a single thin section.

The granodiorite is slightly darker and fine-grained than the granitic pods. Modes are shown in Table 2. The groundmass plagioclase is typically subhedral and is occasionally surrounded by an anhedral albite rim. Plagioclase are commonly well-zoned and often contain apatite, and are moderately to heavily sericitized. Quartz is interstitial and often contains apatite needles. Microcline frequently is interstitial and frequently includes plagioclase. Myrmekites are common. The biotite is light to dark brown, and very rarely, occurs as phenocrysts. Hornblende is green, occasionally bleached, euhedral to subhedral, and forms in clots with biotite. These clots often show a strong alignment. Chlorite and magnetite are common alteration products of the biotite and hornblende. Small amounts of hematite and epidote are also present.

The quartz diorite is generally a medium-grained, light grey to grey rock. Large (2-3 cm) quartz and plagioclase phenocrysts are invariably surrounded by biotite and hornblende. The plagioclase phenocrysts are highly sericitized and zoned both compositionally and by inclusion of opaques. On a hand sample scale, these phenocrysts form "bands" up to 16 cm long and 3 cm wide. Most of the microcline in the quartz diorites is found in the vicinity of these "bands".

Modes of the quartz diorite are given in Table 2. Plagioclase is subhedral and anhedral, often highly corroded, and occasionally has anhedral albite rims. Quartz is interstitial. Needles of apatite are common in both quartz and plagioclase. Biotite is green to brown, and forms strongly aligned clusters with green, euhedral and subhedral, hornblende. Chlorite and opaques are common alteration products. Epidote also occurs in small amounts.

TABLE II

Modal Analyses of the Diorites

	(1)	(2)	(3)
AV. Pl %	57.1	59.2	55.3
s.e.	1.7	2.7	2.1
AV. An %	28.5	32.2	32.6
s.e.	0.8	0.5	0.7
AV. Qtz %	17.1	6.5	0.8
s.e.	2.3	1.0	0.3
AV. Kf %	13.2	7.1	---
s.e.	2.2	2.0	---
AV. Hbl %	2.1	11.8	26.8
s.e.	0.8	2.6	3.2
AV. Biot %	6.6	11.6	7.6
s.e.	1.0	2.6	1.6
AV. Chl %	1.3	2.7	8.4
s.e.	0.5	1.3	2.3
AV. Mag %	0.8	1.3	1.2
s.e.	0.5	0.4	0.3

(1) Granodiorites, 11 samples

(2) Quartz diorites, 9 samples

(3) Mafic diorites, 16 samples

s.e. = standard error

Compared to the quartz diorites, the mafic diorites are darker (dark grey), finer-grained, and texturally a much more homogeneous rocks. Although the total compositional variation within the mafic diorites is as great as the variation found in the quartz diorites, it is on a different scale. The quartz diorites exhibit large compositional variations within a sample, whereas the variation in the mafic diorites is between individually homogeneous outcrops.

Plagioclase is generally anhedral, occasionally subhedral, fairly well twinned, and often surrounded by albite rims. Phenocrysts are common and completely sericitized, as are most of the smaller plagioclases. Quartz, when present, is interstitial. Both quartz and plagioclase contain abundant apatite needles. Biotite and hornblende are dark brown and dark green respectively, and infrequently form clots with no noticable alignment. Both are commonly highly altered to chlorite and magnetite. Small amounts of epidote are also found. Very rarely, pyroxene is observed surrounded by hornblende.

CHEMISTRY OF ROCK TYPES

Chemical analyses for the rock types in the Tichka Massif were obtained by conventional X-ray fluorescence and atomic absorbtion techniques. Average compositions are shown in Tables 3 and 4. Variation in chemistry of the Tichka Massif can be seen by examining the diagram (of the type proposed by Larsen, 1938) shown in Figure 3.

The mafic diorites are chemically similar to the average gabbro (Daly, 1933) but because of the more sodic plagioclase (An_{33}) they are classified as diorites.

TABLE III

Chemical Analyses - Granitic Rocks
(in weight %, data normalized to 100%)

	(1)	(2)	(3)	(4)
SiO_2	78.4	71.1	73.7	78.2
s.e.	1.4	0.4	1.2	0.8
Al_2O_3	11.2	14.5	13.3	12.5
s.e.	1.0	0.2	0.5	0.3
FeO*	1.2	3.3	2.5	1.1
s.e.	0.4	0.2	0.4	0.2
MgO	0.1	0.9	0.6	0.4
s.e.	0.0	0.2	0.2	0.2
TiO_2	0.2	0.5	0.4	0.1
s.e.	0.2	0.1	0.1	0.1
CaO	0.7	2.0	1.6	0.7
s.e.	0.3	0.2	0.2	0.3
Na_2O	3.2	4.1	3.8	4.3
s.e.	0.3	0.2	0.2	0.5
K_2O	5.0	3.7	4.1	3.7
s.e.	0.8	0.2	0.3	1.4

* Fe_2O_3 as FeO

(1) Leucogranite pods, average of 4 samples

(2) Biotite quartz monzonite pods, average of 7 samples

(3) All granitic pods, average of 11 samples

(4) Granite from margins, average of 7 samples (data from Williams, in prep.)

s.e. = standard error

TABLE IV

Chemical Analyses - Dioritic Rocks
(in weight %, data normalized to 100%)

	(1)	(2)	(3)
SiO_2	66.7	58.3	51.6
s.e.	0.8	0.5	0.6
Al_2O_3	16.4	18.4	17.7
s.e.	0.4	0.4	0.3
FeO*	4.3	6.9	10.6
s.e.	0.4	0.3	0.3
MgO	1.5	3.3	6.2
s.e.	0.2	0.3	0.4
TiO_2	0.6	1.1	1.5
s.e.	0.1	0.1	0.1
CaO	3.2	5.5	6.8
s.e.	0.3	0.2	0.3
Na_2O	4.7	4.7	3.8
s.e.	0.2	0.1	0.2
K_2O	2.5	1.5	1.6
s.e.	0.2	0.1	0.2

* Fe_2O_3 as FeO

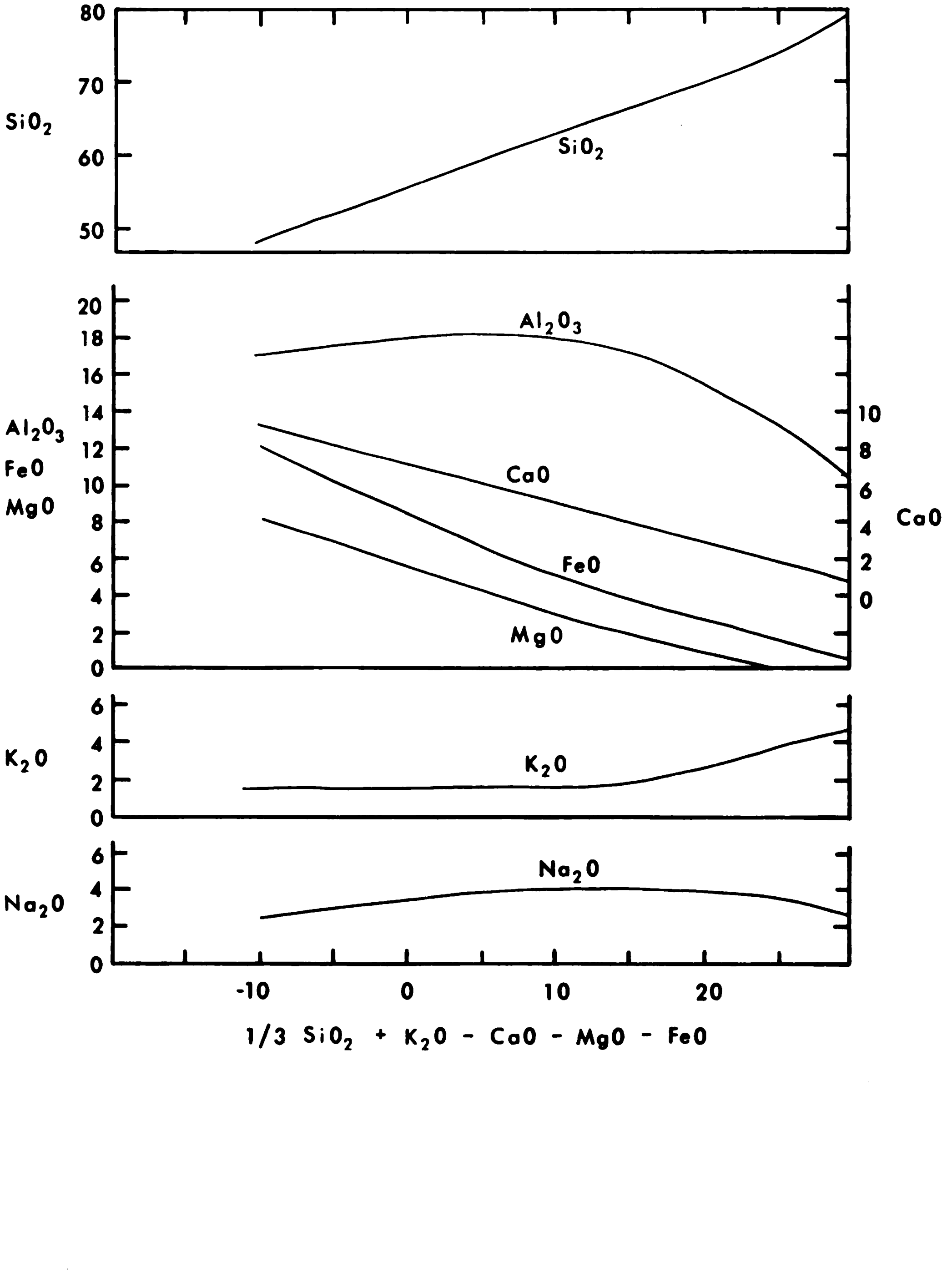
(1) Granodiorites, average of 8 samples

(2) Quartz Diorites, average of 9 samples

(3) Mafic diorites, average of 16 samples

s.e. = standard error

Figure 3 Variation diagram (Larson type) for the plutonic rocks of the Tichka Massif.


SiO_2
80
70
60
50
SiO_2
Al_2O_3
FeO
MgO
20
18
16
14
12
10
8
6
4
2
0
Al_2O_3
CaO
FeO
MgO
10
8
6
4
2
0
CaO
K_2O
6
4
2
0
K_2O
Na_2O
6
4
2
0
Na_2O
-10
0
10
20
$1/3\ SiO_2 + K_2O - CaO - MgO - FeO$

DISCUSSION

The field relationships provide evidence that granitic magmas coexisted with basic magmas in the Tichka Massif (Vogel and Walker, 1975). A fundamental observation that supports this interpretation is the well-defined granitic pods surrounded by dioritic rock, with extremely sharp boundaries between the pod walls and diorite (see Vogel and Walker, Figures 3 and 5, 1975). Also basic to this interpretation is the widespread evidence that granitics, quartz diorites, and mafic diorites had overlapping crystallization histories (Vogel and Walker, Figures 4 and 7, 1975). It would be extremely difficult to account for these relationships by any type of crystal-liquid differentiation model.

With this in mind, one test for the independent origin of the granitic and basic magmas is to use a differentiation model as the null hypothesis. That is, if it can be shown that the major rock types are related by differentiation, the model for the independent origin of the granitic and basic magmas would be invalidated.

Test of Differentiation

In order to test the validity of a differentiation model for Tichka Massif, Chayes' (1968) a least squares approximation method was used. This program evaluates how closely the composition of the assumed starting material (parent) Y may be expressed as a linear combination of the proposed partition products X_i. Multiple regression coefficents (B_i) are chosen so as to minimize the sum of the squares of the residuals S (S = $\sum_{i=1}^{n}(Y - \hat{Y})^2$, where $\hat{Y}$ is an estimate of Y). When the proposed partition products are in the form of weight percent of the oxide, the program tests the mass balance of the system.

An assumption of mass balance is implicit in all differentiation schemes (i.e., a linear combination of the differentiates, X_i, will yield the composition of the parent Y). Conversely, the mixing of two genetically unrelated magmas should not yield a net mass balance. Perfect mass balance is obtained when $S = 0$. $\sum(B) = 1$, and $B_i > 0$ for all i. In practice, if $S \sim 0$, $\sum(B) \sim 1$, and any negative B_i are small enough to ignore, we will be satisfied that a net system mass balance has been maintained (Chayes, 1968).

In order to minimize the effects of local inhomogeneities, all of the chemical data was plotted on variation diagrams of the type proposed by Larsen (1938) and compositions were obtained between equi-spaced intervals (fields) from those curves. These were used as X_i for input.

Initially, a hypothetic parent (Y_a) having the average composition of the mafic diorites was used. When run with X_i values that were confined to the mafic diorites, values of S = 0.03. $\sum(B)$ =1.02, and all positive B_i were produced. Additional hypothetical parents were also tried; all yielded substantially poorer approximations to the ideal.

The parent having been chosen as a mafic diorite, it is then possible to test the differentiation model - i.e., all of the rock types are due to differentiation of a common parental material.

Using Y_a (mafic diorite) as a parent, the X_i values were expanded to include the entire sequence of rock types, from mafic diorite to leucogranite, found in the massif. This run yield S = 0.24, $\sum(B)$ = 0.99, and two negative B_i values of -0.52 and -0.21. Although the $\sum(B)$ is close to the ideal, the S value is high. The presence of two negative B_i values bears closer examination.

Chayes (1968) lists three possible explanations for the presence of one or more negative values of B_i, which are the amounts of X_i used to form the parent (Y_a, in this case). His explanations are: (a) Materials of the composition whose coefficients are negative were <u>added</u> to the magma to generate the other partition products, or; (b) in relation to the uncertainty attached to each of them, the negative coefficients do not differ significantly from zero, the rather absurd explanation of a zero coefficient being simply that an observed portion of the complex was neither added to nor extracted from the parent magma, or; (c) the associated uncertainty is so large that an observed negative coefficient is not incompatable with a significantly positive parent value. Since the first two explanations imply rejection of the hypothesis that the X_i values are differentiates of the parent magma, the possibility of analytic error was first examined.

Although examination of the individual residuals did not reveal any component to be the major source of error, TiO_2 and MgO were eliminated from the program, because their percent total variation tends to be the highest due to the small total amounts involved. Aside from lowering the value of S to 0.18, the elimination of these oxides did not produce significant change. That is, the two negative B_i values still occurred.

Contamination from a genetically unrelated source could also influence the results. Because field relations indicate that andesitic volcanics were assimilated (Vogel and Walker, 1975), the effect of adding andesitic compositions to the parent magma was examined. No significant changes in the output occurred (two negative B_i coefficients remained).

In addition, parent compositions and field widths were varied, and entire rock sequences were omitted, in an attempt to eliminate the negative B_i coefficients. A total of 48 program runs were made; none of which, from the standpoint of the B_i coefficients, produced acceptable results.

Based on the results of this test, a differentiation model for the origin of all the rock types found in the massif must be rejected.

Partial Fusion

Since the differentiation model is not able to account for the production of the various rock types found in Tichka Massif, a mechanism for the production of independent granitic and basic magmas must be considered. Partial fusion of the lower crust has been suggested as a major method for producing granitic magmas (Tuttle and Bowen, 1958; Wyllie and Tuttle, 1959; Winkler, 1967; Pinwinski and Wyllie, 1968; Pinwinski, 1968, 1973; Brown and Fyfe, 1970; Fyfe, 1971, 1973; Brown, 1973; Presnall and Bateman, 1973).

One of the major prerequisites for a lower crustal origin of granitic magmas is that the temperature must be raised substantially above that which can be accounted for by normal geothermal gradients (Pinwinski, 1968; Pinwinski and Wyllie, 1968; Presnall and Bateman, 1973; Younker, 1974). Younker (1974) has shown that significant amounts of crustal melting can be produced by the emplacement of mantle derived magmas into the lower crust. In addition, he shows that the extent of melting is a function of the original temperature of the crust and the size and temperature of the intruding magma body.

In their work on the Sierra Nevada Batholith, Presnall and Bateman (1973) determined that the system Ab-An-Or-Qz-H_2O is representative of the compositions of most felsic rocks and the lower crust. Although this system is water saturated, while most granitic melts are highly undersaturated (Pinwinski, 1968; Pinwinski and Wyllie, 1968; Presnall and Bateman, 1973), differences in water content, or pressure, will not significantly alter the phase relationships for the system (Presnall and Bateman, 1973).

The Ab-An-Or diagram can be treated as a ternary representation of the Ab-An-Or-Qz-H_2O system; assuming the constant presence of quartz and water vapor. Equilibrium or fractional fusion of any composition within this system will yield a liquid of granitic composition along the liquidus univariant line. This work by Presnall and Bateman (1973) provides a means to test a partial fusion model for the origin of the granitic rocks found in the Tichka Massif.

The granitic rocks, as well as the granodiorites and quartz diorites, found in the Tichka Massif are well represented by the Ab-An-Or ternary projection; since they typically contain greater than 70 % Ab+An+Or+Qz.

When plotted on the Ab-An-Or ternary projection (Figure 4), the leucogranite pod and granite margin samples fall directly on the liquidus univariant line; exactly as would be expected if they were the result of fractional fusion of lower crustal material. The biotite quartz monzonite pods, the granodiorites, and the quartz diorites fall along a line extending away from the liquidus univariant line and towards the Ab-An plane. This is the predicted result of equilibrium fusion, where excess heat has forced the liquid composition off the liquidus univariant line (Presnall and Bateman, 1973).

Younker (1974) has shown that equilibrium fusion of lower crustal material can only occur if, after a period of preheating via volcanic activity, a mantle derived magma intrudes crustal rock and subsequently cools. No evidence of preheating exists in the rocks surrounding the Tichka Massif; that is volcanics and volcanoclastics are virtually absent in the stratigraphic record and there is no regional metamorphism.

Figure 4   Normative proportions of Ab-An-Or normalized to 100 percent. The curved line is the univariant equilibrium after Presnall and Bateman (1973). Closed squares, granite pods and margins; X, quartz monzonite pods; circles, granodiorites; triangles, quartz diorites.

In addition, because with the equilibrium fusion, the magma produced is in constant equilibrium with the residual crystals, subsequent fractional crystallization, a differentiation process, is a requirement of equilibrium fusion (Presnall, 1969; Presnall and Bateman, 1973). On the basis of the observed field relationships (Vogel and Walker, 1975) and the results of the least squares approximation method presented above, a differentiation model was rejected. Taking this, and the lack of extensive volcanism and regional metamorphism, into account, an equilibrium fusion model must also be rejected.

Since fractional fusion of lower crustal material will form small amounts of granitic magma which are isolated from the residual crystals (Presnall, 1969; Presnall and Bateman, 1973), no subsequent fractional crystallization is required. Heat for fraction fusion is much less than equilibrium fusion, and crustal preheating is not necessary (Younker, 1974).

The failure of the biotite quartz monzonite pods to fall along the liquidus univariant line, may be the result of contamination of initially leucogranite pods by surrounding material.

Conclusion

The results of this study support a model for independent origin of the granitic and dioritic magmas coexisting in the Tichka Massif, Morocco. Based on the field relationships, mineralogy and major element geochemistry presented above, a model for the emplacement of the Tichka Massif can be summarized as follows:

1. Differentiated mantle material (mafic diorite) in the lower crust
2. Heat from the mafic diorite magma causes fractional fusion of lower crustal material, producing granitic magma.
3. During emplacement of the massif to a higher crustal level, granitic magma is incorporated in the form of "pods" by the basic magma. Mixing is prevented by the viscosity difference between the pods and the basic magma (Vogel and Walker, 1975).
4. Assimilation of andesitic volcanics by the mafic diorite and differentiation during flowage forms quartz diorites and granodiorites.
5. Due to density difference, the granitic pods rise through the basic magma as it is emplaced, some pods coalescing at the margins of the massif (Vogel and Walker, 1975).

6. The granitic pods are frozen in place as the surrounding dioritic material crystallizes.

A further test for this model should be a comparison of the Sr 87/86 ratios for the granites and the mafic diorites (in progress). If this model is correct, the mafic diorites should represent a primitive ratio whereas the granite should relatively higher (Fullagar, 1971).

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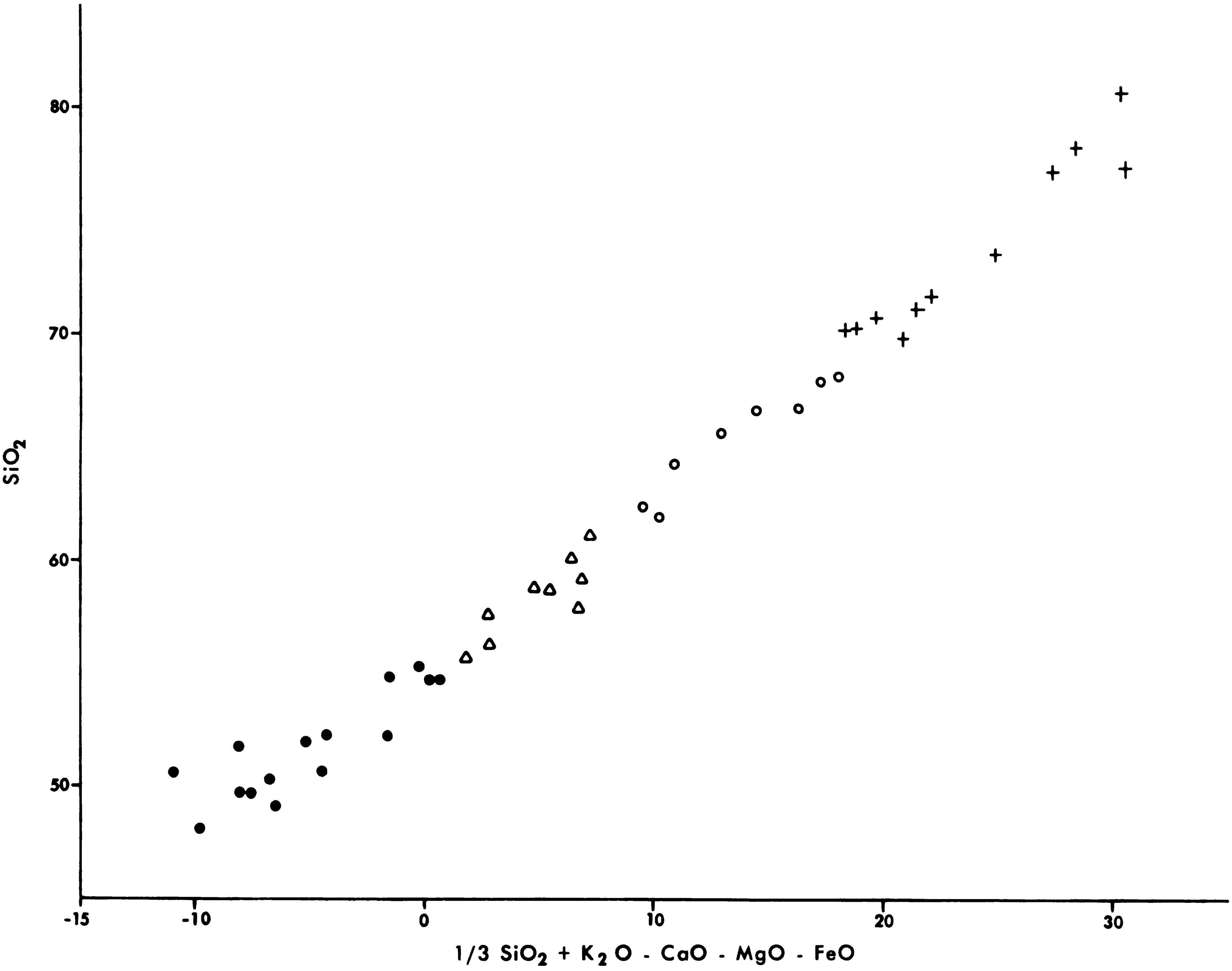
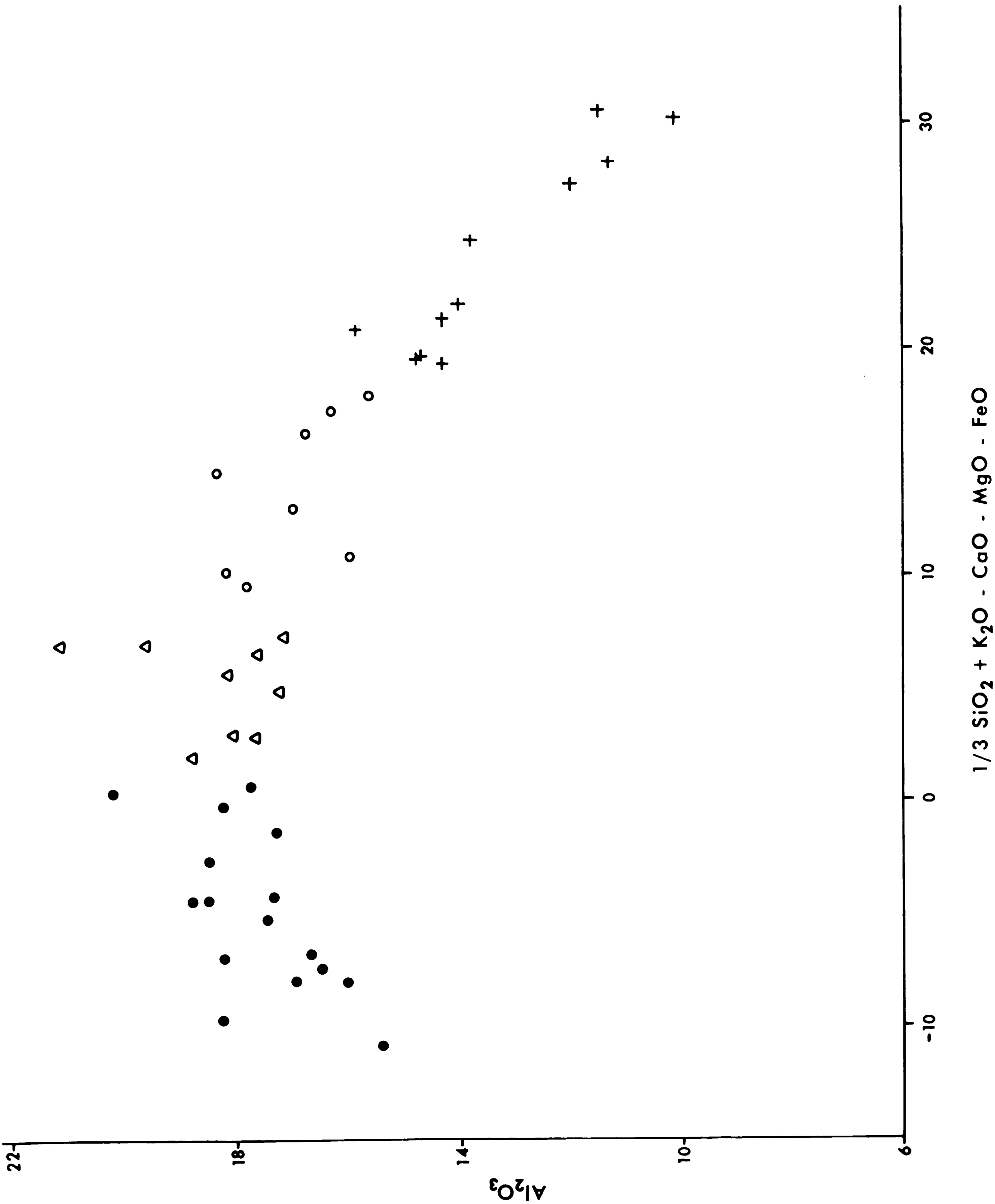
APPENDIX

Variation diagrams (Larsen type) for the plutonic rocks of the Tichka Massif. Squares, granite pods and margins; X, quartz monzonite pods; circles, granociorites; triangles, quartz diorites.


80
70
60
50
SiO$_2$
-15
-10
0
10
20
30
1/3 SiO$_2$ + K$_2$O - CaO - MgO - FeO


Al$_2$O$_3$
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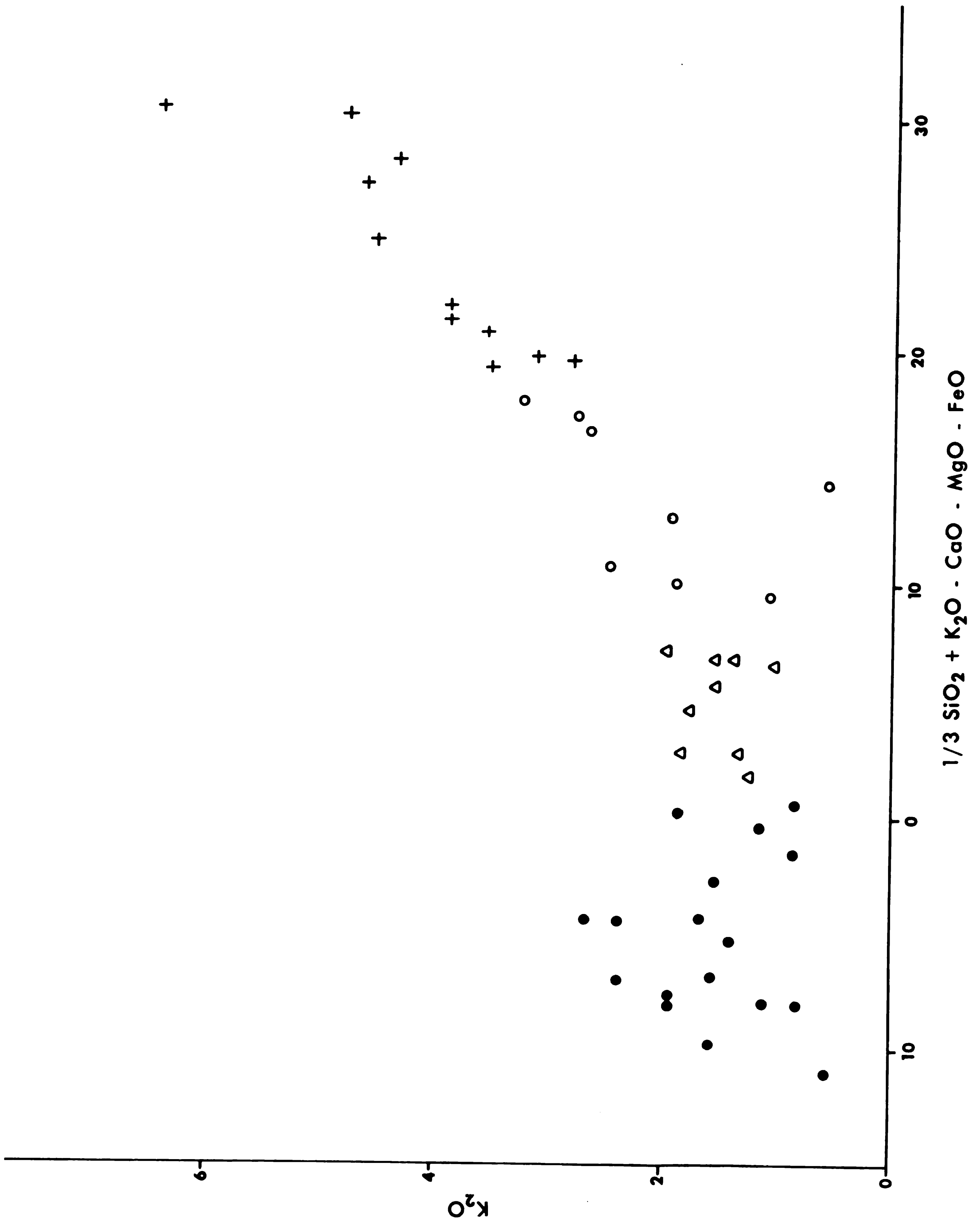
18
14
10
6
1/3 SiO$_2$ + K$_2$O - CaO - MgO - FeO
-10
0
10
20
30


K2O
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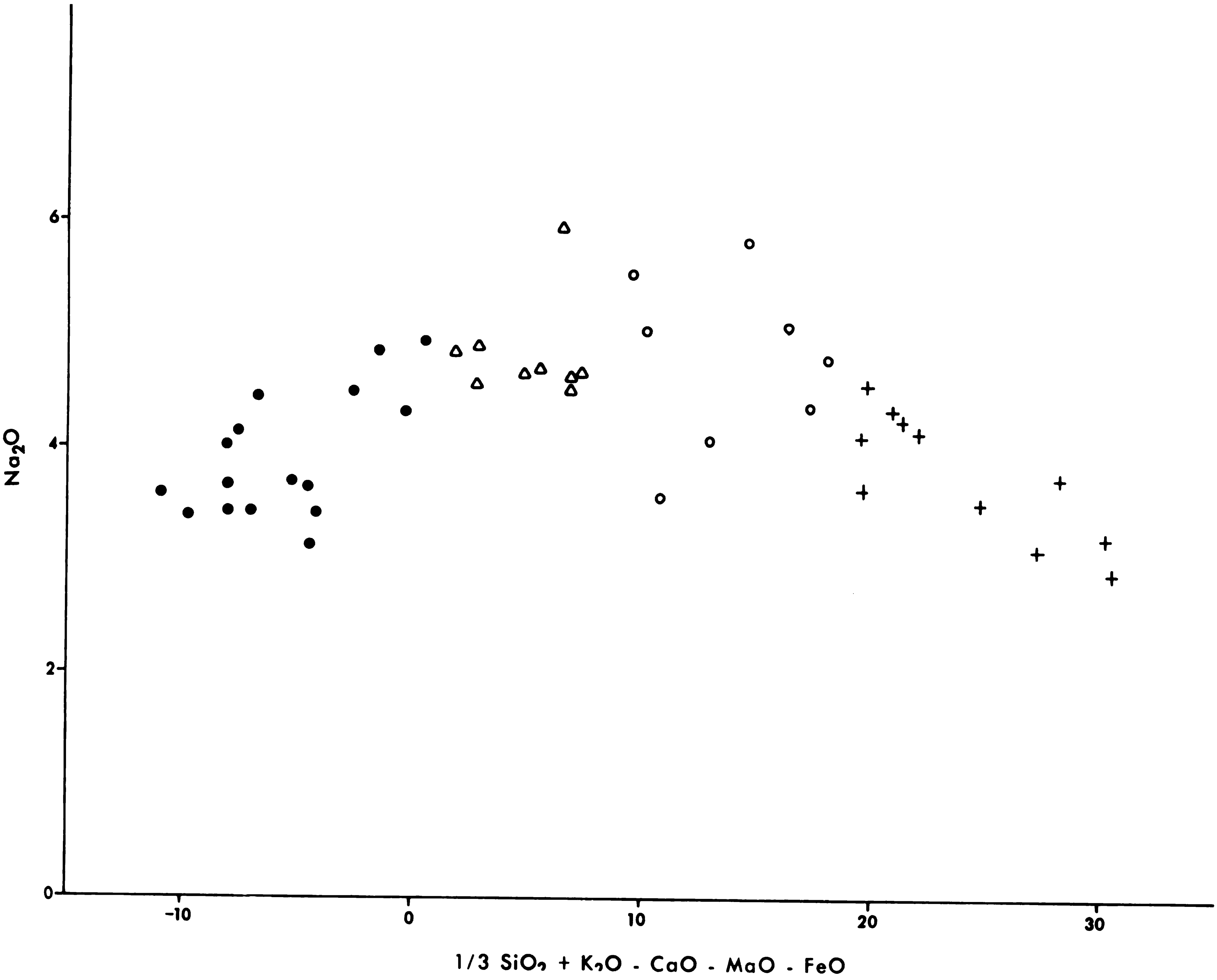
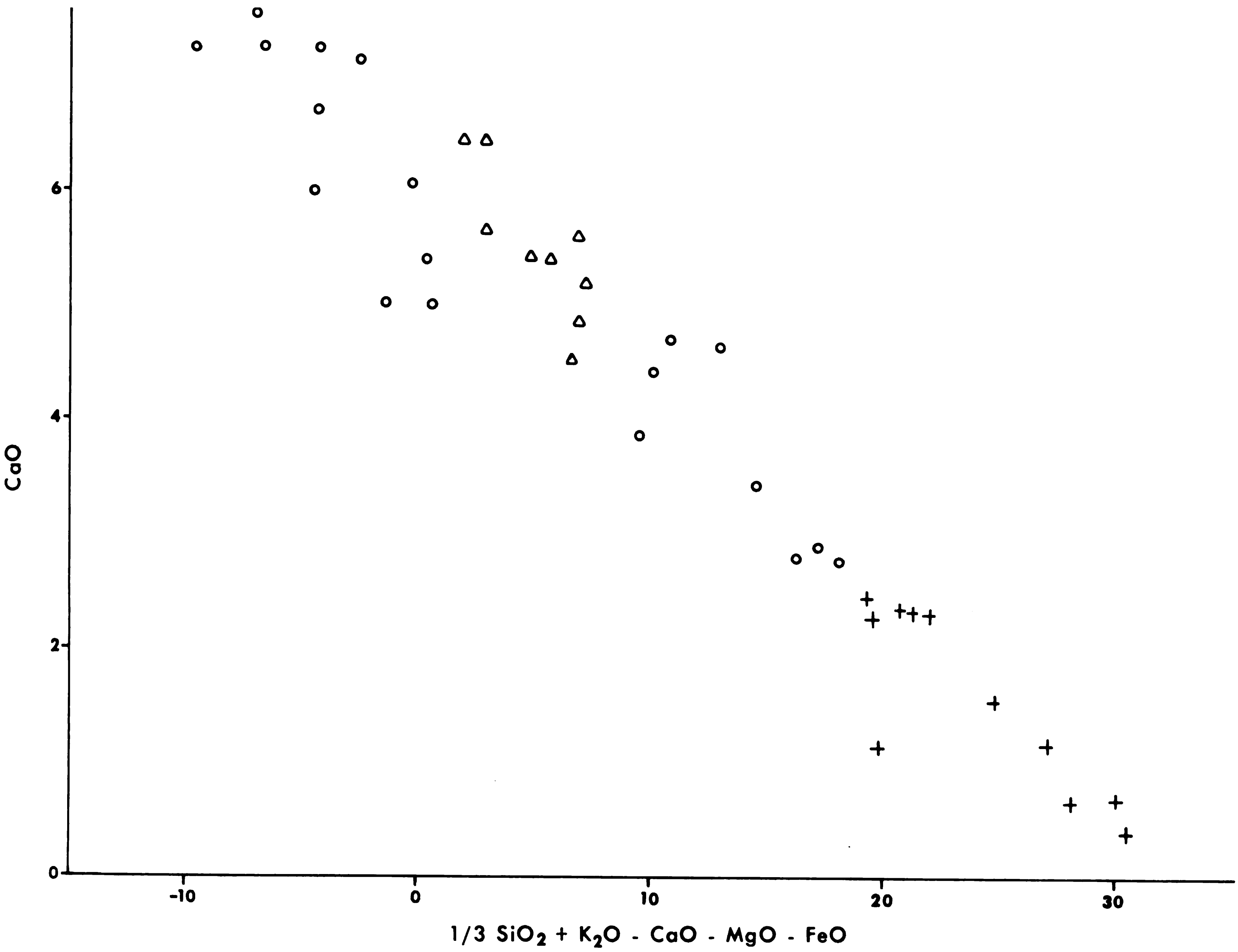
2
4
6
1/3 SiO2 + K2O - CaO - MgO - FeO
10
0
10
20
30


6
4
2
0
Na$_2$O
-10
0
10
20
30
1/3 SiO$_2$ + K$_2$O - CaO - MaO - FeO


CaO
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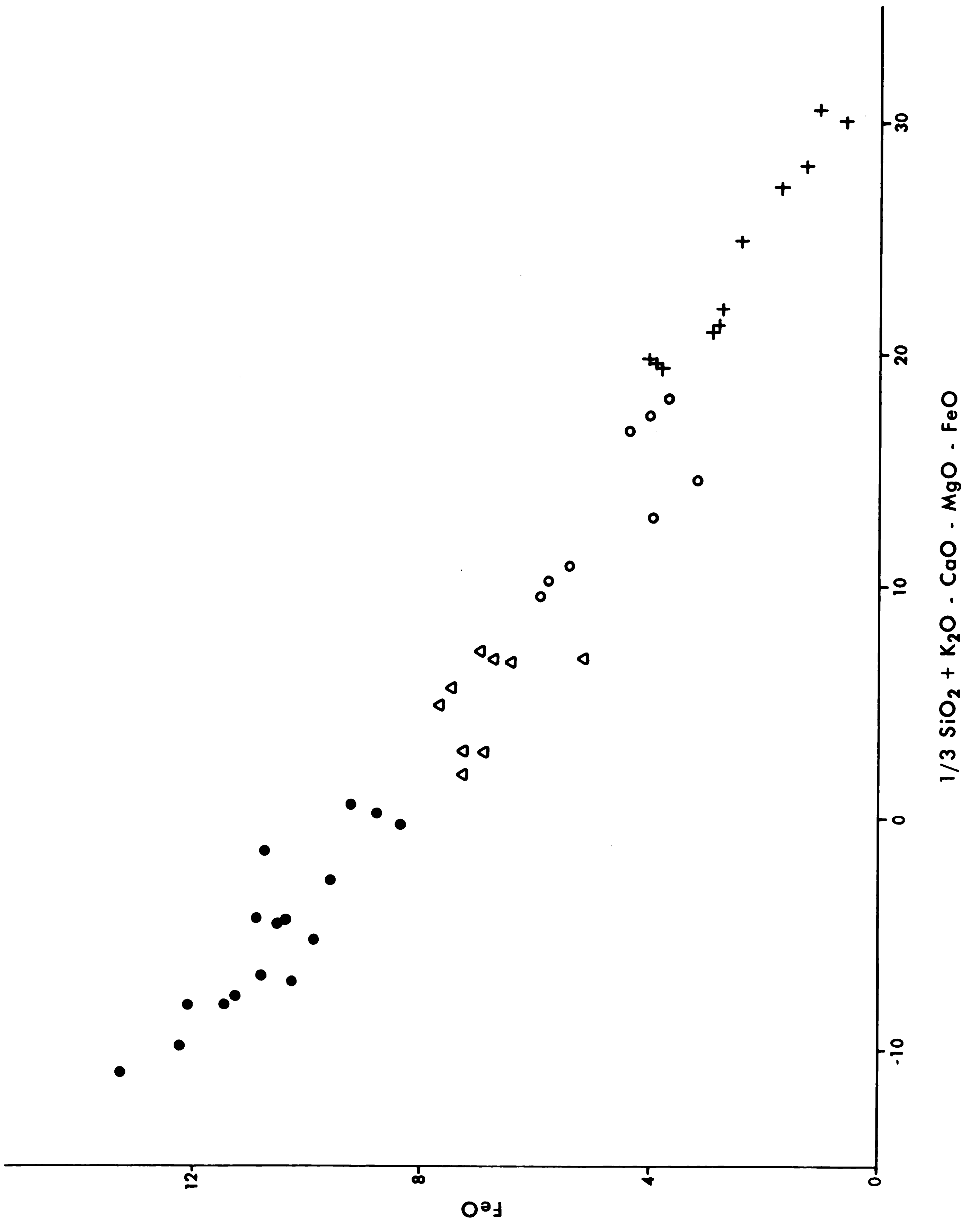
4
2
0
-10
0
10
20
30
$1/3\ SiO_2 + K_2O - CaO - MgO - FeO$


FeO
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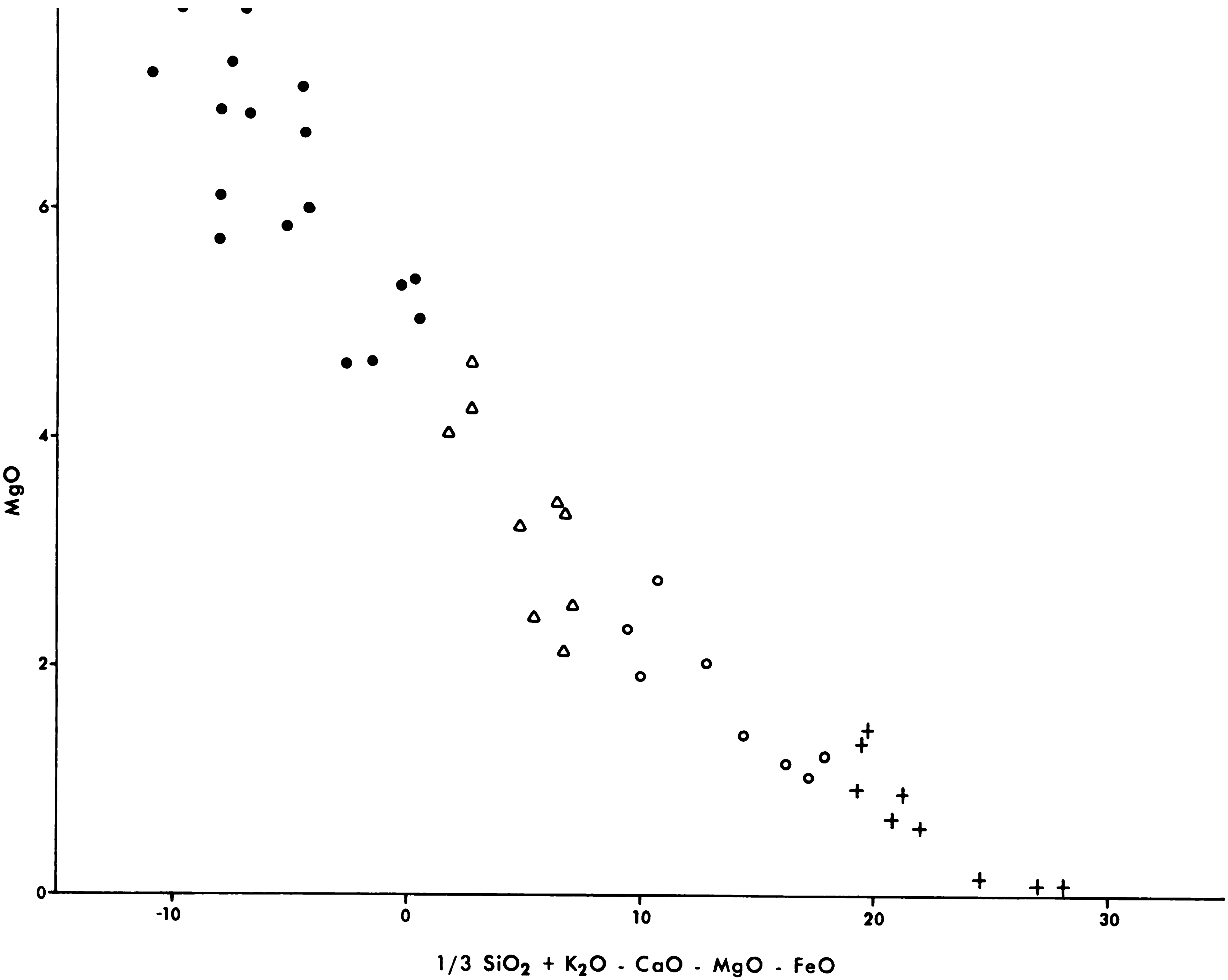
8
4
0
-10
0
10
20
30
1/3 SiO_2 + K_2O - CaO - MgO - FeO


MgO
6
4
2
0
-10
0
10
20
30
1/3 SiO$_2$ + K$_2$O - CaO - MgO - FeO