

# Data of Geochemistry

## *Sixth Edition*

*Chapter N.* Chemistry of Igneous Rocks

Part 1. The Chemistry of the Peralkaline Oversaturated Obsidians

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GEOLOGICAL SURVEY PROFESSIONAL PAPER 440-N-1



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## *Sixth Edition*

MICHAEL FLEISCHER, *Technical Editor*

### *Chapter N. Chemistry of Igneous Rocks*

#### Part 1. The Chemistry of the Peralkaline Oversaturated Obsidians

By RAY MACDONALD *and* D. K. BAILEY

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*Tabulation and discussion of chemical analyses of peralkaline, quartz-normative obsidians, the nature of chemical variation within these rocks, and a revised nomenclature*



**UNITED STATES DEPARTMENT OF THE INTERIOR**

**ROGERS C. B. MORTON, *Secretary***

**GEOLOGICAL SURVEY**

**V. E. McKelvey, *Director***

Library of Congress catalog-card No. 72-600256

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For sale by the Superintendent of Documents, U.S. Government Printing Office  
Washington, D.C. 20402 - Price 75 cents  
Stock Number 2401-00253

# DATA OF GEOCHEMISTRY, SIXTH EDITION

Michael Fleischer, *Technical Editor*

The first edition of the Data of Geochemistry, by F. W. Clarke, was published in 1908 as U.S. Geological Survey Bulletin 330. Later editions, also by Clarke, were published in 1911, 1916, 1920, and 1924 as Bulletins 491, 616, 695, and 770. This, the sixth edition, has been written by several scientists in the Geological Survey and in other institutions in the United States and abroad, each preparing a chapter on his special field. The current edition is being published in individual chapters, titles of which are listed below. Chapters already published are indicated by boldface.

- CHAPTER A. The chemical elements
- B. Cosmochemistry
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- F. **Chemical composition of subsurface waters**, by Donald E. White, John D. Hem, and G. A. Waring
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- M. Phase equilibrium relations of the common rock-forming oxides with water and (or) carbon dioxide
- N. **Chemistry of igneous rocks, Part 1, The chemistry of the peralkaline oversaturated obsidians**, by Ray Macdonald and D. K. Bailey
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## DATA OF GEOCHEMISTRY

# CHEMISTRY OF IGNEOUS ROCKS

## PART 1. THE CHEMISTRY OF THE PERALKALINE OVERSATURATED OBSIDIANS

By RAY MACDONALD<sup>1</sup> and D. K. BAILEY<sup>2</sup>

### ABSTRACT

Peralkaline rocks are one of the characteristic products of non-orogenic magmatism, and the development of peralkaline silicic magmas continues to be a problem of special interest to petrologists. The problem is complicated by the fact that crystallization of these highly alkaline melts commonly results in significant chemical changes, such that the study of quenched liquids (glasses) is probably the only reliable approach to magma compositions. In this report, all acceptable analyses of oversaturated peralkaline obsidians are listed and compared in an attempt to provide a sound basis for further studies of peralkaline silicic magmatism.

One hundred and thirteen analyses of peralkaline silicic obsidians are tabulated, along with CIPW norms, modal data, and trace element analyses where available. The rocks are classified using a scheme slightly modified from that of Lacroix into comendites, pantellerites, comenditic trachytes, and pantelleritic trachytes. Though there is a continuous chemical transition between comendites and pantellerites, several parameters may be used to distinguish the two groups, including the agpaitic index and the FeO and Al<sub>2</sub>O<sub>3</sub> contents. Variations in the comendites are discussed. Within the pantellerites, there are two subgroups: high-silica types, and varieties closely similar to those from the type area, Pantelleria. Though data are still very scarce, it is possible to characterize individual volcanoes by their trace element contents.

### INTRODUCTION

#### PETROGENETIC IMPORTANCE OF PERALKALINE ROCKS

In the rocks of the earth's crust, molecular excess of Al<sub>2</sub>O<sub>3</sub> over Na<sub>2</sub>O+K<sub>2</sub>O is prevalent, and the generation and survival of melts with the opposite characteristic present special problems. Peralkaline magmas are characteristically, if not exclusively, developed in non-orogenic magmatism and are frequently associated with magmas of mantle origin. An understanding of peralkaline petrochemistry is an essential prerequisite to unraveling the relations between the magma types and eventually to deciphering magma generation and development in the deep crust and mantle. The results given here are an attempt to define the present limits of knowledge in one group of peralkaline rocks—those containing normative quartz.

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### AIMS OF THE COMPILATION

In order to define critical experimental studies, we began in 1967 to collect all the available analytical data on peralkaline silicic rocks to form a comprehensive picture of their chemistry and phase relations. It soon became clear that the volcanic rocks had undergone post-eruptive changes in composition, especially loss of alkalis on crystallization or during hydration of glass, and precise interpretation of their interrelationships was very difficult. Several chemical features of the non-hydrated obsidians suggest that they are probably close to magmatic compositions.

Peralkaline silicic obsidians are uncommon, especially those with less than 20 percent normative quartz. We have attempted to collect suitable specimens from as many localities as possible. Thanks to the generosity of several geologists, we now have a wide range of samples, of which 32 have been analyzed in the Geochemistry Unit of the Geology Department, University of Reading, United Kingdom.

By choosing only obsidian, we may be imposing a selective bias in favor of certain compositions. It could be argued that the glassy condition is a result of some chemical peculiarity not found in magmas that have crystallized. At the present time, however, our compilation covers a wide range of composition; we have been unable to detect systematic differences from crystalline lavas; and experiments show that many of the obsidians are not difficult to crystallize. We suggest that this compilation of obsidian analyses is the logical first step towards quantifying the bases of comparison and that we shall be able to elucidate the more complex crystalline varieties only when the nature of the chemical variation within the obsidians is understood.

By confining our study to oversaturated peralkaline rocks we have adopted two arbitrary composition boundaries; no petrogenetic significance is implied. In particular, metaluminous rhyolites with agpaitic index close to 1 are excluded though they are obviously closely connected with comenditic rocks. On Easter Island, for



example, some of the rhyolitic obsidians have small amounts of normative acmite; others have small amounts of normative anorthite, though they belong to the same phases of volcanic activity. Similarly, we have not included here any discussion of the geographical distribution, geology, or petrography of the analyzed specimens, as these features can be properly evaluated only when all peralkaline silicic rocks are considered.

#### ACKNOWLEDGMENTS

S. A. Malik, D. A. Bungard, J. M. C. Palmer, and Mrs. L. Porteous of the Geochemistry Unit, Department of Geology, University of Reading, made many of the analyses quoted here. The chemical analytical procedures and controls were largely developed by J. E. Thomas. Unpublished analyses of obsidians from Nevada were kindly made available by the U.S. Geological Survey. Dr. D. S. Sutherland allowed us to use three unpublished analyses of pantellerites from Kenya collected under the auspices of the East African Geological Research Unit. Dr. G. A. R. Till and the staff of the Computer Unit, Department of Geology, University of Reading, computed the correlation coefficients. J. Smith and J. Watkins helped in producing the diagrams, and Miss V. Fulford and Miss L. Johnson patiently typed versions of the manuscript. Drs. Felix Chayes, Michael Fleischer, and R. L. Smith suggested many detailed and valuable improvements to the manuscript. To all these people we express our grateful thanks. Ray Macdonald acknowledges with thanks receipt of a University of Reading research fellowship during the period 1967-70.

#### SECONDARY HYDRATION AND CRYSTALLIZATION OF PERALKALINE SILICIC GLASSES

Following the earlier work of Ross and Smith (1955) and Friedman and Smith (1958), D. C. Noble and his co-workers in the U.S. Geological Survey have shown that the compositions of peralkaline silicic glasses can be extensively modified on secondary hydration and on crystallization. The major chemical changes so far investigated are tabulated below:

##### Secondary hydration:

- Na.....Almost invariably lost to some degree (Noble, 1967, 1970).
- K.....Generally lost, but may be gained on prolonged contact with ground water (Noble, 1967).
- Si.....May be leached from porous hydrated glasses (Noble, 1967).
- F, Cl.....Significant amounts may be added or re-

moved by ground water (Noble and others, 1967).

Mg.....Added by ground water (Noble, 1966).

##### Crystallization (including devitrification):

- Na.....Lost in variable amounts, roughly dependent on the peralkalinity of the glass (Carmichael, 1962; Noble, 1965, 1970; Ewart and others, 1968; Romano, 1969).
- F, Cl.....On average, 50 percent of F and 80 percent of Cl lost from the specimens studied (Noble and others, 1967; Carmichael, 1962; Noble, 1965; Romano, 1969).
- Fe.....More or less oxidized (Romano, 1969; Rosholt and Noble, 1969).
- U.....Some 20-60 percent lost, probably removed by ground water (Rosholt and Noble, 1969).

The three sets of analyses given in table 1 (A-E, 1-2, and 3-5) can be used to demonstrate some of the effects of secondary hydration and crystallization on peralkaline volcanic rocks, using projections in the system  $\text{Na}_2\text{O}-\text{K}_2\text{O}-\text{Al}_2\text{O}_3-\text{SiO}_2$  developed by Bailey and Macdonald (1969). The glassy parts of the flows show a range of peralkalinity (fig. 1) from the mildly peralkaline comendite (table 1, No. 3) through the comendite (table 1, No. 1) to the strongly peralkaline pantellerites (table 1, D and E). It is clear from table 1 and from figures 1 and 2 that both crystallization and hydration

TABLE 1.—Effect of hydration and devitrification on glassy, peralkaline silicic rocks

[Data in percent except for ratios]

	A	B	C	D	E	1	2	3	4	5
$\text{SiO}_2$ .....	68.25	68.80	68.50	68.60	68.00	73.98	71.70	75.37	73.32	71.94
$\text{Al}_2\text{O}_3$ .....	10.90	11.15	10.96	10.64	11.34	11.28	10.94	11.95	11.76	11.89
$\text{Fe}_2\text{O}_3$ .....	5.80	5.50	4.20	2.88	3.16	1.71	2.00	0.84	0.95	1.28
$\text{FeO}$ .....	1.15	1.29	2.58	3.59	2.42	1.80	1.48	0.99	0.81	0.60
$\text{MgO}$ .....	0.73	0.75	0.76	0.45	0.45	.....	.....	.....	.....	.....
$\text{CaO}$ .....	0.49	0.49	0.49	0.49	0.53	.....	.....	.....	.....	.....
$\text{Na}_2\text{O}$ .....	5.28	5.24	6.00	6.36	7.76	5.33	4.63	4.43	4.29	4.02
$\text{K}_2\text{O}$ .....	4.92	4.90	4.86	4.80	4.72	4.55	4.85	4.82	4.66	4.52
$\text{H}_2\text{O}$ .....	0.42	0.31	0.09	0.25	0.00	0.02	0.10	0.04	0.17	0.82
$\text{H}_2\text{O}^+$ .....	0.57	0.53	0.33	1.18	0.56	0.16	2.90	0.45	2.77	3.32
$\text{TiO}_2$ .....	0.65	0.57	0.53	0.65	0.65	.....	.....	.....	.....	.....
$\text{P}_2\text{O}_5$ .....	0.05	0.08	0.07	0.05	0.06	.....	.....	.....	.....	.....
$\text{MnO}$ .....	0.25	0.22	0.25	0.27	0.21	.....	.....	.....	.....	.....
$\text{Cl}$ .....	0.26	0.22	0.31	0.35	0.51	.....	.....	.....	.....	.....
F.....	0.15	0.12	0.12	0.20	0.20	.....	.....	.....	.....	.....
$\text{Na}_2\text{O}/\text{K}_2\text{O}$ .....	1.07	1.07	1.23	1.33	1.64	1.17	0.95	0.92	0.92	0.89
$\text{Na}_2\text{O}+\text{K}_2\text{O}$ .....	10.20	10.14	10.86	11.16	12.48	9.88	9.48	9.25	8.95	8.54
$\text{FeO}/(\text{FeO}+\text{Fe}_2\text{O}_3)$ .....	0.17	0.19	0.38	0.55	0.43	0.51	0.43	0.54	0.46	0.32
Fe as FeO.....	6.38	6.24	6.36	6.18	5.27	3.34	3.28	1.75	1.67	1.75

A-E. From pantelleritic lava, Fossa della Pernice, Pantelleria (Romano, 1969, table 1, A-E). A, from lower part of flow; B, interior, holocrystalline part of flow; C, transitional between glassy and crystalline parts of flow; D, from glassy crust, partly hydrated; E, from glassy crust, but removed along flow from D.

1, 2. Nonhydrated glass and hydrated dense glass from the comenditic Grouse Canyon Member of the Belted Range Tuff, Nevada (Noble, 1967, table 1, laboratory Nos. D100317, D100393).

3-5. Nonhydrated glass, hydrated dense glass, and hydrated porous glass from the comenditic Spearhead Member of the Thirsty Canyon Tuff, Nevada (Noble, 1967, table 1, laboratory Nos. D100320, D100394, D100454).

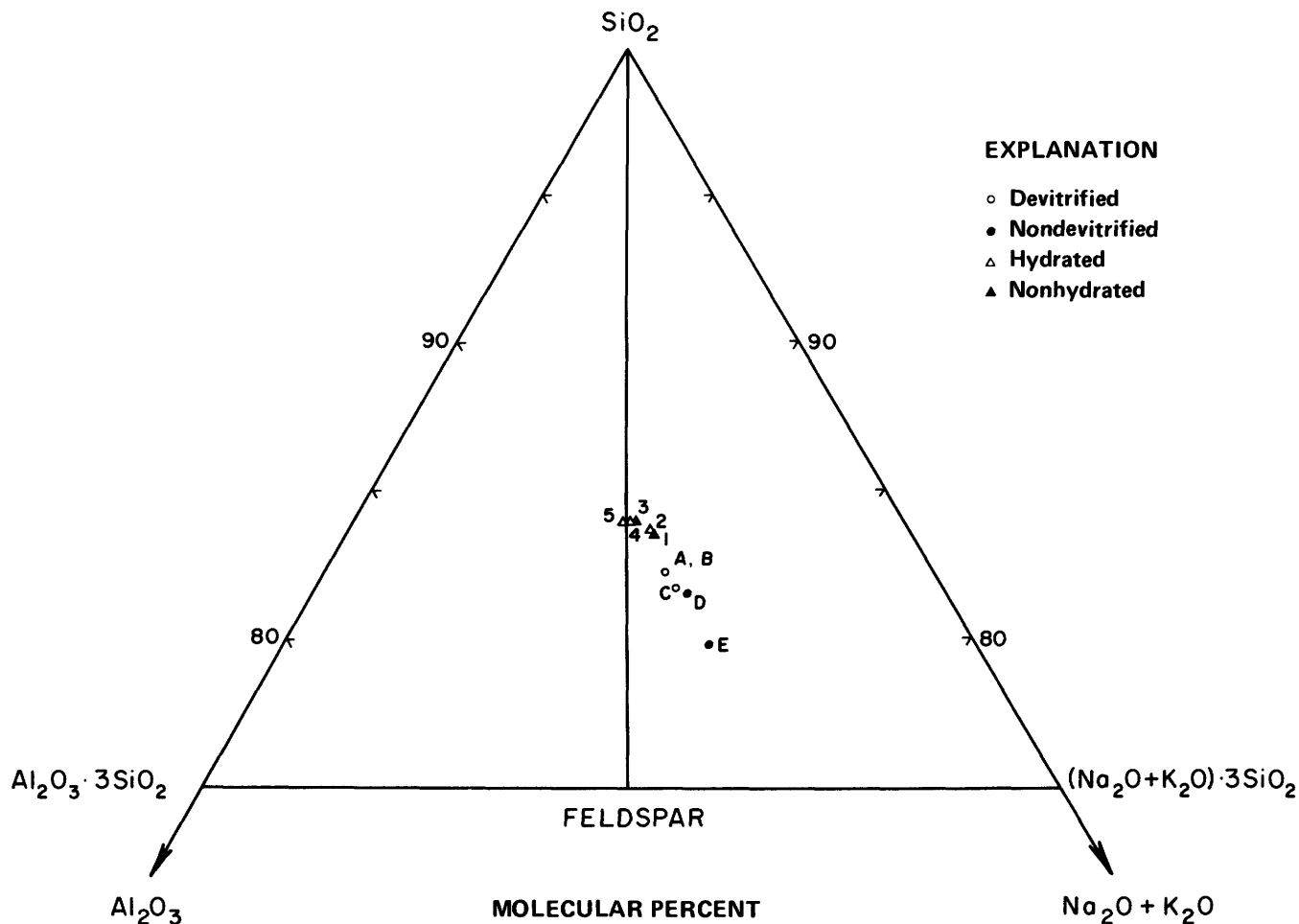


FIGURE 1.—Part of a molecular  $\text{SiO}_2\text{-Al}_2\text{O}_3\text{-(Na}_2\text{O+K}_2\text{O)}$  diagram showing some of the effects of hydration and devitrification on peralkaline glasses. Specimens identified as in table 1. In all cases, the rocks have become less peralkaline when hydrated or devitrified.

have had marked effects on the compositions of the rocks; the altered facies are less peralkaline and the sodium-potassium ratios are strikingly different. The more peralkaline glasses obviously show the greatest changes. We do not, however, suggest that all the variation in the Pantellerian specimens (table 1, A-E) is necessarily a result of these processes. For example, specimen E, which has the highest content of alkalis and may thus be considered as a "control" sample, contains 0.9 weight percent less Fe as FeO and has a lower  $\text{Fe}^{+2}/\text{Fe}^{+3}$  ratio than the partly hydrated specimen D. Since iron is not normally added or removed and the oxidation ratio normally increases during crystallization or hydration, the figures may indicate that there is a small but real chemical variation within this flow due to other processes.

**DATA SELECTION**

The compilation includes all published analyses of peralkaline silicic obsidians and glass separates known

to us, and which we considered reliable, plus 20 unpublished analyses. The total number of analyses is 113.

During the data collection, analyses were rejected for the following reasons:

1. The total did not lie within the limits 99-101 percent.
2. Any one of the oxides  $\text{SiO}_2$ ,  $\text{Al}_2\text{O}_3$ ,  $\text{Fe}_2\text{O}_3$ , FeO,  $\text{Na}_2\text{O}$ , and  $\text{K}_2\text{O}$  was not reported.
3. Three or more of the oxides  $\text{TiO}_2$ , MnO, MgO, CaO,  $\text{H}_2\text{O}^+$ , and  $\text{P}_2\text{O}_5$  were not reported.
4. The analysis has been shown to be untrustworthy. For example Zies (1960) has found that Washington's (1913) original analyses of Pantellerian hyalopantellerites are partly in error, especially in the  $\text{TiO}_2$  figures.

In this compilation we compare the compositions of volcanic rocks from various localities. In doing so, we assume that the analyses being examined represent magmatic liquid compositions. About 70 percent of the analyses are of porphyritic obsidians, however, and Noble (1965, p. B88) has stressed, with special refer-

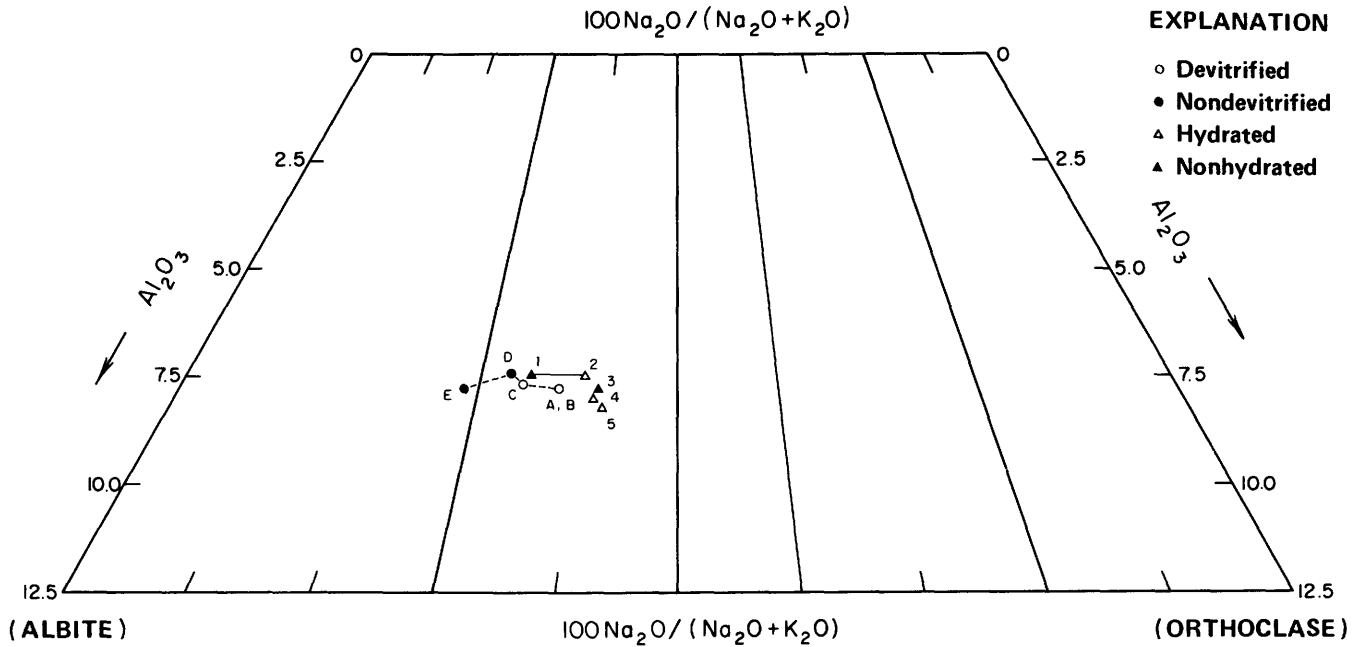


FIGURE 2.—Quadrilateral diagram, as devised by Bailey and Macdonald (1969), showing loss of some original sodium in glassy rocks as a result of devitrification or hydration. Specimens identified as in table 1.

ence to pantellerites, that porphyritic rocks will not generally represent liquid compositions because of “the vagaries of crystal accumulation and separation.” This statement assumes that segregation of crystals is a general process—we would argue that this segregation needs to be proven for rhyolite magmas. Our examination suggests that segregation may have only minor effects. Of all porphyritic obsidians for which modal data are available, only 14 have > 8 percent phenocrysts by volume and none has > 20 percent (fig. 3). It might be expected that if those obsidians with high crystal

content were partly accumultic, they would tend to show low values of the agpaitic index, because they have been diluted mainly with alkali feldspar. Yet those phenocryst-rich rocks occur at all values of agpaitic index (fig. 4).

We do not exclude the possibility that crystal accumulation has occurred in some of these lavas and indeed have suggested (Macdonald and others, 1970) the possibility for one trachyte from Kenya (analysis 107), but the data suggest that this is not typical.

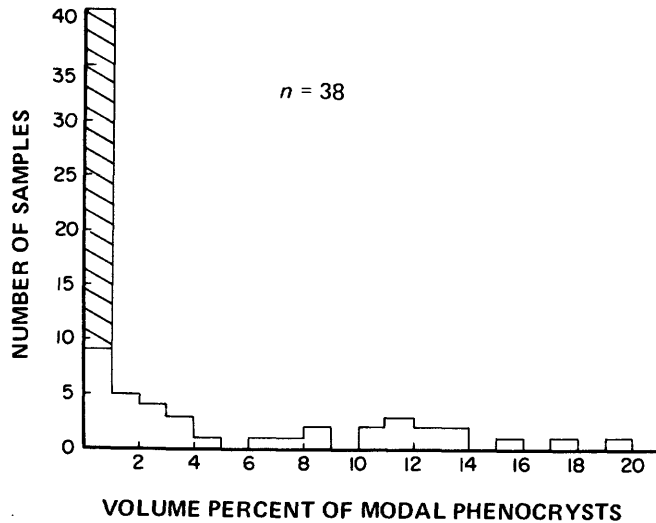


FIGURE 3.—Frequency diagram showing volume percent of modal phenocrysts in samples of porphyritic obsidian. The patterned area represents the number of aphyric samples.

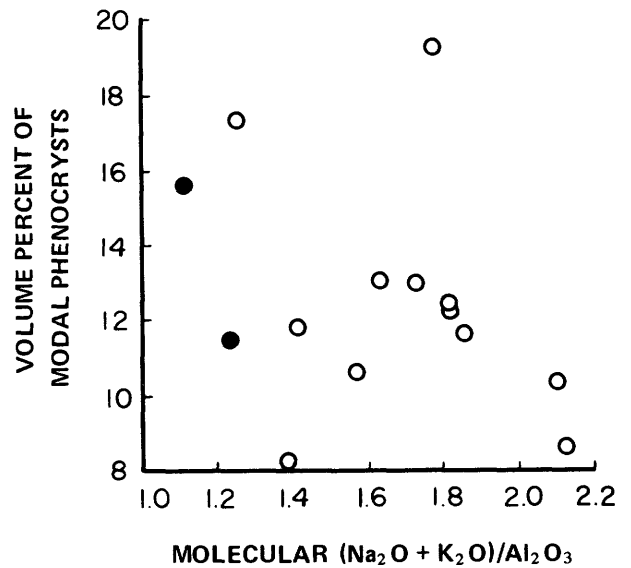


FIGURE 4.—Relations between volume percent of modal phenocrysts and agpaitic index in samples of porphyritic obsidian having > 8 percent of phenocrysts.

## COMPILATION OF ANALYSES

The major element analyses are compiled in tables 2-4 using the revised nomenclature of figure 5. Within each table, the analyses are grouped geographically. Analyses of two obsidians which lack adequate geographic information are given in table 10. Trace element data are given in tables 5-8. Details of individual specimens, including modal analyses where available, are given on pages N22-25. Here the rock names are those applied by the original authors.

All published norms have been checked before incorporation into the tables, and where adjustments have been made, the adjustment is mentioned in the specimen description. In several cases, the di and hy molecules had to be recalculated to wo+en+fs and en+fs, respectively.

The calculation of normative NaCl, NaF, and CaF<sub>2</sub> involves discarding part of the oxygen content of the analysis when the molecular weights of the pure molecules are used. The part discarded is insignificant for most rocks but is important in the fluorine- and chlorine-rich peralkaline lavas, as it results in low totals for the norm. For example, 0.5 and 1.0 percent (by weight) chlorine in an analysis, when calculated as normative hl, results in a lowering of the weight total of the norm by 0.11 and 0.22 percent, respectively. Also, 0.5 and 1.0 percent (by weight) fluorine, calculated as CaF<sub>2</sub> or NaF, lower the total by 0.21 and 0.42 percent, respectively. We have not included this excess oxygen in the

norms, but it has resulted in some cases in a fairly large discrepancy between percent oxides (by weight) and the norm.

## NOMENCLATURE

The terminology of peralkaline silicic extrusive rocks is fortunately quite uncomplicated, and it is possible to group the rocks simply into (1) peralkaline trachytes with q < 10 percent and (2) rhyolites of the comendite and pantellerite groups (Lacroix, 1927, 1930; Noble, 1968). The old term "quartz-keratophyre," as used for alkali rhyolites, refers to altered rocks (Johannsen, 1932). Noble (1968) has distinguished a group of volcanic rocks intermediate between peralkaline trachytes and rhyolites as "trachytic soda rhyolites," but for simplicity we have preferred to extend the terms "comendite" and "pantellerite" to cover these intermediate types.

Pantellerite was coined by Foerstner (1881) for alkali rhyolites from the island of Pantelleria in the Mediterranean, and Washington (1913), in a redescription of the rocks from the island, introduced the term "hyalopantellerite" for the glassy varieties. In recent literature the term "pantellerite" has tended to become synonymous with hyalopantellerite (Noble, 1965, p. B88). Comendite is a name devised by Bertolio (1895) for alkali rhyolites from Le Comende, San Pietro Island, Sardinia. Both comendites and pantellerites from the type areas are one-feldspar rhyolites, normally containing phenocrysts of alkali feldspar in the range anortho-

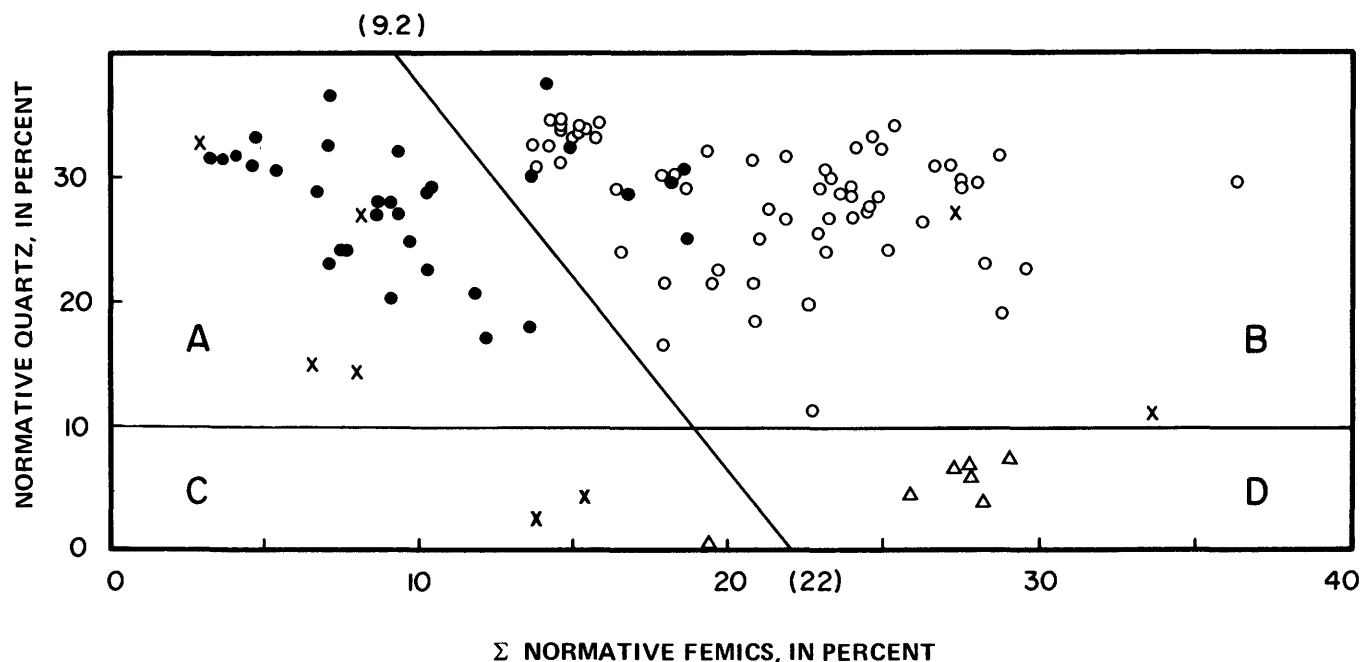


FIGURE 5.—Classification scheme for peralkaline silicic obsidians, modified from Lacroix (1927) and Noble (1968) to include trachytic varieties. The boundary line is arbitrary. Specimens are plotted using the nomenclature of the original authors: ●, comendite; ○, pantellerite; △, pantelleritic trachyte; ×, rocks termed simply rhyolite, trachyte, obsidian, and so forth. In our terminology: A, comendite; B, pantellerite; C, comenditic trachyte; and D, pantelleritic trachyte.

clase to sanidine  $\pm$  green pyroxene (which, when analyzed, appears to be sodic hedenbergite), aenigmatite, and quartz in a groundmass of the same minerals  $\pm$  aegirine, riebeckite to arfvedsonite, biotite, and accessory minerals. Fayalite and iron oxides are scarce phenocrysts in some of the Pantellerian pantellerites. The mineralogy of the type specimens from the two areas seemed to Johannsen (1932) to be so similar that, with the agreement of Washington (Johannsen, 1932, p. 66), he suggested that the term "comendite" be dropped in preference to the older term "pantellerite."

Despite the petrographic similarities, Lacroix (1927, 1930, 1934) was able to show that significant chemical differences existed between the more typical members of the two groups, but he also stressed that there was a continuous chemical transition between comendites and pantellerites and that any division made between them on these grounds would be purely arbitrary.

Some petrologists might question, from the evidence of the petrography and chemistry, whether it is necessary to separate the two groups. We feel that there are sufficient important differences to make such a distinction necessary: in particular, the feldspar-liquid relationships seem to be rather different, and this difference must be of importance in the petrogenesis of the two suites (Bailey and Macdonald, 1969, and unpub. data; Nicholls and Carmichael, 1969, p. 273). Similarly, the term "comendite" as used by us includes rocks which are so trivially peralkaline that some workers would call them alkali rhyolites. However, we prefer to retain the latter term for high-SiO<sub>2</sub> metaluminous compositions and to retain comendite for peralkaline rhyolites. This usage is not really an abuse of the original rock name. The type specimens from Sardinia cover a range in composition from those near pantellerite to metaluminous varieties (Johnsen, 1912).

Lacroix (1927) suggested that 12.5 percent normative femic minerals be used as an arbitrary division between comendites (<12.5 percent) and pantellerites. Noble (1968) has adopted this figure in a recent study of peralkaline rhyolite glasses. In order to incorporate the peralkaline trachytes into this classification, we have used a slightly modified version of Lacroix's division, based on normative femic minerals and normative quartz (fig. 5). The boundary line is arbitrary. In the area between 25 and 35 percent normative quartz, the new division is effectively the same as that of Lacroix and Noble, but in less siliceous compositions—that is, approaching Noble's (1968) trachytic soda rhyolites—the boundary is increasingly displaced towards increasingly femic compositions.

The division between trachyte and rhyolite is taken at the conventional 10 percent normative quartz, and

the composition field can now be split into the following four areas (fig. 5): A, comendites; B, pantellerites; C, comenditic trachytes; and D, pantelleritic trachytes. The analyses are compiled in tables 2-8 under these headings. These analyses are plotted in figure 5, the symbols representing the terminology used by the original authors. The old and new names agree fairly well, though compositions lying near the boundary line show some overlap. An example of this overlap is the suite of lavas (table 3, Nos. 91-103) from Mayor Island, New Zealand, which, according to figure 5, forms a series in the pantellerite field, spreading from types near the boundary to types well into the field. While Ewart, Taylor, and Capp (1968), on the basis of the report by Chayes and Zies (1962), and Noble (1968) have preferred to call the Mayor Island lavas pantellerites, Nicholls and Carmichael (1969) have termed them "comendites" and pointed out the differences between them and the type pantellerites. Chayes and Zies (1962) had implied that normative sodium metasilicate (ns) might be used to distinguish pantellerites from comendites because it seemed to be rare or absent in comendites but ubiquitous in (hyalo-) pantellerites. Subsequently, Ewart, Taylor, and Capp (1968, p. 123) termed the Mayor Island lavas "pantellerites" rather than comendites because of the presence in them of "a significant proportion of the normative ns molecule." This distinction is verified by the collection of analyses in tables 2-4. Of the comendites, 13 have no ns; the other 16 have <2 percent. All but three pantellerites have >2 percent ns, of which one from Sardinia (analysis 46) may be altered (p. N14). The low value in another, from Nevada (analysis 90), is due to making abnormally large amounts of NaF. It should be stressed here that this distinction applies to obsidians only. On crystallization, both comendites and pantellerites tend to lose alkalis, and ns is rare in crystalline varieties.

## PETROCHEMISTRY

The chemical features which distinguish peralkaline rhyolites, especially pantellerites, from alkaline and calc-alkaline rhyolites were clearly recognized by Lacroix (1927, 1930) and include high contents of Na, Fe, Mn, Ti, and Zr and low contents of Ca, Mg, and P. Most striking are the low molecular Al<sub>2</sub>O<sub>3</sub> contents, which by definition are less than the sum of molecular Na<sub>2</sub>O + K<sub>2</sub>O. More recent work has also shown that peralkaline rhyolite obsidians are strongly enriched in fluorine and chlorine (Bowen, 1937; Zies, 1960; Carmichael, 1962; Lovering, 1966; Noble, 1965, 1968; Noble and Haffty, 1969) and in the residual trace elements and are very depleted in certain other trace metals.

**CHEMICAL VARIATION IN COMENDITES AND PANTELLERITES**

Since rhyolite and trachyte magmas are largely composed of SiO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub>, Na<sub>2</sub>O, and K<sub>2</sub>O, systematic chemical differences between comendites and pantellerites should be revealed most clearly in the proportions of these elements. In figures 6 and 7 the analyses are plotted in the system (Na<sub>2</sub>O+K<sub>2</sub>O)-Al<sub>2</sub>O<sub>3</sub>-SiO<sub>2</sub>, using simple projections devised by Bailey and Macdonald (1969).

The more peralkaline nature of the pantellerites is easily shown in figure 6 by projecting lines from the SiO<sub>2</sub> apex through the sample points towards the alkali-alumina baseline. Such a line, with alkali-alumina ratio of 55.5:44.5, separates the two groups with almost no overlap.

The variation in alkali ratios is shown in figure 7. As the pantellerites are consistently more peralkaline than the comendites, the plotting of all the analyses in this single projection (Bailey and Macdonald, 1969) involves the loss of the dimension of SiO<sub>2</sub> content. The

value 100 Na<sub>2</sub>O/(Na<sub>2</sub>O+K<sub>2</sub>O) and the alumina content are, however, unambiguously represented. Both groups show a range of values of 100 Na<sub>2</sub>O/(Na<sub>2</sub>O+K<sub>2</sub>O), the pantellerites between 64 and 77, and the comendites between 56 and 72. All those comendites with values >66 are from three localities—New Guinea, Easter Island, and Iceland. They are only marginally peralkaline: their alkali ratios are more akin to those of metaluminous rhyolites. Eleven of the thirteen pantellerites with values <66 are from one volcano at Chabbi, Ethiopia (table 3, Nos. 69–79) (Macdonald and Gibson, 1969), and one is a Sardinian lava which is possibly altered (Noble and Haffty, 1969, p. 508). With the exception of these specimens, there is a general tendency for the pantellerites to show higher Na<sub>2</sub>O/K<sub>2</sub>O ratios (fig. 11).

In the rhyolites the progression from comendite to pantellerite is marked by an increase in peralkalinity, and since, during normal fractionation processes more evolved liquids are usually increasingly peralkaline (Carmichael and MacKenzie, 1963; Bailey and Schairer,

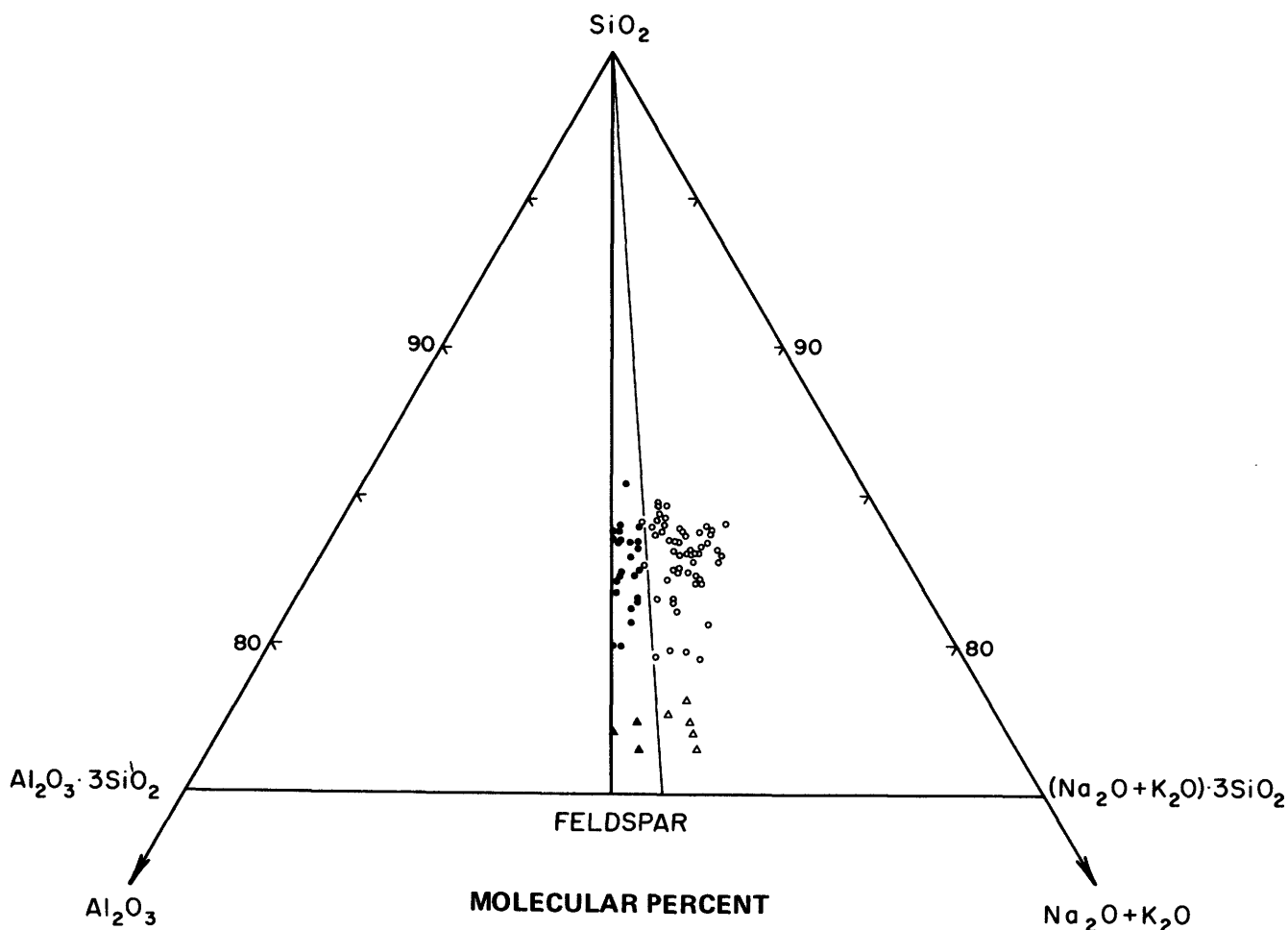


FIGURE 6.—Part of a molecular SiO<sub>2</sub>-Al<sub>2</sub>O<sub>3</sub>-(Na<sub>2</sub>O+K<sub>2</sub>O) diagram showing available analyses of comendites (●), pantellerites (○), comenditic trachytes (▲), and pantelleritic trachytes (△). The thin line that is radial from the SiO<sub>2</sub> apex represents the apaitic index (Na<sub>2</sub>O+K<sub>2</sub>O):Al<sub>2</sub>O<sub>3</sub>::55.5:44.5 and effectively separates comenditic from pantelleritic rocks.

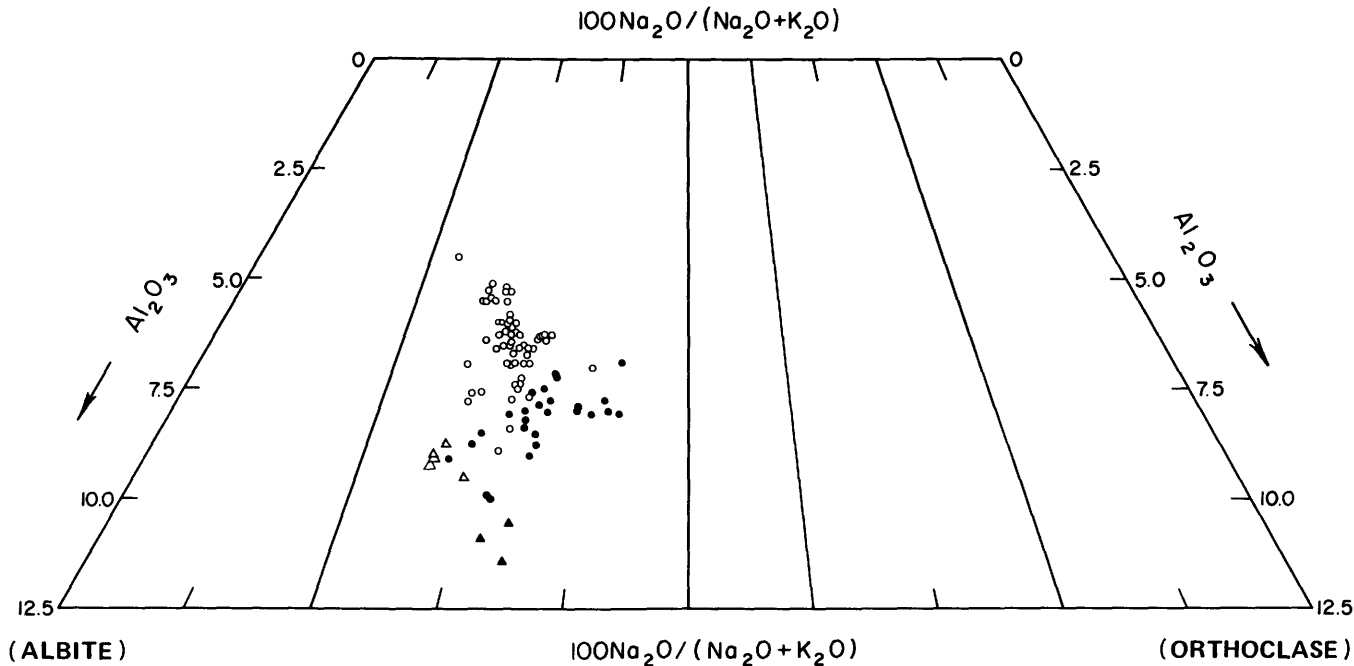


FIGURE 7.—Variation in  $\text{Na}_2\text{O}/(\text{Na}_2\text{O}+\text{K}_2\text{O})$  in comenditic and pantelleritic obsidians (including trachytic varieties). Symbols as in figure 6. See text for explanation. The pantellerite having  $100\text{Na}_2\text{O}/(\text{Na}_2\text{O}+\text{K}_2\text{O})=59.8$  is from Sardinia (analysis 46) and has possibly lost some of its original sodium content.

1964), the most useful representation of the chemical variation between the two groups is in terms of increasing peralkalinity, of which the simplest measure is the agpaitic index  $(\text{Na}_2\text{O}+\text{K}_2\text{O})/\text{Al}_2\text{O}_3$ .

In the series peralkaline trachyte to rhyolite, the variation in  $q$  is more marked than change in agpaitic

index. To describe the chemical variation over the whole range of oversaturated peralkaline obsidians then requires three variables: agpaitic index, normative quartz, and the unknown (for example, element or element ratio). This involves the use of three-axes diagrams, the contouring of rectilinear diagrams, or the placing of rela-

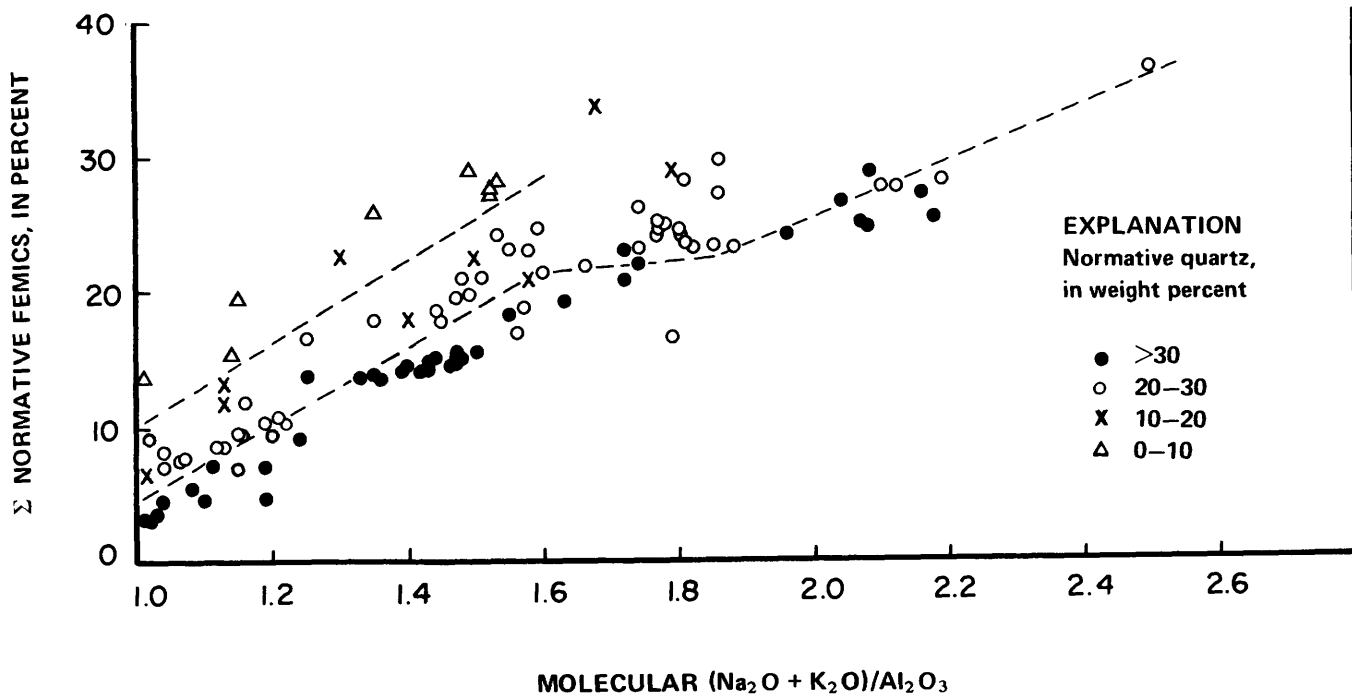


FIGURE 8.—Sum of normative feldspars plotted against agpaitic index  $(\text{Na}_2\text{O}+\text{K}_2\text{O})/\text{Al}_2\text{O}_3$  for all analyses of comenditic and pantelleritic obsidians (including trachytic varieties). Dashed lines show approximate boundaries of normative quartz contents.

tively narrow limits on the range of quartz contents shown in any diagram. The contouring method has been used with reasonable success in figures 8 and 9, but the scarcity of analysis of rocks with less than 20 percent q makes it difficult to extend the contours towards the trachytic rocks. We have, therefore, chosen the third alternative to display the variation in chemistry of comendites and pantellerites and have plotted in figures 10, 11, 14, and 15 only those analyses where the q content is greater than 20 percent. Only 9 trachytes and 10 specimens with  $10 < q < 20$  have been omitted by this scheme.

Correlation coefficients for all pairs of the following variables have been computed (table 9): all major elements, agpaite index, Fe as FeO,  $FeO / (FeO + Fe_2O_3)$ , and  $Na_2O / K_2O$ . All analyses were used for these calculations, such that the maximum degrees of freedom were 111. Any correlation  $> 0.25$  is significant at the 1-percent level. As the relationships between agpaite index and various elements and element ratios shown diagrammatically in figures 10 and 11 are based only on

rocks with normative quartz  $> 20$  percent, their correlation coefficients will be slightly different (and usually higher) than those given in table 9.

*Silicon.*—Though comendites have generally higher values of  $SiO_2$  than the pantellerites, there is a considerable scatter within each group. Part of the scatter may be a result of variable quartz fractionation (Ewart and others, 1968; Bailey and Macdonald, 1969), but the free  $SiO_2$  content does appear to show a nonsystematic variation (Noble, 1968). A group of high silica pantellerites may be distinguished from those from the type area (p. N14).

*Titanium.*—The increase in  $TiO_2$  with increasing agpaite index is irregular, but statistically significant (table 9). The highest values are between 0.6 and 0.7 percent.

*Aluminum.*—The regular decrease in  $Al_2O_3$  from comendite to pantellerite has already been stressed by Noble (1968). It is notable that 11 percent  $Al_2O_3$  effectively separates the two groups, only four rocks being exceptional in this case, one of them being the Sardinian

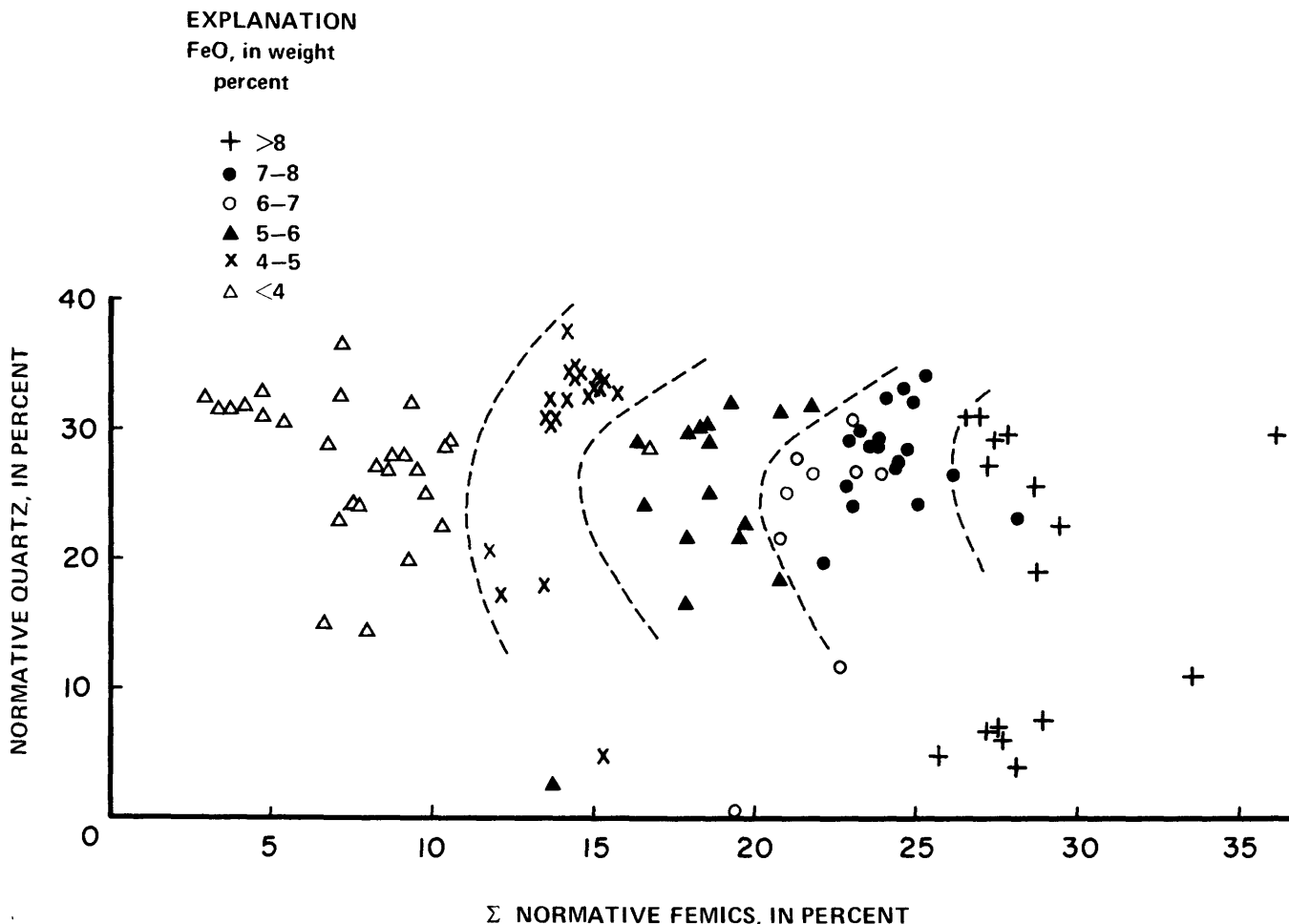


FIGURE 9.—Sum of normative femics plotted against normative quartz for all analyses of comenditic and pantelleritic obsidians (including trachytic varieties). Dashed lines show approximate boundaries of FeO values.



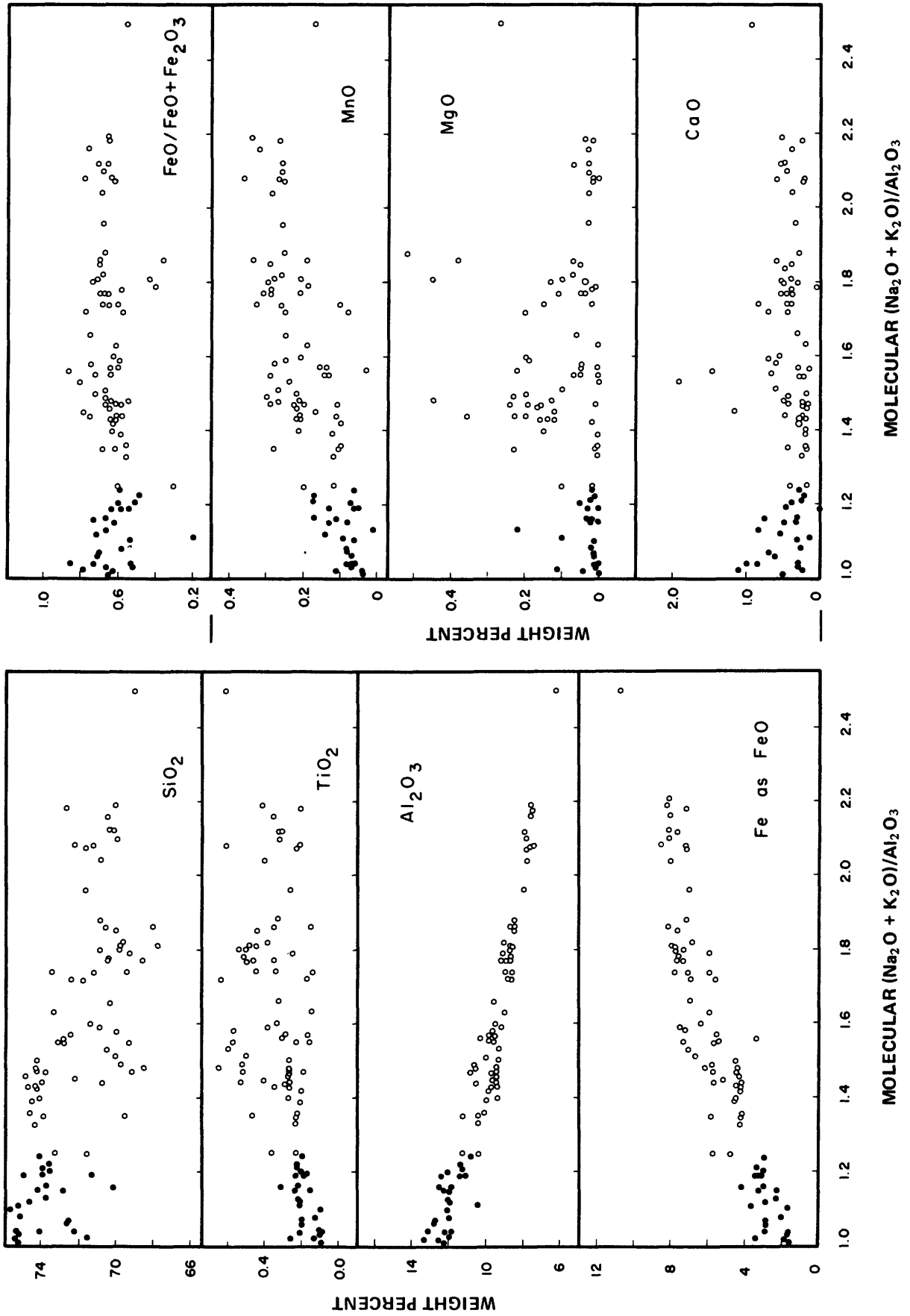


FIGURE 10.—Variation diagrams for SiO<sub>2</sub>, TiO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub>, FeO, FeO/(FeO+Fe<sub>2</sub>O<sub>3</sub>), MnO, MgO, and CaO versus agpaitic index in comendites (●) and pantellerites (○). Only rocks with >20 percent normative quartz have been plotted.

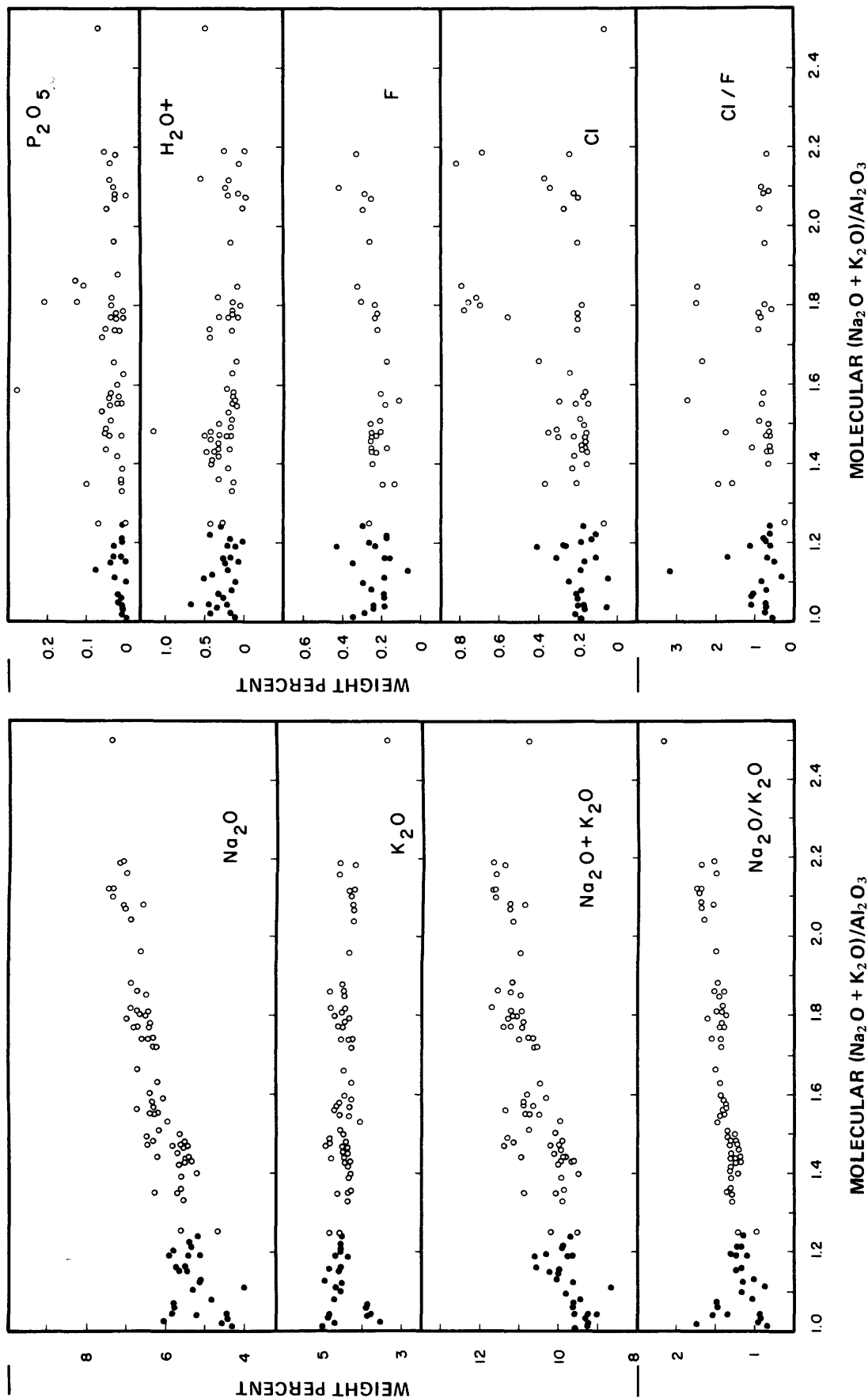


FIGURE 11.—Variation diagrams for  $\text{Na}_2\text{O}$ ,  $\text{K}_2\text{O}$ ,  $\text{Na}_2\text{O}+\text{K}_2\text{O}$ ,  $\text{Na}_2\text{O}/\text{K}_2\text{O}$ ,  $\text{P}_2\text{O}_5$ ,  $\text{H}_2\text{O}+$ ,  $\text{F}$ ,  $\text{Cl}$ , and  $\text{Cl}/\text{F}$  versus agpaite index in comendites (●) and pantellerites (○). A pantellerite from Nevada (analysis 90) with  $\text{F} = 1.30$  percent, has been omitted from the fluorine diagram. Only rocks with  $>20$  percent normative quartz have been plotted.

comendite (analysis 1) suspected of being altered (p. N14).

*Iron.*—Noble (1968) has also demonstrated the remarkably regular increase of iron with increasing peralkalinity and 4 percent iron as FeO makes a very effective boundary between the groups. Noble, Chipman, and Giles (1968) have already proposed a 4 percent total of FeO and MnO as a simple parameter for distinguishing comendites and pantellerites. This parameter is potentially useful in that it may survive devitrification and recrystallization.

The ratio  $\text{FeO}/(\text{FeO} + \text{Fe}_2\text{O}_3)$  shows a relatively restricted range, most analyses falling between 0.55 and 0.75. Peralkalinity varies directly with total iron, therefore, but is independent of oxidation state. The two Sardinian specimens (analyses 1 and 46) have exceptionally low values of the ratio, and two of the remaining three rocks with  $<0.5$  are Pantellerian rocks analyzed by Romano (1968).

*Manganese.*—Table 9 and figure 10 show a highly significant increase of MnO in the pantellerites.

*Magnesium.*—Figure 10 shows a wide scatter of points. Noble, Haffty, and Hedge (1969) have claimed that most comenditic and pantelleritic glasses contain  $<0.05$  percent MgO. Our data indicate that half of the pantellerites have  $\text{MgO} > 0.05$  percent. This result does not occur simply because of our dealing with whole rocks rather than with glasses, as the tielines joining available rock-glass pairs indicate (fig. 12). However, this point cannot be emphasized, because of the known difficulties of analyzing for Mg in low concentrations. For example, of the five analyses with  $\text{MgO} > 0.3$  percent, three are Pantellerian pantellerites analyzed by Romano (1968, 1969). Since earlier analyses by Washington, Zies, and Carmichael of similar rocks do not show such high MgO figures, Romano's values may possibly be too high.

*Calcium.*—Figure 10 shows a scatter of points. The data do not support Noble's (1968) suggestion that CaO is on the average higher in pantellerites than in comendites.

*Sodium and potassium.*—Whereas  $\text{K}_2\text{O}$  remains fairly constant,  $\text{Na}_2\text{O}$  increases steadily with agpaite index. As a result,  $\text{Na}_2\text{O} + \text{K}_2\text{O}$  and  $\text{Na}_2\text{O}/\text{K}_2\text{O}$  also rise in the pantellerites (fig. 7).

*Phosphorus.*— $\text{P}_2\text{O}_5$  is uniformly very low, only 11 percent of the specimens having values  $>0.05$  percent.

*Water.*—Water is low, only four samples having  $\text{H}_2\text{O} + > 0.5$  percent. Because pulverized nonhydrated glasses tend to adsorb water during sample preparation, many analyses of  $\text{H}_2\text{O} +$  in these rocks are probably slightly high. Thus, the average figure for our compilation ( $\text{H}_2\text{O} + = 0.23$  percent in 88 samples, omitting analysis 44 which may be partly hydrated) may most

closely approach the true amount of water in peralkaline rhyolite magmas ( $q > 20$  percent).

An unexplained feature of  $\text{H}_2\text{O} +$  distribution between crystals and glasses in certain pantellerites is shown in figure 12. In all specimens, the glass analysis shows lower  $\text{H}_2\text{O} +$  than the bulk rock, yet none of the analyzed phenocryst minerals from the sample (Carmichael, 1962) appear to contain sufficient water to satisfy the bulk figure.

*Fluorine and chlorine.*—Most specimens contain between 0.15 and 30 percent fluorine; several rocks from Kenya and one from Nevada have exceptionally high values. Chlorine content is variable and is generally less than 0.4 percent. Of 12 analyses with chlorine  $>0.4$  percent, nine are from Pantelleria, one is from Nevada, and two are from Kenya. This chlorine enrichment results in abnormally high chlorine-fluorine ratios for the Pantellerian lavas (Noble and Haffty, 1969, p. 506). Noble and Haffty also suggest that "most silicic glasses of both peralkaline and nonperalkaline chemistry appear to contain significantly more F than Cl \* \* \*. The Sardinian specimens, which have Cl contents of 0.1 percent or less \* \* \* appear more normal in this aspect of their chemistry." Our data indicate that this is not true for comendites, at least, and that the Sardinian specimens (analyses 1 and 46) have the lowest chlorine-fluorine ratios of all the samples and cannot therefore be considered typical.

*Summary.*—Although there is a complete chemical transition between the two groups, pantellerites are by definition more femic than comendites. They are also more peralkaline (fig. 6); an agpaite index of 1.25 is, with very few exceptions, the maximum for comendites and the minimum for pantellerites. Four percent iron as FeO and 11 percent  $\text{Al}_2\text{O}_3$  also seem to distinguish the two groups very effectively.

The chemistry of those rhyolites with  $>20$  percent normative quartz is marked by an extremely regular variation in agpaite index, iron, manganese, and  $\text{Na}_2\text{O}/\text{K}_2\text{O}$  (figs. 10 and 11; compare Noble, 1968). The statistical analysis (table 9) makes it clear that there are strong positive correlations between  $\text{Na}_2\text{O}$  and iron as FeO (correlation coefficient  $r = 0.83$ ),  $\text{Na}_2\text{O}$  and MnO ( $r = 0.71$ ), and MnO and iron as FeO ( $r = 0.84$ ) for all peralkaline silicic obsidians. All three oxides also show significant increase with increasing  $\text{TiO}_2$  ( $r > 0.66$ ). Other marked features are the strong negative correlations between  $\text{SiO}_2$  and each of  $\text{Na}_2\text{O}$ , iron as FeO, MnO, CaO, and  $\text{TiO}_2$ .

#### SUBGROUPS WITHIN THE COMENDITES

During this study we had full analyses of only 29 comenditic obsidians, an insufficient sample to justify the establishment of rigid chemical subgroups. Further-

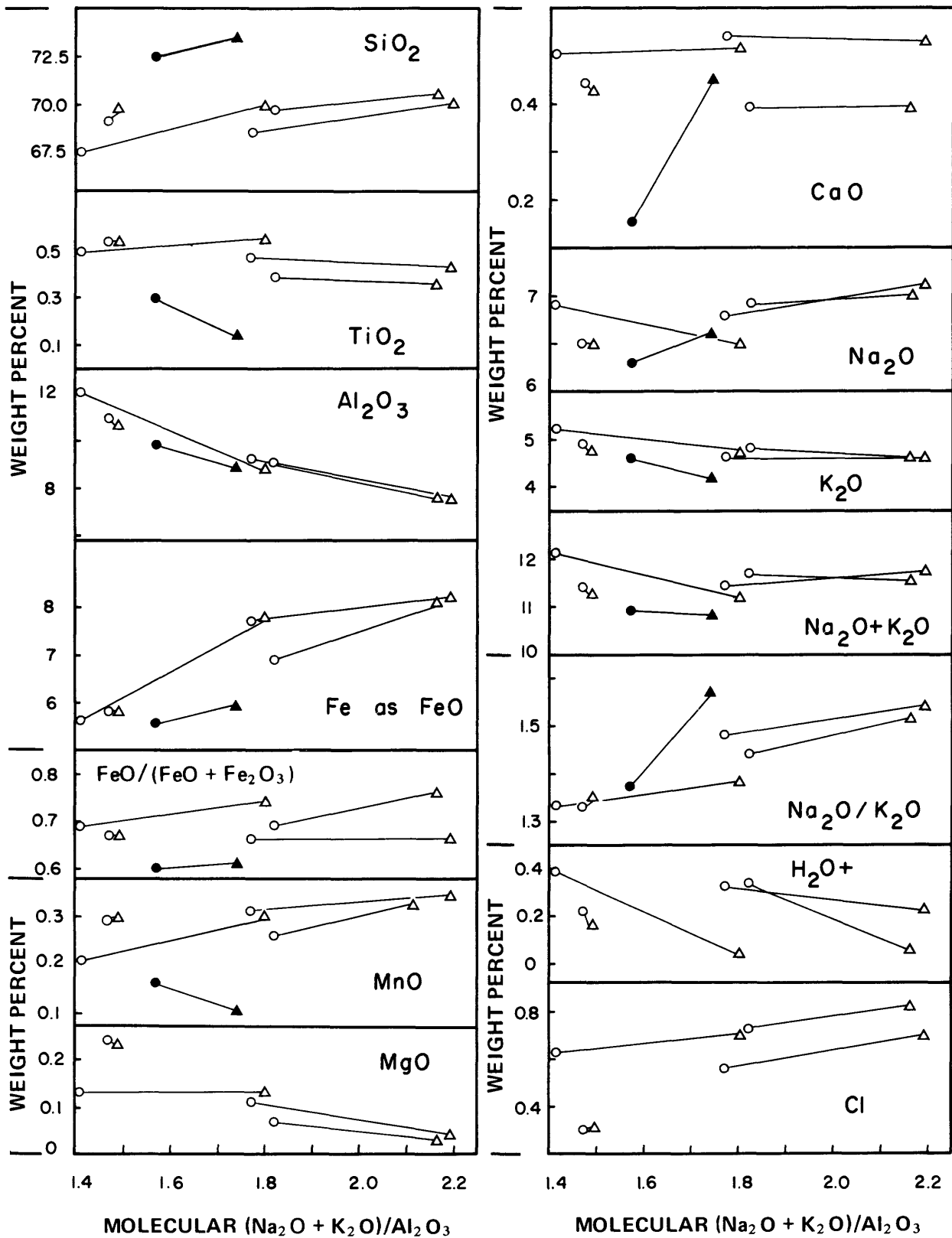


FIGURE 12.—Variation diagrams using agpaite index  $(\text{Na}_2\text{O} + \text{K}_2\text{O})/\text{Al}_2\text{O}_3$  as abscissa. Tielines connect whole-rock (circles) and glass (triangles) pairs.  $\circ-\Delta$ , Pantelleria (analyses 33-40).  $\bullet-\blacktriangle$ , Mayor Island, New Zealand (analyses 97, 98).

more, whereas the pantellerites have distinctive chemical features, the comendites are a more heterogeneous group, grading into the wider spectrum of calc-alkaline rhyolites. A few useful generalizations may be made about variation within the group.

A glassy comendite from Sardinia (analysis 1) has been described by Chayes and Zies (1962), along with a glassy pantellerite (analysis 46) termed "comendite" by Chayes and Zies (1964). Both rocks, however, have low values of  $\text{FeO}/(\text{FeO} + \text{Fe}_2\text{O}_3)$ ,  $\text{Cl}/\text{F}$ , and  $\text{Na}_2\text{O}/\text{K}_2\text{O}$ , while the comendite seems to have a low  $\text{Na}_2\text{O}$  value and perhaps high  $\text{H}_2\text{O}$ . These features, together with the color of the specimens described by Chayes and Zies as bluish gray, make us suspect that these Sardinian specimens are altered (hydrated?), a conclusion already reached by Noble and Haffty (1969), partly on the basis of the low sodium contents.

Two very broad subgroups can be distinguished among the comenditic obsidians: Subgroup A, those from Ethiopia, Kenya, western United States, and western Iceland, and subgroup B, those from Ascension, Bouvet, and Easter Islands, New Guinea, and also one specimen from eastern Iceland (analysis 16). With the obvious exception of the western Icelandic rocks, this grouping corresponds to the division of comenditic obsidians into continental and oceanic types by Bailey and Macdonald (1970). The main difference between them is that subgroup A is more siliceous, all having >25 percent normative quartz, whereas rocks of subgroup B have <25 percent. This more siliceous character is, as might be expected, accompanied by slightly lower  $\text{Al}_2\text{O}_3$ ,  $\text{FeO}$ ,  $\text{TiO}_2$ , and  $\text{CaO}$ . An interesting distinction is that fluorine content is greater than chlorine content in subgroup A, whereas the situation is reversed in subgroup B. The ratios of  $\text{Na}_2\text{O}$  to  $\text{K}_2\text{O}$  also tend to be different;  $\text{Na}_2\text{O}/\text{K}_2\text{O}$  in subgroup A ranges from 0.86 to 1.24 and in subgroup B ranges from 1.17 to 1.26 in rocks from Bouvet and Ascension Islands and from 1.36 to 1.71 in rocks from Easter Island and eastern Iceland. The higher values in these last obsidians are a result of low  $\text{K}_2\text{O}$  contents, the only rhyolites in the compilation having less than 4 percent  $\text{K}_2\text{O}$ , except for one pantellerite from Fantālē volcano, Ethiopia (analysis 54).

#### SUBGROUPS WITHIN THE PANTELLERITES

The chemistry of the pantellerites is more distinctive than that of the comendites, and their unusual characteristics have made them widely studied. We distinguish two transitional subgroups: Subgroup A, those from the type area, Pantelleria, and closely similar rocks from Chad, Ethiopia, Kenya, Nevada, and Socorro Island and subgroup B, a high-silica group. The high-silica group is not the same as the "quartz-pantellerite" subdivision of Johanssen (1932). Rocks from both of our

subgroups may carry quartz phenocrysts. The best developments of high-silica pantellerites are in the volcanoes of Mayor Island, New Zealand, and Chabbi, Ethiopia; some specimens from Mayor Island are, however, akin to type pantellerites (subgroup A) and this similarity has produced some confusion of nomenclature in the literature.

The high-silica pantellerites differ from the type hyalopantellerites not only in their higher  $\text{SiO}_2$  values, but also in lower  $\text{TiO}_2$  and  $\text{CaO}$  (fig. 13). They are also lower in iron (as  $\text{FeO}$ ). All the Chabbi rocks and some of those from Mayor Island also have lower  $\text{Na}_2\text{O}/\text{K}_2\text{O}$  ratios, and the subgroup may be considered as transitional towards the comendites. The Chabbi lavas have higher  $\text{TiO}_2$  and  $\text{MnO}$  contents than the Mayor Island lavas.

Within subgroup A, the exceedingly high chlorine contents of the Pantellerian rocks have already been mentioned (p. N12); certain of the Tibesti and Fantālē obsidians are rich in  $\text{CaO}$  (fig. 10).

The only published analysis (table 3, No. 104) of a subgroup A pantellerite in the ocean basins is from Socorro (Bryan, 1970). A recently discovered glassy pantelleritic dike on Iceland (Haraldur Sigurdsson, written commun., 1969) is transitional to the high silica group in having low  $\text{FeO}$ ,  $\text{TiO}_2$ , and  $\text{CaO}$  contents. In view of this scarcity of strongly peralkaline rocks in the oceans, Coombs' (1963) use of the term "pantellerite trend" to describe the oceanic alkali basalt-rhyolite series could be more accurately replaced by the term "comenditic trend" of Chayes (1970). Similarly, the "impression" gained by Bailey and Schairer (1966, p. 149) that oceanic lavas are more clearly peralkaline than continental was mistaken.

Further data will almost certainly modify the generalizations made in this section, but a closer definition of subgroups within both comendites and pantellerites may well prove petrogenetically useful.

#### TRACHYTE OBSIDIANS

Analyses of nonhydrated peralkaline trachytic glasses are exceedingly rare in the literature. Only seven published analyses and two analyses made recently at Reading are given in table 4. This scarcity seems to reflect a true scarcity of these rocks in nature, East Africa being the only area where oversaturated glassy trachytes appear to crop out in any abundance. The East African trachytes are strongly peralkaline; comenditic trachyte magma may be rarer still if comendites can be derived from metaluminous trachytes. For petrogenetic purposes it might have been instructive to include analyses of these metaluminous types in the compilation, but this inclusion would have widened the scope of the work far beyond our original intentions.

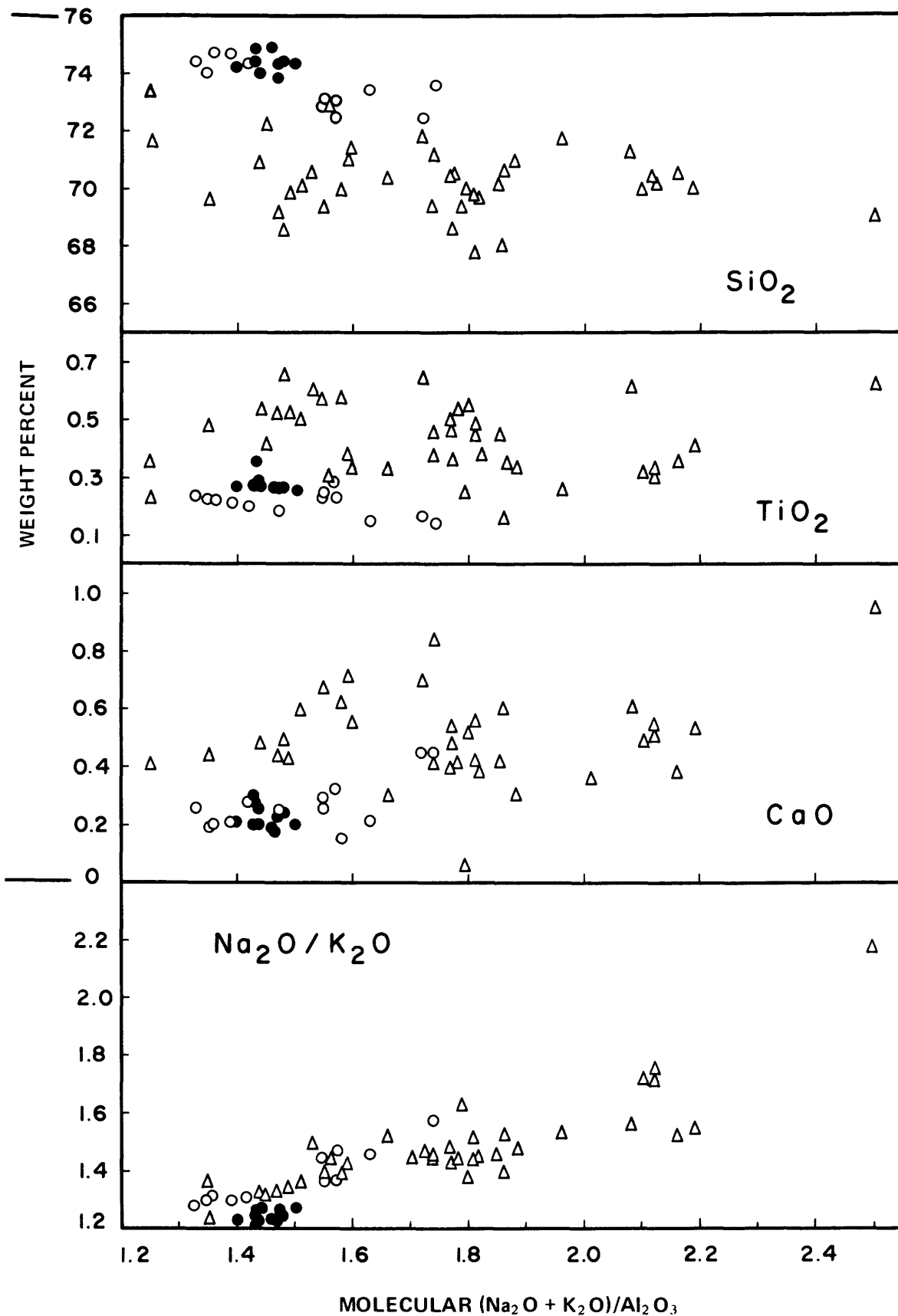


FIGURE 13.—Variation diagrams showing the subgroups within the pantellerites. High-silica pantellerites: ●, Chabbi, Ethiopia; ○, Mayor Island, New Zealand. △, Pantellerian pantellerites and similar types. The Sardinian specimen (analysis 46) has been omitted. Rocks having CaO > 1 percent were also omitted from the CaO diagram to preserve the scale.

In view of the importance of trachytes in the study of peralkaline rhyolites (Carmichael and MacKenzie, 1963; Bailey and Schairer, 1964), we prefer merely to stress the paucity of data on peralkaline trachytic glasses and to single out this field of research as requiring immediate attention.

Of the three analyses plotting in the comenditic trachyte field (fig. 5), one (analysis 107) is almost certainly a pantellerite trachyte which has lost alkalis on devolatilization and which has been enriched in cumulus feldspar phenocrysts (Macdonald and others, 1970). The two remaining analyses (analysis 105 from Kerguelen and 106 from Pitcairn Island) are both of oceanic trachytes.

The pantelleritic trachytes are all from central Kenya. Compared to the pantellerites with which they are broadly associated, they are enriched predictably in  $Al_2O_3$ ,  $TiO_2$ ,  $Fe_2O_3+FeO$ ,  $MnO$ ,  $MgO$ , and  $CaO$ . Rather surprisingly perhaps, these trachytes are only marginally less peralkaline than the pantellerites; the significance of this feature has been discussed by Macdonald, Bailey, and Sutherland (1970).

#### TRACE ELEMENTS

One aim of the geochemist is to determine as accurately as possible the behavior of trace elements during magmatic processes, and it is important, therefore, that the rocks studied be representative of the composition of the magmas from which they were formed. Available data indicate that this is not normally the case in crystallized peralkaline silicic rocks, because various minor elements may be lost during devitrification and (or) hydration (Noble, 1968; Rosholt and Noble, 1969) or during the slower cooling of plutonic bodies, losses apparently connected with the high mobility of the residual traces in fugitive alkaline solutions. As was the case for the major elements, it is necessary to use only nonhydrated glasses to estimate the true magmatic abundances. Very few trace element analyses have been published, especially of comenditic obsidians, and we have accordingly started an analytical program to try to fill some of the more critical gaps. The results for 13 elements, taken from Ray Macdonald, D. K. Bailey, and G. R. Angell (unpub. data) are given in table 7, and published data are compiled in table 5. Table 5 is not exhaustive, as we have used only those specimens for which acceptable major element analyses are also available.

The limited data available (table 5) indicate that, relative to the "average granite" (Taylor, 1964; Taylor and White, 1966) and calc-alkaline rhyolites from New Zealand (Ewart and others, 1968) and Arran, Scotland (Nicholls and Carmichael, 1969), the comendites and pantellerites show strong enrichment in Hf, La, Mo, Nb,

Ta, Y, Yb, Zn, and Zr, and moderate to strong enrichment in B, Be, Cd, Ga, Li, Sn, and perhaps Th and U. This enrichment is accompanied by a very marked depletion in Ba, Cr, Sr, V, and probably Sc. Concentrations of Co, Cs(?), Cu, Ni, Pb, and Rb seem to be similar to those in calc-alkaline types, except for those pantellerites with high agpaitic index, which may show enrichment in rubidium. Data from Mayor Island (Ewart and others, 1968) also indicate a strong enrichment in rare earths (analyses 91-95, tables 5 and 6).

#### VARIATIONS IN COMENDITES AND PANTELLERITES

As a result of the scarcity of data for the comendite obsidians, this discussion must be restricted to barium, copper, nickel, strontium, lead, rubidium, thorium, yttrium, cerium, lanthanum, niobium, zinc, and zirconium. Figures 14 and 15 show the variations of some of these elements with respect to the agpaitic index.

*Barium.*—Most pantellerites are strongly depleted in barium, except for those from Gariboldi volcano, Ethiopia, where barium values reach 680 ppm (parts per million). Barium values as high as 600 ppm from the vitreous parts of a pantelleritic welded ash-flow tuff which erupted from the nearby volcano Fantālē (Gibson, 1970) indicate that the Fantālē rocks may also be relatively barium-rich. On the other hand, Chabbi volcano, part of the same chain of Quaternary pantellerite volcanoes on the Ethiopian Rift Valley floor, is more "normal," with barium values in the pantellerites between 50-60 ppm.

The oceanic comendites of Bouvet and Easter Islands also show relative barium enrichment.

*Copper.*—All specimens are uniformly low in copper. Only a comendite from Nevada (analysis 12) contains >12 ppm.

*Nickel.*—All specimens are also low in nickel; 10 ppm is the maximum value recorded, and most rocks contain <5 ppm.

*Strontium.*—The pantellerites have strontium values as high as 12 ppm. The higher values in the comendites, as much as 42 ppm, might be expected as these rocks are transitional to calc-alkaline rhyolites (table 5). The claim by Noble, Haffty, and Hedge (1969) that most peralkaline glasses have <5 ppm strontium is only partly true, even for the pantellerites. Using this figure as the normal maximum amount, they noted that some Pantellerian specimens then had "anomalously" high strontium values, but the new data show that this feature is shared by many of the Gariboldi flows, whereas Gibson (1970) reports strontium values as high as 40 ppm from glassy lenses in the Fantālē welded tuff. Barberi, Borsi, Ferrara, and Innocenti (1969) have given values of 13 and 14 ppm for two pantellerites from Pantelleria. The spread of strontium concentra-

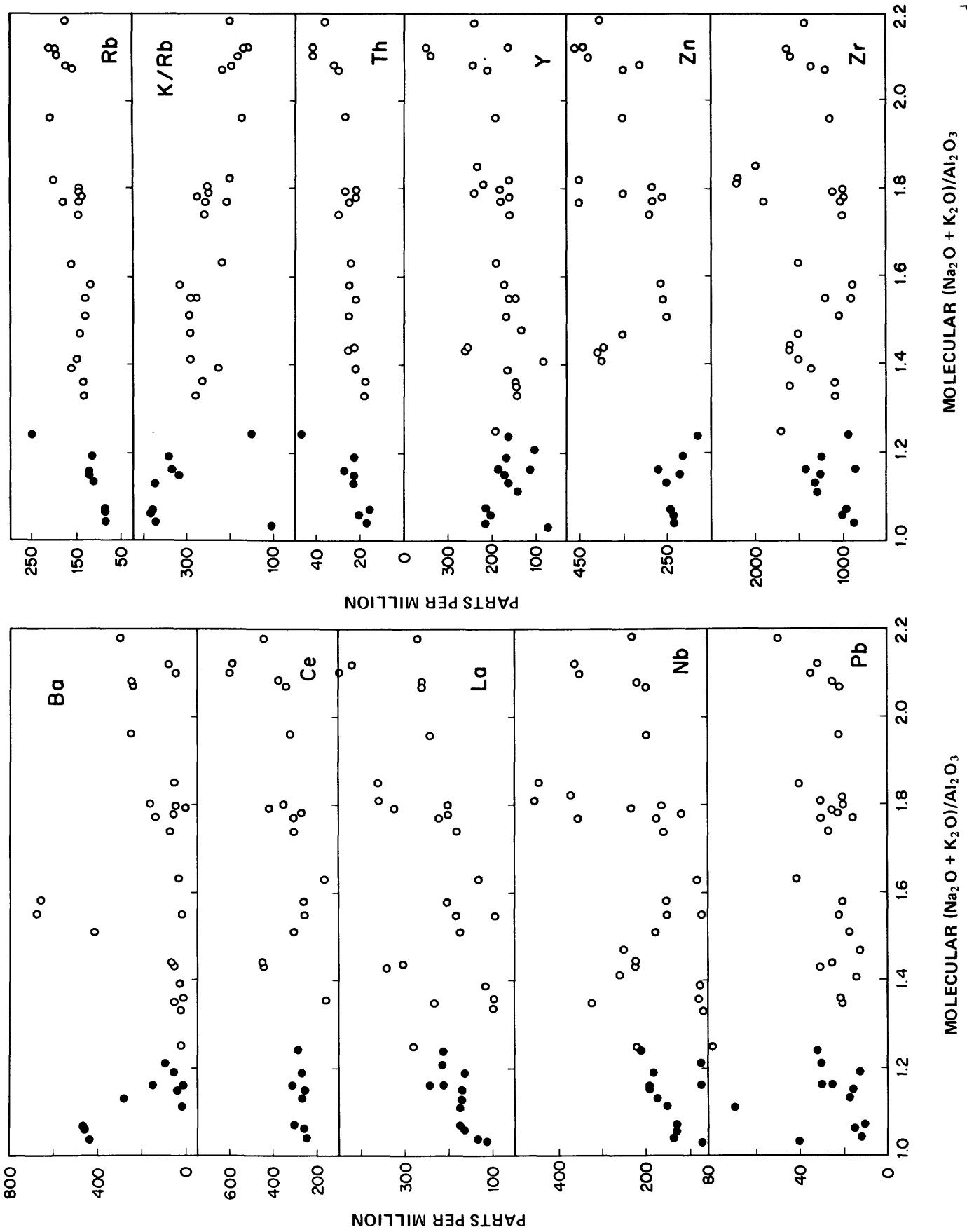


FIGURE 14.—Variation diagrams for trace elements in comendites and pantellerites: ●, comendite; ○, pantellerite. To preserve the scale, analysis 90 has been omitted from all but the barium diagram, analysis 11 from the zirconium diagram, and analysis 15 from the niobium diagram.



tions is therefore larger than that indicated by Noble, Haffty, and Hedge (1969), who seem to have been influenced by the analyses of comenditic glasses from the western United States, which do have <5 ppm strontium.

*Lead, rubidium, thorium, and yttrium.*—Only a narrow range of concentrations is shown for rubidium, thorium, yttrium, and lead, and there is no tendency for these elements to co-vary with agpaite index. There is a slight decrease in K/Rb ratio in more peralkaline rocks.

*Cerium, lanthanum, niobium, zinc, and zirconium.*—These five elements are grouped together because, although there is a wide scatter of points in the pantellerites for each, it can be shown that the scatter is largely due to marked relative differences in concentrations in rocks from different areas. Thus the pantellerites from Pantelleria, Chabbi, and central Kenya generally contain more lanthanum, niobium, and zinc, and those from Chabbi and central Kenya, more cerium than those from Gariboldi, which in turn are enriched in cerium, lanthanum, and niobium compared to the Mayor Island rocks (fig. 15). The Pantellerian specimens are particularly enriched in niobium and zirconium. In contrast to these four elements, the Mayor Island pantellerites are not depleted in zirconium; they contain amounts comparable to the Chabbi and Pantellerian rocks and rather more than the Gariboldi specimens.

Despite these areal variations, within each suite there is a tendency for Ce, La, Nb, Zn, and Zr to increase with increasing agpaite index, a feature best displayed by the Gariboldi rocks (fig. 15).

#### TRACE ELEMENTS IN PERALKALINE TRACHYTES

Data are available for only four pantelleritic and one comenditic trachyte glasses (table 8), all of which were collected in central Kenya. Their trace element contents are similar to those of the Kenyan pantellerites and lie within the composition ranges of all pantellerites.

#### DISCUSSION

The remarkably regular variation shown by the major elements in the comendites and pantellerites is not also shown by the trace elements (fig. 14). Though there is a tendency within individual suites for elements such as Ce, La, Nb, Zn, and Zr to increase in more peralkaline rocks, superimposed on the trends are large differences in abundances due to geographical location. It is possible, for example, to distinguish the lavas of Gariboldi volcano from those of Pantelleria on the basis of their trace element contents, whereas the pantellerite from Nevada has considerably higher values of the

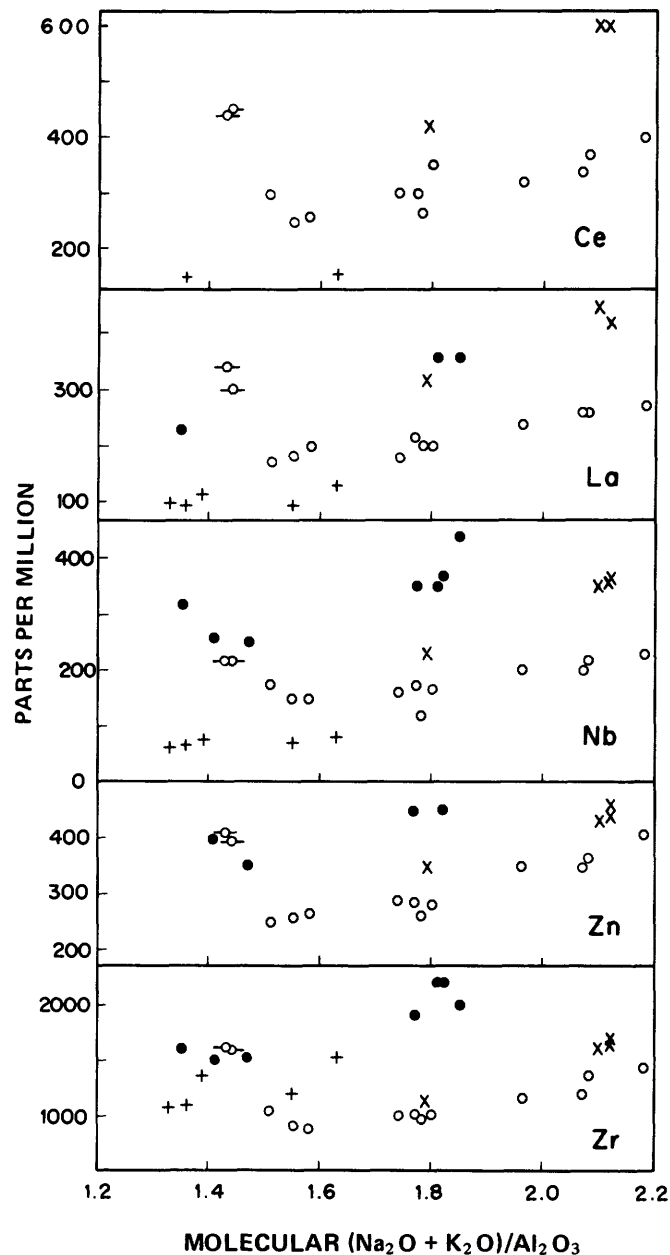


FIGURE 15.—Variation diagrams showing trace element associations in pantellerites. X, Kenya; +, Mayor Island; -O-, Chabbi; ●, Pantelleria; ○, Gariboldi. Data from tables 5 and 7. The pantellerite from Nevada (analysis 90) has been omitted from the diagram to preserve the scale.

residual elements than any other analyzed peralkaline glass. The subgroups so distinguished are not the same as those based on the major element analyses. The Chabbi rocks, belonging to the high-silica group of pantellerites, have a trace element suite broadly similar to those of the type pantellerites, and the Gariboldi rock was classed as a type pantellerite on the basis of major elements. The preliminary data seem to indicate the possibility that each volcano is characterized by its trace element association and that the differences be-

tween volcanoes mark real differences in the minor-element chemistry of the source materials.

## REFERENCES

- Bailey, D. K., and Macdonald, Ray, 1969, Alkali-feldspar fractionation trends and the derivation of peralkaline liquids: *Am. Jour. Sci.*, v. 267, p. 242-248.
- 1970, Petrochemical variations among mildly peralkaline (Comendite) obsidians from the oceans and continents: *Contr. Mineralogy and Petrology*, v. 28, p. 340-351.
- Bailey, D. K., and Schairer, J. F., 1964, Feldspar-liquid equilibria in peralkaline liquids—the orthoclase effect: *Am. Jour. Sci.*, v. 262, p. 1198-1206.
- 1966, The system  $\text{Na}_2\text{O}-\text{Al}_2\text{O}_3-\text{Fe}_2\text{O}_3-\text{SiO}_2$  at 1 atmosphere, and the petrogenesis of alkaline rocks: *Jour. Petrology*, v. 7, p. 114-170.
- Barberi, Franco, Borsi, S., Ferrara, G., and Innocenti, F., 1969, Strontium isotopic composition of some recent basic volcanites of the southern Tyrrhenian Sea and Sicily Channel: *Contr. Mineralogy and Petrology*, v. 23, p. 157-172.
- Bertolio, Sollmann, 1895, Sulle comenditi, nuovo gruppo di rioliti con aegirina: *Accad. Lincei Roma, Rend.*, v. 4, p. 48-50.
- Bowen, N. L., 1937, Recent high-temperature research on silicates and its significance in igneous geology: *Am. Jour. Sci.*, 5th ser., v. 33, p. 1-21.
- Broch, O. A., 1946, Two contributions to Antarctic petrography: *Norske Vidensk.-Acad. Oslo, Norwegian Antarctic Exped. Sci. Results*, v. 2, no. 25, 32 p.
- Bryan, W. B., 1970, Alkaline and peralkaline rocks of Socorro Island, Mexico: *Carnegie Inst. Washington Year Book* 68, 1968-69, p. 194-200.
- Butler, J. R., and Smith, A. Z., 1962, Zirconium, niobium and certain other trace elements in some alkali igneous rocks: *Geochim. et Cosmochim. Acta*, v. 26, p. 945-953.
- Butler, J. R., and Thompson, A. J., 1967, Cadmium and zinc in some alkali acidic rocks: *Geochim. et Cosmochim. Acta*, v. 31, p. 97-105.
- Carmichael, I. S. E., 1962, Pantelleritic liquids and their phenocrysts: *Mineralog. Mag.*, v. 33, No. 257, p. 86-113.
- 1967, The iron-titanium oxides of salic volcanic rocks and their associated ferromagnesian silicates: *Contr. Mineralogy and Petrology*, v. 14, p. 36-64.
- Carmichael, I. S. E., and MacKenzie, W. S., 1963, Feldspar-liquid equilibria in pantellerites—an experimental study: *Am. Jour. Sci.*, v. 261, p. 382-396.
- Chayes, Felix, 1970, Rhyolites of the oceanic islands. *Carnegie Inst. Washington Year Book* 68, 1968-69, p. 177.
- Chayes, Felix, and Zies, E. G., 1962, Sanidine phenocrysts in some peralkaline volcanic rocks: *Carnegie Inst. Washington Year Book* 61, 1961-62, p. 112-118.
- 1964, Notes on some Mediterranean comendite and pantellerite specimens: *Carnegie Inst. Washington Year Book* 63, 1963-64, p. 186-190.
- Coombs, D. S., 1963, Trends and affinities of basaltic magmas and pyroxenes as illustrated on the diopside-olivine-silica diagram: *Mineralog. Soc. America Spec. Paper* 1, p. 227-250.
- Edwards, A. B., 1938, Tertiary lavas from the Kerguelen archipelago: *British, Australian, New Zealand Antarctic Research Exped. 1929-1931, Repts.*, ser. A, v. 2, no. 5, p. 69-100.
- Ewart, Anthony, Taylor, S. R., and Capp, A. C., 1968, Geochemistry of the pantellerites of Mayor Island, New Zealand: *Contr. Mineralogy and Petrology*, v. 17, p. 116-140.
- Foerster, Enrico, 1881, Nota preliminare sulla geologia dell'Isola di Pantelleria secondo gli studii fatti negli anni 1874 e 1881: *Com. Geol. Italiano Boll.*, v. 12, p. 523-556.
- Friedman, Irving, and Smith, R. L., 1958, The deuterium content of water in some volcanic glasses: *Geochim. et Cosmochim. Acta*, v. 15, p. 218-228.
- Gibson, I. L., 1970, A pantelleritic welded ash-flow tuff from the Ethiopian Rift Valley: *Contr. Mineralogy and Petrology*, v. 28, p. 89-111.
- Hieke Merlin, Oplina, 1953, Le vulcaniti acide dell'Africa orientale: *Padova Univ. Ist. Geologia e Mineralogia Mem.* v. 18, [no. 1], 46 p.
- Johannsen, Albert, 1932, The quartz bearing rocks, Volume 2 of A descriptive petrography of the igneous rocks: Chicago, Ill., Univ. Chicago Press, 428 p.
- Johnsen, Arrien, 1912, Die Gesteine der Inseln S. Pietro und S. Antioco (Sardinien): *Akad. Wiss. Preuss., Abh.* 2, Phys-Math Kl, p. 1-82.
- Lacroix, Alfred, 1927, Les rhyolites et les trachytes hyperalkalins quartzifères, à propos de ceux de la Corée: *Acad. Sci. [Paris] Comptes Rendus*, v. 185, p. 1410-1415.
- 1930, Les roches hyperalkalines du massif du Fantale et du col de Balla: *Soc. Géol. France Mém.*, v. 14, p. 89-102.
- 1934, Volcanisme et lithologie. Mission au Tibesti (1930-1931) dirigée par M. Dalloni: *Acad. Sci. Paris, Mém.*, v. 61, p. 169-366.
- 1936a, Composition minéralogique des roches volcaniques de l'Ile de Pâques: *Acad. Sci. [Paris] Comptes Rendus*, v. 202, p. 527-530.
- 1936b, Composition chimique des laves de l'Ile de Pâques: *Acad. Sci. [Paris] Comptes Rendus*, v. 202, p. 601-605.
- Lovering, J. F., 1966, Electron microprobe analyses of chlorine in two pantellerites: *Jour. Petrology*, v. 7, p. 65-67.
- McCall, G. J. H., 1967, Geology of the Nakuru-Thomson's Falls-Lake Hannington area: *Kenya Geol. Survey Rept.* 78, 122 p.
- Macdonald, Ray, Bailey, D. K. and Sutherland, D. S., 1970, Oversaturated peralkaline glassy trachytes from Kenya: *Jour. Petrology*, v. 11, p. 507-517.
- Macdonald, Ray, and Gibson, I. L., 1969, Pantelleritic obsidians from the volcano Chabbi (Ethiopia): *Contr. Mineralogy and Petrology*, v. 24, p. 239-244.
- Morgan, W. R., 1966, A note on the petrology of some lava types from east New Guinea: *Geol. Soc. Australia Jour.*, v. 13, pt. 2, p. 583-591.
- Nicholls, John, and Carmichael, I. S. E., 1969, Peralkaline acid liquids—a petrological study: *Contr. Mineralogy and Petrology*, v. 20, p. 268-294.
- Noble, D. C., 1965, Gold Flat Member of the Thirsty Canyon Tuff—a pantellerite ash-flow sheet in southern Nevada: *U.S. Geol. Survey Prof. Paper* 525-B, p. B85-B90.
- 1966, Comenditic volcanic rocks in the western United States [abs.]: *Geol. Soc. America Spec. Paper* 87, p. 117-118.
- 1967, Sodium, potassium, and ferrous iron contents of some secondarily hydrated natural silicic glasses: *Am. Mineralogist*, v. 52, p. 280-286.
- 1968, Systematic variation of major elements in comendite and pantellerite glasses: *Earth and Planetary Sci. Letters*, v. 4, p. 167-172.
- 1970, Loss of sodium from crystallized comendite welded tuffs of the Miocene Grouse Canyon Member of the Belted Range Tuff, Nevada: *Geol. Soc. America Bull.*, v. 81, p. 2677-2687.
- Noble, D. C., Chipman, D. W., and Giles, D. L., 1968, Peralkaline silicic volcanic rocks in northwestern Nevada: *Science*, v. 160, p. 1337-1338.

- Noble, D. C., and Haffty, Joseph, 1969, Minor-element and revised major-element contents of some Mediterranean pantellerites and comendites: *Jour. Petrology*, v. 10, p. 502-509.
- Noble, D. C., Haffty, Joseph, and Hedge, C. E., 1969, Strontium and magnesium contents of some natural peralkaline silicic glasses and their petrogenetic significance: *Am. Jour. Sci.*, v. 267, p. 598-608.
- Noble, D. C., Smith, V. C. and Peck, L. C., 1967, Loss of halogens from crystallized and glassy silicic volcanic rocks: *Geochim. et Cosmochim. Acta*, v. 31, p. 215-223.
- Prior, G. T., 1903, Contributions to the petrology of British East Africa: *Mineralog. Mag.*, v. 13, p. 228-263.
- Rohleder, H. P. T., and Hitchen, C. S., 1930, Vulkanologische Beobachtungen längs der Bahnlinie Adis Abeba-Djibouti (Abessinien): *Zeitschr. Vulkanologie*, v. 12, p. 269-289.
- Romano, Romolo, 1958, New petrochemical data of volcanites from the Island of Pantelleria (Channel of Sicily): *Geol. Rundschau*, v. 57, p. 773-783.
- 1969, Sur l'origine de l'excès de sodium (ns) dans certaines laves de l'Île de Pantelleria: *Bull. Volcanol.*, v. 33, p. 694-700.
- Rosholt, J. N., and Noble, D. C., 1969, Loss of uranium from crystallized silicic volcanic rocks: *Earth and Planetary Sci. Letters*, v. 6, p. 268-270.
- Ross, C. S., and Smith, R. L., 1955, Water and other volatiles in volcanic glasses: *Am. Mineralogist*, v. 40, p. 1071-1089.
- Taylor, S. R., 1964, Abundance of chemical elements in the continental crust—a new table: *Geochim. et Cosmochim. Acta*, v. 28, p. 1273-1285.
- Taylor, S. R., and White, A. J. R., 1966, Trace element abundances in andesites: *Bull. Volcanol.*, v. 29, p. 177-194.
- Washington, H. S., 1913, The volcanoes and rocks of Pantelleria—Part 2, Petrography: *Jour. Geology*, v. 21, p. 683-713.
- 1917, Chemical analyses of igneous rocks: U.S. Geol. Survey Prof. Paper 99, 1201 p.
- 1921, Obsidian from Copan and Chichen Itza: *Washington Acad. Sci. Jour.*, v. 11, p. 481-487.
- Zies, E. G., 1960, Chemical analysis of two pantellerites: *Jour. Petrology*, v. 1, p. 304-308.

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TABLES 2-10

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## EXPLANATION TO TABLES 2-8

No attempt has been made to specify the composition of the feldspar and pyroxene phenocrysts because, except where the phenocrysts have actually been analyzed, sufficient data are rarely given, especially in older papers, to accurately identify the mineral species. Abbreviations for phenocrysts are as follows: F is alkali feldspar; Q, quartz; P, pyroxene; O, olivine; A, aenigmatite (including cossyrite); AB, amphibole; IO, opaque ores; and AP, apatite. Figures in parentheses, for example F(2), refer to modal percentages; tr. in parentheses indicates trace. Colln. is collection number; lab., laboratory number. Rock names used below are those applied by the original authors.

## COMENDITES

## EUROPE

*Sardinia*

1. Comendite, Le Fontane, Isola San Pietro. Analyst: E. G. Zies (fluorine by V. C. Smith). Phenocrysts: F(9.3), Q(6.0), tridymite and others (0.3). References: Chayes and Zies, 1962, table 7, colln. 40B5. Analysis of feldspar phenocrysts given in same paper. Trace element data from Noble and Haffty, 1969.

## AFRICA

*Chad*

2. Comendite obsidian, Tarso Toussidé, Tibesti Mountains. Analyst: F. Raoult. Phenocrysts: F, P, O, IO. Reference: Lacroix, 1934, p. 190, No. 1.

*Ethiopia*

3. Comendite obsidian, Sardo, Afar. Analyst: O. Hieke Merlin. Phenocrysts: None. Reference: Hieke Merlin, 1953, table 2.  
Belongs to Aden Series Volcanics.

*Kenya*

4. Rhyolite obsidian, south shore, Lake Naivasha. Analyst: A. Willman (fluorine by E. S. Shepherd). Phenocrysts: F, rare; O, very rare. Reference: Bowen, 1937, table 1, No. 6, colln. NLB 248.
5. Comendite obsidian, top of flow, north portal of Njorowa Gorge, Lake Naivasha. Analyst: A. Willman (fluorine by E. S. Shepherd). Phenocrysts: None. Reference: Bowen, 1937, table 1, No. 8, colln. NLB 246.
6. Rhyolite obsidian (comenditic), south shore, Lake Naivasha. Analyst: S. Goldich (fluorine by E. S. Shepherd). Phenocrysts: None. Reference: Bowen, 1937, table 1, No. 9, colln. NLB 249.
7. Comendite obsidian, exact locality unknown, Rift Valley. Analysts: S. A. Malik, D. A. Bungard, J. M. C. Palmer. Phenocrysts: None. Reference: Bailey and Macdonald, 1970, table 1, No. 11, colln. EAK 7.
8. Comendite obsidian, Kongoni farm, Naivasha. Analysts: S. A. Malik, D. A. Bungard, L. Porteous. Phenocrysts: F, including F-Q intergrowths (10.2), Q(1.3), P(tr.), vesicular specimen 29.2% pores, by volume. Reference: Bailey and Macdonald, 1970, table 1, No. 10, colln. 43/3/S/85.

## UNITED STATES

*Idaho*

9. Comendite glass, Big Southern Butte. Analysts: V. C. Smith, J. Haffty. Reference: Noble, 1968, table 1, No. 1, lab. D101042.

*Nevada*

10. Comendite glass, Spearhead Member, Thirsty Canyon Tuff, Black Mountain volcanic center, Nye County. Analysts: V. C. Smith, J. Haffty, H. Neiman. Reference: Noble, 1968, table 1, No. 2, lab. D100737.
11. Comendite glass, basal glassy zone of Grouse Canyon Member, Belted Range Tuff, Silent Canyon volcanic center, Nye County. Analysts: V. C. Smith, J. Haffty, H. Neiman. Phenocrysts: None. References: Noble, 1968, table 1, No. 3, lab. D100317. Trace element data from Noble, 1970.
12. Comendite glass, lowermost part of Grouse Canyon Member, Belted Range Tuff, Silent Canyon volcanic center, Nye County. Analyst: E. S. Daniels. Phenocrysts: None. Reference: Noble, 1970, table 1, No. 2, lab. D100209.
13. Comendite glass, lowermost part of Grouse Canyon Member, Belted Range Tuff, Silent Canyon volcanic center, Nye County. Analyst: E. L. Munson. Phenocrysts: None. Reference: Noble, 1970, table 1, No. 3, lab. D101090.
14. Comendite glass separate, basal glassy zone of Spearhead Member, Thirsty Canyon Tuff, Black Mountain Volcanic center, Nye County. Analysts: V. C. Smith and others. References: Partial analysis in Noble, 1967, table 1, No. 2A, lab. D100320. Complete analysis from U.S. Geological Survey files.
15. Comendite glass separate, basal glassy zone of Spearhead Member, Thirsty Canyon Tuff, Black Mountain volcanic center, Nye County. Analysts: C. L. Parker and others. References: Partial analysis in Noble, 1967, table 1, No. 2B, lab. D100437. Complete analysis from U.S. Geological Survey files, trace element data from Noble and Haffty, 1969.

## ATLANTIC OCEAN

*Iceland*

16. Obsidian, Oraefajokull, Eastern Iceland. Analyst: I. S. E. Carmichael. Phenocrysts: P(0.3), O(0.3), IO(0.1), plagioclase (2.1). Reference: Carmichael, 1967, table 5, No. 2. Analyses of pyroxene, olivine, and iron-titanium oxides given in same paper.  
This rock and perhaps that from Ljosufjoll (analysis 17) are the only ones in this compilation that contain plagioclase phenocrysts.
17. Comendite obsidian, Ljosufjoll. Analysts: S. A. Malik, D. A. Bungard, L. Porteous. Phenocrysts: F(1), P(tr.), O(tr.), plagioclase(?). Reference: Bailey and Macdonald, 1970, table 1, No. 7, colln. 491.  
See comment for specimen 16.
18. Comendite obsidian, Midhyrna. Analysts: S. A. Malik, D. A. Bungard, L. Porteous. Phenocrysts: F(<1), P(tr.), IO(tr.). Reference: Bailey and Macdonald, 1970, table 1, No. 8, colln. 295.  
Composition of feldspar phenocrysts is Or<sub>85</sub>.
19. Comendite obsidian, Hrafninnusker. Analysts: S. A. Malik, D. A. Bungard, L. Porteous. Phenocrysts: None. Reference: Bailey and Macdonald, 1970, table 1, No. 9, colln. 423.

*Ascension Island*

20. Comendite obsidian, Middleton's Ridge. Analysts: S. A. Malik, D. A. Bungard, J. M. C. Palmer. Phenocrysts: F, very scarce (<1). Reference: Bailey and Macdonald, 1970, table 1, No. 1, colln. 15375.

*Bouvet Island*

21. Comendite obsidian, Lars islet. Analyst: E. Klüver. Phenocrysts: F. Reference: Broch, 1946, p. 16.  
Broch's norm in error; the corrected norm is given in table 2.
22. Comendite obsidian, Lars islet. Analysts: S. A. Malik, D. A. Bungard, J. M. C. Palmer. Phenocrysts: F(2.5). Reference: Bailey and Macdonald, 1970, table 1, No. 3, colln. WJ18B.
23. Comendite obsidian, Lars islet. Analysts: S. A. Malik, D. A. Bungard, J. M. C. Palmer. Phenocrysts: F(<1). Reference: Bailey and Macdonald, 1970, table 1, No. 2, colln. B2.

## PACIFIC OCEAN

*Easter Island*

24. Banded hyperalkaline obsidian, Rana Kau. Analyst: F. Raoult. Phenocrysts: F, P, O. References: Analysis from Lacroix, 1936b, p. 603, phenocryst assemblage from Lacroix, 1936a, p. 529.
25. Comendite obsidian, slopes of Rana Kau. Analysts: S. A. Malik, D. A. Bungard, J. M. C. Palmer. Phenocrysts: Very scarce(?) zircon. Reference: Bailey and Macdonald, 1970, table 1, No. 5, colln. 17518.
26. Comendite obsidian, Motu Iti islet. Analysts: S. A. Malik, D. A. Bungard, J. M. C. Palmer. Phenocrysts: None. Reference: Bailey and Macdonald, 1970, table 1, No. 4, colln. 17525.
27. Comendite obsidian, northwest side of Cerro Orito. Analysts: S. A. Malik, D. A. Bungard, J. M. C. Palmer. Phenocrysts: None. Reference: Bailey and Macdonald, 1970, table 1, No. 6, colln. 17691.

*New Guinea*

28. Aegirine obsidian, southeast floor of Lamonai crater, Ferguson Island. Analysts: L. Castanelli, R. L. Bruce. Phenocrysts: Sparse, F, P. Reference: Morgan, 1966, table, No. 29.
29. Pumiceous aegirine obsidian, close to crater, Oian cone, Ferguson Island. Analysts: L. Castanelli, R. L. Bruce. Phenocrysts: Sparse F, P. Reference: Morgan, 1966, table, No. 30.

PANTELLERITES  
EUROPE*Pantelleria*

30. Hyalopantellerite, Gelkhamar. Analyst: E. G. Zies (fluorine by V. C. Smith). Phenocrysts: F(10.7), Q(0.8), P(0.2), A(0.8). Reference: Zies, 1960, p. 307, colln. PRC 2000.  
Re-analysis of Washington's (1913) specimen A. Further revised analysis given by Noble and Haffty (1969) including fluorine figure. New  $Al_2O_3$  (corrected for trace element interference) = 8.29,  $MgO$  = 0.07,  $Na_2O$  = 6.48,  $K_2O$  = 4.44,  $ZrO_2$  = 0.27. Analysis of feldspar phenocrysts in Chayes and Zies (1962, table 8); trace element data from Noble and Haffty (1969).
31. Hyalopantellerite, Costa Zeneti. Analyst: E. G. Zies (fluorine by V. C. Smith). Phenocrysts: F(ca. 2). Reference: Zies, 1960, p. 307, colln. PRC 2007.  
Re-analysis of Washington's (1913) specimen D. Further revised analysis and trace element data given by Noble and Haffty (1969), including fluorine figure. New  $Al_2O_3$  (corrected for trace element interference) = 11.08,  $Na_2O$  = 6.34,  $K_2O$  = 4.61,  $ZrO_2$  = 0.17.

32. Hyalopantellerite, Cuddia Gadir. Analyst: E. G. Zies (fluorine by V. C. Smith). Phenocrysts: F(8.8), Q(2.2), P(0.1), A(0.4), IO(0.1). Reference: Chayes and Zies, 1964, table 19, colln. 44B5.

Slightly revised analysis and trace element data given by Noble and Haffty, 1969, including fluorine figure. New  $Al_2O_3$  (corrected for trace element interference) = 8.15,  $Na_2O$  = 6.60,  $K_2O$  = 4.41,  $ZrO_2$  = 0.29. Analysis of feldspar phenocrysts in Chayes and Zies, 1964.

- 33, 34. Porphyritic pantellerite obsidian and separated (residual) glass, exact locality not given. Analyst: I. S. E. Carmichael. Phenocrysts: F(10.7), P(0.5), O(0.4), A(tr.), IO(0.2). References: Carmichael, 1962, table 6, Nos. 1R and 1G, colln. 5748; trace element data for 33 from Nicholls and Carmichael, 1969.

Chlorine computed from mode and analyzed chlorine content of glass. Analyses of feldspar, pyroxene, and olivine given in Carmichael (1962), with revised feldspar and pyroxene values in Nicholls and Carmichael (1969).

- 35, 36. Porphyritic pantellerite obsidian and separated (residual) glass, exact locality not given. Analyst: I. S. E. Carmichael. Phenocrysts: F(18.0), Q(0.1), P(0.3), O(tr.), A(0.9), IO(tr.). References: Carmichael, 1962, table 6, Nos. 2R and 2G, colln. 3112; trace element data for 35 from Nicholls and Carmichael, 1969.

Chlorine computed from mode and analyzed chlorine content of glass. Analyses of feldspar, pyroxene, and aenigmatite given in Carmichael (1962), with revised feldspar and pyroxene values in Nicholls and Carmichael (1969).

- 37, 38. Porphyritic pantellerite obsidian and separated (residual) glass, exact locality not given. Analyst: I. S. E. Carmichael. Phenocrysts: F(9.4), Q(2.0), P(tr.), A(0.9). References: Carmichael, 1962, table 6, Nos. 3R and 3G, colln. 5749; trace element data for 37 from Nicholls and Carmichael, 1969.

Chlorine computed from mode and analyzed chlorine content of glass. Analyses of feldspar and aenigmatite given in Carmichael (1962), with slightly revised feldspar values in Nicholls and Carmichael (1969).

- 39, 40. Porphyritic pantellerite obsidian and separated (residual) glass, exact locality not given. Analyst: I. S. E. Carmichael. Phenocrysts: F(1.2), P(tr.), O(tr.). References: Carmichael, 1962, table 6, Nos. 4R and 4G, colln. 3114; trace element data for 39 from Nicholls and Carmichael, 1969.

Chlorine computed from mode and analyzed chlorine content of glass. Analysis of feldspar phenocrysts given in Carmichael (1962), with a slightly revised value in Nicholls and Carmichael (1969).

41. Pantellerite, Cuddia Attalora. Analyst: R. Romano. Phenocrysts: No data. Reference: Romano, 1968, table 1, No. 28.
42. Pantellerite, Cuddia da Khamma. Analyst: R. Romano. Phenocrysts: No data. Reference: Romano, 1968, table 1, No. 29.
43. Pantellerite, Cala di Tramontana. Analyst: C. Sturiale. Phenocrysts: No data. Reference: Romano, 1968, table 1, No. 31.
44. Pantellerite, Fossa della Pernice (same flow as analysis 39). Analyst: R. Romano. Phenocrysts: No data. Reference: Romano, 1969, table 1, analysis D.
45. Pantellerite, Fossa della Pernice (same flow as analysis 38). Analyst: R. Romano. Phenocrysts: No data. Reference: Romano, 1969, table 1, analysis E.

Same analysis given in Romano (1968, table 1, No. 27), but with different values of MnO (0.25) and P<sub>2</sub>O<sub>5</sub> (0.19). No explanation of this difference offered.

### Sardinia

46. Comendite, Capo Sandolo, San Pietro. Analyst: E. G. Zies (fluorine by V. C. Smith). Phenocrysts: F(13.7), Q(3.6), P(<0.1), A(<0.1), AB(0.1). References: Chayes and Zies, 1964, table 19, colln. 39B3; fluorine and trace element data from Noble and Haffty, 1969. Analysis of feldspar given in Chayes and Zies (1964).

### AFRICA

#### Chad

47. Pantellerite obsidian, Wantagoi, Tibesti Mountains. Analyst: F. Raoult. Phenocrysts: No data. Reference: Lacroix, 1934, p. 191, No. 7.
48. Pantellerite obsidian, western flank, Emi Koussi. Analyst: F. Raoult. Phenocrysts: No data. Reference: Lacroix, 1934, p. 191, No. 8.
49. Pantellerite obsidian, fragments, Enneri Gonoa. Analyst: F. Raoult. Phenocrysts: F. Reference: Lacroix, 1934, p. 191, No. 9.

#### Ethiopia

50. Comendite obsidian, Entotto, Shoa. Analyst: O. Hieke Merlin. Phenocrysts: None. Reference: Hieke Merlin, 1953, table 2.

Belongs to Trap Series Volcanics, Magdala group.

#### Aden Series Volcanics:

51. Comendite obsidian, Monte Agelu, near Gauani, Hararge. Analyst: O. Hieke Merlin. Phenocrysts: None. Reference: Hieke Merlin, 1953, table 2.
52. Pantellerite obsidian, south side of Fantālē volcano, Shoa. Analyst: F. Raoult. Phenocrysts: F, Q, P, A. Reference: Lacroix, 1930, p. 95, analysis A.
53. Porphyritic pantellerite obsidian, south side of Fantālē volcano, Shoa. Analyst: F. Raoult. Phenocrysts: F, Q, Q-F intergrowths, A, AB. Reference: Lacroix, 1930, p. 95, analysis B.
54. Opaque pantellerite obsidian, north side of Fantālē volcano, Shoa. Analyst: F. Raoult. Phenocrysts: No data. Reference: Lacroix, 1930, p. 97, analysis D.
55. Pantellerite, Fantālē volcano, Shoa. Analyst: C. S. Hitchen. Phenocrysts: No data. Reference: Rohleder and Hitchen, 1930, p. 281, No. 6.
56. Pantelleritic obsidian bomb, Mojjo, Shoa. Analyst: C. S. Hitchen. Phenocrysts: No data. Reference: Rohleder and Hitchen, 1930, p. 281, No. 8.
- 57-68. Pantellerite obsidians, Gariboldi volcanic complex. Analysts: S. A. Malik, D. A. Bungard, J. M. C. Palmer, L. Porteous. Phenocrysts: 57—F, Q, P, A, AB; 58—F very scarce; 59—F(2.6), P(0.1), O(<0.1), IO(<0.1); 60—none; 61—F(6.7), P(0.4), O(tr.), IO(0.5); 62—F(1.5), P(0.1), O(tr.), IO(tr.); 63—F(1.8), P(0.2), IO(0.1); 64—F(0.2), P(tr.); 65—none; 66—F(1.4), P(0.1), A(0.1); 67—F(1.0), P(tr.), O(tr.); 68—F(4.1), Q(1.8), P(0.1), A(0.4), AB(0.1). Reference: Unpublished analyses of specimens collected by Dr. J. W. Cole and supplied to us by courtesy of Dr. I. L. Gibson (colln. G69, G77, G110, G320, G414, G417, G427, G429, G437, G444, G446, and G445, respectively).
- 69-79. Pantellerite obsidians, Chabbi volcano. 69, 75, 78, and 79—east vent; 71, 72, and 74—hot cone; 73 and 77—main vent; 76—north vent; 70—northeast vent. Analysts: R. Mac-

donald and S. A. Malik. Phenocrysts: None. Reference: Macdonald and Gibson, 1969, table, Nos. 1-8, 11-13.

#### Kenya

80. Phonolitic obsidian, Lake Nakuru. Analyst: G. T. Prior. Phenocrysts: F, P, O (all very scarce). Reference: Prior, 1903, p. 245.
81. Soda rhyolite (pantellerite) obsidian, Eburru. Analyst: A. Willman (fluorine by E. S. Shepherd). Phenocrysts: None. Reference: Bowen, 1937, table 1, No. 7, colln. NLB 230.
82. Pantellerite obsidian (Plr<sub>2</sub>), east of Cedar Hill, Eburru. Analysts: S. A. Malik, D. A. Bungard, J. M. C. Palmer. Phenocrysts: F, P, A, AB. Reference: Dr. D. S. Sutherland, unpub. analysis, colln. 43/3/S/12.
83. Pantellerite obsidian (Plr<sub>2</sub>), south of Cedar Hill, Eburru. Analysts: S. A. Malik, D. A. Bungard, J. M. C. Palmer. Phenocrysts: F(10.0), P(0.3), A(tr.), AB(0.1). Reference: Dr. D. S. Sutherland, unpub. analysis, colln. 43/3/S/36.
84. Pantellerite obsidian, block in agglomerate (Qvf), about 1 mile east of Cedar Hill, Eburru. Analysts: S. A. Malik, D. A. Bungard, J. M. C. Palmer. Phenocrysts: F(3.7), P(tr.), A(tr.). Reference: Dr. D. S. Sutherland, unpub. analysis, colln. 43/3/S/44.
85. Pantellerite obsidian (Plr<sub>1</sub>), Eburru-Gilgil road. Analyst: H. Lloyd. Phenocrysts: F, Q-F intergrowths, A, AB. Reference: Dr. D. S. Sutherland, unpub. analysis, colln. 43/3/S/56.
86. Pantellerite obsidian, lens in pumiceous deposit, Kinangop escarpment. Analyst: M. Thind. Phenocrysts: P, very scarce. Reference: Dr. D. S. Sutherland, unpub. analysis, colln. 43/3/S/20.
87. Glassy soda-rhyolite (pantellerite), Lake Naivasha. Analyst: G. T. Prior. Phenocrysts: None. Reference: Prior, 1903, p. 246.
88. Pantellerite obsidian, south shore, Lake Naivasha. Analyst: I. S. E. Carmichael, J. Hampel. Phenocrysts: F(5.5), Q(0.7), P(0.3), A(0.3), AB(1.8). Reference: Nicholls and Carmichael, 1969, table 1, colln. 121-R. Analyses of feldspar, aenigmatite, amphibole, and residual glass calculated from mode given in same paper.
89. Pantellerite obsidian, band intercalated in pumice (Qvf), quarry, south of Masai Gorge, South Lake Road, Naivasha. Analyst: M. Thind. Phenocrysts: None. Reference: Dr. D. S. Sutherland, unpub. analysis, colln. 43/3/S/2.

### UNITED STATES

#### Nevada

90. Pantellerite glass separate, ash-flow sheet, Gold Flat Member, Thirsty Canyon Tuff, Black Mountain volcanic center, Nye County. Analysts: D. F. Powers and others. Reference: Noble, 1965, table 1, No. 1, lab. D100126.
- Slightly revised trace element data for this(?) rock (lab. not specified) given by Noble and Haffty (1969, table 1, No. 6). In parts per million—Be 5.6, Co <5, Cr 1, Cu 3, Ga 44, La 58, Mo 9, Nb 67, Ni 5, Pb 210, Sc 7, Sn 52, Sr 1.5, Y 490, Yb 55.

### NEW ZEALAND

#### Mayor Island

91. Glassy pantellerite, flow 1a, young dome. Analyst: K. Bose. Phenocrysts: F(9.2), P(0.2), A(0.5), IO(tr.). Reference: Ewart, Taylor, and Capp, 1968, table 4, No. 1, colln. P29537.

Chlorine content computed from mode and analyzed chlorine content of glass. Analyses of pyroxene and aenigmatite given in same paper.

92. Pantellerite obsidian, Opo Bay. Analyst: K. Bose. Phenocrysts: F(6.3), Q(1.5), P(0.1), A(0.2). Reference: Ewart, Taylor, and Capp, 1968, table 4, No. 2, colln. P29553.  
Chlorine content computed from mode and analysed chlorine content of glass. Analysis of aenigmatite given in same paper.
93. Pantellerite obsidian, northwest of Tarewakoura. Analyst: K. Bose. Phenocrysts: F(3.3), P(<0.1), A(<0.1). Reference: Ewart, Taylor, and Capp, 1968, table 4, No. 3, colln. P29543.
94. Pantellerite obsidian, Te Marawhero Point. Analyst: K. Bose. Phenocrysts: F(0.6), P(<0.1), A(<0.1). Reference: Ewart, Taylor, and Capp, 1968, table 4, No. 4, colln. P29560.
95. Pantellerite obsidian, Oira Bay. Analyst: K. Bose. Phenocrysts: F(0.6), P(tr.), A(tr.), IO(tr.). Reference: Ewart, Taylor, and Capp, 1968, table 4, No. 5, colln. P29532.
96. Glassy pantellerite, flow 2, young dome. Analyst: J. A. Ritchie. Phenocrysts: F(8.9), Q(3.7), P(<0.1), A(0.4). Reference: Ewart, Taylor, and Capp, 1968, table 4, No. 7, colln. 29117. Analysis of feldspar given in same paper.
- 97, 98. Pantellerite obsidian and separated (residual) glass, flow 3, young dome. Analyst: J. A. Ritchie. Phenocrysts: F(8.1), Q(2.0), P(0.3), A(0.2). Reference: Ewart, Taylor, and Capp, 1968, table 4, Nos. 8R and 8G, colln. P29118. Analysis of feldspar phenocrysts given in same paper.
99. Glassy pantellerite, north shore of Opo Bay. Analyst: E. E. Munson, J. Haffty. Phenocrysts: <1 percent total, mainly F. Reference: Noble, 1968, table 1, No. 4, lab. D100406.  
Sample collected in 1956 for R. L. Smith (who provided phenocryst data) and used in study of D/H ratios by Friedman and Smith (1958). Probably same flow as analysis 94 from Te Marawhero Point.
- 100, 101. Comendite obsidian and separated (residual) glass, Omapu Bay. Analysts: I. S. E. Carmichael, J. Hampel. Phenocrysts: F(3.5), Q(0.8), P(0.1), A(0.1). Reference: Nicholls and Carmichael, 1969, table 1, colln. NZC-2R and 2G.  
Published norm of 2R in error; the corrected norm is given in table 3.
- 102, 103. Comendite obsidian and separated (residual) glass, young dome lavas, south side of island. Analysts: I. S. E. Carmichael, J. Hampel. Phenocrysts: F(3.1), A(tr.). Reference: Nicholls and Carmichael, 1969, table 1, colln. NZC-7R and 7G. Analysis of feldspar given in same paper.

## MEXICO

104. Pantellerite obsidian, Socorro Island. Analyst: H. B. Wiik. Phenocrysts: F, P, A, IO. Reference: Bryan, 1970, table 13, No. 1, colln. S138. Analyses of feldspar, pyroxene and aenigmatite phenocrysts given in same paper.

COMENDITIC TRACHYTES  
OCEANIC ISLANDS*Kerguelen, Indian Ocean*

105. Obsidian trachyte, Baie de la Mouche, Ile de Cormorans. Analyst: F. Raoult. Phenocrysts: F, P. Reference: de la Rue, in Edwards, 1938, table 17, No. 2.

*Pitcairn Island, Pacific Ocean*

106. Trachyte obsidian, exact locality not given. Analyst: I. S. E. Carmichael. Phenocrysts: F(0.6), P(0.1), O(tr.), IO(tr.). Reference: Carmichael, 1962, table 6, No. 6R, colln. 12095.

## AFRICA

*Kenya*

107. Glassy trachyte, block in agglomerate, northeast of Menengai. Analysts: S. A. Malik, D. A. Bungard, J. M. C. Palmer. Phenocrysts: F(about 10), P(0.3), O(0.3), IO(0.2). Reference: Macdonald, Bailey, and Sutherland, 1970, table 1, colln. 43/1/S/6a. Highly vesicular specimen (38.6 percent pores, by volume), thought to be partially accumultic.

## PANTELLERITIC TRACHYTES

## AFRICA

*Kenya*

108. Pantellerite trachyte, caldera floor, Menengai. Analyst: Mineral Resources Division (Overseas Geol. Survey). Phenocrysts: No data. Reference: McCall, 1967, table 2, analysis N, colln. 43/1192.
109. Pantelleritic trachyte obsidian, block in agglomerate, northeast of Menengai. Analysts: S. A. Malik, D. A. Bungard, J. M. C. Palmer. Phenocrysts: F(1-3), AP. Reference: Macdonald, Bailey, and Sutherland, 1970, table 1, colln. 43/1/S/5.
110. Pantelleritic trachyte obsidian, block in agglomerate, northeast of Menengai. Analysts: S. A. Malik, D. A. Bungard, J. M. C. Palmer. Phenocrysts: F(1). Reference: Macdonald, Bailey, and Sutherland, 1970, table 1, colln. 43/1/S/6.
111. Pantelleritic trachyte obsidian, lava exposed in caldera wall below Valley Farm, west side of Menengai. Analysts: S. A. Malik, D. A. Bungard, J. M. C. Palmer. Phenocrysts: F, scarce. Reference: Macdonald, Bailey, and Sutherland, 1970, table 1, colln. 43/1/S/11.
112. Pantelleritic trachyte obsidian, crater rim, Longonot volcano. Analysts: S. A. Malik, D. A. Bungard, L. Porteous. Phenocrysts: F(0.5), P(0.4). Reference: Macdonald and Bailey, unpub. analysis, colln. LON 1.
113. Trachyte obsidian, Ol Doiyo Nyegi volcano. Analysts: S. A. Malik, D. A. Bungard, L. Porteous. Phenocrysts: F, P, O, IO. Reference: Unpublished analysis of specimen collected by Dr. L. A. J. Williams (colln. W486).



TABLE 2.—Chemical analyses and norms of comenditic obsidians

[Details of the specimens are given on p. N22. Data in weight percent except for ratios and indices. Tr. indicates trace]

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
<b>Chemical analyses</b>															
SiO <sub>2</sub> .....	75.31	74.70	73.80	75.55	75.03	73.96	72.9	74.2	75.33	75.25	73.98	73.84	73.69	75.37	75.29
Al <sub>2</sub> O <sub>3</sub> .....	10.43	11.97	12.10	12.31	11.10	11.40	12.33	10.84	12.29	11.99	11.23	11.80	11.28	11.95	12.12
Fe <sub>2</sub> O <sub>3</sub> .....	3.22	.83	.82	.69	1.31	1.65	1.30	1.23	.59	.90	1.71	1.01	1.83	.84	.88
FeO.....	.80	2.13	1.56	1.17	1.84	1.95	2.14	1.86	1.09	1.25	1.80	2.07	1.74	.99	.99
MgO.....	.10	Tr.	.22	.04	None	.03	.02	.02	.00	.02	.02	.08	.01	.00	.01
CaO.....	.13	.54	.84	.23	None	None	.50	.30	.43	.27	.24	.29	.21	.33	.33
Na <sub>2</sub> O.....	3.99	5.12	5.10	4.65	5.09	5.41	5.66	5.17	4.29	4.79	5.33	5.40	5.35	4.43	4.42
K <sub>2</sub> O.....	4.65	4.51	4.95	4.69	4.56	4.36	4.66	4.53	4.93	4.67	4.55	4.50	4.53	4.82	4.88
H <sub>2</sub> O.....	.33	.....	.09	None	.01	.02	.....	.09	.04	.05	.02	.01	.01	.04	.04
H <sub>2</sub> O+.....	.51	.33	.22	.15	.08	.13	.05	.30	.09	.15	.16	.17	.43	.45	.36
TiO <sub>2</sub> .....	.21	.21	.22	.13	.19	.17	.24	.20	.10	.13	.22	.22	.22	.11	.11
ZrO <sub>2</sub> .....	.18	.....	.....	.....	.....	.....	.18	.....	.04	.09	.14	.....	.....	.....	.....
CO <sub>2</sub> .....	.....	.....	.....	.....	.....	.....	.....	.....	.00	.....	.02	.01	.....	.....	.....
P <sub>2</sub> O <sub>5</sub> .....	.03	.....	.08	.01	Tr.	Tr.	.04	.01	.00	.....	.01	.01	.01	.02	.01
S.....	.....	.....	.....	.01	.01	.01	.....	.....	.....	.....	.....	.....	.....	.....	.....
MnO.....	.09	.14	.01	.04	.06	.05	.13	.06	.04	.08	.17	.17	.17	.07	.07
Cl.....	.05	.....	.19	.21	.27	.41	.26	.18	.19	.18	.13	.11	.11	.18	.18
F.....	.18	.....	.06	.23	.42	.63	.22	.30	.34	.25	.17	.16	.17	.25	.24
Subtotal.....	100.26	100.53	100.26	100.06	99.97	100.23	100.53	99.29	99.89	100.07	99.95	99.80	99.76	99.85	99.93
O=(F,Cl).....	.09	.....	.07	.16	.24	.33	.15	.17	.18	.14	.10	.10	.10	.15	.14
Total.....	100.17	100.53	100.19	99.90	99.73	99.85	100.38	99.12	99.71	99.93	99.85	99.70	99.66	99.70	99.79
Agpaitic index <sup>1</sup> .....	1.11	1.12	1.13	1.02	1.19	1.19	1.15	1.24	1.01	1.08	1.21	1.16	1.22	1.04	1.03
Fe as FeO <sup>2</sup> .....	3.70	2.88	2.30	1.79	3.02	3.44	3.31	2.97	1.62	2.06	3.34	2.98	3.39	1.75	1.78
FeO/(FeO+Fe <sub>2</sub> O <sub>3</sub> ) <sup>2</sup> .....	.20	.72	.66	.63	.58	.54	.62	.60	.65	.58	.51	.67	.49	.54	.53
Na <sub>2</sub> O/K <sub>2</sub> O <sup>3</sup> .....	.86	1.14	1.03	.97	1.12	1.24	1.24	1.14	.86	1.03	1.17	1.20	1.18	.92	.91
<b>Molecular:</b>															
SiO <sub>2</sub> .....	85.4	83.4	82.9	83.6	83.9	83.4	82.3	83.9	83.8	83.6	83.4	83.0	83.3	84.0	83.8
Al <sub>2</sub> O <sub>3</sub> .....	6.9	7.8	8.0	8.1	7.3	7.6	8.2	7.2	8.1	7.9	7.5	7.9	7.6	7.8	8.0
Na <sub>2</sub> O+K <sub>2</sub> O.....	7.7	8.8	9.1	8.2	8.8	9.0	9.5	8.9	8.1	8.5	9.1	9.1	9.1	8.2	8.2
100 Na <sub>2</sub> O/(Na <sub>2</sub> O+K <sub>2</sub> O).....	56.6	63.4	60.7	59.3	63.1	65.4	65.5	63.4	56.6	60.6	64.2	64.4	64.2	58.2	57.7
<b>CIPW norms</b>															
Q.....	36.5	28.2	27.0	32.7	32.5	33.1	24.9	31.9	31.4	30.4	29.2	28.0	28.9	31.7	31.4
or.....	27.5	26.7	29.5	27.3	27.2	26.1	26.7	26.7	29.5	27.8	27.2	26.7	26.7	28.4	28.9
ab.....	27.6	36.7	34.6	35.1	31.4	33.5	33.3	30.4	35.1	35.6	32.5	35.6	33.0	34.6	35.1
ac.....	3.4	2.3	2.3	.....	3.7	.....	3.7	3.7	.....	2.4	5.1	2.8	5.1	1.4	.9
ns.....	.....	.9	1.1	.....	.....	.....	.8	1.5	.....	.....	1.3	1.6	1.5	.....	.....
di:	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
wo.....	.....	1.2	1.3	.....	.....	.....	.2	.....	.....	.....	.....	.1	.....	.....	.....
en.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
fs.....	.....	1.3	1.2	.....	.....	.....	.2	.....	.....	.....	.....	.1	.....	.....	.....
hy:	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
en.....	.3	.....	.3	.1	.....	.1	.....	.1	.....	.1	.1	.1	.....	.....	.....
fs.....	.....	2.6	1.3	1.3	2.9	2.0	3.6	3.2	1.5	2.1	3.2	3.6	3.0	1.5	1.3
mt.....	2.1	.....	.....	.9	.....	2.3	.....	.....	.9	.....	.....	.....	.....	.5	.3
il.....	.5	.4	.5	.3	.5	.3	.5	.4	.2	.3	.5	.5	.5	.2	.2
ap.....	.1	.....	.2	.....	.....	.....	.1	.....	.....	.....	.....	.....	.....	Tr.	Tr.
Z.....	.3	.....	.....	.....	.....	.....	.3	.....	.....	.2	.2	.....	.....	.....	.....
CaF <sub>2</sub> .....	.1	.....	.2	.3	.....	.....	.5	.4	.7	.3	.3	.3	.3	.5	.5
NaCl.....	.1	.....	.3	.4	.5	.7	.4	.3	.3	.3	.2	.2	.2	.3	.3
NaF.....	.3	.....	.....	.3	.8	1.4	.....	.3	.....	.2	.....	.....	.....	.....	.....
cc.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Other.....	( <sup>0</sup> )	.....	.....	( <sup>0</sup> )	.....	.....	.....	.....	( <sup>0</sup> )	.....	.....	.....	Tr.	.....	.....
Σ femics <sup>4</sup> .....	7.1	8.7	8.6	2.9	7.1	4.7	9.7	9.3	3.3	5.4	10.5	9.1	10.4	4.1	3.7

See footnotes at end of table.

TABLE 2.—Chemical analyses and norms of comenditic obsidians—Continued

	16	17	18	19	20	21	22	23	24	25	26	27	28	29
Chemical analyses—Continued														
SiO <sub>2</sub> .....	71.52	74.3	75.8	73.6	71.4	69.47	69.5	70.2	74.22	72.6	72.3	72.7	69.80	69.60
Al <sub>2</sub> O <sub>3</sub> .....	13.35	12.01	12.14	12.04	12.40	12.84	13.25	12.55	12.25	12.78	13.18	12.87	14.90	14.60
Fe <sub>2</sub> O <sub>3</sub> .....	.74	.88	.80	1.26	1.22	1.41	1.05	1.14	.40	.88	.82	.86	1.17	.84
FeO.....	2.72	1.46	.94	1.87	2.14	3.70	3.21	3.10	2.52	2.02	2.25	2.06	1.98	2.10
MgO.....	.05	.00	.01	.05	.03	.17	.02	.02	Tr.	.01	.01	.01	.20	.20
CaO.....	1.12	.32	.30	.38	.47	.71	.88	.77	.98	.69	.84	.62	.59	.48
Na <sub>2</sub> O.....	5.97	5.36	5.22	5.74	5.90	5.66	5.87	5.72	5.21	5.77	5.88	5.76	6.15	6.25
K <sub>2</sub> O.....	3.49	4.58	4.48	4.51	4.70	4.83	4.98	4.82	3.82	3.84	3.78	3.89	4.50	4.50
H <sub>2</sub> O.....	.05	.22	.14	.18	-----	.04	-----	-----	.16	-----	-----	-----	.08	.11
H <sub>2</sub> O+.....	.42	.23	.12	.00	.20	.35	.13	.25	.67	.31	.22	.27	.26	.52
TiO <sub>2</sub> .....	.26	.15	.09	.20	.23	.29	.32	.31	.09	.20	.21	.20	.30	.29
ZrO <sub>2</sub> .....	-----	-----	-----	-----	.18	-----	.20	.21	-----	.14	.11	.14	-----	-----
CO <sub>2</sub> .....	-----	-----	-----	-----	-----	.12	-----	-----	-----	-----	-----	-----	.06	.07
P <sub>2</sub> O <sub>5</sub> .....	.02	.00	.00	.01	.03	.03	.03	.03	Tr.	.02	.01	.01	.03	.04
S.....	-----	-----	-----	-----	-----	.01	-----	-----	-----	-----	-----	-----	-----	-----
MnO.....	.11	.08	.06	.07	.13	.13	.12	.11	.06	.08	.08	.07	.10	.10
Cl.....	-----	.17	.25	.19	.26	.28	.25	.31	.05	.21	.20	.20	-----	-----
F.....	-----	.34	.29	.26	.23	-----	.16	.18	-----	.19	.18	.18	-----	-----
Subtotal.....	99.82	100.10	100.64	100.36	99.52	100.04	99.92	99.72	100.43	99.74	100.02	99.84	100.12	99.70
O≡(F,Cl) <sub>2</sub> .....	-----	.18	.18	.15	.16	.06	.12	.15	.01	.13	.12	.12	-----	-----
Total.....	99.82	99.92	100.46	100.21	99.36	99.98	99.80	99.57	100.42	99.61	99.90	99.72	100.12	99.70
Agpaitic index <sup>1</sup> .....	1.01	1.15	1.10	1.20	1.19	1.13	1.13	1.16	1.04	1.07	1.04	1.06	1.01	1.04
Fe as FeO <sup>2</sup> .....	3.39	2.25	1.66	3.00	3.24	4.97	4.16	4.13	2.88	2.81	2.99	2.83	3.03	2.86
FeO/(FeO+Fe <sub>2</sub> O <sub>3</sub> ) <sup>2</sup> .....	.79	.62	.54	.60	.64	.72	.75	.73	.86	.70	.73	.71	.63	.71
Na <sub>2</sub> O/K <sub>2</sub> O <sup>2</sup> .....	1.71	1.17	1.16	1.27	1.26	1.17	1.19	1.19	1.36	1.50	1.54	1.48	1.37	1.39
Molecular:														
SiO <sub>2</sub> .....	81.9	83.0	83.4	82.6	81.6	81.2	80.7	81.4	83.4	82.4	82.1	82.3	79.9	79.9
Al <sub>2</sub> O <sub>3</sub> .....	9.0	7.9	7.9	7.9	8.4	8.8	9.1	8.6	8.1	8.5	8.8	8.6	10.0	9.9
Na <sub>2</sub> O+K <sub>2</sub> O.....	9.1	9.1	8.7	9.5	10.0	10.0	10.2	10.0	8.5	9.1	9.1	9.1	10.1	10.3
100 Na <sub>2</sub> O/(Na <sub>2</sub> O+K <sub>2</sub> O).....	72.1	63.7	63.7	66.0	65.5	64.1	64.6	64.3	67.2	69.4	70.1	69.4	67.3	67.8
CIPW norms—Continued														
Q.....	20.3	28.9	31.0	27.0	22.7	17.9	17.1	20.5	27.1	24.1	23.0	24.1	15.0	14.4
or.....	20.6	27.2	26.7	26.7	27.8	28.4	28.9	28.4	22.5	22.8	22.2	22.8	26.6	26.6
ab.....	49.3	36.2	37.2	36.7	37.7	39.3	40.9	37.7	41.7	44.0	46.6	44.5	51.6	50.0
ac.....	1.4	2.8	2.3	3.7	3.7	4.2	3.2	3.2	1.2	2.5	.9	2.3	.4	2.4
ns.....	-----	.7	.1	1.3	1.5	.4	.9	1.1	.2	.1	-----	-----	-----	-----
di:														
wo.....	2.3	-----	-----	-----	.2	1.0	1.4	1.1	2.0	.8	1.2	.8	1.0	.7
en.....	.1	-----	-----	-----	.1	.1	.1	.1	-----	-----	-----	-----	.2	.1
fs.....	2.5	-----	-----	-----	.1	1.1	1.5	1.2	2.3	.9	1.3	.9	.9	.7
hy:														
en.....	-----	-----	-----	.1	-----	.4	-----	-----	-----	-----	-----	-----	.3	.4
fs.....	2.0	2.5	1.7	3.2	3.7	5.5	4.2	4.2	2.3	2.6	2.2	2.6	1.6	2.9
mt.....	.3	-----	-----	-----	-----	-----	-----	-----	-----	-----	.7	-----	1.5	-----
il.....	.6	.3	.2	.5	.5	.5	.6	.6	.2	.4	.4	.5	.6	.6
sp.....	-----	-----	-----	-----	.1	-----	-----	-----	-----	-----	-----	-----	.1	.1
Z.....	-----	-----	-----	-----	.3	-----	.3	.3	-----	.2	.2	.2	-----	-----
CaF <sub>2</sub> .....	-----	.5	.4	.6	.5	-----	.3	.4	-----	.4	.4	.4	-----	-----
NaCl.....	-----	.2	.5	.4	.4	.5	.4	.5	.1	.4	.4	.4	-----	-----
NaF.....	-----	.3	.3	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
cc.....	-----	-----	-----	-----	-----	.3	-----	-----	-----	-----	-----	-----	.1	.2
Other.....	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
Σ femics <sup>4</sup> .....	9.2	6.8	4.7	9.4	10.3	13.6	12.2	11.8	8.2	7.7	7.1	7.5	6.6	8.0

<sup>1</sup> Molecular (Na<sub>2</sub>O+K<sub>2</sub>O)/Al<sub>2</sub>O<sub>3</sub>.  
<sup>2</sup> By weight.  
<sup>3</sup> Normative hematite, 0.6 percent.  
<sup>4</sup> Normative corundum, 0.4 percent.  
<sup>5</sup> Normative corundum, 0.1 percent.  
<sup>6</sup> Sum of normative femic constituents, as defined by Washington (1917).

TABLE 3.—Chemical analyses and norms of pantelleritic obsidians and separated glasses

[Details of the specimens are given on p. N23. Asterisk indicates residual glass separated from the whole rock sample having the preceding number. Tr. indicates trace. Data in weight percent except for ratios and indices]

	<sup>1</sup> 30	<sup>1</sup> 31	<sup>1</sup> 32	33	* 34	35	* 36	37	* 38	39	* 40	41	42	43	44
<b>Chemical analyses</b>															
SiO <sub>2</sub> -----	69.81	69.56	70.07	67.5	69.9	68.6	70.1	69.7	70.5	69.2	69.8	68.00	67.75	69.40	68.60
Al <sub>2</sub> O <sub>3</sub> -----	8.59	11.27	8.40	12.0	8.8	9.2	7.6	9.1	7.6	10.9	10.7	8.73	8.80	8.66	10.64
Fe <sub>2</sub> O <sub>3</sub> -----	2.28	1.87	2.29	1.8	2.1	2.7	2.9	2.2	2.0	2.0	2.0	5.60	4.75	2.75	2.88
FeO-----	5.76	4.18	5.62	4.0	5.9	5.3	5.6	4.9	6.3	4.0	4.0	3.19	3.69	5.38	3.59
MgO-----	.10	.23	.05	.13	.13	.11	.04	.07	.03	.24	.23	.38	.45	.15	.45
CaO-----	.42	.44	.42	.50	.52	.54	.53	.39	.39	.44	.43	.60	.56	.84	.49
Na <sub>2</sub> O-----	6.46	6.28	6.50	6.9	6.5	6.8	7.1	6.9	7.0	6.5	6.5	6.74	6.74	6.34	6.36
K <sub>2</sub> O-----	4.49	4.60	4.47	5.2	4.7	4.6	4.6	4.8	4.6	4.9	4.8	4.82	4.46	4.34	4.80
H <sub>2</sub> O-----	.05	.02	.03	.02	Nil	.03	.04	.01	Nil	.02	.01	.06	.00	-----	.25
H <sub>2</sub> O+-----	.14	.13	.08	.38	.04	.32	.23	.33	.05	.22	.17	-----	-----	.44	1.18
TiO <sub>2</sub> -----	.45	.47	.44	.49	.54	.46	.41	.38	.35	.52	.52	.35	.48	.37	.65
ZrO <sub>2</sub> -----	.25	.12	.31	.22	.20	.24	.28	.30	.27	.21	.20	-----	-----	-----	-----
CO <sub>2</sub> -----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
P <sub>2</sub> O <sub>5</sub> -----	.13	.10	.11	.04	.04	.04	.05	.04	.04	.04	.05	.13	.21	.05	.05
SO <sub>3</sub> -----	.06	.06	.02	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
S-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
MnO-----	.28	.28	.29	.21	.30	.31	.34	.26	.32	.29	.30	.19	.21	.33	.27
Cl-----	.76	.37	.79	.62	.70	.56	.69	.72	.82	.30	.31	-----	-----	-----	.35
F-----	.30	-----	.32	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	.20
Subtotal-----	100.33	100.17	100.21	100.01	100.37	99.81	100.51	100.10	100.27	99.78	100.02	98.79	98.10	99.05	100.76
O≡(F,Cl) <sub>2</sub> -----	.30	.16	.31	.14	.16	.13	.16	.16	.18	.07	.07	-----	-----	-----	.16
Total-----	100.03	100.01	99.90	99.87	100.21	99.68	100.35	99.94	100.09	99.71	99.95	<sup>2</sup> 98.79	<sup>3</sup> 98.10	99.05	100.60
<b>Agpaitic index <sup>4</sup></b>															
Fe as FeO <sup>5</sup> -----	7.81	5.86	7.68	5.62	7.79	7.73	8.21	6.88	8.10	5.80	5.80	8.24	7.97	7.86	6.18
FeO/(FeO+Fe <sub>2</sub> O <sub>3</sub> ) <sup>5</sup> -----	.72	.69	.71	.69	.74	.66	.66	.69	.76	.67	.67	.36	.44	.66	.55
Na <sub>2</sub> O/K <sub>2</sub> O <sup>5</sup> -----	1.44	1.37	1.45	1.33	1.38	1.48	1.54	1.44	1.52	1.33	1.35	1.40	1.51	1.46	1.33
<b>Molecular:</b>															
SiO <sub>2</sub> -----	83.1	81.6	83.3	79.8	82.8	82.1	83.0	82.2	83.2	81.4	81.6	82.1	82.3	83.2	81.6
Al <sub>2</sub> O <sub>3</sub> -----	6.0	7.8	5.9	8.4	6.2	6.5	5.3	6.3	5.3	7.5	7.4	6.2	6.3	6.1	7.4
Na <sub>2</sub> O+K <sub>2</sub> O-----	10.9	10.6	10.9	11.8	11.0	11.4	11.7	11.5	11.5	11.1	11.0	11.6	11.3	10.7	11.0
100 Na <sub>2</sub> O/(Na <sub>2</sub> O+K <sub>2</sub> O)-----	68.4	67.3	69.1	66.9	67.7	69.2	70.1	68.5	69.8	66.9	67.3	68.1	69.9	68.9	66.9
<b>CIPW norms</b>															
Q-----	28.7	21.5	29.8	16.6	27.5	24.2	29.6	26.7	30.8	21.4	22.6	22.6	23.2	26.3	21.5
or-----	26.7	27.2	26.1	30.6	27.8	27.2	27.2	28.4	27.2	28.9	28.4	28.4	26.1	25.6	28.4
ab-----	18.9	32.5	18.3	33.0	18.9	21.5	13.6	19.9	13.6	28.8	28.3	18.3	20.4	20.4	27.8
ac-----	6.5	5.5	6.5	5.1	6.0	7.8	8.3	6.5	6.0	6.0	6.0	16.2	13.9	7.9	8.3
ns-----	4.9	2.7	5.1	3.5	5.6	5.4	7.4	6.0	7.7	4.0	4.2	4.8	4.9	5.6	3.3
di:															
wo-----	-----	.2	-----	.9	.9	1.0	1.0	.7	.7	.8	.8	.9	.6	1.6	.3
en-----	-----	.1	-----	.1	.1	.1	Tr.	.1	.1	.1	.1	.2	.1	.1	.1
fs-----	-----	.1	-----	1.0	1.0	1.2	1.1	.7	.7	.8	.9	.9	.6	1.7	.3
hy:															
en-----	.3	.6	.1	.3	.3	.2	.1	.2	.1	.5	.5	.8	1.0	.3	1.0
fs-----	10.4	7.3	10.1	6.0	9.4	8.4	9.2	8.1	10.9	6.3	6.2	4.8	5.7	8.2	5.8
mt-----	.8	.9	.8	.9	1.1	.9	.8	.8	.8	.9	.9	.6	.9	.7	1.2
il-----	.3	.2	.3	.1	.1	.1	.1	.1	.1	.1	.1	.3	.5	.1	.1
ap-----	.4	.2	.5	.4	.4	.4	.4	.4	.4	.4	.4	-----	-----	-----	-----
Z-----	.4	.3	.4	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	.4
CaF <sub>2</sub> -----	1.3	.6	1.3	.9	1.2	.9	1.2	1.2	1.3	.5	.5	-----	-----	-----	.6
NaCl-----	.3	-----	.3	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
cc-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
Σ femics <sup>6</sup> -----	23.6	17.9	23.3	17.9 <sup>f</sup>	24.5	25.1	28.0	23.2	27.1	19.5	19.7	29.5	28.2	26.2	20.8

See footnotes at end of table.

TABLE 3.—Chemical analyses and norms of pantelleritic obsidians and separated glasses—Continued

	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59
<b>Chemical analyses—Continued</b>															
SiO <sub>2</sub> .....	68.00	73.34	72.24	65.78	71.82	70.88	72.82	71.30	70.52	69.06	70.99	71.63	72.8	71.7	69.9
Al <sub>2</sub> O <sub>3</sub> .....	11.34	10.41	9.68	12.45	8.65	10.59	10.30	7.42	9.30	6.30	9.18	11.31	7.57	7.94	9.70
Fe <sub>2</sub> O <sub>3</sub> .....	3.16	3.57	1.10	2.65	1.53	1.42	1.44	1.96	1.38	4.98	3.15	2.41	2.54	2.38	1.86
FeO.....	2.42	1.60	4.24	3.61	5.55	4.41	2.99	6.79	5.72	6.26	4.67	3.56	4.96	4.98	5.58
MgO.....	.45	.10	.12	.96	Tr.	.36	.22	.00	.00	.27	.19	.02	.02	.08	.05
CaO.....	.53	.20	1.16	1.64	.70	.48	1.48	.60	1.92	.94	.71	.41	.26	.36	.62
Na <sub>2</sub> O.....	7.76	4.68	5.72	6.64	6.26	6.21	6.69	6.63	5.98	7.37	6.07	5.61	7.20	6.64	6.32
K <sub>2</sub> O.....	4.72	4.82	4.37	4.32	4.28	4.75	4.67	4.26	4.01	3.39	4.24	4.56	4.22	4.34	4.55
H <sub>2</sub> O.....	.00	.18	.14	.17	.08	.07	.04	.03	.14	Tr.	.02	-----	.06	-----	-----
H <sub>2</sub> O+.....	.56	.41	.30	.04	.44	.16	.10	.19	.18	.47	.22	.25	.02	.17	.13
TiO <sub>2</sub> .....	.65	.23	.41	1.07	.64	.53	.30	.61	.60	.61	.38	.36	.21	.26	.57
ZrO <sub>2</sub> .....	-----	.24	.21	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	.17	.13
CO <sub>2</sub> .....	-----	-----	.26	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
P <sub>2</sub> O <sub>5</sub> .....	.06	.00	-----	.07	-----	.05	-----	.00	.06	.07	.28	.07	.03	.03	.04
SO <sub>2</sub> .....	-----	-----	-----	-----	-----	-----	-----	-----	-----	.47	-----	-----	-----	-----	-----
S.....	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
MnO.....	.21	.12	.17	-----	.25	.11	.03	.36	.24	.17	.25	.20	.27	.26	.28
Cl.....	.51	.07	.18	.13	-----	.18	.30	-----	-----	.06	-----	-----	.25	.20	.16
F.....	.20	.26	-----	-----	-----	.17	-----	-----	-----	-----	-----	-----	.34	.26	.20
Subtotal.....	100.57	100.23	100.30	100.03	100.20	100.37	100.49	100.15	100.05	100.42	100.35	100.39	100.75	99.67	100.09
O≡(F,Cl) <sub>2</sub> .....	.20	.13	.04	.03	-----	.11	.11	-----	-----	.01	-----	-----	.20	.15	.12
Total.....	100.37	100.10	100.26	100.00	100.20	100.26	100.38	100.15	100.05	100.41	100.35	100.39	100.55	99.52	99.97
Apaitic index <sup>4</sup> .....	1.58	1.25	1.45	1.30	1.72	1.44	1.56	2.08	1.53	2.50	1.59	1.25	2.18	1.96	1.58
Fe as FeO <sup>5</sup> .....	5.27	4.82	5.24	6.00	6.93	5.69	3.39	8.56	6.96	10.75	7.51	5.73	7.25	7.08	7.26
FeO/(FeO+Fe <sub>2</sub> O <sub>3</sub> ) <sup>5</sup> .....	.43	.31	.79	.58	.78	.76	.87	.78	.81	.56	.60	.60	.66	.63	.75
Na <sub>2</sub> O/K <sub>2</sub> O <sup>5</sup> .....	1.64	.97	1.31	1.38	1.46	1.31	1.43	1.56	1.49	2.17	1.43	1.23	1.71	1.53	1.39
Molecular:															
SiO <sub>2</sub> .....	79.8	84.2	83.8	79.6	83.8	82.2	82.4	84.0	83.6	84.1	83.5	82.7	83.8	83.8	82.6
Al <sub>2</sub> O <sub>3</sub> .....	7.3	7.0	6.6	8.9	6.0	7.3	6.9	5.2	6.5	4.5	6.4	7.7	5.1	5.5	6.7
Na <sub>2</sub> O+K <sub>2</sub> O.....	12.3	8.8	9.6	11.5	10.2	10.5	10.7	10.8	9.9	11.3	10.1	9.6	11.1	10.7	10.7
100 Na <sub>2</sub> O/(Na <sub>2</sub> O+K <sub>2</sub> O).....	71.4	59.8	66.7	67.7	69.2	66.7	68.4	70.4	69.1	76.8	68.5	65.5	72.0	69.9	68.0
<b>CIPW norms—Continued</b>															
Q.....	18.5	30.1	29.9	11.4	30.6	25.1	28.6	31.7	26.7	29.5	27.2	24.0	34.2	32.3	25.4
or.....	27.3	28.4	26.1	23.4	25.6	28.4	27.8	25.6	23.4	20.0	25.0	27.2	25.0	25.6	26.7
ab.....	32.0	26.7	25.2	37.2	20.4	27.8	26.7	14.2	25.7	13.6	23.6	32.5	15.2	16.8	24.6
ac.....	9.3	9.7	3.2	7.9	4.2	4.2	1.4	6.0	4.2	14.3	9.2	6.9	7.4	6.5	5.3
ns.....	4.5	-----	4.0	2.1	6.5	4.4	6.1	8.2	4.9	7.4	4.0	1.6	7.7	7.0	5.3
di:															
wo.....	.4	-----	1.7	3.2	1.4	.2	2.8	1.3	3.9	1.8	.7	.6	-----	-----	.6
en.....	.1	-----	.1	1.1	-----	.1	.3	-----	.1	.1	.1	-----	-----	-----	.1
fs.....	.3	-----	1.8	2.2	1.6	.2	2.8	1.5	4.5	1.9	.7	.7	-----	-----	.6
hy:															
en.....	1.0	.3	.2	1.3	-----	.9	.2	-----	-----	.6	.4	.1	.1	.1	.1
fs.....	3.5	2.6	5.5	2.7	8.2	7.1	2.4	10.5	5.3	8.8	7.3	5.7	9.3	9.4	9.3
mt.....	-----	.2	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
il.....	1.2	.5	.8	2.0	1.2	1.1	.6	1.2	1.2	1.2	.8	.8	.4	.5	1.1
ap.....	.1	-----	-----	.2	-----	-----	-----	-----	-----	.2	.7	.2	Tr.	.1	.1
Z.....	-----	.4	.3	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	.2	.2
CaF <sub>2</sub> .....	.4	.3	-----	-----	-----	.4	.2	-----	-----	-----	-----	-----	.4	.5	.4
NaCl.....	.8	.1	.3	.2	-----	.3	.5	-----	-----	.1	-----	-----	.4	.4	.3
NaF.....	-----	.3	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	.4	.1	-----
cc.....	-----	-----	.6	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
Σ femics <sup>6</sup> .....	20.8	13.6	17.9	22.7	23.1	18.6	16.8	28.7	24.0	36.3	24.4	16.6	25.3	24.1	22.9

See footnotes at end of table.

TABLE 3.—Chemical analyses and norms of pantelleritic obsidians and separated glasses—Continued

	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74
Chemical analyses—Continued															
SiO <sub>2</sub> .....	71.7	70.1	71.0	70.5	70.4	71.2	70.9	69.3	72.3	74.4	74.4	74.2	74.3	74.3	74.3
Al <sub>2</sub> O <sub>3</sub> .....	7.86	10.00	8.81	8.76	8.70	8.95	7.86	9.88	7.74	9.42	9.41	9.40	9.35	9.44	9.48
Fe <sub>2</sub> O <sub>3</sub> .....	2.76	2.31	2.28	2.21	3.24	2.26	2.53	1.99	2.61	1.77	1.65	1.74	1.28	1.61	1.79
FeO.....	4.69	4.63	5.40	5.37	4.68	5.05	5.82	5.50	4.92	2.88	2.90	2.90	3.34	2.82	2.90
MgO.....	.02	.10	.04	.04	.02	.02	.03	.07	.02	.16	.13	.15	.20	.12	.16
CaO.....	.26	.60	.36	.40	.41	.41	.40	.67	.24	.20	.24	.21	.20	.28	.18
Na <sub>2</sub> O.....	7.07	6.19	6.68	6.44	6.43	6.49	6.94	6.32	7.08	5.33	5.49	5.23	5.66	5.29	5.52
K <sub>2</sub> O.....	4.21	4.55	4.41	4.52	4.47	4.52	4.24	4.54	4.16	4.29	4.39	4.26	4.44	4.39	4.48
H <sub>2</sub> O.....	.07	.....	.16	.....	.....	.....	.08	.....	.08	.....	.....	.....	.....	.....	.....
H <sub>2</sub> O + .....	.00	.14	.00	.20	.14	.15	.04	.14	.10	.47	.41	.40	.32	.36	.31
TiO <sub>2</sub> .....	.24	.50	.51	.50	.52	.45	.41	.57	.22	.35	.27	.27	.26	.27	.27
ZrO <sub>2</sub> .....	.....	.16	.....	.15	.13	.14	.....	.13	.....	.25	.25	.25	.25	.25	.25
CO <sub>2</sub> .....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
P <sub>2</sub> O <sub>5</sub> .....	.03	.04	.04	.03	.03	.02	.05	.04	.03	.....	.....	.....	.....	.....	.....
SO <sub>3</sub> .....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
S.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
MnO.....	.26	.27	.29	.29	.29	.26	.29	.29	.27	.22	.21	.21	.22	.21	.20
Cl.....	.21	.19	.19	.20	.20	.20	.28	.15	.23	.16	.16	.16	.17	.16	.16
F.....	.26	.21	.24	.23	.22	.22	.30	.18	.29	.25	.25	.24	.25	.23	.23
Subtotal.....	99.64	99.99	100.41	99.84	99.88	100.34	100.17	99.77	100.24	100.15	100.16	99.62	100.24	99.73	100.23
O≡(F,Cl) <sub>2</sub> .....	.16	.13	.14	.14	.14	.14	.19	.12	.17	.15	.15	.14	.15	.14	.14
Total.....	99.48	99.86	100.27	99.70	99.74	100.20	99.98	99.68	100.07	100.00	100.01	99.48	100.09	99.59	100.09
Agpaitic index <sup>4</sup> .....	2.07	1.51	1.80	1.77	1.78	1.74	2.04	1.55	2.08	1.43	1.43	1.40	1.50	1.43	1.47
Fe as FeO <sup>5</sup> .....	7.18	6.71	7.45	7.36	7.60	7.09	8.10	7.29	7.27	4.47	4.39	4.47	4.49	4.27	4.51
FeO/(FeO+Fe <sub>2</sub> O <sub>3</sub> ) <sup>5</sup> .....	.63	.67	.73	.71	.59	.69	.70	.73	.65	.62	.64	.63	.72	.64	.62
Na <sub>2</sub> O/K <sub>2</sub> O <sup>5</sup> .....	1.68	1.36	1.51	1.42	1.44	1.44	1.64	1.39	1.70	1.24	1.25	1.23	1.27	1.21	1.23
Molecular:															
SiO <sub>2</sub> .....	83.5	82.6	83.1	83.1	83.2	83.1	83.5	82.4	83.7	84.7	84.4	84.8	84.3	84.7	84.3
Al <sub>2</sub> O <sub>3</sub> .....	5.4	6.9	6.0	6.1	6.0	6.2	5.4	6.9	5.3	6.3	6.3	6.3	6.3	6.3	6.3
Na <sub>2</sub> O+K <sub>2</sub> O.....	11.1	10.5	10.9	10.8	10.8	10.7	11.1	10.7	11.0	9.0	9.3	8.9	9.4	9.0	9.4
100 Na <sub>2</sub> O/(Na <sub>2</sub> O+K <sub>2</sub> O).....	71.7	67.6	69.7	68.4	68.9	68.6	71.3	68.0	72.2	65.2	65.4	65.1	65.9	64.4	65.0
CIPW norms—Continued															
Q.....	32.2	25.1	29.1	28.6	28.3	29.0	30.9	23.9	33.2	34.3	34.1	34.1	33.9	34.4	33.5
or.....	25.0	26.7	26.1	26.7	26.1	26.7	25.0	26.7	24.5	25.6	26.1	25.6	26.1	26.1	26.7
ab.....	16.8	26.2	20.4	19.9	19.9	21.0	16.8	25.7	16.8	24.1	23.6	24.1	23.6	23.6	23.6
ac.....	7.9	6.5	6.5	6.5	9.7	6.5	7.4	6.0	7.4	5.1	5.1	5.1	3.7	4.6	5.1
ns.....	7.3	4.1	6.2	6.0	5.1	5.9	7.1	4.6	7.2	3.3	3.8	3.1	4.4	3.4	3.8
di:															
wo.....	.....	.5	.....	.1	.1	.1	.....	.8	.....	.....	.....	.....	.....	.....	.....
en.....	.....	.1	.....	.1	.1	.1	.....	.1	.....	.....	.....	.....	.....	.....	.....
fs.....	.....	.5	.....	.1	.1	.1	.....	.8	.....	.....	.....	.....	.....	.....	.....
hy:															
en.....	.1	.2	.1	.1	.....	.1	.2	.1	.4	.3	.4	.5	.3	.4	.4
fs.....	8.7	7.7	9.6	9.6	8.2	8.9	10.6	9.0	9.2	5.1	5.1	5.1	5.9	5.0	5.1
mt.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
il.....	.5	.9	1.0	.9	1.0	.9	.8	1.1	.4	.6	.6	.6	.6	.6	.6
ap.....	Tr.	.1	.1	.....	.....	.....	.1	.1	Tr.	.....	.....	.....	.....	.....	.....
Z.....	.2	.....	.2	.2	.2	.2	.....	.2	.....	.4	.4	.4	.4	.4	.4
CaF <sub>2</sub> .....	.4	.4	.4	.5	.5	.5	.5	.4	.3	.3	.3	.3	.3	.4	.3
NaCl.....	.4	.3	.3	.4	.4	.4	.5	.2	.4	.3	.3	.3	.3	.3	.3
NaF.....	.2	.....	.1	.....	.....	.....	.2	.....	.3	.....	.....	.....	.....	.....	.....
cc.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Σ femics <sup>6</sup> .....	24.9	21.0	23.9	23.9	24.8	23.0	26.6	23.1	24.6	14.8	15.2	14.6	15.4	14.3	15.3

See footnotes at end of table.

TABLE 3.—Chemical analyses and norms of pantelleritic obsidians and separated glasses—Continued

	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89
<b>Chemical analyses—Continued</b>															
SiO <sub>2</sub> .....	73.8	74.0	74.1	74.9	74.8	64.00	70.36	70.4	70.0	66.4	70.45	71.39	70.61	70.13	70.86
Al <sub>2</sub> O <sub>3</sub> .....	9.54	9.46	9.62	9.46	9.69	10.43	9.63	7.95	7.92	9.73	8.99	9.57	8.59	7.97	8.48
Fe <sub>2</sub> O <sub>3</sub> .....	1.73	1.91	1.76	1.53	1.61	6.30	1.72	2.47	2.63	2.53	2.33	2.48	2.52	2.77	2.40
FeO.....	2.97	2.65	2.84	2.87	2.92	8.36	5.42	5.97	5.78	6.83	5.22	4.22	5.96	5.27	5.02
MgO.....	.19	.23	.20	.17	.14	.34	.06	.08	.08	.02	.05	.20	.07	.07	.52
CaO.....	.23	.25	.20	.20	.30	1.45	.30	.50	.48	.77	.48	.55	.61	.55	.30
Na <sub>2</sub> O.....	5.62	5.42	5.53	5.49	5.53	7.59	6.73	7.35	7.37	7.60	6.71	6.39	6.77	7.46	6.63
K <sub>2</sub> O.....	4.43	4.41	4.37	4.47	4.38	4.59	4.43	4.31	4.28	4.41	4.55	4.40	4.46	4.24	4.50
H <sub>2</sub> O.....															
H <sub>2</sub> O +.....	.49	.30	.29	.40	.37	.17	.01	.18	.23	.19	.07	Nil	.35	.10	.06
TiO <sub>2</sub> .....	.26	.27	.29	.27	.28	.78	.33	.32	.32	.59	.35	.33	.15	.30	.20
ZrO <sub>2</sub> .....	.25	.25	.24	.24	.25			.26	.26	.16				.22	.33
CO <sub>2</sub> .....															
PO <sub>2</sub> .....							.03	.04	.03	.06	.01	.02		.04	.02
SO <sub>2</sub> .....															
S.....															
MnO.....	.23	.21	.22	.22	.22	.37	.25	.26	.26	.26	.21	.21	.34	.26	.25
Cl.....	.17	.16	.16	.16	.16		.40	.33	.34	.23		.32		.37	.42
F.....	.25	.25	.25	.25	.24		.17	.40	.41	.30		.41			.69
Subtotal.....	100.16	99.77	100.07	100.63	100.89	99.88	99.94	100.77	100.39	100.08	99.42	100.84	100.18	100.25	100.67
O≡(F,Cl) <sub>2</sub> .....	.15	.15	.15	.15	.14		.16	.24	.25	.18		.25		.08	.39
Total.....	100.01	99.62	99.92	100.48	100.75	99.88	99.78	100.53	100.14	99.90	99.42	100.59	100.18	100.17	100.28
Agpaitic index <sup>4</sup> .....	1.47	1.44	1.44	1.46	1.43	1.68	1.66	2.12	2.10	1.79	1.77	1.60	1.86	2.12	1.88
Fe as FeO <sup>5</sup> .....	4.53	4.37	4.43	4.25	4.37	9.54	6.97	8.20	8.19	9.11	7.32	6.45	8.23	7.77	7.18
FeO/(FeO+Fe <sub>2</sub> O <sub>3</sub> ) <sup>5</sup> .....	.63	.58	.62	.65	.64	.33	.76	.71	.68	.73	.69	.63	.70	.66	.68
Na <sub>2</sub> O/K <sub>2</sub> O <sup>5</sup> .....	1.27	1.23	1.27	1.23	1.26	1.65	1.52	1.71	1.72	1.72	1.47	1.45	1.52	1.76	1.48
Molecular:															
SiO <sub>2</sub> .....	84.1	84.4	84.3	84.4	84.3	79.6	82.4	82.8	82.8	80.7	82.8	83.0	83.0	82.8	83.1
Al <sub>2</sub> O <sub>3</sub> .....	6.4	6.4	6.4	6.3	6.4	7.6	6.6	5.5	5.5	6.9	6.2	6.5	6.0	5.5	5.8
Na <sub>2</sub> O+K <sub>2</sub> O.....	9.5	9.2	9.3	9.3	9.3	12.8	11.0	11.7	11.7	12.4	11.0	10.5	11.0	11.7	11.1
100 Na <sub>2</sub> O/(Na <sub>2</sub> O+K <sub>2</sub> O).....	65.9	64.9	65.9	65.4	65.4	71.3	69.9	72.1	72.6	72.4	69.2	68.7	69.9	72.7	69.2
<b>CIPW norms—Continued</b>															
Q.....	32.9	33.3	33.1	34.5	33.7	11.0	26.6	29.5	29.0	19.2	27.1	27.7	27.1	23.8	30.0
or.....	26.1	26.1	26.1	26.7	26.1	27.2	26.1	25.6	25.0	26.1	26.7	26.1	26.1	25.1	26.7
ab.....	24.1	24.1	24.6	23.6	25.2	27.8	24.6	16.8	17.3	25.2	21.0	24.6	19.4	17.4	18.3
ac.....	5.1	5.5	5.1	4.2	4.6	18.0	5.1	7.2	7.9	7.4	6.7	7.4	7.4	8.0	6.9
ns.....	3.8	3.3	3.5	4.0	3.5	3.7	5.6	8.0	7.6	6.8	6.5	4.3	6.8	7.9	4.8
di:															
wo.....						3.0				.5	1.0		1.3	1.0	
en.....						.4				.1	.1		Tr.	Tr.	
fs.....						3.0				.5	1.1		1.4	1.2	
hy:															
en.....	.5	.6	.5	.4	.4	.5	.2	.1	.1		.1	.5	.2	.2	1.3
fs.....	5.4	4.8	5.0	5.1	5.1	3.5	9.8	10.9	10.6	11.6	8.3	7.7	9.9	8.5	9.2
mt.....															
il.....	.6	.6	.6	.6	.6	1.5	.6	.6	.6	1.2	.7	.6	.3	.6	.6
ap.....							.1	.1	Tr.	.1				.1	
Z.....	.4	.4	.4	.4	.4			.4	.4	.2				.3	
CaF <sub>2</sub> .....	.3	.4	.3	.3	.4		.4	.6	.7	.6		.8			.4
NaCl.....	.3	.3	.3	.3	.3		.6	.5	.6	.4		.5		.6	.7
NaF.....								.2	.2			.1			1.1
cc.....															
Σ femics <sup>6</sup> .....	15.7	15.2	15.0	14.6	14.6	33.6	21.8	27.5	27.5	28.8	24.5	21.3	27.3	27.5	23.2

See footnotes at end of table.

TABLE 3.—Chemical analyses and norms of pantelleritic obsidians and separated glasses—Continued

	90	91	92	93	94	95	96	97	98	99	100	101	102	103	104
Chemical analyses—Continued															
SiO <sub>2</sub> .....	69.25	73.4	74.6	73.1	74.4	74.7	72.4	72.5	73.5	74.00	74.30	74.29	72.79	73.02	68.91
Al <sub>2</sub> O <sub>3</sub> .....	9.10	9.05	9.95	9.60	10.4	10.1	8.8	9.8	8.9	10.41	9.88	9.73	9.77	9.56	10.83
Fe <sub>2</sub> O <sub>3</sub> .....	3.70	2.35	1.96	2.15	1.94	1.93	2.5	2.3	2.4	1.68	1.65	1.91	2.04	2.00	2.91
FeO.....	2.61	3.80	2.80	3.75	2.50	2.45	3.4	3.5	3.8	2.74	2.81	2.71	3.57	3.75	4.56
MgO.....	.01	<.01	<.01	<.01	<.01	<.01	.2	<.1	.15	.01	.02	.01	.05	.05	.22
CaO.....	.06	.21	.21	.26	.26	.20	.45	.15	.45	.19	.23	.25	.29	.32	.24
Na <sub>2</sub> O.....	7.00	6.20	5.60	6.20	5.55	5.60	6.3	6.3	6.6	5.69	5.68	5.80	6.39	6.32	6.96
K <sub>2</sub> O.....	4.29	4.25	4.30	4.30	4.35	4.25	4.3	4.6	4.2	4.37	4.32	4.38	4.36	4.30	4.46
H <sub>2</sub> O.....	.01	.....	.....	.....	.....	.....	.....	.10	.....	.05	Nil	Nil	Nil	Nil	.10
H <sub>2</sub> O+.....	.14	.15	.18	.16	.16	.29	.....	.15	.....	.13	.32	.18	.08	Tr.	.26
TiO <sub>2</sub> .....	.25	.15	.21	.23	.24	.22	.17	.....	.14	.23	.20	.19	.25	.23	.40
ZrO <sub>2</sub> .....	.78	.21	.18	.16	.15	.15	.....	.....	.....	.14	.20	.22	.16	.17	.....
CO <sub>2</sub> .....	.00	.21	.10	.11	<.01	.05	.....	.....	.....	.....	.....	.....	.....	.....	.....
P <sub>2</sub> O <sub>5</sub> .....	.01	.01	.01	.01	.01	.01	.06	.04	.03	.01	.02	.01	.02	.02	.02
SO <sub>3</sub> .....	.08	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
S.....	.....	.02	.02	.01	.02	.03	.....	.....	.....	.....	.....	.....	.....	.....	.....
MnO.....	.19	.19	.12	.14	.12	.10	.08	.16	.10	.10	.10	.11	.13	.14	.25
Cl.....	.78	.24	.23	.....	.....	.....	.....	.....	.....	.21	.22	.22	.21	.17	.....
F.....	1.80	.....	.....	.....	.....	.....	.....	.....	.....	.13	.....	.....	.....	.....	.....
Subtotal.....	99.56	100.44	100.47	100.18	100.10	100.08	98.66	99.89	100.27	100.09	100.00	100.01	100.11	100.05	100.12
O ≡ (F,Cl) <sub>2</sub> .....	.72	.05	.05	.....	.....	.....	.....	.....	.....	.10	.05	.05	.05	.04	.....
Total.....	98.84	100.39	100.42	100.18	100.10	100.08	98.66	99.89	100.27	99.99	99.95	99.96	100.06	100.01	100.12
Agpaitic index <sup>4</sup> .....	1.79	1.63	1.39	1.55	1.33	1.36	1.72	1.57	1.74	1.35	1.42	1.47	1.55	1.57	1.50
Fe as FeO <sup>5</sup> .....	5.94	5.92	4.57	5.69	4.25	4.19	5.65	5.57	5.96	4.25	4.30	4.43	5.41	5.55	7.18
FeO/(FeO+Fe <sub>2</sub> O <sub>3</sub> ) <sup>5</sup> .....	.41	.62	.59	.64	.56	.56	.58	.60	.61	.62	.63	.59	.64	.65	.61
Na <sub>2</sub> O/K <sub>2</sub> O <sup>5</sup> .....	1.63	1.46	1.30	1.44	1.28	1.32	1.47	1.37	1.57	1.30	1.31	1.32	1.47	1.47	1.56
Molecular:															
SiO <sub>2</sub> .....	82.3	83.9	84.2	83.5	83.9	84.1	83.7	83.0	83.7	83.7	84.0	84.0	83.2	83.4	81.2
Al <sub>2</sub> O <sub>3</sub> .....	6.4	6.1	6.6	6.5	6.9	6.7	6.0	6.6	6.0	6.9	6.6	6.5	6.6	6.4	7.5
Na <sub>2</sub> O+K <sub>2</sub> O.....	11.3	10.0	9.2	10.0	9.2	9.2	10.3	10.4	10.3	9.4	9.4	9.5	10.2	10.2	11.3
100 Na <sub>2</sub> O/(Na <sub>2</sub> O+K <sub>2</sub> O).....	71.1	69.0	66.2	68.5	66.2	66.7	68.9	67.5	70.2	66.7	66.7	67.1	69.1	68.9	70.4
CIPW norms—Continued															
Q.....	23.9	32.1	32.4	30.2	31.1	32.5	31.3	29.1	31.7	30.7	32.6	32.6	29.6	30.3	19.8
or.....	25.6	25.0	25.6	25.4	25.7	25.1	25.6	27.2	25.0	26.1	25.5	25.9	25.8	25.4	26.4
ab.....	22.5	23.1	27.2	25.4	29.3	28.3	21.0	24.6	22.0	28.8	26.8	25.7	26.0	25.2	30.9
ac.....	10.6	6.9	5.5	6.2	5.6	5.6	7.4	6.5	6.9	5.1	4.8	5.5	5.9	5.8	8.4
ns.....	.4	4.6	2.8	4.6	2.6	3.0	5.6	5.0	6.1	2.8	3.3	3.6	4.6	4.8	4.3
di:															
wo.....	.....	.....	.2	.2	.5	.3	.8	.2	.9	.....	.5	.5	.5	.6	.5
en.....	.....	.....	.....	.....	.....	.....	.1	.....	.1	.....	.1	.....	.....	.....	.1
fs.....	.....	.....	.3	.3	.6	.3	.8	.3	1.0	.....	.5	.6	.6	.7	.4
hy:															
en.....	.....	.....	.....	.....	.....	.....	.4	.....	.4	.....	.....	.....	.1	.1	.5
fs.....	4.8	7.1	4.8	6.3	3.8	4.0	5.3	5.9	6.0	5.1	4.5	4.3	5.9	6.0	7.6
mt.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
il.....	.5	.3	.4	.4	.5	.4	.3	.6	.3	.5	.4	.4	.5	.4	.8
ap.....	.....	Tr.	Tr.	Tr.	Tr.	Tr.	.1	.1	.1	.....	.1	Tr.	.1	.1	Tr.
Z.....	1.1	.3	.3	.2	.2	.2	.....	.....	.....	.2	.3	.3	.2	.3	.....
CaF <sub>2</sub> .....	.1	.....	.....	.....	.....	.....	.....	.....	.....	.3	.....	.....	.....	.....	.....
NaCl.....	1.3	.4	.4	.....	.....	.....	.....	.....	.....	.4	.4	.4	.4	.3	.....
NaF.....	2.8	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
cc.....	.....	.4	.2	.3	.....	.1	.....	.....	.....	.....	.....	.....	.....	.....	.....
Σ femics <sup>6</sup> .....	16.4	19.3	14.2	18.3	13.6	13.7	20.8	18.6	21.8	13.8	14.2	14.9	18.2	18.5	22.6

<sup>1</sup> Additional analytical data on this sample given in the explanation to tables 2-8.  
<sup>2</sup> Also loss on ignition, 0.46 percent.

<sup>3</sup> Also loss on ignition 0.95 percent.  
<sup>4</sup> Molecular (Na<sub>2</sub>O+K<sub>2</sub>O)/Al<sub>2</sub>O<sub>3</sub>.  
<sup>5</sup> By weight.

<sup>6</sup> Sum of normative femic constituents, as defined by Washington (1917).

TABLE 4.—*Chemical analyses and norms of comenditic and pantelleritic trachyte obsidians*

[Details of the specimens are given on p. N25. Tr. indicates trace. Data in weight percent except for ratios and indices]

	Comenditic				Pantelleritic				
	105	106	107	108	109	110	111	112	113
<b>Chemical analyses</b>									
SiO <sub>2</sub> .....	64.96	63.0	62.5	63.40	63.1	62.7	62.8	61.1	62.3
Al <sub>2</sub> O <sub>3</sub> .....	15.06	15.8	15.21	12.06	12.41	12.50	12.36	12.59	12.99
Fe <sub>2</sub> O <sub>3</sub> .....	.65	2.6	1.15	3.50	2.05	2.04	2.11	1.64	3.87
FeO.....	4.32	3.3	5.55	5.70	6.97	6.90	6.94	7.54	4.67
MgO.....	Nil	.42	.33	.31	.16	.18	.18	.23	.35
CaO.....	1.58	1.9	1.45	.99	1.12	1.20	1.13	1.20	1.28
Na <sub>2</sub> O.....	6.79	6.4	7.18	7.95	8.43	8.52	8.42	8.56	7.44
K <sub>2</sub> O.....	5.45	5.1	5.20	4.55	4.57	4.72	4.54	4.68	4.80
H <sub>2</sub> O.....	.26	.03	---	.03	---	---	---	.13	.14
H <sub>2</sub> O + .....	.52	.24	.30	.24	.14	.19	.05	.00	.03
TiO <sub>2</sub> .....	.59	.60	.75	.73	.69	.69	.70	.65	.82
ZrO <sub>2</sub> .....	---	.11	.03	---	.13	.12	.13	---	---
P <sub>2</sub> O <sub>5</sub> .....	.05	.12	.14	.10	.09	.10	.09	.11	.12
MnO.....	.15	.18	.28	.40	.35	.35	.36	.33	.28
Cl.....	---	---	.10	---	.23	.22	.23	.24	.13
F.....	---	---	.17	---	.36	.34	.36	.30	.26
Subtotal.....	100.38	99.8	100.34	99.96	100.80	100.77	100.40	99.30	99.48
O ≡ (F,Cl) <sub>2</sub> .....	---	---	.09	---	.20	.19	.20	.18	.14
Total.....	100.38	99.8	100.25	99.96	100.60	100.58	100.20	99.12	99.34
Agpaitic Index <sup>1</sup> .....	1.14	1.01	1.15	1.49	1.52	1.52	1.52	1.53	1.35
Fe as FeO <sup>2</sup> .....	4.91	5.64	6.59	8.85	8.82	8.74	8.84	9.02	8.16
FeO/(FeO + Fe <sub>2</sub> O <sub>3</sub> ) <sup>2</sup> .....	.87	.56	.83	.62	.77	.77	.77	.82	.55
Na <sub>2</sub> O/K <sub>2</sub> O <sup>2</sup> .....	1.25	1.25	1.38	1.75	1.84	1.81	1.85	1.83	1.55
Molecular:									
SiO <sub>2</sub> .....	77.4	77.1	76.5	78.2	77.4	77.1	77.4	76.6	77.7
Al <sub>2</sub> O <sub>3</sub> .....	10.6	11.4	10.9	8.7	9.0	9.1	9.0	9.2	9.5
Na <sub>2</sub> O + K <sub>2</sub> O.....	12.0	11.5	12.6	13.1	13.6	13.8	13.5	14.2	12.8
100 Na <sub>2</sub> O/(Na <sub>2</sub> O + K <sub>2</sub> O).....	65.5	65.6	67.8	72.7	73.5	73.3	73.9	73.4	70.2
<b>CIPW norms</b>									
Q.....	4.7	2.6	0.3	7.5	6.8	6.0	6.7	4.2	4.8
or.....	32.2	30.0	30.6	26.7	27.2	27.8	26.7	27.8	28.4
ab.....	47.2	52.9	49.3	37.2	38.3	38.3	38.8	38.3	39.8
ac.....	1.8	.9	3.2	10.2	6.0	6.0	6.0	4.6	11.1
ns.....	2.0	---	1.7	4.4	5.7	5.9	5.5	6.3	2.2
di:									
wo.....	3.1	3.6	2.2	1.9	.9	1.0	.9	1.2	1.5
en.....	---	.8	.2	.2	.1	.1	.1	.1	.2
fs.....	3.6	3.0	2.2	1.9	.9	1.0	.9	1.3	1.5
hy:									
en.....	---	.2	.6	.7	.3	.3	.3	.5	.7
fs.....	3.7	.6	7.3	8.1	11.4	11.1	11.2	12.1	6.3
mt.....	---	3.2	---	---	---	---	---	---	---
il.....	1.1	1.2	1.4	1.4	1.4	1.4	1.4	1.2	1.5
ap.....	.1	.3	.3	.2	.3	.3	.3	.3	.3
Z.....	---	.2	Tr.	---	.2	.2	.2	---	---
CaF <sub>2</sub> .....	---	---	.3	---	.7	.7	.7	.6	.6
NaCl.....	---	---	.2	---	.4	.4	.4	.4	.2
Σ femics <sup>3</sup> .....	15.4	13.8	19.4	29.0	27.7	27.8	27.3	28.2	25.9

<sup>1</sup> Molecular (Na<sub>2</sub>O + K<sub>2</sub>O)/Al<sub>2</sub>O<sub>3</sub>.

<sup>2</sup> By weight.

<sup>3</sup> Sum of normative femic constituents, as defined by Washington, 1917.



TABLE 5.—Trace element contents, in parts per million, of comendite and pantellerite obsidians, compiled from published data

[Specimen numbers are those used for major element analyses (tables 2 and 3). A, Average granite, from Taylor (1964), Taylor and White (1966). B, average rhyllitic volcanic rock, Taupo volcanic zone, New Zealand, from Ewart, Taylor, and Capp (1968). C, Average Arran pitchstone from Nicholls and Carmichael (1969). N.d. indicates not detected]

	Comendites						Pantellerites					
	1	11	12	15	30	31	32	33	35	37	39	
B	40	10	N.d.	30	30	10	30	---	---	---	---	
Ba	10	90	10	<5	50	50	50	---	---	---	---	
Be	10	80	10	6	11	5	10	---	---	---	---	
Cd	---	---	---	---	---	---	---	.70	.67	.48	.86	
Co	<5	N.d.	N.d.	<2	<5	<5	<5	.9	.2	1.0	.2	
Cr	<1	1	1	<1	<1	<1	<1	---	---	---	---	
Cs	---	---	---	<5	---	---	---	---	---	---	---	
Cu	8	2	16	<1	5	3	7	4.5	2.5	7.5	1.5	
Ga	28	39	36	30	45	43	44	---	---	---	---	
Hf	---	---	---	---	---	---	---	---	---	---	---	
La	170	210	240	110	360	230	360	---	---	---	---	
Li	---	---	---	78	---	---	---	---	---	---	---	
Mo	2	5	4	5	22	22	18	19.2	14.1	17.3	16.8	
Nb	150	70	70	70	450	320	440	260	350	370	250	
Ni	2	N.d.	N.d.	<2	3	4	3	.4	1.0	3.5	.7	
Pb	70	30	30	40	30	20	40	14	16	20	12	
Rb	---	---	---	390	---	---	---	150	180	200	140	
Sc	2	4	6	<2	4	6	4	---	---	---	---	
Sn	16	7	7	6	24	14	24	---	.8	---	---	
Sr	6	<5	6	2	7	3	9	<5	<5	<5	<5	
Ta	---	---	---	---	---	---	---	12.0	23.7	18.5	17.7	
Th	---	---	---	---	---	---	---	---	---	---	---	
U	---	---	---	---	---	---	---	---	---	---	---	
V	<5	N.d.	N.d.	<5	<5	<5	<5	---	---	---	---	
Y	140	100	110	78	220	140	230	85	180	160	180	
Yb	14	8	8	6	20	10	19	---	---	---	---	
Zn	---	---	---	---	---	---	---	400	450	450	350	
Zr	1800	100	860	---	2200	1600	2000	1500	1900	2200	1500	
K/Rb	---	---	---	104	---	---	---	290	210	200	290	
A.I. <sup>5</sup>	1.11	1.21	1.16	1.03	1.81	1.35	1.85	1.41	1.77	1.82	1.47	

	Pantellerites										
	46	88	190	191	92	93	94	195	A	B	C
B	80	---	100	---	---	---	---	---	15	---	---
Ba	20	---	5	31	27	18	20	8.6	600	870	---
Be	9	---	60	11	9.8	8.5	8.1	8.2	5	N.d.	---
Cd	---	---	---	---	---	---	---	---	.2	N.d.	.08
Co	<5	---	<2	N.d.	N.d.	N.d.	N.d.	N.d.	2	N.d.	1.4
Cr	<1	---	<1	N.d.	N.d.	N.d.	N.d.	N.d.	10	1.7	---
Cs	---	---	10	6.5	6.4	4.9	4.5	5.2	5	3.3	---
Cu	6	---	17	5.5	3.3	3.4	3.4	5.6	10	6	5
Ga	36	---	42	40	36	34	36	32	20	16	---
Hf	---	---	<100	23.5	---	---	---	15.5	4	4.5	---
La	280	---	610	130	113	93	97	95	50	23.4	---
Li	---	---	260	79	71	56	67	59	30	35	---
Mo	7	---	6	24	---	---	---	12.6	2	2.6	1.6
Nb	220	365	640	31	76	71	63	69	20	5.6	17
Ni	2	---	<2	N.d.	N.d.	N.d.	N.d.	N.d.	4	N.d.	1.1
Pb	80	---	220	41	---	---	---	21	30	13	13
Rb	---	225	950	162	160	129	130	134	145	108	160
Sc	3	---	<5	1.0	1.0	.6	.7	.7	6	4.7	---
Sn	20	---	50	7.2	---	---	---	5.7	3	1.3	---
Sr	7	10	2	4.7	1.9	1.1	1.8	.3	235	125	85
Ta	---	---	---	---	---	---	---	---	3.5	---	---
Th	---	---	---	23.6	21.8	---	17.9	17.4	17	11.3	---
U	---	---	---	6.9	6.4	---	5.4	5.1	4.8	2.5	---
V	<5	---	<5	N.d.	N.d.	N.d.	N.d.	N.d.	40	8.5	---
Y	190	160	450	190	165	145	140	145	40	27.5	32
Yb	19	---	54	16.1	---	---	---	9.2	0.18	3.55	---
Zn	---	460	---	---	---	---	---	---	40	---	52
Zr	1700	1650	6300	1520	1360	1190	1090	1100	180	160	230
K/Rb	---	156	37	218	223	277	278	263	240	249	230
A.I. <sup>5</sup>	1.25	2.12	1.79	1.63	1.39	1.55	1.33	1.36	---	---	---

<sup>1</sup> Additional trace element data given in explanation to tables.  
<sup>2</sup> Includes I, n.d.; In, 0.23; Tl, 0.93.  
<sup>3</sup> Includes I, 0.47; In, 0.18.  
<sup>4</sup> Probably reflects contamination (Noble, 1965).  
<sup>5</sup> Agpaite index is molecular (Na<sub>2</sub>O + K<sub>2</sub>O)/Al<sub>2</sub>O<sub>3</sub>.

TABLE 6.—Additional rare-earth-element data, in parts per million, for Mayor Island pantellerites (91, 95), average granite (A), and average Taupo volcanic zone rhyolite (B)

[From Ewart, Taylor, and Capp (1968)]

	91	95	A	B
Ce	158	150	100	43.5
Pr	30	32.5	10	6.4
Nd	125	89	31	18.2
Sm	26	17.8	5.0	5.5
Eu	1.89	1.12	.47	1.0
Gd	22.5	14.4	2.9	4.3
Tb	4.6	3.18	.15	1.15
Dy	21	14.4	.90	4.8
Ho	7.7	4.75	.17	1.4
Er	16.8	11.3	.45	3.9
Tm	1.82	1.13	.08	.46

TABLE 8.—Trace element contents, in parts per million, of peralkaline trachyte obsidians from central Kenya

[Specimen numbers are those used for major element analyses (table 4). Analyst, G. R. Angell, Grant Institute of Geology, Univ. of Edinburgh. All analyses by X-ray fluorescence]

	107	109	110	111	112
Ba	30	<20	<20	<20	20
Ce	230	470	440	430	360
Cu	5	5	10	7	12
La	145	390	380	380	280
Nb	130	285	270	285	220
Ni	<5	<5	7	5	7
Pb	15	27	17	30	25
Rb	90	170	160	170	155
Sr	<5	<5	<5	<5	5
Th	20	40	37	40	35
Y	90	190	180	180	150
Zn	150	275	300	305	290
Zr	385	960	930	975	1010
K/Rb	480	223	245	222	251
A.I. <sup>1</sup>	1.15	1.52	1.52	1.52	1.53

<sup>1</sup> Agpaite index is molecular (Na<sub>2</sub>O+K<sub>2</sub>O)/Al<sub>2</sub>O<sub>3</sub>.

TABLE 7.—New determinations, in parts per million, of trace elements in comendite and pantellerite obsidians

[Specimen numbers are those used for major element analyses (tables 2 and 3). Analyst: G. R. Angell, Grant Institute of Geology, Univ. of Edinburgh. All analyses by X-ray fluorescence]

	Comendites							
	7	8	20	22	23	25	26	27
Ba	35	<20	50	235	150	470	440	460
Ce	250	280	260	260	310	300	240	250
Cu	10	10	10	7	10	12	12	12
La	165	210	160	170	210	170	130	160
Nb	190	210	180	175	190	130	135	130
Ni	<5	7	<5	<5	<5	<5	<5	5
Pb	15	32	12	17	25	10	12	15
Rb	120	250	115	110	120	35	35	35
Sr	<5	5	<5	15	12	25	42	25
Th	22	47	22	22	27	15	17	20
Y	170	160	170	160	185	210	210	200
Zn	220	180	215	250	270	240	235	235
Zr	1250	930	1235	1300	1410	960	370	1000
K/Rb	315	150	339	372	333	375	369	380
A.I. <sup>1</sup>	1.15	1.24	1.19	1.13	1.16	1.07	1.04	1.06

TABLE 9.—Trace element contents, in parts per million, of peralkaline trachyte obsidians from central Kenya (continued)

	Pantellerites							
	57	58	59	60	61	62	63	64
Ba	295	250	660	240	420	165	140	60
Ce	400	320	260	340	300	350	300	270
Cu	10	7	<5	10	5	7	7	5
La	270	240	200	260	170	200	220	200
Nb	230	200	150	200	175	165	175	120
Ni	<5	7	5	5	<5	7	<5	<5
Pb	50	22	20	22	17	20	30	22
Rb	175	210	120	160	130	145	145	135
Sr	7	10	10	5	7	5	5	<5
Th	37	27	25	30	25	22	25	22
Y	240	190	170	210	170	130	180	160
Zn	405	350	265	350	250	280	285	260
Zr	1440	1160	895	1200	1055	1005	1025	970
K/Rb	200	172	315	218	290	252	259	275
A.I. <sup>1</sup>	2.18	1.96	1.58	2.07	1.51	1.80	1.77	1.78

TABLE 10.—Trace element contents, in parts per million, of peralkaline trachyte obsidians from central Kenya (continued)

	Pantellerites							
	65	67	68	77	79	82	83	84
Ba	75	630	245	60	50	30	50	<20
Ce	300	250	370	450	440	590	600	420
Cu	10	7	5	<5	<5	10	12	5
La	130	180	260	300	340	420	450	320
Nb	160	150	220	220	220	360	350	230
Ni	5	5	5	10	<5	5	<5	<5
Pb	27	22	25	25	30	32	35	25
Rb	145	130	175	125	125	210	195	145
Sr	<5	12	10	<5	<5	7	<5	<5
Th	30	22	32	22	25	42	42	27
Y	160	160	240	255	260	350	340	240
Zn	290	260	365	395	410	440	430	350
Zr	1010	915	1370	1600	1605	1670	1600	1120
K/Rb	259	290	197	290	291	170	182	252
A.I. <sup>1</sup>	1.74	1.55	2.08	1.44	1.43	2.12	2.10	1.79

<sup>1</sup> Agpaite index is molecular (Na<sub>2</sub>O+K<sub>2</sub>O)/Al<sub>2</sub>O<sub>3</sub>.

TABLE 9.—*Coefficients of correlation for various element and element ratio pairs*

[The number of analyses used for each variable was as follows: SiO<sub>2</sub> 113, ZrO<sub>2</sub> 62, TiO<sub>2</sub> 113, Al<sub>2</sub>O<sub>3</sub> 113, Fe<sub>2</sub>O<sub>3</sub> 113, FeO 113, MnO 112, MgO 113, CaO 113, Na<sub>2</sub>O 113, K<sub>2</sub>O 113, P<sub>2</sub>O<sub>5</sub> 95, H<sub>2</sub>O+ 109, H<sub>2</sub>O- 68, F 68, Cl 88, agpaitic index 113, Fe as FeO 113, FeO/(FeO+Fe<sub>2</sub>O<sub>3</sub>) 113, Na<sub>2</sub>O/K<sub>2</sub>O 113. CO<sub>2</sub> has been omitted because the number of analyses (15) is too small to be statistically meaningful]

ZrO <sub>2</sub> .....	SiO <sub>2</sub>		ZrO <sub>2</sub>															
	0.1098																	
TiO <sub>2</sub> .....	-.8332	-0.1937		TiO <sub>2</sub>														
Al <sub>2</sub> O <sub>3</sub> .....	-.2410	-.4656		0.0672		Al <sub>2</sub> O <sub>3</sub>												
Fe <sub>2</sub> O <sub>3</sub> .....	-.4244	.4413		.4138	-0.4666		Fe <sub>2</sub> O <sub>3</sub>											
FeO.....	-.6546	-.0300		.6382	-.4246		0.3711		FeO									
MnO.....	-.6192	.1215		.7023	-.4057		.5049		0.8266		MnO							
MgO.....	-.4861	-.0772		.5849	.1377		.3977		.1144		0.2642		MgO					
CaO.....	-.6868	-.3978		.6357	.4064		.0489		.3553		.2087		0.3856		CaO			
Na <sub>2</sub> O.....	-.8148	.0710		.6606	-.1839		.4879		.8176		.7057		.3050		0.4231		Na <sub>2</sub> O	
K <sub>2</sub> O.....	-.3250	-.1588		.2726	.4113		-.0612		-.0685		.0519		.2766		.1606		-0.0049	
P <sub>2</sub> O <sub>5</sub> .....	-.3753	-.1383		.4002	-.1616		.4970		.3369		.2104		.3611		.3406		.3312	
H <sub>2</sub> O+.....	.1021	.1620		-.0351	.1131		-.0325		-.2493		-.1191		.1600		-.0059		-.2275	
H <sub>2</sub> O-.....	-.0366	-.0935		.1125	.2747		-.0735		-.1711		-.1672		.0628		.2290		-.2043	
F.....	-.1110	.8121		-.0712	-.2193		.3508		.0844		.0906		-.0277		-.2342		.2070	
Cl.....	-.2478	.5209		.1269	-.2982		.2206		.3357		.3367		-.0403		-.1012		.3613	
Agpaitic index.....	-.2194	.4081		.2582	-.8582		.6008		.7295		.6409		.0347		-.0891		.6235	
Fe as FeO.....	-.6789	.1110		.6620	-.5208		.7045		.9205		.8439		.2548		.2924		.8303	
FeO/(FeO+Fe <sub>2</sub> O <sub>3</sub> ).....	-.2103	-.2916		.1910	.0876		-.5489		.4976		.2103		-.1907		.3788		.2925	
Na <sub>2</sub> O/K <sub>2</sub> O.....	-.5892	.1285		.4705	-.3396		.4690		.7580		.5872		.1517		.3239		.8907	
K <sub>2</sub> O																		
P <sub>2</sub> O <sub>5</sub> .....	-0.1801		P <sub>2</sub> O <sub>5</sub>															
H <sub>2</sub> O+.....	-.0242	0.0968		H <sub>2</sub> O+														
H <sub>2</sub> O-.....	.1612	-.1258		0.3185		H <sub>2</sub> O-												
F.....	-.1743	-.1399		-.1475	-0.2169		F											
Cl.....	.1663	-.0446		-.1170	-.3806		0.5485		Cl									
Agpaitic index.....	-.2796	.3322		-.1918	-.2924		.2795		0.4252		Agpaitic index							
Fe as FeO.....	-.0781	.4590		-.2053	-.1609		.1810		.3400		0.8103		Fe as FeO					
FeO/(FeO+Fe <sub>2</sub> O <sub>3</sub> ).....	-.0693	-.0510		-.1583	-.1254		-.2144		.1240		.0781		0.1494		Fe FeO+Fe <sub>2</sub> O <sub>3</sub>			
Na <sub>2</sub> O/K <sub>2</sub> O.....	-.4490	.4294		-.1788	-.2391		.2465		.2438		.6842		.7767		0.2866			

TABLE 10.—*Chemical analyses and norms of two obsidians*

[Not included in tables 2-4 because the localities at which the flows crop out are not known, and thus the specimens cannot be related to any geologic information. Tr. indicates trace. Data in weight percent except for ratios and indices]

	A1	A2
SiO <sub>2</sub> -----	75.88	75.2
Al <sub>2</sub> O <sub>3</sub> -----	9.67	11.7
Fe <sub>2</sub> O <sub>3</sub> -----	2.23	1.7
FeO-----	.83	.5
MgO-----	.21	.1
CaO-----	.72	.4
Na <sub>2</sub> O-----	5.13	5.2
K <sub>2</sub> O-----	4.56	4.6
H <sub>2</sub> O-----	} .38	{ .04
H <sub>2</sub> O+-----		{ .13
TiO <sub>2</sub> -----	.10	.19
ZrO <sub>2</sub> -----	-----	.16
P <sub>2</sub> O <sub>5</sub> -----	-----	.04
MnO-----	Tr.	.15
<b>Total</b> -----	<b>99.71</b>	<b>100.11</b>
<b>Agpaitic Index</b> -----	<b>1.38</b>	<b>1.16</b>
Fe as FeO-----	2.84	2.03
FeO/(FeO+Fe <sub>2</sub> O <sub>3</sub> )-----	.27	.77
Na <sub>2</sub> O/K <sub>2</sub> O-----	1.13	1.13
	A1	A2
<b>Molecular:</b>		
SiO <sub>2</sub> -----	84.8	83.5
Al <sub>2</sub> O <sub>3</sub> -----	6.4	7.7
Na <sub>2</sub> O+K <sub>2</sub> O-----	8.8	8.8
Na <sub>2</sub> O/(Na <sub>2</sub> O+K <sub>2</sub> O)-----	63.4	63.2
Q-----	35.2	29.7
or-----	26.7	27.2
ab-----	24.6	34.6
ac-----	6.5	5.1
ns-----	2.7	.9
di:		
wo-----	1.5	.7
en-----	.4	.3
fs-----	1.2	.5
hy:		
en-----	.1	-----
fs-----	.3	.3
il-----	.2	.5
ap-----	-----	.1
Z-----	-----	.2
Σ femics-----	12.9	8.4

- A1. Pantelleritic obsidian bead, found as an artifact, Chichen Itza, Mexico. Analyst: H. S. Washington. Phenocrysts: None. Reference: Washington (1921, table 2, No. 1).
- A2. Comenditic obsidian, Caucasus, U.S.S.R. Analyst: R. Thomas. Phenocrysts: No data. Reference: Butler and Smith (1962, table 2, colln. 6059). Also contains, in parts per million, Rb 220, Y 90, Nb 70, Ta 5.5, K/Rb 170 (Butler and Smith, 1962, table 1), Zn 225, Cd 0.22 (Butler and Thompson, 1967, table 1).



