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ON THE GRAPHICAL REPRESENTATION OF THE CALCIFEROUS AMPHIBOLES.*

A. F. HALLIMOND,

Assistant Curator, Museum of Practical Geology, London.

ABSTRACT

A series of 196 amphibole analyses have been calculated to atomic ratios according to the standard structural formula $(Ca,Na)_2Na_{1-2}(Mg,Al)_5(Si,Al)_8O_{22}(OH,F)_2$, attention being confined to those with $Ca > 1.5$ atoms to the unit cell. There is a well defined upper limit at $Ca = 2$ atoms, and a fairly sharp lower limit to Si at 6 atoms. The analyses are represented on a triangular diagram having as co-ordinates (*a*) the number of atoms of Si, and (*b*) the number of alkali atoms allotted to the vacant space. Nearly all the present minerals can be derived from tremolite by two substitutions, Al_4/Si_2Mg_2 and Na_2Al_2/Si_2, while a third substitution, NaAl/CaMg would give rise to glaucophane-like minerals not included in the present list. There is shown to be a general relationship between the type of amphibole and the nature of the parent-rock. Values are given for the volume of the unit cell containing 24 O; they are very uniform, increasing a little toward hastingsite. Work on basaltic hornblende is briefly summarized.

I. INTRODUCTION

The Island of Tiree in the Hebrides consists largely of highly metamorphosed gneiss, &c., in which there occurs a small but interesting outcrop of marble containing inclusions of several minerals, particularly hornblende and pyroxene. Examples of these have been analyzed and a description is in preparation, but it has proved difficult to discuss the results on account of the lack of recent lists of the published analyses. In the present paper an endeavor has been made to provide a working list and brief discussion for a series of selected fairly complete analyses of the calciferous amphiboles. The analyses, which are listed in Table 1 in order of diminishing silicon-content, have been calculated to atomic ratios for $(O, OH, F) = 24$ atoms in accordance with the customary presentation in terms of the cell-formula. Attention has been confined to fairly complete analyses of good material with more than 1.5 calcium atoms in the unit cell. These comprise a majority of the amphiboles; they include tremolite, actinolite, common hornblende, pargasite, hastingsite, and basaltic hornblende, but not the less calciferous members of the glaucophane and allied series.

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Analyses approximating to 2Ca (cf. Berman and Larsen, 1931) are especially numerous, and by limiting the discussion to the present section of the group, in which Ca is nearly constant, it has been possible to plot the data on a ternary diagram (Fig. 2) having as co-ordinates: (*a*) the number of Si atoms (progressively replaced by Al); and (*b*) the number of Na, K atoms allotted to the vacant space in the cell-formula. In addition to these variables, the common isomorphous replacements (Al, Fe) and (Fe, Mn, Mg) have a considerable range; they greatly affect the optical properties, and have therefore been widely discussed in the literature, but their theoretical interest is relatively small, though they are important for some petrological aspects of the amphibole group. The present diagram shows a well-marked relation between the type of amphibole and the nature of the parent-rock.

When the density is known, it is possible to calculate the volume of the unit cell as implied in the cell-formula. These values (V) have been given in Table 1. They are generally constant throughout the group, but so far as can be ascertained in the absence of more accurate data, the volume of unoxidized hornblende increases somewhat from amphiboles with low alkali toward the hastingsite end of the series.

II. Calcium Content

It is generally accepted that many amphiboles contain approximately 2Ca in the unit cell. The present list affords an opportunity to verify the extent of this limitation. Figure 1 is a frequency diagram in which the ordinate shows the number of analyses that have a calcium content

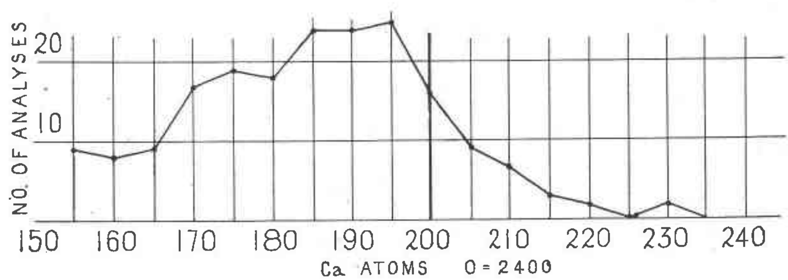

Fig. 1. Incidence of amphibole analyses with more than 1.5 (×100) Ca atoms.

(×100) falling within the corresponding division of the abscissa. For example, there are 25 analyses with values between 192.5 and 197.5 Ca. The limit at 200 is very clearly indicated by a sharp drop in the number of analyses above that value; in only 14 analyses does Ca exceed 200 by more than a reasonable analytical error. Whether the latter values are real or are due to imperfections in material or analysis, it is clear that the limit at 200 is substantially valid, although the minerals have formed under a wide range of natural conditions.

Among the published analyses with high Ca which have been omitted from Table 1, several are given in Eitel's list (1922) and there are a few recent analyses, but they are either of fibrous varieties or liable to error in other ways, so that it still appears doubtful whether any amphibole has been found with Ca substantially greater than 2 atoms.

For values of Ca below 170 there is also a distinct falling off in the number of analyses (Fig. 1), the most frequent value being near 190. This probably reflects the relative scarcity of rocks of the types capable of yielding well-crystallized amphiboles with low Ca, for Kunitz (1930) shows the existence of a continuous series towards glaucophane.

III. Cell-formula.[1] $(Ca,Na)_2Na_{1-2}(Mg,Al)_5(Si,Al)_8O_{22}(OH)_2$

The general formula used is that with 24 atoms of (O,OH,F), first proposed for tremolite ($8SiO_2 \cdot 5MgO \cdot 2CaO \cdot H_2O$) by W. T. Schaller (1916) and confirmed and extended by x-ray methods to other amphiboles by B. E. Warren (1930). Recent work on the water content suggests that amphibole crystals can undergo two types of chemical alteration without loss of structure. In the first, hydrogen is evolved by reaction between the water and ferrous oxide present. In the second, water is lost or gained. The amount concerned in the latter reaction does not usually exceed $\frac{1}{2}H_2O$, and according to Posnjak and Bowen (1931) this water is held more loosely and is evolved at a lower temperature than the $1H_2O$ of the formula, which is lost at 900°C. If this water is extraneous to the formula, the additional oxygen atoms must be held in some kind of solid solution in the lattice. This would seem to imply that oxidation also could take place (probably very slowly) by the direct access of $\frac{1}{2}O$, which is sufficient

[1] The present writer (1931) has drawn attention to the use in x-ray work of the terms 'chemical formula,' 'ion,' &c., outside their already established usage. 'Cell-formula,' a term reasonably free from objection, seems to be coming into general use to indicate the atomic contents of the unit cell (sometimes the cell contains more than one formula-unit). 'Atom' has been used instead of 'ion,' since the question of ionization is not here under discussion; Evans (1939, p. 5) adopts the same procedure 'for the sake of brevity': it appeared on the whole better to avoid a term which might seem to prejudge a subject still under investigation, even for the silicates where 'ionization' has been widely accepted. The general cell-formula as given above is used to show the atomic replacements, but it is not a precise statement of the actual composition, since it does not indicate the necessary valency-compensations. Innumerable analyses have established that these silicates belong to a general system of which the oxides are conveniently taken as components (phase rule). This also underlies the synthetic researches at the Washington Geophysical Laboratory. Schaller's formula (above) is rigorous in stating the composition in terms of the components, and it would appear logically more satisfactory to employ oxide-formulae (indicating one less variable) in place of those here used. This has not been done because of their inconvenient length, but the sacrifice in clarity should be noted.

to convert one atom of Fe″ to Fe‴. In this way a basaltic hornblende might perhaps be formed with a total content of $24\frac{1}{2}$O in the unit cell. As is well known, some minerals (e.g., vogtite) gain oxygen in this way much more easily than others: the property is used in magnetic separations. For hornblende, the loss of hydrogen by the first reaction (internal oxidation) seems well established, but direct oxidation may not be impossible if time is available.

When calculated in the standard way, both the atomic numbers and the volume of a hornblende with $24\frac{1}{2}$O would be proportionately too low. The difference is, however, small, and no attempt at such a distinction can be made in the table. It is, besides, more convenient for the purpose of comparison to have all the analyses calculated by a standard method, even if the result may be considered to differ slightly from that for the true unit cell. Fortunately, neither of the two co-ordinates adopted for plotting the present analyses is seriously affected either by a small difference in the total oxygen or by errors and omissions in the determination of water and fluorine.

There is evidence that some amphiboles may have special varieties of crystal-structure, just as chamosite differs from the normal chlorites. The *c*-axis is sometimes doubled (Greenwood and Parsons, 1931). Only *x*-ray research in each case can decide whether this is so, but the analyses as given clearly represent a group with a very characteristic and limited range of composition, in which nearly every example has been shown to fall within the range of properties generally accepted as characterizing an amphibole. Even if some members should ultimately be separated on special grounds, it will add to the practical value of the list if they are included, since they fall within the range of amphibole composition.

IV. Explanation of Table 1[2]

Table 1 (at the end of this paper) contains atomic ratios for 196 analyses collected from the literature. No doubt it is still incomplete, even within the limitations adopted in choosing the analyses, but it may perhaps serve for a general survey of this section of the group. There has been great difficulty in deciding how far older and less complete analyses should be omitted: amphibole analyses abound in the literature; Eitel's list (1922) already contains 336 analyses and many have since been published (see Wang, 1939; Winchell, 1931; etc.). The chief class omitted is the fibrous amphiboles, including many nephrite rocks, for which there

[2] The author desires to express his thanks to Professor C. E. Tilley for numerous references in this list, and to Mr. C. F. Davidson for two entries. He is also greatly indebted to Dr. L. J. Spencer for editorial advice and assistance in preparing the manuscript for the printer.

is a risk that the presence of other minerals may have been overlooked. Apart from a few uralitic hornblendes, the present list is confined to normally good crystalline material. Early analyses have in some cases been included if not replaced by later work; there are some incomplete analyses, but most analyses deficient in water and fluorine or alkalis have been omitted. It must be confessed that the choice is in some ways arbitrary, yet a more rigorous selection might at present give an inadequate impression of the group. No doubt the frequency of analyses has been partly determined by the occurrence of favorable material; neverthelsss the amphiboles seem to form a well-defined natural group with a more limited range than that of the general cell-formula, unless this is written to indicate the observed limits.

A few analyses with exceptional water content have been placed at the end of the table, and others are cited by Kennedy and Dixon (1936). In such cases it is uncertain whether the total oxygen is to be taken as 24.

The left-hand page of the table shows the serial number, corresponding with the numbered points on Fig. 2, the locality and original name given by the author for the mineral, the mode of occurrence, and the reference. On the right-hand page is the serial number, followed by the atomic ratios calculated from the analysis. Beyond the vertical line are five columns giving the chief distinctive values in the cell-formula, and the cell-volume where a density is available.

A few detailed comments are made in the following notes:

Occurrence.—Only a very brief indication has been possible in this column. The rock-names are those given by the respective authors, and the word 'crystal' has been used where the analysis was made on isolated material, often 'from a collection.' Although the parent-rock of an occurrence may have been separately described, experience shows that it is unsafe to assume that all the crystals, even from a well-known locality, will be alike. This is notably true of Edenville (nos. 11, 96, 103, 109) where there is a wide difference in Al/Si and Mg/Fe. An exception has been made for a number of analyses of crystals from New York State, Ontario, &c., which have been counted as from 'limestone contact?'; they are probably nearly all from highly metamorphosed rocks in or near limestones of pre-Cambrian age. A typical area is described by Agar (1923). Many hornblendes were formed during later changes that have obscured the original structure of the rock: there is then often a corresponding uncertainty in the description of the occurrence.

Si, Al, Ti.—Amphiboles are quite common with all degrees of replacement of Si from 800 down to 600. A few have lower values, but the frequency diminishes almost as sharply as that for the Ca content already discussed.[3] Thus there are 25 analyses with Si between 590 and 610, 11 between 570 and 590, and only 2 below 570. If Ti were included with Si in the Z group,[4] the value for (Si, Ti) would in practically every case exceed 600, but the

[3] A similar limit appears to exist in the mica group, where a ratio 6 $SiO_2:K_2O$ is predominant (cf. Hallimond, 1926) though the cell-formula has since been shown to contain four Si-positions.

[4] The groups (Ca, Na, K), (Mg, Mn, Fe, Al) and (Si, Al) are conveniently referred to as X, Y and Z, following Machatschki (1929).

frequency-distribution would then indicate a limit at a higher value than the simple ratio Si=600, for allowance must be made for a 'spread' of about ± 10 units which would be caused by the usual errors in analysis, even if a sharp limit existed.

Fe‴.—The amount of Fe_2O_3 present often agrees with that common in rock-forming silicates. A number of high values have been explained as due to subsequent oxidation to 'basaltic hornblende'; but nos. 70 and 77 (Purcell diorite), and some from nepheline-rocks, seem unlikely to have undergone subsequent reaction.

Fe″, Mn, Mg.—Magnesian amphiboles are the most common, but there is a fairly complete range between Fe″ and Mg. Berman (1937) notes that pure actinolite does not seem to have been found.

Ca, Na, K.—Ca has been discussed above. The alkalis, after allowing for some Na replacing Ca, are represented as co-ordinate *b* in Fig. 2. There seems to be a relative absence of potassium in glaucophane and other amphiboles where Ca is replaced by Na (cf. Kunitz's lists). In the present list K:Na often reaches 1:3 or more, and in 14 analyses K is substantially equal to or greater than Na. Perhaps the large K atom is more readily accommodated tn the 'vacant space' than in the Ca position.

H, F.—The radicales OH, F are, as is well known, especially liable to errors in determination. F is often ignored altogether, while some methods for H_2O are now known to give inaccurate results on account of the formation of hydrogen by reaction with FeO. H− has been omitted, the value given being usually H+ or sometimes the 'total' hydrogen. Before any weight is attached to a particular analysis the method used should be taken into account. Still, it seems likely that (OH, F) is in many cases really below the value 200 implied in the simple cell-formula.

Total equivalent.—Atomic replacements in the crystal must satisfy the condition that the total "negative" valencies equal those of the 'positive' atoms. Actually this is assumed in making the analysis, for the constituents are returned as oxides. It is only verified experimentally so far as the total of the analysis equals 100% (after allowing for F). The total equivalent for the elements in the foregoing columns should equal 4800. If F is present, the negative equivalent for 2400 atoms (O, F) will be 4800−F, and the total of all the columns including F will therefore be 4800. This has been checked for all the analyses in Table 1 within the limits of error in calculation, i.e. ± 10. But it must be emphasized that this is only a check on the arithmetic by which the atomic numbers are calculated from the equivalent numbers for the oxides in the analysis. Any imaginary set of oxide equivalents, if calculated in the usual way, would give an accurate valency check even if it did not agree with the amphibole formula.

R‴ in Y-group.—This is the amount of Al, Fe‴ left in the *Y*-group after enough Al has been allotted to complete Si, Al=800. This R‴ may, of course, be regarded as 'compensating' particular valency changes such as Na/Ca, but it seems best to regard the question in a more general way: there are various atomic replacements all subject to the condition that the total 'metal' valency should equal that of (O, F). The nature of the substitutions actually operative in these amphiboles will be discussed more fully below.

Titanium is nearly always returned as TiO_2, and is believed to be present in the amphiboles in that state of oxidation. In *x*-ray formulae it is usually assigned to the *Y*-group. If so present, it can be regarded as a group of the type $MgO \cdot TiO_2$ replacing Al_2O_3. Consequently the total value here given for R‴ in *Y* includes 2 Ti in all cases where Ti is present.

Y-residue.—Much interest has centered on the fact that the total of the elements in the *Y*-group commonly shows a small excess, up to about $\frac{1}{2}$ atom, above the value 500 required by the formula. The values for this excess are shown here. It is present even in some of the most recent analyses. One possible cause is the substantial value of the total concerned, for the value assigned to the *Y*-group depends upon all the elements present in both *Y* and

Z, and it is conceivable that some systematic over-estimation might still occur. Another cause, which is much more certainly operative, is the effect of the loss of water from the crystal, or its underestimation in analysis, and the omission of fluorine. At the end of Table 1 the effect of such errors has been shown by recalculating a typical analysis (no. 173) with the addition of (*a*) 1% water and (*b*) 1% fluorine. Most of the atomic values do not show any serious difference, but those for *Y* and *Y*-residue have diminished by no less than 28 units for 1% H_2O. This is a substantial proportion of the excess commonly noted in hornblende analyses, and it is clear that in many instances the *Y*-value might average about 500 if the estimation were more complete.

So far as it is real, the excess (if attributed to Mg atoms) would presumably be assigned either to the Ca positions, by analogy with cummingtonite, or directly to the vacant space. The mineral 'hexagonite' which occurs with kupfferite at Edwards, N. Y., has recently been twice analyzed. Both analyses (nos. 14 and 17) show an excess of *Y* above 500, with a deficiency of Ca, so that the excess Mg (Mn according to Warren, 1930) could be assigned to dissolved kupfferite; Na is so low that the value for the vacant space is negative unless the excess for the *Y*-group is so included. No. 36 has similar values, but in the other analyses the larger content of Na renders it difficult to draw any direct conclusion.

Atoms in vacant space (v. sp.).—Where Ca falls below 200 the difference has been attributed as usual to the presence of glaucophane and analogous formulae, in which Ca is replaced by Na. The total value for Ca+Na+K, less 200, therefore represents the residue of alkali atoms which it is customary to assign to the vacant space in the amphibole structure.

Logically, the content of the vacant space should be increased by the residue from the *Y*-group, even if this replaces Ca as indicated in the preceding section. This procedure, though attractive in theory, has been avoided because of the relatively large errors affecting the *Y*-residue. For the reasons given, it is subject to an uncertainty of 30 units or more, while the value here used for the vacant space depends on the direct determination of Ca, Na, K with only a slight indirect error due to water, &c.

The content of the vacant space has been taken as the second co-ordinate (*b*) for plotting in Fig. 2. If the vacant space can hold only one atom, the crystal-structure will require that *b* cannot exceed 100; this limit is fairly well fulfilled, but there are several higher values, and there would be more if the *Y*-residue were included.

F, OH.—For convenience, the totals have been listed, but they are often inaccurate or defective. The value rarely exceeds 200; a few values exceeding 250 are placed at the end of the table. Attention may here be directed to analyses by Jakob (1937).

V. Graphical Representation

Apart from the substitutions (Fe, Mn, Mg), (Fe, Al), etc., the analyses in Table 1 can be described in terms of two variables, (*a*) the number of Si atoms, and (*b*) the number of atoms allotted to the vacant space. A third variable in the amphibole formula is the degree of replacement of Ca by Na, but this has been eliminated by choosing analyses with approximately two atoms of calcium.

(There is another variable that may at first sight appear independent, namely the amount of R‴ in the *Y*-group, but if the others are known this is determined by the condition that the total equivalent shall equal 4800; it is thus not an independent variable.)

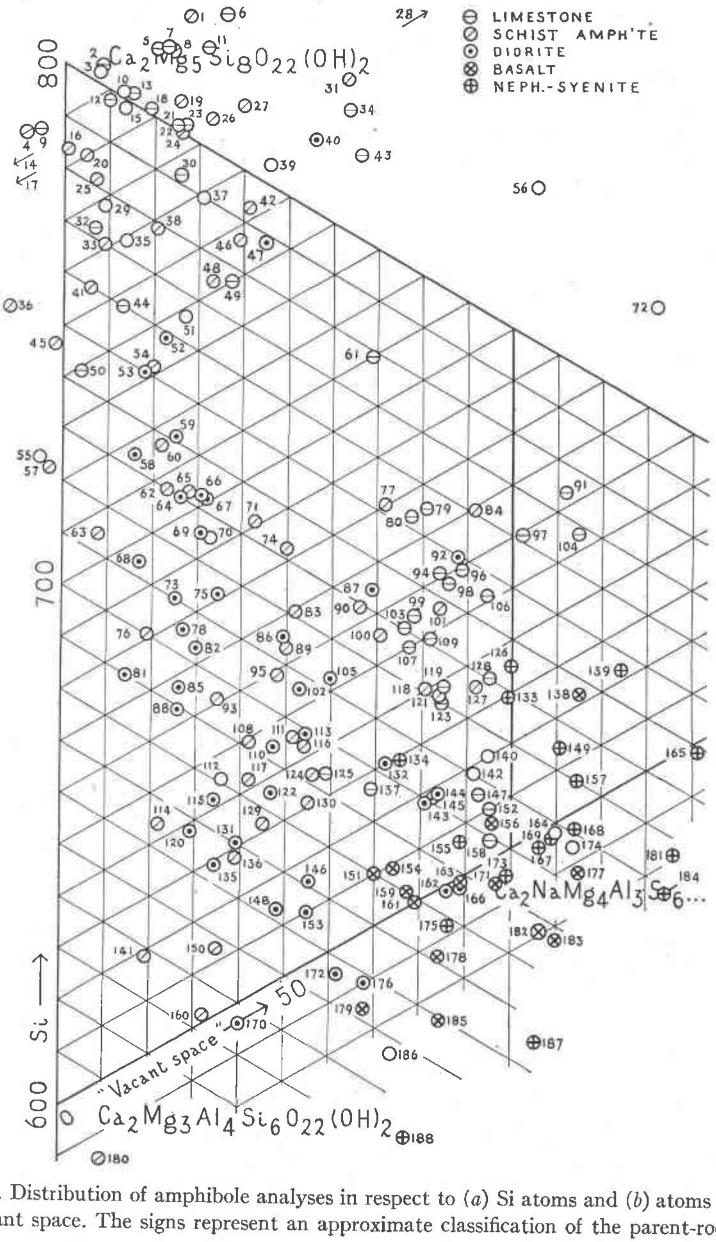

FIG. 2. Distribution of amphibole analyses in respect to (*a*) Si atoms and (*b*) atoms in the vacant space. The signs represent an approximate classification of the parent-rocks.

It is possible therefore to represent the analyses upon a plane diagram having (*a*) and (*b*) as co-ordinates. This has been done in Fig. 2 which is a triangular diagram of the usual type with *a* and *b* measured from the bottom corner of the triangle. (Note. For convenience the bottom corner has been taken at $a=600$.) At the top corner ($a=800$, $b=0$) is pure tremolite-actinolite. The lower side of the triangle is not, of course, theoretically the lower limit for Si, but there are relatively few analyses with $Si<600$; they have been represented by extending the area somewhat to include lower values. As regards *b*, if there is only one atom in the vacant space the theoretical limit will be 100. The area permissible is therefore limited on the right by the heavier vertical line at $b=100$.

Errors.—The maximum analytical error for Si may reasonably be put at 10 units (one small division in Fig. 2); and that for *b* at a somewhat larger value. When allowance is made for this uncertainty there are still a few analyses appreciably beyond the upper side of the triangle, but none on the left, except the Edwards mineral (nos. 14, 17). Only four points lie seriously to the right of the line $b=100$. (A pargasite from Rossie (Agar, 1923) giving $a=642$, $b=178$ has been omitted.)

VI. Substitutions and Component Formulae

The composition of an amphibole plotted within the triangle (Figs. 2 and 3) can be represented as a mixture of three components (phase rule) at the apices of the triangle. They can be derived from tremolite by the following substitutions (Warren, 1930):

Mineral	*Formula*	*Substitution*
Tremolite	$Ca_2\ Mg_5\ Si_8O_{22}(OH)_2$	———
Ts	$Ca_2\ Mg_3Al_4Si_6O_{22}(OH)_2$	Al_4/Mg_2Si_2
Ha′	$Ca_2Na_2Mg_5Al_2Si_6O_{22}(OH)_2$	Na_2Al_2/Si_2

If the total number of molecules is taken as 200, the molecular proportion of tremolite is given by $Si-600$ and that of Ha′ by the content of the vacant space. These are the co-ordinates *a* and *b* of Fig. 2, if measured from the bottom corner of the triangle shown.

The second component above has been termed Ts since the substitution $Al_2/MgSi$ is that by which the 'Tschermak molecule' is derived from diopside. The third is obtained by a substitution that maintains the valency, but does not satisfy the condition that there must be no change in the number of atoms: it is only possible because the Na is assigned to the vacant space. If only one space is available, this component itself and other compositions to the right of $b=100$ are impossible, but it is convenient to complete the triangle so as to give a 3-component representation. Analyses with Si below 600 would of course require the choice of similar components with further substitution. For the third component the term Ha′ (from hastingsite) has been employed. Hastingsite itself lies at a point midway along the lower side of the triangle, with the composition $Ca_2NaMg_4Al_3Si_6O_{22}(OH)_2$ (Berman and Larsen, 1931), and represents the limiting composition possible according to the present structural theory. The name has been used for amphiboles with lower Ca (Wolff, 1937), but the present formula seems to represent the composition for which the name is usually employed (cf. Billings, 1928). The original hastingsite from Dungannon (no. 184) has an exceptional value for b; two concordant new analyses (no. 169) agree well with the present formula, though rather low in Ca.

VII. Relation between Types of Amphibole and the Parent-rocks

The 'occurrence' column in Table 1 indicates the conditions of formation of the amphibole. The parent-rocks can be very roughly classified into five main divisions: limestone, schist and amphibolite, diorite, basalt, and nepheline-syenite. These have been distinguished by using special signs for the representative points in Fig. 2. The signs are not scattered irregularly over the figure, but are grouped in limited areas, each type of parent-rock yielding amphiboles of a characteristic range in composition. The areas have been outlined more clearly in Fig. 3, which illustrates the general conclusion to be drawn from the present series of analyses.

(1) *Limestone.*—There is a curious lack of amphibole analyses in the area around $a=710$, $b=50$. As a result, the limestone amphiboles fall into two separate groups. One is the tremolite-actinolite series, grading into common hornblende and occupying an area near the top corner of the diagram; the other is the pargasitic type, with a notable content of alkalis. Broadly speaking, the tremolite group probably originate by the metamorphism of a normal impure limestone, while the pargasites have usually gained alkali by the access of solutions. The vacant area, with only one analysis, is unexpected and is the more remarkable in being avoided also by amphiboles of the schist and diorite groups.

(2) *Schist and amphibolite.*—No precise limits can be assigned to these rock-names, the amphibolites in particular being often of obscure origin. The range is extensive and the relationships of these rocks are the subject of extensive detailed researches which are, of course, outside the scope of the present paper. Generally, they originate by metamorphism under conditions of somewhat lower grade (cf. Tilley, 1938) than those that yield hornblende by direct crystallization from a melt. Deer has discussed the question of grade for nine amphiboles from Glen Tilt and has indi-

cated the nature of the chemical changes toward the lower-grade amphiboles. His conclusions can be illustrated, in part, by the plotting of the Glen Tilt data in Fig. 2; with lower grade the points tend to lie nearer the tremolite corner of the triangle. Several uralitic hornblendes are also included in this section. The area extends down the left side of the triangle with a bulge that overlaps part of the pargasite area.

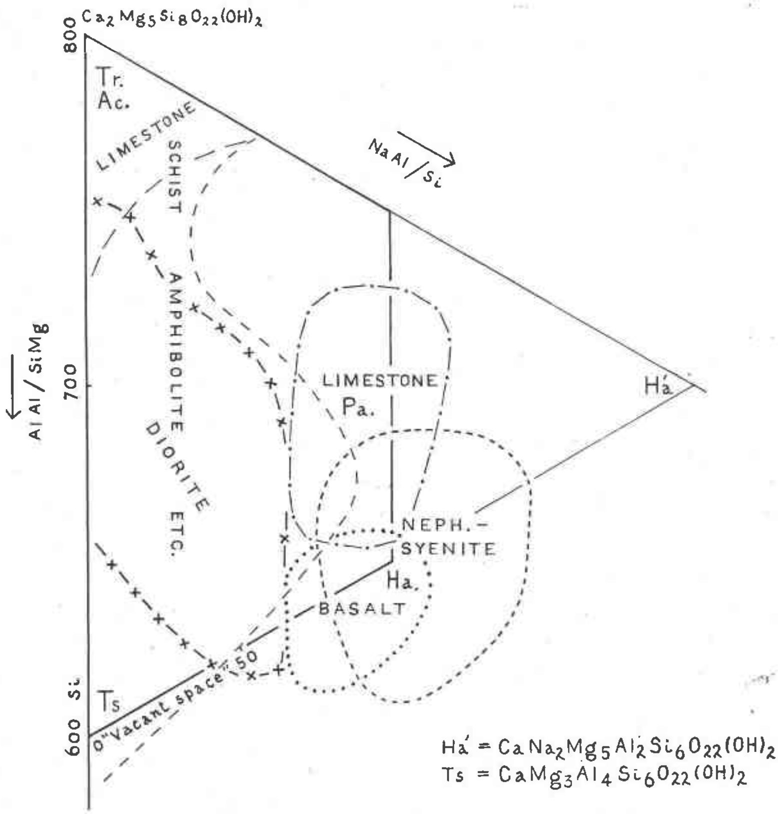

FIG. 3. Approximate limits of composition of amphiboles derived from various rocks.

(3) *Diorite* (including quartz-monzonite, quartz-latite, appinite, syenite, gabbro, hornblende-gneiss, etc.).—The area, which includes the 'common hornblendes,' is rather sharply defined; it extends obliquely from the left-hand margin toward hastingsite, but terminates at $b=65$, where a sparsely occupied vertical space separates the diorite area from those for pargasitic limestone and basalt. Several 'diorite' signs to the right of the boundary belong to amphiboles from veins and from andesite, not from typical diorite.

(4) *Basalt* (umptekite, trachydolerite, tuffs and volcanic bombs.)—This area is also well defined, the general composition being near to hastingsite. Magnesian amphiboles predominate, in contrast with the nepheline-syenites.

(5) *Nepheline-syenite* (essexite, foyaite, hornblende-monchiquite, tephrite).—The area partly overlaps those for basalt and pargasitic limestone. A majority of these amphiboles are high in iron.

Such are the broad outlines of the relation to the parent-rocks. It must be emphasized that only the calciferous amphiboles are represented: alkali-amphiboles would require the addition of a co-ordinate for Na/Ca at right angles to the plane of the diagram, and would pass over to other classes of parent-rock such as glaucophane-schist that are represented only by outlying examples in the present table (cf. also Berman and Larsen, 1931).

Further distinctions could no doubt be drawn within the present groups; but the lack of precise definition of the rock-names themselves, and the limits of accuracy in analysis, will indicate that caution must be used in the smaller groups.

VIII. Basaltic Hornblende

Many experiments have been made on the effect of heat on the amphiboles. Allen and Clement (1908) found for tremolite that with sieved powder (120 mesh to 1 inch) a period of 10 to 30 hours was required to reach constant weight. Up to about 850° the water lost progressively increased without important change in optical properties. Above this temperature there was a steeply increased loss, reaching (at 900°C.) from 40 to 60% of the water content. A tremolite which lost 85% of its water-content at 923° regained a nearly equal amount of water in a bomb at 400°.

Posnjak and Bowen (1931) used Allen and Clement's material (above). They found that the water-content was higher than recorded by the latter. Constancy was obtained in about 24 hours at each temperature and there was a progressive loss in weight up to about 900°; beyond this a loss of 2.1% took place, corresponding with $1H_2O$ in the formula, but this dehydration was at first very slow. Samples heated at 900° for 24 hours showed some *x*-ray lines for pyroxene, which had formed in parallel orientation round the grain-margins. There is no suggestion that basaltic hornblende was formed in these changes.

Barnes (1930) includes a review of earlier experiments with steam, carbon dioxide, and nitrogen, which yielded basaltic hornblende. Numerous experiments were made on tremolite and hornblende, samples of which were heated in hydrogen and in air at about 850° for three hours 'in order to be sure that the change proceeded to completion' (p. 398). Iron-free amphiboles (pargasites) showed little change in optical properties, while those richer in iron yielded basaltic hornblende in air but no change in hydrogen. The characteristic 'basaltic' change is therefore attributed to (internal) oxidation of the ferrous iron.

Barnes also gives a diagram showing that the ratio Fe_2O_3:FeO does not usually exceed from 0.5 to 0.9 (wt,%) in common hornblendes, but is higher in basaltic hornblendes, of which the artificially oxidized material is an extreme example. Densities of hornblende before and after heating were 3.175–3.215 and 3.258–3.320 for Lanark Co. (106) and Renfrew Co., (119) respectively, corresponding with the contraction observed by Kôzu (1927).

Kennedy and Dixon (1936), for a hornblende showing abnormal water content, etc. (no. 195), record details of water loss. Tilley (1938) has pointed out, however, that the parent-schists contain fine-grained chlorite and that the peculiarities of this analysis can be explained as due to admixed chlorite. Belyankin and Donskaya (1939) obtained results for the dehydration of no. 189.

These results seem to indicate that amphiboles normally contain up to $\frac{1}{2}H_2O$ which is believed to be outside the formula and is released progressively up to 900°C., together with $1H_2O$ or less which forms part of the lattice and is lost at 900°. Constancy is reached in 24 hours (for powdered mineral) in the first case, but the second reaction is much slower until temperatures above 950° are reached. If FeO is present, there is a balanced reaction between FeO, Fe_2O_3, H_2O in the crystal and hydrogen, etc., in the surrounding gas. This takes place rapidly (3 hours) at 850°, yielding basaltic hornblende; it is presumably limited by the available FeO-content.

In natural hornblendes, as in the chlorites (Hallimond, 1939), the defect in H_2O sometimes appears to exceed the total Fe_2O_3, in which case an interchange of the type $Mg(OH)_2/AlOOH$ might be supposed to operate during the formation of the crystal.

IX. Cell-volumes

The volume in chemical units associated with 24(O, OH, F) can be readily obtained by the formula $V = 2400/O \times \rho$, where O is the total equivalent number for (O, OH, F) as used in the course of calculating the atomic values in Table 1, and ρ is the density.

The values have been given in the last column of Table 1. They are very uniform throughout the series, rarely going outside the range 270–

285. On closer consideration, however, caution must be observed in interpreting these figures, for they are subject to special sources of error. (1) An error of 1% in the water content causes the volume to be 6 units too high. Data given by Parsons (1930) (nos. 4–8) are consistent, but the water content is rather below that required by the usual tremolite formula. For tremolite, therefore, the most probable volume seems to be 275. (2) The densities given by Barnes show a contraction of about 5 units in V on the formation of basaltic hornblende, the results of which are therefore not directly comparable with those for tremolite. If the basaltic hornblendes could be replaced by normal amphiboles, there would presumably be a general increase in volume toward the hastingsite end of the series. The risk of inaccuracy in the data makes it difficult to discuss individual analyses, but the increase would apparently be of the order of 10 units.

KEY TO ABBREVIATIONS USED IN TABLE 1

Left-hand pages: Ab., albite—Ac. actinolite—Am., amphibole—Amp'te., amphibolite—Ba., basaltic hornblende—Bk., barkevikite—Ca., carinthine—Carb., carbonate—Ed., edenite—Fe., ferrohastingsite—Gr., grammatite—Ha., hastingsite—He., hexagonite—Ho., hornblende—Hu., hudsonite—Hy., hydroamphibole—Ka., kaersutite—Ma., magnesiohastingsite—Or., orthoclase—Pa., pargasite—Pla., plagioclase—Pyr., pyroxene—Sm., smaragdite—So., soretite—Tr., tremolite—Ur., uralite.

Right-hand pages: * not stated by the author; tr. trace or less than 0.05%; n.d. not determined; — so in original analysis.

The headings are explained in notes to the table; (*a*) and (*b*) are the co-ordinates plotted in Fig. 2

†*Notes on analyses in Table 1*

16. A very similar analysis is given by Kreutz, p. 918.
42. Kreutz, p. 948, says there are two hornblendes in this rock; see no. 121.
44. An earlier Edenville analysis is cited by Kreutz, p. 917.
51. A very similar analysis is given by Washington, 1923.
104. The mean of analyses by Harrington and Stanley.
107. The summation has been made correct by taking Al_2O_3 as 14.13%.
109. Kreutz, p. 948, says that besides the light-coloured 'edenite' a black hornblende occurs embedded in limestone as at Pargas.
111. Also a similar analysis 'from an amphibolite bed.'
121. See no. 42.
124. A similar analysis is cited by Doelter, II, i, p. 617.
147. Analysis not yet published. Contributed by permission of the Director, H. M. Geological Survey, London.
174. A similar analysis by Washington, 1908, has lower alkalis.
183. A similar analysis in Parsons has K>Na.
184. The original hastingsite. See no. 169.

TABLE 1. ANALYSES OF CALCIFEROUS AMPHIBOLES CALCULATED TO ATOMIC RATIOS FOR (O, OH, F) = 2400.

For abbreviations, etc. see key on preceding page.

No.	*Locality*	*Name*	*Occurrence*	*Authors*
1	Cumberland, Rh. I.	Ac.	Chlorite-ac.-hortonolite vein	Johnson & Warren
2	Packenham, Ont.	Am.	Limestone contact?	Parsons
3	Ham I., Alaska	Tr.	With diopside	Allen & Clement
4	Sulzer, Alaska	Ur.	*	Parsons
5	Pierrepont, N. Y.	Am.	Limestone contact?	Parsons
6	Sarahsburg, N. Y.	Tr.	Limestone contact?	Parsons
7	Gouverneur, N. Y.	Tr.	Limestone contact?	Parsons
8	Zillerthal, Tyrol	Am.	*	Parsons
9	Switzerland	Tr.	Crystalline limestone	Kreutz, p. 915
10	Kupferberg, Silesia	Ac.	Crystals	Kunitz
11	Edenville, N. Y.	Ed.	Limestone contact?	Winchell
12	Lee, Mass.	Tr.	Dolomite marble	Penfield & Stanley, p. 31
13	Richville, N. Y.	Tr.	Crystals	Penfield & Stanley, p. 31
14	Edwards, N. Y.	Tr.	With kupfferite	Allen & Clement
15	Kishengarh, India	Ho.	With nepheline-syenite	Heron
16	Greiner, Tyrol†	Ac.	Crystals in talc	Penfield & Stanley, p. 32
17	Edwards, N. Y.	He.	Limestone contact? See 14	Kunitz
18	Ossining, N. Y.	Tr.	Limestone contact?	Allen & Clement
19	Berkeley, Cal.	Ac.	Schist	Blasdale
20	Kaveltorp, Sweden	Gr.	With blende and chalcopyrite	Johansson
21	Gouverneur, N. Y.	Tr.	Limestone contact?	Allen & Clement
22	Russell, N. Y.	Am.	Limestone contact?	Parsons
23	Russell, N. Y.	Tr.	Limestone contact?	Allen & Clement
24	Kragerö, Norway	Ac.	Pseudomorphous after diopside	Hillebrand
25	Start, Devon	Ho.	Ho.-epidote-albite-schist	Tilley, 1938, p. 504
26	Start, Devon	Ho.	Ho.-clinozoisite-albite-schist	Tilley, 1938, p. 505
27	San Pablo, Cal.	Ac.	Schist	Blasdale
28	Haut du Faîte, Vosges	Am.	Amphibole-biotite granite	Weyberg
29	Rhode Island	Ac.	Crystals	Kunitz
30	St. Lawrence Co., N. Y.	Am.	Limestone contact?	Parsons
31	Coll I., Hebrides	Ho.	Amphibolite	Duparc & Pearce, 1908
32	Russell, N. Y.	Ac.	Crystals	Penfield & Stanley, p. 33
33	Loch Gair, Argyll	Ho.	Chlorite-epidote-ab.-amp'te.	Wiseman, p. 368
34	Russell, N. Y.	Ho.	Crystalline limestone	Kreutz, p. 929
35	Arendal, Norway	Ac.	Crystal	Kunitz
36	Start, Devon	Ho.	Ho.-talc-chlorite-schist	Tilley, 1938, p. 506
37	'Piz Valesa'	Ac.	*	Kunitz
38	Kussuolinkivaara, Finl.	Am.	Ho.-or.-pyr.-spinel-carb.-rock	Mikkola & Sahama
39	Snarum, Norway	Ho.	Crystal	Kreutz, p. 926
40	Washington, D. C.	Ho.	Gabbro	Clarke, 1910, p. 266
41	Billy Goat Creek, N. Z.	Ac.	Ab.-stilpnomelane-ac.-schist	Hutton, 1940, p. 14
42	Saualpe, Carinthia†	Ca.	Eclogite	Kunitz
43	Djagdalik, Afghanistan	Pa.	Cipolin limestone	Barthoux
44	Pierrepont, N. Y.†	Ac.	With calcite	Penfield & Stanley, p. 34
45	Coronet Peak, N. Z.	Ac.	Ab.-epidote-ac.-calcite-schist	Hutton, 1940, p. 13
46	Ravenberget, Norway	Ho.	Altered from pyroxene?	Kolderup
47	Biella, Piedmont	Am.	Druse in syenite	Zambonini
48	Sudbury, Ont.	Ho.	Margin of xenolith in gabbro	Jones
49	Monteagle, Ont.	Ho.	Limestone contact?	Parsons
50	New Hampshire	Ac.	Limestone	Kunitz
51	Kragerö, Norway†	Ac.	Crystal	Penfield & Stanley, p. 34
52	Carsphairn, Scotld.	Ho.	From pegmatite in ho. hybrids	Deer, 1937
53	Esasi, Japan	Ho.	Diorite	Harada, p. 281
54	Signal Peak, Colo.	Ho.	Xenolithic crystal in granodiorite	Pabst
55	Nordmarken, Sweden	Ac.	Crystals	Kunitz
56	Cheremshanka R., Ural	Ho.?	Augite-pegmatite	Belyankin, 1910, a

TABLE 1

No.	(a) Si	Al	Ti	Fe'''	Fe''	Mn	Mg	Ca	Na	K	H	F	R''' in Y	Y− res.	(b) v. sp.	F, OH	V
1	796	17	tr.	1	85	1	435	214	14	tr.	76	?	14	35	28	76	279
2	795	23	1	11	50	2	466	188	16	5	77	*	31	48	9	77	278
3	794	2	—	—	—	—	500	203	3	2	209	nil	−4	−4	8	209	
4	792	51	tr.	24	135	4	329	178	9	4	98	*	67	35	−9	98	277
5	792	21	2	15	48	2	467	190	22	9	63	7	32	47	21	70	279
6	791	22	1	5	12	2	524	197	23	16	*	37	20	57	36	37	280
7	791	23	1	10	3	1	518	190	21	12	63	12	26	47	23	75	277
8	790	33	tr.	14	50	2	465	179	39	6	59	*	37	54	24	59	279
9	790	22	—	1	7	1	485	188	6	1	196	7	13	6	−5	203	274
10	788	12	11	*	22	*	458	190	18	5	209	*	11	−9	13	209	
11	788	21	1	1	26	1	464	209	20	3	141	9	12	2	32	150	
12	788	29	2	nil	6	tr.	490	193	13	4	142	16	21	15	10	158	275
13	787	21	*	2	2	2	510	190	17	8	109	37	10	24	15	146	275
14	786	10	tr.	4	nil	15	506	157	21	3	225	10	0	21	−19	235	
15	786	49	tr.	31	216	7	251	175	31	7	61	16	66	40	13	77	290
16	783	21	nil	2	61	3	449	185	13	3	182	5	6	19	1	187	278
17	783	5	*	11	*	24	525	154	14	3	197	*	0	49	−29	197	
18	782	20	1	3	3	tr.	485	205	11	3	201	5	7	−6	19	206	
19	780	58	*	—	87	*	390	160	66	—	165	*	38	15	26	165	271
20	780	21	*	7	20	6	477	186	15	4	159	41	8	11	5	200	273
21	776	27	1	4	nil	—	483	183	32	10	183	44	9	−9	25	227	
22	775	37	1	14	43	2	462	186	26	14	55	59	28	34	26	114	277
23	775	30	1	6	12	1	470	189	25	13	158	53	13	−5	27	211	
24	774	25	—	21	97	—	378	194	21	11	193	—	20	−5	26	193	279
25	774	45	3	12	139	nil	325	190	15	2	194	*	37	−2	7	194	278
26	773	24	2	nil	114	2	378	193	39	tr.	214	*	−1	−5	33	214	275
27	772	34	*	—	70	*	405	182	53	5	240	*	6	−19	40	240	
28	771	71	2	8	146	5	321	180	103	11	49	*	54	24	94	49	
29	768	34	*	31	212	*	257	193	16	*	195	*	33	2	9	195	278
30	766	34	2	23	50	2	444	183	32	11	36	111	27	21	26	147	277
31	766	51	3	70	67	1	376	211	46	6	*	*	93	34	63	*	289
32	765	42	1	26	55	tr.	422	181	22	4	149	34	35	11	7	183	271
33	761	41	5	28	187	3	285	173	27	9	202	*	40	10	9	202	
34	760	36	—	9	17	2	461	172	68	23	190	37	5	−15	63	227	275
35	759	49	*	16	49	*	427	200	14	*	202	*	24	0	14	202	
36	759	60	2	5	86	2	394	188	nil	nil	221	*	28	8	−12	196	272
37	759	76	*	30	214	7	198	156	69	6	212	*	66	−15	31	212	279
38	758	108	5	7	54	2	411	204	13	4	42	*	83	45	21	42	
39	758	52	2	27	87	*	385	156	87	3	105	68	41	11	46	173	276
40	758	54	—	39	101	1	333	222	32	2	121	*	51	−14	56	121	
41	754	67	8	42	182	4	247	160	44	2	192	*	79	4	6	192	
42	752	61	*	13	50	3	404	197	31	13	211	*	26	−17	41	211	
43	750	84	8	—	3	1	502	202	52	12	23	*	53	51	66	23	280
44	747	45	3	33	80	8	404	182	22	9	136	47	31	20	13	183	276
45	747	65	4	52	128	tr.	312	157	41	tr.	206	*	73	9	−2	206	
46	747	53	2	49	98	2	345	194	43	2	176	*	53	−4	39	176	
47	744	104	11	36	90	tr.	349	212	26	7	29	*	106	34	45	29	
48	742	124	4	23	68	3	349	210	12	11	92	*	97	13	33	92	273
49	740	83	4	33	147	2	325	192	33	12	98	*	64	34	37	98	280
50	739	73	*	31	175	*	284	195	9	*	218	*	43	2	4	218	275
51	738	73	14	28	65	4	413	162	59	6	115	21	67	35	27	136	272
52	736	74	18	31	175	4	258	187	27	9	190	*	77	−4	23	190	
53	732	83	18	66	170	4	243	172	33	13	131	*	117	16	18	131	
54	732	125	10	87	131	—	254	172	35	13	33	*	164	39	20	33	
55	727	37	16	61	307	9	142	195	*	*	229	*	57	−1	−5	229	281
56	724	82	6	49	69	5	325	198	83	25	129	52	67	−40	106	181	

TABLE 1 (*continued*)

No	Locality	Name	Occurrence	Authors
57	Sådholm, Sweden	Ur.	Uralite-porphyrite	Sederholm
58	Butte-Plumas Cos., Cal.	Am.	Quartz-am.-diorite	Clarke, 1910, p. 266
59	Glen Tilt, Scotland	Ho.	Coarse appinite	Deer, 1938, no. 3
60	Loch-na-Craige, Scot.	Ho.	Garnet-bi.-epidote-ab.-amp'te.	Wiseman, p. 382
61	Eganville, Ont.	Ho.	Limestone contact?	Winchell
62	Glen Tilt, Scotland	Ho.	Hornblendite xenolith	Deer, 1938, no. 6
63	Loch-na-Craige, Scot.	Ho.	Biotite-epidote-ab.-amp'te.	Wiseman, p. 383
64	Radauthal, Harz	Ho.	Gabbro, uralitic	Kunitz
65	Glen Tilt, Scotland	Ho.	Quartz-or.-pla.-ho.-rock	Deer, 1938, no. 5
66	Garabal Hill, Scotland	Ho.	Hornblende-gabbro (modified)	Nockolds, 1940
67	S. Felix, Cortegana	Ho.	Diorite	Kunitz
68	Tioga Road, Cal.	Am.	Quartz-monzonite	Turner
69	Bornthal, Saxony	Ho.	Diorite	Kunitz
70	Filipstad, Sweden	Ho.	Zoned crystal	Daly
71	Hohen Waid, Baden	Ho.	Garnet-rock	Erdmannsdörffer
72	Wausau, Wis.	Bk.	Umptekite	Weidman, 1907
73	Walkerville, Mont.	Ho.	Quartz-monzonite	Clarke, 1900
74	Umhausen, Tyrol	Ho.	Altered eclogite	Hezner, 1903
75	Sheep Cr., Colo.	Ho.	Quartz-latite	Larsen & others
76	Glen Tilt, Scotland	Ho.	Hornblende-schist xenolith	Deer, 1938, no. 9
77	Gabbi, Lapland	Ho.	Effusive amphibolite	Kulling
78	Purcell sills, B.C.	Am.	Diorite	Rice
79	Pargas, Finland	Pa.	Limestone contact	Laitakari
80	Pargas, Finland	Pa.	Limestone contact	Kreutz, p. 933
81	Cabo de Gata, Spain	Ho.	Dacite	Osann
82	Dry Gulch, Colo.	Ba.	Quartz-latite	Larsen & others
83	Sommervik, Norway	Ho.	Altered from pyroxene?	Kolderup
84	Chester, Mass.	Ho.	Amphibolite	Duparc & Pearce, 1908
85	Purcell sills, B.C.	Am.	Diorite with chalcopyrite and pyrrhotine	Rice
86	Beaver Creek, Cal.	Am.	Hornblende-gabbro	Turner
87	Ernsthofen, Hesse	Ho.	Luciite-porphyrite	Klemm
88	Glen Tilt, Scotland	Ho.	Pyroxene-appinite	Deer, 1938, no. 4
89	Ipponmatu, Japan	Ho.	Amphibolite	Tsuboi, 1936
90	Nieripeivi, Sweden	Ho.	Zoisite-amphibolite	Du Rietz
91	Ulisna Muduna, Ceylon	Am.	Inclusion in metam. limestone	Coomaraswamy
92	Ilmen Mts., Ural	Ho.	Granodiorite	Belyankin, 1910, b
93	Carlingford, Ireland	Ho.	Junction hybrids	Nockolds, 1935
94	Renfrew, Ont.	Ho.	Crystal	Penfield & Stanley, p. 39
95	Kantalahti, Finland	Ho.	Altered eclogite	Eskola
96	Edenville, N. Y.	Ho.	Limestone contact? with pyroxene	Hawes
97	Franklin, N. J.	Am.	Limestone contact?	Parsons
98	Warwick, N. Y.	Pa.	Limestone contact?	Winchell
99	Amity, N. Y.	Ed.	Limestone contact?	Parsons
100	Kleinhöhe, Alsace-Lor.	Ho.	Hornblende-gneiss	Rhein
101	Schlossberg, Austria	Ho.	Amphibolite	Marchet
102	S. Cristobal, Colo.	Ho.	Andesite dike	Larsen & Irving
103	Edenville, N. Y.	Pa.	Limestone contact?	Winchell
104	Grenville, Quebec†	Ho.	Limestone contact?	Penfield & Stanley, p. 49
105	Mt. Wati, Uganda	Ho.	Quartz-hypersthene-diorite	Groves
106	Lanark Co. Ont.	Ho.	Limestone contact?	Barnes
107	Amity, N. Y.†	Pa.	Limestone contact?	Winchell
108	Glen Tilt, Scotland	Ho.	Injected hornblende-schist	Deer, 1938, no. 8
109	Edenville, N. Y.†	Ho.	Crystals	Penfield & Stanley, p. 40
110	Brocken, Harz	Ho.	Diorite ('granite' Kunitz p. 207)	Kunitz
111	Palmer Center, Mass.†	Ho.	Amphibolite dike	Clarke, 1910, p. 21
112	Skudeskunksjär, Nor.	Bk.	Crystal	Gossner & Spielberger, p. 118
113	Plauen, Saxony	Ho.	Syenite	Kunitz
114	Glen Tilt, Scotland	Ho.	Hornblende-schist	Deer, 1938, no. 7
115	Eulengebirge, Silesia	Ho.	Diorite	Kunitz

TABLE 1 (*continued*)

No.	(*a*) Si	Al	Ti	Fe'''	Fe''	Mn	Mg	Ca	Na	K	H	F	R''' in Y	Y− res.	(*b*) v. sp.	F, OH	V
57	724	117	3	37	151	*	304	183	9	5	141	n.d.	84	36	−3	141	281
58	717	137	10	29	80	6	348	172	34	10	134	*	103	27	16	134	
59	716	101	13	72	95	2	312	178	34	13	134	12	115	11	25	146	278
60	716	140	14	33	222	3	158	168	39	15	206	*	118	−14	22	206	
61	710	110	4	64	146	5	286	153	89	27	116	9	92	25	69	125	
62	707	133	12	39	100	2	337	184	29	10	61	64	103	29	23	125	
63	706	149	8	32	214	3	198	163	19	26	202	*	103	9	8	202	
64	704	98	8	31	61	*	429	200	23	3	161	*	49	31	26	161	276
65	704	110	16	60	96	2	322	187	28	12	157	tr.	105	10	28	157	277
66	702	124	12	27	116	1	343	175	53	3	165	*	77	25	31	165	—
67	701	118	5	40	105	*	338	204	28	*	180	*	69	7	32	180	272
68	696	122	13	54	131	6	285	187	21	9	182	3	98	7	17	185	275
69	695	125	*	22	125	*	353	197	28	6	203	*	42	20	31	203	272
70	693	132	10	87	202	20	192	202	24	7	72	—	132	36	33	72	281
71	691	220	5	55	247	21	72	185	31	27	57	27	166	1	43	84	287
72	688	189	tr.	62	305	tr.	58	197	60	75	39	*	139	2	132	39	
73	685	119	16	56	130	7	275	180	22	23	229	13	92	−12	25	242	
74	682	248	4	44	101	—	255	162	68	20	53	*	182	34	50	53	
75	681	167	19	55	113	4	292	176	39	20	64	37	141	31	35	101	
76	681	160	19	40	101	1	311	163	32	24	193	—	118	13	19	193	275
77	680	177	11	22	122	tr.	290	183	79	10	159	*	101	2	72	159	—
78	678	230	*	173	113	n.d.	110	174	53	w.Na	*	*	281	4	27	—	—
79	676	182	1	7	18	*	435	188	69	24	67	84	67	19	81	151	275
80	676	178	tr.	8	18	tr.	436	182	72	23	84	80	62	16	77	164	271
81	676	153	20	59	139	7	310	168	40	6	84	*	128	64	14	84	276
82	673	135	24	160	35	5	298	178	39	21	19	16	216	30	30	35	
83	669	218	1	39	197	2	166	209	42	1	155	*	128	−8	52	155	
84	669	101	13	140	150	1	270	213	68	11	*	*	136	44	92	*	273
85	667	207	*	176	185	n.d.	89	168	58	w.Na	*	*	250	24	26	—	
86	666	180	10	31	100	2	310	196	45	8	190	nil	97	−1	49	190	
87	665	255	15	83	153	*	121	175	84	10	75	*	233	−8	69	75	
88	663	165	19	66	84	2	317	175	34	17	168	tr.	133	17	26	168	277
89	663	234	3	24	78	2	317	157	86	7	171	*	127	21	50	171	
90	663	240	7	20	130	2	279	184	76	6	69	*	137	41	66	69	
91	663	229	*	tr.	*	*	446	202	110	*	56	*	92	38	112	56	290
92	662	188	9	54	166	4	246	196	68	24	71	*	122	29	88	71	
93	661	155	23	18	287	*	167	172	46	17	228	*	80	11	35	228	
94	661	148	9	78	132	6	284	159	100	25	65	87	105	18	84	152	276
95	659	227	15	21	221	2	194	193	31	24	87	*	137	39	48	87	
96	659	215	*	36	177	6	262	191	81	17	39	*	110	55	89	39	
97	659	146	14	67	123	4	301	165	95	42	52	87	100	14	102	139	277
98	658	203	5	13	27	1	429	197	74	15	95	11	84	36	86	106	
99	656	162	10	10	20	1	462	193	67	18	42	138	48	21	78	180	275
100	656	252	—	56	152	—	215	231	28	12	10	*	164	31	71	10	
101	655	203	21	47	187	2	200	230	33	21	52	*	147	15	84	52	283
102	654	200	20	53	112	2	304	177	60	16	78	n.d.	147	45	53	78	
103	654	227	tr.	4	12	1	429	189	77	10	127	12	85	27	76	139	
104	653	204	7	3	9	1	442	206	77	32	38	72	74	19	115	110	273
105	652	159	45	94	177	*	173	199	50	11	96	*	195	0	60	96	
106	651	197	10	52	93	4	325	186	72	37	74	14	120	32	95	88	283
107	650	234	tr.	39	10	1	425	192	75	10	127	15	123	59	77	142	
108	649	183	41	56	109	2	269	186	36	21	93	41	170	9	42	134	278
109	649	209	17	31	164	2	262	191	72	19	70	19	123	34	82	89	279
110	646	183	15	25	153	*	295	192	55	*	204	*	84	17	47	204	
111	646	196	19	56	163	5	209	189	34	29	192	*	136	−6	52	192	279
112	645	213	*	34	285	10	194	164	61	11	97	*	92	81	36	97	278
113	645	198	11	53	144	*	277	173	57	24	163	*	118	28	54	163	273
114	644	250	20	56	109	3	234	169	42	11	138	11	189	14	22	148	275
115	642	189	18	36	160	*	272	181	41	12	200	*	102	16	34	200	274

TABLE 1 (*continued*)

No.	*Locality*	*Name*	*Occurrence*	*Authors*
116	Senftenberg, Austria	Ho.	Anorthosite-amphibolite	Morozewicz
117	Clemgia, Switzerland	Ho.	Biotite-hornblendite	Hezner, 1909
118	Kammegg, Austria	Ho.	Amphibolite	Marchet
119	Renfrew Co., Ont.	Ho.	Limestone contact?	Barnes
120	Lindenfels, Odenwald	Ho.	Gabbro	Kunitz
121	Gertrusk, Carinthia†	Ca.	Eclogite	Koritnig
122	Arendal, Norway	Ho.	Crystal from syenite	Kunitz
123	Pargas, Finland	Pa.	Limestone contact	Laitakari
124	Cullakenee, N. Car.†	Sm.	Corundum-serpentine contact	Genth
125	Pargas, Finland	Pa.	Limestone contact	Laitakari
126	Stavarnsjö, Norway	Bk.	Elaeolite-syenite	Kunitz
127	Ristjåkko, Lapland	Ho.	Hornblende-schist	Kulling
128	Iron Hill, Colo.	Ma.	Metam. limestone with nepheline rocks	Billings
129	Salaja, Ural	Pa.	Amphibole-trap-granulite	Loewinson-Lessing
130	'Barnaschka-Kudnik'	Ho.	Amphibolite	Kunitz
131	Glen Tilt, Scotland	Ho.	Glen Tilt diorite	Deer, 1938, no. 1
132	Beerberg, Thuringia	Ho.	Diorite	Kunitz
133	Skuttersundskjär, Nor.	Bk.	Elaeolite-syenite	Kunitz
134	'S. Vincent'	Ba.	Essexite	Kunitz
135	Glen Tilt, Scotland	Ho.	Coarse appinite	Deer, 1938, no. 2
136	Yokodake, Japan	Ho.	Amphibolite	Tsuboi, 1935
137	Custer Co., Idaho	Am.	Contact (?)-metam. limestone	Shannon
138	Kilimanjaro, E. Africa	Ho.	Sodic lavas	Washington & Merwin
139	Heum, Norway	Ho.	Ho.-feldspar vein with nepheline	Brögger
140	Shoal Creek, N. Car.	Ha.	Crystals	Kunitz
141	Glenelg, Scotland	Ho.	Garnet-amphibolite (altered eclogite)	Alderman
142	White Mts., N. H.	Ha.	Crystals	Kunitz
143	Österskär, Sweden	Ho.	Pegmatite	Geijer
144	Koswinsky, N. Ural	So.	Anorthite-diorite veins	Duparc & Pearce, 1903
145	Montville, N. J.	Ac.	Serpentine	Eakins
146	Garabal Hill, Scotland	Ho.	Davainite 'early'	Nockolds, 1940
147	Tiree, Hebrides†	Pa.	Inclusion in metam. limestone	Unpublished
148	Garabal Hill	Ho.	Appinitic diorite	Nockolds 1940
149	Square Butte, Mont.	Bk.	Sodalite-syenite	Lindgren & Melville
150	Glenelg, Scotland	Ho.	Kyanite-garnet-amphibolite	Tilley, 1937
151	Linosa, Mediterranean	Ka.	Volcanic lapilli	Washington, 1908, p. 192
152	Mansjö, Sweden	Pa.	Centre of pyroxene dike	Eckermann
153	Jackson, N. H.	Fe	Nordmarkite	Billings
154	Almunge, Sweden	Ha.	Umptekite	Quensel
155	'Tejedatal'	Ba.	Essexitic phonolite	Kunitz
156	Mte. Somma, Italy	Ho.	Crystals	Penfield & Stanley, p. 41
157	Hukusinzan, Japan	Ha.	Sodalite-nepheline-syenite	Harada, p. 283
158	Pargas, Finland	Pa.	Limestone contact	Parsons
159	Todtenköpfchen, Rhön	Ho.	Hornblende-basalt	Galkin
160	Titianul, Hungary	Ho.	Pla.-garnet-quartz-biotite-amp'te.	Vendl, 1932
161	Dôgo, Oki Is., Japan	Ka.	Basaltic dike	Tomita
162	Shabō-zan, Formosa	Ho.	Hornblende-andesite	Ichimura
163	'Isleta-Krater'	Ba.	Volcanic bomb	Kunitz
164	Cornwall, N. Y.	Hu.	Quartz-felspar aggregate	Weidman, 1903
165	Cuttingsville, Vt.	Ho.	Ho. syenite with nepheline rocks	Eggleston
166	Stenzelberg, Siebeng.	Ho.	Andesite	Rammelsberg
167	S. Vincente, C. Verde	Bk.	Foyaite	Kunitz
168	Copinshay, Orkney	Ba.	Hornblende-monchiquite	Flett
169	Dungannon, Ont.	Ha.	Nepheline-syenite	Walker
170	Stockholm, Sweden	Ho.	Pegmatite	Geijer
171	Madeira	Ba.	Trachydolerite	Kunitz
172	Shabō-zan, Formosa	Ba.	Hornblende-andesite	Ichimura
173	Montreal, Canada	Am.	Coarse-grained essexite	Harrington
174	Kaersut, Greenland†	Ka.	Crystal	Gossner & Spielberger, p. 121

TABLE 1 (*continued*)

No.	(*a*) Si	Al	Ti	Fe'''	Fe''	Mn	Mg	Ca	Na	K	H	F	R''' in Y	Y– res.	(*b*) v. sp.	F, OH	V
116	642	259	3	25	132	4	256	180	61	12	145	*	132	21	53	145	278
117	642	189	20	55	46	*	404	174	49	19	106	*	126	56	42	106	280
118	640	217	33	34	185	2	210	210	47	24	71	*	157	21	81	71	280
119	638	178	12	108	215	tr.	167	177	82	26	95	20	148	18	85	115	287
120	638	193	12	39	188	*	255	181	39	9	206	*	94	25	29	206	276
121	637	238	14	19	59	*	328	175	88	21	191	*	122	−5	84	191	274
122	637	209	4	51	162	*	251	176	48	23	210	*	105	14	47	210	271
123	636	223	10	18	139	*	305	190	58	36	41	82	97	31	84	123	285
124	636	292	—	8	41	*	350	189	61	6	128	*	136	83	56	128	—
125	635	214	8	4	72	*	410	197	38	24	50	104	69	43	59	154	273
126	635	201	5	77	234	13	143	173	110	19	149	*	123	8	100	149	273
127	635	231	15	76	169	1	167	170	110	12	141	*	172	−6	92	141	—
128	635	185	17	43	86	4	350	153	130	12	176	*	97	20	95	176	279
129	632	306	—	35	120	tr.	252	157	88	tr.	102	—	173	45	45	102	—
130	631	227	3	33	134	*	310	187	54	14	155	*	97	38	55	155	275
131	631	178	31	32	190	3	257	182	29	27	202	—	103	21	39	202	281
132	630	209	15	57	137	*	276	197	51	24	130	*	126	24	72	130	276
133	629	218	3	88	225	17	137	173	111	15	120	*	141	17	99	120	274
134	629	223	20	97	80	*	278	198	60	17	60	*	189	27	75	60	277
135	629	206	31	37	111	2	305	185	31	19	136	39	135	21	34	175	277
136	628	219	35	23	153	4	252	173	64	2	192	*	140	14	39	192	—
137	627	209	tr.	82	371	tr.	34	197	38	34	138	*	118	23	69	138	—
138	622	220	47	52	73	n.d.	315	192	92	31	20	n.d.	188	29	115	20	—
139	622	199	51	91	125	2	225	196	96	32	nil	15	214	14	124	15	—
140	620	210	8	56	269	*	136	168	98	29	212	*	102	− 1	95	212	275
141	619	233	11	65	96	2	316	185	19	15	150	*	139	42	19	150	282
142	618	191	17	114	286	6	53	155	117	20	196	*	157	−15	92	196	279
143	618	222	3	83	322	15	70	170	72	39	130	5	129	33	81	135	—
144	618	198	20	111	125	tr.	269	201	70	13	51	—	167	41	84	51	284
145	618	292	*	8	7	2	411	196	62	25	111	*	118	38	83	111	—
146	616	200	26	44	107	1	323	185	58	12	198	*	112	17	55	198	—
147	614	275	9	37	74	1	310	204	40	49	83	19	144	20	93	103	279
148	614	211	29	45	149	tr.	251	184	53	11	229	*	128	−1	48	229	—
149	614	309	15	45	291	2	60	180	91	40	26	*	198	36	111	26	279
150	613	294	8	29	112	1	259	172	47	16	198	*	152	16	35	198	272
151	610	174	96	98	46	1	280	196	63	11	20	14	274	5	70	34	270
152	610	260	5	16	38	*	382	212	56	27	156	5	97	10	95	160	273
153	610	237	39	51	353	17	53	170	57	28	65	*	176	60	55	65	291
154	609	206	10	92	342	13	33	169	65	40	217	*	127	5	74	217	—
155	607	218	30	137	103	*	222	201	68	20	46	*	222	17	89	46	282
156	607	235	4	84	138	13	262	198	51	47	78	2	134	43	96	80	281
157	606	245	16	105	294	18	36	165	110	39	88	*	188	20	114	88	—
158	604	254	5	21	42	1	399	203	65	27	16	140	89	26	95	156	274
159	603	248	56	82	61	*	264	194	61	22	48	*	245	14	77	48	275
160	602	325	12	80	130	4	183	161	52	19	99	*	231	36	32	99	278
161	600	251	79	52	92	2	247	174	75	30	37	*	261	23	79	37	278
162	599	210	33	131	3	9	315	187	70	29	122	*	206	0	86	122	—
163	599	226	46	84	80	*	291	194	66	29	72	*	201	26	89	72	280
164	598	231	13	90	317	11	46	184	101	25	141	14	145	6	110	155	—
165	598	250	13	73	208	16	170	209	98	34	50	*	147	28	141	50	268
166	598	265	3	117	97	3	254	205	33	51	48	*	186	37	89	48	278
167	597	224	14	137	217	10	95	187	105	14	128	*	186	−6	106	128	278
168	597	296	62	47	68	4	218	202	49	63	35	*	264	−8	114	35	280
169	597	284	14	99	295	8	53	164	91	54	36	*	194	50	109	36	286
170	596	269	12	51	295	5	98	161	40	39	205	4	140	67	40	209	—
171	595	230	48	76	74	*	303	199	81	17	67	*	197	26	97	67	280
172	595	195	35	127	103	7	231	220	29	13	150	*	187	−7	62	150	—
173	595	257	52	33	108	8	294	190	90	19	36	n.d.	189	47	99	36	288
174	593	196	116	6	118	1	281	176	111	27	59	*	227	11	114	59	282

TABLE 1 (*continued*)

No.	*Locality*	*Name*	*Occurrence*	*Authors*
175	Grosspriessen, Bohemia	Ba.	Tephrite	Kunitz
176	Mt. Wati, Uganda	Ho.	Biotite-hornblende-tonalite-gneiss	Groves
177	Bilin, Bohemia	Ba.	Crystals	Penfield & Stanley, p. 47
178	Uturyôtô, Korea	Ka.	Volcanic ejectamenta	Harada, p. 282
179	L. Balaton, Hungary	Ba.	Tuff-breccia	Vendl, 1924
180	Seigertshausen, Hesse	Ho.	Large phenocrysts in basalt	Trenzen
181	Ditro, Transylvania	Am.	Elaeolite-synenite pegmatite	Mauritz
182	Lukow, Bohemia	Ba.	Crystal	Kreutz, p. 958
183	Lukow, Bohemia†	Ba.	Crystal	Kawano
184	Dungannon, Ont.†	Ha.	Nepheline-syenite	Adams & Harrington
185	Yôdôdô, Korea	Ba.	Crystal	Kawano
186	Kaersut, Greenland	Ka.	Plagioclase and alk.-felsp.	Washington, 1908, p. 198
187	Fuerte Ventura, Canary	Bk.	Essexite	Kunitz
188	Mt. Royal, Canada	Ba.	Dioritic phase in essexite	Bancroft & Howard
	Hydrous amphiboles			
189	Kashinskaya, Ural	Ac.	*	Belyankin & Donskaya
190	Gabbi, Lapland	Ho.	Uralite-porphyrite	Kulling
191	Bracken Creek, N. Z.	Ac.	Actinolite-schist	Hutton, 1940, p. 15
192	Goryczkowi Pośredni	Am.	Diorite	Weyberg
193	Lieserschlucht, Carin.	Ho.	In clefts in eclogite	Heritsch
194	Mortojäkko, Lapland	Ho.	Amphibolite	Kulling
195	Start, Devon	Hy.	Amphibole-talc-chlorite-schist	Kennedy & Dixon
196	Pavone, Piedmont	Ho.	Hornblende-gabbro	Van Horn

Effect of error in water and fluorine

Analysis no. 173 above
Do. recalculated with addition of 1% H_2O
Difference
Do. recalculated with addition of 1% F
Difference

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TABLE 1 (*continued*)

No.	(a) Si	Al	Ti	Fe'''	Fe''	Mn	Mg	Ca	Na	K	H	F	R''' in Y	Y− res.	(b) v. sp.	F, OH	V
175	592	261	29	86	47	*	321	196	66	24	59	*	197	36	86	59	280
176	590	219	40	80	208	*	196	163	43	62	142	*	169	33	68	142	
177	587	305	19	80	27	tr.	310	188	90	37	40	1	210	28	115	41	274
178	587	245	73	45	92	1	267	198	58	28	87	—	223	10	84	87	276
179	585	258	41	60	73	1	272	175	64	29	205	*	185	−10	68	205	276
180	585	389	13	27	111	*	270	164	33	12	23	*	227	−5	9	23	
181	581	244	82	73	134	6	198	181	109	46	—	*	262	18	136	—	
182	581	320	28	61	28	9	308	198	73	35	25	5	218	35	106	30	275
183	577	254	49	99	13	1	302	190	79	41	95	3	228	−5	110	98	
184	575	229	19	160	309	9	34	178	107	49	39	*	202	35	134	39	295
185	575	227	68	90	88	1	264	169	90	25	110	3	228	13	84	113	
186	573	244	112	13	107	8	287	170	83	20	57	*	254	44	73	57	277
187	560	228	56	112	135	4	210	199	78	28	106	*	212	5	105	106	280
188	556	220	94	69	157	1	256	187	70	20	37	*	233	53	77	37	
Hydrous amphiboles																	
189	726	60	2	12	75	1	412	163	22	w.Na	342	2	0	−12	−15	344	
190	708	118	7	17	94	tr.	301	189	36	3	324	*	57	−55	28	324	
191	697	73	13	30	104	3	372	144	10	3	375	7	15	−7	−43	382	
192	679	104	7	37	77	8	321	179	38	16	402	—	34	−67	33	402	
193	648	174	6	45	178	2	213	178	18	26	336	nil	79	−34	22	336	
194	644	258	9	44	115	8	185	167	68	9	269	*	164	−77	44	269	
195	625	159	6	5	93	3	468	120	6	2	398	nil	0	64	−72	398	286
196	581	258	tr.	44	131	tr.	285	185	81	12	273	—	83	−1	78	273	274
Effect of error in water and fluorine																	
	595	257	52	33	108	8	294	190	90	19	36	n.d.	189	47	99	36	288
	582	251	51	33	106	8	288	186	88	19	135	—	168	19	93	135	282
	13	6	1	—	2	—	6	4	2	—	99	—	21	28	6	99	6
	589	254	51	33	107	8	291	188	89	19	36	47	178	33	96	83	286
	6	3	1	—	1	—	3	2	1	—	—	47	11	14	3	47	2

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