Re-examination of the mineral tuhualite

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Summary.—X-ray study of tuhualite from Mayor Island, New Zealand, has shown it to be orthorhombic, space-group either $Cmca = D_{2h}^{18}$ or $C2ca = C_{2v}^{17}$. Unit-cell dimensions are $a = 14 \cdot 31$ Å., $b = 17 \cdot 28$ Å., $c = 10 \cdot 11$ Å., and $a : b : c = 0 \cdot 828 : 1 : 0 \cdot 585$. Goniometric measurements give $a : b : c = 0 \cdot 8243 : 1 : 0 \cdot 5658$. $a\{100\}$ dominant with forms $s\{011\}$, $p\{021\}$, $c\{001\}$, $b\{010\}$, $n\{101\}$, $m\{110\}$, $q\{111\}$. Crystals with $b\{010\}$ dominant are rare. Three good cleavages, a (100), b (010), c (001). $\alpha = 1 \cdot 608$, $\beta = 1 \cdot 612$, $\gamma = 1 \cdot 621$; $\gamma - \alpha = 0 \cdot 013$. $2V = 61_{\beta}^{\circ} - 70_{v}^{\circ}$, positive; $\beta = b$, $\gamma = c$, $\alpha =$ colourless to pale lavender, $\beta =$ violet, lavender, $\gamma =$ intense purplish-blue; $\gamma > \beta > \alpha$. Sp. gr. 2·89 (measured), 2·86 (calculated).

An analysis of carefully purified material leads to the possible formula:

$$H_9(Na,K,Mn)_{12}Fe_6''(Al,Fe''',Mg,Ti)_9[Si_8O_8]_{15}.$$

Details of alteration phenomena and associated minerals are given. Occurrence is held to result by crystallization from magma quite impoverished in lime due to early fractionation of aegirine-hedenbergite, and perhaps aegirine-augite, in the intratelluric stage.

TUHUALITE is a constituent of ejectamenta on Mayor Island, New Zealand, at and in the vicinity of Opo Bay at the southern extremity of the island, and occurs *in situ* in banded rhyolites that outcrop along the base of the caldera wall just north-east of Tutaretare (1162 feet). Mayor Island, the Maori name for which is Tuhua, lies in latitude 37° 20′ South and longitude 176° 15′ East, within the Bay of Plenty off the east coast of North Island, New Zealand. The island is a volcanic cone with an elevation of 1274 feet above sea-level. The rocks are acidic in character and consist of a series of lavas, often pure obsidians, and tuffs, and most if not all of these have comenditic affinities.

The first record of the paragenesis and properties of tuhualite is found in a preliminary account of some volcanic rocks from North Island, New Zealand, by Marshall (1932, p. 202). In that paper attention was called to the presence in comendites on Mayor Island of 'a supposedly new amphibole with the extraordinary pleochroism, colorless to purplish violet to deep violet', in association with the sodic ferromagnesian constituents aegirine, cossyrite, and arfvedsonite; the last mineral was subsequently shown to be riebeckite (Marshall, 1936A, p. 341).

Later, Marshall (1936B) published a more detailed paper on tuhualite. Crystallographic measurements that were secured with the aid of a stage

goniometer are reported and these data led to the belief that the mineral was orthorhombic with $a:b:c = 0.915:1:0.512$. On the basis of these data Marshall came to the conclusion that his previous opinion that the mineral was an amphibole was an incorrect one. Some optical data, determined by other workers, are reported, and finally Marshall listed four analyses of comendites made by Mr. F. T. Seelye, one supposedly devoid of tuhualite, which in the present writer's opinion do not differ in any significant degree from one another. However, on the basis of the supposed differences between these analyses Marshall calculated a composition for tuhualite itself (table III, anal. B).

The petrography of the Mayor Island sodic rhyolites had been investigated previously; von Wolff (1904) described material donated by Thilenius, and J. A. Bartrum (1926) carefully studied specimens collected by J. A. Thomson during the latter's visit to the island in 1920, and also some thin sections lent to him by Speight. Marshall visited the island on at least two occasions and collected the material that formed the basis of three papers (Marshall, 1932, 1936A, 1936B).

The new analysis and the crystallographic and X-ray studies of tuhualite reported on herein were made with material obtained from specimens collected by Marshall himself, and some incidental observations on mineral association were made with material collected by others. A few crystal measurements were also performed on material given to the writer by Dr. P. G. Harris, who had in the first place obtained it from Marshall.

Occurrence of tuhualite.

In the material examined by this writer tuhualite has been found to occur as follows: (a) As a constituent of crudely microspherulitic aggregates of felspar, quartz, aenigmatite, riebeckite, and aegirine in the groundmass of both non-porphyritic and coarsely porphyritic comendites; and there appears to be every gradation between this association and microstructure and that in which tuhualite in irregular, moss-like outline, almost pigmentary in form, is intimately associated with alkali-felspar, quartz, and any one or combination of the sodic ferromagnesian constituents on a microcrystalline scale with or without marked flow structures. In a number of instances tuhualite is sufficiently abundant to produce deep blue areas that are quite obvious megascopically. However, it should be pointed out that the percentage of tuhualite in these areas is low and in no case has the present writer found it to make up 50 % of such areas (cf. Marshall, 1936B, p. 335). (b) More

or less equidimensional subeuhedral isolated crystals up to 0·25 mm. in diameter, which are often situated in portions of the rock somewhat more coarsely crystalline than the average. (*c*) As euhedra (1·5 mm. in length) in very porous, pale grey zones in comendite, and in steam cavities where the best euhedra have been noted; these may occur alone or with either stout euhedra of aegirine or flat prismatic crystals of riebeckite, or both.

In many of the rhyolites examined, most of which were devoid of tuhualite, a pale greenish-yellow to orange-yellow mineral of serpentinous appearance was recognized; it is especially well developed in the dark-coloured, finely banded rocks from the crater area and gives rise to the narrow yellow bands therein as seen in hand specimens. For it the following properties have been determined: $\gamma - \alpha < 0.010$; $n = 1.547\text{--}1.551$; pleochroism not recognizable.

A second, but uncommon, yellow mineral of irregular outline occurs in the tuhualite-bearing comendites, and this may be the material commented upon by Marshall (1936B, p. 336), although it is quite uncertain whether Marshall was referring to this or to the more abundantly developed yellow serpentinous material just mentioned. It has the following optical properties: $\alpha = 1.603 \pm 0.003$, $\beta = 1.613$, $\gamma = 1.620$, $\gamma - \alpha = 0.017$. Optic axial angle measurements gave: $82° (-)$, $66° (-)$; for a strongly zoned crystal: inner zone $= 64° (-)$, outer zone $= 72° (-)$. Dispersion is strong in most fragments with $\rho < v$, although this is absent in a few instances. Pleochroism is faint, with $\alpha =$ pale yellowish-green, $\gamma =$ pale yellow; $\gamma \geqslant \alpha$. At least one good cleavage is evident with extinction oblique thereto. In the yellow mineral noted by Marshall lamellar twinning appeared to be common; this property was not observed in any of the examples studied at this time.

The similarity of the refractive indices of this mineral to those of tuhualite is interesting, especially so since instances have been found occasionally where crystals exhibit gradations from tuhualite-like material outwards into the clear yellow mineral of unknown composition.[1]

Physical properties.

Tuhualite is excessively brittle, so much so that any attempt to release a crystal from attachment to a vesicle wall causes severe fracturing of the crystal. Accordingly the fragments used for X-ray and other work

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[1] A very faint X-ray diffraction pattern obtained from a minute amount of this mineral exhibited two lines at $d = 3.45$ Å. and 3.35 Å. in order of decreasing intensity.

never exceeded 0·25 mm. Three good pinacoidal cleavages are present, but that perpendicular to the vertical crystallographic axis, the acute bisectrix, appears to be superior to the other two.

It was found that most of the crystal fragments were contaminated by adhering quartz or felspar, or both, and therefore specific gravity determinations were made by repeatedly centrifuging the pure mineral powder obtained for analysis in methylene iodide-bromoform-acetone mixtures; a value of 2·89±0·02, corrected for determination made at 20° C., was obtained, and this corresponds closely with values secured from seven fragments whose purity could not be absolutely guaranteed, 2·88±0·02. Hardness, determined with a fine needle point on the surfaces of a crystal cemented to a glass slide, is about 3 to 4.

Refractive indices and pleochroism for tuhualite as analysed were found to be: $\alpha = 1·608 \pm 0·001$, $\beta = 1·612$, $\gamma = 1·621 \pm 0·003$, $\gamma - \alpha = 0·013$; α = colourless to very pale pink, β = violet or lavender, γ = intense purplish-blue; $\gamma > \beta > \alpha$, with much less difference between β and γ than between β and α.

The limits of error are much wider in the case of the γ-vibration direction of the refractive index ellipsoid owing to intense absorption, even in fragments less than 20 microns in thickness. Refractive indices for the α-vibration direction in a number of crystal fragments not included in the analysed material were: 1·604, 1·609, and 1·606. These values possibly indicate a range of chemical composition from grain to grain, and zoning was clearly observed during measurement of 2V, although colour and pleochroism did not seem to be correspondingly affected.

The values obtained for the analysed material reported on in this paper differ appreciably from those determined for a crystal of tuhualite by the present writer in 1935 at the request of Marshall. The reason for this discrepancy is not clear at this stage.

The mineral is optically positive, and optic axial-angle measurements made in monochromatic light of wavelengths 4900 Å. and 6026 Å. (values for the latter in parentheses) gave a distinct range of values as follows: analysed material 70° (61°–62°), crushed crystal fragments 76°, 78°, 76° (70°, 72°, 69°); a zoned crystal gave 76° (68°) for centre, 80° (70°) for median zone, and 91° (82°) for a narrow peripheral zone. Dispersion of the optic axes is strong with $\rho < v$, and the optic axial plane is parallel to (010), that is, $\beta = b$. Elongation positive, $\gamma = c$.

As distinct from gradation of tuhualite into the yellow mineral of undetermined composition, clearly a magmatic reaction, tuhualite has undergone changes due to weathering. There is no doubt that the end-

products are red-brown patches of limonitic iron oxides, but intermediate stages are less clear. Early in the breakdown, however, a slight loss of colour with almost complete loss of pleochroism and diminution in bire-fringence takes place, and in the few instances observed such crystals were optically negative (change of sign) with 2V close to 30°. A later
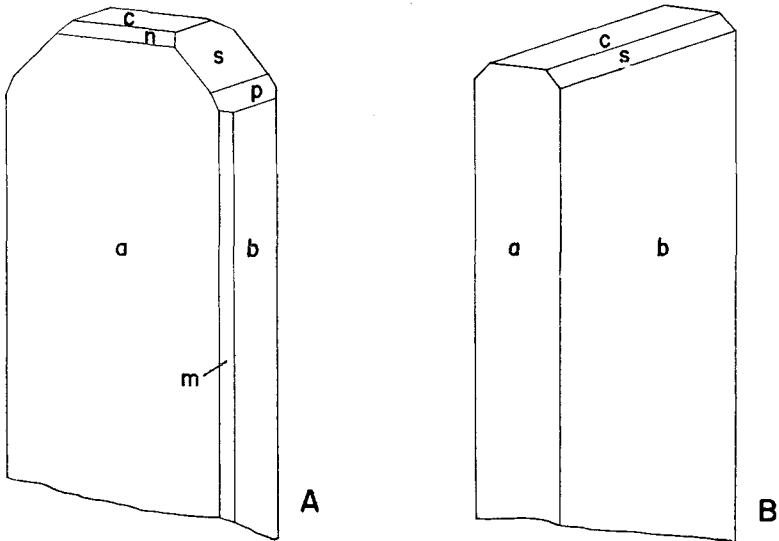

FIG. 1. Crystals of tuhualite from Mayor Island. A, common habit; B, rare habit.

stage involves development of isotropy and appearance of iron stain, although moderate absorption in lavender remains. Rare crystal frag-ments, colourless but otherwise comparable to tuhualite, have been recognized; to what stage in the decomposition process such fragments belong, if they do, is unknown.

When the Gladstone and Dale formula $(n-1)/D = K$ is applied to tuhualite the value of K, 0·2154, derived from the physical con-stants, approximates fairly closely to that obtained from the composition (0·2183); these values are comparable to those found for close-packed structures.

Morphology.

Examination of crystals that were carefully removed from steam cavities shows that the form $a\{100\}$ is usually dominant with $s\{011\}$, $p\{021\}$, $c\{001\}$, and $b\{010\}$ about equally developed (fig. 1A). $m\{110\}$ and $n\{101\}$ are slightly less well developed in the crystal figured (fig. 1A);

on the other hand, a few stumpy crystals were found to exhibit about equal development of the forms $a\{100\}$, $b\{010\}$, $m\{110\}$, with $c\{001\}$, $n\{101\}$, and $s\{011\}$ as the only terminal forms. Rarely crystals were noted with $b\{010\}$ dominant, $a\{100\}$, $c\{001\}$, and $s\{011\}$ as sole forms (fig. 1B). $q\{111\}$ appears to be uncommon.

No crystals were found suitable for accurate goniometric treatment owing to small size and to curvature or irregularity of faces. However, approximate measurements were made, in some instances with the Fedorov stage and stage micrometer, and these data are compared with Marshall's values and the angles calculated from the structural cell in table I. Since the X-ray data were secured from a greater number of measurements more weight should be attached to the values in column C of table I.

TABLE I. Angle table for tuhualite: A, based on goniometric measurements (zone adjusted, [001]; b (010) at $\phi = 0°$) compared with B, angles based on the measurements of Marshall (1936B), and C, angles calculated from the X-ray data. Marshall also cites aq 52·0° (calc. 58° 39′).

	A.		B.		C.	
	ϕ.	ρ.	ϕ.	ρ.	ϕ.	ρ.
n (101)	90° 00′	34° 30′	—	—	90° 00′	35° 15′
s (011)	0° 00′	29° 30′	0° 00′	27° 24′	0° 00′	30° 22′
p (021)	0° 00′	48° 00′	0° 00′	50° 24′	0° 00′	49° 29′
m (110)	50° 30′	90° 00′	47° 42′	90° 00′	50° 18′	90° 00′
q (111)	50° 30′	42° 00′	—	—	50° 18′	42° 33′

X-ray study.

A camera of diameter 114·59 mm. and manganese-filtered iron-radiation, $Fe\text{-}K_\alpha = 1·9373$ Å., were used to obtain powder photographs of tuhualite as analysed. Many of the reflections, however, are weak and diffuse, particularly in the region of high 2θ values, and therefore it was not possible to measure the latter with acceptable accuracy. The X-ray powder data are set out in table II together with indices and spacings that have been calculated from the lattice dimensions secured from rotation and Weissenberg photographs, obtained with the crystal fragment figured (fig. 1A): $a = 14·31 \pm 0·03$ Å., $b = 17·28 \pm 0·03$ Å., $c = 10·11 \pm 0·03$ Å. Cell volume $= 2499·96$ Å.³, and with the sp. gr. a cell weight of $7224·88 \times 10^{-24}$ g. is found.

This leads to an axial ratio of $a:b:c$ of $0·828:1:0·585$. Calculation of the density from the relation $D = 1·66030 \sum A/V$ and employing the formulary quantities in column D of table IV gave 2·86, a figure that is slightly less than that determined experimentally.

Systematic indexing of the Weissenberg patterns indicated that the space-group is either $Cmca = D_{2h}^{18}$ or $C2ca = C_{2v}^{17}$.

TABLE II. Powder pattern of tuhualite, Opo Bay, Mayor Island; Fe-K_α radiation with λ 1·9373 Å. Camera diameter 114·59 mm. Intensities estimated visually.

hkl.	d (obs.)	d (calc.)	I.	hkl.	d (obs.)	d (calc.)	I.
020	8·62	8·62	s	004	2·522	2·528	vw
200	7·16 (A)	7·16	vs	062		2·52	
220	5·515	5·515	s	531	2·490	2·485	m
130	5·34	5·34	vvw	442	2·416	2·42	w
002	5·04	5·05	w	204	2·378	2·382	vvw
221	4·85	4·85	s	153		2·379	
310	4·57	4·60	vw	171	2·362	2·366	vw
022	4·35	4·36	s	423		2·36	
040	4·315	4·32	s	461	2·184	2·19	s
202	4·115	4·12	vw	353	2·147	2·153	vw
041	3·96	3·97	w	—	2·078	—	vvw
222	3·71	3·72	s	—	2·053	—	vvw
240		3·70		—	2·002	—	w
330	3·67	3·67	m	—	1·974	—	w
132		3·67		—	1·937	—	vvw
400	3·58	3·58	m	—	1·887	—	vvw
241	3·47	3·475	s	—	1·86	—	vw
331		3·455		—	1·839	—	vw
420	3·31	3·305	m	—	1·789	—	w
042	3·285	3·285	m	—	1·767	—	vvw
113	3·22	3·22	m	—	1·726	—	s
151	3·18 (C)	3·19	s	—	1·669	—	vvw
421	3·14	3·145	m	—	1·653	—	vvw
242	2·97	2·984	m	—	1·550	—	vw
402	2·926	2·921	w	—	1·535	—	vw
060	2·87	2·88	vw	—	1·501	—	vvw
133		2·851		—	1·483	—	vw
061	2·766 (B)	2·77	s	—	1·452	—	w
422		2·766					
440	2·75	2·755	vvw				
441	2·657	2·659	m				
043		2·658					

And numerous other lines at greater 2θ values that could not be measured with desirable accuracy.

A, B, and C: Most prominent lines, decreasing in intensity in order A to C.

Chemical composition.

A large sample of comendite, approximately 820 g. in weight, was broken down to < 30 micron particle size by crushing, screening, and elutriation. The total bulk of this material was then centrifuged in a bromoform-acetone mixture of density 2·70, and from the heavy fraction so obtained an apparently pure sample of tuhualite weighing 0·92 g. was secured by repeated centrifugal fractionation. As purification of the

sample proceeded, fine-grinding carefully performed under alcohol was required in order to free tuhualite particles from contaminating quartz, felspar, riebeckite, &c. The separation was carried out approximately quantitatively, and the small quantity recovered gives a good indication of the percentage of tuhualite in the rock in spite of the fact that the original sample exhibited many deep-blue patches. It will be recalled that Marshall (1936B, p. 335) expressed the opinion that the blue patches contained approximately 50 % of tuhualite.

Scarcity of material did not permit any chemical tests beyond those that indicated that tuhualite is not noticeably affected by either hot concentrated HCl or H_2SO_4 after five minutes of such treatment. Analyses of comendite and tuhualite are set out in table III, and analysis C of

TABLE III. Analyses of comendite and tuhualite from Opo Bay,
Mayor Island, New Zealand.

		A.	B.	C.
SiO_2	...	72·28	75·36	62·93
Al_2O_3	...	9·75	9·33	0·63
Fe_2O_3	...	4·44	3·61	14·09
FeO	...	1·43	2·33	9·58
MgO	...	0·28	0·06	0·42
CaO	...	0·44	0·25	tr. ?
Na_2O	...	4·96	4·75	7·11
K_2O	...	4·50	4·06	1·74
H_2O^-	...	1·04	0·21(−)	0·38
H_2O^+	...	0·68	0·12(−)	1·61
TiO_2	...	0·23	0·23	0·42
P_2O_5	...	0·04	—	nil
MnO	...	0·14	0·18	0·81
		100·44	100·16	99·72
O for F	...	0·03		
		100·41		

A. Comendite, Mayor Island. Anal. F. T. Seelye (Marshall, 1936A, p. 343). Also S 0·02, ZrO_2 0·03, rare earths 0·10, Cl 0·02, F 0·06 %. B_2O_3, NiO, BaO, SrO, and CO_2 0·00 %.
B. Marshall's analysis of tuhualite arrived at by calculation (Marshall, 1936B, p. 335). Negative values for water are neglected in summation.
C. Tuhualite, Mayor Island. Anal. C. Osborne Hutton.

this table has been recalculated to determine the number of atoms of each kind in the empirical unit-cell (table IV), with full consideration given to the probable errors incurred in the physical measurements and chemical analysis.

On the basis of the calculations summarized in table IV, the actual numbers of (O,OH) atoms in the unit-cell lie between 119·90 and 122·42,

TABLE IV. Empirical unit-cell contents of tuhualite with probable errors based on the assessed errors of the chemical analysis and the physical data.

			A.		B.	C.	D.	E.
SiO_2	...	...	62·93 ±0·20	Si	45·89 ± 0·46		45·45	0·43
Al_2O_3	...	...	0·63 ± 0·30	Al	0·53 ±0·26		0·53	0·50
Fe_2O_3	...	...	14·09 ±0·40	Fe'''	7·72 ± 0·23		7·65	0·60
MgO	...	...	0·42 ±0·10	Mg	0·44 ± 0·11		0·45	0·65
TiO_2	...	...	0·42 ± 0·04	Ti	0·22 ± 0·02		0·22	0·68
FeO	...	...	9·58 ± 0·30	Fe''	5·83 ± 0·18		5·78	0·75
MnO	...	...	0·81 ±0·02	Mn	0·49 ±0·01		0·49	0·80
Na_2O	...	...	7·11 ±0·20	Na	10·04 ± 0·30		9·95	0·95
K_2O	...	...	1·74 ±0·06	K	1·61 ± 0·05		1·59	1·33
H_2O	...	...	1·61 ±0·25	(OH)	7·83 ± 1·22		7·75	—

$\delta a/a = 0·00209$; $\delta b/b = 0·00173$; $\delta c/c = 0·00296$; $\delta D/D = 0·00692$.
D (corrected) = 2·89 ± 0·02.
Conversion factor $F = (abcD)/(1·6603 \times 99·34) = 43·804$.
Cell volume = 2499·96 Å.³
Cell weight = $7224·88 \times 10^{-24}$ g.
% oxygen in tuhualite = $121·16 \times 16/F = 44·25$ %.
Error due to the FeO determination $(F\delta P/2m) = 0·091$.
Total error in Σ (O,OH) = 1·26.
Total error in O = 1·21.
Σ (Al,Fe''',Mg,Ti) = 8·99 ± 0·37.
Σ (Mn,Na,K) = 12·14 ± 0·33.
Σ (O,OH) = 121·16 ± 1·26.
Total iron as Fe_2O_3 = 24·74 ± 0·25.

Possible formula of tuhualite: $H_9(Na,K,Mn)_{12}Fe_6''(Al,Fe''',Mg,Ti)_9[Si_3O_8]_{15}$.

A. Weight % of oxides (= P).
B. Empirical unit-cell contents, FPm/M (Min. Mag., 1954, vol. 30, p. 481).
C. δE = assessed probable errors due to $\delta_c E$ (derived from the chemical analysis) and $\delta_p E$ (derived from the physical data).
D. Number of atoms on the basis of 120 (O,OH) atoms to the unit-cell.
E. Ionic radii according to Pauling.

and accordingly 120 is suggested as a probable figure in this instance. Further, the integers 9, 6, and 12 are clearly within the limits of error for the Fe''', Fe'', and Na groups. It might be pointed out that inclusion of Mg with the Fe''' group rather than with Fe'' is more appropriate in view of the values of the ionic radii concerned. The amount by which Si departs from the integral value of 45 suggests possible quartz impurity in the analysed material, but if this is the answer, the weight % of quartz contaminant would not appear to exceed 0·6.

Accordingly it is suggested that the empirical unit-cell contents of tuhualite may be represented by the formula:

$$H_9(Na,K,Mn)_{12}Fe_6''(Al,Fe''',Mg,Ti)_9(Si_3O_8)_{15}.$$

Petrogenesis.

Comendites and pantellerites are well developed in widely scattered localities Sardinia, Pantelleria, Queensland, New South Wales, and British East Africa, to mention a few and they have been closely studied. But in none of these occurrences has tuhualite been observed in the acid lavas, and since its optical properties are so distinctive it is unlikely that it could have been overlooked. Accordingly, the unique occurrence of tuhualite in Mayor Island rocks is doubly interesting since the composition of these rocks (table III, analysis A) does not differ in any significant detail from many described from Sardinia, Pantelleria, and East Africa. One is therefore tempted to conclude that critical conditions of temperature and pressure rather than unique composition of magma might be the important factor in permitting crystallization of this mineral.

Study of numerous specimens shows that tuhualite has crystallized either in association with quartz and felspar in the groundmass, or at the latest stage, often accompanied by riebeckite and aegirine, in vesicles, and the present study has not shown it to be a member of the intratelluric mineral assemblage which includes quartz, sanidine, sodic pyroxene, and aenigmatite.

Incomplete study shows that the phenocrystic pyroxene is often strongly zoned, with wider extinction angles than those usually recognized for aegirine. For several phenocrysts the following properties were found:[1] $\alpha \wedge c = 25°$, $2V = 72°$ ($-$); $\alpha \wedge c = 23°$, $2V = 88°$ ($+$), $\rho < v$ strong; $\alpha \wedge c = 12°$, $\gamma = 1.785$. A marked decrease in extinction angle was evident in some peripheral zones. These data suggest that much of the phenocrystic pyroxene is aegirine-hedenbergite rather than aegirine in composition, with perhaps diopside also entering into the composition. For crystals separated from vesicles much smaller extinction angles were generally represented, and the following data appeared to be typical: $\alpha = 1.758$, $\gamma = 1.810$, $\alpha \wedge c = 0$ to $2°$; dispersion not strong. Incomplete as these data are it would seem as if the vesicle crystals are closer to aegirine in composition than is the phenocrystic material.

Therefore it is suggested that early separation of hedenbergitic or diopsidic aegirine in the form of phenocrysts has more or less exhausted the originally small supply of lime, but not of alkalis and iron, in the magma; this has resulted, at a later stage, in crystallization of

[1] Fedorov stage determinations employing hemispheres of $n = 1.649$; angles of tilt were corrected.

aegirine,[1] with presumably negligible calcium content, and tuhualite devoid of that element. Accordingly an appeal to special pressure-temperature conditions would seem to be unnecessary.

References.

BARTRUM (J. A.), 1926. New Zealand Journ. Sci. Techn., vol. 8, p. 214.
MARSHALL (P.), 1932. Ibid., vol. 13, p. 198 [M.A. 5–294].
—— 1936A. Trans. Roy. Soc. New Zealand, vol. 66, p. 337 [M.A. 7–45].
—— 1936B. Ibid., vol. 66, p. 330 [M.A. 6–536].
WOLFF (F. von), 1904. Centr. Min., p. 208.

[1] Rare earths were detected qualitatively in a very small sample of aegirine separated from vesicles in the comendites, a circumstance not uncommon in such pyroxenes (H. S. Washington and H. E. Merwin, Amer. Min., 1927, vol. 12, p. 236). Undoubtedly this accounts, in some measure at least, for the rare earths reported in the comendite analysis, but for which a location was not indicated by Marshall (1936A, p. 343).