The nature of 'ameletite'

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Summary. Originally described in phonolitic rocks from the Dunedin district, New Zealand, ameletite was considered by Marshall (1929) to be a chlorine-bearing sodium aluminium silicate, probably a feldspathoid, and later, a zeolite of unspecified composition. Optical, X-ray, and chemical data on several 'ameletite'-bearing felsic volcanic rocks from the type area indicate that material previously designated as ameletite is variously nepheline and mixtures of sodalite, analcime, phillipsite, and nepheline. Criteria thought to be characteristic of ameletite are discussed.

THE name ameletite was given by Marshall (1929) to 'a mineral of ill-defined characters . . . at first considered to be allotriomorphic nepheline'. It was said to be abundant in the majority of trachytoid phonolites of the Dunedin volcanic district, New Zealand, to the exclusion of nepheline or sodalite. Marshall also reported ameletite in trachytoid phonolites of Rarotonga, Huahine, and Raiatea Islands in the Cook and Society groups. The essential characterization of the mineral was based on 'the trachytoid phonolite of Tainui Quarry, Anderson's Bay' in which it was reported to occur as crystals of definite form and as interstitial material, without coexisting nepheline or sodalite. Properties included rectangular or occasional hexagonal sections, definite cleavage parallel to one of the quadrangular sections, refractive index less than anorthoclase but higher than sodalite, birefringence 0·003, solubility in dilute hydrochloric acid, and preferential staining by iron oxides during weathering. Marshall's analysis of the acid-soluble fraction (12·5 % of the rock) of the Tainui Quarry is set out in table I, analysis 5; together with two other similar analyses, it suggested the formula $12SiO_2.6Al_2O_3.9Na_2O.\frac{1}{2}NaCl$.

In 1947 Marshall abandoned the view that ameletite contained chlorine, the chlorine content of the rock being referred to sodalite. He now believed ameletite to be a zeolite on the basis of various staining effects with aniline dyes and silver nitrate, and with iron oxides during

TABLE I. Compositions of some Dunedin felsic volcanic rocks and acid-soluble fractions

	1	2	3	4	5
SiO_2	59·68	57·88	57·38	37·88	36·67
TiO_2	0·30	0·14	0·15	0·76	—
Al_2O_3	17·99	18·82	19·17	20·24	34·70
Fe_2O_3	2·93	3·54	5·51	10·08	—
FeO	3·10	1·88	0·71	6·17	—
MnO	0·09	0·17	0·05	0·40	—
MgO	0·29	0·27	0·17	0·99	—
CaO	1·77	1·11	0·36	1·59	1·80
Na_2O	7·25	7·13	4·41	11·17	24·18
K_2O	5·25	5·55	5·79	1·47	0·86
H_2O+	0·74	1·60	3·30	4·23	—
H_2O-	0·60	1·80	3·18	2·52	—
P_2O_5	0·09	0·05	0·05	0·50	—
Cl	0·45	0·27	0·02	2·65	2·15
	100·53	100·21	100·25	100·65	100·66
less O $\equiv$ Cl	0·10	0·06	—	0·60	0·48
Total	100·43	100·15	100·25	100·05	100·18
Norms					
Qz	—	—	8·78		
Or	31·02	32·79	34·23		
Ab	48·99	45·47	37·18		
An	2·80	4·03	1·42		
Ne	4·89	6·96	—		
Hl	0·74	0·44	0·04		
C	—	—	5·15		
Di	4·66	0·91	—		
Hy	—	—	0·42		
Ol	0·96	0·62	—		
Mt	4·25	5·14	2·01		
Il	0·57	0·27	0·29		
Hm	—	—	4·12		
Ap	0·21	0·13	0·13		
Rest	1·34	3·40	6·48		
Total	100·43	100·16	100·25		
Differentiation index	84·9	85·2	80·2		

1. Feldspathoidal trachyte (sodalite–analcime–phillipsite–aenigmatite trachyte), Tainui Road, Dunedin (OU 20701, Grid Reference S164/172682). Anal. G. I. Z. Kalocsai.

2. Aenigmatite phonolite, Logan Point quarry, Dunedin (Grid Reference S164/173722 approx.). Unpublished analysis of 'unweathered portion of sample' by F. T. Seelye for P. Marshall. (Cr_2O_3, BaO not found; S, CO_2 trace.)

3. 'Deep weathered crust' of rock 2, above. Unpublished analysis by F. T. Seelye for P. Marshall.

4. Composition of acid-soluble fraction of feldspathoidal trachyte, Tainui Road, Dunedin (analysis 1 above). Anal. G. I. Z. Kalocsai.

5. Composition of acid-soluble fraction according to Marshall (1929) and attributed by him to ameletite. (Analysis includes 0·30 % SO_3.)

advancing rock weathering; these effects were attributed to base exchange. They were particularly carefully described for the phonolite of the Logan Point quarry, Dunedin, said to contain about 10 % ameletite, usually idiomorphic, 5 % sodalite, and 5 % interstitial zeolite. In the 1947 paper the material previously referred to as allotriomorphic nepheline was regarded as interstitial zeolites, especially analcime, natrolite, and chabazite.

It seems clear from Marshall's own statements that his original description was based on a mixture of mineral species, including sodalite and zeolites. Nevertheless, he obviously intended that the name 'ameletite' should continue to be applied to the mineral of nepheline-like habit in the phonolitic rocks of the 'Tainui Quarry, Andersons Bay', and of the Logan Point quarry. The former must be accepted as the type locality. Petrographic, mineralogical, and chemical data on specimens from an abandoned quarry at Musselburgh Rise, near Andersons Bay, Dunedin (almost certainly Marshall's 'Tainui Quarry'), from a quarried site in the same or a closely allied mass at Tainui Road, ¼ mile to the south of the Musselburgh Road quarry, and from the Logan Point quarry, are set down in the sequel.

Petrography and mineralogy

In thin section the feldspathoidal trachyte from the Musselburgh Rise quarry (OU 10713, 20703–20706)[1] is seen to consist of dominant laths of alkali feldspar, green calciferous clinopyroxenes and aenigmatite, rarer fayalitic olivines, which are extensively replaced by greenish fibro-lamellar alteration products, and small accessory grains of opaque oxides. The clinopyroxenes, aenigmatite, and olivine display a spongy habit. There are also scattered idiomorphic, sometimes sieved, grains showing the optical properties and habit of nepheline, relatively abundant isotropic material interstitial to the other components and subsequently identified as allotriomorphic sodalite, and small interstitial pools of a complexly twinned zeolite, identified as phillipsite. The nepheline is penetrated by films of a colourless, isotropic mineral of very low refractive index, probably sodalite or analcime or both, and by films of a greenish clay mineral of higher refractive index and birefringence, which becomes brown on oxidation during more advanced weathering. This is evidently the origin of the natural ferruginous staining recorded

[1] OU numbers refer to specimens in the collection of the Geology Department, University of Otago.

by Marshall for 'ameletite'. The rock is generally massive and homogeneous, though a small cognate inclusion of zeolite syenite and an exotic xenolith of zeolitized basalt have been observed. A small vein system in one part of the quarry contains a mesolite-like mineral ($\alpha_{min} = 1{\cdot}500$, $\gamma_{max} = 1{\cdot}507$), the fibres at the centres of the veins being tipped with tiny prisms of natrolite.

Specimens from the Tainui Road locality (OU 10714, 20701, 20702) are very similar. However, nepheline is much less common and analcime occurs in the groundmass. In view of its relatively low feldspathoid content (cf. table I, analysis 1), the rock may appropriately be termed a sodalite–analcime–phillipsite–aenigmatite trachyte rather than a phonolite.

The Logan Point rocks (OU 20629–20634) differ in containing more abundant idiomorphic nepheline, and less olivine, magnetite, and zeolite. In slightly weathered specimens the nepheline is penetrated by films of clay minerals as described above and acquires a ferruginous stain similar to that figured by Marshall (1947) for idiomorphic ameletite from the same quarry. Patches and films of almost isotropic clay minerals of low refractive index appear in more strongly weathered specimens.

After crushing to pass a 300-mesh sieve, representative samples of the Musselburgh Rise, Tainui Road, and Logan Point rocks were centrifuged in bromoform–alcohol mixtures to separate the felsic components and divide them into fractions with differing densities. These were examined by immersion and X-ray powder diffraction methods.

The diffractograms show that the Tainui Road concentrates (OU 20701) contain dominant alkali feldspar (Or_{41} wt. %, determined by the method of Orville, 1958), sodalite ($a = 8{\cdot}877 \pm 0{\cdot}004$ Å, Cu-$K\alpha_1$; $n = 1{\cdot}488$), analcime ($a = 13{\cdot}72 \pm 0{\cdot}01$ Å, Cu-$K\alpha$; $n = 1{\cdot}488$) and subordinate phillipsite ($\alpha = 1{\cdot}493$, $\gamma = 1{\cdot}497$). The composition of the alkali feldspar was determined on material homogenized at 900° C for 24 hours from which zeolites and feldspathoids had been removed by dilute HCl and Na_2CO_3. Rare grains of rectangular and hexagonal outlines observed in thin sections are believed to be nepheline and one or two grains with a refractive index greater than 1·534 were observed in the felsic concentrates. The presence of nepheline in this rock was not confirmed by X-ray data however, and it is evidently a very minor constituent. The Musselburgh Rise concentrates (OU 20703) contain alkali feldspar, sodalite, nepheline, and phillipsite, whereas the Logan Point concentrates (OU 20630) contain alkali feldspar, nepheline

(ω near 1·537), and sodalite ($a = 8{\cdot}879 \pm 0{\cdot}004$ Å, Cu-$K\alpha_1$), as confirmed by their X-ray patterns. Films of low density material (sodalite or zeolite or both) are sufficiently pervasive in the Musselburgh Rise nephelines to promote the greatest concentration of nepheline in the fraction of specific gravity less than 2·4, and to make measurements of refractive indices very difficult. All lines in the X-ray patterns were accounted for by the minerals listed.

Discussion

It is clear from the preceding data that the 'ameletite' of Marshall (1929) from 'Tainui Quarry' is a mixture of sodalite and nepheline, probably with phillipsite and analcime; that of Marshall (1947) from Logan Point is simply idiomorphic nepheline in various stages of alteration. In this connexion it is interesting to note that Ulrich (1891, p. 143) had reported 'unmistakable small idiomorphic nephelines' in the Logan Point phonolite.

It is pertinent to inquire into the significance of the acid extraction analysis of the Tainui rock, said to represent the composition of ameletite (Marshall, 1929), and, in view of the importance placed by Marshall (1947) on staining and weathering effects, to examine the chemical changes produced by weathering of the Logan Point rock.

Marshall's analysis of the acid extract from the Tainui rock, and a new determination by G. I. Z. Kalocsai, are set out in table I, analyses 4 and 5. Kalocsai's analysis was carried out on that part of the rock dissolved in 1:5 HCl for 45 min, Cl being determined on a separate fraction dissolved in nitric acid. The rock is 17 % acid soluble and contains 4·89 % normative nepheline, primarily represented by predominant sodalite, subordinate analcime, and minor phillipsite. Some of the Cl in the acid extract is presumably derived from apatite. If Cl in the sodalite is 2·5–2·6 %, then sodalite accounts for about 40 % of the acid-soluble material or 7 % of the rock, additional soda suggesting about 10 % analcime in the acid-soluble fraction. The normative nepheline content of the rock has been reduced somewhat by alteration of the olivine. The composition of the remaining 50 % of the acid-soluble fraction is not incompatible with decomposition products of olivine and other mafic materials. The new analysis is comparable with that of Marshall in SiO_2 and total R_2O_3, but otherwise the agreement is poor. Clearly, Marshall's analysis does not represent any single mineral species.

Table I lists a new analysis of the Tainui feldspathoidal trachyte together with hitherto unpublished analyses of 'fresh' Logan Point phonolite and of the weathered crust on it, carried out by F. T. Seelye at the request of Marshall (analyses 1 to 3). The relatively high Fe_2O_3 : FeO ratio of the 'fresh' Logan Point rock suggests that it is not free of oxidation; the amount of normative nepheline is less than indicated by the quantity of feldspathoid observed in thin sections. It is clear that the main effects of more advanced weathering, apart from increased oxidation and increased H_2O content, are leaching of nepheline and sodalite with consequent loss of Na_2O and Cl. Normative nepheline, diopside, and olivine disappear, normative magnetite and albite decrease, and normative quartz, corundum, hypersthene, and hematite appear in their place. In thin sections of the brown weathered crust, green pyroxene and aenigmatite are partially replaced by ferruginous clay minerals, but many grains are surprisingly fresh. Alkali feldspars are little affected but the feldspathoids are partially or completely replaced by colourless and ferruginous clay minerals and eventually disappear.

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