

*Low-potash gismondine from Ireland and Iceland.*

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*Summary.* Gismondine is recorded from the Tertiary basalts of the North Atlantic region, from a total of some 40 localities in Antrim and Iceland. It occupies a well-marked position in the sequence of zeolite zones in the lavas, and the characteristic associates are chabazite, thomsonite, and phillipsite. Five new chemical analyses of gismondine from these localities show a negligible content of potash, and indicate plagioclase-type substitution, giving a series ranging from near  $\text{Ca}_8\text{Al}_6\text{Si}_{16}\text{O}_{64}\cdot 34\text{H}_2\text{O}$  to near  $\text{Na}_{2.5}\text{Ca}_{5.5}\text{Al}_{13.5}\text{Si}_{18.5}\text{O}_{64}\cdot 34\text{H}_2\text{O}$ . Substitution of NaSi for CaAl leads to a decrease in refringence, birefringence, and density.

THE rare zeolite, gismondine, does not appear hitherto to have been recorded from the British Isles<sup>1</sup> or from the Tertiary volcanic rocks of the North Atlantic region. Specimens of a mineral collected in Northern Ireland by the writer in 1947, from Bruslee Quarry in the Antrim Basalts, were identified as gismondine, and a re-examination of the material has confirmed this identification. Since then the mineral has been found at several other localities in the same general area in Antrim.

Examination of the extensive Antrim zeolite collection of the late F. N. Ashcroft, now in the British Museum (Natural History), and of the collections of the Geological Survey for Northern Ireland, has resulted in gismondine being identified in specimens from 13 additional localities and it is clear that the mineral is quite widespread in parts of Antrim.

Whilst engaged in geological mapping in eastern Iceland in 1957–61 the writer collected gismondine from a number of localities in the extensive Tertiary basalt outcrop there. The mineral is locally abundant in an environment similar to that of the Antrim occurrences, one that differs in certain particulars from that of most previously known gismondine localities. This paper is based on the examination of gismondine from a total of some 40 localities equally distributed between Antrim and Iceland.

<sup>1</sup> The Belfast Municipal Museum contains a specimen of gismondine (Belfast Nat. Hist. & Phil. Soc. Coll., no. 1916. 640) collected by J. McAdam, but there appears to be no record of the locality from which it was obtained; it is almost certainly from Antrim.

Hintze (1897) lists a number of gismondine localities in a belt stretching from Westphalia to Bohemia; in Italy in the leucite of the Capo di Bove area; in Sicily in Val di Noto; in France in the Puy-de-Dôme area and in the Ardèche; and in cavities in metamorphic rock near Zermatt, Switzerland. Daubrée (1879) found gismondine associated with other zeolites at the hot springs of Plombières. Gismondine has since been recorded from the USSR (M.A. 2-299); from ankaratrite on Kauai, Hawaii (Dunham, 1933); from the Enogerra granite, Queensland (Min. Mag. 24-541); from the Lake Balaton area of Hungary (M.A. 7-117); and from the Îles de la Madeleine in West Africa.

The previously-known gismondine localities are for the most part in volcanic rocks of Quaternary or late Tertiary age, and in many cases are in volcanic rocks of rather unusual type, such as leucite-bearing lavas. The localities in Antrim and Iceland, on the other hand, are in older Tertiary rocks, probably Eocene in age, and the gismondine occurs in lavas that are normal olivine-basalts.

#### *Gismondine localities in Antrim.*

Some of the best Antrim gismondine has been collected from Bruslee Quarry, near Ballyclare. Parts of two Tertiary basalt flows are seen in the quarry: the red amygdaloidal top of the lower flow, and the massive basal and middle portions of the upper. The gismondine occurs in the relatively sparse amygdales in the interior of the upper flow. These are usually horizontally flattened by flow, and often measure 5 cm or more in size. A fair proportion of them contain gismondine, mostly as chalky-white radiating aggregates lining the cavities. A near-colourless variety is also sometimes seen, and octahedron-like crystals up to 8 mm have been encountered. One specimen of the chalky-white gismondine from this locality was selected for chemical analysis (G. I, table II).

The gismondine at Bruslee Quarry is associated with faröelite, chabazite of habits<sup>1</sup> 1 and 2, apophyllite, gyrolite, saponite, and pre-zeolite calcite. Levyne is fairly abundant, but seldom shares an amygdale with other zeolites. Amygdales in the top of the lower flow contain mostly chabazite and faröelite.

Gismondine is more abundant in a second quarry one mile from Bruslee. About four thin and highly amygdaloidal basalt flows are exposed in this quarry. Gismondine is abundant in parts of the quarry as chalky-white cavity-linings, and one specimen was separated for

<sup>1</sup> The crystal habit of chabazite is recorded in the notation of Walker (1951, pp. 778-780).

chemical analysis (G. 2, table II). The gismondine is associated with chabazite of habits 1 and 2 and white saponite; other minerals seen in this quarry include faröelite, calcite, levyne, phillipsite, apophyllite, and hair-like mesolite.

Other Antrim localities for gismondine are listed in the appendix. These include two localities represented by specimens in the collection of the Geological Survey of Northern Ireland. One, a specimen of amygdaloidal basalt collected by Mr. H. E. Wilson from Glenoe, contains white, powdery gismondine associated with chabazite of habit 2 and faröelite. Gismondine occurs in the other in a similar association in a core from a depth of 60 ft from the Upton Park no. 2 borehole, Templepatrick. I am indebted to the Director of the Geological Survey of Northern Ireland for permission to examine specimens and to publish this note. On a field trip to the Slemish dolerite plug in January 1960, conducted by Dr. J. Preston, I collected specimens of gismondine from dolerite pegmatites on the western face of the dolerite mass, and am indebted to Dr. Preston for permission to publish data on the mineral at this locality.

All of the Antrim localities mentioned above are distributed within a circle of 6 miles radius, and it is likely that a careful search within this area would bring to light many other localities. Examination of the Ashcroft collection has revealed the presence of gismondine at 11 additional localities and these considerably extend the known limits of gismondine. These localities are also listed in the appendix. The mineral is rare at these localities and typically forms milky-white linings to small amygdales in the massive interior of basalt flows. There is no evidence that Ashcroft identified gismondine as such at any of these localities. I am indebted to the Keeper of Minerals at the British Museum (Natural History) for allowing me to work on the Ashcroft collection, and for permission to publish this note.

#### *Gismondine localities in eastern Iceland.*

Gismondine is quite abundant in amygdales in feldspar-porphyrritic basalts of the Graenavatn group (Walker, 1959, p. 382) at an altitude of around 3000 ft on the mountains Eyrarfjall, Sauddalsfell, Hoffell, and Godaborgarfjall, on the ridge between Reydarfjördur and Fáskrúdsfjördur. Some of the best specimens were collected from Eyrarfjall, where the lavas contain chabazite of habit 1-2, thomsonite (faröelite), phillipsite, and some levyne. In one specimen, which was selected for chemical analysis (G. 35, table II), gismondine occurs in a cavity 4 cm in diameter,

as aggregates up to 7 mm of octahedron-like crystals, perfectly fresh and, when in grains, quite clear and transparent. Another specimen analysed chemically (G. 37, table II) came from the south-western face of Hoffell; in it, gismondine lines a cavity more than 10 cm long as radiating aggregates that are remarkably similar to those of faröelite.

Gismondine is also widespread and locally abundant in basalts on either side of Fagridalur, between Reydarfjörður and Egilsstaðir. One specimen, of chalky-white gismondine in radiating aggregates up to 3 mm, was separated for analysis (G. 22, table II); it was collected from olivine-basalt in one of the tributaries on the western side of the Kaldakvísl stream west of Fagridalur. Other gismondine localities in eastern Iceland are listed in the appendix.

#### *Description of the minerals.*

Practically all of the specimens examined show gismondine in aggregates, and although crystal faces appear on the outer surfaces of the aggregates, goniometric measurements are impracticable. In the field, aggregates of gismondine are readily confused with faröelite and phillipsite. There are times (e.g. specimens G. 33 and 37) when, were it not for the presence of smoother-surfaced aggregates of faröelite in the same cavity, the gismondine would have been indistinguishable in the field from faröelite. It is likely that many occurrences of gismondine in Iceland and elsewhere have been missed for this reason.<sup>1</sup> Gismondine is readily determined optically, however, being distinguished from faröelite by its negative sign, and from phillipsite and most other zeolites by its relatively high refringence.

On account of the radiating aggregate character it is difficult to obtain reliable data on the optical orientation, although in aggregates the acute bisectrix,  $\alpha$ , is parallel to the elongation of the individuals. Twinning is habitually present, and cruciform twinning is sometimes clearly visible in the hand specimen. In some aggregates the individuals radiate over a range of a few tens of degrees; in others, over 180 degrees or more. Seen in thin section, the aggregates are commonly branching and fern-like.

In view of the scarcity of optical and density data on gismondine, a considerable number of determinations have been made on the Antrim and Icelandic material, as summarized in table I. Some determinations

<sup>1</sup> The labels of some of Ashcroft's Antrim specimens refer to the milky-white gismondine as 'altered faröelite'. In the circumstances this is quite an understandable error.

TABLE I. Density and optical properties of gismondine.

Locality.	Density.	$\alpha$ .	$\beta$ .	$\gamma$ .	$\gamma-\alpha$ .	Condition.
G. 1	2.26	1.530	1.537	1.541	0.011	clear
	2.13	1.534	1.541	1.547	0.013	chalky
	—	1.532	1.539	1.546	0.014	chalky
G. 2	2.15-7	{ 1.530	1.537	1.542	0.012	milky
		{ 1.535	1.541	1.545	0.010	
G. 3	—	1.529	1.537	1.541	0.013	clear
G. 4	—	1.525	—	1.533	0.008	milky
G. 5	—	1.525	1.533	1.535	0.010	chalky
G. 7	—	1.528	1.531	1.534	0.006	milky
G. 9	2.16	—	—	—	—	chalky
G. 11	—	1.533	—	1.541	0.008	milky
G. 14	2.24-7	(1.534)	—	(1.541)	0.007	milky
	—	1.534	1.541	1.544	0.010	milky
G. 16	2.14-6	{ pr. 1.516	—	1.527	0.011	milky
		{ di. 1.528	—	1.538	0.010	
	2.12	—	—	—	—	milky
G. 19	2.14	—	—	—	—	chalky
G. 20	—	1.529	1.534	—	—	chalky
G. 21	2.24	(1.525)	1.534	—	—	clear
G. 22	2.16-20	1.529	1.536	1.545	0.016	chalky
G. 23	2.22	1.524	—	—	—	clear
	—	{ pr. 1.512	1.516	(1.518)	0.006	clear
		{ di. 1.521	1.525	1.527	0.006	
G. 24	2.15-9	(1.531)	—	(1.538)	0.007	milky
G. 26	2.22	(1.524)	1.531	(1.534)	0.010	clear
G. 27	—	1.525	—	1.534	0.009	chalky
G. 33	2.25	1.529	1.537	(1.541)	0.012	clear
	2.21	1.523	1.531	1.533	0.010	clear
G. 35	2.22	1.522	1.528	1.530	0.008	clear
	2.23	1.529	1.535	(1.537)	0.008	clear
	—	1.525	—	1.532	0.007	clear
G. 36	2.16	(1.521)	—	(1.527)	0.006	chalky
G. 37	2.20	1.515	—	1.523	0.008	clear

## New data on gismondine from other areas:

A	—	(1.536)	1.544	1.550	0.014	clear
B	—	1.534	1.544	1.549	0.015	clear
C	—	1.534	1.543	1.549	0.015	clear
D	—	1.533	1.541	1.547	0.014	clear

## Data from literature:

1	2.265	—	1.5385	—	—	
2	2.278	—	—	—	—	
3	—	1.5308	1.5402	1.5484	0.0176	
4	—	1.538	1.543	1.548	0.010	

A. Îles de la Madeleine, W. Africa (B.M. 1955, 208).

B. Vesuvius (B.M. 60103).

C. Schiefenberg, Salesl, Bohemia (B.M. 1918, 108).

D. Vallerano, Rome (B.M. 95123).

1. Capo di Bove (Hintze, 1897).

2. Capo di Bove (Caglioti, 1927).

3. Salesl, Bohemia (Hibsch, 1917).

4. Kauai, Hawaii (Dunham, 1933).

pr. proximal end of individuals in zoned aggregate.

di. distal end of individuals.

have also been made on material from elsewhere, kindly supplied by the Keeper of Minerals from the collection of the British Museum (Natural History). Refractive indices were determined by the immersion method, and are for sodium D light. Except for those values in parentheses, which are less reliable, they are correct to  $\pm 0.003$  or better. Density was measured by suspension of small grains in mixtures of bromoform

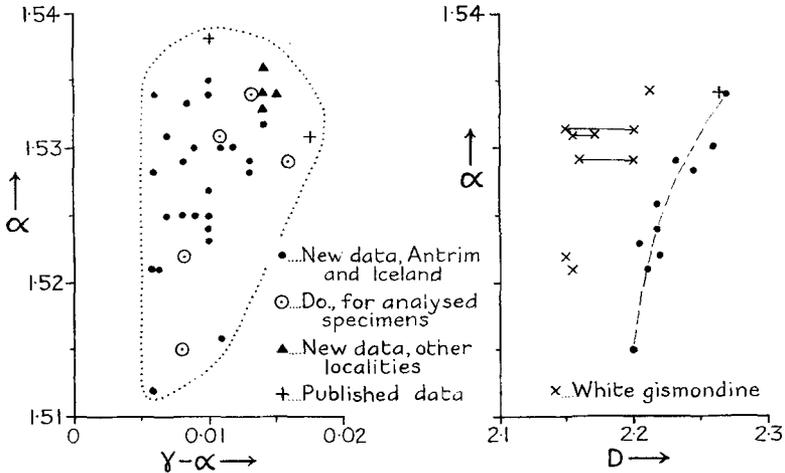


FIG. 1. Diagrams illustrating the variations in optical properties and density of gismondine.

and a mineral oil; the density of the mixtures was obtained from a graph relating refractive index and density based on two standards, one at either end of the gismondine range; the density of the standards was determined at 20–22° C by weighing on a chemical balance, and corrected to water at 4° C. The identity of the gismondine from practically every locality was checked by X-ray powder photographs.

The published optical data on gismondine are in agreement with the present results, but the new data have trebled the known range in refractive index of gismondine; the variation in refractive index and birefringence is summarized on the diagram, fig. 1. The known range in density has likewise been extended. The correlation between refringence and chemical composition is shown by fig. 2, on which the refractive indices of the five newly analysed specimens of gismondine have been plotted; one other gismondine has been included on the diagram, that from Salesl, Bohemia (Hibsch, 1917), the only published analysis of

low-potash gismondine for which a complete set of optical data are available. It can be seen that substitution of NaSi for CaAl reduces the refringence and birefringence.

The gismondine aggregates are commonly zoned, with a small difference in refringence between core and rim. In one specimen, G. 23, which shows exceptionally pronounced zoning, a core with  $\alpha$  about 1.512 and

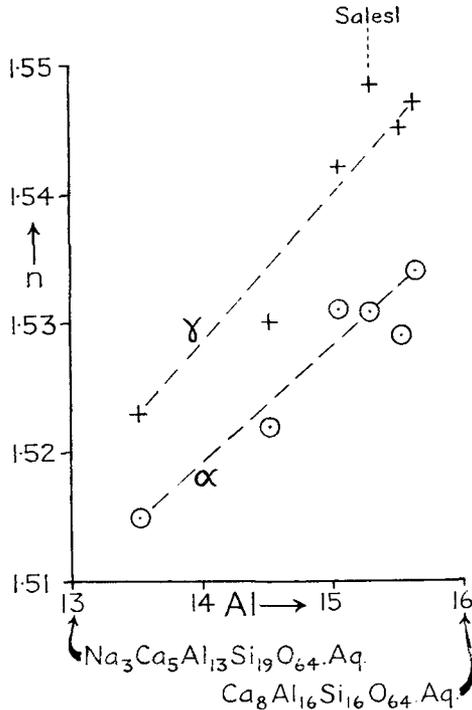


FIG. 2. Correlation of refractive indices and chemical composition for the low-potash gismondine series. Data for gismondine from Salesl, Bohemia, is included with the Antrim and Icelandic data on this diagram.

$\gamma$  about 1.518 is succeeded by a rim with  $\alpha$  1.521,  $\gamma$  about 1.527; in another, G. 16, the turbid core has  $\alpha$  near 1.516,  $\gamma$  near 1.527, and the clear rim has  $\alpha$  1.528,  $\gamma$  1.538. These variations indicate that the CaAl content increases from the core outwards.

The optic axial angle varies from  $15^\circ$  to near  $90^\circ$ , always with negative sign. In general  $2V$  increases with increasing refringence and, presumably, CaAl content, but the relationship is not a simple one.

More than half of the gismondine observed in this study is a milky-white or chalky-white variety that is somewhat altered in appearance. The first impression is that this variety has suffered weathering, but closer inspection of the exposures fails to reveal any systematic difference in environment of the clear and white varieties; moreover, the chalky-white specimen (G. 9) from the Upton Park borehole came from a depth of 60 ft and the chalky appearance thus seems unlikely to be related to present-day weathering. Moreover, the associated minerals chabazite, faröelite, phillipsite, levyne, and apophyllite, this last a mineral that weathers readily (Walker, 1960, p. 518), are always perfectly fresh. Inspection of the chemical analyses gives no reason to suspect that alteration has taken place. Seen in thin section, the white gismondine is turbid, but is otherwise optically normal and has the same refractive indices as clear gismondine from the same locality.

The density of the white gismondine is systematically lower than that of the clear variety. The density of ten specimens of the former averages 2.15; of ten specimens of the clear variety, 2.23. Chalky gismondine from Bruslee quarry has a density of 2.13, while clear gismondine from the same locality with almost identical refractive indices has a density of 2.26. The plot of density against refractive index, fig. 1, reveals that a close correlation exists between the two for clear gismondine, but not for the white variety. The density of pieces of clear gismondine from the same specimen is sensibly uniform; that of white gismondine varies commonly by about 0.03 or more. The white colour of this variety of gismondine, the relatively low and variable density, and the turbidity seen in thin section are regarded as due to contained air in the mineral.

The refractive indices calculated by the rule of Gladstone and Dale (Larsen, 1923; Jaffe, 1956) for the clear gismondine of specimens G. 35 and G. 37 are 1.531 and 1.524 respectively; the corresponding measured values  $\frac{\alpha + \beta + \gamma}{3}$  are 1.527 and 1.519, in remarkably close agreement. For the three analysed specimens of white gismondine the agreement is poor: the calculated value is 0.015 lower than the measured for G. 1 and G. 22, and 0.019 lower for G. 2, and this poor agreement is clearly due to the measured density being too low. The density calculated for the measured refractive index of specimen G. 1 is 2.26, which is identical with the measured density of a clear specimen from the same locality. These relationships are compatible with the turbidity being due to enclosed air.

Thomsonite associated with gismondine forms radiating aggregates,

of the variety faröelite (Hey, 1932). The aggregates are commonly zoned, and in view of the scarcity of data on zoning of the zeolites, some typical data are included here. In general, the refringence of the zoned aggregates of thomsonite increases outwards from the core to the periphery of the aggregate; occasionally a reversal is observed at the distal ends of the individuals, where later thomsonite of sphaerostilbite habit has a lower refringence than the latest faröelite. The following optical data were measured on thomsonite coexisting in the same cavity with gismondine:

	Locality.	$\alpha$ .	$\beta$ .	$\gamma$ .	
Antrim:	G. 1	1.521	1.526	—	faröelite
		1.518	1.523	—	later sphaerostilbite
	G. 33	1.515	1.517	1.525	proximal end
		1.528	1.530	1.539	distal end
Iceland:	G. 22	1.515	1.518	1.527	proximal end
		1.528	1.531	1.542	intermediate zone
		1.521	1.524	—	distal end

Levyne, associated with gismondine at Bruslee, is in thin tablets several millimetres in size, and is optically uniaxial and negative, with  $\epsilon$  1.505,  $\omega$  1.510. Phillipsite forms interpenetrant twins; in G. 35 these are up to 4 mm long, and are optically biaxial and positive with  $\alpha$  1.498,  $\beta$  1.500,  $\gamma$  1.502.

#### *Chemistry of gismondine.*

Chemical analyses were made of five specimens of gismondine, table II, carefully selected to cover the whole range of refringence shown on fig. 1: two from Antrim, and three from Iceland. The material used for the analyses was handpicked under a stereoscopic binocular microscope, and the purity of the powder checked by immersion in refractive index oils before analysis. In some it proved impracticable to remove all traces of chabazite, but the content of chabazite was very low.  $\text{TiO}_2$ ,  $\text{MnO}$ ,  $\text{MgO}$ , and  $\text{P}_2\text{O}_5$  were looked for but were not detected.  $\text{BaO}$  was also looked for and was not detected, but in view of the small amounts of powder used for this determination, the lower limit of detection probably corresponds to 0.1–0.3 %  $\text{BaO}$  in the mineral.

The X-ray study by Kraus (1939) indicates that the unit cell of gismondine contains  $\text{Ca}_8\text{Al}_{16}\text{Si}_{16}\text{O}_{64}\cdot 32\text{H}_2\text{O}$ , and the new analyses have been calculated on the basis of 64 oxygen atoms per unit cell. The new analyses depart from this formula in their lower content of Ca and Al, in their higher content of Si, and in the presence of minor amounts of

TABLE II. New analyses of gismondine.

	G. 37 (p. 565).	G. 35 (p. 308).	G. 2 (28. 60).	G. 22 (p. 489).	G. 1 (28.21).	A.
SiO <sub>2</sub> ...	40.38	38.03	35.83	35.43	34.92	33.87
Al <sub>2</sub> O <sub>3</sub> ...	25.00	26.61	27.17	28.14	28.21	28.74
Fe <sub>2</sub> O <sub>3</sub> ...	0.02	0.002	0.04	0.04	0.10	—
MgO ...	—	n.f.	—	n.f.	n.f.	—
CaO ...	11.76	12.81	14.24	14.22	14.67	15.81
BaO ...	tr.	n.f.	tr.	n.f.	n.f.	—
Na <sub>2</sub> O ...	2.02	1.32	0.90	0.56	0.57	—
K <sub>2</sub> O ...	0.18	0.07	0.07	0.10	0.04	—
H <sub>2</sub> O ...	21.05	21.58	21.98	21.72	21.53	21.58
	100.41	100.42	100.23	100.21	100.04	100.00

Atomic proportions calculated on the basis of 64 oxygens to the unit cell:

Si ...	18.51	17.62	16.88	16.62	16.44	16.00
Al ...	13.51	14.53	15.08	15.55	15.65	16.00
Ca ...	5.78	6.36	7.19	7.15	7.40	8.00
Na ...	1.80	1.18	0.82	0.51	0.52	—
K ...	0.10	0.07	0.04	0.10	0.04	—
H <sub>2</sub> O ...	32.17	33.38	34.51	34.01	33.82	34.00
Si+Al ...	32.02	32.15	31.96	32.17	32.09	32.00
D ...	2.20	2.22	2.16*	2.18*	2.13	(*average values)
γ ...	1.523	1.530	1.542	1.545	1.547	
β ...	—	1.528	—	1.536	1.541	
α ...	1.515	1.522	1.531	1.529	1.534	
γ-α ...	0.008	0.008	0.011	0.016	0.013	

G. 37 (p. 565) Clear gismondine, Hoffell, Fáskrúdsfjörður, E. Iceland.

G. 35 (p. 308) Clear gismondine, Eyrarfjall, Reydarfjörður, E. Iceland.

G. 2 (28.60) Chalky-white gismondine, quarry near Ballyclare, County Antrim, Ireland.

G. 22 (p. 489) Chalky-white gismondine, Kaldakvísl, W. of Fagradalur, E. Iceland.

G. 1 (28.21) Chalky-white gismondine, Bruslee quarry, Ballyclare, County Antrim, Ireland.

Analyst: I. S. E. Carmichael.

(G. 35 and G. 22 contain a small amount—less than 1 %—of chabazite as impurity. G. 2 contains approximately 2 % of chabazite.)

A. Composition calculated from the formula Ca<sub>3</sub>Al<sub>16</sub>Si<sub>16</sub>O<sub>64</sub>·34H<sub>2</sub>O.

Na and K. These departures are readily accounted for by plagioclase-type substitution of NaSi for CaAl, fig. 3. These analyses have a slightly higher content of water, the average being 33.58, perhaps favouring 34H<sub>2</sub>O per unit cell. The water content of the 7 analyses of gismondine published since 1900 (Doelter, 1921; Caglioti, 1927) averages 32.5 per unit cell (table III).

The new analyses differ from most published analyses of gismondine in having a very much lower content of alkalis and a negligible content

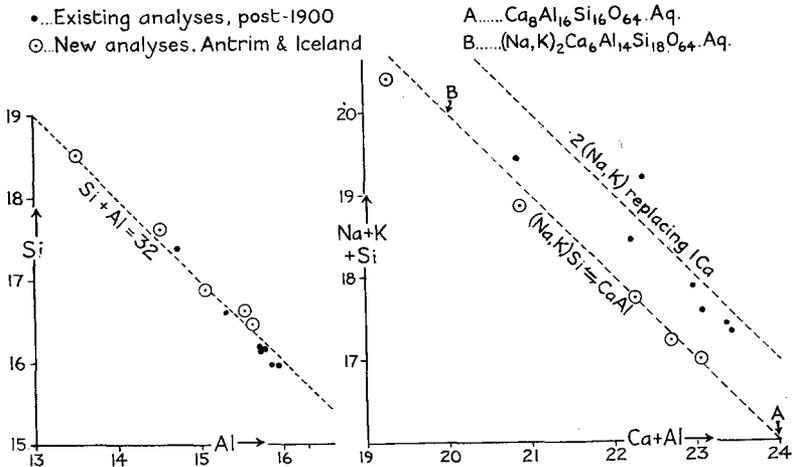


FIG. 3. Left: The extent of Si-Al substitution in gismondine. Right: Chemical variations in the newly analysed, low-potash gismondines, which lie near the lower dashed line, can be explained by plagioclase-type substitution, whereas  $\text{Ca} \rightleftharpoons 2(\text{K},\text{Na})$  substitution also operates in the previously-analysed, potash-rich gismondines.

TABLE III. Published (post-1900) analyses of gismondine, recalculated on the basis of 64 oxygen atoms per unit cell.

	1.	2.	3.	4.	5.	6.	7.
Si ...	15.95	16.17	15.98	16.12	17.38	16.60	16.14
Al ...	15.95	15.71	15.87	15.74	14.73	15.31	15.79
Ca ...	7.43	7.38	7.55	6.64	6.11	6.91	7.18*
Na ...	—	—	—	1.66	0.36	1.84	—
K ...	1.48	1.42	1.36	1.42	1.70	—	1.74
H <sub>2</sub> O ...	33.29	33.44	33.61	32.10	30.97	31.58	32.96
Si+Al ...	31.90	31.88	31.85	31.86	32.11	31.91	31.93

\* Includes 0.05 Ba, 0.01 Sr.

- 1. Vallerano, Rome. Zambonini, 1902
  - 2. Capo di Bove, Rome. Zambonini, 1902
  - 3. Mostacciano, Rome. Zambonini, 1902
  - 4. Nicolstadt, Silesia. Sachs, 1904
  - 5. Capo di Bove, Rome. Tschermak, 1917
  - 6. Salesl, Bohemia. Tschermak, 1917
  - 7. Capo di Bove, Rome. Caglioti, 1927
- } Quoted in Doelter, 1921.

of potash: K averages less than 0.1 per unit cell, in contrast with the average of 1.5 atoms of K per unit cell in the 7 analyses referred to above, table III. The high content of K in most of the published analyses is

best explained by substitution of  $2(K,Na)$  for  $1Ca$  in addition to substitution of  $(Na,K)Si$  for  $CaAl$  (fig. 3) (cf. Winchell, 1925). The lower content of potash in the Antrim and Iceland gismondines may be due to their occurrence in normal olivine-basalts<sup>1</sup> instead of in alkali-rich, feldspathoid-bearing volcanics, or it may reflect their greater geological antiquity, with more possibility for later compositional changes to take place after initial formation.

### *Paragenesis.*

Gismondine is seldom the sole occupant of its amygdale. Of 173 gismondine-bearing amygdalites examined from Antrim and Iceland, 87 % contain chabazite in addition to gismondine, 39 % contain thomsonite (faröelite), 4 % contain phillipsite, 3 % contain levyne, and 3 % contain other minerals; in only 3 % of the amygdalites is gismondine unaccompanied. Of the chabazite accompanying gismondine, 91 % has the form  $\{10\bar{1}1\}$  alone.

The following sequences of minerals have been observed in amygdale-fillings:

chabazite-gismondine	...	...	...	...	...	...	...	5	localities
chabazite-gismondine-thomsonite	...	...	...	...	...	...	...	10	„
chabazite-gismondine-thomsonite-chabazite	...	...	...	...	...	...	...	3	„
gismondine-thomsonite	...	...	...	...	...	...	...	1	„
gismondine-thomsonite-chabazite	...	...	...	...	...	...	...	1	„
chabazite-gismondine-chabazite-thomsonite	...	...	...	...	...	...	...	3	„
chabazite-gismondine-phillipsite	...	...	...	...	...	...	...	1	„
gismondine-phillipsite	...	...	...	...	...	...	...	2	„
phillipsite-gismondine	...	...	...	...	...	...	...	1	„
phillipsite-gismondine-thomsonite	...	...	...	...	...	...	...	2	„
levyne-gismondine-thomsonite-apophyllite	...	...	...	...	...	...	...	1	„

It can be seen that gismondine is most frequently preceded by chabazite, and in turn followed by thomsonite or chabazite. Only one undoubted example has been noted of replacement of one mineral by another: in that, gismondine is partially replaced by phillipsite.

In two recent papers (Walker, 1960 *a, b*) a regular distribution of zeolites in flat-lying zones of regional extent has been described from Tertiary basalt lavas in Antrim and Iceland. The uppermost zeolite zone in each area is characterized by an assemblage in which chabazite and thomsonite are predominant, accompanied by smaller amounts of phillipsite and levyne and sparse apophyllite and gyrolite. Below the

<sup>1</sup> The 11 available analyses of Antrim olivine-basalt lavas average only 0.3 %  $K_2O$ , and 8 new analyses of olivine-basalts and feldspar-porphyrific basalts from eastern Iceland average only 0.33 %  $K_2O$ .

chabazite-thomsonite zone comes a zone in which these minerals are joined by analcime and other zeolites.

In both Antrim and Iceland, most of the localities at which gismondine has been found are in the lower half of the chabazite-thomsonite zone; in five only has gismondine been found in the underlying analcime zone (this vol., p. 183). The association of gismondine with chabazite, thomsonite, and phillipsite appears to be characteristic of other areas as well. The Antrim and Iceland localities are all in olivine-basalts, the relatively silica-poor zeolites gismondine, chabazite, thomsonite, phillipsite, and levyne being especially characteristic of the silica-undersaturated basalts (cf. Coombs *et al.*, 1959).

There are general geological grounds in Antrim and Iceland for supposing that the chabazite-thomsonite assemblage is the lowest-temperature one. This is borne out by the occurrence of a similar mineral assemblage to that in the chabazite-thomsonite zone at the hot springs of Plombières (Daubrée, 1897) and at other hot springs; and by the occurrence of the chabazite-thomsonite-phillipsite assemblage, with or without gismondine, in the lavas of many late-Tertiary or Quaternary volcanoes at a level where the supposed deeper zeolite zones, if present, have not yet been revealed by erosion.

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*Appendix: List of gismondine localities.*

Locality or specimen number given in parentheses. Assoc: associated minerals (*an* analcime; *ap* apophyllite; *ch* chabazite; *ga* garronite; *gm* gmelinite; *gy* gyrolite; *he* heulandite; *le* levyne; *me* mesolite; *na* natrolite; *ph* phillipsite; *st* stilbite; *th* thomsonite, farsöelite). Locations shown on map, this vol., p. 184.

*Antrim:*

- G. 1 (28.21) Bruslee quarry, 0.1 mile SE. of trig. point 550 ft, 1½ miles SE. of Ballyclare. Lat. 54° 44' N; long. 5° 58' W. One specimen from this locality analysed, table II. Assoc: *ch, th, le, ap, gy*, and much calcite.
- G. 2 (28.60) Quarry near trig. point 436 ft, ¾ mile ESE. of Ballyclare. Lat. 54° 44½' N; long. 5° 59' W. One specimen from this locality analysed, table II. Assoc: *ch, th, me, ap, le, ph*, and much saponite and calcite.
- G. 3 (28.62) Quarry on SE. side of Craig Hill, Ballyclare, with zeolites in rare veins in basalt. Assoc: *ch, th, saponite*, and calcite.
- G. 4 (20.109) In basalt of composite flow and underlying flows near trig. point 1116 ft, Skerrywhirry, 11 miles E. of Ballymena. Assoc: *ch, th*.
- G. 5 (20.52) Roadside quarry E. of trig. point 1050 ft, Shane's Hill, 5 miles SW. of Larne. Assoc: *ch, th, le*.
- G. 6 (20.112) Quarry ¼ mile SW. of Kilwaughter crossroads, ¾ mile S. of Kilwaughter Castle. Assoc: *ch, na, an, th, ga*, calcite.
- G. 7 (20.110) Dolerite pegmatites on W. side of Slemish dolerite intrusion. Assoc: *ch, th*.
- G. 8 Geological Survey specimen from well 1¼ miles SW. of Glencoe. Assoc: *ch, th*.
- G. 9 Geological Survey specimen from depth of 60 ft in Upton Park No. 2 borehole, ¾ mile N. of Templepatrick. Assoc: *ch*.
- G. 10 Ashcroft coll., locality 44/1; quarry at 850 ft, ¼ mile SSE. of summit of Carnearney Hill. Assoc: *ch, th, le*.
- G. 11 Ashcroft coll., loc. 43/3; quarry 700 yd ESE. of Call Hill farm, near Cookstown Jcn., Randalstown. Assoc: *ch, th, le*.
- G. 12 Ashcroft coll., loc. 51/2; quarry ¼ mile SE. of Nelson's quarry (Min. Mag., 1910, vol. 15, p. 291), Ballyhenry. Assoc: *ch, th, an, ap, gy, me*.
- G. 13 Ashcroft coll., loc. 56/11; quarry 300 yd S. of Nelson's quarry, Ballyhenry. Assoc: *th, me, ap, gy*.
- G. 14 Ashcroft coll., loc. 56/3; quarry 300 ft above Whitewell on NE. slopes of Collinward, N. of Belfast. Assoc: *an, th, ch, ap, gy, me*, and thaumasite.
- G. 15 Ashcroft coll., loc. 57/6; the middle quarry of a string of three at 550 ft on the NW. slopes of Carnmoney Hill, N. of Belfast (Min. Mag., 1910, vol. 15, p. 292). Assoc: *th, me, le, ap, gy, st*, calcite.
- G. 16 Ashcroft coll., loc. 56/6; quarry at 1000 ft on NE. slope of Catcairn Hill (between Squire's Hill and Wolf Hill), Legoniel, Belfast. Assoc: *ch, th, an, ap, gy, le, ph*.
- G. 17 Ashcroft coll., loc. 56/7; quarry on S. side of Catcairn Hill, S. of loc. 56/6. Assoc: *ch, ap, gy, le, ph*.
- G. 18 Ashcroft coll., loc. 56/8; quarry on N. shoulder of Wolf Hill, S. of loc. 56/7. Assoc: *ch, th, ap, le, gy*.
- G. 19 Ashcroft coll., loc. 2 (Londonderry)/4; quarry at Castle Rock. Assoc: *ch*.

*Iceland:*

(Note: Gr. P. = Graenavatn Porphyritic basalt group, a stratigraphic unit named by Walker, 1959, p. 382; the feldspar-porphyritic basalts of this group often contain gismondine.)

- G. 20 (E. 695) In feldspar-porphyrritic basalt at 1950 ft on NE. ridge of Bjölfur, 1 mile NW. of the village of Seydisfjörður. Assoc: *ch, th, ph*.
- G. 21 (p. 958) In olivine-basalt  $\frac{1}{2}$  mile E. of summit of Gagnheiði, 7 miles SW. of Seydisfjörður. Assoc: *ch, th, ph, le*.
- G. 22 (p. 489) In olivine-basalt at 1600–2000 ft on slope W. of Kaldakvísl. Lat.  $65^{\circ} 11' W.$ ; long.  $14^{\circ} 24' N.$  One specimen from this locality analysed, table II. Assoc: *ch, th*.
- G. 23 (pp. 696–698) In Gr. P. at 1700 ft, and in olivine-basalts at 2200 ft on W. side of Fagridalur, 7 miles SSE. of Egilsstadir. Assoc: *ch, th, ph, le*.
- G. 24 (p. 704) In Gr. P. and olivine-basalts above, at 1800 ft on E. side of Fagridalur, opposite G. 23. Assoc: *ch, th*.
- G. 25 (p. 694) In Gr. P. at 1800 ft on NW. ridge of Skagafell, E. of Fagridalur and N. of G. 24. Assoc: *ch, th, le, ph, ga*.
- G. 26 (p. 695) In feldspar-porphyrritic basalt at 1300 ft on N. face of Skagafell, E. of G. 25. Assoc: *ch, th*.
- G. 27 (E. 886) In Gr. P. at 1900 ft on N. face of Skagafell, SE. of G. 26. Assoc: *ch, th*.
- G. 28 In Gr. P. at 2300 ft on NE. face of Skagafell, SE. of G. 27. Assoc: *ch, th, le, ph*.
- G. 29 (E. 641) In olivine-basalt at 1900 ft in stream 3 miles N. of the Efri-Hrúta, W. side Fagridalur. Assoc: *ch, th*.
- G. 30 (p. 690) In olivine-basalt at 1300 ft in Ormstadaá, 8 miles W. of Egilsstadir. Assoc: *ch, th*
- G. 31 (p. 691) In olivine-basalt at 1500 ft in Ormstadaá, W. of G. 30. Assoc: *ch, th*.
- G. 32 (p. 955) In olivine-basalt at 1700 ft in Fanndalsá, 5 miles N. of Eskifjörður. Assoc: *ch, th, me*.
- G. 33 (p. 227 and 230) In feldspar-porphyrritic basalt at 2300 ft, and in Gr. P. at 2800 ft, on SW. face of Teigargerdistindur, N. of Reydarfjörður. Assoc: *ch, th, ph*.
- G. 34 (p. 709) In Gr. P. at 2000 ft on W. side of Fossdalur, S. of the head of Reydarfjörður. Assoc: *ch, th, me, he, ga*.
- G. 35 (p. 308) In Gr. P. at 2900 ft on Eyrarfjall ridge, S. of Reydarfjörður. Lat.  $64^{\circ} 59' N.$ ; long.  $14^{\circ} 06' W.$  One specimen of gismondine from this locality analysed, table II. Assoc: *ch, th, ph, le*.
- G. 36 (p. 564) In Gr. P. at 3000 ft on S. side of Sauddalsfjall, S. of G. 35. Assoc: *ch, th, ph*.
- G. 37 (p. 565) In Gr. P. at 3100 ft on SW. face of Hoffell, N. of head of Fáskrúdsfjörður. Lat.  $64^{\circ} 58' N.$ ; long.  $14^{\circ} 04' N.$  One specimen of gismondine from this locality analysed, table II. Assoc: *ch, th, ph, le*.
- G. 38 In Gr. P. at 2700 ft on SE. shoulder of Godaborgarfjall,  $4\frac{1}{2}$  miles NW. of the head of Fáskrúdsfjörður. Assoc: *ch, th, ph*.
- G. 39 In Gr. P. at 2000 ft in corrie W. of Lambadalstindur, 6 miles W. of the head of Fáskrúdsfjörður. Assoc: *me, ch, an, ph*.
- G. 40 (p. 825) In Gr. P. on N. face Háöxl, near summit, S. of head of Fáskrúdsfjörður. Assoc: *ch, th, ph, ga*.
- G. 41 (p. 271) In Gr. P. at 2500 ft on S. side of Grjóthólatindur, N. of the entrance to Berufjörður. Assoc: *ch, me, th, he, gy*.