

*Chabazite and associated minerals from County
Antrim.*¹

(With Plates XI–XIV.)

By G. F. HERBERT SMITH, M.A., D.Sc., F.G.S.

Assistant in the Mineral Department of the British Museum.

With Topographical Notes by F. N. ASHCROFT,² M.A., F.G.S., and
Chemical Analyses by G. T. PRIOR, M.A., D.Sc., F.R.S., Keeper of
Minerals, British Museum.

[Read June 7, 1910, March 12, 1912, March 17, 1914.³]

TABLE OF CONTENTS.

- I. Introduction.
- II. Topography (F. N. A.).
 - 1. White Head, in the Barony of Lower Belfast.
 - 2. Killyflugh, in the Barony of Lower Toome.
 - 3. Craigahulliar, in the Barony of Carey.
- III. Chabazite (Phacolite, Gmelinite).
 - A. Historical.
 - B. Physical properties.
 - (a) Crystal measurements.
 - (b) Habit.
 - 1. Primitive rhombohedron.
 - 2. Modified rhombohedra.
 - 3. Interpenetrating twinned rhombohedra.

¹ Communicated by permission of the Trustees of the British Museum.

² Formerly F. N. A. Fleischmann.

³ The following were the papers read before the Society: 'On zeolites from the neighbourhood of Belfast,' by F. N. A. Fleischmann, January 21, 1908; 'Phacolite from near Belfast,' by G. F. Herbert Smith, June 7, 1910; 'On the zeolites from Killyflugh and White Head, County Antrim,' by G. F. Herbert Smith and F. N. A. Fleischmann, March 12, 1912; 'On gmelinite and chabazite from Co. Antrim,' by G. T. Prior, March 17, 1914.

4. Double twinning about $c(0001)$ and $r(10\bar{1}1)$; oscillatory crystals.
 5. Simple hexagonal.
 6. Twinned hexagonal.
- (c) Cleavage and optical properties.
- C. Chemical composition (G. T. P.).
- D. Position of gmelinite.
- E. Pseudomorphs and alteration products.
- IV. Associated minerals.
- (a) Analcite.
 - (b) Natrolite and Mesolite.
 - (c) Calcite.
- V. Relation between chabazite, analcite, and natrolite.

I. INTRODUCTION.

EIGHT years ago (in 1907) Mr. F. N. Ashcroft, who for many years has devoted much of his leisure to bringing together choice specimens of the species included in the zeolitic group of minerals, turned his attention to the specimens occurring in the cavities of the basalt of Co. Antrim. He was fortunate enough to secure the services of Mr. Robert Bell, of Belfast, in his quest, and between them they have searched many of the quarries and other places likely to yield good specimens of these minerals. Some of the early specimens obtained through Mr. Bell, which, however, did not include any chabazite, were exhibited by Mr. Ashcroft at the anniversary meeting of the Society, on November 12, 1907. Among the specimens collected two years later were some from the Killyflugh quarry displaying well-formed, twinned crystals of phacolite, which Mr. Ashcroft submitted for examination to the Mineral Department of the British Museum. The character of the crystals and the nature of the mineral association proved to be of such interest that ultimately a systematic study of the specimens was undertaken. Nearly every year Mr. Ashcroft collected further specimens, and he has freely permitted the best of his collection to be used for the purpose of the investigation. Afterwards he presented to the Trustees of the British Museum a typical selection of the specimens collected at the localities described in this paper, including those actually examined in detail.

II. TOPOGRAPHY (F. N. A.).

The specimens of chabazite and the minerals associated with it which are dealt with in this paper came from the three following localities, and mainly from the first of them; altogether nearly 200 specimens were examined.

1. *White Head, in the Barony of Lower Belfast.*

The promontory White Head (Plate XI), some 300 feet in height, lies on the northern shore of Belfast Lough at the point where it merges into the Irish Channel. It gives its name to the town Whitehead, a popular seaside resort lying to the north of it, much frequented by residents of Belfast. Specimens were collected from the quarries on both sides of the headland.

(a) *Quarry¹ on the North Side of White Head.*

This quarry (Plate XII) lies at the extremity of the headland just above the coastguard station at the southern end of the town of Whitehead, and forms a conspicuous scar on the north side of the headland. It was first visited by Mr. Ashcroft on November 22, 1907. His attention had shortly before been directed to the locality by Mr. Bell, who had collected and forwarded to him a number of specimens from the quarry, including several remarkable specimens of gmelinite.

The exposure in the quarry is interesting. Both chalk and basalt are exposed on the face, the former rising to a considerable height above the floor of the quarry at each side of the exposure, especially on the right-hand side of the quarry. The usual layer of earthy rubble with flints separates the chalk and the basalt. The lower part of the basalt is hard, compact, and rudely columnar in structure. It yields no zeolitic minerals, but very occasionally contains flakes of metallic copper. Above this is a thick layer of amygdaloidal basalt upon which rests a bed of boulder clay. On a bank below the level of the quarry floor close to the coastguard station there is an exposure of Greensand. It is from this mass of amygdaloidal basalt, which varies considerably in character, and undoubtedly consists of a number of different flows, that the greater part of the material collected is derived. Unfortunately

¹ According to the Home Office List of Quarries for 1913, published in 1914, this quarry is owned by Messrs. G. Gregg & Sons, Strathkeen, Larne.

the amygdaloidal layers are inaccessible; the specimens were collected from fallen boulders, and it is impossible therefore to state with accuracy their exact horizon.

In November 1907 Mr. Ashcroft collected a number of specimens of gmelinite, and in the following April obtained an additional large series of them by breaking up several large boulders, about 6 feet cube in size. The gmelinite occurs in dense, yellow or white crusts lining very irregularly shaped cavities in a highly decomposed basalt which are connected one with another by narrow seams and stringers. They often show signs of corrosion and are frequently associated with hemispherical, often hollow, aggregates composed of more or less altered natrolite¹ mixed with minute gmelinite crystals, or sometimes with analcite, or less commonly with calcite in modified acute rhombohedra. The gmelinite crystals themselves are usually not homogeneous, being clear and transparent in the outer portions, but opaque in contact with the matrix. Subsequently, similar, but more homogeneous crystals were found; analysis No. 2 (p. 297) was made on these. The smaller gmelinite crystals are often almost water-clear. Both twinned (about r , the usual gmelinite law) and simple crystals were met with, the former being by far the commoner. Occasionally two crops of crystals are present on the same specimen, comparatively large crystals lying in a carpet of small ones, and more rarely the crystals have been more or less dissolved and afterwards redeposited in the form of minute gmelinite crystals. The forms present are always f and m , which in small crystals are smooth, but in large ones marked, the former triangularly parallel to the edges with the two adjacent faces of the form and to the horizontal, and the latter horizontally, owing to twinning or to oscillatory growth. Very rarely is the base c present, and in the case of crystals from two specimens it gives reflections corresponding to the faces r and e , which belong to the phacolite habit. Three specimens of considerable interest showed complex crystals, the component individuals of which are connected by the usual gmelinite mode of twinning about r , but themselves belong to the phacolite habit, and display the forms r and e twinned about c .

In addition, a small series of specimens was obtained the matrix of which is distinctly harder and more compact than in the remainder. They

¹ J. Strachan, Proc. Belfast Naturalists' Field Club, 1908, ser. 2, vol. vi, p. 92, records the occurrence of natrolite at Whitehead, but does not specify the quarry.

resemble specimens obtained from the upper flow on the south side of the headland, and no doubt have come from part of the same flow. These specimens show simple and twinned crystals of gmelinite, associated with fibrous masses of natrolite. The material for analysis No. 1 was obtained from them.

A series of specimens were collected from what appears to be an old land-surface close to the chalk on the right-hand side of the quarry. The seams and cavities in the basalt are lined with a crust of tiny trapezohedra of analcite, mixed with small, fibrous clumps of natrolite and associated with opaque, white and yellowish crystals of gmelinite, often lenticular in shape owing to the rounding of the faces of the form f ; a little nodular calcite also was seen.

According to Mr. Bell large radiating masses of natrolite were at one time obtainable in quantity from the upper amygdaloidal basalt, but have long since become scarce.

Among the specimens collected is one (in halves) of natrolite in fairly stout, radiating prisms, a few of which are terminated by faces; it has no matrix. Several groups of very thin radiating needles implanted on a matrix, similar to that in which the corroded gmelinite occurs, were also collected.

(b) *Quarry on the South Side of White Head.*

This quarry (Plate XIII), which has been abandoned for about twenty years, is situated on the south side of the headland immediately above the portal of the tunnel on the Belfast-Larne Railway piercing the headland, and is not far from the quarry just described. On the face of the quarry and the natural cliff above the quarry a large number of basalt flows are exposed, many of which are highly amygdaloidal. They are very irregular, and the thickness of any particular flow varies considerably over different parts of the quarry face. Often the vesicles are very small, and are solidly plugged with zeolitic material. The whole exposure is now in a very disintegrated and dangerous condition, and falls of rock are frequent. A particularly heavy fall, from high up on the face, took place early in 1910, after the photograph reproduced on Plate XIII was taken, and has covered a great part of the floor of the quarry to a considerable height, leaving only a narrow passage between the pile of boulders and the face of the rock.

Mr. Ashcroft first visited the quarry in April 1908, his attention having been drawn to it by Mr. Bell, and he collected a large number of

specimens on that occasion. They were obtained in situ, being extracted by means of crowbars from the bottom flow on the right-hand side of the quarry at the points indicated by the arrows marked *A* and *B* on Plate XIII. The flow is much decomposed, and varies considerably in colour; not infrequently a hand-specimen of the rock may be partly brick-red and partly grey in colour with a distinct line of demarcation between the two portions.

The cavities are irregular in shape and frequently angular, and vary considerably in size; one exposed on the surface, the contents of which were entirely destroyed by weathering, was at least 60 cm. across in one direction. The quarry was visited by Mr. Bell again a little later in the same year, and a similar series of specimens collected. The minerals represented included chabazite, which was found generally white, but occasionally pinkish in colour, both massive and in crystals; in the latter case, usually in the gmelinite habit, both simple and twinned, and less commonly in the form of the fundamental rhombohedron. The extremely interesting specimen showing small gmelinite crystals in correctly corresponding orientation on a comparatively large rhombohedron (fig. 1) discussed below (p. 289), was received by Mr. Ashcroft in June 1908. Chabazite occurred also in the form of pseudomorphs after calcite (p. 300). Analcite, which was found in the usual form of trapezohedra, lined the outside of the pseudomorphs referred to, and, if the latter were hollow, the inside also. Natrolite was present in the usual needle- or blade-shaped crystals springing out from analcite and chabazite.

Some interesting specimens were found by Mr. Ashcroft in 1909. On two specimens the crystals displayed the forms *r*, *e*, *s*, as in the phacolite habit, but were so intimately twinned as to appear hexagonal, as in the gmelinite habit, and each crystal was composed of individuals of this kind connected by twinning about *r*, the typical gmelinite law. In February 1914 a series of specimens were obtained from debris which had fallen from one of the upper flows; from which one is uncertain, although undoubtedly the whole series came from the same flow. The rock is much less decomposed and the cavities fewer and more regular in shape than in the case of the specimens previously collected. This series probably came from the same flow as a series collected on the other side of the headland, as was pointed out above (p. 278). These specimens exhibited gmelinite in very pale pinkish-yellow, usually twinned, crystals, and also massive, associated with a considerable amount of natrolite in sheaf-like groups; no analcite was observed.

2. *Killyflugh, in the Barony of Lower Toome.*

This basalt quarry,¹ which for want of an independent name may be conveniently called Killyflugh quarry, is situated about 700 yards north-east of the farm of Killyflugh in the townland of that name, some two miles to the north of the town of Ballymena. It is best reached from this town, by following the main road to Cushendall as far as the point, about 280 yards short of Crowdy Knowe farm and of the second milestone, where two roads branch off, the one north-north-west leading indirectly to Clogh Mills, and the other north-west; some 370 yards down the latter on the right-hand side of the road a small farm-house is reached, and immediately behind, i. e. to the north of it, lies the quarry in question.

The rock-face, as is clearly shown in the photograph reproduced in Plate XIV, fig. 2, consists of hard, compact basalt, which as yet has yielded no cavities containing zeolitic minerals. This flow rests on another consisting of a much decomposed and in parts highly porous basalt, from which the minerals collected were obtained. The contact between the two flows, which is usually invisible, is irregular, but approximately level with the floor of the quarry. Fresh material is consequently sometimes rather difficult to obtain, except when, owing to blasting operations in the lowest part of the rock-face, a hole some few feet in depth has been made exposing the lower flow, or where, as happens here and there, the contact between the two flows rises a few feet above the level of the floor of the quarry. The minerals found, viz. phacolite, analcite, and occasionally mesolite, occur, as far as can be judged, throughout the flow, but the general aspect of the specimens obtained from different points in the quarry varies considerably.

The first specimens obtained were collected, in July 1908, by Mr. Bell from a hole, due to blasting, in what was then the southern corner of the quarry, which two days later was water-logged and shortly afterwards filled in with waste rubble, and also from a small mound opposite the face of the quarry. At the first point the minerals occur lining or completely filling narrow cracks and angular cavities connected with them. In some specimens the rock in immediate contact with the cavities is practically a breccia, consisting of angular fragments of basalt cemented together by the zeolitic minerals. When freely developed,

¹ According to the Home Office List of Quarries for 1913, published in 1914, this quarry is owned by Mr. S. Herbison, of Killyflugh, by whom it is worked for road-metal.

phacolite occurs in large, pale-yellowish crystals, which are sometimes in groups and sometimes isolated; they are associated with colourless analcite crystals, about 2-3 mm. in diameter, which form a continuous crust between the phacolite crystals, and sometimes with fine hairs of mesolite, and more rarely with a little calcite. It was from this point that the material used in the chemical analysis, No. 5 (p. 297), came. On the other hand, the phacolite crystals obtained from the mound, a low grass-grown hummock, were colourless to greyish in tint, and rather similar to, though not so large or so regularly developed as, those found later; they were associated with mesolite, and occurred in irregularly shaped cavities in a much weathered and extremely friable basalt.

On June 8, 1909, Mr. Ashcroft and Mr. Bell collected a large number of specimens from a hole, made by a blast the previous day, which was situated approximately at the foot of the centre of the rock-face. Here much of the rock was extremely porous, and the cavities were often large and very irregular in shape. Phacolite occurred in great quantity in large, greyish crystals scattered singly or in groups all over the walls of the cavities together with minute (about 1 mm. in diameter) isolated crystals of analcite. The walls of the cavities were coated with a very thin, whitish film of kaolin, on which the crystals of phacolite and analcite were superimposed. The crystals of phacolite were remarkable not only for their size and complexity of form (p. 291), but for the fact that only the thin outer shell consists of pure phacolite; internally they are choked with filaments and fragments of the matrix.

The same type of phacolite crystal was collected on many subsequent visits at various points of the quarry. Unfortunately the rock is much decomposed, and the specimens are very liable to crumble away on keeping.

From deep down in the hole just mentioned, about 4 feet below the level of the floor of the quarry, several specimens of a somewhat different type were collected. The matrix, which is rather harder, is studded with small, colourless crystals of phacolite of a simpler habit (p. 290); it also is coated with a thin film of kaolin, which, however, is yellowish in colour. This type, however, could not be seen in situ because of the mass of rubble in the hole.

Early in 1912 Mr. Bell excavated at the foot of another grass-grown mound opposite the centre of the quarry-face, and obtained, in addition to a number of specimens showing phacolite in large, grey crystals, a few

specimens in which the matrix was comparatively hard and solid, and the surface of the cavities was coated with a thin, yellowish film of kaolin studded with large, isolated crystals and groups of phacolite of a deep-yellow colour, together with small, colourless crystals of analcite.

3. *Craigahulliar, in the Barony of Carey.*

Some zeolitic minerals were found in the cutting (Plate XIV, fig. 1),¹ constructed a few years ago to carry the truck line to connect the quarry² on Craigahulliar, a small cliff the face of which is practically entirely occupied by the quarry, with the main road between Portrush and Bushmills. The cutting was made subsequent to the six-inch Ordnance Survey, and consequently does not appear on the map of the district. The truck line joins the main road mentioned about $1\frac{3}{4}$ miles from Portrush, and the entrance to the cutting lies about a third of a mile down the line. The greater part of the cutting, which is about 200 yards long, is situated in the townland of Cloughorr, but a small portion at the southern end is in the townland of Craigahulliar. The boundary between the two townlands runs along the north side of the road between Upper Burnside and Lower Ballymagarry, which crosses the cutting by a bridge a few yards from the southern end.

The cutting was visited by Mr. Ashcroft first on July 19, 1912, and again in May 1913. Along the sides a number of distinct flows, dipping to the south, were well exposed in 1912, but less so in 1913, by which date the sides were fast becoming covered with loose earth and rubble, and in parts overgrown. In one of these flows, consisting of much-decomposed basalt, which is exposed about 20 to 30 yards north of the bridge, phacolite occurs in quantity; but good specimens were rather difficult to obtain owing to the rapid weathering of the surface and the refusal of the Company to allow the banks of the cutting to be interfered with. The crystals were white or yellowish in tint, and often large in size; they were sometimes associated with calcite. A considerable number of the specimens collected were obtained from the sides of a low embankment, about two or three feet high, which carries the truck line

¹ Mr. Robert Bell, the collector, may be seen standing in the cutting.

² According to the Home Office List of Quarries for 1913, published in 1914, this quarry is owned by the Giant's Causeway Columnar Basalt Co., Portrush. The basalt of the quarry, part of which is finely columnar in structure, belongs to the Upper, while that exposed in the cutting belongs to the Lower Basalt Series. At the base of the rock-face and again just above an old iron-mine adit, a few yards to the east of the quarry, a bed of lignite is visible.

between the cutting and the quarry, and from a small dump. There can, however, be no question that this material originally came from the flow mentioned above.

III. CHABAZITE (PHACOLITE, GMELINITE).

A. *Historical.*

The name adopted for this mineral group is due to Bose d'Antic, who gave the name *chabazie*, of somewhat fantastic origin,¹ to the crystals from Oberstein, but it was Haüy² who definitely separated chabazite from analcite by showing³ that what had been taken for cubes were really rhombohedra with interfacial angle of $86^{\circ} 12'$.³ Subsequently, in consequence of differences in crystalline form or in physical characters, additional names were proposed for minerals of similar chemical composition, such as phacolite,⁴ herschelite,⁵ gmelinite,⁶ and levyne.⁷ Among the older writers of mineralogy, Tamnau⁸ considered these minerals to be one species; Breithaupt⁹ included phacolite, gmelinite, and levyne as species of the genus chabazite; while Hausmann¹⁰ merged them together as a single species. Rose,¹¹ on the other hand, left phacolite with chabazite, but separated gmelinite and levyne from it on account of the difference in cleavage and crystalline form. Streng,¹² however, in his elaborate memoir on chabazite argued that gmelinite and levyne were merely varieties of it, because no distinction could be drawn between them in respect of chemical composition, and because the fundamental forms were very simply related to one another. Coming to more recent

¹ 'tiré d'un mot grec, qui désignoit une certaine espèce de pierre,' Journ. d'Hist. nat., 1788, vol. ii, p. 181.

² R. J. Haüy, 'Traité de Minéralogie,' 1801, vol. iii, p. 176.

³ This angle was determined by means of the contact-goniometer, and differs by about a degree from the accepted value, viz. $85^{\circ} 14'$, which was given by W. Phillips in his 'Mineralogy,' 3rd edition, 1823, p. 188.

⁴ A. Breithaupt, Neues Jahrb. Min., 1836, pp. 653, 657.

⁵ A. Lévy, Ann. Phil., 1825, new ser., vol. x, p. 861.

⁶ D. Brewster, Edinburgh Journ. Sci., 1825, vol. ii, p. 262.

⁷ D. Brewster, *ibid.*, p. 332.

⁸ F. Tamnau, Neues Jahrb. Min., 1836, p. 658.

⁹ A. Breithaupt, 'Vollständiges Handbuch der Mineralogie,' 1847, vol. iii, p. 416.

¹⁰ J. F. L. Hausmann, 'Handbuch der Mineralogie,' 1847, pp. 780, 1600.

¹¹ G. Rose, 'Krystallo-chem. Mineralsystem,' 1852, pp. 97, 99, 102.

¹² A. Streng, 'Ber. Oberhess. Ges. Nat.-Heilkunde, 1877, pp. 74-123.

times we find that Dana in the sixth edition of his 'System of Mineralogy,' published in 1892, follows Rose, and under gmelinite remarks 'notwithstanding the close relation of the two species [gmelinite and chabazite] it is most unnatural to merge them in one.' In the second and third editions, published respectively in 1844 and 1850, he had adopted the views of Tamnau as to the identity of these supposedly different species, but in the fourth, published in 1854, and subsequent editions he made gmelinite and levyne distinct species. Hintze¹ likewise places phacolite with chabazite and ranks gmelinite and levyne as sub-species.

B. *Physical Properties.*

(a) *Crystal Measurements.*

The present investigation has tended to confirm Tamnau's conclusion that gmelinite is but a variety of chabazite and not a distinct species; no crystals corresponding to levyne were met with. The name chabazite is therefore applied to the whole group, and it is convenient to retain the term gmelinite for the apparently hexagonal crystals, and to use the term phacolite in a somewhat widened sense for all the crystals, invariably twinned, of rhombohedral habit, and not merely for those lenticular in shape. The unit rhombohedron adopted in this paper is r , the primary rhombohedron of phacolite. Goldschmidt² selected as unit the rare rhombohedron form t , without, however, any general simplification of the indices of the faces.

In the following table are included the well-defined forms that were observed; four of them occurred on phacolite and three on gmelinite.

Table I—Principal Observed Forms.

Phacolite r (10 $\bar{1}$ 1) The most prominent form on phacolite and the plane of twinning for gmelinite; the plane of cleavage on phacolite. Faces usually striated owing to the mutual interference during growth of the component individuals of a twinned crystal.

¹ C. Hintze, 'Handbuch der Mineralogie,' 1897, vol. ii, pp. 1769-1792.

² V. Goldschmidt, 'Krystallographische Winkeltabellen,' 1897, p. 91. The forms of gmelinite are included under chabazite (cf. p. 406). See also 'Atlas der Krystallformen,' 1913, vol. ii, p. 125.

- Phacolite *e* (0112) A common form, but generally relatively small. Smooth or slightly striated, and gave usually distinct reflections.
- „ *s* (0221) Not so common as the preceding. Small, but smooth, and gave good reflections; sometimes showed multiple images.
- „ *a* (1120) Small, and rather rare.
- Gmelinite *f* (2023) The characteristic form of gmelinite. Faces smooth on small crystals; otherwise triangularly marked parallel to the edges bounding them.
- „ *m* (1010) Not so persistent as the preceding and varied considerably in relative size. Faces usually striated horizontally. The plane of cleavage on gmelinite.
- „ *c* (0001) Rare. The plane of twinning of phacolite. Reflections indistinct, and sometimes correspond to faces of the forms *r* and *e*.

In the case of the interpenetrating twinned crystals of phacolite the zones connecting the faces of the form *r* (1011) were considerably striated. Usually numberless images corresponding to vicinal faces were grouped so close together as to afford in the field of the goniometer an almost continuous band over a considerable arc. Brighter images testified to the tendency to the formation of certain definite faces, such as *y* (7189), χ (5167), θ (4156), ϕ (3145), *z* (5279), *o* (2134), and *t* (1123), the most prominent being θ and ϕ . Sometimes the rhombohedron face was replaced almost entirely by these subsidiary faces (cf. figs. 2 and 3).

None of the crystals examined was developed in such a way as to afford really trustworthy measurements of the angular co-ordinates, and implicit reliance cannot be placed on the values obtained. Most of the crystals were rather too large for convenient manipulation on the goniometer, and the faces of any crystals of such sizes are invariably more or less distorted. But even on the tiny, water-clear crystals of gmelinite from the quarry on the north side of White Head the faces generally gave rise to more than one image, and it was impossible to decide which was the best reading. Evidently under the present conditions the crystals have been subject to considerable strain, and their rigidity has

not been sufficient to enable them to withstand it. The pole of symmetry c (0001) was taken as the origin of measurements. The face itself occurred on very few crystals, and even in such cases the reflection given was far too diffuse and dull to be used. The pole had therefore always to be determined indirectly. Generally there were alternate methods of doing so. Thus, supposing the form r were utilized, the position of the pole of symmetry might be determined as the position which gave identical polar distances of three faces of the form, or the zone [$crsm$] might be adjusted so that its edge was parallel to the axis C of the three-circle goniometer, and the pole in question found from the readings for the faces of the forms r on different individuals of the composite crystal. Again, the prism-zone, if sufficiently well developed, might be used, but this rarely happened. The form m (10 $\bar{1}$ 0) was better developed, and occurred oftener than a (11 $\bar{2}$ 0), but it was always striated horizontally—precisely the wrong direction for the purpose in view—so much so, that the zone could not be adjusted with any approach to certainty. In the case of the twinned crystals, however the pole may have been determined, the observations on the crystal were invariably discordant—an indication of distortion. For instance, faces which should theoretically have been in some particular zone lay a degree or two away from it; this peculiarity was very noticeable in the case of the twinned crystals of phacolite. The angular co-ordinates of the faces of any form differed considerably, even on the same crystal, and the polar distances observed for e (01 $\bar{1}$ 2) and s (02 $\bar{2}$ 1) often differed markedly from the values deduced by calculation from the polar distance measured in the case of r .

The obvious question suggested itself—was the difference in habit between phacolite and gmelinite accompanied by a marked change in the fundamental angle? A review of the measurements of crystals from the quarries at White Head—since gmelinite was only met with at this locality—revealed no signs of an alteration in the angle. Thus, in the case of phacolite it varied from 50° 53' to 52° 2', and in the case of gmelinite from 51° 1' to 52° 10'. Taking into consideration the comparatively untrustworthy nature of the measurements, the range in each instance was the same. In the case, however, of a small, simple, glassy crystal of gmelinite from the quarry on the north side, which yielded unusually definite reflections, the following values were observed for the polar distance of f : 39° 57', 40° 11', 40° 13', 40° 13', 40° 15', 40° 16'; the mean value is 40° 11', and the corresponding value of cr 51° 43'. Another crystal—an extremely tiny one—from the same

quarry was set up by means of the prism-faces, and the following values observed for the polar distance of f : $40^{\circ} 4'$, $40^{\circ} 6'$, $40^{\circ} 7'$, $40^{\circ} 8'$, $40^{\circ} 39'$; mean value $40^{\circ} 13'$, cr calculated $51^{\circ} 45'$. It is possible, therefore, that the fundamental angle is slightly larger for the gmelinite than for the phacolite type of crystal. The six best crystals measured from Killyflugh gave the following values for cr : $50^{\circ} 45'$, $50^{\circ} 59'$, $51^{\circ} 3'$, $51^{\circ} 8'$, $51^{\circ} 4'$, $51^{\circ} 20'$, and the corresponding values for the three best crystals from Craigahulliar were $50^{\circ} 35'$, $50^{\circ} 44'$, $51^{\circ} 10'$. If we take the mean of the fundamental angles determined for the best crystals measured, thirty in number, we obtain the value of $51^{\circ} 27'$, which agrees closely with the accepted value ($51^{\circ} 26'$) for chabazite calculated from the rhombohedral angle $85^{\circ} 14'$ ($94^{\circ} 46'$) given by Phillips.¹ The fundamental angle, cf , of gmelinite to be found in present-day textbooks is that given by Pirsson² for crystals from Nova Scotia, viz. $40^{\circ} 18'$, the corresponding angle cr being $51^{\circ} 50'$. Des Cloizeaux³ obtained almost identical values for chabazite and gmelinite, viz. $51^{\circ} 26'$ and $51^{\circ} 29'$ (cf $39^{\circ} 57'$), respectively.

In the following table are given the angular co-ordinates of the principal observed forms calculated from the fundamental angle $cr = 51^{\circ} 26'$.

Table II—Angular Co-ordinates of the Principal Forms.

($a : c = 1 : 1.0860$.)

	ϕ	ρ
$-e$ (0112)	$0^{\circ} 0'$	$32^{\circ} 5'$
$-f$ (0223)	0 0	39 54
r (1011)	0 0	51 26
$-s$ (0221)	0 0	68 16
m (1010)	0 0	90 0
y (7189)	6 35	46 27
χ (5167)	8 57	44 55
θ (4156)	10 53	43 $45\frac{1}{2}$
ϕ (3145)	13 54	42 7
z (5279)	16 6	41 $1\frac{1}{2}$
o (2134)	19 7	39 39
t (1123)	30 0	35 54
a (1120)	30 0	90 0

¹ W. Phillips, 'Mineralogy,' 3rd edition, 1823, p. 138.

² L. V. Pirsson, Amer. Journ. Sci., 1891, vol. xlii, p. 57.

³ A. Des Cloizeaux, 'Manuel de Minéralogie,' 1862, vol. i, pp. 408, 397.

The values observed for e and s differed noticeably from those given above. Thus, in the former instance the mean values observed for the best crystals were $31^{\circ} 50'$, $32^{\circ} 10'$, $32^{\circ} 20'$, $32^{\circ} 20'$, $32^{\circ} 21'$, $32^{\circ} 28'$, $32^{\circ} 30'$, $32^{\circ} 34'$, $33^{\circ} 8'$; the mean value, $32^{\circ} 25\frac{1}{2}'$, is too high, and, indeed, in only one case was the observed mean below the calculated value given in the table. In the latter instance, the corresponding values were $67^{\circ} 12'$, $67^{\circ} 14'$, $67^{\circ} 14'$, $67^{\circ} 17'$, $67^{\circ} 28'$, $67^{\circ} 33'$, $67^{\circ} 43'$, $67^{\circ} 46'$, $67^{\circ} 46'$; the mean value $67^{\circ} 28'$ is too low, and none of the observed means was above the calculated value. The following table includes examples of measurements made in the striated zones:

Table III—Observations made in Striated Zones.

ϕ	ρ	ϕ	ρ	ϕ	ρ
2° 54'	49° 7'	10° 47'	43° 58'	15° 31'	42° 0'
2 57	49 10	10 57	44 4	15 43	41 23
3 45	54 47	11 7	44 5	15 58	41 20
4 1	49 3	11 20	43 50	15 58	41 22
4 5	39 37	11 22	43 39	17 2	39 37
4 59	48 10	11 22	44 0	17 30	41 49
5 0	47 35	11 35	43 45	17 52	38 15
5 14	47 32	11 40	43 16	18 35	40 35
5 25	47 31	11 43	43 0	18 36	40 9
5 37	47 30	11 45	44 11	19 3	39 57
5 53	47 0	11 48	43 30	19 27	39 50
5 53	48 12	12 23	43 6	19 58	43 1
6 16	46 58	12 29	43 50	20 30	39 40
6 34	46 41	13 7	42 45	21 25	36 20
7 5	46 30	13 30	42 50	24 20	33 0
7 7	44 38	13 49	42 21	25 37	37 39
7 25	45 45	13 52	42 40	26 25	36 10
7 37	45 56	13 59	42 40	26 40	37 37
7 40	46 1	14 17	42 30	30 0	35 45
7 47	45 56	14 22	42 19	30 0	36 0
7 50	45 10	14 30	42 0	30 0	36 6
8 30	45 13	14 38	41 0	30 0	36 25
9 3	45 0	14 40	42 22	30 0	36 45
10 13	43 37	14 57	41 45	30 0	36 48
10 28	43 55	15 22	41 58	30 0	36 55
10 35	44 25	15 30	42 50		

Occasionally vicinal faces near e were observed.

(b) *Habit.*

In discussing the various types of habit of the crystals it is convenient to divide them into the following groups, but it must be understood that each grades into the next and no sharp distinction can be drawn between them.

1. *Primitive Rhombohedron.*

Crystals characterized by the unmodified rhombohedron were very rare, and only five specimens containing such crystals were seen; all of them were collected at the quarry on the south side of White Head in the year 1908. The crystals, which are always twinned about c , are mostly small, under 1 mm. across, and their faces are comparatively smooth and entirely free from striations.

The crystal illustrated in fig. 1 is particularly interesting. It consists mainly of a rhombohedron of chabazite, measuring about 2.5 mm. in length with two smaller ones intersecting it in twin position, the faces of which are coated with tiny crystals of gmelinite arranged in parallel position and correctly orientated with respect to it. The number of

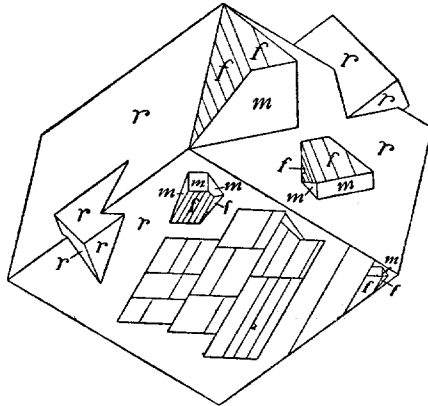


FIG. 1.—Chabazite rhombohedron twinned about c , with Gmelinite in parallel position. From the bottom basalt flow in the quarry on the south side of White Head.

gmelinite crystals was far larger than could conveniently be shown in the drawing. Part of one face, as may be seen from the figure, is largely covered with an intergrown mass of gmelinite which gave reflections corresponding to the forms f ($02\bar{2}3$) and m ($10\bar{1}0$). The mean value of the values of the polar distance determined for the faces r was $51^{\circ} 15'$, and for f $40^{\circ} 1'$. The value for cf calculated from $cr = 51^{\circ} 15'$ is $39^{\circ} 48'$, which is in satisfactory agreement with that observed, considering the comparatively rough character of the measurements. No other crystal of the kind was noticed. A similar crystal from Ireland, the precise locality not being stated, was described and figured by Brooke.¹ The polar distances

¹ H. J. Brooke, *Phil. Mag.*, 1837, vol. x, p. 278.

calculated from the angles given by him are for r $51^{\circ} 26'$ and for f $40^{\circ} 0'$, which are close to those stated above.

2. *Modified Rhombohedra.*

This type lies intermediately between Nos. 1 and 3. Six edges of the primitive rhombohedron are bevelled by faces of the form e (0112), and

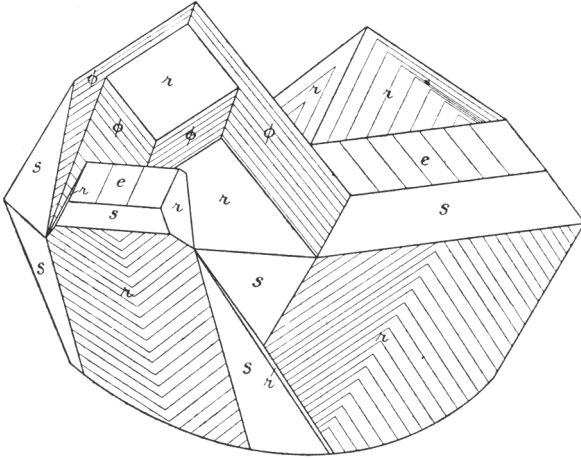


FIG. 8.—Chabazite, rich in forms, twinned about c . From Killyflugh.

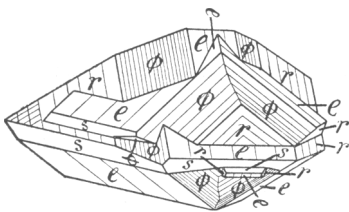


FIG. 2.—Modified rhombohedra from Killyflugh.

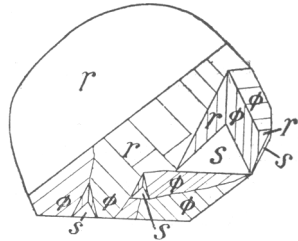


FIG. 4.—Twinned crystal from Craigahulliar.

the form s (02 $\bar{2}$ 1) is often present. The crystals are invariably twinned about c , and the component individuals are to some extent interpenetrant; but not so completely so as in the next type.

This type was very abundant, especially at Killyflugh. At this locality the crystals are small, about 1–2 mm. across, and somewhat yellowish in

tint. The faces e (fig. 2), which are relatively prominent, are slightly striated; those of r considerably striated parallel to the respective intersections with the contiguous faces e , i. e. in zones $[rer]$ and often distorted; while the faces s , which are small, are comparatively smooth. Often the distortion of the faces r has been so great as to lead to their partial replacement by faces such as ϕ (3145). Fig. 3 represents a crystal of this kind from Killyflugh. Others of this type were found at Craighulliar. One of them, which is shown in fig. 4, is interesting because it illustrates so clearly the disturbing effect on the development of the faces r caused by the emergence of a twin individual; where there is no emergence the face is comparatively smooth and free from striations, but the emergence of a twin individual causes a humping round the spot and considerable oscillation spreading from it.

A few crystals of this intermediate type were also met with at the quarry on the south side of White Head.

3. *Interpenetrating Twinned Rhombohedra.*

This, the true phacolite habit, is extremely common, and innumerable crystals of the type shown in fig. 5 were met with. They are comparatively large in size, measuring usually about 10–15 mm. in diameter. The principal occurrence was at Killyflugh, where characteristic crystals were found in great abundance. As was pointed out above (p. 281), they are remarkable for the fact that the whole of the interior is composed of fragments of basalt, only the outer shell, which is extremely thin, consisting of pure phacolite. The habit of the crystals is usually of the kind illustrated in fig. 5 (p. 292). The larger individuals composing the crystal are mutually bounded by planes parallel to the base and to faces of the form m (1010), but each individual is pierced by a varying number of smaller individuals orientated in twin position with respect to it. Occasionally the interpenetration is so intimate and regular that the development becomes pseudo-hexagonal in character. The gnomonic projection of the light-figures formed by the reflection of a pin-hole on the goniometer is depicted in fig. 6. Two bands of light intersect in each pole, representing a face of the form r (1011). In one direction each band soon comes to an end, but in the other it wanes and brightens here and there, particularly in the position corresponding to ϕ (3145), and finally disappears. A little farther on we come to a band extending on either side of the pole e (0112). The phenomenon just seen is repeated on the other side. As was remarked on p. 285, other forms in this

striated zone, such as y (7189), χ (5167), θ (4156), z (5279), σ (2134), and t (1123), were also observed. The reflections given by the faces of the form s (0221), though never absolutely distinct, were only slightly banded, at right angles to the zone $[cs]$. The faces of the principal rhombohedron are invariably striated parallel to the rhombohedron edge, and oscillation, which is undoubtedly stimulated, if not directly caused, by twinning, is always present to a greater or less degree. The prism-faces, which are not common, are small, but comparatively smooth.

Crystals of somewhat similar habit, but rather less translucent, and without the basalt kernel, occurred in the quarry on the north side of

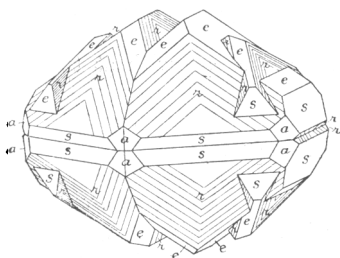


FIG. 5.—Phacolite, twinned about c , from Killyflugh.

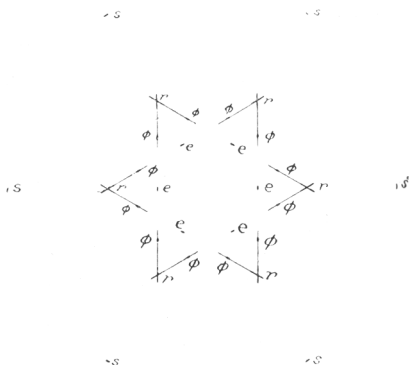


FIG. 6.—Gnomonic projection of Light-figures of Phacolite from Killyflugh.

White Head, and at Craighulliar; at the latter locality they pertained more to the intermediate type described above. No crystals of the phacolite habit were found on specimens from the quarry on the south side of White Head.

4. *Double Twinning about c (0001) and r (10 $\bar{1}$ 1); Oscillatory Crystals.*

On two specimens, of which the one came from the quarry on the north, and the other from that on the south side of White Head, remarkable crystals were observed which consisted of individuals displaying the characteristic forms of phacolite, viz. r (10 $\bar{1}$ 1), e (0112), and to a smaller degree s (0221), together with the customary twinning about the axis c , but severally united by further twinning about r (10 $\bar{1}$ 1), which is the characteristic mode of gmelinite. A crystal of this kind

from the quarry on the north side is depicted in fig. 7. Each of the two individuals shown is twinned about its own axis c , the subsidiary individuals being intimately interpenetrant, while they are mutually connected by twinning about those faces of the form r ($10\bar{1}1$) which are contiguous in the figure; the two faces are parallel. The faces of both the forms r and e are heavily striated parallel to the respective rhombo-

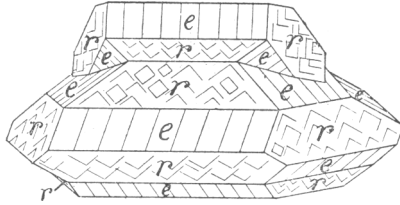


FIG. 7.—Two individuals related by twinning about r , each being twinned about c . From the north side of White Head.

hedron edges, and some oscillation between the faces of the two forms occurs. On the crystal represented other individuals were observed which were related to the lower one by twinning about other faces of

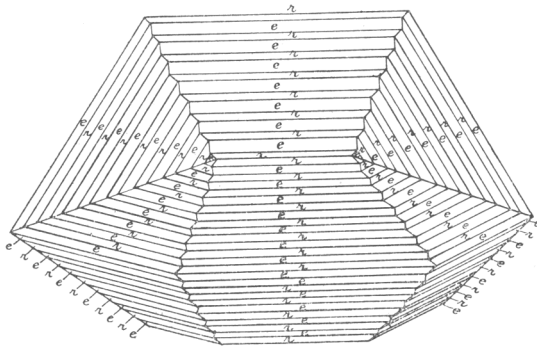


FIG. 8.—Two individuals related by twinning about r , each showing oscillatory twinning about c . From the north side of White Head.

the form r , but, in order to avoid confusing the drawing, they have not been shown. Fig. 8 represents another crystal from the same locality. In this case the twinning about the axis c in each individual is so oscillatory that each face is ribbed in character, and the development simulates hexagonal symmetry. If, in accordance with Haüy's theory of the formation of secondary faces, we imagined the steps to diminish in

size until they become comparable with molecular dimensions, we should expect the resulting crystal to be apparently hexagonal in symmetry, and to have the faces of the form intermediate between r (10 $\bar{1}$ 1) and e (10 $\bar{1}$ 2), which is f (20 $\bar{2}$ 3), the characteristic form of gmelinite. The type here described may therefore be considered as transitional between phacolite and gmelinite, having the forms and modes of twinning characteristic of both.

The crystals off the specimen from the quarry on the south side are a little different, though of the same character. At first sight they might be supposed to be ordinary hexagonal crystals with six prism-faces and corresponding pyramid-faces above and below; but, on examining them, it was seen that the prism-faces are really oscillatory combinations of the forms r (10 $\bar{1}$ 1) and s (02 $\bar{2}$ 1), while the pyramid-faces belong to the form r , and the several individuals are connected by twinning about the faces of this same form. There is the same intimate twinning about the axis c , but the plane of combination seems to be parallel to r instead of to the base as previously. If again we imagined the steps diminished in size until commensurable with molecular dimensions, the reciprocation of the forms r (10 $\bar{1}$ 1) and r (10 $\bar{1}$ 1) leads to the prism-form m (10 $\bar{1}$ 0), and we should anticipate the resulting face to be striated horizontally: this, we shall see below, is the case with gmelinite.

5. *Simple Hexagonal.*

In this—the typical gmelinite—habit the crystals are characterized by a hexagonal prism-form m (10 $\bar{1}$ 0) and six pyramid-faces of the form f (20 $\bar{2}$ 3) above and six below. The latter faces are usually smooth, but are occasionally triangularly marked parallel to their edges. The prism-faces are always striated horizontally.

A large number of such crystals, associated with analcite and natrolite, were found on specimens from the quarry on the south side of White Head. They were usually white, but occasionally pink in colour, and were sometimes corroded. Similar crystals came from the quarry on the north side. On some crystals the prism-faces were relatively unusually large. Some interesting crystals were found on one specimen. They apparently displayed, in addition to the usual forms f (20 $\bar{2}$ 3) and m (10 $\bar{1}$ 0), the basal plane; but examination on the goniometer showed that the reflections from it corresponded to the forms r (10 $\bar{1}$ 1) and e (01 $\bar{1}$ 2). The specimens from the old land-surface contained a number of small, opaque, simple crystals.

6. *Twinned Hexagonal.*

The last group of all is composed of the *gmelinite* type of crystal twinned about the primitive rhombohedron of chabazite. Twinning of this mode is exceedingly common on the crystals occurring on the specimens from the quarries on both sides of White Head.

Since, corresponding to each individual of a twin, there are two sets of three poles r , or six altogether, there may be this number of individuals arranged in twin position with respect to it, and there may further be twinning about the poles of the second set of individuals; repeated twinning of this kind is common, and consequently the crystals met with are most complex in character. Fig. 9 represents a crystal of

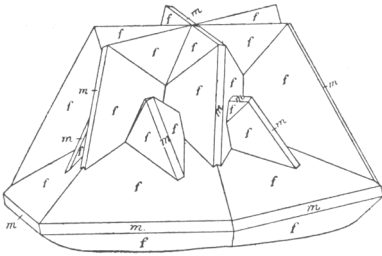


FIG. 9.—Gmelinite (forms fm) twinned about r . From the south side of White Head.

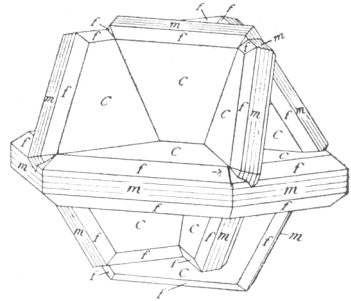


FIG. 10.—Gmelinite (forms cm) twinned about r . From the north side of White Head.

a specimen from the quarry on the south side of White Head. Two sets of twin individuals are shown, the smaller set emerging at the angles between the larger set. The actual crystal showed in addition still smaller individuals in positions corresponding to repeated twinning, but, in order not to cause hopeless confusion in the drawing, they were not inserted. Fig. 10 represents a slightly different crystal which was taken from a specimen from the quarry on the north side. It is noteworthy for the remarkable development of the basal plane in each individual. One set of twin individuals only is shown in the drawing; the companion set occurred on the crystal, but they were very subordinate in size, and any attempt to include them would have unduly complicated the drawing.

(c) *Cleavage and Optical Properties.*

Crystals of the phacolite or rhombohedral type show a distinct cleavage parallel to the faces of the primitive rhombohedron r (10 $\bar{1}$ 1) and another rather less distinct parallel to the prism m (10 $\bar{1}$ 0). The latter cleavage alone, although somewhat more distinctly, is shown by crystals of the gmelinite or pseudo-hexagonal type.

In no instance was the development of the crystals such as to permit of accurate determination of the refractive indices. The double refraction in the phacolite type is very small, probably not more than one or two units in the fourth place of decimals; in the gmelinite type, however, it appears to be a little higher. Measurements with a small refractometer were made on a face polished on a crystal of the phacolite type, and the value 1.490 was obtained for sodium-light; no sign of doubling of the shadow-edge, indicative of double refraction, was observable. In the case of a crystal of the gmelinite type treated in the same way some doubling was discernible, and the extraordinary and ordinary indices of refraction were determined to be 1.480 and 1.490, the double refraction being negative in character.

C. *Chemical Composition* (G. T. P.).

Chemical analyses were made on exceptionally pure crystalline material picked out by Mr. Ashcroft from three occurrences of gmelinite and two of phacolite, viz.:

(1) Gmelinite: colourless crystals from one of the flows above the columnar basalt in the quarry on the north side of White Head.

The rock is an olivine-basalt of somewhat doleritic habit. Olivine is the only porphyritic constituent. The phenocrysts have good crystal outlines, but are all altered, as are also the olivine grains in the matrix, to green and deep-red decomposition products. The felspar is in laths and is partially altered to epidote. The augite, which is of a pale-purplish titaniferous variety, occurs in ophitic patches enclosing and penetrated by the felspar laths.

(2) Gmelinite: yellowish crystals from the quarry on the north side of White Head.

The rock in the cavities of which the crystals occur is much finer grained than No. 1, but is similar in other respects. Olivine is the only porphyritic constituent and is all altered. The phenocrysts occur in

a matrix of needle-like felspar laths, augite grains, altered glass, and skeleton crystals of magnetite.

(3) Gmelinite: very pale pinkish-yellow crystals from one of the upper flows of basalt in the quarry on the south side of White Head.

The rock is practically identical in characters with the basalt (No. 1) on the north side of White Head.

(4) Phacolite: colourless crystals from the cutting on Craigahulliar.

The basalt, which, though slightly finer grained, is otherwise almost precisely similar to Nos. 1 and 3 from White Head, consists of altered porphyritic olivine in a matrix of felspar laths, olivine grains, and ophitic patches of pale-purplish augite.

(5) Phacolite: pale-yellowish crystals from the basalt on the left hand in the southern corner of Killyflugh quarry.

The basalt is somewhat similar to that of White Head (No. 1), but is finer grained and less porphyritic. Olivine is all altered, the felspar is in small laths, and the augite is purplish, but occurs in grains instead of in ophitic patches.

The results of the analyses, which were made on air-dried material, are as follows:

	1.	2.	3.	4.	5.
SiO ₂	46.64	46.75	47.81	48.61	48.82
Al ₂ O ₃	20.04	19.79	19.73	18.06	18.53
CaO	7.00	8.25	5.01	8.19	8.81
SrO	0.22	0.23	0.02	0.60	0.26
K ₂ O	0.63	0.33	0.31	2.13	1.20
Na ₂ O	3.81	2.17	6.13	0.33	0.37
H ₂ O	21.84	22.09	21.56	21.68	22.09
	<hr/>	<hr/>	<hr/>	<hr/>	<hr/>
	100.18	99.61	100.57	99.60	100.08
Sp. Gr.	2.09	2.07	2.06	2.09	2.09

The molecular ratios are as follows:

	1.		2.		3.		4.		5.	
SiO ₂	0.7735	or 3.96	0.7753	or 4.13	0.7929	or 4.13	0.8061	or 4.48	0.8096	or 4.54
Al ₂ O ₃	0.1961	„ 1	0.1936	„ 1.03	0.1930	„ 1	0.1767	„ 0.98	0.1813	„ 1.02
CaO	0.1248	„	0.1471	„	0.0894	„	0.1461	„	0.1571	„
SrO	0.0021	„	0.0022	„	0.0002	„	0.0058	„	0.0025	„
K ₂ O	0.0067	„ 1	0.0035	„ 1	0.0033	„ 1	0.0226	„ 1	0.0127	„ 1
Na ₂ O	0.0615	„	0.0350	„	0.0989	„	0.0053	„	0.0060	„
H ₂ O	1.2132	„ 6.22	1.2271	„ 6.53	1.1977	„ 6.24	1.2043	„ 6.70	1.2271	„ 6.88

The weights used in the analyses were about 1 gram for the main analysis, 0.5 gram for the alkalis, and 0.3 to 0.4 gram for the water determinations. The specific gravities were made on about 1 gram of material by means of a 3 c.c. pycnometer.

The analyses of gmelinite show a predominance of soda over potash as compared with those of phacolite, but this has probably no significance as a distinction of species, since the same predominance is shown by analyses of herschelite and seebachite of which the crystals are of typically phacolite habit.

As regards chemical composition the molecular ratios exhibit the same peculiarities which have been noted particularly in the case of nepheline and analcite. Whereas the ratio of alumina to the combined lime and alkalis conforms closely to equality, that of the silica and of the water to alumina varies considerably and in only one case approaches at all closely to simple ratios.

The formulae deduced from the molecular ratios are as follows :

- (1) $[12\frac{1}{2}\text{CaAl}_2\text{Si}_4\text{O}_{12}\cdot 6\text{H}_2\text{O} + 7\text{Na}_2\text{Al}_2\text{Si}_4\text{O}_{12}\cdot 6\text{H}_2\text{O}] + 4\text{H}_2\text{O}$
- (2) $[15 \quad \quad \quad + 4 \quad \quad \quad] + 1\frac{1}{2}\text{SiO}_2 + 9\text{H}_2\text{O}$
- (3) $[9 \quad \quad \quad + 10 \quad \quad \quad] + 3\text{SiO}_2 + 6\text{H}_2\text{O}$
- (4) $[15 \quad \quad \quad + 3\text{K}_2\text{Al}_2\text{Si}_4\text{O}_{12}\cdot 6\text{H}_2\text{O}] + 8\text{SiO}_2 + 12\text{H}_2\text{O}$
- (5) $[16 \quad \quad \quad + 2 \quad \quad \quad] + 9\text{SiO}_2 + 15\text{H}_2\text{O}$

The gmelinites agree more closely than the phacolites with the usually accepted formula $(\text{Ca}, \text{K}, \text{Na})_2 \text{Al}_2\text{Si}_4\text{O}_{12}\cdot 6\text{H}_2\text{O}$, but in all the analyses, except No. 1, there is an excess, which becomes considerable in the case of the phacolites, of silica and water over that required by the formula. The similar behaviour of nepheline and analcite in this respect has been discussed more especially by H. W. Foote and W. M. Bradley.¹ They regard the excess of silica in the case of nepheline, and of silica and water in the case of analcite, as present in solid solution and prefer to leave open the question as to what form the excess takes. In the case of nepheline, W. T. Schaller² and N. L. Bowen³ suggest that the excess takes the form of the albite molecule $\text{NaAlSi}_3\text{O}_8$. Previously, in order to explain the excess in the case of analcite, F. W. Clarke and

¹ H. W. Foote and W. M. Bradley, *Amer. Journ. Sci.*, 1911, vol. xxxi, p. 25, and 1912, vol. xxxiii, pp. 433 and 439.

² W. T. Schaller, *Journ. Washington Acad. Sci.*, 1911, vol. i, p. 109.

³ N. L. Bowen, *Amer. Journ. Sci.*, 1912, vol. xxxiii, p. 49.

G. Steiger¹ had made the similar proposal that the formula should be written $\text{NaAlX.H}_2\text{O}$, in which X represents $n\text{SiO}_4 + m\text{Si}_2\text{O}_6$.

In the present case a somewhat similar explanation may be doubtfully advanced to account for the excess of silica, viz. that in the atomic arrangement in the crystals the calc-felspar grouping $\text{CaAl}_2\text{Si}_2\text{O}_8$ may form a layer and be partially replaceable not only by the nepheline molecule $\text{Na}_2\text{Al}_2\text{Si}_2\text{O}_8$, but also to some extent by the alkali-felspar grouping $(\text{Na,K})\text{AlSi}_3\text{O}_8$. This might be equivalent to adopting for chabazite the formula $(\text{Ca,Na}_2,\text{K}_2)\text{Al}_2\text{Si}_2\text{O}_8.2\text{H}_2\text{SiO}_3.4\text{H}_2\text{O}$, in which the first part can be partially replaced by $(\text{K,Na})\text{AlSi}_3\text{O}_8$. This formula is similar to the $\text{Na}_2\text{Al}_2\text{Si}_2\text{O}_8.2\text{H}_2\text{SiO}_3$ once proposed by Doelter² for analcite, which was dismissed perhaps somewhat too readily by Clarke and Steiger³ on the ground that there was little splitting off of silica on boiling with sodium carbonate solution.

D. Position of Gmelinite.

The reasons for supposing that gmelinite is a variety of chabazite, and not a distinct species, are of the following character :

1. The values of the axial ratios, whether calculated from the phacolite or the gmelinite type of crystal, are the same within the limits of errors of observation.

2. Gmelinite is evidently rhombohedral and not hexagonal in symmetry, because the twin individuals always occur in sets of three.

3. All types of crystals may be met with between, on the one hand, the simple primitive rhombohedron and, on the other hand, the complexly-twinned pseudo-hexagonal crystals.

4. The chemical composition of gmelinite does not differ materially from that of any other type of chabazite; the principle of isomorphism will account for any difference there may be.

The only contrary argument, which was assumed to be conclusive by Rose and later writers, consists in the difference in cleavage. Too much stress, however, should not be laid upon this. If the gmelinite type arises, as would appear to be the case, from a very intimate oscillatory twinning of the forms $r(10\bar{1}1)$ and $e(01\bar{1}2)$, no surprise need be felt because the cleavage parallel to the primitive rhombohedron is no longer observable, or because the prism-cleavage has become more conspicuous.

¹ F. W. Clarke and G. Steiger, *Amer. Journ. Sci.*, 1899, vol. viii, p. 251.

² C. Doelter, *Neues Jahrb. Min.*, 1890, vol. i, p. 138.

³ F. W. Clarke and G. Steiger, *loc. cit.*

E. Pseudomorphs and Alteration Products.

Among the specimens collected from the bottom flow in the quarry on the south side of White Head are some that exhibited steeply-pyramidal and irregularly-shaped masses which have evidently resulted from the epimorphic coating of other crystals or irregular fragments that had subsequently disappeared. The coat consists in both instances of a thin layer of massive chabazite, which both inside and outside is covered with a dense mass of minute trapezohedra of analcite interwoven with thin, slender needles of natrolite. In at least one case of the pyramidal-shaped mass the interior is completely filled up by analcite and natrolite. The shape of these tapering pseudomorphs suggests that they have originated from the formation of epimorphs on steep scalenohedra of calcite, a suggestion supported by the fact that such crystals have been found in massive chabazite on specimens from Craigahulliar (p. 302). The polar distance from c and azimuth from the zone [cf] in the case of the form Ω , (6. 5. II. 1) characterizing the Craigahulliar crystals are respectively $83^{\circ} 56'$ and $27^{\circ} 0'$, and the angles over the top and of the basal section are therefore $12^{\circ} 8'$ and $54^{\circ} 0'$. Anything approaching accuracy in the measurement of the pseudomorphs with a contact-goniometer is quite out of the question owing to the roughness of the surfaces. The angle over the top appears to be about 15° ; where the pseudomorph was fractured the section is distinct and the measured angle, 55° , is probably fairly accurate. The irregularly-shaped masses, on the other hand, have no doubt at one time coated fragments of basalt, and, in fact, in some instances the basalt kernel is still in position.

The specimens from the same locality which show the small globules of calcite (p. 304) display in addition spiky growths, about 2–5 mm. in length and about 1–2 mm. in diameter at the base, tapering upwards. On examination, these growths are found to be in two parts, viz. a core and a covering sheath. The latter, which is white, is composed of chabazite enclosing a little natrolite, and on it are perched the usual brilliant trapezohedra of analcite. The core, which is stained on the surface a pale greenish-yellow, consists of massive analcite enclosing a heterogeneous mass of minute needles of natrolite.

On many of the specimens from the bottom flow on the south side of White Head in 1908 the layer of chabazite lining the cavities in the basalt betrays obvious signs of corrosion, being partially fretted and eaten away. The first product of the alteration appears to be analcite, which is found in comparatively large crystals (up to about 2 mm.

across). The second product is natrolite, which occurs in the usual prismatic crystals, sometimes feathery at the free ends (cf. p. 302); it is always accompanied by analcite in extremely tiny crystals. The chabazite seems to have been originally of the gmelinite habit.

IV. ASSOCIATED MINERALS.

The minerals associated with chabazite in the cavities and seams in the amygdaloidal basalt are analcite and natrolite in considerable amount, and to a far lesser extent calcite and mesolite.

(a) *Analcite.*

This mineral occurs in typical trapezohedral crystals n (211), which are usually transparent and often water-clear, without trace of colour, and small in size, rarely exceeding a millimetre across, and often quite minute. The crystals exhibit the usual distortions, the faces giving on the goniometer multiple images of the signal, and under the polarizing microscope the crystals showing anomalous double refraction. Discrimination between it and chabazite in small fragments under the microscope is not easy, since the mean refractive indices are nearly the same and there is little difference in the amount of double refraction.

All the localities yielded specimens of analcite. On one interesting specimen from the quarry on the south side of White Head the mineral has the form of extremely thin, hexagonal, colourless plates penetrated by needles of natrolite. Measurement by revolving the spider-line of the upper nicol showed that the angles of the hexagon are not all equal, and the plates are evidently flattened parallel to one of the faces of the form n (211). On another specimen from the same locality, crystals of analcite are piled on one another to form a columnar mass. The specimens from the old land-surface in the quarry on the north side yield mainly analcite. Sometimes there are two crops, isolated crystals lying on a continuous carpet of tiny crystals. At Killyflugh the mineral occurs as a crust of tiny crystals of such perfect transparency that their colour is apparently that of the background. A few crystals of analcite were found on some of the specimens from Craigahulliar.

(b) *Natrolite and Mesolite.*

Natrolite was found in considerable quantity at the quarries on both sides of White Head, but at neither of the other two localities. It occurred in the usual prismatic crystals, with the forms m (110) and o (111). Three types of aggregation were observed.

1. In globular masses. The structure at the centre is almost massive, the component crystals being pressed tightly together, but farther out the several crystals had room for independent growth; the larger the globule the thicker are the component needles.

2. In distinct crystals, springing out from analcite or decomposed chabazite.

3. Often in the case of both the previous modes of occurrence the condition under which crystallization has taken place has changed from the metastable to the labile, and we find the comparatively stout prismatic crystals terminating in a number of feathery branches.

Delicate hair-like crystals of mesolite accompanied phacolite at the Killyflugh quarry; they are almost optically isotropic.

(c) *Calcite.*

This mineral was found in some abundance on specimens from Craighulliar, and to a more limited extent on those from the quarries on either side of White Head; it was not observed on specimens from Killyflugh.

On the specimens from Craighulliar two kinds of crystals were seen. The first characterizes the crystal embedded in massive chabazite. The shape is tapering, and is due to the prominent development of a steep scalenohedron. A partially developed crystal was successfully removed from the matrix, and on goniometric examination of it the faces were found severally to lie in zones connecting the cleavage faces. The most trustworthy value of the distance from the pole e (0112) as determined from the readings was $83^{\circ} 4'$. The scalenohedron is therefore Ω_1 (6. 5. II. 1), the corresponding calculated value of which is $83^{\circ} 14'$. A reading, giving the value $88^{\circ} 15'$ as the distance from e (0112), was obtained for a small face lying on an edge with a small cleavage face at the top; the corresponding face has the indices (22. 21. $\bar{43}$. 1), the calculated value for which is $88^{\circ} 15\frac{1}{2}'$. A number of small crystals, under a millimetre in length, of the type illustrated in fig. 11, occur perched on the twinned crystals of phacolite. The faces of the form f (0221), which are smooth and gave good reflections, were used for

setting up the crystal for measurement on the three-circle goniometer. The mean value for the distance cf , viz. $63^\circ 8'$, agrees closely with the accepted value, $63^\circ 7'$. The form M ($40\bar{4}1$) was determined from the fact that the faces lay in the zone $[cf]$ on the side of the axis remote from f , and the observed values for the distance cM were $75^\circ 46'$, $75^\circ 50'$, $75^\circ 52'$, the corresponding calculated value being $75^\circ 47'$; the faces being small gave only faint reflections. The faces of the form Ω_1 (6. 5. II. 1) are dull and give indistinct reflections; nevertheless, the observed values for the distance and azimuth (the azimuth of f being taken as zero), viz. $83^\circ 39'$, $26^\circ 58'$; $83^\circ 3'$, $26^\circ 42'$, are in satisfactory agreement with the corresponding calculated values $83^\circ 56'$,

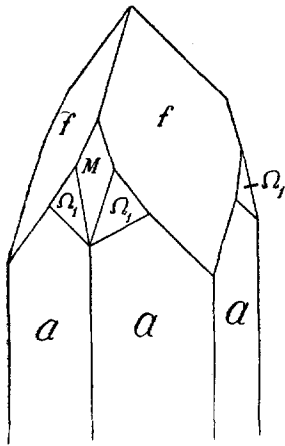


FIG. 11.—Calcite from Craighulliar.

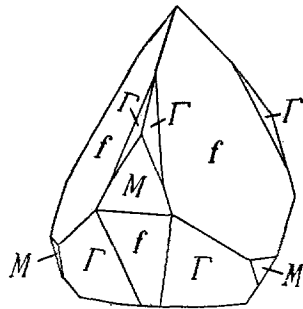


FIG. 12.—Calcite from White Head.

$27^\circ 0'$. The prism-faces are very dull, and give reflections diffused in the zone with Ω_1 . Measurements were obtained which pointed to the presence of minute faces of the form (22. 21. $\bar{4}3$. 1), the observed and calculated values of the distance and azimuth being respectively $88^\circ 5'$, $28^\circ 59'$; $88^\circ 26'$, $29^\circ 14'$.

Crystals (fig. 12) similar to the latter type, but still smaller in size, were found on a few specimens from the quarry on the north side of White Head. One crystal was removed for determination of the forms present, which proved to be f (0221), M ($40\bar{4}1$), and Γ (3584). As before, the faces f were used for setting up the crystal. The observed and calculated values of the distances for the three forms respectively

are f $63^{\circ} 8'$, $63^{\circ} 7'$; M $76^{\circ} 5'$, $75^{\circ} 47'$; Γ $59^{\circ} 59'$, $59^{\circ} 55'$. The corresponding values of the azimuth of Γ , that of f being taken as zero, are $21^{\circ} 42'$, $21^{\circ} 47'$. Very much larger crystals, 15–20 mm. in length, of similar form, were found occurring alone.

On some of the specimens, collected from the bottom flow in the quarry on the south side, tiny, white balls, about 0.7 mm. in diameter, of spherulitic calcite, are sprinkled sparingly on a carpet of needle-like crystals of natrolite closely interwoven with tiny trapezohedra of analcite. A few needles of natrolite with most minute flakes of analcite spring out from the spherulites.

V. RELATION BETWEEN CHABAZITE, ANALCITE, AND NATROLITE.

That a very close relationship subsists between the three zeolitic minerals, chabazite, analcite, and natrolite, as regards not only their chemical composition, but also their physical properties, is shown below.

Natrolite.— $\text{Al}_2\text{O}_3 \cdot \text{Na}_2\text{O} \cdot 3\text{SiO}_2 \cdot 2\text{H}_2\text{O}$.

Hardness 5. Specific gravity 2.3. Refractivity 1.483.

Orthorhombic: $a : b : c = 0.9785 : 1 : 0.3536$.

We may, however, transform the axes so that the poles (110), (1 $\bar{1}$ 0), (001), (401) become respectively (100), (001), (010), (111), and express the fundamental constants in the following form:

$$a : b : c = 0.9893 : 1 : 0.9893; \beta = 91^{\circ} 14\frac{1}{2}'.$$

Analcite.— $\text{Al}_2\text{O}_3 \cdot \text{Na}_2\text{O} \cdot 4\text{SiO}_2 \cdot 2\text{H}_2\text{O}$.

Hardness 5. Specific gravity 2.3. Refractivity 1.487. Cubic.

Chabazite.— $\text{Al}_2\text{O}_3 \cdot \text{Na}_2\text{O} \cdot 4\text{SiO}_2 \cdot 6\text{H}_2\text{O}$, to take the simplest formula to which the composition approximates.

Hardness 5. Specific gravity 2.1. Refractivity 1.485.

Rhombohedral; $a : c = 1 : 1.0860$.

The fundamental constants may, however, be expressed in the form

$$a : b : c = 1 : 1 : 1; \alpha = \beta = \gamma = 94^{\circ} 24'.$$

In all three instances, therefore, the crystalline arrangement is actually or approximately cubic.



Photo by R. Welch.

WHITE HEAD FROM THE NORTH SHOWING THE LARGE QUARRY.

Seaside quarry.

G. F. H. SMITH, F. N. ASHCROFT, AND G. T. PRIOR: CHABAZITE FROM CO. ANTRIM.

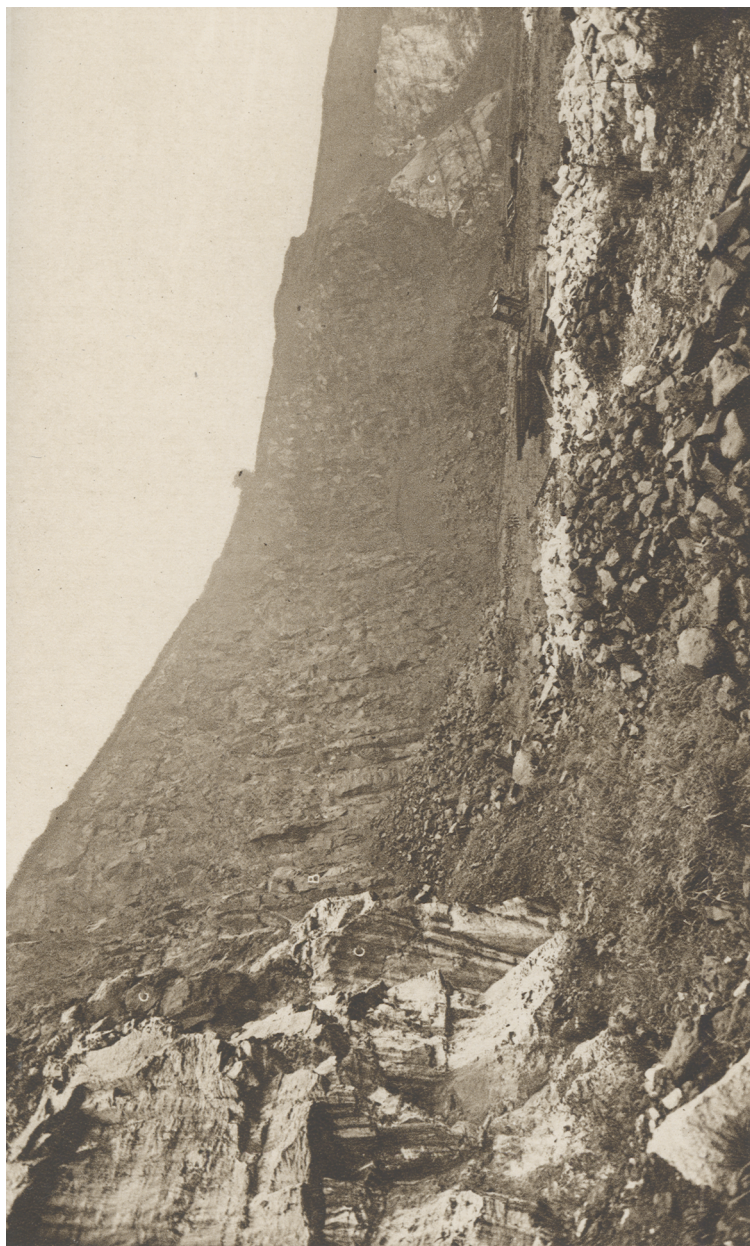


Photo by R. H. D. S. H.

QUARRY ON THE NORTH SIDE OF WHITE HEAD.

C = Chalk. B = Basalt.

Swain's quarry.

G. F. H. SMITH, F. N. ASHCROFT, AND G. T. PRIOR: CHABAZITE FROM CO. ANTRIM.

← B
← A

↑ A
↑ B



Photo by R. Welsh.

DISUSED QUARRY ON THE SOUTH SIDE OF WHITE HEAD.

The arrows indicate approximately the points in the lowest flow from which specimens were obtained.

Swazigraevitz.

G. F. H. SMITH, F. N. ASHCROFT, AND G. T. PRIOR: CHABAZITE FROM CO. ANTRIM.



Swaingraveure.

Photo by R. Welsh.

CUTTING LEADING TO THE QUARRY ON CRAIGAHULLIAR.



Swaingraveure.

Photo by R. Welsh.

"KILLYFLUGH" QUARRY NEAR BALLYMENA.

G. F. H. SMITH, F. N. ASHCROFT, AND G. T. PRIOR: CHABAZITE
FROM CO. ANTRIM.