The amygdale minerals in the Tertiary lavas of Ireland. II. The distribution of gmelinite.

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[Read 4 June 1959.]

Summary. Mapping of the distribution of zeolites in the Antrim basalts has revealed that gmelinite is confined to a narrow zone along the eastern seaboard of Antrim. This zone comprises less than 1% of the area of the basalts, but in it gmelinite is extremely abundant. The gmelinite zone is superimposed upon the lava pile, and the minerals in it are clearly later than the lavas; it is in the form of a dome, elongated north-west and traceable for 18 or 24 miles in this direction, and is found in the basal parts of the lava pile, locally reaching a height of some 500 feet in the pile. The zone may be related in its position and origin to the Islandmagee fault zone. Gmelinite frequently forms a parallel overgrowth on chabazite. Superimposed upon the southern part of the gmelinite zone is a zone of late chabazite and heulandite containing, *inter alia*, parallel overgrowths of late chabazite on simple or twinned gmelinite.

A STUDY of the amygdale minerals in the Tertiary basalts of the Garron Plateau area (Walker, 1951) showed that the zeolites and the crystal habits of chabazite have a regular vertical distribution in the lavas. The present paper concerns the distribution of the zeolite gmelinite. This mineral is confined to a narrow belt of lavas along the eastern seaboard of Antrim, referred to in this paper as the gmelinite zone, but within this restricted zone it is extremely abundant. Superimposed upon the gmelinite zone in its southern part, and encroaching also upon the other adjacent zeolite zones, is a zone of late chabazite and heulandite, which is also described below.

In what follows, after the minerals have been described, the shape and relations of the gmelinite zone are considered, and the conclusons to be drawn from this study reviewed.

Previous work.

Gmelinite has long been known to occur in the east of Antrim, and most mineral collections contain specimens. Bryce referred to gmelinite as occurring at Glenarm and in Islandmagee in 1833, and in 1837

Brooke described crystals of chabazite from Glenarm with a parallel overgrowth of gmelinite. Portlock, in his excellent summary of the amygdale minerals of the Antrim Basalts, published in his memoir of 1843, gave as localities Islandmagee, Black Head, Glenarm, Portrush, and several places in County Londonderry.[1] This list was repeated by Greg and Lettsom (1858) and Hintze (1897).

The only work published since then is the paper by Smith and Ashcroft (1916) dealing, among other topics, with chabazite and gmelinite from Whitehead, Islandmagee. Apart from this paper, very little has been added to the knowledge of the minerals of the gmelinite zone since the time of Bryce and Brooke over a century ago.

The only other British record of gmelinite is that by Heddle (1901) from Talisker, Skye, and a specimen from this locality in the Royal Scottish Museum, Edinburgh, is unquestionably gmelinite. Farther afield, gmelinite is much more restricted in occurrence than many other zeolites. Hintze (1897) listed as localities Skye, Vicenza (Italy), Cyprus, Andreasberg (Harz), Austria, Nova Scotia, New Jersey, Mexico, and Victoria (Australia). Since then gmelinite has been recorded from a few other localities (Sicily, Dana 6th edn., app. ii, p. 46; S. Rhodesia, M.A. **6**-159; Russia, M.A. **2**-299, **8**-298).

Geological environment.

The best exposures of gmelinite-bearing basalts in Antrim are in the outliers on the peninsula of Islandmagee, where there are excellent cliff-sections around the north and east coasts. Unfortunately there are very few exposures inland. Other exposures of gmelinite-bearing basalts are found at Whitehead; Black Cave, north of Larne; and along the basalt escarpment, often precipitous, east and south-east of Glenarm, where good specimens may be collected from screes and slipped debris.

In these exposures a thickness of up to about 600 feet of basalt lavas is exposed, embracing in north Islandmagee and near Glenarm the whole of the Lower Basalts (Cole, 1912) and the lower part of the Upper Basalts. Both series of lavas are composed almost exclusively of olivine-basalts (Tomkeieff, 1934), with some picrite-basalts. In Islandmagee they include the best exposures in Antrim of thin pahoehoe flow-units, with pipe-amygdales at the base and ropy tops. Every flow contains

[1] Portlock's identification of gmelinite at Portrush and localities in Co. Londonderry is doubtful; the present writer has not seen gmelinite in the field there or in mineral collections. Phacolite, which is sometimes pink and closely resembles gmelinite, was probably misidentified as gmelinite.

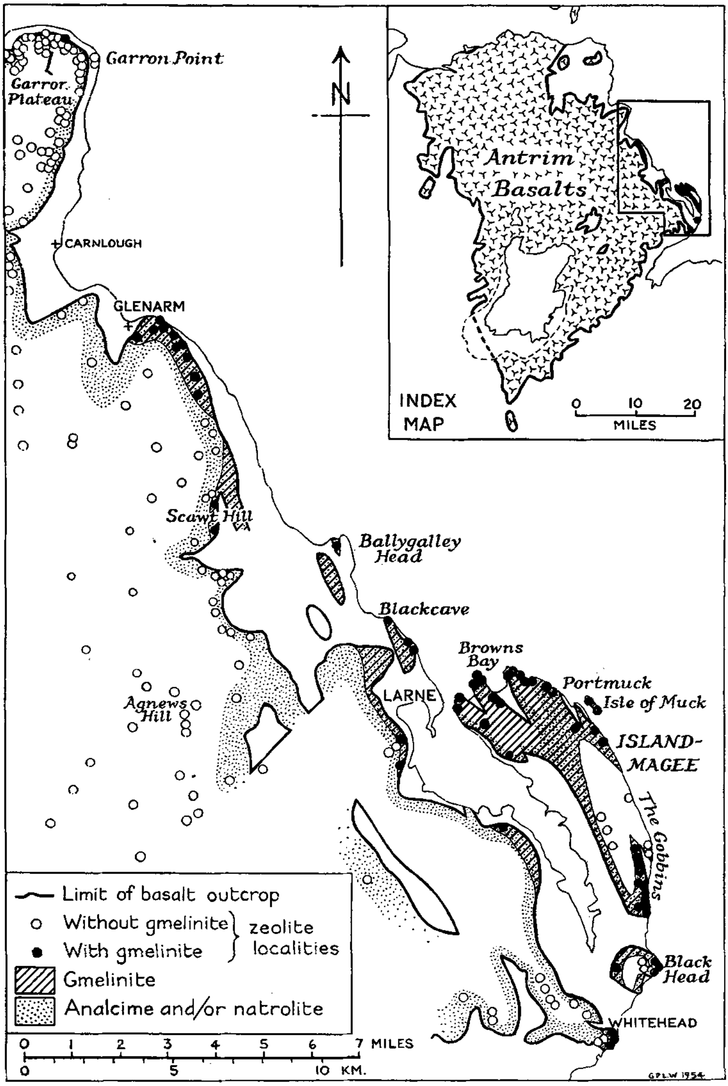

FIG. 1. Map showing the distribution of gmelinite in the Antrim Basalts.

zeolites and other secondary minerals such as calcite in amygdales and also in the body of the rock, and these minerals form probably around 10 % of the basalt pile.

The minerals.

Gmelinite is one of a rich suite of secondary minerals, many of which accompany it in the same cavity, and the following list includes most of the minerals that are found:

Gmelinite. The index mineral of the gmelinite zone, it is perhaps the most abundant zeolite in it. It occurs as well-formed crystals up to about 1 cm. but normally several mm. in diameter. Only rarely does the mineral form radiating aggregates, unlike many of the other zeolites. It is usually pink in colour, and is optically uniaxial negative, with mean refractive index ranging from 1·470 to 1·485 and birefringence from about 0·002 to 0·005.

The crystals are combinations of the forms $r\{10\bar{1}1\}$, $\rho\{01\bar{1}1\}$, $m\{10\bar{1}0\}$, and $c\{0001\}$. The following five main habits may be distinguished (fig. 2):

Rhombohedral habit: forms m, r, and ρ, with r and ρ unequally developed. There is usually a curved concave vicinal strip in the zone $r\rho$ along the terminal edges. Also commonly present are vicinal faces in the zones rm, ρm, and mm.

Pyramidal habit: forms m, r, and ρ, with r and ρ equally developed. Vicinal faces in the zone $r\rho$ are usually absent or inconspicuous. This is the most common habit.

Tabular habit: as pyramidal habit, but with c present. As c increases in relative size, the crystals become thin and platy. The faces of c are rarely bright and plane. The crystals usually have a basal parting.

Prismatic habit: as pyramidal habit, but elongated along the c-axis with prominent m faces which are usually strongly striated horizontally.

Twinned habit: crystals, generally of tabular habit, but sometimes pyramidal, showing twinning on r in which several individuals are united to form a twin of unusual complexity (Smith and Ashcroft, 1916, figs. 9, 10).

Chabazite occurs as well-formed crystals usually up to 5 mm. in diameter and often pink in colour, like the gmelinite. The habit is 2 or 3, following the nomenclature used by Walker (1951), and only rarely are forms other than $\{10\bar{1}1\}$ prominent, except in the late chabazite zone.

Optically the chabazite is negative, and either uniaxial or biaxial with small optic axial angle. Refractive indices measured range from 1·470, rather lower than that of chabazite found elsewhere in the Antrim Basalts, to about 1·494, with a birefringence of the order of 0·003.

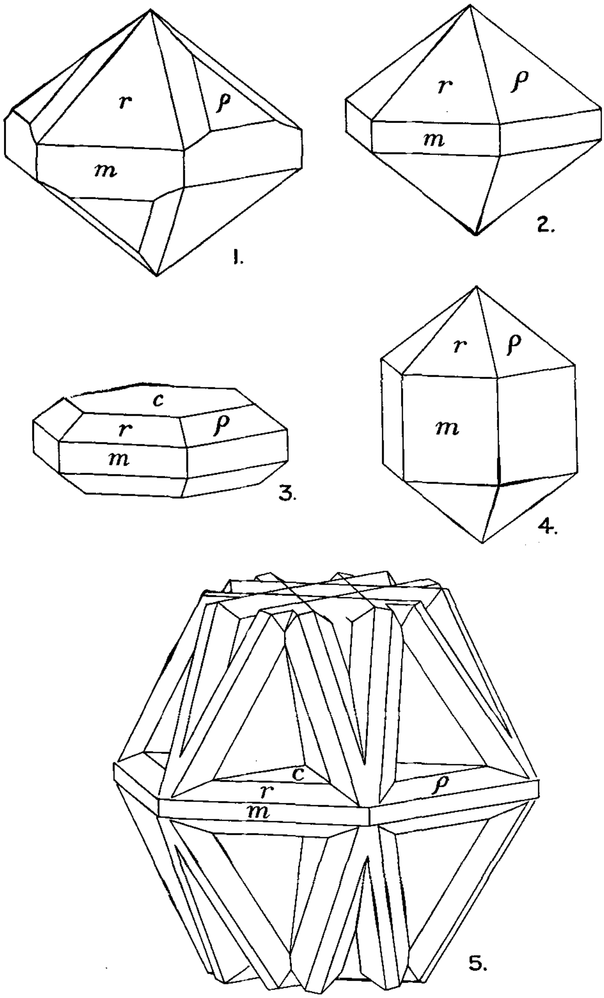

FIG. 2. The five crystal habits of gmelinite in Antrim. Forms present: $r\{10\bar{1}1\}$, $\rho\{01\bar{1}1\}$, $m\{10\bar{1}0\}$, and c $\{0001\}$. The drawing of the twin-crystal is idealized, and for clarity some edges are omitted.

Levyne is quite common and widespread, as small platy crystals which tend to occur alone in a cavity, although they may at times be associated with other zeolites. It is often pink in colour. Levyne from the gmelinite zone is uniaxial negative, with mean refractive index 1·489 to 1·495, and birefringence about 0·002–0·006. The levyne commonly shows the oriented overgrowth of a fibrous mineral, probably an alteration product, as is common elsewhere in Antrim (Walker, 1951).

Analcime is abundant in much of the gmelinite zone, and differs in three ways from that found elsewhere in the Antrim Basalts. It forms small, transparent and glassy crystals rather than the large, dull white crystals which are usual elsewhere. Although the crystals are usually of simple habit, with {211} alone, other forms are sometimes developed; these include {100}, {332}, and rarely {111}, forms which have not been observed elsewhere in the British Tertiary (Heddle, 1899). Finally, at a number of localities radiating aggregates of glassy analcime are found, and again these have not been observed elsewhere in Antrim.

Natrolite is fairly common as stout, prismatic crystals terminated by {111}, much stouter than are usual elsewhere in Antrim; the crystals are either in loose aggregates or closely spaced in compact masses with radiating structure. Perhaps the best natrolite is seen in the quarries at Whitehead, now unfortunately disused, and at Glenarm. Optically it is biaxial positive, with refractive indices varying little from γ 1·488, β 1·478, and α 1·476.

Thomsonite is represented by the variety faröelite, as more or less hemispherical radiating aggregates of closely-packed acicular crystals elongated parallel to *c*. It is either white or pink. Although quite common, thomsonite is much less abundant in the gmelinite zone than in most of the remainder of the Antrim Basalts, and much of it may have been converted to other zeolites. Optically it is biaxial positive, with β ranging from 1·515 to 1·526, and γ 1·523 to 1·535.

Phillipsite, although fairly widespread, is seldom abundant. Perhaps, the best material may be collected from the coast south-east of Portmuck, Islandmagee. The crystals are normally pink, deeper in colour than gmelinite, and are nearly always in radiating aggregates; when in single crystals the habit sometimes closely resembles a rhombic dodecahedron.

Calcite is extremely abundant throughout the gmelinite zone, in cavities and in veins probably related to the faulting. *Aragonite* is present in much smaller amount, in radiating aggregates. *Quartz* and *chalcedony* have not been observed, and neither have *apophyllite* and *gyrolite*, although Portlock (1843) recorded apophyllite from Islandmagee. Bryce (1833) recorded *gismondine* from the Gobbins, Islandmagee, but the mineral referred to is almost certainly the mixture of chabazite and heulandite found in the late chabazite–heulandite zone. Specimens of this aggregate, labelled gismondine, are often found in the older mineral collections. Of the rarer minerals, *scolecite* and *mesolite* are sometimes encountered, usually as chalk-like matted aggregates of minute fibres, and *native copper* and *malachite* have been found by the writer in minute amounts at several places. Exceptional are the amygdale minerals near Portmuck, Islandmagee, developed near intrusive dolerite dykes (Walker, 1948), which include *andradite, apatite, magnetite, diopside, ilmenite,* and *sphene.*

The order of crystallization.

In the gmelinite zone most of the amygdale minerals listed above may coexist at the same locality, and many of them in the same cavity, although there is a tendency for levyne and to a lesser extent analcime and phillipsite to occur alone in a cavity. The limited available evidence points to levyne and phillipsite as the earliest zeolites to crystallize, levyne preceding phillipsite; they were probably followed closely by chabazite and thomsonite.

The more sodic zeolites, gmelinite, analcime, and natrolite, came later. Gmelinite unquestionably follows chabazite, for at every locality where the two are associated—and they are associated at most localities—some of the gmelinite forms minute crystals in a parallel overgrowth on chabazite, as figured by Brooke (1837). Analcime and natrolite are later than gmelinite.

Calcite is very abundant throughout the zone, especially so near faults, and it may be either earlier or later than the zeolites. The earliest calcite is often in small hemispherical radiating aggregates. Aragonite tends to fill the amygdale in which it occurs, but whenever zeolites are seen associated with it they are of later formation. Much of the aragonite has subsequently been replaced by a sugar-grained aggregate of calcite.

Discussion of the late chabazite–heulandite zone is deferred (p. 214), but it may be noted that in this zone the two index minerals are later than all the other amygdale minerals described above.

The colour of the minerals.

A striking feature of the gmelinite zone is the pink colour of many of the minerals. Gmelinite is usually pink, and so are the associated chabazite, phillipsite, thomsonite, and levyne, these minerals being almost invariably white in the remainder of the Antrim Basalts outside the gmelinite zone. It would appear that the conditions which were favourable to the formation of gmelinite were also those which promoted a pink coloration of the minerals. The minerals of the late chabazite–heulandite zone are, however, white.

It is interesting to note that, at Garron Point, Glenarm, and a few places farther south the extreme edge of the gmelinite zone is not quite coincident with the edge of the zone of coloration, and a little colourless gmelinite appears. The gmelinite collected by Heddle at Talisker, Skye, is similarly colourless.

The shape of the gmelinite zone.

Gmelinite has been found by the writer at some sixty localities in Antrim. Its western limit is marked by a line trending north-west that can be traced for 18 miles from Whitehead past Larne and Scawt Hill to near Glenarm. This line is extended to 24 miles if account is taken of the occurrence of gmelinite at a single locality near Garron Point. The eastern limit of gmelinite in the lavas is nowhere seen, lying somewhere off the coast, and the greatest known width of the gmelinite zone is 3½ miles in north Islandmagee.

In the lower 50 to 100 feet of the lava pile within the limits of the gmelinite zone there are no localities at which gmelinite is not present. The distribution at higher levels in the lavas is much more restricted. On the escarpment south of Larne gmelinite is found in quarries at the base of the lavas, but is absent in the large quarries on Carnduff Hill 100 to 200 feet higher up. At Whitehead the quarries and coast exposures in the lowermost 100 feet of lavas are rich in gmelinite, but this mineral is not found in road cuttings at the top of the headland some 200 feet above the base of the lavas. A similar relationship is found in the southern half of Islandmagee: the Black Head outlier does not bear gmelinite in the several small openings at the top of the cliffs near the lighthouse, but gmelinite is abundant lower down along the shore, and at the base of the lavas on the west side of the outlier. At the Gobbins, gmelinite is abundant in the lower 100 feet of lavas but is absent from most of the road cuttings 100 feet or so higher up.

In the southern half of Islandmagee, then, the roof of the gmelinite zone is exposed, and the zone has a thickness of the order of 100 or 200 feet. In the north of Islandmagee, on the other hand, the thickness is much greater, gmelinite being distributed throughout the Lower Basalts and in at least the lower 100 feet of the Upper Basalts, near Brown's Bay. That is, the gmelinite zone attains a height of at least 500 feet in the lava succession.

The conclusion to be drawn on the shape of the zone is that it forms

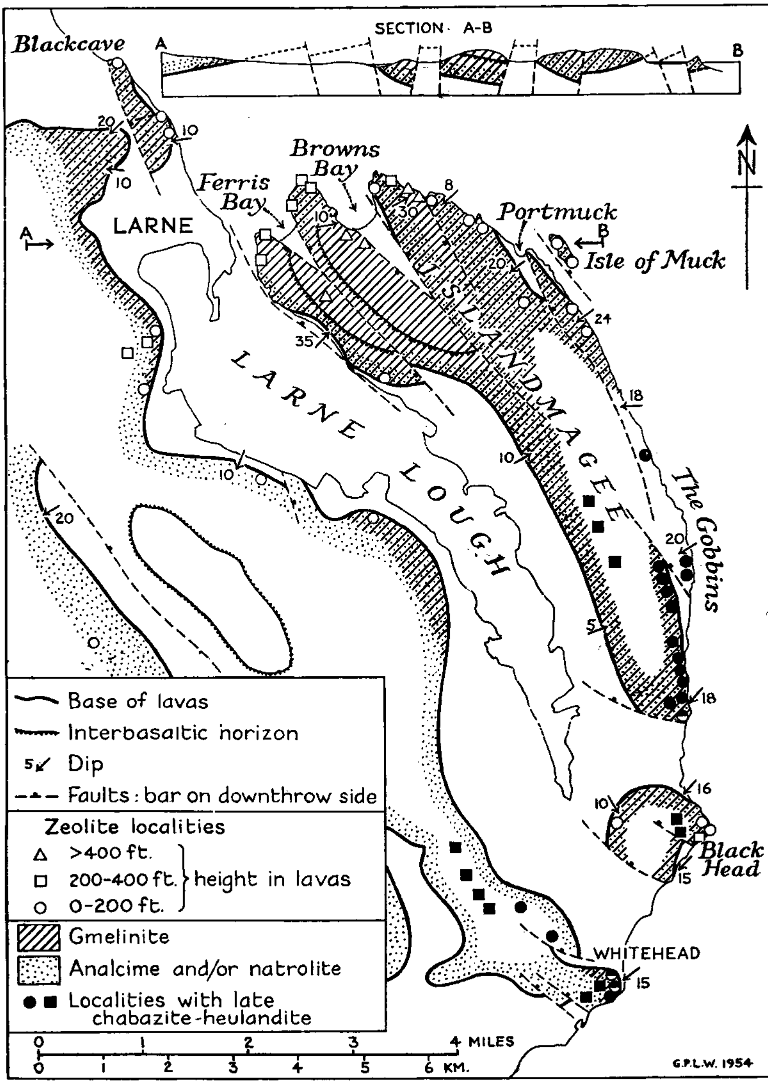

FIG. 3. Geological map of Islandmagee showing the distribution of amygdale minerals. The known faults of the Islandmagee fault zone are indicated on the map and section above.

an elongated dome trending north-west, less than 100 feet thick along the western margin but up to 200 feet thick at Black Head and at least 500 feet in north Islandmagee, where the zone has its greatest known width. The greatest known lateral extent of the zone is at the base of the lava pile.

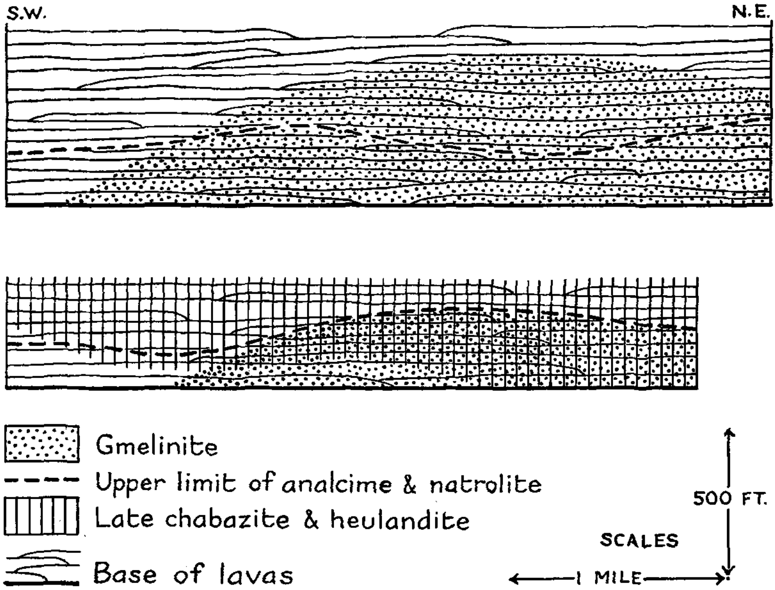

FIG. 4. Diagrammatic sections across the gmelinite zone: above, in north Islandmagee; below, in south Islandmagee. The lavas are indicated schematically.

The distribution of gmelinite habits.

Following the success achieved in mapping the distribution of chabazite habits in Antrim (Walker, 1951), an attempt was made to map the distribution of gmelinite habits. Unfortunately the nature of the exposures makes this very difficult, for nowhere in the gmelinite zone are exposures found that are more than 200 or 300 feet high, and exposures inland from the coastal cliffs are almost non-existent. The extensive faulting adds to the difficulty.

The only relationship that has been established is the marked tendency for crystals of platy, twinned, and prismatic habits to be confined to the upper and lateral marginal parts of the gmelinite zone, the pyramidal and rhombohedral habits being characteristic of the remainder of the zone. Thus gmelinite of prismatic habit is developed along the edge of the zone at Garron Point, Glenarm, near Scawt Hill, and to a limited extent at Whitehead, and the platy and twinned habits at Whitehead and where the gmelinite zone is thin north of Black Head and at the Gobbins.

The age and origin of the gmelinite zone.

The gmelinite zone is clearly superimposed upon the lava pile, and gmelinite must have been formed at some time after the eruption of the Lower Basalts and at least part of the Upper Basalts.

When one attempts to correlate the gmelinite zone with some geological feature, it is seen to be roughly coincident with the Islandmagee fault zone, a fracture belt without known parallel elsewhere in the Antrim Basalts. In Islandmagee and in adjacent parts of the mainland the basalt lavas are cut by a set of large north-west-trending faults into narrow strips tilted in different directions. The gmelinite zone attains its greatest known thickness where the fracturing is most intense, in the area of the horsts of Brown's Bay and Ferris Bay in the north of Islandmagee.

Most of the faults in the Islandmagee fault zone are not indicated on published geological maps; those known to the writer have been inserted on the accompanying map, fig. 3. Collectively they have a throw of over 3000 feet (not all throw in the same direction) and are probably related to the formation of the North Channel between Ireland and Scotland.

One is tempted to postulate the formation of gmelinite through the agency of hot solutions rising along the faults, but the gmelinite zone appears to have been itself shifted by some of these faults. The Gobbins fault appears to have downfaulted the gmelinite zone to below sea-level on the east side, whereas gmelinite is found in the lower 100 feet of lavas on the west side. Along the Castlerobin fault in north Islandmagee, which has a downthrow of the order of 300 or 400 feet west, gmelinite is of different habit on opposite sides of the fault, and is much less abundant on the downthrow side.

Although sought for, only a single convincing example of a bedded floor to an amygdale was found. In this example the cavity was floored with red zeolitic material and its upper surfaces lined with gmelinite. It was found on the western shore of Brown's Bay in a fault block tilted at 10°, the bedded floor being likewise tilted and showing that tilting postdated the formation of the bedded deposit. It is assumed that tilting and faulting were essentially contemporaneous.

The limited available evidence would appear to indicate that the bulk of the faulting postdated zeolitization, but the areal relationship of the gmelinite zone and the Islandmagee fault zone seems too close to be coincidental. Perhaps the faults were initiated before gmelinite crystallized, although the larger part of the faulting took place later.

Zeolitization by dykes.

In three sea-stacks ½ mile north-west of Portmuck, Islandmagee, a large dyke of olivine-dolerite cuts a succession of thin flows of olivine-basalt and has caused considerable alteration to a distance of some 15 feet from the contact (Walker, 1948). This alteration includes extensive zeolitization of the lavas. Amygdales and veins in the lavas near the dyke contain zeolites accompanied by andradite, apatite, magnetite, soda-diopside, ilmenite, sphene, and calcite. Thomsonite and natrolite are very much more abundant near the dyke than in the lavas farther away, and similar relationships are found with another (probably related) dyke on the Isle of Muck.

These are clear examples of development of zeolites in the hydrothermal aureoles about a dyke, but the effect is very local. On one of the stacks north-west of Portmuck a small dyke cuts the main dyke and is chilled against it, and its amygdales contain gmelinite and a mineral assemblage similar to that in the lavas in the whole district. One is forced to the conclusion that although some zeolites were formed by dykes at Portmuck, the bulk of the zeolitization and the regional formation of gmelinite in the lavas postdated the intrusion of the dykes.

The relative age of faults and dykes in Islandmagee can be inferred from the following evidence: with the exception of the Gobbins fault, the faults of Islandmagee do not carry dykes despite the easy path they would presumably offer to the passage of basaltic magma; and the dykes in Islandmagee invariably cut the lavas approximately normal to the stratification. In the fault blocks the lavas are sometimes tilted quite steeply, but this relationship still holds, and the dykes must have been tilted with the lavas. This evidence indicates that dyke intrusion antedated faulting and tilting of the lavas.

The distribution of analcime and natrolite.

In the country west of the gmelinite zone, the distribution of amygdale minerals follows the same pattern as that worked out (Walker, 1951) for the Garron Plateau area. Two distinct amygdale mineral assemblages may be mapped; the one, characterized by the abundance of analcime or natrolite or both, together with other zeolites such as chabazite, forms a nearly continuous zone in the lowermost few hundred feet of the lava pile; the other, characterized by the abundance of chabazite and thomsonite to the exclusion of analcime and natrolite, overlies it. Evidence from the Garron Plateau area indicates that chabazite and thomsonite mostly crystallized before the formation of north-west-trending faults, analcime and natrolite after.

The distribution of analcime, natrolite, chabazite, and thomsonite appears to be exactly the same within the gmelinite zone, analcime or natrolite or both being encountered almost everywhere in the lowest few hundred feet of the lavas but not higher up in the lava pile in northern and central Islandmagee. The distribution of analcime and natrolite thus appears to be completely unrelated to that of gmelinite, and both of these minerals are later than gmelinite.

Late chabazite and heulandite.

As noted above, the crystallization of chabazite before gmelinite is well established throughout the gmelinite zone. In the southern half of Islandmagee and at Whitehead, however, there has manifestly been a second period of deposition of chabazite, of different character and appearance to the early chabazite, and closely associated with fine-grained granular heulandite. So distinctive is this second generation that the area of lavas in which it occurs has been mapped and is referred to as the late chabazite–heulandite zone.

The late chabazite–heulandite zone is notable for the remarkable overgrowths formed by the late zeolites. The following effects have been noted:

Fine-grained, granular aggregates of late chabazite and heulandite form a layer up to several mm. thick on the pre-existing minerals; on needles of natrolite, which are nearly always replaced by the late zeolites; on slender scalenohedra of calcite;[1] on hemispherical aggregates of thomsonite, the earlier mineral being often altered to a white chalky substance or replaced by chabazite and heulandite; and on crystals of chabazite, gmelinite, and levyne. The best examples of these overgrowths are found west of the two quarries at Whitehead and in landslips south of the Gobbins.

Late chabazite is commonly observed as a parallel overgrowth on early chabazite. Sometimes the overgrowth is thickest on the lateral edges and corners, as in a small quarry west of Whitehead town. The

[1] A scalenohedron near $\{13.11.\overline{24}.2\}$ is particularly characteristic.

habit of the late chabazite is higher than that of the early (the late has habit 3, the early habit 2, following the notation of Walker, 1951) and as a result little facets of $\{01\bar{1}2\}$ and $\{02\bar{2}1\}$ appear on crystals which originally showed $\{10\bar{1}1\}$ alone.

Late chabazite forms a parallel overgrowth on gmelinite, and usually replaces it as well.

The parallel overgrowths of late chabazite on gmelinite are particularly interesting. When the layer of chabazite is thin or discontinuous, crystals which show faces of both chabazite and gmelinite are the result, and there is little doubt that some crystals described by Smith and Ashcroft (1916) from Whitehead were of this type. Occasionally the overgrowth of late chabazite is clearly visible in hand specimens.

More commonly the late chabazite forms a thick and continuous parallel overgrowth on the gmelinite and largely or completely masks the faces of the earlier mineral, although the general shape of the gmelinite is retained. In nearly all cases the underlying gmelinite has been converted to chabazite.

Typical crystals of this second type from the landslips on the coast south of the Gobbins have the overall shape of tabular gmelinite but with the prism and rhombohedron faces coated with chabazite in parallel orientation, and with $\{0001\}$ coated with granular heulandite. The gmelinite has been converted into chabazite, with loss of its presumed original pink colour, but the basal parting which is so characteristic of gmelinite of tabular habit is preserved as thin air films, imparting a pearly lustre to $\{0001\}$ of the paramorph.

The most remarkable crystals are those in which chabazite forms a parallel overgrowth on gmelinite twins, as found in slips south of the Gobbins and also in road cuttings above the entrance to the Gobbins cliff path. Such crystals must be among the most complex known, for seven or more individuals of tabular gmelinite of the original twin are each coated and replaced by a twin-crystal of chabazite, giving a total of 14 or more chabazite individuals. Each chabazite individual has 18 faces—six each of $\{10\bar{1}1\}$, $\{01\bar{1}2\}$, and $\{02\bar{2}1\}$, neglecting vicinal faces—giving a total of 252 faces. Such a crystal gives reflections from the whole complement of 252 faces, apart from the few missing where the crystal is attached to the rock. In such twins, trios of $\{02\bar{2}1\}$ faces of chabazite, grouped around the main triangular re-entrants of the twin, reflect light almost simultaneously.

It has long been known that the axial ratios of chabazite and gmelinite are closely related, and Smith, from the evidence supplied by crystals at

Whitehead, regarded the two minerals as identical. Pirsson (1891) had concluded that the discrepancy in the relation c (chabazite) $= 3/2\ c$ (gmelinite) was too great for identity of gmelinite with chabazite, and more recently Bannister (Hey, 1950) has established that they are separate mineral species from X-ray study. That there is a close relationship between the structure of the two minerals is clear from the frequency of parallel overgrowths and paramorphs.

Tomkeieff (1934) has analysed the chabazite, presumably late chabazite, from the Gobbins, and proved it to be rather lower in silica and higher in alumina and soda than most analysed chabazite.

Shape and relations of the late chabazite–heulandite zone.

The late chabazite–heulandite zone embraces the southern half of Islandmagee and the ground near Whitehead. At the Gobbins it extends to the base of the lavas, but at Black Head and Whitehead the base of the zone is 100 feet or more higher. The zone appears to be unrelated to the gmelinite zone, being superimposed upon it and upon the contiguous zeolite assemblage zones west of Whitehead, and there is no evidence that it has been shifted by any of the faults. It does not seem possible at present to relate it to any geological feature or episode.

Conclusions.

Mapping of the distribution of gmelinite has shown clearly its restriction to a zone of small extent in the east of Antrim, a zone the boundaries of which can be accurately delineated and the shape of which can be deduced to be dome-like. The zone is clearly superimposed on the lavas, which establishes the lateness of zeolitization in the volcanic history of the area. The following general sequence of events has been deduced, although it is clear that there must be considerable overlapping of the events:

Eruption of lavas, approx. 500 feet thick (Lower Basalts) and dykes.
Interval; formation of laterite of interbasaltic horizon.
Eruption of lavas (Upper Basalts) and dykes.
Levyne and phillipsite formed, followed by chabazite and thomsonite.
Initiation of faulting in Islandmagee fault zone (?).
Gmelinite formed.
Main period of faulting in Islandmagee fault zone, and tilting of fault blocks.
Analcime and natrolite formed.

Late chabazite and heulandite formed.

Erosion of the area to the present land surface.

It is believed that development of gmelinite in eastern Antrim was related to the fault zone there and perhaps due to heated waters rising along the fractures. When one considers the restricted occurrence of gmelinite, however, it seems that the situation may not have been quite as simple as this, and some unknown factor may have played a part in the development of the mineral.

In Antrim the writer looked for gmelinite at some 700 localities scattered over the 1500 square miles of the Antrim Basalts, but succeeded in finding it at only some 60 localities along the eastern seaboard, covering about 12 square miles of the basalt plateau. Farther afield, there are large areas of basalts containing zeolites but not bearing gmelinite. In Scotland, for example, the apparent absence of gmelinite in the Carboniferous basalts of the Midland Valley and the Tertiary lavas of Mull, and its extreme rarity in Skye are features of which account must be taken in considering its genesis. Gmelinite does not appear to have been recorded at all from the immense piles of zeolite-bearing Tertiary basalts in Iceland, the Faroes, and Greenland, or from many other extensive spreads of basalt lavas.

Clearly gmelinite requires very unusual conditions for its formation in rocks, conditions that in Antrim prevailed only in the extreme east but there succeeded in producing an abundance of the mineral.

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