The amygdale minerals in the Tertiary lavas of Ireland. IV. The crystal habit of calcite.

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Summary. Calcite is widespread in amygdales associated with the zeolites; the characteristic forms being {02$\bar{2}$1} and a steep scalenohedron in the zone [$\bar{1}$101], usually {13.11.$\overline{24}$.2}. Crystals from one locality have faces of {16.1.$\overline{17}$.0}, a form new to calcite.

Calcite is widespread in amygdales and veins in the Antrim Basalts. Broadly, two types of occurrence may be distinguished: a regional type, in which the calcite is associated in amygdales with zeolites in zones of regional extent; and a local type, in which the mineral is one of an assemblage characterizing certain restricted regions in the lavas or is developed in close proximity to faults. These two types of geological environment are reflected by systematic differences in the crystal habit of the calcite. It is the habit of the regional calcite with which this paper is more especially concerned: what might be termed the 'normal' habit of amygdale-calcite, in contradistinction to the 'abnormal' habits of the local categories of occurrence.

Of all the Antrim minerals, calcite shows the greatest diversity of crystal habit, but despite the great variety certain relationships stand out very clearly. The regional calcite, although very variable, is characterized by the presence, and usually the predominance, of one or other or both of *f*{02$\bar{2}$1} and a steep scalenohedron in the zone [$\bar{1}$101], most commonly *W*{13.11.$\overline{24}$.2}. Often these are the only forms developed, but of the others that are found *M*{40$\bar{4}$1}, *r*{10$\bar{1}$1}, and *c*{0001} are the most prevalent. Twinning on *e*{01$\bar{1}$2} is very common, this being practically the only twin-law represented. Of the local occurrences of calcite, that in the plumose-calcite–aragonite–quartz zone in the north-western part of the Antrim Basalts (Walker, 1960) has *e*{01$\bar{1}$2} as the predominant, and often the only, form (there may be a later overgrowth of calcite of 'normal' habit); and the calcite that is so abundant in close proximity to faults, for example in Islandmagee and along the north of the Garron Plateau, often has *v*{21$\bar{3}$1} prominently developed.

Crystal habit of the regional ('normal') calcite.

Crystals of steep scalenohedral habit are very prevalent, having been found by the writer at more than 100 localities in the basalts, commonly encrusted by thomsonite. The faces are usually rounded by solution and only rarely can reliable measurements of interfacial angles be made. The steep scalenohedron appears always to belong to the zone $[\bar{1}101]$, easily recognized because the faces show striations parallel to the lateral edges that are parallel to the trace of the $r\{10\bar{1}1\}$ cleavage. The few reliable measurements that have been made indicate that[1] $W\{13.11.\overline{24}.2\}+R12$ is the most abundant of these scalenohedra. Others that have been established as occurring are $\{9.7.\overline{16}.2\}+R8$, $\{11.9.\overline{20}.2\}+R10$, and $\{6.5.\overline{11}.1\}+R11$. Scalenohedra for which measurements were insufficiently reliable to enable the form to be definitely established are $\{32\bar{5}1\}+R5$, $\{7.5.\overline{12}.2\}+R6$, $\{15.13.\overline{28}.2\}+R14$, and a very steep form near $\{31.29.\overline{60}.2\}+R30$. All but the last form are listed in Palache's tables (1940). Curved zones of vicinal faces approximating to steep scalenohedra are common on crystals of this habit. Crystals of rhombohedral habit with $f\{02\bar{2}1\}$ predominant are equally abundant in Antrim, and even more characteristic of the Chalk immediately below the lavas.

The only other study of the habit of calcite in the Antrim Basalts is that by Smith and Ashcroft (1916); they described from Craigahulliar Quarry a crystal of scalenohedral habit with $\{6.5.\overline{11}.1\}$ together with a small face of $\{22.21.\overline{43}.1\}$. Other crystals from the same locality had $\{11\bar{2}0\}$ and small faces of $\{13.11.\overline{24}.2\}$, terminated by $\{10\bar{1}1\}$ and $\{40\bar{4}1\}$. From Whitehead they described crystals with $\{02\bar{2}1\}$ predominant, with $\{04\bar{4}1\}$ and a scalenohedron, $\{35\bar{8}4\}$, lying in a zone other than $[\bar{1}101]$.

One of the best localities for calcite is a quarry almost at the top of the little hill, Baird's Brae, at Roughfort. This quarry was repeatedly visited by the writer over a period of several years, and many thousand calcite crystals seen. Three lava flows are exposed in the quarry, and the red tops of the two lower flows have abundant amygdales up to one or two inches and exceptionally as much as one foot in diameter. These, and sparse veins, contain an abundance of calcite in crystals seldom more than an inch long, and chabazite of habits 3 to 5 (Walker, 1951). Sparse cavities in the interior of the flows contain apophyllite and gyrolite and rare thomsonite and natrolite. A few cavities have been seen containing

[1] The Naumann symbol of the scalenohedron is given following the Miller-Bravais symbol; $+R$ is the rhombohedron of the lateral edges, namely $\{10\bar{1}1\}$, and the figure following gives the intercept on c.

TABLE I. Frequencies of scalenohedra in the zone $[\bar{1}101]$ of calcite.

Miller-Bravais Index	*Naumann Symbol*	*Frequency (Palache)*	*Antrim: number of localities*
$\{22.21.\overline{43}.1\}$	+R43	—	1 (Smith and Ashcroft)
$\{31.29.\overline{60}.2\}$	+R30	—	—
$\{21.19.\overline{40}.2\}$	+R20	2	1 (not established)
$\{9.8.\overline{17}.1\}$	+R17	3	—
$\{17.15.\overline{32}.2\}$	+R16	2	—
$\{8.7.\overline{15}.1\}$	+R15	5	—
$\{15.13.\overline{28}.2\}$	+R14	2	2 (one not established)
$\{7.6.\overline{13}.1\}$	+R13	10–25	—
$\{13.11.\overline{24}.2\}$	+R12	10–25	6 (including one by Smith and Ashcroft)
$\{6.5.\overline{11}.1\}$	+R11	10–25	4 (including one by Smith and Ashcroft)
$\{11.9.\overline{20}.2\}$	+R10	2	1
$\{54\bar{9}1\}$	+R9	10–25	—
$\{9.7.\overline{16}.2\}$	+R8	5	1 (not established)
$\{43\bar{7}1\}$	+R7	> 25	—
$\{23.17.\overline{40}.6\}$	+R6$\frac{2}{3}$	1	—
$\{11.8.\overline{19}.3\}$	+R6$\frac{1}{3}$	4	—
$\{7.5.\overline{12}.2\}$	+R6	3	1 (not established)
$\{10.7.\overline{17}.3\}$	+R5$\frac{2}{3}$	7	—
$\{13.9.\overline{22}.4\}$	+R5$\frac{1}{2}$	1	—
$\{19.13.\overline{32}.6\}$	+R5$\frac{1}{3}$	6	—
$\{32\bar{5}1\}$	+R5	> 25	2 (one not established)

aragonite and pale green plumose calcite, the quarry lying at the edge of a zone of basalts a few square miles in extent containing the plumose-calcite–quartz–aragonite assemblage. Practically all the calcite crystals seen had either *f* or a steep scalenohedron of the zone $[\bar{1}101]$, and the range of habits encountered is illustrated by fig. 1. Some crystals have *f* alone; others have *f* and *W* together; and perhaps the commonest crystals are scalenohedral in habit with *W* terminated by *f*, with or without *M*, or by *r* or *c*. Crystals tabular on *c* are very rare. Characteristic features are the rounding by solution of the faces of *f*; the usually rough condition of *r*, and even more so of *c*, although bright faces of both are seen on occasion; and the generally strong striations on the scalenohedron faces parallel to the lateral edge, striations that are heightened by solution, and some of which may be due to narrow faces of less steep scalenohedra, the faces of which are curved and give multiple reflections. The characteristic scalenohedron is *W*, as is shown by the following measurements[1] made on two crystals:

$$(hk\bar{i}l):(\bar{h}i\bar{k}l) = 65°\,18', \ 65°\,02', \ 65°\,15', \ 65°\,19', \ 65°\,15', \text{ average } 65°\,13' \text{ (cf. } 65°\,10' \text{ calculated for } W);$$

[1] All the measurements were by single-circle goniometer.

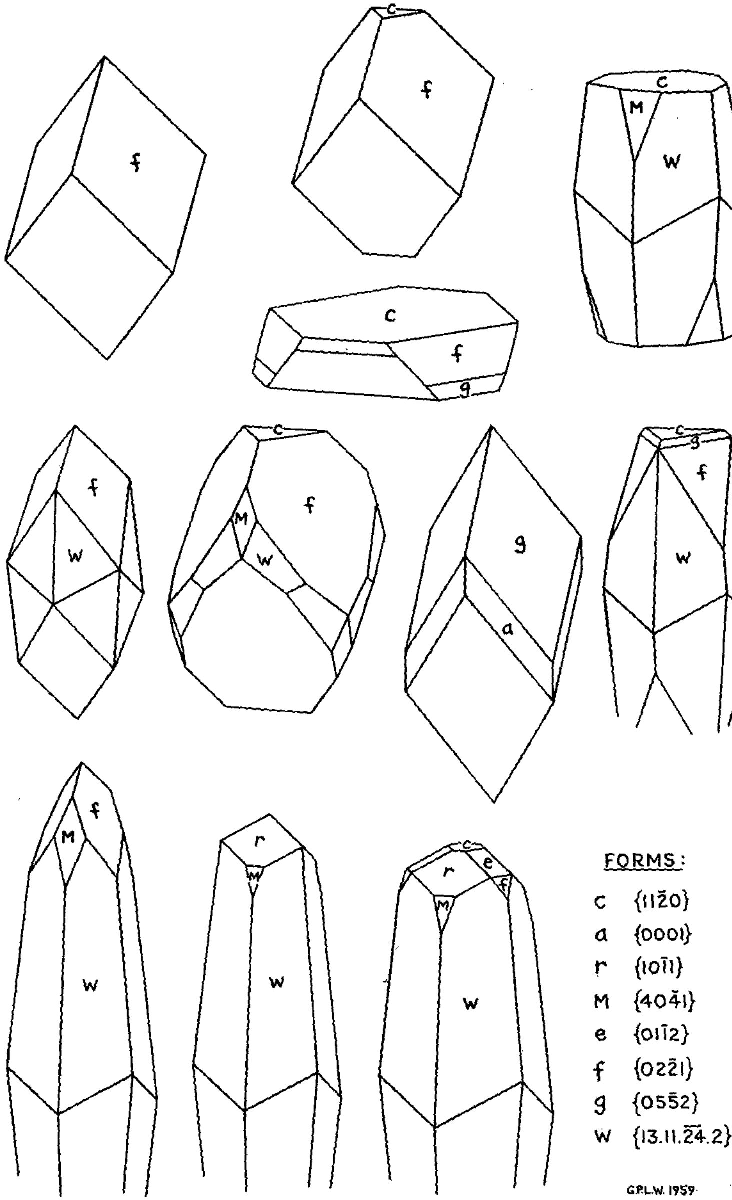

FIG. 1. Calcite habits encountered at Roughfort (Baird's Brae) Quarry.

$(hk\bar{i}l):(i\bar{k}\bar{h}l) = 54^\circ\,17', 54^\circ\,01', 54^\circ\,03', 54^\circ\,10'$, average $54^\circ\,08'$ (cf. $54^\circ\,13'$ calculated for W).

Little is known of the relative age of crystals of different habits, but some ghost crystals found in one vein had *f* predominant in the core,

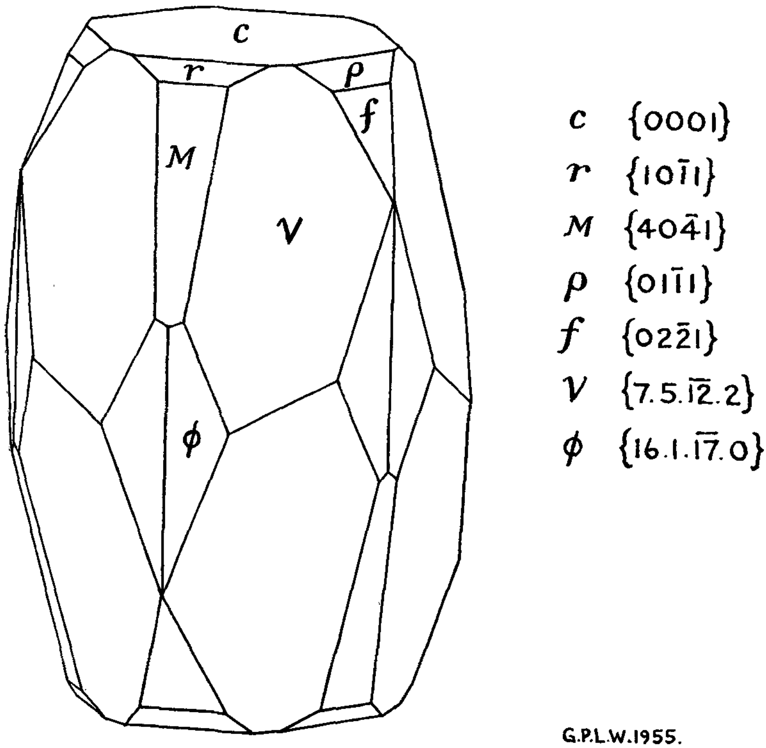

FIG. 2. Calcite from Roughfort showing the new form {16.1.$\overline{17}$.0}.

whereas the later calcite was of scalenohedral habit with *W* predominant. The habits described above are invariably later than plumose calcite, on which *e* is the main form.

A large basalt quarry 0·4 miles NE. of trig. point 607′ on Baird's Brae, Roughfort, has sparse plumose calcite in veins with a parallel overgrowth of calcite of scalenohedral habit. One of the specimens is interesting as bearing a form that is new for calcite, namely the dihexagonal prism {16.1.$\overline{17}$.0}. The crystals that bear this form are short, stumpy, and barrel-shaped (fig. 2) and consist of a steep scalenohedron terminated by c, and with small faces of M, r, f, and probably $\rho\{01\bar{1}1\}$, giving the following interfacial angles:

$c{:}M$ = 75° 48′, 75° 50′, 75° 42′, average 75° 47′ (cf. calculated value, 75° 47′);
$c{:}r$ = 44° 44′, 44° 40′ (cf. 44° 36′ calculated).

The dihexagonal prism forms pairs of very bright faces, slightly striated near their join due to a little oscillatory combination. The faces give perfect signals. Measured values of the angle $(hl\bar{k}0){:}(k\bar{l}\bar{h}0)$ are 5° 59′, 5° 54′, 6° 02′ for one crystal, average 5° 58′. Calculated values for this interfacial angle for possible dihexagonal prisms of high index are: $\{13.1.\overline{14}.0\}$ = 7° 20′, $\{15.1.\overline{16}.0\}$ = 6° 22′, $\{16.1.\overline{17}.0\}$ = 6° 01′, $\{17.1.\overline{18}.0\}$ = 5° 45′, $\{19.1.\overline{20}.0\}$ = 5° 13′. These values show that the present prism is most probably $\{16.1.\overline{17}.0\}$, which is a form new to calcite.

The scalenohedron faces on these crystals are striated and unfortunately give multiple reflections in the zone $[\bar{1}101]$, the peak of the reflections corresponding roughly to $\{7.5.\overline{12}.2\}$+R6. Scalenohedral crystals from another vein in the same quarry and terminated by M and f show a steeper form; the faces gave exceptionally good signals, and the following angles were measured:

$(hk\bar{i}l){:}(\bar{h}i\bar{k}l)$ = 65° 39′, 65° 35′, 65° 35′, average 65° 36′;
$(hk\bar{i}l){:}(i\bar{k}\bar{h}l)$ = 53° 44′, 53° 36′, 53° 41′, average 53° 40′;
$(hk\bar{i}l){:}(10\bar{1}1)$ cleavage = 45° 50′, 45° 49′.

These angles agree very well with the calculated values 65° 35′, 53° 40′, and 45° 41′ respectively for $\{6.5.\overline{11}.1\}$+R11. The same crystals also have faces of a less steep scalenohedron, which is probably $\{9.7.\overline{16}.2\}$, though the faces did not give very reliable reflections.

Another locality that has yielded much calcite is a large quarry in four basalt flows on the northern slope of Carnmoney Hill, north of Belfast. The amygdales in the flows contain chabazite and thomsonite, with smaller amounts of apophyllite, gyrolite, mesolite, and sparse stilbite. Calcite is abundant in amygdales and in veins accompanying a sharp flexure in the quarry, and it shows considerable habit variation. Most of the crystals found are of steep scalenohedral habit, but many show f alone or predominant. The faces of this form are very readily dissolved, and this often leads to the development of a flat solution scalenohedron. Unusually interesting were crystals, found in a vein some years ago, of a rhombohedron, $\{03\bar{3}2\}$, closely simulating a cube.

The calcite at this locality illustrates a feature often encountered in the Antrim crystals: when it occurs in veins, the crystals are very commonly twinned on $e\{01\bar{1}2\}$. In many veins all of the crystals are twinned, and have the characteristic platy habit due to infilling of the re-entrant angle of the twin. Such twinning is confined to the calcite of veins, being never found in amygdales, and it seems likely that twinning was initiated by stress during growth of the crystals.

A few crystals suitable for measurement were collected from basalt lavas on the shore at Heddles Port, Islandmagee. The crystals show a steep scalenohedron, the faces of which give excellent reflections, and the following interfacial angles were measured on three crystals:

$(hk\bar{i}l):(\bar{h}i\bar{k}l) = 65°\ 07'$, $65°\ 07'$, $65°\ 31'$, $64°\ 53'$, $65°\ 34'$, average $65°\ 12'$;
$(hk\bar{i}l):(i\bar{k}\bar{h}l) = 54°\ 16'$, $53°\ 49'$, $54°\ 18'$, $53°\ 57'$, $54°\ 21'$, $54°\ 23'$, $53°\ 57'$, average $54°\ 09'$.

These values agree well with the calculated values of 65° 10′ and 54° 13′ respectively for *W*.

Several small crystals from the Middle lava series of Bengore Head show a steep scalenohedron terminated by various combinations of *r*, *f*, and *M*. All but *f* gave good reflections, and the following angles were measured on one crystal for the scalenohedron:

$(hk\bar{i}l):(\bar{h}i\bar{k}l) = 65°\ 25'$, $65°\ 08'$, $65°\ 28'$, average $65°\ 20'$;
$(hk\bar{i}l):(i\bar{k}\bar{h}l) = 53°\ 53'$, $54°\ 08'$, $54°\ 05'$, average $54°\ 02'$;

these again agree well with the calculated values for *W*.

In a large basalt quarry beside the railway in the glacial overflow channel 3 miles east of Ballymoney most of the calcite is a dull grey plumose variety in which *e* is the predominant form. Minute brilliant crystals formed as a parallel overgrowth on a substratum of plumose calcite are stumpy scalenohedral in habit, terminated by *M*, *f*, and other forms. The following angles were measured on one crystal:

$(hk\bar{i}l):(\bar{h}i\bar{k}l) = 65°\ 30'$;
$(hk\bar{i}l):(i\bar{k}\bar{h}l) = 53°\ 33'$, $53°\ 37'$, average $53°\ 35'$.

These values agree well with the calculated values 65° 35′ and 53° 40′ respectively for $\{6.5.\overline{11}.1\}+R11$. There is also present a less steep scalenohedron in the same zone with $(hk\bar{i}l):(kh\bar{i}\bar{l}) = 30°\ 47'$, indicating probably either $\{32\bar{5}1\}$ or $\{17.11.\overline{28}.6\}+R4\frac{2}{3}$, for which the corresponding calculated angles are respectively 29° 16′ and 31° 18′.

Large cavities in basalt in a quarry a short distance east of Portadown contain brown calcite with *f* modified by a steep scalenohedron. Measured angles for this scalenohedron are:

$(hk\bar{i}l):(\bar{h}i\bar{k}l) = 64^\circ\ 00'$;
$(hk\bar{i}l):(i\bar{k}\bar{h}l) = 55^\circ\ 06'$.

These values may indicate $(15.13.\overline{28}.2)+R14$ for which the corresponding calculated angles are respectively 64° 28′ and 55° 04′; the reflections are not good enough to enable this form to be established.

Zeolites (faröelite, chabazite, and a little stilbite) follow the brown calcite at this locality, and are followed in turn by colourless calcite of steep scalenohedral habit, terminated by *r*, *f*, and *M*. One brilliant crystal, of stumpy scalenohedral habit, gave the following measured values:

$(hk\bar{i}l):(\bar{h}i\bar{k}l) = 65^\circ\ 12', 65^\circ\ 15', 65^\circ\ 08'$, average $65^\circ\ 12'$;
$(hk\bar{i}l):(i\bar{k}\bar{h}l) = 54^\circ\ 13', 54^\circ\ 11', 54^\circ\ 08'$, average $54^\circ\ 11'$;
$(hk\bar{i}l):(kh\bar{i}\bar{l}) = 12^\circ\ 26'$.

These agree well with the calculated values 65° 10′, 54° 13′, and 12° 27′ respectively for *W*. The lateral edges of the scalenohedron are bevelled by brilliant faces of $a\{11\bar{2}0\}$. On another crystal of similar habit the short terminal edges of *W* are bevelled by bright faces of a rhombohedron that must be $\{09\bar{9}1\}$.

Crystals collected from the shore west of Kinbane Head show a steep scalenohedron for which the following angles were measured (the faces gave rather diffuse reflections, but the values first cited are probably reliable):

$(hk\bar{i}l):(\bar{h}i\bar{k}l) = 65^\circ\ 53', 65^\circ\ 46', 66^\circ\ 03'$, average $65^\circ\ 54'$;
$(hk\bar{i}l):(i\bar{k}\bar{h}l) = 53^\circ\ 07', 53^\circ\ 15', 53^\circ\ 31'$, average $53^\circ\ 18'$.

These values agree well with the calculated values 66° 07′ and 53° 00′ respectively for $\{11.9.\overline{20}.2\}+R10$.

Crystals from a quarry at the western end of Keady Mountain show a steep scalenohedron terminated by *r* and *M*. Measured angles for the scalenohedron are:

$(hk\bar{i}l):(\bar{h}i\bar{k}l) = 61^\circ\ 37'$;
$(hk\bar{i}l):(i\bar{k}\bar{h}l) = 56^\circ\ 25'$;
$(hk\bar{i}l):(kh\bar{i}\bar{l}) = 49^\circ\ 12'$ to $50^\circ\ 22'$.

These values agree roughly with the scalenohedron $\{21.19.\overline{40}.2\}+R20$, but the crystals are not good enough to enable this form to be established.

Brilliant crystals of acute scalenohedral habit from a quarry ½ mile south-east of Ballyclare gave reliable measurements indicating the scalenohedron to be $\{13.11.\overline{24}.2\}$+R12. Two minute crystals from the Langford Lodge borehole[1] were also measured; a single measurement on one incomplete crystal of scalenohedral habit from a depth of 880 ft. indicates $\{15.13.\overline{28}.2\}$+R14 as the scalenohedron present, and a crystal from 1350 ft. has $\{6.5.\overline{11}.1\}$+R11 as the predominant form.

Discussion.

It is quite clear from the measurements that several steep scalenohedra in the zone $[\overline{1}101]$ are represented in Antrim. Unfortunately measurable crystals are very scarce in Antrim, and it is reasonable to suppose that as the number of measurable crystals is increased so the number of scalenohedra established would likewise increase. Calcite is readily dissolved by meteoric waters, and most of the crystals collected by the writer have been dissolved to some extent; the scalenohedron faces give multiple reflections, and measurement is useless. A list of known scalenohedra in the zone $[\overline{1}101]$ steeper than +R5 is given in table I together with Palache's (1940) data on the frequency (the number of localities from which the form has been recorded).

Crystals of steep scalenohedral habit are so common and characteristic of the regional type of occurrence in Antrim that one is prompted to inquire if this habit may be typical of basaltic regions elsewhere. The limited available data in the literature does not lend much support to the idea that they are. For example, of the sixty illustrations of calcite from the Tertiary basaltic region of the North Atlantic in Goldschmidt's Atlas (1913) only three (fig. 1002 from the Faröes; figs. 2001 and 2 from Skye) are of this habit. On the other hand, the writer's observations in the Tertiary basalts of eastern Iceland suggest that in fact the Antrim type of habit is very widespread. The reason why this habit is so poorly represented in the literature is probably that crystals with the regional type of occurrence are rather small and inconspicuous; where calcite is most abundant and conspicuous it is in a geological environment of the local type. Thus the well-known Helgustadir Iceland Spar deposit is situated in altered basalts within an aureole of intense hydrothermal alteration about a Tertiary volcanic centre (Walker, 1959).

[1] The writer is indebted to the Director of the Geological Survey of Northern Ireland for permission to examine specimens and to publish this note.

The basic uniformity in habit throughout the normal zeolite zones of the Antrim Basalts presents further evidence that crystal habit is not due to chance, but is controlled by the conditions obtaining at the time of crystallization. Exactly what those conditions were in the case of Antrim cannot at present be deduced, but the conditions must have been similar to those under which zeolitization took place, for the regional type of calcite is usually associated with zeolites and commonly precedes them in amygdales. Goldschmidt illustrates calcite of similar steep scalenohedral habit from a number of localities, notable from Andreasberg and Zellerfeld in the Harz, and from Framont in Belgium, which suggests that similar conditions may obtain elsewhere than in basic lavas. One must suppose that the various steep scalenohedra require closely similar conditions for their formation.

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