

GEOLOGY & LOCAL HISTORY.

HAIGH, (W.D.).

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In *R.I.A. Proc.*, xxxii (1914), section B, no. 3, pp 17-33.

III.

THE CARBONIFEROUS VOLCANOES OF PHILIPSTOWN IN
KING'S COUNTY.

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[Read APRIL 27. Published JULY 2, 1914.]

ABOUT three miles to the north of Philipstown in King's County and close to the boundary of Meath, a number of small hills rise from the great central limestone plain and form a conspicuous feature over a very large area of this part of the country.

The chief of these is Croghan Hill, which, on approaching it from the south, stands out as a conical eminence rising with steep grassy slopes to a height of 769 feet above sea-level, and about 460 feet above the general level of the plain. It slopes more gently to the north for three-quarters of a mile before descending somewhat abruptly to the level of the plain beyond, and forms a pleasing contrast to the great area of brown bog-land which surrounds it. This forms a centre round which a group of minor hills are clustered, the whole occupying an area of approximately four square miles.

On reference to the one-inch Geological Survey map¹ of the district, it will be observed that the area is mapped as greenstone (diorite) and greenstone ash; and these rocks with a few bands of limestone extend over the greater part of the area. In the explanatory memoir of the district,² the greenstones are treated as intrusive; but the greenstone ash seems to be regarded as interstratified in the Carboniferous limestone, although, as is pointed out in the memoir, there is no direct proof of this, owing to the lack of a continuous section.

There are two main outcrops of these igneous rocks, separated from each other by a band of limestone. One includes Croghan Hill and the surrounding district to the south and east, while the other lies to the west and extends northwards, as a crescent-shaped band, round the base of the hill. A smaller

¹ Geol. Surv. Ireland: Sheets 109 and 110.

² Geol. Surv. Ireland: Explanations to sheets 98, 99, 108 and 109, 1865, p. 18.

area occurs in the northern angle of the limestone band dividing the two main outcrops, about three-quarters of a mile north-north-east of the summit of the hill. About one and a half miles in a south-westerly direction basalt is seen overlying limestone in a quarry, half a mile north of Clonearl House in the Clonearl demesne.

Again, at Castle Barnagh, close to Philipstown, there is a small projecting knoll of intrusive rock.

Croghan Hill is a volcanic neck which rises through the Carboniferous limestone, and was the main vent through which the ash now covering a large portion of the area was ejected. It is now but the stump of what must have been a much higher and larger cone, while the ash covered a more extensive area than at present, but long continued denudation has worn it down to its present size, exposing to view the internal structure of the volcano, with its central pipe or vent now choked with intrusive material round which lies the ash originally ejected through the vent. Croghan Hill though the chief, is not the only vent in the district. It forms a centre round which a group of subsidiary vents have been opened, each of which probably remained active for a time, throwing out its ash and adding to that being deposited from the main vent. But towards the close, when the volcanic activity was subsiding and the explosive violence which gave rise to the ash had ceased, the lava welled up quietly from below, filling the vents and forming a plug of basalt. Such plugs being much harder and more resistant to weathering than the surrounding limestone, now stand out as low hills.

Although the basalt has welled up and choked the vents, there seems to have been no extensive outpouring of lava, as no sheets occur in the district. The basalt overlying the limestone in the Clonearl quarry is probably an intrusive sill which denudation has exposed. The limestone here dips at 15° to the east and is overlain directly by the basalt, which has a rude vertical columnar structure. No trace of ash is visible between the two, although the actual junction can be seen for some distance along a drain at the northern end of the quarry. The limestone, which is composed of dark shaly and cherty bands, has not been altered to any extent by the intrusion.

The ash and breccia comprising the greater part of the igneous material in the district is of a very uniform character. It has a greenish colour, and often contains fragments of chert and limestone embedded in it, and generally specks of pyrite can be seen. The fragmentary material is set in a calcareous ground mass. On weathering it sometimes shows a spheroidal structure, and lines of bedding were observed in one or two instances, but these were generally very obscure. This ash is well seen round the sides of

Croghan Hill in the projecting crags. The fragmentary material in the ash varies from the size of a walnut to dust so fine that it can only be observed with the aid of a microscope. It consists of angular and subangular pieces of pale grey vesicular pumice; the vesicles are often filled with calcite and a green chloritic mineral. In describing this ash Sir A. Geikie¹ says: "I am not aware of any other necks so homogeneously filled up with one type of pyroclastic material, and certainly there is no other example known in the British Isles of so large and uniform a mass of fragmentary pumice." The ash is very calcareous and in some parts might be described as an ashy limestone. It is hard to account for the presence of so much calcareous material in the ash, unless, as Sir A. Geikie suggests, the vents were opened on the floor of the carboniferous sea, when fine calcareous silt would find its way down into the interstices of the ash, and into the pores of the pumice. Although percolating water containing carbonate of lime in solution may have added to this, it does not seem likely that this process would in itself be adequate to so thoroughly saturate the ash.

The limestone directly underlying the ash, in the few sections visible, is a dark impure shaly rock, very similar lithologically to the "Calp" or "Middle limestone" so well developed in the neighbourhood of Dublin. The ash contains fragments of the limestone and chert embedded in it, and in a few instances pieces of basalt were found enclosed in the ash. Some of these limestone and chert fragments were distinctly angular, and had evidently been blown out of the vent when it was first opened, and thus became embedded in the accompanying ash. Other pieces are quite rounded and have all the appearance of water-worn pebbles and boulders. Similar rolled pebbles have been found in the volcanic area near Limerick, and in describing these Mr. J. R. Kilroe² says: "The more natural way of accounting for the circumstance is to attribute them to the action of waves on an exposed mass of basic lava, the results of attrition being then distributed over the neighbouring sea-floor, where ash was accumulating." The majority of the pebbles found in the Croghan Hill ash are not basalt, but chert and limestone, particularly chert.

If the ash was deposited directly on the dark, shaly limestone while the latter was accumulating on the sea-floor, the sea must have been a shallow one, and the vent, with its surrounding limestone, was probably a small volcanic island, against which the waves of this shallow sea beat, breaking down the limestone shore and finally eroding away the softer limestone,

¹ "Ancient Volcanoes of Great Britain," vol. ii, 1897, p. 39.

² *Memoirs Geol. Surv. Ireland*, "Geology of the Country round Limerick," 1907, p. 39.

which left the more resistant chert to be entombed in the ash. This seems a possible explanation of the fact that the larger number of pebbles found in the ash are chert.

That the igneous material, which forms the necks, actually breaks through the Carboniferous limestone can be seen in several sections. In a quarry, about half a mile east of the summit of Croghan Hill, dark limestone with bands of shale and many crinoid stems occur. The limestone here is much disturbed, and the bedding is rather obscure; but it sometimes dips towards the centre of the hill, and sometimes a little east or west of it. The limestone strata are penetrated by a neck which rises a little further to the east, and close to the edge of the bog, showing clearly that the igneous material has been forced up through the limestone. Similarly, about three-quarters of a mile south-east of this point, near Barrysbrook House, the igneous material may again be seen breaking through the limestone. A like feature may be observed by the roadside at Gorteen, on the south-western side of Croghan Hill, where "the limestones have been thrown into a highly inclined position, dipping towards the east at 60° or more, and their truncated ends abut against the sides of the neck."¹ At Glenmore holy wells, one-third of a mile north-north-east of the summit of the hill, black, shaly and cherty limestone are seen dipping south at a low angle into the body of the hill; a little north-west from this, on the hill, grey limestone is exposed, and several other outcrops of a similar limestone are seen round this point. This grey limestone runs south-west in a curved band, and is well seen on the road a short distance west of Gorteen. At this point a quarry is opened, and the rock is seen to be a hard, grey limestone, much jointed, and has all the appearance lithologically of the Lower limestone; but, owing to the lack of fossil evidence this cannot be definitely ascertained.

On passing over this band of grey limestone, in a northerly direction, the black, shaly limestone again appears, and is now seen to dip northwards at about 20° under the ash, which covers the surface between this point and the bog to the north. The dark, shaly limestone is also seen a little east of this but here it has a north-easterly dip. As mentioned above, this limestone has all the appearance of the Middle limestone or "Calp," and in all probability represents the basement beds of this series. This is overlain directly by the ash and underlain by the compact grey or Lower limestone, the latter being brought to the surface by an anticlinal fold, as the black limestone is seen dipping south under the main ash on Croghan Hill and dips north under the ash surrounding Boston; the grey limestone being exposed on the surface

¹ Sir A. Geikie, "Ancient Volcanoes of Great Britain," vol. ii, 1897, p. 38.

between the two outcrops. It seems to have been over this bed of black, shaly limestone that most of the ash was originally deposited, the Croghan Hill ash and that in the neighbourhood of Boston being at one time a continuous bed. The small anticlinal fold, just north of the main vent, was probably caused by the disturbances that took place at the close of the carboniferous period when the Hercynian folds were formed. From the summit of this anticline, the ash and the underlying bed of black, shaly limestone have been worn away, separating the ash into two parts, and exposing the upper beds of the Lower limestone.

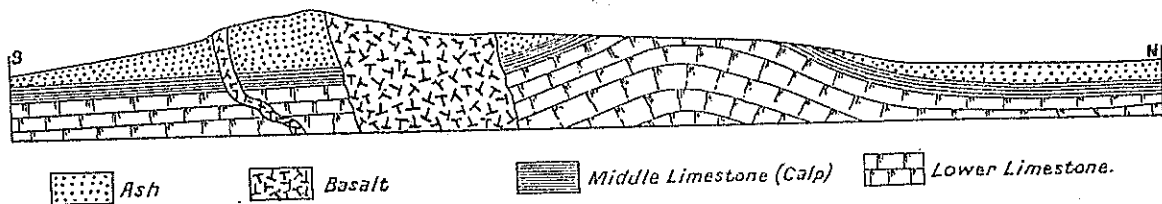


FIG. 1.—Diagrammatic Section across Croghan Hill.

No very conclusive evidence of the interstratification of the ash and limestone was observed, but a few instances occur which throw some light on the age of the volcanic eruptions. As noted by Sir A. Geikie,¹ one of these can be seen near Gorteen on the south-west side of the hill. Here there is a band of limestone only a few feet thick, with ash above and below it, and, although the junction between the two is well defined, no trace of any volcanic material can be seen in the limestone. Pieces of chert and limestone are, however, of common occurrence in the ash. Another instance occurs at the most easterly neck, just north of Coolmount House, where the limestone, much undulating, appears to dip below the ash. On the northern side of this neck the limestone is seen, again rapidly undulating, and it finally plunges southwards beneath the ash on the hill. The ash, which here overlies the limestone, shows a series of divisional planes suggestive of bedding, which dip south parallel with the limestone. About two hundred yards west of this point a well has been sunk to a depth of twelve feet. This passes through about six feet of dark limestone with bands of shale and chert. This is seen to be underlain by a bluish, grey clayey material which is highly calcareous, and when examined had all the appearance of weathered ash, as it consisted of small vesicular fragments of pale grey pumice lying in a clayey matrix. This material appears to be ash weathered in situ, which has been decomposed by the infiltrating of water through the over-lying limestone. This limestone is evidently a continuation of the dark, shaly beds which occur a little further to the east, where they

¹ *Op. cit.*, p. 39.

dip south beneath the ash on the hill, and it thus appears to be interstratified between the two beds of ash. Hence the volcanic eruptions which gave rise to the ash were intermittent during the deposition of the black, shaly limestone, and are probably of Middle Carboniferous Limestone age. Although as Sir A. Geikie suggests, the band of stratified rock seen in the section near Gorteen, on the western side of the hill, may be a large included mass lying within the vent itself, this does not appear to be the case with the limestone near the most easterly neck, which seems to be a continuation of the beds underlying the bog to the north. The ash found below this limestone is probably a lenticular mass that thins out and finally disappears northwards. It would seem from this that a portion of the ash is contemporaneously interstratified in the lower beds of the Middle Carboniferous Limestone series.

Although volcanic eruptions are a conspicuous feature of Carboniferous times, both in England and the south of Scotland, this period was one of comparative quiescence in Ireland, as the only undoubted volcanic rocks of this date so far known occur in the neighbourhood of Limerick, and have recently been re-investigated by the Geological Survey.¹

In the south-western headlands, about Bantry Bay, various igneous rocks occur which consist of "greenstone," ash, and breccia. It is possible that these are of Carboniferous slate age, but they may be of later date.

In the Limerick area the first volcanic phenomena manifested themselves in Upper Old Red Sandstone times, and, after a period of rest, they broke out again in a minor way during the deposition of the Lower limestone. But it was not until the incoming of the Middle limestone epoch that the eruptions reached their maximum. Then the volcanic action declined and eventually disappeared.

In the Croghan Hill area there is no evidence to show that any eruption took place as early as the Old Red Sandstone and Lower Carboniferous limestone epochs; but it appears that shortly after the beginning of the Middle limestone epoch volcanic activity commenced. That physical conditions underwent a change is shown by the difference in the two limestones which exist in the area. Volcanic activity took place shortly after the argillaceous conditions of deposition set in, as no great thickness of the black shaly limestone was observed in any section between the ash and the underlying grey limestone. This condition very much resembles that which occurs in the Limerick area, as will be seen by the following quotation from the memoir²:—"From what has been set forth above regarding the lithological

¹ Geo. Surv. Ireland, "Geology of the Country round Limerick," 1907.

² *Ibid.*, p. 19.

difference noticeable in the rocks of this higher member of the limestone group [Middle Limestone], it seems obvious that corresponding differences of an interesting character prevailed in the conditions of contemporaneous deposition. There is little doubt that the sudden change, and diversity in character and contents, in the higher series, was accompanied, if not caused, by the commencement and continuance for a time of volcanic activity in the region."

The movements which occurred immediately preceding or during the volcanic eruptions may have caused the local undulations in the sea-floor, and, as suggested for the Limerick district, may have caused the abrupt alteration and diversity of conditions which gave rise to the deposition of the argillaceous type of limestone.

The ash of the Croghan Hill district bears a close resemblance to much of that which occurs in the Limerick area, and is similar to that of Carboniferous Age in Scotland and central England.

It is of a pale colour, very uniform in character, and contains much calcareous material.

Another rather striking feature, which tends to connect the Limerick and Croghan Hill volcanic areas, is that they lie on a line which is parallel to the Caledonian axes of folding, which played so conspicuous a part in the topography of the country. It is not a little remarkable that such a line marks the boundary of the rocks of Atlantic affinities, occurring in the Lower Carboniferous series in Great Britain and Ireland.¹ This line passes just south of the Scottish carboniferous volcanic areas, and the series of rocks both in Ireland and Scotland belong to a province of a distinctly Atlantic type. In the south of Scotland the Atlantic type is overlapped by a series of dykes and sills of late Carboniferous age, or even later, consisting of sub-alkaline rocks, which belong to a Pacific province; but no such type of rock has been found in the Carboniferous intrusions in Ireland.

DESCRIPTION OF THE VOLCANIC ROCKS.

The igneous rocks occurring in the district are roughly divisible into two main types, which can be classed as pyroclastic and intrusive. The pyroclastic rocks are breccias and tuffs. The fragmentary material composing these breccias and tuffs consists mainly of basic lapilli, which were blown out of the vent, being in a liquid form at the time of the explosion, since this glassy material contains oval, much elongated, and tubular bodies produced by the drawing out of steam-cavities, most of which have now become filled

¹ A Harker, "Natural History of Igneous Rocks," 1909, p. 107.

with calcite or a green chloritic mineral. This ash falling in showers into the sea became mixed with epiclastic material, such as limestone and chert, the whole finally consolidating to the compact rock which now forms the breccia or ash of the district (fig. 2).



FIG. 2.—x 8.

The intrusive rocks occur for the most part as solid pipes, filling up the vents from which the ash was ejected. One of these intrusions forms the core of Croghan Hill itself, with the ash surrounding it; and the smaller cones standing out, particularly on the eastern and northern sides, as low hills round the base of the main vent, were probably parasitic cones fed by channels from the chief pipe of the volcano. Towards the close of activity, when the explosions which gave rise to the ash had ceased, the lava rose quietly from below, and solidified in

the vents. An examination of these intrusions produced no evidence to show that they took place at different intervals, nor any indication of the successive protrusion of progressively different types of lava. The petrographic types, having much in common, and not being possessed of great variety, seem to point to the conclusion that they were intruded simultaneously from a common magma, the small variation in composition being due to local physical causes in the magma at the time of intrusion. The rock varies from a blue-black fine-grained basalt to a more doleritic type where the plagioclase is distinct, and in a few instances a more basic type passing into a limburgite. All have a more or less prevalent amygdaloidal structure; the amygdales are generally composed of calcite, but often contain serpentine.

In one locality in Croghan demesne Professor Watts¹ calls attention to a noticeable feature in these volcanic rocks. This is the occurrence in them of lumps of a highly crystalline material quite distinct from the enclosing rock. The enclosures referred to vary in size up to a foot in diameter, and are doubtless blocks caught up by the lava in its ascent. These rocks are described by Professor Watts. One specimen "contains relics of garnets, surrounded by rings of kelyphite, embedded in a mosaic of felspar, with a mineral which may possibly be idocrase." He describes another specimen as containing "the relics of garnets preserved as kelyphite, set in a matrix of quartz-grains, much strained, and containing a profusion of crystals of greenish-yellow or red

¹ Geol. Surv. Ireland, "A Guide to the Collection of Rocks and Fossils," p. 38.

sillimanite. This appears to be a metamorphic rock, and may be a fragment of some sediment enclosed in the igneous rocks." From an examination of one of these rock-sections it appears to be a fragment of a sedimentary rock which has been broken off and enclosed by the lava in its ascent. The quartz crystals contain numerous cracks which are filled with a brown glass. The liquid mass was evidently forced into the interstices of the rock and into the cracks in the crystals. In this feature the rock much resembles that in a dolerite dyke from Ross Harbour Point on the shore of Lower Lough Erne.¹ The interest of these rocks is obvious, as giving some indication of the character of the floor of the country below the Carboniferous and, perhaps, below the Silurian strata.

The various outcrops of the intrusive rocks will now be described in detail, beginning with the more northern outcrops. About three quarters of



FIG. 3.— $\times 8$.

a mile north-north-east of the cairn on the summit of Croghan Hill, a circular-shaped knoll rises about two hundred feet above the level of the plain. It is surrounded on the north, west, and south sides by ash, which in turn is surrounded by limestone, the limestone abutting directly against the intrusive rock on the western side. This is a dark-blue compact, slightly amygdaloidal rock, the amygdales being composed of calcite (fig. 3). It is fine-grained and crystalline, and it shows good idiomorphic crystals of augite set in a matrix of smaller

crystals. The pyroxene, which occurs in two generations, has generally the purplish tinge which is taken as an indication of the presence of titanium. The larger crystals sometimes show zonal structure, and a gradation in colour, being brown or purple on the outside, and fading away to a perfectly clear pyroxene at the centre. Much olivine was originally present in the rock, both as crystals and irregular blebs, but it now only exists as pseudomorphs in calcite and chlorite, and often presents a mosaic structure, the cracks of which in some cases still show traces of iron oxide. Some of these pseudomorphs have a perfect olivine outline, while others occur as irregular grains and patches scattered through the ground. No fresh olivine was seen in the rock. Much titaniferous magnetite was originally present, but it is now mostly altered into leucoxene. A few crystals of apatite were also observed. Amygdales occur filled with calcite, which show a radial structure round the edges,

¹ Geol. Surv. Ireland, Explan. Mem., Sheet 32, pp. 43 and 21.

as reddish brown pleochroic flakes, which, though it occurs in isolated patches, is usually seen as a mantle round the iron ore grains which are scattered abundantly in the rock. This intrusion appears to belong to the lamprophyre group, and might be described as a mica-augite-lamprophyre. It has a specific gravity of 2.88.

The ash over the whole area is of a very uniform character, having a greenish colour, and enclosing fragments of chert, limestone, and basalt. The fragmentary material for the most part is a highly vesicular pumice, the vesicles being generally filled with calcite. The pumiceous fragments are angular, sub-angular, and rounded, and are set in a calcareous cement, which is now generally represented by white calcite, but which undoubtedly consisted in large part originally of limestone. On weathering, the rock often gives rise to a curious mosaic structure due to projecting fragments of pumice. In some instances the calcareous cement is stained red with iron oxide. In the calcite material between the fragments, spherulitic areas occur, in which lie a number of microlites of felspar in an almost opaque white ground. In some of these areas the microlites lie haphazard, but in others crystallization seems to have taken place from the outer rim, the microlites radiating towards the centre (fig. 8). The spherules are probably concretions, similar to those described from a tuff from Torres Strait.¹

In the Irish examples the spherules are probably composed of complex lime silicates, from which the felspar has crystallized as a product of secondary change. On the south-west side of the hill, near Gorteen, a small outcrop of a tuff appears, which differs in character from the main mass. It is a brittle greyish rock, containing patches of a slightly altered brown glass. In section these brown patches have a flecked appearance, which is probably due to minute enclosures of feldspathic material. The interstices between the glass is filled in with felspar in which secondary crystallization has taken place. The rock is a palagonite tuff. Just north of the summit of Croghan Hill, the ash is of a very compact nature, with a bluish-green colour. It contains many joint planes along which it splits very readily. These planes



FIG. 8.— $\times 8$.

¹ Haddon, Sollas, and Cole, "Geology of Torres Strait." *Trans. Royal Irish Academy*, 30, p. 419: cf. I. Friedlaender, "Über die Kleinformen der vulkanischen Produkte." *Zeitschrift für Vulkanologie*, Band I, Heft I, Jan. 1914, p. 37, fig. 13.

are horizontal, three or four occurring in the space of an inch, and they pass through the fragments of pumice. The closeness of the joints gives the rock

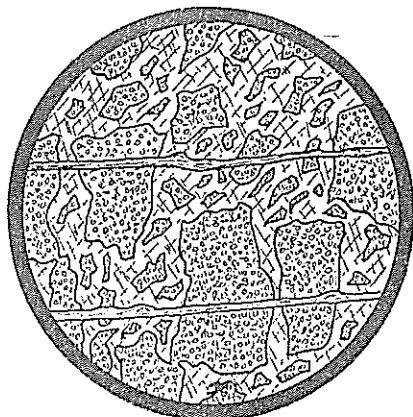


FIG. 9.— $\times 8$.

a shaly appearance when shattered (fig. 9). The ash over the whole district is unstratified except at the most easterly outcrop, where a suggestion of bedding is seen, and again in a small exposure north of the summit, where the weathered surface of a projecting crag shows alternate beds of coarser and finer material, the beds being about a foot in thickness.

The uniformity in character and pumiceous nature of this breccia distinguishes it as "one of the most remarkable breccias anywhere to be found in the volcanic records of the British Isles."¹

SUMMARY.

Croghan Hill and the smaller hills surrounding it are a series of volcanic vents, from which the fragmentary pumice, now forming the green ash and breccia of the district, was ejected.

The volcanic eruptions took place in the Carboniferous sea during the deposition of the cherty and shaly zone at the junction of the Lower and "Calp" (Middle) Limestone.

They are consequently of the same age as the major outbursts of volcanic rocks during the Carboniferous Period in the neighbourhood of Limerick.

From the number of rounded fragments of chert and limestone found in the ash, these vents seem to have formed small volcanic islands in the Carboniferous sea, which, at that epoch, was shallow over a large part of Ireland. Towards the close of the volcanic activity, when the explosion which gave rise to the ash had ceased, the lava welled quietly up from below and solidified in the vents.

No sheets or sills occur in the district, with the exception of that seen in the quarry on the Clonearl estate. This mass, from its columnar structure and absence of ash, appears to be a sill which has been intruded into the Carboniferous Limestone.

The intrusive material filling the necks is of a basic nature. It varies from a dolerite in which the plagioclase is distinct, to a blue-black fine-grained basalt, some portions being more basic and passing into limburgite

¹ Sir A. Geikie, "Ancient Volcanoes of Great Britain," vol. ii, 1897, p. 39.

The basalt from many of the outcrops shows the glomero-porphyrific structure, and where an appreciable quantity of felspar is present, it occurs generally with irregular boundaries, notched by the intrusion of idiomorphic crystals of augite and magnetite. This is, perhaps, the most noticeable feature to be observed in this series of rocks. The intrusive sill in the Clonearl quarry is the most basic rock occurring in the district, and is a true limburgite.

At Castle Barnagh a small intrusive knoll occurs which is composed of a rock best described as a mica-augite-lamprophyre.

The ash is of a very uniform nature throughout the district. It is composed of angular, sub-angular, and rounded fragments of a pale, greenish grey basic pumice, the vesicles of which are filled with calcite. The ash encloses rounded fragments of chert and limestone, the whole being held together by a cement of calcite.