A STUDY OF BALLSTONE AND THE ASSOCIATED BEDS IN THE WENLOCK LIMESTONE OF SHROPSHIRE.

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WITH NOTE ON SOME REEF-STRUCTURES IN GOTLAND.

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[Read March 6th, 1914.]

	PAGE
I.—Introduction	193
II.—Historical Summary	194
III.—General Description of the Wenlock Limestone of Shropshire and Herefordshire	196
IV.—Description of <i>ballstone</i>	199
V.—Description of the Associated Beds	202
VI.—Selected Quarries and Faunal Notes	203
VII.—Comparison of the Wenlock Limestone of Wenlock Edge with that of other Areas in England	210
VIII.—Comparison of <i>Ballstone</i> with Similar Structures in Palæozoic Limestones	212
IX.—Summary.—Conclusions	221
Appendix.—Note on Some Reef-Structures in Gotland	225

I.—INTRODUCTION.

THE Wenlock Limestone of Wenlock Edge and the adjoining district is intimately known to most geologists, but there are certain features developed in these beds to which we would direct further attention.

No geologist who has visited the region can have failed to notice the peculiar lenticular structure which the limestone assumes in certain parts. In an evenly-bedded limestone an irregular ball-shaped or lenticular mass of unstratified limestone is found to occur, which a closer inspection reveals to be crowded with fossils. This development of the limestone has received from the Shropshire quarrymen the name of *ballstone*. On our first visit our attention was at once arrested by these structures, and we have in consequence made a study of these beds with the hope of satisfying ourselves as to the causes which have produced them. In the following paper we describe the structure of *ballstone* and the occurrence in *ballstone* of an attached colonial fauna which differentiates the beds from the normal limestone series, and we compare the *ballstone* structure of the Wenlock Limestone of Wenlock Edge with similar structures found in Palæozoic limestones elsewhere.

In 1910 an excursion of the International Geological Congress to the Island of Gotland afforded us an opportunity of examining the limestones of the same and higher horizons in which similar structures may be seen, but on an even grander scale.

We are glad to take this opportunity of thanking Dr. Teall, by whose suggestion our attention was directed to the Wenlock Limestone, and Mr. Allen, Mr. J. Allen Howe, and Mr. Lang, for their kind help in facilitating our work in various ways, and the officials at Jermyn Street and the Natural History Museum (British Museum), and Dr. G. J. Hinde. Also we are most grateful for facilities so freely given us by the owners and managers of the numerous quarries we visited, more especially to Mr. J. E. Boulton, of Bradley, and to the manager of the Lilleshall Company's Quarry, Presthope, and also to Mr. Hayward, of Tickwood Hall, for kind permission to explore in his woods.

II.—HISTORICAL SUMMARY.

In an early paper,* "On the Sedimentary Deposits which occupy the Western Parts of Shropshire and Herefordshire, etc.," Murchison stated that the lower beds in Wenlock Edge contain many concretions of very great size and of highly crystalline structure. In 1839 "The Silurian System"† was published, and his description of the Wenlock Limestone given therein still remains the best and fullest account. He described the beds from Lincoln Hill to Presteign and pointed out the difference between the limestone in the northern area and that in the southern. When describing the chief calcareous masses he wrote that in some quarries "all traces of bedding are wanting, and the whole calcareous mass is made up of concretions sometimes of immense size, surrounded by beds of shale and impure limestone These large concretions are called *ballstones*."

In Siluria‡ he added the statement that "this rock (Wenlock Limestone) is indeed distinguishable from all the inferior strata by the very great abundance of its corals, the profusion of which makes it resemble in many places a coral reef."

Prestwich§ described the structure of the Wenlock Limestone of Wenlock, Gleedon, and Tickwood as "concretionary and the fracture conchoidal. The masses . . . frequently form large irregularly rounded blocks, highly crystalline and pure. They are termed *ballstones*."

In 1841 Lyell|| described the corals of the Wenlock Limestone as still retaining the position in which they grew, and

* "On the Sedimentary Deposits which occupy the Western Parts of Shropshire and Herefordshire," etc. *Proc. Geol. Soc.*, (1833).

† "The Silurian System." London, 1839.

‡ "Siluria," 5th Ed. (1872), p. 119.

§ *Trans. Geol. Soc.* Ser. 2, vol. v, part iii. (1840).

|| "Some Remarks on the Silurian Strata between Aynstry and Wenlock." *Proc. Geol. Soc.* (1841).

argued that those parts of the Wenlock Limestone in which the corals preserve their natural position were produced at a moderate depth below the surface. This conclusion, he said, is supported by the occurrence with them of inverted and broken corals, which were fragments which had been broken off by the action of the waves and thrown down upon the reef.

In 1865 the Rev. J. D. la Touche read a paper at the British Association,* "On the Nodules of the Limestone of Wenlock Edge," and in 1869 a paper† "On Spheroidal Structure in Silurian Rocks," in both of which he described "huge masses of limestone called *ballstones* . . . which vary in size from a few feet to 50 ft. in thickness, and their length . . . is in some cases more than 100 yds.," and he stated his reasons for thinking that these "concretions give plain evidence of having been formed subsequently to the deposition of the whole stratum."

In his "Handbook of the Geology of Shropshire" (1884) his description of the Wenlock Limestone is very short, and he adds no material details.

The Rev. W. S. Symonds,‡ in his "Records of the Rocks" published in 1872, made the suggestion that "Wenlock Edge may have been a barrier reef which was formerly prolonged to the outlying mass at Botville."

Messrs. Davidson and Maw§ estimated the thicknesses of the several subdivisions of the Upper Silurian Rocks of Shropshire, and ascertained that the compact limestone is from 80 to 90 ft. in thickness.

Lapworth and Watts,|| in "The Geology of South Shropshire," describe the Wenlock Limestone as "generally in thin beds separated by shale bands, but where the limestone becomes thicker it is highly concretionary, and large lumps of pure crystalline limestone occur—these are called *ballstones*. . . . Sometimes considerable thicknesses of the limestone are made up of corals . . . still in their position of growth." The description given by these authors¶ in the Jubilee Volume of the Geologists' Association adds nothing to their earlier account.

References to the Wenlock Limestone are also made by Sir H. de la Beche,** Dr. John Phillips,†† S. P. Woodward,‡‡ Wethered§§ (who described its microscopic structure), E. S. Cobbold,||| and Dr. H. C. Sorby.¶¶

* *Rep. Brit. Assoc.* (1865), sections, p. 76.

† *Rep. Brit. Assoc.* (1869), sections, p. 95.

‡ Symonds, W. S., "Records of the Rocks," p. 175 (1872).

§ Davidson & Maw. *Geol. Mag.*, N.S., dec. ii, vol. viii (1881).

|| *Proc. Geol. Assoc.*, vol. xiii (1894).

¶ "Geology in the Field," ch. xxx, p. 739 (London, 1910).

** *Mem. Geol. Surv.*, vol. i, pp. 39-41 (1846).

†† *Mem. Geol. Surv.*, vol. ii, part i, pp. 128-222 (1848).

‡‡ *Geol. Mag.*, p. 42 (1864).

§§ *Quart. Journ. Geol. Soc.*, vol. xlix, p. 236 (1893).

||| Church Stretton. *Geology* (1901).

¶¶ *Quart. Journ. Geol. Soc.*, vol. lxiv, p. 209 (1908).

Most of these writers have noted the presence of *ballstone* in Wenlock Limestone, and many refer to the fact that corals in the limestone often retain the position in which they grew, but none have noted the connection, viz., that it is in the *ballstone* rock that the coral fauna is in the position of growth.

III.—GENERAL DESCRIPTION OF THE WENLOCK LIMESTONE OF SHROPSHIRE AND HEREFORDSHIRE.

The Geological Survey map* shows that the Wenlock Limestone crosses the southern half of the county of Shropshire in a N.E.—S.W. direction, appearing near Lincoln Hill, Coalbrookdale, from under the Upper Coal Measures (which may there be seen to rest discordantly upon it), and continuing as far as Craven Arms—a distance of over twenty miles. The outcrop forms a conspicuous feature in the landscape, due to the hard bands of limestone, which, resting on the softer Wenlock shales, stand out as a steep escarpment facing west, whilst eastward the beds fall away gently, following the dip slope. The northern part of this ridge is called Benthall Edge, but the remaining portion, as far south as Craven Arms, is known as Wenlock Edge. North of Wenlock the limestone shows two deep folds parallel to the main elevation, and the outcrop is over a mile wide, but near Wenlock the long dome of Windmill Hill runs in a N.N.E.—S.S.W. direction. In each case *ballstone* masses form the core of the elevation.

Most of the Edge is between 600 and 700 ft. high; but near Westwood and Presthope Quarries it reaches the height of 891 ft. and 899 ft. respectively. South of Craven Arms the beds are faulted to the south, and the strike from there follows a more southerly direction. As the formation passes into the county of Herefordshire the limestone becomes very thin and occasionally disappears altogether. Near Wigmore Abbey, in this county, the axis of the folds changes again, and, from being nearly N. and S. at Leintwardine, it turns to E. by N., and the beds form the well-known Ludlow loop. This transverse fold is about ten miles long, with an average width of about six miles, and the Wenlock Limestone can be traced by the low uneven escarpment which circles round the central low-lying Wenlock Shales. To the south are two small, faulted, subsidiary folds, in which the Wenlock Limestone is again exposed. Near the village of Lingen, at the S.W. end of the main fold, the outcrop ceases. There is a well-marked difference between the Wenlock Limestone of the northern and southern parts of the outcrop. The change occurs near Presthope, five miles south of Wenlock. Following this

* Sheets 61 N.E., S.E., S.W., 55 N.W.

natural division, we shall give a brief description of the beds under two heads :—

(a) The northern, or *ballstone* beds, from Lincoln Hill to Presthope. (b) The southern beds, from Presthope to Presteign.

(a) Between Lincoln Hill and Presthope quarries and exposures in the limestone are very numerous. The beds at the base of the Wenlock Limestone can be seen at Lincoln Hill, where on a steep dip slope a very fossiliferous horizon is exposed, which yields a rich fauna of brachiopods and small corals; but the most complete section is on Harley Hill, near Wenlock, where the high road has been cut through the escarpment of Wenlock Edge to a depth of about 40 or 50 ft. The beds consist of nodular courses of hard limestone with shale partings an inch or two thick, with a fauna containing brachiopods, crustacea and a few corals. Resting on these is a thick series of regularly bedded nodular white limestones, in which minute trilobites and *beyrichia* occur.

These beds, when determining the thickness of the Wenlock Limestone, were included by Murchison,* but were excluded by Davidson and Maw.† Lithologically it seems impossible to draw a line below which it can be said that the beds are Wenlock Shales and above which they are Wenlock Limestone; the beds change gradually from shales with occasional strings of limestone nodules to nodular limestone beds with occasional shale partings. Davidson and Maw restricted the term Wenlock Limestone to that part of the series which consists of solid courses of limestone, and the beds above, this is what we describe in the following paper as *ballstone* and the associated beds, and which we hope to show is a special development of limestone within the Wenlock Limestone; consequently we do not limit the term Wenlock Limestone to the 90 ft. of Davidson and Maw, but include Murchison's upper and lower beds.

Resting on the comparatively unfossiliferous lower beds are the richly fossiliferous coral series which contain *ballstone*. These beds may be examined everywhere in the long series of quarries from Lincoln Hill to Presthope. They are from 90 to 100 ft. thick, but will not be described now as a detailed account is given later. On the *ballstone* series rests the highest bed of the Wenlock Limestone, which consists of bands of irregularly shaped nodules with shale partings.

(b) South of the bold cliffs of Ippikin's Rock and the Major's Leap, and the quarries at Presthope, there is a very considerable change in the limestone. All the richly fossiliferous deposits cease; only regularly bedded limestone bands with shale partings remain. The layers are very seldom platy, but more frequently there are bands of calcareous nodules with a large amount of shale,

* "The Silurian System. p. 213.

† *Geol. Mag.*, dec. 2, vol. viii (1881), p. 103.

and in those quarries where the more regular limestone courses occur there are shale partings of varying thicknesses and often a thick shale band about a foot wide. A sandy tough limestone makes its appearance in two areas of the district; these are between Craven Arms and Adfortin, and at the Limebrook Nunnery, near Lingen. In one small area, at the eastern point of the Ludlow loop, at Pitch Coppice, there occur some small fossiliferous unstratified lenticles, and the surrounding stratified limestone is also much more fossiliferous there than in other parts. These contain many corals, as well as those fossils, chiefly brachiopods, which are found throughout. The large stromatopora and the crinoidal and bryozoan banks, common in the northern development, are practically absent.

We shall now give some further details of the exposures between Presthope and Presteign. At Roman Bank, on the top of the cliff overlooking Longville, is a long quarry, with the exposures facing westward. Here nodular limestone courses alternate with narrow shale bands; the main shale band is about four inches wide, with a subsidiary narrower one, whilst still narrower ones wrap round the calcareous nodules. Here and there are some more solid calcareous flags.

Continuing farther south to Craven Arms there are a number of quarries which present very similar features, with only slight variations. These features are: regular thin-bedded nodular beds, crystalline, and blue-grey in colour, bound solidly together, but the material between the beds and around the nodules weathers very quickly on exposure; also, one or two clayey shale bands, about six or eight inches wide, are present.

From Craven Arms to Adfortin the limestone is seen in solid wall-like sandy courses, alternating with thin shale bands. This limestone is quite the most sandy and the least calcareous of any between Lincoln Hill and Presteign, with the exception of the quarry at Limebrook Nunnery, Lingen, but there the limestone is more nodular.

The quarries of the Ludlow loop, with the exception of those fossiliferous ones at the bend, previously mentioned, are very much alike. All have nodular courses and shale partings. In Elton Lane, just below Mrs. Shakespear's classical locality of Ludlow Shales, there are two Wenlock Limestone quarries, in which a shale band, a foot wide, is a noticeable feature; it is accompanied by nodular courses and a band of solid grey-blue limestone.

Further west, between the village of Wigmore and the end of the outcrop at Lingen, the limestone is much more impure and consists of nodular and regular flaggy courses, with sandy shale bands.

IV.—DESCRIPTION OF BALLSTONE.

The name *ballstone* has been given by the Shropshire quarrymen to a certain kind of limestone, and it is so called by them from the shape which it generally assumes. This limestone, after a little experience in the field, is easily recognisable from its external appearance and from its internal structure and composition.

It is the most highly valued part of the limestone, as it can be used for cement making, for which the "measures" (as the surrounding limestone courses are called) are not suitable. *Ballstone* occurs (as already stated) only between Lincoln Hill and Presthope, and it is only found in the upper half of the Wenlock Limestone series; the beds in which it occurs consist of courses of hard nodular stratified limestones, which (when near *ballstone*) contain a rich fauna of corals and stromatoporoids, or, of solid courses of a finer detrital limestone in platy layers composed largely of encrinital and bryozoal fragments. They are separable into three lithological groups, or series, to be described later; *ballstone* originates most frequently in the lowest series, and, rising from a flat base, transgressively crosses the bedding of the stratified limestone, which is not disturbed, and may pass up through all the series and almost to the top of the Wenlock Limestone.

In shape the *ballstone* masses are generally ovoid or lenticular, and these are themselves most frequently composed of smaller lenticular or phacoidal masses, which fit closely together (Plate 33.A and B). Sometimes the *ballstone* is partly divided by wedge-shaped portions of the surrounding stratified limestones which penetrate into the mass, but generally the stratified limestones stop abruptly where they abut against *ballstone*. Near the top of *ballstone*, however, the stratified beds, instead of ceasing abruptly, curve over the *ballstone*. The sides of *ballstone* in section thus present either a rounded even appearance, or, when the stratified beds and *ballstone* penetrate into each other, a frilled edge. In worked-out quarries the former presence of a large mass of *ballstone* may often be inferred from these fingers or wedges of *ballstone* left in the walls of the quarries (Plate 35.A).

The size of *ballstone* masses varies greatly, but some have evidently been very large and may have reached a height of 60 to 80 ft. Murchison* described the mass of *ballstone* in the Yell quarry (the site of which we have not identified) as laid bare to a depth of 80 ft. The only *ballstone* mass of equivalent thickness now exposed is that forming the highest part of Wenlock Edge, at Ippikin's Rock and the Major's Leap.

* "The Silurian System" (1839), p. 211.

In the large quarries of Bradley, Gleedon, Windmill Hill, Westwood, and the Lilleshall Company's quarry, masses from 50 to 60 ft. high were probably formerly present, but much of the most solid limestone from the quarries has been already removed, and the masses now being quarried are not more than 30 to 40 ft. high. Small ball or oval shaped masses up to 12 or 14 ft. in height may be seen in most of the disused quarries on Benthall Edge, Gleedon Hill, and Wenlock Edge.

In structure *ballstone* presents a striking contrast to the adjacent stratified limestone, for it is essentially unstratified throughout, due to the large and irregular growths of corals and stromatoporoids. Its appearance and structure varies in different parts according to the preponderance of large ball-shaped fossils such as the stromatoporoids or favositids, or of the branching corals such as the cyathophyllids, and it presents, after weathering, in the one case a hummocky irregular appearance, in the other a more uniform structure, although stratification is equally absent.

In composition *ballstone* normally consists of a matrix of fine flour-like impalpable blue-grey or green mud, which surrounds and is intimately associated with a rich coral and stromatoporoid fauna, which is generally upright and apparently in the position occupied during life. Bryozoa are also common, occasional brachiopods and gastropods occur but are relatively few, and crustaceans are rare. The fossils are but little broken and the minute structure is well preserved.

In some *ballstones* branching corals form the chief structural element, in others the larger stromatoporoids, such as *Stromatopora carteri* Nich. or *Actinostroma*, build up the main mass. Elsewhere various species of *Heliolites*, *Favosites* and *Halysites* preponderate, but everywhere the colonies are in the position of growth and are enveloped either in a fine flour-like mud or by fine detrital fragments.*

BRADLEY ROCK.

ANALYSES† OF BALLSTONE AND MEASURES.

<i>Ballstone.</i>									
Lime	.	.	.	.	.	.	.	.	42.60
Magnesia	.	.	.	.	.	.	.	.	1.84
Alumina	.	.	.	.	.	.	.	.	4.09
Ferric Oxide	{	.	.	.	.	.	.	.	1.21
Ferrous Oxide		.	.	.	.	.	.	.	
Silica	.	.	.	.	.	.	.	.	13.80
Carbon Dioxide	.	.	.	.	.	.	.	.	36.41
Phosphoric Acid	.	.	.	.	.	.	.	.	0.05
									100.00

* Cf. E. W. Skeats, "The Chemical Composition of Limestones from Upraised Coral Islands." *Bull. Mus. Comp. Zoology, Harvard College*, vol. xlii, pp. 83, 119.

† We are indebted to Mr. Boulton for these analyses.

[Photo by Miss M. S. Johnston.]

A.—QUARRY NORTH OF BLAKEWAY HOLLOW LANE, SHOWING THE
LENSES IN BALLSTONE.

[Photo by Miss M. S. Johnston.]

B.—SHADWELL ROCK, SHOWING THE CURVED SURFACE OF THE LENSES IN
BALLSTONE.

Measures Stone.

Lime	54.75
Magnesia	0.49
Alumina }	0.60
Ferric Oxide }	
Ferrous Oxide }	
Silica	1.45
Carbon Dioxide, &c.	42.71
Phosphoric Acid	Trace
	<hr/> 100.00

The large amount of silica and alumina in the *ballstone* analysis is very remarkable. Possibly the great hardness of *ballstone* may be due to the high percentage of silica.

It is a striking fact that in *ballstone* the rich fauna of corals and stromatoporoids is found to be generally in the position of growth, while the fossils found in the adjacent stratified beds are more frequently lying on their sides or even completely overturned.

The following Table gives the proportion of fossils in the position of growth or overturned in *ballstone* and *measures*.

Area 8 feet square. Number counted 40.

Localities.	BALLSTONE.			MEASURES.		
	Upright	Overturned	% Upright	Upright	Overturned	% Upright
Gleedon ...	35	5	87.5	4	36	10
Lilleshall ...	38	2	95	12	28	30
Blakeway Hollow	39	1	97.5	3	16	7.5
Westwood and Another	37	3	92.5	7	33	17.5

We have already referred to the lens-shaped masses of which *ballstone* rock is generally made up. We shall now describe these structures a little more fully.

In the large quarries of Bradley, Westwood and the Lilleshall Company's quarry, a section through *ballstone* reveals in each case a rough network of more or less regular and closely-fitting lenses from 4 ft. to 6 ft. in diameter, while at Gleedon they are somewhat smaller. These lenses apparently have only a slight relation to the faunal colonies; occasionally their boundaries follow the outline of a large stromatoporoid, or a lens is seen to consist of one single species of coral, but more often a lens encloses a variety of fossils. Occasionally a branching coral is found extending into several adjoining lenticles. Often the

lenticles fit closely together, but sometimes there is space between their gently curving surfaces, which are then covered with a fine interstitial deposit. This occasionally shows the effects of squeezing, sometimes becoming thickened, when it assumes a laminated appearance, or it may be eliminated altogether. The surface of the lenses is occasionally striated or slickensided. The signs of movement between the lenses do not always indicate movement in the same direction, but it has evidently been gentle, as the lenses are not overturned, and the contained fauna remains upright and uncrushed.

V.—DESCRIPTION OF THE ASSOCIATED BEDS.

Under the term "Associated Beds" we include those beds which connect the unstratified *ballstone* masses together and are in immediate contact with them (Pl. 34.A and B). These beds are termed *measures* by the quarrymen, and are burnt for lime. They are all regularly stratified, though they vary in structure. In Harley Hill cutting, west of Much Wenlock, are the lowest beds of Wenlock Limestone, and they contain a fauna in which occur *beyrichia* and *trilobites*, quite unlike that found higher up in the series where the *ballstone* masses occur. There are two faults at the top of Harley Hill, which have let down a wedge-shaped section of the upper beds, and which contain small portions of *ballstone*, though none is seen outside the faults either east or west. Above the beds containing *beyrichia* come the lowest beds associated with *ballstone*. They are nodular and thinly bedded, and divided by layers of shale. Usually they are very unfossiliferous, but as they approach *ballstone* fossils become more numerous, encrinites and brachiopods being the most abundant; gastropods, chiefly *Horiostoma*, are common in certain quarries, as in those of Smokey Hole and Bradley Rock. These thin, regular, nodular beds, with here and there a decided band of shale an inch or two thick, attain a thickness of some 30 ft. *Ballstone* originates in these beds, into whose regular strata here, as in the higher series, it sends out protuberances from the central mass. The beds abut against the unstratified rock or gently curve over the lower mounds. Fossils of all kinds similar to those found in *ballstone* are found in these beds, but over 80 per cent. of the corals and stromatoporoids are overturned. Many bryozoa occur in these beds; the greater number are of the ceramaporidæ and similar mat-shaped forms. Resting on these strata there is usually a band of about 3 ft. of more compact beds, but they are not so persistent as the other lithological series, which fall naturally into three divisions, and which may be traced from one end of the *ballstone* area to the other—namely, two series of nodular beds

[Photo by Miss M. S. Johnston.]

A.—BLAKEWAY HOLLOW LANE QUARRY, SHOWING LITHOLOGICAL CHARACTERS OF THE STRATIFIED BEDS. NODULAR BEDS BELOW, PLATEY LAYERS ABOVE.

[Photo by Miss M. S. Johnston.]

B.—THE SAME QUARRY, SHOWING THE INOSCULATION OF BALLSTONE AND STRATIFIED BEDS.

and one of platey layers. The compact beds are sometimes merged into the top of the lower nodular series below them, which are then divided from the upper nodular series by a more definite shale parting. Although both these series are in nodular layers, they can be easily distinguished lithologically from each other, as the lower series is of thick, long-shaped nodules, with some platey layers and defined shale partings, whilst the nodules in the higher beds are thinner and more knobbly, with a good deal of shale between and around them. This upper nodular series, which is usually between 5 ft. and 6 ft. thick, weathers very quickly to a whitish colour. *Ballstone* rises into and through it, and usually it is not very fossiliferous except in the near vicinity of *ballstone*, when it contains similar fossils.

Above the two nodular series comes a third series which consists of platey layers, divided by thin shale beds. The plates are usually from 3 in. to 5 in. thick and are very regular. These beds are extremely fossiliferous throughout; the corals and stromatoporoids are overturned and broken and the pieces often cemented together, with brachiopods, bryozoa, and an occasional gastropod. The bryozoa are of the branching forms, and three species of *cænites* are very common. In a few quarries a still higher series of beds occur, which are more nodular, impure, and of a brownish colour. This colour distinguishes them from all the other beds, which are grey or bluish grey. The most noteworthy fossil in them is a small round variety of *Labechia*,* which is only found where these upper beds appear, viz., at Bradley Rock, Shadwell Rock, and in a disused quarry at Presthope. There is very little vertical variation in the fauna; the variation is more lateral, from one quarry to another. The change in the genera of bryozoa from the bottom to the top and the occurrence of the small form of *Labechia* in the top beds are the most noteworthy vertical faunal changes that we have observed.

VI.—SELECTED QUARRIES, AND FAUNAL NOTES.

We shall now give a detailed description of three quarries from which the evidence for the generalised accounts has been obtained, viz., Bradley Rock, the Lilleshall Coal Company's Quarry at Presthope, and a disused quarry in Blakeway Hollow Lane.

Bradley Rock.—This is one of the three most important Wenlock Limestone quarries in Shropshire, and is the most northerly one at present being worked. It is situated on the east side of the Wenlock branch of the G.W. Railway, just before it enters the charming valley known as Farley Dingle. The limestone is in the form of a gentle dome whose main axis is N. 10 E.—S. 10 W.

* Cf. *Labechia conferta* Lonsd. and *L. scabiosa* Nich. "British Stromatoporoids," pp. 153-161, Pl. iii, figs. 7-15; Pl. xx, figs. 1 and 2 and figs. 4-6.

which is continued northward into Bradley Coppice and which dies out a little to the south at Bradley Farm.

The quarry consists of two parts, and the following description is confined to the northern half.

The name "Bradley Rock" expresses the general character of the beds, which consist of a very solid stratified limestone from 40 to 50 ft. thick, in which occur masses of still harder *ballstone*. At the base the beds are nodular, with narrow shale partings blue-grey in colour; above these are very hard nodular limestone courses in which the ballstone masses are found. Resting on these are 10 ft. to 15 ft. of limestone in platy layers, which vary from 1 in. to 4 in. in thickness and consist largely of fragments of encrinurites or of bryozoa. The highest bed is formed of bands of irregular shaped nodules of varying sizes with shale partings. This bed is recognisable from its rich brown colour, and in it is found the thin plate-like *Labecheia*.

We shall now describe the *ballstone*-masses seen on the south, east, and north faces of the quarry, and the surrounding stratified limestones. In 1911 the beds then being worked on the south side were seen to consist of solid courses of a stratified compact nodular grey-blue limestone with thin partings of shales. The beds were very fossiliferous, but the corals were rarely found in the position of growth. The dip in this part of the quarry was 13 W. 20 N., but near by on the east face the dip was 5 E. 10 N., showing that the beds had turned over. Between these two dips lay a mass of *ballstone*. The rock was entirely unstratified, and consisted of an impure, fine, calcareous mud surrounding colonies of cyathophylloid corals. Adjoining this mass was *ballstone* of a slightly different character, containing a fine branching coral covering an area of 6 ft. square; above it were solid stratified limestones. On the east side, but farther north, a fault crosses the quarry E. 20 N.—W. 20 S., marked by a band of crushed rock; adjoining was another mass of *ballstone*. The stratified beds associated with it consisted of hard regular nodular courses of limestone (no shale partings being visible except where the rock was weathered), and they contained a large assemblage of fossils.

In the centre of the east face in 1911 and 1913 a large mass of *ballstone* was to be seen. It was entirely unstratified, but was made up of broad undulating bands consisting of smaller ovoid lenticles or of angular-shaped irregular lenticular masses. The stratified nodular series were found to cease as they reached the *ballstone* mass, or wedges penetrated only a short distance into it, and between the lenticles. The *ballstone* contained a great variety of corals and stromatoporoids, a large proportion of which were in the position of growth. In 1911 *ballstone* filled the lower 20 ft. to 25 ft. of the north-east corner of the quarry, and was composed of a fine flour-like matrix, which surrounded the

usual erect coral fauna. It was remarkable for the large size and regular shape of the phacoidal masses, each of which was wrapped round by a finely drawn out calcareous mud. Above the *ballstone* mass were solid limestone courses consisting of half-formed but hard nodules or of narrow 2 in. to 3 in. bands of hard limestone consolidated together. Above these were the top platy beds composed of detrital limestone, and on the top of all the beds of ochreous or brown-coloured nodules. By 1913 this part of the quarry had been considerably cut back and the *ballstone* at the base removed, revealing solid nodular beds below, with *ballstone* left above, now merely a finger of what had been a large mass. The middle part of the north face shows no *ballstone* at present, but consists of solid limestone courses or measures similar to those described.

An important series of shear planes is to be seen in Bradley Rock. The planes are curved, or nearly straight, perpendicular or inclined. The general direction of the axes is N.E.—S.W., while the dip of the planes varies in different parts of the quarry. The surfaces of the planes are often slickensided, in some cases they are scored by parallel grooves,* some four to six inches across, which seem to be parallel to the dip of the beds. The grooves are occasionally covered with grooved calcite or with fine calcite crystals in lines parallel to the grooving. These divisional planes traverse both *ballstone* and measures alike. There are also two main series of joints in the quarry, the faces of which are often densely covered with calcite.

Lilleshall Company's Quarry.—This large quarry (Plate 35.B) is on the dip slope just below the Church Stretton Road, two-thirds of a mile south-west of Presthope, and is the last quarry to the south in which *ballstone* occurs. The dip of the beds in the quarry reaches 17°, direction E. 40 S. Speaking generally, the limestone of the quarry is peculiarly hard and crystalline, even the nodular stratified portions being very close and compact. The total depth of the quarry is about 70 ft., and *ballstone* occurs throughout the whole thickness. In the deepest part in 1910 a large mass of *ballstone*, about 30 ft. in. height, was displayed. It was composed of a blue, muddy, flour-like but hard crystalline limestone matrix, in which were blobs of larger crystals and calcite veins, and it contained the usual coral fauna. In structure it consisted of lenticular or somewhat rectangular masses, of a large size; here and there between them were traces of the stratified nodular beds, which occasionally swept round the *ballstone* masses. By 1913 the *ballstone* rock had been cut through, and the normal stratified beds were exposed. The quarry face just below the road gives an excellent exposure of the upper beds, which rest on a platform of rock, above the *ballstone*

* These parallel grooves I believe to have been formed by the ends of the hard *ballstone* lenses indenting the softer beds as they moved by.—M. C. C.

just described. Here again is a great mass of *ballstone*, and there is evidence of shifting and movement between the lenses composing it, slickensided surfaces, sometimes covered with a fine greenish mud, being frequent, and shallow grooving, caused possibly by the pressure of the lenses against each other, is common. Yet in each case that we examined we noted that the lens-shaped masses had not been overturned, and this was clear from the fact that the corals in them were almost uniformly in the position of growth.

The lower stratified beds of the quarry consist of nodular courses, with occasional narrow shale partings, while the upper beds, though also nodular, contain, as everywhere, a large proportion of broken fragments of bryozoa and of encrinite stems, as well as corals. The vertical lithological changes in the stratified beds, which may be traced in the quarries of Benthall Edge and in some of those of Wenlock Edge, are indicated here also, but wherever *ballstone* is present in large amount, as in the Lilleshall quarry, the sequence is less easily identified.

Blakeway Hollow Lane Quarry.—The large and most western disused quarry (Plates 34.A-B and 35.A) to the north of Blakeway Hollow Lane shows very regular bedding, and as the vertical sides are weathered it affords an excellent typical example of the structure of the Wenlock Limestone of the northern part of the Edge. The lowest beds in the quarry are of nodular crystalline limestone, in courses 1 in. to 3 in. thick, with thin layers of shale between, in all about 10 ft. thick; above these a wider layer of shale occurs, and above again are 3 ft. of five solid bands of limestone. These bands, however, are not always present in all quarries, and when absent the lower nodular beds come higher up and are divided from the upper series of nodular beds by a 3 in. to 4 in. layer of shale. These upper beds are 5 ft. 6 in. thick and are composed of more rounded and disconnected nodules, with more shale between, and they weather more quickly and whiter than the lower ones. The highest part of the section is composed of platey layers, with very thin partings of shaly material, and is 8 ft. 6 in. thick. These platey layers are from 2 in. to 6 in. thick and are usually crowded with fossils. *Ballstone* has been entirely removed from the centre of the quarry, but on walking round the walls, the beds in the lowest division are seen to be, as it were, intruded into here and there by lenticular unstratified limestone, against which the stratified layers end, or, in the case of the higher beds, over which they gently curve. This unstratified limestone is *ballstone*. On the western side it has protruded in uneven masses from below the floor of the quarry into the two nodular series, and again occurs in the high platey beds as an isolated mass where the base depresses the stratified beds. Across the northern side the beds have not been worked so deeply, and *ballstone* in many places is the floor of the quarry, with the platey

[Photo by Miss M. S. Johnston.]

A.—BLAKEWAY HOLLOW LANE QUARRY, SHOWING REMNANTS OF
BALLSTONE IN QUARRY WALL.

[Photo by Miss M. S. Johnston.]

B.—THE LILLESHELL COMPANY'S QUARRY, PRESTHOPE. SECTION
THROUGH BALLSTONE.

beds, containing fossil fragments, forming the cliff behind. On the eastern side the quarry wall is crowded with stromatoporoids and corals, but as it is the very edge of the *ballstone* and much mixed with the regular strata, the greater number are broken and overturned.

DESCRIPTION OF THE OLDER QUARRIES BETWEEN LINCOLN
HILL AND PRESTHOPE, TOGETHER WITH FAUNAL NOTES
ON ALL THE QUARRIES.

The old quarries of Lincoln Hill have already been referred to in the description of the lowest beds. The *ballstone* masses once present have been almost completely worked out, and the quarries now present no special features.

Overlooking the River Severn on the south bank is the large quarry of Benthall Edge, the first of a long series cut in the escarpment. This quarry has not been worked for many years, and the faces are dusty and often obscure. At the base is a blue nodular crystalline limestone; the nodules are separated one from another and wrapped round by fine blue-grey shales, and small portions of *ballstone* occur. Resting on these beds are harder courses of limestone; these are followed by a nodular series of beds, which are more platey than those below. Dividing these beds from those above is a hard band of limestone a foot or more thick. Above this band the beds consist of more persistent platey layers, an inch or two thick, with an occasional stouter layer. Remnants of *ballstone* are found also in the upper beds. From the presence of these small portions of *ballstone* at Benthall Quarry it seems probable that the centre of this large quarry formerly contained a core of *ballstone*. This view is strongly supported by the fact that this quarry has been one of the most noted collecting grounds for Wenlock Limestone fossils. Many species of Favositidæ, Heliolitidæ, Halysitidæ, Cyathophyllidæ, Strombodidæ, etc., may still be found. Stromatoporoids do not occur in such abundance as in other places, but *Stromatopora typica* Rosen. and *S. discoidea* Lonsd. are common. The sequence of beds found in this quarry may be traced in the long series of quarries of Benthall Edge.

Below the gateway to the path leading from Benthall to Buildwas there are several isolated balls in the stratified beds, evidently the protuberant remains of a larger mass of *ballstone*. The fossils contained in them are generally in the position of growth. In a quarry face a little to the south a large overturned block of *ballstone*, composed of a colony of *Cyathophyllum*, occurs in stratified beds, and near by a similar but smaller block composed largely of *Heliolites interstincta-decipiens* Lind.; they are both typical *ballstone* lenses. The stratified beds in which

they lie belong to the platy layers, and are composed of comminuted fragments of encrinites, corals, and stick-like forms of bryozoa cemented together and forming a typical *beach-rock*. The presence of the overturned lenses of *ballstone* among undisturbed stratified beds suggests that the lenses of *ballstone* were formed very shortly after the consolidation of *ballstone*, and prior to the deposit of the *beach-rock*.

The limestone ridges of Benthall and Wenlock Edges are divided by a dome-shaped hill called Tickwood, which is riddled with very ancient and overgrown quarries. In many of these *ballstone* fragments occur, indicating that there was formerly most probably a central core of *ballstone* of which these were the ramifying projections. The dip of the beds supports this view, as it is roughly quaquaversal, varying from N.E., S.E., and S.W., and in amount from 5° to 35° . Of the fossils found, species of *Omphyma* and *Cyathophyllum* are especially abundant, and *Stromatopora carteri* Nich. occurs.

A brook has carved out a steep gully between the Tickwood and the beginning of Wenlock Edge. To the south-west are many disused and almost continuous quarries; these are followed by Bradley Rock, already described, but on the fossils of which we here append a few notes. It contains a very rich assemblage; all the more common Wenlock Limestone fossils occur. *Strombodes*, which appears to be largely confined to the northern quarries, is found here in great abundance. Gastropods and brachiopods are common in places.

Farley Dingle Brook divides Bradley Rock from Gleedon Hill. Here the limestone of the numerous quarries is traversed by many small faults, with a general direction N. 10 E.—S. 10 W., which is parallel to those of Bradley Rock, and the stratified beds exhibit distinct folding.

In the central quarry (Pl. 36.A) the *ballstone* mass attained great dimensions. The fossiliferous components vary in different parts of the *ballstone*. In the north-east it is composed of beautiful stromatoporoids, nearly every one in the position of growth. In the north-west it is made up of very small fragments of encrinites mixed with other broken fossils and a very small species of *Cyathophyllum*, which is in the position of growth, and is enveloped by finely comminuted material. On the south-east side of Gleedon Hill there is a large development of encrinital rock, which contains the large stems and many crowns of *Crotalocrinus rugosus*. Miller. Although broken stems, plates, and occasional calyces are found all through the limestone of the district, yet in no other locality is this species so abundant. The other remarkable development of encrinites in the Wenlock Limestone is the pink encrinital limestone of the Lilleshall Company's quarry at Presthope, and a lesser development at Stretton Westwood, but in both cases the encrinital limestone is part of the *ballstone*

masses, whilst at Gleedon the encrinites form beds in the *measures*.

The next quarries farther south which call for special mention are Shadwell Rock and Standhill Rock. The limestone here is folded into a gentle anticline nearly at right angles to the general direction of Wenlock Edge. There is not much *ballstone* now remaining in these quarries. In Shadwell Rock (Pl. 33.B) the regular strata are very nodular until the platy beds are reached, and these, as the quarry is high up in the limestone, are overlain by the brown nodular beds, which contain the small *Labechia*, *Heliolitidae* and *Favositidae*, together with *Thecia swindernana* Goldf., and *Halysites catenularis* Linn. abound in both quarries, and colonies of *Cyathophyllum articulatum* Wahl. attain a great size. The genera of Stromatoporoids are chiefly *Clathrodictyon* and *Actinostroma*. Annelid jaws and a specially fine branching bryozoa are found in Shadwell Rock in the blue shale and on the nodules.

Adjoining Blakeway Hollow Lane are half a dozen large quarries close together; only one is now worked. *Ballstone* occurs in all. There are few signs of movement in this group of quarries, except some slickensiding on the *ballstone* lenticles. The stratified beds come up regularly to *ballstone* and either gently curve over or stop abruptly against it.

About a mile beyond the outskirts of Much Wenlock, on the Church Stretton road, are the large quarries of Stretton Westwood. They are from 40 ft. to 60 ft. in height, and extend for some distance below the roadway. Both old and new quarries show the remains of *ballstone* in various parts. In the older quarry large growths of a fine species of *Cyathophyllum* occur together with *Halysitidae* and branching bryozoa, whilst in the newer quarry the huge development of *Cyathophyllum truncatum* Linn. is very noticeable. Almost everywhere the colonies are in the position of growth, extending upwards and outwards, sometimes passing without change of direction from one lens into neighbouring ones. The broken encrinite stems so abundant in some portions of the *ballstone* have been stained pink, and make with the accompanying fine green mud an ornamental marble. The last appearance of *ballstone* in the Edge is between Presthope and Easthope, where it attains a great development. The unstratified masses of Ippikin's Rock and Major's Leap form the upper part of the escarpment—a cliff about 60 ft. high. Stratified rocks come between the two masses of *ballstone* and occur as nodular beds below and platy beds at the top. The rocks are all very much weathered and often covered with lichens, so that it is almost impossible to find many fossils, but near by, in the Lilleshall Company's quarry (already described), they are very abundant, and *Stromatopora typica* Rosen. and *Actinostroma intertextum* Nich. are common, and Strombodes is also found. The Stromatoporoids

with astrorhizi occur in greater numbers at the two ends of the area, while *Stromatopora carteri* Nich., *Clathrodictyon striatellum* d'Orb., *C. fastigiatum* Nich., are most numerous in the central portion.

In the meadows of Hilltop Farm, where the beds have been thrown into a gentle anticlinal fold parallel to the general strike, a quarry exhibits the last remnants of *ballstone*, with the platy beds curving over, and south of a line drawn from this farm to Major's Leap no *ballstone* seems to be developed, and the beds are all regularly stratified, varying little in composition and formation, until the limestone ceases at Lingen in Herefordshire.

VII.—COMPARISON OF THE WENLOCK LIMESTONE OF WENLOCK EDGE WITH THAT OF OTHER AREAS IN ENGLAND.

We have examined the chief outcrops of the Wenlock Limestone in other areas and find a similar but much less extensive development of *ballstone*, in a few localities. It will be seen from the following description that in the Ludlow area, and at Malvern and Ledbury, solitary instances of coral-bearing unstratified limestones occur in the stratified limestones. At Woolhope there is a long series of low ball-shaped unstratified masses, which are comparable to *ballstone*, whilst at Usk there is a limestone in one old quarry showing similar structure. At Rushall, near Walsall, *ballstone* certainly is present, but at Castle Hill and the Wren's Nest, Dudley, we found no trace.

Rushall.—At Rushall, north of Walsall, the Wenlock Limestone occurs in three narrow bands, amongst shale beds. The lowest has a fauna like the shaly limestone beds of Lincoln Hill; the second contains many small stromatoporoids, corals, and encrinites; the third and highest, seen in the Midland Railway cutting by the canal bridge, shows a development of *ballstone*. Halysites, Cyathophyllum, Favosites, Heliolites, and other corals occur, in the position of growth, with the blue-green mud permeating the whole. The stratified beds come up to the unstratified mass of *ballstone* and cease abruptly as at Wenlock Edge. Near by, at the Cement Works of the East Anglia Company, the limestone brought up from the underground workings is precisely similar to unweathered *ballstone*, the matrix consisting of unstratified, compact, fine, impalpable, calcareous flour-mud of a blue-green colour.

Dudley.—We could discover no *ballstone* in the Dudley outcrops of Wren's Nest, Castle Hill, and Mon's Hill. None of the limestone which we were able to examine had any likeness to *ballstone* material, nor was there any appearance of lenticular unstratified rocks.

Murchison* described the Dudley Limestone as "indistinguishable from that of Wenlock, like which it occasionally runs into large concretions . . . here called *crogs*, which present just the same appearance of interfering with the stratification which has been described at Wenlock."

J. W. Salter,† in his "Notes on the Fossils of the Wenlock Limestone of Dudley," wrote: "The corals are . . . numerous, and though there is no evidence that the Dudley Limestone possessed the character of a coral reef, yet the floor of the sea must have been nearly covered with them. They are chiefly solitary forms, however."

We are indebted to Mr. J. J. Addenbrook, of Tipton, for some information on *crog-balls* and for his kindness in obtaining a specimen of the rock for us from the lower seam of the Wren's Nest Limestone Working. *Crog-balls* occur in the solid limestone seams, and vary in size; occasionally they are 26 ft. to 30 ft. high, and reach to the top of the seam. The limestone of which they are formed is peculiarly hard, and is superior in quality to the surrounding limestone. No corals occur in the *crogs*, nor do they contain lens-shaped masses within them.

We find no likeness between the specimen of *crog* that was sent us and *ballstone*. Dr. J. G. Hinde, to whom we submitted the specimen, states that a microscopic examination shows that it is mainly composed of the stems, cups and arms of crinoids, a striking feature being the number of brachioles of crinoids (in which it resembled a slide made from limestone from Cilfeigan Quarries, Usk), and that small pieces of girvanella and polyzoa are also present.

From the absence of evidence indicating the presence of rock similar to *ballstone* we conclude that *ballstone*, as known in Shropshire, is not present in the Dudley Limestone.

Malvern.—We examined the Wenlock Limestone of the Malvern Hills between Suckley Wood and Clinchers Mill, and found only one unstratified lenticular mass of the nature of *ballstone*. This was at Croft Farm Quarry, and it showed all the characteristic structure. Near Tundridge Mill, and also in Coneygree Wood, we noted indications of unstratified lenticular limestone.

Murchison,‡ describing the Wenlock Limestone of the Malvern Hills, stated that "the lithological character is similar to that at Wenlock and Dudley, . . ." but adds: "It very rarely contains any of the large concretions. . . ."

The development of the Wenlock Limestone in the Malvern and Ledbury areas suggests that the conditions of deposition approximated more closely to those prevailing in Shropshire, south of Presthope, and in Herefordshire than to those in the

* "Silurian System," p. 484.

† *Mem. Geol. Surv.*, "S. Staffs Coal Field," p. 114 (1859).

‡ "The Silurian System," p. 413 (1839).

Wenlock district. There are no signs of large attached coral colonies, though there is some evidence here and there of small isolated colonies.

Woolhope.—The Woolhope area has the largest occurrence of *ballstone* of any of the exposures outside the Wenlock area. For some distance along the north-eastern half of the ring of Wenlock Limestone are quarries in which unstratified rock occurs. The fossils are the same as those which are found in *ballstone* at Wenlock; the greater number are in the position of growth and are in a matrix of blue mud. From the structure and character of the limestone we conclude that it was formed under similar conditions to those obtaining at Wenlock Edge.

Usk.—The Wenlock Limestone in which are numerous quarries forms an irregular faulted ring round the Wenlock Shales. The rock in most places shows two divisions; the lower consists of solid, highly crystalline, stratified limestone beds, in layers of varying thickness, composed of dense masses of monticuliporoids, encrinurites, and small brachiopods; the upper is of nodular courses, with much shale, the chief fossils found being corals.

Murchison,* writing of the beds of Glascoed Common, says: "The analogy with the Shropshire beds is completed by finding many large concretions or *ballstones* 10 ft. to 12 ft. thick, which swell out suddenly and throw off the strata either abruptly or in undulations, for which reason the workmen here call them 'old horses,' meaning that the regular beds ride athwart them. In these *ballstones* the limestone is as crystalline as in Wenlock Edge and contains chain coral and other characteristic fossils."

Only in one quarry did we see beds answering to this description, and this was in an old quarry near Coed-y-paen, where is a rock quite similar in all respects to *ballstone* of Wenlock Edge and which could be identified at once. In an adjoining quarry, now being worked, is a highly crystalline pink encrinital limestone, very similar to that to be seen in the Lilleshall Quarry.

VIII.—COMPARISON OF BALLSTONE WITH SIMILAR STRUCTURES IN PALÆOZOIC LIMESTONES.

Gotland.—In 1898 certain Silurian limestones near Visby were described by Dr. Carl Wiman† as coral reefs. He stated that the cliffs near Visby, which project into the sea, are formed of unstratified or faintly stratified limestone, while those at the head of the bays are composed of stratified limestone on the same horizon as the unstratified beds. The unstratified compact lens-shaped limestone interferes sharply with the clearly stratified limestone, or the limestone with clay marls, within which it is inter-

* *Op. cit.*, p. 440.

† "Ueber Silurische Korallenriffe in Gotland." *Bull. Geol. Inst. Upsala*, vol. iii (1898).

[Photo by Miss M. S. Johnston.]

A.—GLEEDON HILL QUARRY, SHOWING STRATIFIED BEDS WITH SMALL FAULTS. SECTION ABOUT 80 FEET.

[Photo by Miss M. S. Johnston.]

B.—HOBURGEN, GOTLAND. REEF LIMESTONE AND STRATIFIED CRINOIDAL LIMESTONE, AND MARL SHALES.

polated. The reef rock is normally lenticular in form, and in the face of the cliffs the stratified beds can be seen to bend round the lenses of unstratified limestone.

Further details of the reefs are given by Dr. H. Hedstrom,* from which we extract the following particulars. In northern Gotland reef-formations play a predominant part at certain horizons of both lower and upper Gotlandian age. In the grey marl shales of the lower cliff levels (Horizon II †) small reefs occur, and in the upper portions of the coast sections (Horizon III ‡) at Visby the reefs are specially well developed and prominent, stretching in horizontal direction often for $\frac{1}{2}$ to 1 kilometre. They are composed of non-stratified accumulations, chiefly of stromatoporoids, in addition to which there occur, but less plentifully, corals of the genera *Halysites*, *Heliolites*, *Favosites*, etc., as well as some bryozoa.

The fine sea-cliff north of Visby, called Korpklint (Plate 37.A) is formed largely of *reef-limestone*. Regular stratified limestones as they approach the cliff become rich in crinoid fragments and increase in thickness, until a real crinoid limestone is formed. On these solid encrinital beds the reef rests, and they also surround the base. The lower part of the reef is thus equivalent to the crinoid limestone nearest to the reef; farther away from the reef there occur fine to dense flakey limestones, and finally marl shales with limestone seams. The middle and upper parts of the reef are replaced by conglomerate-like and oolitic limestones, or by bituminous limestone and marl layers.

At Korpklint, Horizon III (Lower Gotlandian) is developed entirely as *reef-limestone*, but in the cliffs of Högklint and Galgberget only the upper part of Horizon III is *reef-limestone*. At Hallbro Castle Hill, south of Visby, reefs occur associated with beds of Upper Gotlandian age.

An account of the reefs of Southern Gotland has been given by Dr. H. Munthe.§ He described Southern Gotland as a rather low plain, from which in places there rise hills|| isolated by erosion and having limestone at the top; these hills commonly consist of reef limestone. From his account, and from what we ourselves observed, we give the following particulars. The reef limestones are of wide extent, they are unstratified, and occur on various horizons, contain different faunas, and are surrounded by beds differing in lithological structure and faunal contents. Some reef features are strikingly exhibited in the vicinity of the isolated hill Hoburgen (Plate 36.B). The bare western steeps of this hill

* "The Silurian Stratigraphy in the Neighbourhood of Visby. Guides des Excursions en Suède, 1910." Reprinted from *Geol. Fören. i Stockholm Förhandl.* Bd. xxxii, H. 4 (1910).

† Horizon II equivalent to Lindström's *c*.

‡ Horizon III equivalent to Lindström's *d* and *e*, *vide op. cit.*, p. 8.

§ "On the Sequence of Strata in Southern Gotland." Guides des Excursions en Suède, 1910. Reprinted from *Geol. Fören. i Stockholm Förhandl.* Bd. xxxii, H. 5 (1910).

|| Cf. "The Mound Limestone." *Geol. Survey, Wisconsin*, vol. i (1862).

consist for the most part of reef and crinoid limestones, resting upon beds of oolite and sandstone. The crinoid limestone, which is nearly destitute of fossil remains other than fragments of crinoidea, is more or less replaced by marly reef limestone, which contains a somewhat rich fauna. The reef rock builds up nearly the whole steep cliff, about 130 ft. in height. Its higher part is equivalent to the reddish crinoid limestone—the Hoburgen marble, and in places the youngest parts rest upon this marble, the highest of the series. The Hoburgen marble is formed of red and green crinoidal fragments, and bears a striking similarity to the red and green crinoidal marble of the Lilleshall Company's Quarry, Wenlock. Another development on this horizon in Ascoseras Limestone is well seen in Hamra Parish, where the reef is formed chiefly of stromatoporoids and of large fragments of crinoids with marly sediments filling the interspaces.

On our visit to the Island of Gotland as members of the International Geological Congress, under the guidance of Herr Dr. Munthe and Herr Dr. Carl Wiman, we observed in the reefs the same structural characters which we have described in *ballstone*, and found they bore a similar relation to the neighbouring stratified rocks. Many of the corals and stromatoporoids which we examined in the reefs were in the position of growth. The reefs were seen to be made up often of large lens-shaped masses of limestone, similar to those we have described in *ballstone*, and this structure was confined to the reefs of Gotland, as it is to *ballstone* in Shropshire. The differences between the reefs of Gotland and *ballstone* appeared to be due, not to any inherent differences, but to be the result of the longer continuance in time of the reef-phase in Gotland, which has introduced a greater variety into the fauna of the reefs, and also into the lithology and faunas of the associated beds, both at the base of and surrounding the reefs. In Shropshire *ballstone* originates probably always on the same horizon, and rests always on a nodular limestone, with narrow shale partings, which surrounds the lower part, while the upper part is associated with more solid limestones and with detrital beds, formed largely of encrinites and bryozoa. In Gotland reef limestones were developed on several horizons of both Lower and Upper Gotlandian age, and are found to rest sometimes on marls, occasionally on sandstone capped with an oolite bed, sometimes on solid crinoidal limestones, and the strata which surround the reefs are consequently also more varied than in Shropshire, and include beds of oolite, sandstone, *Sphæræcodium* limestones, etc., besides crinoidal and bryozoal limestones.

Norway.—Dr. Kjer,* in his important work on the Upper Silurian of the Christiania district, has described coral-reef facies

* "Das Obersilur im Kristianiagebiete." Christiania, 1908.

[Photo by Miss M. S. Johnston.]

A.—KORPKLINT NORTH OF VISBY, GOTLAND. REEF AND CRINOIDAL LIMESTONES. (HORIZON III)

[Photo by Miss M. S. Johnston.]

B.—REEF-LIMESTONE, SOUTH OF KORPKLINT, GOTLAND. (HORIZON III.)

in his zones 7*b* and 8*c*.* He states that the coral-reef facies of zone 8*c* in the western development of the Christiania district shows great similarity to the Wenlock Limestone as he saw it in Shropshire.† The beds consist of thick, compact, irregularly deposited limestone masses, which alternate with irregularly bedded, sharp, wedge-shaped partings of shales or nodular limestones. Corals generally occur in great abundance. The commonest reef-builders are Favosites and Stromatopora, but Haly-sites, Syringopora, and such colonial Rugose corals as *Colum-naria næstianum* Kjerulf., *Cyathophyllum articulatum* His., and *Acerularia ananas* L. also play an important part.

Dr. Kiær states that he has found coral reefs at the commencement of their formation occurring as small upright reefs and he has also met with them as massive limestone reefs, which may reach a thickness of 25 m. (82 ft.)‡ They appear, he says, to be a line of isolated coral reefs,§ surrounded by great stretches of even-bedded limestones and shales.

In 1910 we had the pleasure of visiting, under the kind guidance of Dr. and Mrs. Kiær, some of the exposures in the Ringerike district. There were only two developments of the limestone which we thought at all similar to *ballstone*, viz., at Geitö and Bragsö. At Bragsö in regularly stratified limestone (8*c*) occurs a mass of unstratified limestone containing many corals and stromatoporoids; many were observed to be in the position of growth. At Geitö the development was similar. Both occurrences of unstratified limestone are of small size. We did not see the reef facies at Holsfjord, where Dr. Kiær states|| there is the best development. The small reefs we saw are not comparable in size and importance to *ballstone* in Shropshire, but they reminded us of the isolated colonies we have referred to as occurring in other areas in England.

United States.—In the Clinton and Niagara Limestones, lenticular, unstratified masses of limestone, occurring in well-stratified beds, have long been known and often described.

Clifton J. Sarle¶ has given an account of structures somewhat similar to *ballstone* in his paper, "On Reef Structures in the Clinton and Niagara Strata of Western New York." In the Clinton Upper Limestone at Rochester, N.Y., and Niagara River, are irregularly bedded masses, of which over 140 examples have been observed. The workmen call them *boulders* because of their shape and superior hardness. "These masses," he says, "are limited to the upper half of the Upper Limestone, or project into the Niagara

* Correlated with parts of the Upper Llandovery and Wenlock Shale, *op. cit.*, pp. 546 to 551, and 568.

† He, however, correlates our Wenlock Limestone with his lowest Ludlow zone 9*a*, *op. cit.*, pp. 549-551.

‡ *Op. cit.*, p. 79.

§ *Op. cit.*, p. 81.

|| *Op. cit.*, p. 81.

¶ *The American Geologist*, Nov., 1901.

strata above. . . . The strata above and below the lenses are often so strongly bent in conformity to these less yielding masses as to produce an arching or doming of the overlying Rochester Shales and a sagging or basin-like depression which extends into the Clinton Upper Shale beneath. . . . Shale partings thin out as they reach the lens or encroach but a little distance upon it. . . . Only by weathering is the true character of these masses clearly brought out . . . then they prove to be mainly composed of a remarkable development of fistuliporid or other bryozoan forms.* . . . The explanation of origin is found in the bryozoan matter. . . . These organisms are always in the position of growth, and practically do not occur outside of the lenses. . . . Some growths, with a fine sedimentary coating filling the pores, have an appearance of concretions. . . . Concretions appear, however, to be entirely lacking."

In this description considerable likeness will be observed in many respects between the *boulders* of the Upper Clinton Lime stone and *ballstone*. In their method of interference with, and occurrence in, the stratified beds they are strikingly similar. The differences are seen when we consider the chief constructive element. The organisms which play the chief part in the structure of the Clinton *boulders* are bryozoa; on the other hand, in *ballstone* the important constructive organisms are everywhere corals and stromatoporoids. There is also a distinction between them, in that the fauna of the *boulders* shows a greater difference from that of the surrounding beds than does the fauna of the *ballstone* masses from that of the adjacent stratified beds. Another difference is that the *boulders* are often surrounded by shale beds, and they are apparently much smaller in size than *ballstone*, but these may be due to the choice of habitat and to the nature of the structures formed by bryozoal colonies, or may indicate that the destruction of the bryozoal colonies had proceeded further than of those in *ballstone*.

In the period succeeding the Clinton, conditions (in certain regions) became more favourable for the growth of corals, and large coral colonies established themselves in the Niagara seas, and the reefs described by Professor Chamberlin and Dr. Grabau in these beds seem exactly comparable with *ballstone*.

Professor T. C. Chamberlin,† in the "Geology of Wisconsin, 1873-79," gave the following general description of the conditions under which certain beds in the Niagara Limestone were formed: "For sixty miles along the eastern borders of the State, and probably extending south into Illinois, there lay a chain of barrier reefs. They now appear as irregular domes and prominences of rock. . . . The individual reefs differed measurably from each other

* Cf. The Permian Bryozoa Reef of Beacon Hill, Durham. Described by C. T. Trechman. *Quart. Journ. Geol. Soc.*, vol. lxix (1913), p. 201.

† "Geology of Wisconsin," vol. i, p. 183.

in the prevailing forms of life. The reefs themselves are composed of the comminuted relics of the life that grew upon them in all stages of destruction. There may be seen coralline masses standing erect in the rock precisely as they grew. . . . In other instances only remnants of masses are left. . . . There are detached fragments showing various signs of wear, and also coarse and fine detritus, the ultimate product of the comminuting process. These combined make up the mass of the reef rock. . . . On the sides and at the bases there accumulated a mixture of fragments and calcareous sands, growing finer and finer as the distance from the parent reef increased. . . . The ancient Niagara seas presented the simultaneous accumulations of three classes of calcareous rock, viz., the brecciated, the granular, and the compact, all derived essentially from the same source—the relics of the reef life."

In his description of reefs in the Racine beds near Milwaukee, Chamberlin* notes that "where the strata approach the reef the fauna is much amplified"

Dr. Amadeus W. Grabau has described structures comparable to *ballstone* in both Silurian† and Devonian‡ Limestones. In his account of the Limestone lenses of the Clinton (Niagara Falls) he wrote: § "At intervals in the Upper Clinton Limestone may be seen large, lenticular masses of compact, hard, apparently structureless limestone, often concretionary, and not infrequently showing numerous smooth and striated surfaces of the type known as 'slickensides,' and which are indicative of shearing movements." In the railway cut under Lewiston Heights, lenses occur entirely embedded in the limestone, from which they are differentiated by their structureless character.

In 1902 he read a paper before the Geological Society of America on Palæozoic Coral Reefs.|| The following excerpt is taken from his description of the coral reef of Shoonmaker Quarry, Wauwatosa, Wisconsin, in Niagara Limestone: "No bedding is visible in the reef portions, which appear to consist mainly of stromatoporoids . . . recognisable as a rule only on the weathered surfaces, the general aspect of the fresh face being that of extreme massiveness of the rock, with a total absence of stratification. Around the reef, however, the rock is bedded and granular, and it may be seen in many places dipping away from the central reef portion." Near Cedarberg, in Groth's Quarry, "the reef exposed is about 30 or 40 ft. in thickness, while the length from north to south is perhaps 300 ft."

In 1911 Dr. Grabau visited Shropshire with us and assured

* *Op. cit.*, vol. ii (1877), p. 367.

† "Palæontology and Geology of Niagara Falls and Vicinity." *Bull. N.Y. State Museum*, vol. ix (1901).

‡ *American Geologist*, vol. xxviii (1901).

§ *Op. cit.*, p. 99.

|| *Bull. Geol. Soc. America*, vol. xiv, pp. 337-352.

us that *ballstone* was exactly similar in character to the reef beds in Silurian strata of New York. A fine branching cyathophyllum, in the position of growth, surrounded by impalpable blue mud, at Shadwell Rock, he recognised as the structural equivalent of the bryozoa which form the reefs in the Clinton Limestone, and which are similarly enveloped in a fine rock flour.

Belgium.—The writings of the late M. Dupont* on the origin of the Carboniferous and Devonian Limestones, and his coral reef theories dating from 1881, are well known. In his division of the Devonian Limestones, into Unstratified or Massive, and Stratified, or Detrital—his explanation being that the want of stratification in the limestone is due to the presence of a rich stromatoporoid† or coral fauna—and in his detailed analysis of the stratified or detrital limestones, some almost as pure as the unstratified and with a rich fauna, at other times impure and intercalated with shales, we recognise characteristics similar to those described in this paper. Further likenesses are found in his description of the “Coral Islands of Roly and Philippeville.”‡ These are a series of isolated hills, which recall the hills of South Gotland,§ formed of unstratified reef limestone and the “irregular domes of Wisconsin,”|| as well as the “reef knolls” of Yorkshire,¶ with which they have been compared,** and the chains of hills of Kertsch and Taman.††

Later writers ‡‡ have contributed many further particulars on the unstratified or reef development of the Carboniferous Limestone in Belgium.

Yorkshire.—Mr. R. H. Tiddeman§§ in 1888 directed attention to certain limestone knolls found in the Carboniferous Limestone, which he described as “reef knolls,” and which he regarded as having been built up by the gradual accretion of animal remains in a manner similar to coral reefs, and the form of the outcrop he considered an original feature. A different explanation of their origin was offered by Dr. Marr||| in a paper

* *Bull. de l'Acad. Roy. de Belg.*, Ser. 3., T. 2 and 3 (1880); Ser. 3, T. 5 (1883).

† de Dorlodot has shown that some of these are really fenestellidæ. “Véritable nature des prétendus stromatoporoïdes du Waulsortien.” *Bull. Soc. Belg. Geol., Pal. et Hydrol.*, xxv, p. 119 (1911).

‡ *Bull.: Mus. Roy. d'Hist. Nat. de Belg.* T. 1, 2 (1882). *Bull. Soc. Belg. Geol., Pal. et Hydrol.*, vi, (1892).

§ H. Munthe, *op. cit.*, p. 183.

|| Chamberlin, *op. cit.*

¶ R. H. Tiddeman, *op. cit.*

** J. E. Marr. *Quart. Journ. Geol. Soc.*, vol. lv (1899), p. 358.

†† N. Andrussov, “Die Fossilien Bryozoenriffe des Halb-Inseln Kertsch und Taman,” vol. i, Introduction, *et seq.* Cf. also the coralliferous limestone hills of Old Radnor.

‡‡ The following amongst others: Dewalque, Lohest, etc., *Ann. Soc. Geol. Belg.*, T. 20, (1892-3). Abbé H. de Dorlodot, “Le Calcaire Carbonifère de la Belgique et ses relations stratigraphique avec celui du Hainaut français,” *Soc. Geol. du Nord*, Annales 22-23 (1894-95). M. J. Harroy, “Les masses de calcaire construit et leur relations avec les schistes qui les environnent contribution à l'étude du frasien,” *Ann. Soc. Geol. Belg.*, T. 37, M. p. 315 (1909-10). Abbé A. Carpentier, *Mém. Soc. Geol. du Nord*, T. vii (1913). M. F. Delhay, *Ann. Soc. Geol. Belg.*, 1908 and 1913. E. Maillieux, *Bull. Soc. Belg. Geol., Pal. et Hydrol.*, xxvii (1913).

§§ *Rep. Brit. Assoc.*, 1889. *Congrès Geol. Internat.* 1888, Londres, 1891.

||| “On the Limestone Knolls of the Craven District of Yorkshire and Elsewhere.” *Quart. Journ. Geol. Soc.*, vol. lv (1899), p. 327.

read before the Geological Society in 1899, when he attempted to show that the typical knolls of the Craven District of Yorkshire owe their origin to orogenic movements, and he stated that these knoll-shaped masses of limestone in other areas only occur in regions affected by profound earth-movements. The late Mr. J. R. Dakyns,* in a paper read on the same occasion, supported Mr. Tiddeman's reef theory of the origin of the knolls. In 1901 Mr. Tiddeman† replied in the *Geological Magazine* to Dr. Marr, whose views he was unable to accept. Six years later Mr. A. Wilmore‡ read a paper before the British Association entitled, "A Contribution to our Knowledge of the Limestone Knolls of Craven," in which he stated that the more massive knolls appear to be due to irregular aggregations of submarine débris; "folding has ridged up these massive limestones. . . . The smaller knolls are due to folding." In 1910 he§ continued "the long controversy" in his description of the Carboniferous Limestone south of the Craven Fault.

A short visit paid to the district in 1913 gave us the opportunity of examining some of the knolls, and from what we saw, and from the descriptions of the beds which have been published, we draw the following comparisons between the special features exhibited by the limestone knolls and those observed in *ballstone*. Both consist of unstratified limestone masses (containing occasional stratified layers) which rise transgressively in well-stratified limestones. In both the stratified limestones are found dipping away from the central unstratified masses. Both the limestone knolls and *ballstone* contain a richer fauna than that of the surrounding beds, and which occurs in colonies||; some species swarm in one particular place and are only found sparingly elsewhere. The faunas of both are generally rich in corals, well preserved. In both are found branching corals (cyathophyllidæ) surrounded by a fine calcareous matrix.¶ The stratified beds surrounding *ballstone* are slightly different in composition from *ballstone*, while those not far from the knolls show remarkable lithological differences. The following differences are noticeable. There is no coarse brecciated rock associated with *ballstone*, which in the limestone knolls is a marked feature.** In *ballstone* the coral fauna is frequently in the position of growth, but in the knolls there is no evidence that this is the case. No change between the coral fauna of *ballstone* and that of the associated beds has yet been noted, but between the fauna of the knolls and of the stratified limestones it is probable that there is non sequence,††

* "The Limestone Knolls between Skipton and Grassington:" *Quart. Journ. Geol. Soc.*, vol. lv (1889), p. 359.

† "On the Formation of Reef Knolls." *Geol. Mag.*, dec. iv, vol. viii (1901), p. 20.

‡ *Geol. Mag.*, dec. v, vol. iv (1907), p. 37.

§ *Quart. Journ. Geol. Soc.*, vol. lxxvi, p. 539.

|| *Quart. Journ. Geol. Soc.*, vol. lxxvi, p. 574.

¶ *Quart. Journ. Geol. Soc.*, vol. lxxvi, pp. 552 and 565 (1910).

** Tiddeman, "Congrès Geol. Internat.," 1888, p. 321 (Londres, 1891).

†† *Quart. Journ. Geol. Soc.*, vol. lxxvi, p. 584.

the fauna of the knolls being apparently slightly older* than that of the adjoining stratified beds. The presence in *ballstone* of erect coral growths make it clear that the suggestions† advanced by Dr. Marr and Mr. A. Wilmore to explain the origin of the limestone knolls of Craven do not offer an explanation of the origin of *ballstone*.‡

Russia.—N. Andrussov, in his great work on the fossil bryozoal reefs of the Peninsula of Kertsch and Taman,§ now in course of publication, gives a detailed account of bryozoal colonies which are developed on a large scale in the Tertiary deposits round the Sea of Azov and the Black Sea. We draw attention to them because the *Membranipora* reefs and their relations to the surrounding strata, which he describes and figures, bear a striking structural resemblance to *ballstone* and to the reef structures described by Sarle,|| and they illustrate the kind of rock structure which a growing colony has formed in Miocene times, and show its relation to the surrounding stratified deposits, both lithologically and faunistically. The bryozoal masses of the *Membranipora Limestone*, to which the name "reef" is applied, occur at the top of the Sarmatische Stufe and extend up into the Maötische Stufe above. The *Membranipora Limestone* consists of vast ovoid, or lenticular, unstratified calcareous masses, composed of large undisturbed colonies of *Membranipora*. On the outer part, between the long bryozoal growths, various species of Maötic shells are found entangled, and the cracks and fissures of the *Membranipora Limestone* are filled in and the masses surrounded by alternating hard beds and mussel detritus layers, in which is the ordinary Maötic fauna. In the neighbourhood of the unstratified limestone masses the stratified Maötic Limestones bend correspondingly over them, the dip gradually diminishing in the higher lying strata above. Andrussov considers that bryozoal rudist, and other reefs possessed their own special characteristics, which should be studied in relation to similar recent structures, but he adds that, unfortunately, no recent bryozoal reefs are known with which the reefs he has described may be compared.

* *Quart. Journ. Geol. Soc.*, vol. lxi, p. 585.

† Cf. Lamplugh, "On Some Effects of Earth Movement in the Isle of Man." *Quart. Journ. Geol. Soc.*, vol. lvi, p. 21; and Lapworth (Discussion), p. 23.

‡ Since these brief notes on the Belgian reefs and on the Yorkshire "reef-knolls" were first written, a paper by Dr. A. Vaughan, on the "Correlation of Dinantian and Avonian," has been read before a meeting of the Geological Society, in which Mr. Tiddeman's view of the nature of the Clitheroe Knolls was confirmed. [See *Abst. Proc. Geol. Soc.*, No. 954, p. 68, and Discussion, p. 69.]

§ N. Andrussov, "Die Fossilien Bryozoenriffe des Halb-Inseln Kertsch und Taman."

|| *Op. cit.*

IX.—SUMMARY AND CONCLUSIONS.

1. Between Lincoln Hill and Presthope the Wenlock Limestone shows a large development of solid limestone. This is found to be due to the presence of large unstratified masses called *ballstone* lying in hard courses of stratified limestones.

2. The *ballstone* masses and the adjacent solid stratified limestones contain a rich coral and stromatoporoid fauna, in the one case enveloped in, and intimately surrounded by, a fine-grained, flour-like, unstratified calcareous matrix; in the other, occurring in the nodular courses or in the platy layers composed of broken fossil fragments.

3. An average of over 90 per cent. of the corals and stromatoporoids are found to be in the position of growth in *ballstone*, while only 16 per cent. are in the position of growth in the adjacent stratified beds.

4. The fauna of the adjacent stratified limestones is very similar to that of *ballstone*, from which it has chiefly been derived.

5. Unstratified *ballstone* rock has been compared with unstratified rock masses occurring in stratified limestones elsewhere to which writers have applied the term "reef," and the structures are found to be strikingly similar and to be due to a growth in place of different forms of rock-builders, and to occur at different geological epochs.

CONCLUSIONS.

Ballstone rock is the relic in place of large coral and stromatoporoid colonies still in the positions in which they originally grew. The absence of coarse brecciated rock suggests that the colonies lived in comparatively calm or sheltered waters, whilst the fine flour-like matrix or silt in which the colonies are embedded is indicative of destructive wave-action at no very great distance, which has supplied the material intercepted by the branching corals and caught in the interspaces between the colonies. Such conditions are analagous to those now found behind a barrier reef* or in a lagoon. That the colonies were originally of greater extent but subsequently suffered destruction is deduced from the presence of the large and identical coral fauna found scattered and overturned in the adjacent stratified beds; evidence for believing that this destruction was subsequent to the consolidation of the reef has already been given.† Indications of the shallowness of the waters in which the colonies flourished are gathered from the absence of long thin branchless coral stems such as are developed in deep waters,‡ and from the abundance and variety of the

* Cf. Chamberlin and Salisbury. *Geology*, vol. ii (1906), p. 407.

† Pages 207 and 208.

‡ F. Wood Jones, "Corals and Atolls" (1910), p. 94.

bryozoa, and from the character of the sediments on which they rest.

The colonial and attached character of the fauna of the Wenlock Limestone occurring in *ballstone* suggests that the fauna should not be regarded as the normal or standard Wenlock Limestone fauna, but that it is a peculiar fauna due to the special conditions under which it lived. Similar attached colonies are found to occur not seldom in stratified limestones, and to present in common with each other certain special features of their own, which differentiate them lithologically and often faunistically from the stratified beds surrounding them. To the masses of rock formed by these colonies the term "reef" has often been applied, and to follow modern usage such beds might be said to have been formed during a reef-phase,* but they can hardly come under Mr. E. E. L. Dixon's inclusive term "lagoon-phase," as defined and explained by him in his Note on Lagoon-Phases.†

The reef-phase during Upper Silurian times was developed over a wide area; the fauna of the Niagara Limestone and of some of the limestones of Gotland and of the Wenlock Limestone is known to be strikingly similar. Stuart Weller‡ points out that the distributional evidence of the Silurian strata is favourable to the existence of a North Polar connection§ between the Silurian seas and those of the interior of North America, and that the likeness is greater between the fauna of the Mississippi Valley and North Europe than between that of New York and North Europe.|| We would point out that it is also in this very region of the Mississippi Valley that beds formed during the reef-phase of the Niagara Limestone are best developed, and would suggest that the greater similarity in the faunas may be partially explained by this fact.

Although at each end of the "broad thoroughfare"¶ which joined Wisconsin** and Iowa to Gotland and Wenlock there is evidence of a reef-phase, information on the Silurian beds round the present Arctic Ocean is too imperfect to determine if any scattered reef colonies dwelt between.

The term "zoogene reef"†† is strictly applicable to the special facies (such as *ballstone*) formed during a reef-phase. It would include structures formed by various reef-builders such as bryozoa,

* A. Vaughan, "The Avonian of the Avon Gorge." *Proc. Bristol Nat. Soc.*, Ser. iv, vol. i (1906), p. 79.

† Mr. E. E. L. Dixon and Dr. A. Vaughan on the "Carboniferous Succession in Gower," *Quart. Journ. Geol. Soc.*, vol. lxxvii (1911), pp. 511 and 512.

‡ "The Silurian Fauna interpreted epicontinently." *Journ. of Geol.*, vol. vi (1898); cf. vol. iv (1896).

§ E. O. Ulrich, "Revision of the Palæozoic Systems," *Bull. Geol. Soc. Am.*, vol. xxii (1911); A. W. Grabau, "Early Palæozoic Delta Deposits," *Bull. Geol. Soc. Am.*, vol. xxiv (1913).

|| Chamberlin and Salisbury, *Geology*, vol. ii (1906), p. 410. Grabau, "Guide to the Geology and Palæontology of Niagara Falls and Vicinity," *op. cit.*, p. 127.

¶ Chamberlin and Salisbury. *Geology*, vol. ii, p. 400.

** T. C. Chamberlin. *Geology of Wisconsin*, vol. i, p. 183 (1873-79); vol. ii, p. 365.

†† Andrussov, *op. cit.*, p. 5.

as well as corals and stromatoporoids. The use of the narrower term "coral reef" * for Palæozoic structures has been objected † to on various grounds, but the objections are largely met when the varied forms which it is now known modern coral reefs assume are recognised and the amount of denudation and the different modifications to which the Palæozoic reefs have been subjected is considered. And even though the modern great reef-builders were absent from the Palæozoic seas, and we are ignorant of the mode of life and conditions under which the ancient reef-builders flourished, yet the analogies between the structures they raised are so numerous ‡ as to warrant the retention of the ancient and useful term "coral-reef" § to indicate certain types of rock structure of considerable size formed by attached coral colonies in Palæozoic seas.

On the origin of the lenses within *ballstone* we have submitted some evidence || which suggests that the lenses were formed prior to the deposition of the regularly stratified limestones which surround *ballstone*, and to the formation of the grooved and slickensided planes which traverse the limestone ¶ here and there. The shape of the lenses is sometimes suggestive of the natural forms of some perfect coral colonies ; but the fact that the lenses are not often composed of one colony and its friends alone, and that the branches of a colony in one lens may be seen occasionally to extend into neighbouring lenses, make it clear that the lens form is not an organic growth. The phacoidal, or lens-shape, is very commonly the result of earth-movements, and it is possible that some of the more irregular wedge-shaped blocks may have been so formed, and there is evidence of some shifting and movement between the lenses ; but this is not everywhere the case (as the example of the branching coral just quoted shows). If the phacoidal form were due to earth-movements it must have been impressed on the rock mass shortly after its consolidation and before the deposition of the stratified beds, for it is unlikely that *ballstone* alone, and none of the stratified beds, could receive this structure, and the finding of overturned lens-shaped masses of *ballstone* in the stratified beds supports this view.

Most writers on the Wenlock Limestone have described it as concretionary. It seems to us most probable that the large lenses of *ballstone* are due to slight contraction following some process of concentration and adhesion of the rock-flour which took place during, or shortly subsequent to, the consolidation of

* Cf. J. Walther's definition of a coral reef. *Einleitung in die Geologie*, iii (1894), p. 909.

† Jukes-Browne, "The Building of the British Isles," p. 14.

‡ Cf. T. Wayland Vaughan, "Physical Conditions under which Palæozoic Coral Reefs were Formed," *Bull. Geol. Soc. Amer.*, vol. xxii (1911).

§ N. Yakowlew, "Les Recifs Coralliens existents-ils dans le Palæozoic," *Bull. du Com. Geol.*, Tome xxx, St. Petersburg (1911).

|| Pages 207 and 208.

¶ Page 205.

the coral rock and subsequent to the death of the corals. The formation of lenses accompanied the reef-phase apparently in Gotland and the United States as well as at Wenlock and Rushall. One element common to each is the fine rock-flour, and the explanation of the development of the lens form might perhaps be sought for in its fine impalpable structure and chemical composition* inducing adherence under peculiar physical conditions,† and the high percentage of silica shown to be present in *ballstone* may not be without significance.

* Abbé de Dorlodot, "Véritable nature des prétendus stromatoporoïdes du Waulsortien." *Bull. Soc. Bel. Geol. Pal. Hydrol.*, xxv. (1911), pp. 129-130.

† Cf. James H. Gardner, "Physical Origins of Certain Concretions." *Journal of Geology*, vol. xvi (1908), p. 454.