No. IV.—On Zonal Work in Lower Carboniferous Rocks, with some Remarks on the Collection of Fossils. By R. G. Carruthers, F.G.S., of H.M. Geological Survey.

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The subject of this communication has already been brought before the Society by Mr. James Neilson.* Still, even when considered from a purely zonal standpoint, Carboniferous palæontology is inevitably associated with so many side issues that a further review of the present state of affairs may not be unwelcome.

In the British Isles zonal work on the Lower Carboniferous rocks is based entirely on the researches of Dr. Arthur Vaughan; and rightly so, for they bid fair to resolve a problem which, only a few years ago, was thought to be practically incapable of solution. Yet it should not be forgotten that Belgian geologists initiated the zoning of the Carboniferous Limestone many years ago. The basis of the Belgian scheme was comprehensive in nature; fishes, cephalopods, brachiopods, and corals were all utilised, besides a certain amount of purely lithological data. The zones thereby established were ill-defined and somewhat unsatisfactory. One result, however, was made clear; the limestone was divided into an upper part, termed Visean, and a lower part, called Tournaisian; (at first a middle or Waulsortian division was also recognised, but this is now regarded as a special phase of the Visean).

These two great divisions have been recognised in several European countries, and have proved of considerable use to stratigraphers. Where originally investigated, that is to say, in Belgium itself and in north-eastern France, their exact relationship to each other is, unfortunately, obscure. The conformable passage of the Tournaisian down into the Upper Devonian can be demonstrated, and also the passage of the Visean up into Upper Carboniferous strata, but the actual

*Article on "Review of Fifty Years' Work: Palæontology," in the "History of the Geological Society of Glasgow," pp. 139-164. (1908.)

junction between the Tournaisian and Visean themselves has apparently not been observed. It is not yet clear, therefore, whether an interval of time elapsed between their deposition or whether they are partly equivalent, the faunal differences arising in some degree from the effect of distinctive physical conditions in the two provinces.

As far as England is concerned, Belgian geologists were able to recognise a full sequence of their zones in the Avon gorge, near Bristol, and they were also of opinion that in north-west Yorkshire an enormous overlap occurs, so that on Ingleborough Visean strata rested directly on pre-Carboniferous rocks; their conclusions, however, for long remained almost unknown to British geologists.

Dr. Vaughan's work, although of much later date, was of an entirely independent character. His scheme, in which brachiopods and corals alone were used, was originally drawn up from data obtained in the gorge of the river Avon, near Bristol. At this locality the whole of the Carboniferous Limestone, from the conformable junction with the Old Red Sandstone right up to the Millstone Grit, is displayed in one continuous series of magnificent cliff sections. Observations subsequently made have resulted in the addition of two other zones or sub-zones (D_3 and P) cut out in the Avon section by the Millstone Grit.

As now established, there are six main zones, divided in turn into sub-zones, and separated by passage beds possessing subzonal value. The full sequence is outlined in tabular form on the opposite page, a few of the more important and characteristic fossils being given with each subdivision; the reader should, however, consult the original paper for fuller details.

Following the application of this zonal scheme in England, Wales, and Ireland, the main zonal succession has not only been found to hold good to a remarkable extent, but stratigraphical features of the first importance have been discovered whose existence had previously been unsuspected. We have, for instance, the demonstration of a strong unconformity within the Limestone itself in South Wales, and of the Upper Visean age of the Derbyshire massif. The suggestion by Belgian geologists that the whole of the Tournaisian is cut out by

overlap in north-west Yorkshire has been independently confirmed, and a similar overlap has also been discovered in North Wales. Finally, in the far west of Ireland, the great limestone tablelands of County Clare have revealed a complete zonal sequence, differing but slightly from that found in the Bristol district itself.

Deductions such as these have widened our knowledge of Carboniferous stratigraphy in a very remarkable degree, and they have followed Dr. Vaughan's original paper so rapidly that one is apt to forget how hopeless the outlook for zonal work appeared only a few years ago. It is therefore all the more regrettable that difficulties of a special nature, hereafter detailed, attend an application of the scheme to Scottish strata.

OUTLINE SCHEME OF THE AVONIAN ZONES.

		ZONES.	SUB-ZONES.	CHARACTERISTIC FOSSILS.
Avonian.	Visean.	'*Posidonomya*' or P	Upper P	
			Middle P	
			Lower P	*Michelinia favositoides* — *Martinia ovaliglabra*
		'*Dibunophyllum*' or D	D_3	*Cyathaxonia rushiana*, *Productus scabriculus*
			D_2	*Dibunophyllum* ψ (? = *D. turbinatum*), *Cyathophyllum regium*, *Lonsdaleia floriformis*, *Productus giganteus*
			D_1	*Carcinophyllum* sp., *Chonetes* aff. *comoides*; *Dibunophyllum* θ, *Productus hemisphericus*
		'*Seminula*' or S	S_2	*Productus cora* [Dav.] mut. S_2
			S_1	*Lithostrotion basaltiforme*; *Productus semireticulatus*, mut. S_1 (spinose form)
			δ	
	Tournaisian.	'*Caninia*' or C		*Michelinia grandis*, *Syringothyris laminosa*; *Caninia gigantea*
		'*Zaphrentis*' or Z	γ	*Caninia cornucopiæ* — *Zaphrentis konincki*
			Z_2	*Zaphrentis omaliusi*
			Z_1	*Zaphrentis delanouei* — *Cliothyris glabistria*
			β	
		'*Cleistopora*' or K	K_2	*Spiriferina octoplicata* — *Cleistopora geometrica*
			K_1	*Productus bassus*
			α	
		'*Modiola*' phase or M		*Cliothyris royssii*

When reading Dr. Vaughan's original paper, one of the first criticisms to be made by those interested in the palæontology of the Scottish Carboniferous rocks is that the names of certain species familiar in our Carboniferous Limestone Series appear low down in the Tournaisian. At first sight it would seem, therefore, that these species have much greater vertical range with us than in extra-Scottish areas, for it has long been known that our Limestone Series must lie high in the Visean. And, as a matter of fact, the point has been noted by Mr. Neilson in the article referred to at the head of this paper. As far as this difficulty is concerned, however, it should not be forgotten that minute structural differences may be of great zonal importance, and that it by no means follows that the English and Scottish fossils are identical, although for the present the same name may be allotted to them.

A difficulty of greater moment lies in the fact that (at any rate, so far as the corals are concerned) the zones are not in continuous genetic sequence, so that the apparent range of most of the species does not represent the full length of their existence in the scheme of evolution, but depends rather on the duration of the particular physical conditions favourable to their existence. The fauna of each zone does not represent direct descendants from the immediately preceding zone, but usually marks an immigration of quite different stocks, brought in by a change of conditions. Further, any one gens (or group of closely related species) may recur, with little change, after a variable interval of time. During that interval the gens must have flourished elsewhere, so that we cannot say that the mere occurrence of the same species in two or more areas necessarily takes place in the same time-zone at each place.

These objections do not affect the value of the scheme when used in a broad sense, but are only pointed out as a caution when finer stratigraphical details are needed, or in correlating areas which are, geographically, far apart.

Again, in any two districts it may happen that at one and the same time conditions of existence were very different, and, in consequence, the faunal assemblages of these districts have little in common. It is for this very reason that an extension of the scheme to Scotland is hardly practicable at the present

time. A brief consideration of the facts should make this apparent.

In the first place, the equivalents of most of the English zones lie, in Scotland, in the Calciferous Sandstone series, which (except in small areas along the Border) is to all intents and purposes barren of brachiopods and corals. But, this fact apart, even our most fossiliferous beds, in the Limestone Series, present great difficulties in zonal work, for the following reason:—The Upper and Lower Limestone Groups of Scotland (together comprising the Carboniferous Limestone Series) are known to be, broadly speaking, of Upper Visean age. The Lower Group has been traced by most careful field work down through the North of England into the Yoredale Limestones, which, near Ingleborough, overlie the main massif of the Carboniferous Limestone, still of Visean age.

Now, the corals and brachiopods of the two Scottish Limestone Groups, and also of the Yoredale rocks, belong to a particular faunal phase, which persists right up to the end of the Lower Carboniferous period (*i.e.*, up to the break in the Carboniferous flora and fishes that occurs in the Millstone Grit). But south of Ingleborough, and in Ireland also, wherever zonal work has been done, this particular faunal phase has only been found in the Upper *Dibunophyllum* (or D_2) subzone, and two totally different phases supervene before the upper limit of the Lower Carboniferous rocks is reached in the Millstone Grit. These new phases are represented in the *Cyathaxonia rushiana* (or D_3) and the *Posidonomya* (or P) sub-zones. In so far as the corals are concerned, it can be said that not one single species peculiar to the D_3 or P subzones has yet been found in the Scottish rocks.*

To sum up, therefore, the particular physical conditions favourable to the development of the D_2 phase, persisted in Scotland right on to the close of the Lower Carboniferous period; in the Midlands and in the south-west of England, and in Wales and Ireland, these conditions obtained for a comparatively short time, and were succeeded by others of a quite different kind. And although we know that our Car-

* James Thomson was mistaken in his identification of the genus *Cyathaxonia*. The genus, however, is known to occur in the Lower Limestone Group, but *C. rushiana* has not yet been definitely recognised, the cottish species being extremely close to the Tournaisian *C. cornu*.

boniferous Limestone series must contain the time equivalents of the D_2, D_3, and P sub-zones, the faunal succession is so different in the two cases that comparative correlations are hardly practicable in the present state of our knowledge.

The necessity of obtaining the genetic range of species before their zonal value can be ascertained is, in my opinion, an essential matter. To illustrate the argument some concrete examples may be utilised. Take, for instance, such well-known fossils as *Productus latissimus* and *Nautilus nodiferus*. Most Scottish geologists use these fossils zonally, as indicative of Upper Limestone strata. But for what reason are they commonly found in the Upper Limestones only? Is it because they were not evolved until Upper Limestone times, or were they established previously, living in outside areas, until the onset of favourable physical conditions during the deposition of the Upper Limestone group allowed of their introduction to Scottish areas? If the latter cause be the true one, then it is clear that these species do not, after all, necessarily point to an Upper Limestone position, but may appear on lower horizons also. And, as a matter of fact, this is the case, for we know of typical specimens of *P. latissimus* in the Lower Limestone near Paisley, and of *Nautilus nodiferus* from the Lower Limestone (Hosie) beds of the East Kilbride basin.

Take, again, the case of those large cup corals, the Clisiophyllids. These are usually considered as characteristic of the Lower Limestones, and not to occur in the Upper Group. Yet they are extraordinarily abundant in the Upper Limestones at Bruntsfield Castle, Midlothian, and also near Linlithgow and Cumnock, where they differ but slightly, if at all, from those found in the Lower Limestones. Their limitation, in most parts of Scotland, to the Lower Group is quite evidently due to generally unfavourable conditions in Upper Limestone times, and to that cause only.

These cases may serve as illustrations of the inadvisability of taking the apparent restriction of fossils to one stratum (or group of strata) as an absolute fact until the reason is known. What is needed is the determination of the *genetic* range of each species, *i.e.*, the relative length of time that species flourished, from its inception to the decline and replacement by direct descendants. This genetic range must almost invariably

be much longer than the range noted in any one district or locality. In Carboniferous times physical conditions were hardly ever so stable as to allow of a species passing through its whole evolutionary existence in one district without a temporary banishment to other regions. And as the causes that occasioned this banishment are not of necessity expressed lithologically (for instance, they may have arisen from slight changes in temperature), safety is only assured by taking the full genetic range of a species as its zone.

Zones based on genetic series are, of course, extremely difficult to obtain. One of the best examples is perhaps that afforded by Dr. Rowe's researches on the chalk sea urchins, belonging to the genus *Micraster*. In this case the various species of *Micraster* were collected at all horizons in the chalk, and arranged in one long evolutionary series; the varying characters assumed by each species from its rise to its fall were noted, and also the passage forms linking species to species. As a result, the exact genetic range of each form was determined, and not merely a range governed by the duration of the particular physical conditions favourable to that species. Now, all our experience supports the conclusion that evolutionary changes are of a synchronous nature over very wide areas. Consequently this work on the *Micraster* species has led to the establishment of an exact and genetic zonal scale, which has been applied to the Upper Cretaceous rocks with the greatest success.

Beyond doubt work of this nature has been greatly facilitated in both Cretaceous and Jurassic rocks by the long-continued prevalence of physical conditions favourable to one special form of life. It is well known that this was not the case in Lower Carboniferous times. Nevertheless, the immense difficulties thereby introduced are somewhat lessened in our Carboniferous Limestone series by the stratigraphical exactitude which has been attained therein. Although we cannot hope to obtain a long, vertical suite of any one gens from a single locality, we can at least build up such a suite by following the limestones from place to place until a good series of fossils has been collected. In this way the diversity of physical conditions, at first such a stumbling block, may actually be turned to advantage.

I would suggest, therefore, that when collecting fossils for zonal purposes, large numbers of specimens should be gathered wherever possible. All the forms that centre round a particular species, or group of species, should be collected (*i.e.*, the specimens should belong to the same gens). The efforts of the collector should be turned towards the accumulation of a strictly average assemblage from each locality rather than the collection of abnormal or finely preserved material. Any limestone that appears to be barren of the particular gens sought for should, if possible, be followed into districts where it happens to be productive.

Assemblages obtained in this manner should be collected from every possible horizon and over as wide an area as possible. And, finally, each of these assemblages should be subjected to the closest scrutiny with the object of finding, if possible, some change of an evolutionary nature. Probably any such changes will be of slight amount, but every point should be noted in the hope that it may eventually prove of value. For instance, in the case of the brachiopods, both external characters (general shape of the shell, nature of ribbing, &c.) and internal characters (teeth, muscle markings, &c.) should be noted and any interrelationship observed; and similarly with the corals. Any arbitrary distinctions between species or varieties may be used, provided that the ultimate designation is, if need be, corrected before publication. This latter point should be attended to; modern palæontology is already sufficiently burdened by the necessity of changing names wrongly used by old writers, without adding modern authors to the list.

As already mentioned, it is probable that any evolutionary changes observed will not only be of slight amount, but will take place with extreme slowness. Consequently the genetic range of each species in a gens may be of considerable extent. Nevertheless, by ascertaining the percentages of each species or variety, and also by using, in conjunction, the ranges of several gentes, smaller divisions may be possible. Genetic zones determined in this manner should be capable of a very wide application.

Work of this kind has a bearing on many other problems

besides those of a purely stratigraphical nature. We learn not only the lines of evolution followed by certain fossils, but may hope to throw light on some of the numerous questions dealing with the influence of physical environment, on the relative value of faunal and lithological lines as time indices, and directions of migration. The field of investigation is, indeed, a very wide one, and one may hope that it will lead to many lines of research which are comparatively new to Scottish geologists.

Continual references to the papers on which the foregoing remarks are based have been purposely omitted. For these details the reader is referred to a good bibliography appended to Mr. Douglas's recent paper on "The Carboniferous Limestone of County Clare," *Quart. Journ. Geol. Soc.*, vol. lxv. (1909), p. 582. To that list may be added a note by M. Delépine (appearing in the "Comptes Rendus des Séances de l'Académie des Sciences (Géologie), Paris, 1910") dealing with the recognition of Dr. Vaughan's zones in the Carboniferous Limestone of Belgium. As this articles goes to press, Mr. Stanley Smith has published a paper on "The Faunal Succession of the Upper Bernician" (Trans. Nat. Hist. Soc. of Northumberland, Durham, and Newcastle-upon-Tyne, new series, vol. iii., part 3, pp. 591-645), which is of particular interest to Scottish geologists, as the strata concerned in many ways approximate to our own.

Finally, I would call special attention to the monograph by Professor T. M'Kenny Hughes on "Ingleborough," published in the *Proceedings* of the Yorkshire Geological Society in the years 1901, 1902, 1905, 1906, 1907, and 1908. The two concluding articles of this series (*loc. cit.* vol. xvi., part ii. (1907), pp. 177-196, and vol. xvi., part iii., pp. 253-320) deal especially with the Carboniferous rocks, and are the embodiment of a lifetime's experience of the district. They are full of invaluable facts and of advice to those who wish to engage in Carboniferous work, and a reference to them should on no account be omitted.