PHYSICAL HISTORY OF THE CARBONIFEROUS ROCKS IN UPPER AIRE-DALE.

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During the last few years the rocks in this area have been mapped in considerable detail by the Geological Survey, and the results which are coming out seem likely to throw much light upon the physiography of Carboniferous seas and perhaps upon the genesis of some limestones of other ages.

It was always a puzzle to those geologists who knew the ground how it came to pass that the well-known and very persistent series of the several limestones of the Yoredale Beds ran with such regularity over the great area of the Yorkshire dales and yet were not recognizable over the area of Bowland and the southern part of Craven.

Until the area of which we now speak was carefully surveyed, it was assumed that there was a rapid transition of type in the Carboniferous Rocks between Clitheroe and the big fells north of Settle and Malham, but as to the cause of such a rapid change no explanation was forthcoming. Even Professor Phillips, who knew the country perhaps best of any among the old pioneers of Geology, often expressed himself to me as quite unable to account for it. If there is one thing more clearly brought out than another by the mapping in detail of this ground, it is this, that there is absolutely no transition from one type to the other. The two types run unchanged in their respective areas and with complete discordance with each other, quite up to a common boundary where the differences are rather accentuated than smoothed down. They might be Jews and Samaritans, agreeing in nothing save a common boundary to their territories and a determination to have nothing to do with one another.

The line of demarcation is given by the Craven Faults, and more particularly by that which runs by the south end of Malham Tarn and that which passes between Malham Cove and Malham.

With these preliminary remarks we may introduce a table showing the rocks in the two areas and their principal divisions and thicknesses.

TABLE OF THE CARBONIFEROUS ROCKS IN CRAVEN.

Southern or Bowland Type.	Feet.		Feet.	Northern or Yoredale Type.
COAL MEASURES (Ingleton)	1,500	← The great Craven faults. →	...	COAL MEASURES (Incomplete near the faults in this area.)
MILLSTONE GRITS	3,900		..	MILLSTONE GRITS (Incomplete near the faults in this area.)
BOWLAND SHALES	300,-1,000		400—900	YOREDALE SERIES
PENDLESIDE GRITS (inconstant)	0 - 250			
PENDLESIDE LIMESTONE (with Knoll-Reefs)	0—400		400—800	THE CARBONIFEROUS LIMESTONE (with conglomerates at base).
SHALES, with Limestones	2,500			
CLITHEROE LIMESTONES (with Knoll-Reefs)	×3,250 No base.			

The rocks on both sides of these faults seem to have been formed on slowly subsiding areas, but the Bowland area appears to have been subsiding more quickly and to a greater extent than the area occupied by the Yoredale type. It represents the downthrow side of the faults. The other side of the faults of course is relatively an upthrow.

The question next arises: When did these earth-movements take place?

We know that some of the movements have occurred since the deposition of the Permian rocks, because these have in places, near as Ingleton, been tilted up at high angles thereby; but we also know that a far greater part of them were going on before the Permian rocks were deposited, because these lie at different places by unconformity on all the members of the Carboniferous—a series which shows near Burnley a vertical thickness of three miles of rocks without base or completed top. The movements necessary to subject so great a thickness of rocks to denudation in all its members before the advent of the Permian epoch must have been enormous. We may, therefore, well believe, and indeed can hardly doubt, that the crust was subjected to great movements during Carboniferous times.

When further we consider how great is the discrepancy between the rocks of the two areas in series and in thickness—that the Craven Faults form the boundary, and that a sharp one, between them—that these two series proceed from that boundary with scarcely any change, one as far as the Tyne, and the other to the western limit of the Carboniferous Rocks on the seaside plain of Lancashire—that the greater thickness is on the downthrow side of the faults—if we take all these points, I say, into consideration, it is impossible to come to any other conclusion than this :—

That the Craven Faults were to a very considerable extent going on during the formation of these rocks and that they are responsible for the lack of agreement between the two series which were being simultaneously deposited in the two adjacent areas.

This appears at first sight to be a rather large subject to be introduced into a description of the small valley of the Upper Aire, but it so happens that it was this valley in the neighbourhood of Malham together with the adjacent country on either side, along the faults westwards to the Ribble and eastwards to the Wharfe, which gave the key to unlock the mystery to which I have alluded. I had long suspected that these faults had been at work in Carboniferous times, but until this particular piece of ground lately fell to my lot to map, the actual demonstration was wanting. I then not only found my suspicions confirmed, but the uncompromising nature of the two adjacent types set forth in a manner most unmistakeable.

If we are driven to the conclusion that the movements of the Craven faults and the consequent alterations of conditions of deposit were the causes of the two distinct series in the areas north and south of the faults, several interesting questions arise. We may expect that on the downthrow side we shall get a series of deposits of which a greater portion has been formed under deeper water conditions than we shall find on the upthrow, or rather lesser downthrow, side.

Though doubtless the movements proceeded by fits and starts, and were not always at uniform rates, still there will be a greater number of beds representing shallow than deep water conditions.

If we can ascertain which beds are which, we shall be able to get a juster notion of the relative rate, duration and extent in depth of the several successive movements which combined have brought about the final results. *Relative* only, for so far we have no positive scale to give us either the rate of the earth movements or of the formation of the deposits whose character was dependent on them.

There is in the first place much presumptive evidence to be gained by consulting the Table of Rocks by any one who has a little personal knowledge of them. For instance, let us take (on the shallow side) the Carboniferous Limestone, 400 ft. It is nearly all a whitish or light crystalline limestone. Shales are seldom seen in it or are very thin. On the deeper side this is represented by Pendleside Limestone 0—400 ft., Shales with Limestone 2,500 ft., Clitheroe Limestone 3,250 ft. Of these three the first is very variable in thickness and sometimes absent; the second consists much more of shale than limestone, and its contained limestones are often, in fact usually, very impure, besides being untraceable for any distance; and the third, the Clitheroe Limestone, includes great thicknesses of shale. Then to go higher. The Yoredale Series on the shallow side contains many beds of pure limestone, persistent for the most part throughout the area. The Bowland shales on the deeper side contain no limestones at all.

What is the general result to be gleaned here? This: that in the shallower waters the limestones predominate, in the deeper waters the shales and mud.

But we must be cautious; all limestones are not shallow-water deposits; all muds are not deposited in deep waters. There are differences in limestones, and we are enabled to determine that some of them are of shallow water formation and others probably made at greater depth.

There are two very distinct kinds of limestone in the country on the downthrow side of the faults, the black, or blue as it is often called, and the white or light coloured limestone. They are not only distinct in lithological character but in bedding and general arrangement, as well as in their form in the mass, and the character which they give to the landscape. The black limestone is always well, evenly, and usually thinly bedded, and contains shaley partings.

The strike, except in a contorted country, is generally very regular and continuous. On minute examination this rock is found to be full of Foraminifera, and fragments of other organisms in a state of disintegration, though perfect fossils of certain kinds frequently occur in it. It would be called by a geologist a distinctly well stratified rock; it gives good regular features along its strike, and extends over wide areas.

The white limestones south of the faults, on the other hand, are notable for their comparatively massive character and irregular bedding. They occur sporadically, rising into big mounds of conical form which usually rest on the black limestones. They contain great quantities of Cephalopods, Brachiopods, Lamellibranchs, Gasteropods, Corals, etc., and these are often in a wonderfully perfect state, and, from the way in which they compose the rock, appear to have lived and died on the spot.

The general structure of these big mounds, or Knoll-Reefs, as I have called them, is very peculiar. They do not obey the rules of dip and strike which are usually found to obtain in ordinary parallel-bedded deposits, and any one seeking to apply these rules to them in mapping will be landed in numerous puzzles and difficulties. When, however, from the examination of several of them, the general structure is once mastered, their peculiar forms soon become easy of comprehension. Where they are quite perfect, a condition in which weathering has seldom left them, they are seen to consist of a flat top, the dip of which usually agrees with that of the other rocks of the country around in every direction and angle of dip, and steep sides all round, the dip of which is away from the centre of the hill. This dip averages 30° to 35°, but may be much higher or lower, in proportion as the dip of these flanking beds is increased or lessened by the general dip of the country round. The dip of the flat at the top is a plane of deposition, which was once horizontal. The dip of the flanking beds represents on the other hand an *original angle of deposit*, plus or minus any subsequent tilting by movements of the crust.

In other Knoll-Reefs, which have been cut into by weathering or quarrying, we find that the beds within, though sometimes obscure, present the usual dip of the country, but following them outwards we find them running into, and continuous with, the flanking beds.

It is pretty obvious from their structure that the internal beds represent successive layers, limited in their area, of growths of organisms, and that they pass into steeply-shelving banks of similar *débris* lying on the flanks of the knoll at an angle of rest. The study of the fossils composing these respective beds quite confirms this idea.

From these and other considerations, which would be too long to enter into here, there can be very little doubt that the mounds, or knoll-reefs, have been formed in a similar way to coral reefs, by growth upwards under favourable conditions of the animals of which they are composed, and by the piling up by waves, perhaps also in some places by winds, of the resulting débris. This has no doubt been going on upon a slowly sinking area, and it is a remarkable fact that none of these mounds so far have been found except on the sinking area on the downthrow side of the Craven Faults.

It is evident from facts collected in this area that large portions of those reefs, if not all successively, have been exposed to the wash of the waves between wind and water, as is the case with coral-reefs. Breccias composed of fragments of limestone, mostly sharply angular, some more rounded, and others, less frequently, worn into pebbles, have been found abundantly in many places. In some cases the breccia forms part of the inner beds of the reef; in others it is well developed in the flanking beds; and elsewhere we find beds of breccia formed on the sea bottom adjoining the reef, and inter-bedded with the lowest beds of shale accumulated on the sea bed from which the knoll has grown up.

Here then we have good evidence of these white limestones having been formed in shallow water, so shallow that the breakers could play upon, break up, and re-arrange them on the shore platform above, or consign them to deep water below.

Furthermore, some of the white limestones in certain places present phenomena which suggest that they have been formed, or rather re-constructed from calcareous débris, by wind-drifting, or have at any rate been consolidated in the open air, but as this matter is still under examination, I must postpone any further remarks on this part of my subject.

Although the white limestones, from their sporadic distribution, their physical structure, and their material, are evidently, if not coral-reefs, something formed in a kindred way, the black limestones show marked contrast to them in every way, and evidently have had a totally different origin. Most of these black limestones, which to the eye appear to be structureless, are found, when sliced and examined by the microscope, to be to a very large extent made up of Foraminifera and fragments of other organisms in a state of minute disintegration. Not that there is altogether a lack of larger and more perfect specimens, but these are not nearly so abundant as in the white limestones. Then the strongly marked bedding, so regular and parallel, the frequent alternations with thin beds of shale, and the wide and uninterrupted spread of these deposits, are all suggestive of deposition in waters which were not shallow, and in which similar conditions prevailed over wide areas.

Without going further into the evidence here, we may say that it is highly probable that the black limestones are successive floors of the ocean bed of Carboniferous times, and that the white limestones are the islands which dotted its surface.

These conclusions are derived from minute examination of a wide area, and it now remains to apply them to a part of it, the Upper Aire Valley. The portion of the Aire Basin which I propose to allude to is that N. and N.E. from Skipton, containing the head waters of the Aire from Malham Tarn downwards and its tributaries, Winterburn Beck, Flasby Beck, Linton Beck, and Skipton Brook.

If we take these areas in order from the South, as seen in one-inch maps, 60 and 61 (New Series) of the Geological Survey, we shall find that, after leaving that portion of the valley which cuts the Millstone Grit Series with its escarpments, we have (1) a great anticline which runs E.N.E. and W.S.W. from Skipton, passing by or near Bolton Abbey; next (2) a syncline of which the centre lies near Gargrave, and which brings down in its fold the Millstone Grits along a line from Flasby Fell, or Sharp Haw (pronounced Sharpa), to the Wharfe at Bolton Strid. (3) North of this comes another anticline, marked by the limestones running from near Otterburn to Grassington, also on the Wharfe. (4) A lesser anticline runs out from this, budding off as it were from it on the North, near Airton, and this is succeeded by (5) A small syncline lying just south of the village of Malham.

We have already stated that the white limestones are only sporadic in their distribution. We may also state that they occur on at least two, and probably more horizons. Referring to the Table of Rocks, we may say that they occur both in the Clitheroe Limestone and in the Pendleside Limestone. They are far more abundantly distributed on the former horizon in the Clitheroe District than in this northern part. On the other hand they are commoner in this part on the horizon of the Pendleside limestone than on any other.

The great anticline of limestone so much worked near the Leeds and Liverpool Canal to the north east of Skipton at Haw Park and Skibeden is mostly of black limestone. It is probably of the same horizon as the Bold Venture Quarries at Chatburn, and certainly belongs to the Clitheroe set of Limestones.

The big patch of limestone extending from Otterburn by Winterburn and Hetton to Rylstone, is on the Clitheroe horizon, and is all of the black limestone, except a small patch on its surface at Haw Crag Quarry, above Bell Busk, where the limestone has a decided reef character, and perhaps also on the hill east of Winterburn, but this is more doubtful. This anticlinal area of limestone shows a thickness of upwards of 2,000 ft. without a base.

Limestones of reef character also occur near Pot House and Holmes Gill Green, but they are much disturbed, and cannot be regarded as typical examples of reef-knolls.

The Pendleside Limestone is separated from the Clitheroe Limestone below by a thickness of 2,000 or 2,500 feet of shales with impure limestones and mudstones, which may be seen in the Winterburn Valley, in the Aire Valley from Newfield quarry to and beyond Kirby Malham, east of Rylstone, and in other places.

The great interest attaching to them lies in their approaching with this thickness so near to the faults in this area, though entirely absent to the north of them. The range of the Pendleside Limestone may be followed on the maps without much difficulty. It crosses the Aire Valley between Kirby Malham and Malham. A good section of it with beds of reef character may be seen on the east side of the stream here.

A little further south and on to Calton it is much contorted and also faulted. From this village eastwards it is much concealed by drift, but shows again with sections of great interest at the Winterburn Reservoir. Here we have black, well-bedded limestone surmounted by white reef limestone with little bedding, but the upper sloping surface of it as seen, or lately seen, in the dam of the puddle trench, consists of a close breccia of angular fragments of limestone. The Bowland Shales in Calfgill (or Way gill, one-inch map) hard by, are full of beds containing fragments and pebbles of limestone, and even large detached boulders are found in them. These interesting sections will unfortunately be drowned in the waters of the Reservoir.

To the East this limestone is only obscurely shown for some distance, but it swells out again into bigger dimensions at the great long knoll of Swinden, and on the other side of a peaty swamp, containing a trough of Bowland Shales, is conspicuous in a wonderful assemblage of knolls, bearing the names of Skelterton, Carden, Butterhaw, Stebden, Elbolton, and many others, running by Burnsall to the Wharfe. Elbolton and Stebden are extremely fine and conspicuous examples, Stebden in particular rising high towards the Grit Fells, and showing well the quaquaversal dip of its flanking beds. Skelterton appears rather to exhibit a section of the internal economy of a knoll, showing great stools of coral running in beds, the interspaces being filled up with crinoidal remains.

As we trace these beds away on the south side of the anticline they lessen much in feature and thickness, so much so that we cannot follow them with certainty beyond Flasby. On the north side of the Skipton anticline, however, they come in on the same horizon, and may be traced for some miles, exhibiting in places a decidedly brecciated character.

The well-known Draughton Limestone on the south side of that anticline, so popular as an instance of a contorted limestone, is seen on weathered surfaces to be made up of breccia in some of its beds, a fact which I believe has hitherto escaped notice. This is well seen also in a quarry close to the right side of the road, where there is a limekiln, on the way from Skipton, just before getting to Draughton.

The general arrangement of the Pendleside Limestone in this area is a dark, well-bedded limestone below, with white crystalline limestone above ; where thin, the latter often consists of a breccia, but where thick, it grows into great knolls ; and these appear to increase in size, and frequency in proximity to the Craven Fault.

We started to follow the range of the Pendleside Limestone in the Aire valley, between Malham and Kirby Malham. To resume it there :—we find that it dips to the north and disappears beneath the Bowland Shales, which are seen in several places, but this is only for a short distance, for it rises quickly again and forms those two great knolls between which the village of Malham snugly nestles. Then comes the fault, not very clearly seen in the river course, then Malham Cove, and further east Gordale Scar, two of the grandest features of the district.

Breccias of fragments of limestone occur in the lower part of the Bowland Shales in ascending Tranlands Beck where the first little stream joins it from the north, and still better are they seen higher up the same little gill, near the " M " of Malham on the one-inch map, close to " Heads Barn."

Further to the south and west good exposures of these beds may be studied in the gill a few hundred yards above Pott House, and a greater thickness in Newton Gill about a mile east of Long Preston. East of Malham we have already alluded to breccias at Winterburn Reservoir. They occur also between Carden and Elbolton Knolls, and in two or three places beyond the village of Thorpe in the Wharfe valley. At these localities they are all in Bowland Shales.

If we ascend to the top of the crags above Malham Cove, we soon find ourselves upon the great plateau of the Mountain Limestone proper. This, though broken at the foot of Malham Tarn, by the North Craven Fault, which throws up its base, and shows us how thin it is, and crossed by many minor faults, is one and the same as the great spread of Mountain Limestone which lies beneath all the Yorkshire dales and extends north to beyond the Tyne valley. We have crossed the Fault, and in so doing have exchanged the Clitheroe or Bowland series for the Yoredale type, and if we could realise the state of affairs when these rocks were forming, we should probably say that we had left a deep sea dotted with islands and come on to a wide and long and shallow reef.

The long history of that reef and its denizens from its early foundation on a slowly sinking plateau of slate rocks, to its last phase when the animals which lived on it, and formed it, had to succumb to conditions fatal to their existence, the recurrence oft-repeated of favouring or fatal environments, the movements of submergance and emergence connected therewith, the set of tides and currents, the transport of material, these and many other matters may be read in the Mountain Limestone and Yoredale Series, but as yet they are written only in the rocks.