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INGLEBOROUGH.

PART I. PHYSICAL GEOGRAPHY.

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In most studies there are two simple ways of giving a student an idea of the methods and leading facts. One is by explaining the principles and stating the results of observation in some definite order, generally with a view to establishing positions from each of which the advance to the next is most easily effected. The other method is to take some limited portion of the subject, some concrete example, some complex object, and describe it fully, offering such explanations of each difficulty as may be possible without much previous knowledge. This latter method is sometimes employed in teaching language by attempting first the interpretation of selected passages instead of beginning with the rudiments of grammar, or in Science by the description of some representative form. It is always usefully employed in the case of those who have some preliminary knowledge of the elements of the subject.

In Geology, however, the method does not appear to have been systematically tried, though perhaps there is no other subject in which this method can be so well applied or be suitable for such a large proportion of its students.

In the following Memoir I have endeavoured to put together some notes on one well-defined area in such a manner as it appears to me will be most useful for students who wish to avail themselves of this concrete method of teaching the principles of Geology.

I had no trouble about the selection of a district, for I have long arrived at the conclusion that, of all the districts in the world that it has fallen to my lot to visit, there is not one to compare to Ingleborough and its surroundings for the grandeur and variety of its problems, or the clearness and accessibility of the evidence upon which we must depend for their solution.

There are few subjects, moreover, with regard to which this term student has so wide a significance as in Geology. Few are too young to collect, and to learn to collect intelligently; and few too old to follow the progress of this ever-expanding study or to carry on the arrangement of and, with experience as a check, to speculate upon the significance of facts observed and collections amassed in the earlier more vigorous years of life.

Having regard, then, to the requirements of those who are getting up the subject as part of their early education, as well as of those who wish to investigate geological phenomena for themselves collectively as Field Clubs or Scientific Societies, or those who rush off alone to take a short holiday in the pursuits of an intellectual character in the open air, I offer this small contribution, in the hope that it may forward their wishes.

I have adopted the stratigraphical rather than the geographical arrangement, because I think it far more useful to work out the details of any district in that manner, and because I feel that those who can pay only one visit to each locality must take the trouble to get up some of the details beforehand.

The position of Ingleborough is known to most visitors to the North of England. It is the grand terraced mountain along whose base you run by rail all the way from Settle to Ingleton

(Plate XXII). It is the bold bluff that travellers from Lancaster northwards see on the north and east standing out like a huge citadel in front of the fells of the West Riding. It is the great brown flat-topped mass along the eastern flanks of which the Settle and Carlisle Railway climbs, giving the traveller a final view of its northern slopes just before he plunges into the great tunnel near the source of the Ribble.

Ribblesdale, Chapel-le-dale, and the valley of the Wenning, almost enclose the mass that may be referred to Ingleborough. Its base spreads over an area of about 30 square miles. It rises

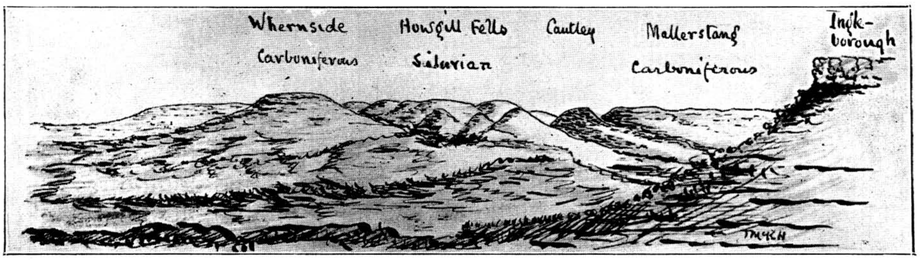


Fig. 1.

THE PLAIN OF THE HOWGILL FELLS SEEN FROM THE WEST SLOPE OF INGLEBOROUGH.

Showing the sea-plain at about 2,000 feet above sea-level.

2,373 feet above the sea—which is seen from its summit opening out on the south-west in Morecambe Bay, between the Claughton Fells and the lower hills of Arnside and Grange.

Turning the other way, we see that it is one of many similar masses which close up to form the Great Plateau of the West Riding, Whernside and Penyghent being isolated and forming mountains more or less resembling Ingleborough, while Widdle and Dod are less completely hewn out. Only one summit dominates Ingleborough, namely, the hog-backed Whernside, which rises 41 feet higher.

The hummocky mass of the Howgill Fells rises to about the same elevation (Fig. 1), and, carrying our eye along the sky-line further west, we see range after range reaching the

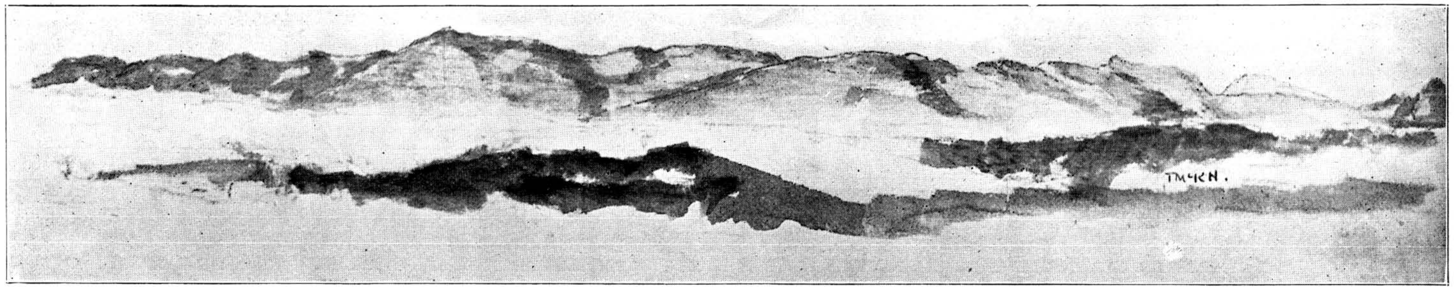


Fig. 2.

VIEW OF THE SOUTHERN GROUP OF LAKE MOUNTAINS FROM ENDMOOR, SEVEN MILES SOUTH OF KENDAL.

Showing the sea-plain at a little over 3,000 feet above sea-level.

same general level up to the base of the Lake Mountains. These in their turn are obviously fragments of a higher plateau, the average elevation of which is some 3,000 feet above sea level; while that on which we stand and which runs up to the base of the higher Lake Mountains is a little over 2,000 (Fig. 2).

What is the origin of this very marked feature in the landscape? We know from the geology of the district that none of these mountains to which I have called attention, either of those which touch the level of the Lake District Plateau, or of those which belong to the West Yorkshire Plateau, owe their present outline to original deposition. Nor is it due to any hard bed down to which denudation, sub-aerial or mixed, had reduced the general surface level. Not only have the valleys which separate one mountain from another been scooped out by various agents of denudation, but the tops have been planed off by denudation of some kind, and we do not in any case see the original highest beds.

In regarding these great plateaux, we are clearly face to face with some phenomenon connected with the greater operations of Nature — something upon which depended the modelling of our highest mountain groups, and the interpretation of which ought to give us the key to the great succession of events of which Geology treats.

There are, however, certain complex operations that come under our observation at the present day which will fully explain the existence of relics of wide-spread plateaux of this character. Along the shore we see the waves twice a day in accordance with wind and tide and local conditions rolling along the *débris* that falls from the cliffs, or is carried down by streams. It uses the boulders and pebbles and sand as ammunition with which to batter down the rocks. It carries on this waste only to a depth of some 60 or 100 feet below sea level, for deep ocean currents do not contribute much to this sort of work.

The sea is always at it, and, if the relative level of land and water remained steady, all the dry land would in time be carried down and spread out below the waters of the sea. There is plenty of room for it all there, for it would take about 36 times all the land that stands above the sea to fill up its bed.

The waves plane all down for some 60 or 100 feet more, and there the surface is protected from further waste.

The plain of the Yorkshire Fells is one of these sea-plains now lifted up some 2,000 feet more or less above sea level. If we want evidence that it is not merely a stage in sub-aerial waste, determined by the same hard and widespread bed which has arrested the action of the frost and ice and rain and streams, we have only to examine the sequence of rocks more closely to obtain the proof. The bed that forms the hill tops is not always the same. Even from Ingleborough to Penyghent we creep on to higher beds, and if we trace the beds further north we shall still find different members of the series capping the Fells. The evidence is clear enough, even in the nearly horizontal strata of the Carboniferous rocks of the district north of Clapham. But we have further proof, and clearer, if we just cross to the north-west from Ingleborough on to the Silurian Fells near Sedbergh (Fig. 1). There the rocks are no longer nearly horizontal, but roll up and down in faulted folds, yet the tops of the hills are all planed off to the level of the sea-plain, which is touched by the Carboniferous Fells north of Clapham. From that it may be traced always at about 2,000 feet above sea level to the base of the Lake Mountains, which are an island, itself the last remnant in that part of England of a now higher sea-plain, undulating at about 3,000 feet above sea level. This is not the only example of these two sea-plains. In Wales the lower or 2,000 foot plain touches the tops of all the higher mountains of South Wales, and, leaving Plinlimmon as an island in Central Wales, laps round the higher or 3,000 foot plain of Snowdonia, just as our 2,000 foot plain runs up to the 3,000 foot plain of the Lake District.

Surely we have here a grand subject for further research. What is the age of these two plains? What basement bed derived its pebbles from the shore of the sea that arrested denudation at the 2,000 foot plain of Yorkshire? and what formation was laid down in the sea that crept across the 3,000 foot plain of Cumberland? Which way did that sea advance, from north, or south, or east, or west?

Geologists, who regarded these phenomena chiefly from the point of view which is forced upon us as we stand upon the coast line, and watch the tremendous power of the waves as they batter the cliffs and lash the shore, called the level surface so produced a *Plain of marine Denudation.*

But there is another set of agents at work reducing all the protuberances of the earth's surface. The air, and rain and rivers, and glaciers, and changes of temperature and moisture are breaking, dissolving, transporting everything down to the sea. There it can do no more; the sea arrests all further sub-aerial waste and reserves for itself the work of removing the last 60 or 100 feet. Geologists who have regarded the great work of degradation chiefly from this inland point of view, have called the level surface down to which the whole land is thus reduced by sub-aerial agencies the *Base-level of Erosion.* Another name suggested by American Geologists for it is *Peneplain*; a word which they would define to mean a region of faint relief, the penultimate result of long-continued action of denudation on a once larger land-mass, whose ultimate result is a base-levelled plain.

Of course it is to both of the agencies above mentioned, acting simultaneously throughout long ages, that we must refer the tremendous results that we have forced upon our attention as we look around from the top of Ingleborough. We will refer to these great plateaux by the shorter term *Sea-plain*; to distinguish them from the *River-plains* or *Bed-plains*, of both which also we have examples round Ingleborough.

It is possible that there might be traces of the action which formed these sea-plains. Fissures filled by *débris* of the Poikilitic and Jurassic sea were found by Charles Moore in the Carboniferous Limestone, near Bristol.

Why should we not find in cracks and fissures on the top of Ingleborough, or of some other parts of our ancient sea-plain, the *débris* washed in by the sea that reduced them to this level?

The sea that planed off the top of Ingleborough lashed the rocky base of the Lake Mountains, which then, however, did not rise more than a thousand feet above its level. But it is to be feared that the denudation which has been going on ever since that time has completely swept away whatever traces were left upon that rocky shore. However, there we see shores which were washed by the sea that planed off the top of Ingleborough.

We have, as I have already pointed out, another fragment of that ancient land in North Wales, where the Snowdonian group represents it, attaining about the same height, viz., a little over 3,000 feet, while all round it there stretches the great 2,000 foot sea-plain, corresponding to that of which the top of Ingleborough forms part.

Just consider for a moment what this means. To reconstruct the upper sea-plain so as to unite Snowdonia with Lakeland you must put back 1,000 feet of rock over all the north-west of England and the whole of Wales, as well as over the intervening sea, in which the mountains of the Isle of Man are the only relic of the former extension of either sea-plain over this area.

Now, denudation implies a corresponding deposition. Where is the great formation built up of the material carried down to the sea when the Ingleborough sea-plain was formed? It must be later than Carboniferous, because Carboniferous rocks were being planed off. Was it Jurassic with its Poikilitic basement bed, or was it Cretaceous, or does it belong to that age of volcanic activity and vast denudation, the Miocene? Or must we refer it to the time of great erosion which immediately preceded glacial conditions here, and so make it correspond to the Osarkian or to the Champlain of America?

As we look out south over the range of hills that trends away to the east from Lancaster and to the flat-topped isolated mass of Pendle, we ask, have we here other outlying fragments of our great West Riding Plateau? But we soon find that their summits do not attain to anything like the level of Ingleborough. This difference of elevation is too great to allow us to consider them now as part of the West Riding Plateau, but may we speculate upon their having originally formed part of the same plateau? And, if so, we have to admit that since the planing off of this great sea-plain all the land south of the Craven faults has dropped many hundred feet. Mr. Tiddeman is of opinion that this downthrow was going on in Carboniferous times. If we could prove that the Claughton Fell level belongs to the West Riding sea-plain, then we should have to admit that the downward movement on the south, whether by fault or by gradual southward slope, or by both, still went on long after the formation of the newest Carboniferous rocks.

The Ingleborough sea-plain is newer than the great faults that run from the Eden Valley down Ravenstonedale to Lunesdale, for the sea planed across the faults that throw the Carboniferous rocks of Mallerstang and the rest of the Yorkshire moorlands on the east against the Silurian of the Howgill Fells on the west (see Fig. 1), leaving them both as parts of the Ingleborough sea-plain.

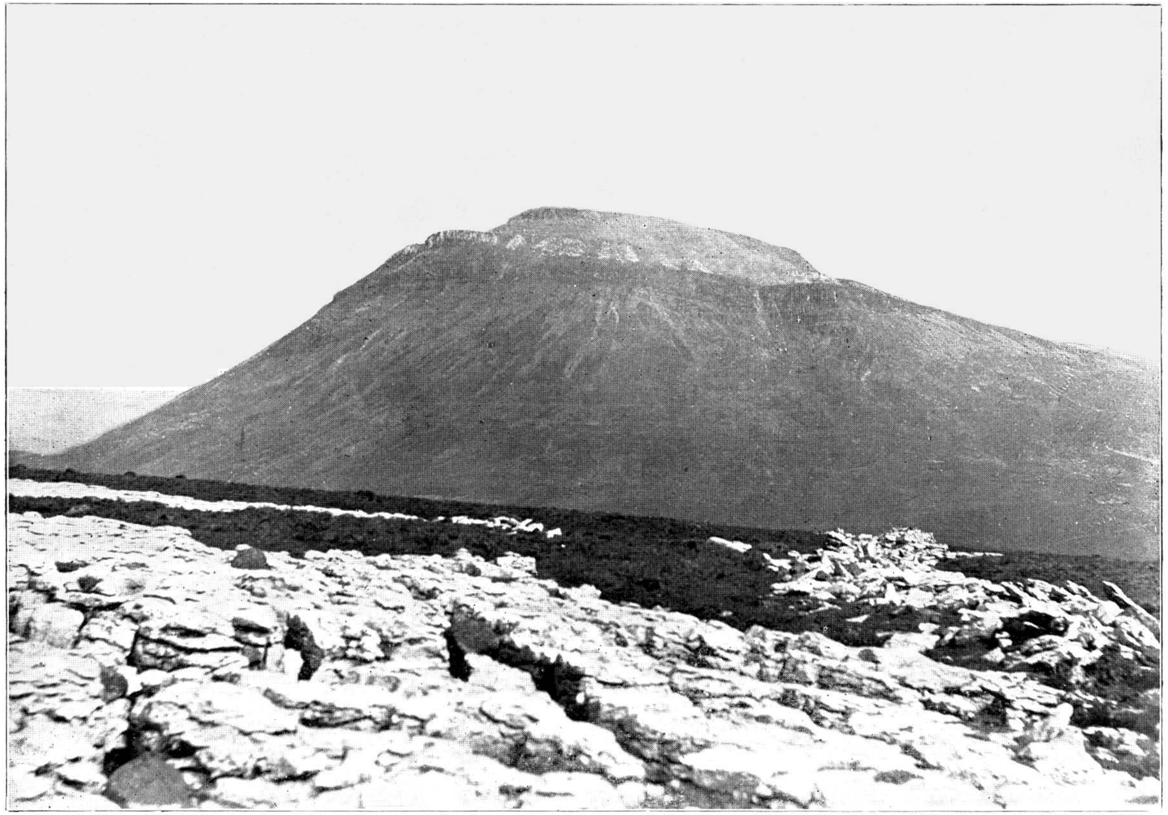
If we could make a guess as to the approximate age of the Ingleborough sea-plain, to what age can we assign the much more ancient sea-plain of Snowdonia and Lakeland? It is a joy to lie on a clear day on the top of Ingleborough and think these questions out.

If the origin of these sea-plains is such as I have described, they must be part of the most constant and continuous operations of Nature. They must be always in process of formation, and must always have been formed. We ought, therefore, to find traces of them in the rocks.

Here on Ingleborough, from which we have the clearest view of two wide sea-plains which form part of the existing surface of the ground, we have also the most stupendous exhibition of a similar plain belonging to a far more remote Geologic past, and, as we were able to trace evidence of the newer plains far afield, and even to find in Wales representatives of both our higher and our lower sea-plain, so also we have satisfied ourselves by an examination of the crags round Ingleborough that there is a similar sea-plain buried under the mass of Carboniferous rocks of which it is built up; and we are able to follow the sea bottom of which it formed part to closely adjoining districts, where valleys were filled up by *débris* from the ancient plain, and further out still to where vast deposits were being accumulated beneath the sea in an area of depression long before that sea had swept across the bare rock on which later the deposits were heaped up out of which Ingleborough was carved out.

We step down from the top of Ingleborough on to the great shelves and ledges of the mountain limestone (Plate XXII.), the explanation of which we will consider later on. We then cross the whole of the Mountain Limestone down to its base, and there we find this other sea-plain of far more ancient date than that on which we stood on the top of Ingleborough.

Here we see the Carboniferous rocks resting on the upturned edges of all the older rocks that make up the country between us and Helvellyn. Here we can study the character of the surface of that old sea bottom. Generally speaking the rocks were evenly planed off, but the tougher rocks, such as the gritty sandstones of Austwick, or those that presented the bed faces to the waves so that they could not be undermined, resisted the various denuding agents more than the slaty or differently inclined beds, and remain in long ridges. We can follow the base of the Carboniferous rocks along the sides of Dale Beck and Moughton and Ribblesdale, and often see that these ridges run through with the strike of the rocks from one of those valleys to the other. It was generally a clean wave-swept surface, with few troughs in which the *débris* from the land could be caught. But there are a few hollows, and those very suggestive. In the first place we notice that finer material is preserved in the deeper depressions only, but sometimes very large boulders remain on the flat, rocky sea bottom, as if the last current had been strong enough to carry away the finer material, but not to remove the large blocks, or the gravel sheltered by them. Curiously enough these are seen in the base of the Mountain Limestone under Norber Brow, on the top of which isolated boulders of Glacial age are perched and challenge comparison.



Photographed by Godfrey Bingley, Headingley, Leeds.

THE SUMMIT OF INGLEBOROUGH FROM RAVENSCAR.

Proc. Yorks. Geol. and Polytec. Soc., Vol. XIV., Plate XXII.

When we come to examine the basement deposits of the Mountain Limestone in detail we find many other curious facts that require explanation. For instance, we find that where the troughs or valleys in the old sea bottom are considerable, the deposit that fills them is generally red, but the conglomerate or sandstones that occur above the level of the depression or extends anywhere over the general surface of the older rocks is never red.

This is first of all a question for the chemist. Where we now find beds containing carbonate of lime in red rocks, as in the cornstones of the old red sandstone, or evidence that there has been carbonate of lime present though now dissolved away, as in the lenticular beds full of casts of fossils in the rusty red Tertiary beds of Kent, these subordinate beds are green.

Therefore we should not expect to find red beds in the main mass of the Mountain Limestone, except the red earthy residuum due to late action of surface waters.

It seems not improbable that in the case before us the oxidized superficial deposits of the adjoining pre-Carboniferous land, when they were swept down and preserved at once in a valley or trough, some of which were perhaps sub-aerial, retained their red colour, but that when the material had long been washed in the surf of the encroaching sea, all the little pellicles of red oxide which coated the grains of sand were removed, and the whole mass lost its colouring matter.

Most of the carbonate of lime was probably derived from organisms which grew on the spot, but the other sediment seems to have come from far and to have been well rolled and washed, as may be inferred from the constant recurrence of bands of quartz pebbles in the lower part of the Mountain Limestone, as well seen near Thornton Force, for instance. They had travelled so far that all the softer sedimentary or other rock in which the quartz veins occurred had been ground down to sand and mud, and only the quartz, rolled into small, perfectly smooth pebbles, survived the long journey. The various forms of life so abundant in the overlying limestone had not yet migrated into this area; therefore fossils are rare in the red *débris* swept into the hollows.

There was no muddy bottom yet for shells to live on, and corals were scoured off the exposed bare rock surface. Only a few fish swam over and left their remains entombed. In one of these hollows I found *Lophodus levissimus* L.Ag. and *Copodus cornutus* L.Ag.

It is interesting to note that these are closely akin to well-known Devonian forms, if not identical species.

We ask what was going on over the surrounding district when this sea-plain was being formed here, and how far does the sea-plain extend? We soon find some evidence bearing on this point as we follow it to the north and west. Instead of resting on a smoothly undulating surface of bare rock, the Mountain Limestone has at its base enormous banks of gravel and sand now deeply stained red.

Along the valley of the Lune, by Kirkby Lonsdale, Barbon, Sedbergh, and Tebay, it lies in a manner suggestive of a long valley with tributaries coinciding in direction with the present drainage system, but it does not resemble the gravel of river terraces. At the mouth of Ullswater high hills are wholly composed of it, and it plunges under the Carboniferous rocks on the east. Here it seems probable, from the form, the composition, and arrangement of the material, that the gravel carried down the steep valleys out of the heart of the Lake Mountains was, some of it perhaps, distributed along the shore, but was mostly swept into the seaward depths of the submerged valleys. The material seems always to be derived from the neighbouring rocks. In these thick masses of sediment no fossils have been found, except derivative fossils in the fragments of older rocks.

Follow the base of the Carboniferous across the sea to the Isle of Man and to North Wales, and we find evidence of similar conditions having prevailed there.

But if we travel on into South Wales we get beyond the sea-plain and its marginal valleys, and there find widespread sands, always with white quartz pebbles, underlying the Mountain Limestone and passing uncomformably across the Old Red of Herefordshire and the Silurian and Bala of Carmarthenshire.

Why fossils are so scarce, so obscure, and of such small use for purposes of correlation in these South Wales beds I cannot say, but in that respect also they resemble our pockets of conglomerate, sandstone, and shale under Ingleborough, or the great red conglomerate of the borders of the Lake District.

Cross the Bristol Channel, and there you find the equivalents of the "Brown stones" of Carmarthenshire split up by shales and limestones in which there are plenty of fossils, but in the great sandstones of the Devonian they are more scarce.

Now, we have got a suggested correlation.

The Old Red of Hereford is not Devonian, but the Devonian of Abergavenny creeps across the Old Red unconformably. There was a mountainous district in the North of England and North Wales, while South Wales and Devonshire sunk beneath the Devonian Sea. By-and-by that sea cut down the mountains of the northern part of our island and determined the level of the sea-plain on which Ingleborough rests while the Lake District still stood above it.

If this be the true story, this sea-plain at the base of Ingleborough is of Devonian age, and the pockets of sediment which lie in it are the last bits of sediment which can be referred to the Devonian before the widespread changes which then took place ushered in the conditions which allowed of the deposition of the Lower Carboniferous Series.

Many are the questions in Physical Geography which may be studied in this wonderful district.

One to which I have had to refer, and which seems at first to be connected with the sea-plains which we have been considering, is the origin of the ledge of Mountain Limestone on which the upper half of the mountain rests as on a table (Plate XXII.). If all the mass of Yoredale shales, sandstones, &c., and overlying Millstone Grit were removed the resulting feature would be much like what we have now, namely, a capping of hard rock which might or might not have a corresponding flat top seen on the adjoining hills. What we have to look into is this: Is this terrace of limestone the margin of a sea-plain which washed the base of the steep slopes of Ingleborough, Whernside, and Penyghent, just as we have inferred that the sea which planed off the top of Ingleborough lashed the base of the Lake Mountains? We have here the question of the distinction between a sea cliff and an escarpment. Fortunately, the example before is easily studied. The rock is one that records the evidence in the most satisfactory way.

The Mountain Limestone everywhere yields along the bedding planes so as to give rise to a bare jointed surface locally known as Clints or Helks, but this is especially the case at the top of the formation where the overlying Yoredale shales are swept off the hard limestone platform on which they rest. If we examine the limestone where newly exposed we notice that the joints are closed and the surface smooth, but, as we leave the margin of the covering deposits, the joints are more and more opened out until the top bed is represented only by a series of long, bolster-like masses, the crevices between which commonly extend down through bed after bed to a depth of from 5 to 15 feet (Fig. 3). In the deep shadows of these fissures, into the bottom of which the heat of the sun never strikes, many a rare fern and flower grows, and every here and there we find a line of funnel-shaped holes opening out into channels in the mass of the rock below. These swallow-holes or pot-holes are apt to lie in rows, each set at a corresponding distance from the margin of the impervious shale or clay that rests upon the limestone. Elsewhere we see how they are formed. The water that falls on the fissured limestone runs into the joints, where it falls, and never can be gathered into runlets. That which falls on the impervious beds above forms streams and rivulets, and where these reach the cavernous rock they open out the fissures, and soon make a way for themselves by chemical and mechanical action, and rush out through caves of their own making to join the rivers in the valley below.

Sometimes the accidents of the mode of distribution of the drift and other superficial deposits, or the occurrence of a belt of broken rock have caused the stream to seek the same inlet long after the impervious shale has been cut back far from where it extended when the hole originated. But, as a rule, the first set of holes is deserted and left dry when, by the cutting back of

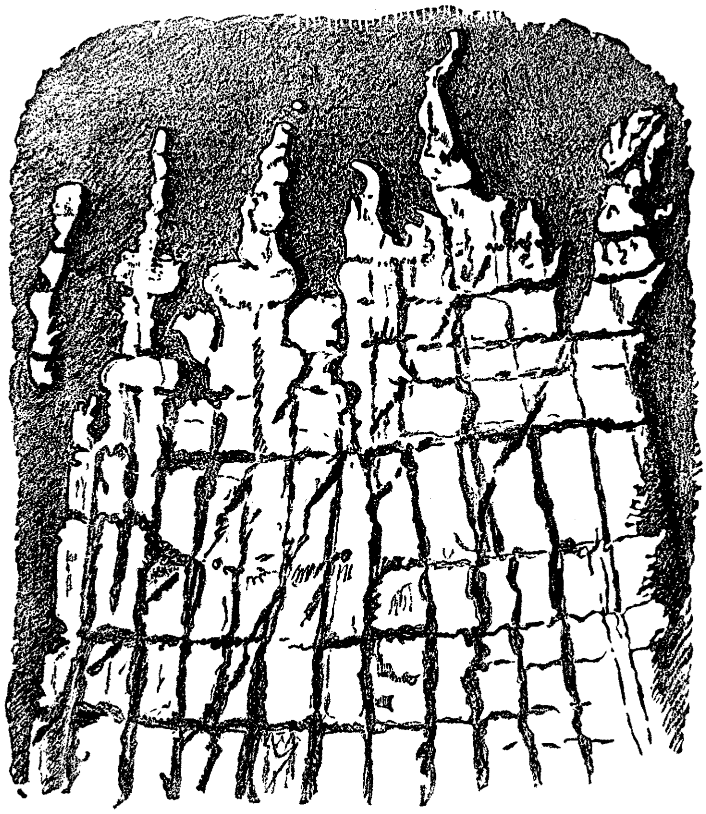


Fig. 3.

GROUND-PLAN SHOWING MODE OF WEATHERING OF MOUNTAIN LIMESTONE.
(1 inch = 2 feet 8 inches.)

[*By permission from the Quart. Journ. Geol. Soc., Nov. 1886.*]

the impervious beds, the streamlets gain access to an inner circle. Thus row after row of such holes remain witness to the constant, though intermittent, recession of the impervious beds on which the water collected that formed them.

This is a sub-aerial action. It is not the way the sea acts on the limestone on the shore where the water cannot seek lower levels through the saturated rock. This, then, is evidence that the steep slope above the terrace of limestone is an escarpment and not a sea cliff.

There is other evidence also. If we go to the Howgill Fells, for instance, on the top of which we found the extension of the West Riding Plateau so clearly marked (see Fig. 1), and where, if the limestone shelves of Ingleborough had been due to the sea, we might expect to find also some traces of the action of shore waves, we cannot detect any cliff corresponding to that which follows the top of the Mountain Limestone of Ingleborough. Moreover, the base of the cliff always corresponds with the top of the Mountain Limestone, even when the movements of the strata have thrown that sometimes much higher, sometimes much lower, while local differences in thickness, texture, and composition affect it irrespective of level. So that for all these reasons, viz., that the surface of the bared limestone shows evidence of the gradual sub-aerial cutting back of the overlying shales; that there are no ancient sea cliffs at the corresponding level in the neighbouring Silurian mountains; and, further, because in this region the level follows the rise and fall of the base of the Yoredale Rocks, and does not appear to have cut horizontally across whatever bed was there, as should be the case were it a sea cliff, we must infer that the steep slope of the Yoredale Rocks above the terrace of Mountain Limestone on Ingleborough is a sub-aerial escarpment and not a sea cliff.

What part in its formation was played by ice action we must reserve till we come to the consideration of the glacial phenomena.

In speaking of these great expanses of level rock, we have had so far no occasion to refer to river-plains. Yet we are not without the most striking examples of river denudation round the base of Ingleborough. The transverse strath, drained by the Wenning, that bounds it on the south, affords much matter for inquiry and speculation. But before we speculate upon its origin, let us look down from the crags round Ingleborough upon the long, straight valleys of Kingsdale, Chapel-le-dale, and Ribblesdale, which are easier of explanation. These three valleys represent three stages in the history of the cutting back of valleys into a mountain mass. The Carboniferous rocks dip gently in a northerly direction, so that the rim of Mountain Limestone is higher and higher the further south we trace it. If, then, anything should sweep the surface of the Mountain Limestone, or of any one and the same bed in it, quite bare, the water would accumulate on it, deepening to the north, until a gorge was cut back from the rim to tap it.

Thus we find in Kingsdale an alluvial flat on one of the lower horizons of the limestone, and the water cutting a little gorge through the rim at Thornton Force (Plate XXIII.), and so eating its way back to tap the valley above. In the case of this great jointed limestone the water does not all wait till it reaches the fall, but, working down into the cracks and opening them out by chemical and mechanical action, often carries all the water away through the crevices so formed, while the water tumbles over the top of the rock only when, after heavy rain, there is more than the subterranean channels can carry. At the north end of Chapel-le-dale, where the valley changes its character and the limestone is much covered by impervious drift, this action is very striking. The greater part of the water of the stream is generally lost in a grand chasm known as Weathercote Cave, and only in very heavy floods fills this to the brim, and overflowing runs on through the surface channel. The water that disappears in the gravel at the bottom of Weathercote Cave boils out below in Jingling Pot and Hurtle Pot, and supplies the stream that runs down Chapel-le-dale.

On the floor of Kingsdale there is Mountain Limestone. In Chapel-le-dale, however, denudation has removed all the limestone, and the valley lies on Silurian and Bala, and perhaps some older rocks. The basement bed of the Carboniferous is seen some way up the hill on either side. But as the rim of the Mountain Limestone arrested denudation and let the stream wind about from side to side, alluvial flats were produced here and there, where there were in old times small tarns, and where after heavy rain flooded meadows may now be seen.

The same conditions must once have prevailed in Chapel-le-dale. There, however, the rim of limestone has long ago been cut back, but the occurrence of beds of greater resisting power in the older rocks has kept up the barrier, and the water breaks from the first falls below Dale House, by many a rapid and cascade, to join the Greta at Ingleton.

On the other side of Ingleborough there is a small, narrow valley, now covered by the pretty artificial lake produced by constructing a high dam just above the village of Clapham.

Further east we find the small valley of Crummack Beck (Plate XXIII.), which is of the same type as Chapel-le-dale. This valley lies chiefly in Silurian and older rocks, but it is here much easier to see the reason for each interruption in the regularity of the features and for the barrier which arrested the cutting back of the stream at its lower end. Hard bands of grit, folded so as to present themselves to the denuding agent in the manner that made them least accessible to its action, are seen crossing the valley near White Stone Lane and barring the outfall east of Southwaite.

One little tarn has been filled up with shell marl and peat, and as these are both useful, the one for dressing the land, the other for fuel, excavations have been made which reveal the whole story of their origin and infilling.

Further east still is Ribblesdale, with its barrier at Swarth Moor and Great Stainforth, and rapids and waterfalls below. This valley has been cut down further through the nearly horizontal limestone rock. Part of it was certainly once occupied by a tarn, in which the trees and nuts brought down by storm, drifted chiefly to the south-west corner, where they are still to be found in the peat. Much of this valley is covered by gravel and alluvial mud, till we follow it up to the great mass of moraine matter about Horton which the river has not yet had time to remove or level.

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THORNTON FORCE.

Photographed by Godfrey Bingley, Headingley, Leeds.

CRUMMACK DALE.

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These dales running north into the base of Ingleborough furnish clear examples of almost every type of river denudation. There are the rapids and waterfalls cutting back to alluvial plains over which streams wandered about, widening their valleys, but doing little to cut their beds deeper; there are the lakes (however caused) being filled with alluvium and peat.

Although they are on a small scale, all the most important phenomena are represented here, and thus we have as part of Ingleborough examples of the sea-plain, of the bed-plain, and of the river-plain all clearly defined and accessible.

I have not touched upon the effect of glacial action on these features which are primarily due to other causes, but we must remember that the ice of the glacial epoch gathered on the heights of the old sea-plain, crushed its way over the Mountain Limestone ledges round the flanks of Ingleborough, and, later on still, pushed long fingers of ice down the deeper valleys, leaving, as it receded, the moraines which still determine or modify denudation.

I cannot name any district in which the ordinary details of denudation and many of its more exceptional operations can be so well studied as within the area which we have included under Ingleborough or in its immediate neighbourhood.

The condensation of the moisture of the winds on the cold rocks working where no rain can reach; the action of water more or less charged with acids on the limestones; the fantastic forms which are thus produced; the effect of this action on a larger scale in the formation of pot-holes, and of underground channels and of valleys by the falling-in of caves; all claim the attention of the geological student. The breaking up of great masses of jointed rock under the influence of frost and the masses that in the thaw are carried over the frozen snow that fills the place where the talus should rest, and form crescentic masses lying some way in front of the cliff; the cutting back of gorges by the removal of block after block, first detached by complex denudation, then lifted out of their bed by the hydrostatic paradox and hurled over the edges of the cliff; all these, too, can be studied here.

The pre-Carboniferous sea-plain was of course never a level surface, but the harder rocks stood out like the enamel in the tooth of an elephant while the softer dentine was worn away. We cannot, however, assume that the ridges of Silurian and Bala rocks which we observe to-day exactly measure the original inequalities of the sea bottom, but they must approximately represent the relative heights. In Chapel-le-dale they rise to a little short of 900 feet, and only fall to between 700 and 800 feet. In Crummack Dale, where the tough Silurian sandstones cross the valley, they rise to only a few feet short of 1,200 feet, but where the Bala shales come out from below the Silurian south of Norber, the ancient surface on which the Carboniferous rocks were deposited falls to 700 feet above sea level (see Fig. 4).

Similarly in Ribblesdale the tough sandstones are seen to throw the base of the Carboniferous rocks up, while the softer beds form troughs into which the earliest Carboniferous sediment was swept. Thus the grits and sandstones of Great Stainforth rise to near 1,250 feet above sea level.

From these observations we should infer that the transverse valleys, such as that on the north side of and parallel to Thwaite Lane between Clapham and Austwick, or that along which the road from Austwick to Stainforth runs on the south side of Moughton Scar, really represent pre-Carboniferous E.S.E. and W.N.W. valleys in the softer beds of the Silurian and Bala. The great height of the base of the Carboniferous in Moughton Scar, above the general level of the Silurian and Bala beds of the low ground between Wharfe and Swarth Moor (see Fig. 5) is not, therefore, a proof of great denudation along that transverse valley since those beds were exposed, but the existing surface probably represents very nearly the original pre-Carboniferous sea bottom.

The difference of level corresponds almost exactly with that seen in section along the west side of Crummack Dale, where the base of the Carboniferous rocks falls from nearly 1,200 feet south-west of Crummack to 700 feet south of Norber (see Figs. 4 and 5).

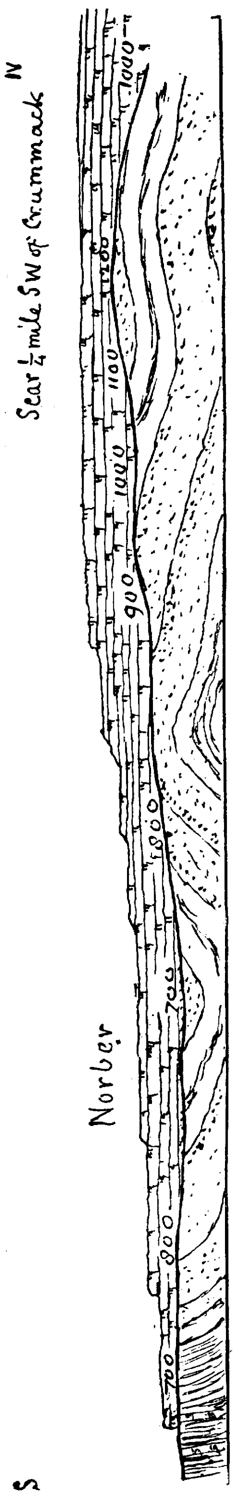
S
Norber
700
800
700
800
900
1000
1100
1200
1000
Scar ¼ mile SW of Crummack
N

Fig. 4.

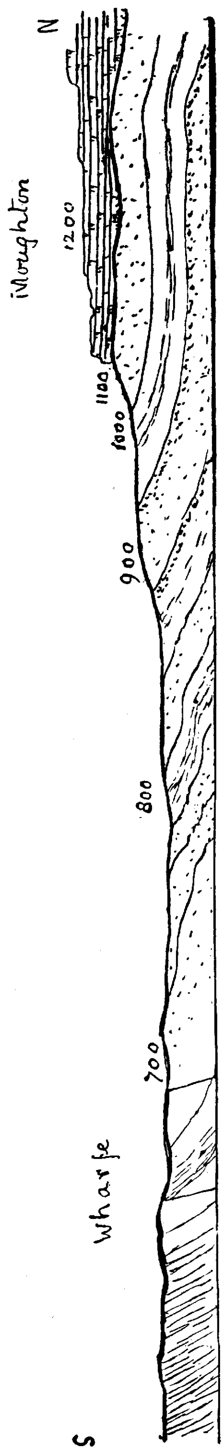
S
Wharfe
700
800
900
1000
1100
1200
Moughton
N

Fig. 5.

The north and south valleys, Kingsdale, Chapel-le-dale, Crummack, and Ribblesdale, have apparently suffered considerable glacial and post-glacial erosion.

FAULTS.—The existence and effect of faults has often been mentioned in describing the relation of the various formations to one another, but the phenomena connected with faults call for special treatment.

Nowhere, even in this district, can the behaviour of the rocks along a great fault be so well studied as in the gorge of the Twis or Greet above Ingleton, at the sharp elbow made by the stream where it is caught in the crushed and fissured rock and carried out of its southerly course for a quarter of a mile or so to the

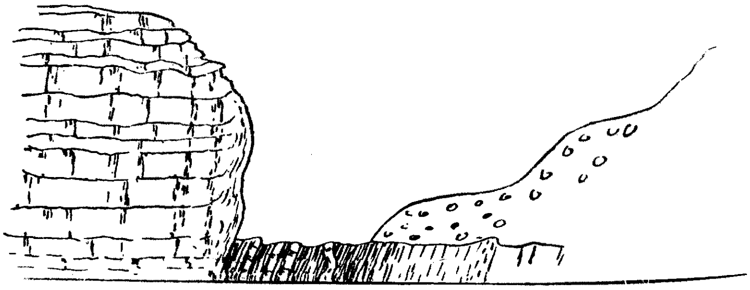

Fig. 6.

SECTION ACROSS THE TWIS OR GREET ABOVE INGLETON.

south-east. The Bala limestones and shales are exposed along the bed of the stream, and pass under a great mass of drift on the left bank, while on the right bank, which is the downthrow side of the fault, the Mountain Limestone stands in a wall some 200 feet high, above which rises a precipitous broken slope for about 200 feet more before we reach the level of the broad limestone terrace through which the gorge has been cut (see Fig. 6).

The upper part of the face of the limestone cliff overhangs its base in agreement with the inclination or hade of the fault to the downthrow side, and sweeps down stream in bold curves which represent the original winding course of the fault. What is most striking in this section is the swelling irregular surface of the exposed side of the fault, showing how much the hade and direction of a great fault may vary within short distances. The rock is not often much shattered, but from its condition where it runs into the hill near the elbow of the stream, and from the tendency to flake which is seen on many parts of the face, it seems probable that there were some outside crushed layers having a rough cleavage parallel to the plane of the fault, but that these have been removed by denudation as the gorge was being cut down.

The exterior portion of the limestone near the fault-face assumes a brownish-yellow colour, and is in places honeycombed or weathered into irregularly rounded cavities such as might be filled by geodes. A chemical examination of the changes in the Mountain Limestone here as it approaches the actual fault would probably yield some interesting results.

The Bala Beds, on the other hand, being composed chiefly of shale instead of massive rock, are crushed and twisted in all directions, and the harder bands are thrust through the softer. Several dykes traverse the series, and from the manner in which the soft shales are moulded round them it is clear that they also, being of a more unyielding nature and unable to accommodate themselves to the general kneading up of the mass as readily as the shales, were broken and thrust in among them.

This proves that they were intruded at an earlier date than the movements which crushed up the Bala Beds, that is, they must be earlier than the fault. As the cleavage of the Green Slates and Coniston Limestone series was contemporary with the folding by which they were upturned, the dykes, being somewhat guided in direction by the cleavage plains, would therefore appear to belong to that enormous interval during which the folded Green Slates and Coniston Limestone series were being reduced to the "peneplain" on which the Carboniferous Rocks were deposited.

The crushing that the dykes themselves have undergone is shown in the veins now filled with carbonate of lime which traverse them. This is especially noticeable in the tough grey felspathic rock with small flakes of black mica, which forms one of the three principal dykes seen here.

We must not imagine that the faults in a district like this took place suddenly. These faults are merely easements during the folding of the rocks, and therefore, as the folding was a slow process, commensurate with the great denudations that planed off the land as it was raised, and with the sedimentation which was the necessary accompaniment of that denudation, so the faults must have been going on continuously or spasmodically while deposits were being laid down. They, however, may indicate periods of more rapid movement, in which the rocks which had

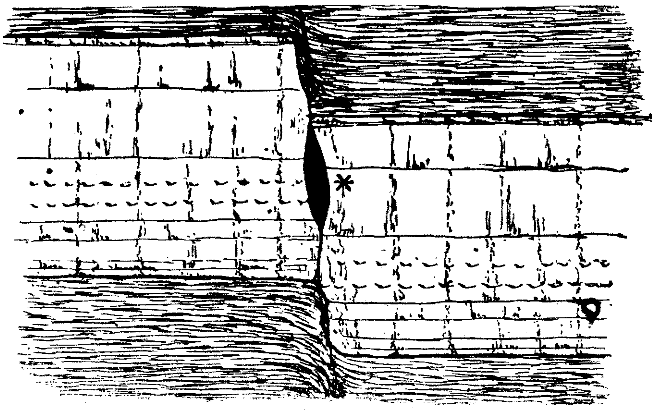

Fig. 7.

not time to bend must break, and they also point to greater inequalities of surface and generally suggest periods of locally changing conditions.

Perhaps there may be some reason for suspecting that the Dam House Bridge fault near Austwick was going on during the accumulation of the basement beds of the Silurian from the difference in the character and thickness of the conglomerate on the north or upthrow side of the fault as compared with that on the south side, and from the great paleontological change which marks the incoming of the Silurian and points to altered geographical conditions.

The fault which crosses the top of Ingleborough has a very small displacement. Indeed, it may be only a shake and crack over a pre-Carboniferous fault below. But it is well worth careful examination, as it has obviously affected denudation, and yet runs over the highest ground in the district. Crossing the south end of the Millstone Grit, it cracks the Main Limestone and the Yoredale Grit, and can be traced as a long peat-covered hollow across the Mountain Limestone below.

A point which is specially deserving of careful attention is forced upon our notice by an examination of the great cliff, which represents one wall of the fault in the Twis valley. If two curved

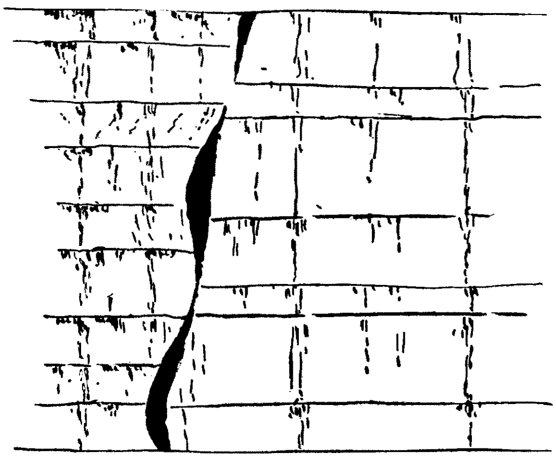

Fig. 8.

rock faces of that kind are relatively shifted, it is clear that the protuberant parts must often hold the walls of the fault apart and spaces be left which, if not filled with crushed material, will offer suitable conditions for the precipitation and crystallisation of mineral matter (see Fig. 7). As a matter of fact, we do find veins and lodes commonly occurring in lenticular cavities which appear to be formed in just that way. Sometimes when the fissure cuts across strata of various degrees of compressibility the more yielding beds are squeezed out, filling the crack completely and even to some extent creeping up between the harder strata; while new minerals are formed between the two walls of the fault only in the lenticular open spaces where the more solid strata hold the opposing sides apart, as shown in Fig. 8. Hence in such a case we have galena, for instance, occurring along the lode in such a place as that indicated by the * in Fig. 7, whereas in the intermediate stages the fault is entirely closed and no ore is found.