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Station, and thence runs into Thornton Beck below Shaw Mill. It is succeeded by a synclinal running from Blubberhouse Moor by Fewston, and thence by John of Gaunt's Castle down the gill in Haverah Park. This is succeeded by an anticlinal which branches out of the Beamsley one at Round Hill, and thence skirting the edge of the ordnance map 92° N.E. runs on to Harrogate.

 GLACIAL PHENOMENA OF WHARFEDALE BETWEEN BOLTON ABBEY AND KETTLEWELL. BY J. R. DAKYNS.

With one singular exception the glacial drift in the basins of the Rivers Wharfe and Nidd, among the Carboniferous Rocks, contains no stones but such as may have come from the rocks cropping out at the surface in those basins. There are no foreigners. We know that the drift material has travelled southward and eastward, because boulders of Carboniferous Limestone are found to the south and east of any outcrop of that formation. Thus in the adjoining area boulders of Carboniferous Limestone have been carried southward across the Aire to the higher part of the Worth valley, and such have also travelled eastward down the Aire valley towards Leeds. There are very few glacial striæ in Upper Wharfedale, because there are not many hard compact rocks fitted for retaining striæ. Limestone is hard and compact enough, but it disappears so rapidly at the surface under the influence of rain water and becomes so fretted into fantastic shapes, that it does not long retain superficial markings except when protected from the weather by a covering of clay. One very good instance of this sort occurs between Conistone and Kettlewell. There I found, under a bed of boulder clay, Limestone Rock, beautifully grooved; the grooves trended along the hillside bounding the valley of the Wharfe. The only other

scratches I got in this district were on Millstone Grit, on the southern part of Hebden Moor; there I found scratches trending N.W. and S.E., and close by some doubtful ones pointing E.N.E. The valley of the Wharfe is crossed at Grasswood, a mile above Grassington, by a barrier of limestone, through which the river runs in a narrow channel. Above the barrier stratified sand and gravel is found. There is all the appearance of this rock barrier being the lower tip of a rock basin filled in with drift and alluvium. It is difficult to say how much of the sand and gravel is of the glacial period and how much is ordinary river gravel. The river gravels probably run back to glacial times. A similar barrier, of coarse gritstone, crosses the valley at the elbow in the stream near Drebley. The hills on either side of the river formed by this rock are called Herd's Hill and Heugh. Herd's Hill has a distinctly glaciated look as seen from a distance, but I could find no scratches for the retention of which the rock is in fact too coarse. I found, however, something like grooves running N.N.E. and S.S.W. This hill, along with the Heugh on the opposite side of the river, forms a prominent bank of grit, stretching across the valley, which it would dam up but for the narrow passage which the river has cut for itself. The drift is piled up against the high side of this dam. Gravel mounds enclose the Heugh on the north-west. These mounds gave no section; externally they have an Esker-like look, as they are moundy and enclose hollows. They reach an altitude of 600 feet above the sea level.

In constructing the puddle trench of the Barden Reservoir for the Bradford Corporation Waterworks, a total thickness of 65 feet of drift was met with. The section, as kindly communicated to me by the resident engineer, was as follows :—

					Ft.
Yellow Clay	...	..	...	...	10
Blue Clay, sandy and strong	.	.	...	...	} 13
Sand and Gravel	...	..	...	...	
Blue Clay, containing limestone boulders and great blocks of grit; hard and water-tight	...		...	...	42

The yellow clay is doubtless merely the weathered part of the blue.

As both grit and limestone occur in place in large masses in this district, it is of no importance finding boulders of one rock lying on the other ; but I may mention that the limestone ridge above Fancarl House, though free from drift and generally bare, is strewn with boulders and blocks of coarse Millstone Grit. I found too a block of limestone on the Kinder Scout Grit Escarpment at the southern end of Crooksior Crag on Embsay Moor, more than 1,200 feet above sea level. The curious round hills forming the Millstone Grit Escarpment south of Barden, between the River Wharfe and the Pateley Bridge road, have limestone boulders on them.

At Gill Bank, near Storrieths, beds of flaggy grit, dipping at 60° to the S.E., presented the appearance, shown in the figures, as if the beds had been turned over southwards and broken. Ice moving from the north might have done this.

This is similar to what has so often been observed by Messrs. Tiddeman and Green in the country described in the Geological Survey Memoir "On the Burnley Coalfield."

The only other case of bending over of the ends of the beds that I am acquainted with in this locality, presents some difficulty. It occurs on the northern slope of hills forming the south part of Barden Moor. In a quarry near Hutchen Gill Gate the beds, which consist of flagstone, are dipping down hill, *i.e.*, to the north at 25° . The top layers are turned over as if by a force acting down hill, *i.e.* from south to north. The slope of the ground does not seem sufficiently great for this bending over to be due to the "weight of the hill," as it is called. On the other hand, it is quite certain that the

great mass of ice moved southward. The annexed figure represents what is seen :—

A B represents the slope of the ground ; C D is a horizontal line. If this bending over was caused by ice it must have been by quite local ice ; for the general movement of the ice of the country was from B to A, not from A to B. As regards the drift material, it is of two sorts, well rounded and bedded sand and gravel, and ordinary boulder drift. This last is the most frequent ; it cannot always be called boulder *clay*, and in the higher part of the dale can seldom be so called except by courtesy, for it often consists of a mass of both rounded and angular stones, of all shapes and sizes, with very little clayey matter at all. The difference between it and boulder *clay* is, however, merely one of degree. When the drift is derived from hard rocks like grit and limestone, there will be a stony deposit with but little clay ; when it comes from shale, there will be much clay.

It is quite impossible, as a rule, to separate the boulder beds from the sand and gravel. The boulder beds, when stony, approximate to gravel in such cases as those in which the contained stones are well rounded ; and, moreover, as the section of the Barden Reservoir shows, the sand and gravel is sometimes intercalated in the midst of boulder clay, consequently no general sequence can be made out ; but near Linton Mill the gravel certainly lies on the top of boulder clay, for there is a steep bank, the upper part consisting of dry gravel, and the lower of wet clay, which throws out the water percolating the first ; but as there is no section it is impossible to tell whether the gravel is a scratched boulder gravel or a water-washed gravel. Near Park Bridge, over the Wharfe, there is above the alluvial flat a bank of coarse gravel : though very rough and unstratified in places, it is on the whole distinctly stratified. It

contains subangular blocks of Millstone Grit about 3 feet in diameter. This gravel continues some way up stream

Opposite Lud Stream Islands there is a gravel in a similar position and apparently of a similar character, but the section is not clean cut. It is surmounted by another bank of gravel (section also not good) apparently of the same general character, but containing much larger subangular blocks of grit. The top of this gravel bank is 75 feet above the river, and from its edge there stretches a gently rising and undulating surface for about one sixth of a mile to the foot of the hill called South Nab. This plateau may be entirely of gravel.

On the left bank of Posforth Beck, a little below the first bend in the stream above its junction with the Wharfe, there is a section in true glacial drift. The material consists of angular *debris* of grits and limestones, and the blocks of the latter are well glaciated. It contains also fine stratified sand, beautifully false-bedded. The boulder-bearing drift seems to wrap round the sand, but the section is not clear. Further down stream there is a similar angular deposit. There are plenty of rounded stones ; but the characteristic feature is angularity.

Pickles Gill, above its junction with Tom Taylor Dike, is full of drift, consisting of angular blocks and pebbles of grit and limestone. The pebbles are mostly of limestone ; and the limestones are glaciated and scratched, particularly the pebbles

It is not necessary to give any more details of sections, as it would merely be a repetition of what has been already said. The general result is that the boulder beds vary from a true boulder clay to a stony mass, which consists sometimes of a heap of angular fragments, while at others it contains a large number of pebbles ; and that in the latter case, on the Millstone Grit area in the south, the larger proportion of the pebbles are of limestone, and that the limestones are generally scratched, the grits but rarely so. Evidently the reason why most of the pebbles are of limestone is that the limestones have come the greater distance.

Further, the true glacial boulder beds are mixed up with finely stratified sand and gravel. Lastly, well water-worn gravels, containing large boulders and angular blocks, line the valley sides

in terraces, like ordinary river terraces. This makes me think that there is no real distinction to be drawn between the older river gravels and the water-worn gravels with boulders, which are generally set down to the glacial period as something quite *sui generis*. I believe on the contrary that the ordinary river gravels run back to glacial times, and gradually merge into the glacial deposits.

I will now consider the solitary case of foreign blocks occurring in the valley of the Wharfe. These consist of Silurian Grits like some of the Silurian Rocks that occur in places in Ribblesdale. In Wharfedale these Silurian boulders are confined to the portion of the valley between Chapel House Lodge and Burnsall, that is, all that I have met with are below Chapel House Lodge and above Burnsall. They are most plentiful about Linton and Threshfield. The greater number of them have long since been cleared off the ground and built into the walls for "throughs," where their remains may still be seen ; but some few I found still lying about on the surface of the land, and some may be seen in the drift cut through by becks descending from Threshfield Moor. I could find none above the general level of the drift of the more open country, which near Threshfield reaches about the height of 800 feet above sea level. I examined the country lying between the site of the boulders and the outcrop of Silurian Rocks in Ribblesdale ; but though there are plenty of Millstone Grit boulders lying on the bare surface of the limestone, not a single Silurian boulder was to be found. It was quite clear that these Wharfedale boulders had not come over the fells from Ribblesdale. Whence and how then did they come ? It may be thought at first sight that they came on floating ice discharged from a glacier debouching at the mouth of Ribblesdale near Settle. But there are great difficulties connected with this view, the chief of which is this : if these boulders drifted eastward from Settle on floating ice, when the sea level was but little higher than the present 800 contour line, and Wharfedale was a fjord, whether filled with ice or water, how did they surmounting the rock barrier at Nether side manage to travel *up* the dale or fjord towards Chapel House ? for assuredly ice, or water carrying ice, was flowing down Wharfedale all the while. This is an insuperable difficulty to the floating ice theory.

I believe that the true explanation is this : At the foot of Kilnsey Crag strong springs break over from the limestone rock, just above the level of the alluvium ; and also in Littondale strong springs break out at the foot of the limestone scars, the hillside below being formed of a mass of detritus, which as completely conceals the underlying rocks as the alluvium at Kilnsey does. Now, seeing that strong springs break out at the foot of scars formed by limestone of great thickness, and that it is only a little way below the springs that we find Silurian boulders in the dale, it seems likely that the springs are thrown out by Silurian rocks in places in the bottom of the valley, hidden from sight by superficial detritus, drift and alluvium, and that our boulders were thence derived. This makes everything simple ; and the thickness it allows to the limestone is quite equal to the thickness of the limestone in Ribblesdale.

In conclusion let me say that thus far the drift phenomena of Wharfedale lend no support to the theory that the whole country was once overridden by an ice cap descending from the pole. There is no evidence here of foreign ice ; but everything is in favour of huge confluent glaciers, or ice-sheets if you like, of home-made ice. Nidderdale, too, supports the same conclusion. There are no foreigners there at all.