Boulder-clay may be entirely different from that referred to by another. This, too, may be illustrated by Mr. Harmer's section of the Eastern Glacial and Post-glacial beds, where, as you saw, and in which I am happy to confirm him from personal observations in Holderness,¹ as clearly distinct a series of beds occurs, as that I have just described. I differ from him and Messrs. Rome and Wood, in considering the beds above the Grey Chalk clay Glacial, there being on the chalk clay as distinct a denudation and unconformability as in the bed F, in the Llandudno sections. Possibly our variance may arise from want of a more distinct definition of the meaning of the term "Glacial." I agree with Mr. Hughes in the opinion he expressed yesterday, that the time is not yet come, when the beds of the eastern and western Drift series should be correlated; but I think I already see evidences of a greater possibility of correlating them, than some of the workers in the eastern districts (whose untiring zeal in the elucidation of those beds is above all praise) are willing to admit.

**Note.**—In the paper on Holderness already referred to, I insisted on the "Grey Clay," as the only "true Glacial Boulder-clay," and which my subsequent observations have only served to confirm.

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**General Section of Drift in neighbourhood of Llandudno.**

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<table>
<thead>
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<tbody>
<tr>
<td>A</td>
<td>Sand-dunes. Thickness very unequal.</td>
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<tr>
<td>B</td>
<td>Blue-black clay without pebbles, 1 foot.</td>
</tr>
<tr>
<td>C</td>
<td>Sands and gravels, about 60 feet.</td>
</tr>
<tr>
<td>D</td>
<td>Red clay, greatest development about 20 feet.</td>
</tr>
<tr>
<td>E</td>
<td>Sands and gravels, greatest development about 20 feet.</td>
</tr>
<tr>
<td>E²</td>
<td>Stratified grey clay, 20 feet.</td>
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<tr>
<td>F</td>
<td>Boulder-clay, greatest development 150 feet.</td>
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<tr>
<td>G</td>
<td>Mountain Limestone Rubble, 3 to 5 feet.</td>
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<tr>
<td>H</td>
<td>Bedded Mountain Limestone.</td>
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V.---**On the Formation of Swallow-holes, or Pits with Vertical Sides, in Mountain-Limestone.**¹²

By L. C. Miall, Esq.

The geologist who rambles through the Mountain-limestone district of Yorkshire is sure to have his attention arrested by the numerous "swallow-holes," or pits, in the rock, into which rills, streams, or even rivers precipitate themselves; and if he can bring his mind to consider the subject sufficiently, without dismissing it at

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¹ See Drift sections of the Holderness Coast, read before Liverpool Geological Society, Dec. 11, 1866, and published in their Proceedings.
² Read in Section C. of the British Association, Liverpool, September, 1870.
once by a reference to some vague natural force, he will come to
perceive the somewhat complex conditions which a complete ex-
planation must satisfy.

The feature which is most likely to impress him, from the number
of examples which he will meet with in a small area, as well as
from its rarity in non-calcareous strata, is the perpendicularity of the
sides of these cavities. The drift and alluvium at the surface may
have converging slopes, beds of shale intersected by the chasm will
only rest at low angles, but a swallow-hole in a thick-bedded lime-
stone has commonly vertical sides, and the weathering which it
undergoes daily does not tend to derange its general shape. We
cannot, I think, dispose of this peculiarity by a summary reference
to the action of carbonic acid dissolved in rain-water. It is necessary
to show further why that force, or any other concerned, should pro-
duce (but only under conditions which are rarely united) a kind of
vertical denudation.

When we collect all the facts of observation which relate to
swallow-holes, we find that the significance of some of them is not
immediately obvious. We recollect many examples of these pits
which have fluted sides, and some have also fluted pillars standing
upright in the midst. We notice that they are very commonly sunk
through a layer of drift or alluvium, which forms a funnel-shaped
mouth, and often chokes up the bottom. They generally receive a
stream of water, and always have an outlet, so that they never fill
during rain. They commonly occur near the outcrop of a bed of
limestone, as might be expected from the greater exposure of the
rock at such points to denuding agents.

It is not often that swallow-holes are sufficiently accessible to
render a minute examination easy. Some of the largest in Craven,
such as Thund Pot and Hellen Pot, are difficult to approach, owing
to the steepness of the drift slopes. There are easily-explored
swallow-holes, which are nearly filled with débris, and present only
a conical pit with grass-grown sides. But there is one spot which
offers every advantage to the inquirer. Near the mountain-road
which leads from Hawes at the head of Wensleydale to Muker in
Swaledale are several of these pits close together. Their fancied
resemblance to churns has acquired for them the local name of
"Buttertubs," and the adjoining road is called Buttertubs Pass.
Here we find a number of perpendicular excavations in the main
limestone of the Yoredale series. The limestone is here about 75
feet thick, and the pits pass downwards from near the top of the
bed to its base. They are striking examples of one form of the
swallow-hole, and present peculiar details which it is not easy to
interpret. Some of them receive runes of water, others are dry.
The sides are vertical, and generally fluted. We observe fluted
pillars also, and remark that the surface of the ground is covered
with drift. On one side is a narrow ravine with a steep face of rock,
a few yards from the Buttertubs. The surface of the limestone near
the edge is bare, or nearly so, and we thus get a good view of the
cavities from level ground, and can approach or enter them from that
side. The floors of most of the pits are covered with débris and rounded pebbles (chiefly of sandstone), which appear to be derived from the drift, and, ultimately, from a bed of grit (the ten-fathom grit), about 150 feet above the main limestone. The water which enters the holes penetrates the limestone horizontally, and escapes beneath it over a ledge of grit.

We have, therefore, in these Buttertubs many features worthy of notice, and unusual opportunities of investigation. I have endeavoured to satisfy myself as to their origin, and shall now offer some remarks on the principal difficulties which suggest themselves. It will be convenient to regard them as the type of that kind of swallow-hole whose mode of formation I shall first describe. It will afterwards appear that there is another and quite distinct sort of swallow-hole, whose walls are only fluted in a few instances and to a trifling extent. They seem to be due to a different set of causes altogether.

Oh searching for some indication of the way in which the Buttertubs had been formed, I was led to examine a miniature swallow-hole, near the road. Here is a little grotto overhung by turf, which masts together the clay and pebbles of the drift. From this spongy roof water drips incessantly upon a ledge of rock two feet below. It has excavated a concave surface or cup, which contains a number of small pebbles smoothed by friction. These pebbles are not of limestone, but of sandstone, and probably come from the ten-fathom grit, which makes a low escarpment higher up on the side of the glen. We hear the rattle of the pebbles amidst the plash of the falling water, and recognize in the sound evidence of continual abrasion; slow indeed, but more rapid than the action of water upon a uniform surface. The ledge is being gradually lowered, and as the excavation proceeds it leaves a scar upon the face of the limestone wall, semicylindrical and with sharp edges, such as would be cut by a gouge. Close by are a score of similar grooves, all formed in the same way; some long completed, but still sharp and clear, others now in process of excavation. Elsewhere we see the same force at work on a larger scale, but a little disguised by accidents of situation or of rock-form, and we find in these cascades, nourished by the accumulated moisture of a retentive soil, and aided in their work by the pebbles which have fallen into the basin, a possible source of the flutings which cover the vertical faces of the pits and of the isolated pillars.

Further observation justifies the conclusion that these large and deep cavities are indeed thus produced, but questions and difficulties arise which can only be removed by an examination of the details in the closest manner. The regular supply of dripping water from the same point, the connexion of the pits with joints or fissures, and the association of some of their most remarkable features with one kind of rock, and one only,—these all require elucidation before we can fully understand how so insignificant a cause can lead to such conspicuous results.

I do not recollect an example of a swallow-hole of this kind
where the surface around has not been covered with alluvium or drift to a considerable depth. On a bare limestone plateau, such as the edge of Malham Cove, and also in non-calcareous strata, the joints weather into fissures, often broad and deep, and we may find flutings of various sizes formed as channels for trickling water, but the pits do not assume the same shape, nor are the flutings vertical and sharp-edged. The similarity of these two kinds of excavations is of a very general kind; and when we come to details it is soon clear that the Buttertubs, for instance, are due to causes less simple than the mere abrading or dissolving action of running water. Constant drip from a tolerable height upon the same place, and the friction of loose pebbles in the receiving basin, appear to be necessary to the production of their characteristic features, and these agents of waste are traceable to the thick alluvial covering. Its absorbent character enables it to act as a sponge, retaining the rainfall, and distributing it slowly and regularly. The overhang of the turf gives the drops an uninterrupted fall, and the sand and pebbles which fall from it help to grind the concave surface below. In some cases I have noticed that on the sides where drift still lies thick the flutings are sharp and still forming, while in another place, where the edge of the pit has been long bared, we have a face of rock weathered irregularly, and losing its grooved appearance till it passes into a plain limestone escarpment.

We must not forget the important influence exerted by those vertical divisions of the rock, formed subsequently to deposition, which are known as joints. In mountain limestone these are commonly conspicuous, though not close-set, except in a thin-bedded stratum, and they are more regular than in most sandstones. Limestone is rarely false-bedded, and its homogeneous character favours the production by expansion and contraction of rectangular dividing planes. To these crevices rain and air get access, and enlarge the cracks into fissures. The edge of many a limestone cliff is thus broken up into cubical blocks, and this is all when the sole weathering agent is equally-distributed rainfall. But when the drip from a spongy mass of alluvium and turf forms the little cascades described above, we have a tendency to produce new and irregular forms by the repeated excavation of semicylindrical grooves in various parts of the vertical faces of rock. The pit enlarges uncertainly, but generally tends to a circular form, leaving now and then isolated pillars, which may rise from a ledge in the pit or from the floor itself, according as they have or have not continued to be acted upon in the same way as the surrounding masses. A small pillar from which the cap of alluvium has been swept, while the swallow-hole has not ceased to grow deeper, shows, by its attachment to the adjacent rock at a greater or less depth, when its base has been removed from the general waste. What happens after this depends upon the accidents of the place. The swallow-hole may enlarge indefinitely, following the course of the principal fissures or extending itself independently, and becoming more or less circular. In other cases its enlargement is arrested by the fall of the alluvium, or
by the collection of the rainfall into one channel. Its sides become less uniformly vertical, the frost detaches blocks of stone, and we get a shallow pit filled with loose rocks and pebbles, and often grass-grown.

Subterranean channels are exceedingly common in a Mountain-limestone district. They are generally, and no doubt correctly, assigned to the action of water passing along fissures of the rock. These concealed water-courses appear to be necessary to the formation and preservation of every sort of swallow-hole. They carry off the grains of sand and particles of mud which would otherwise accumulate so as to check further excavation, and may help to enlarge the pits by their undermining action, causing an occasional slip or subsidence.

It remains to consider why these singular cavities occur only in Mountain limestone. It will be seen that three conditions at least are essential:—1st. Abundant jointing, which facilitates the production of fissures; 2nd. Ready escape of water, which is partly effected by the fissures, and partly by the power of rain-water, to excavate calcareous rock; and, 3d. Alluvium or drift to discharge the collected rain in a suitable manner. The last of these conditions may be present in any place, irrespective of its stratigraphical character; the fissured structure occurs in many rocks other than limestones, but is rarely so conspicuous as in Mountain limestone, which is also peculiarly porous, owing to the solvent action of rain-water, charged with carbonic acid, upon carbonate of lime. The homogeneous character of that rock, too, enables it to be cut readily into definite shapes. For the same reason that a crystalline marble yields to the chisel more accurately than a stratified sandstone or flagstone, it obeys the abrading forces of nature more completely, and exhibits upon its hard and compact surface sharp grooves which have been cut in it by water or agitated pebbles. I show here a specimen of limestone from the brook below the Buttertubs, in which we see cut distinct and sharp the channels of the little streams which have been deflected right and left by a minute projecting fragment of shell or encrinite. Hard as it is to wear, the absence of definite arrangement in its texture renders it ready to assume the precise form which the slight inequalities of pressure and friction tend to impose. Granite does not produce such swallow-holes as these, because it is too impervious to water—its cavities (unless they are merely enlarged fissures) are occupied by pools, and not by cascades. Chalk is too crumbly to preserve a vertical face against falling water, while sandstones, flagstones, and slates are fissile, and conduct the rills along channels which take the direction of the planes of readiest decomposition rather than of the lines of quickest descent.

1 In the discussion which followed, Prof. Ansted referred to swallow-holes occurring in granite in Sark and Cephalonia. Enlarged fissures and pits, which receive streams, are, doubtless, to be met with in strata of all sorts, but swallow-holes of the first class described in the paper, whose characteristic features are vertical sides, fluted surfaces, and isolated pillars, are believed by the author to be restricted to a few formations only.


3 In the discussion Mr. H. Woodward cited the case of underground rivers in the
The kind of swallow-hole which I have just described is, in all important respects, comparable to the moulins of a glacier. We have in both the conditions of homogeneity of rock or ice, of many fissures, of a ready escape of water through or beneath the excavated mass, and of an equal supply of water over a considerable surface.

We come next to the consideration of the second class of swallow-holes, whose existence is due to subsidence of an undermined crust, and not to direct excavation.

Geologists are familiar with the long caverns of mountain limestone districts. In the majority of cases they are fissures enlarged by the running water which passes along them. Ingleborough Cave is upwards of 700 yards in length, and appears to traverse part of the course of two or three parallel fissures, the intervening rock being tunnelled through several times. Many instances occur of subsidence of a portion of the roof of such a cavern, and it is not uncommon to find several openings into the same subterranean channel. In Hellen Pot, near Horton, in Ribblesdale, there are at least three such shafts. When we find a long, irregularly arched, passage, sometimes opening into lofty chambers, and presenting at intervals large apertures, beneath which the floor is encumbered with great blocks of limestone, we naturally conclude that the cavern was first formed by a stream of water, and that weak parts of the roof have subsequently fallen in. This I believe to be the true interpretation. The sides of such chasms are only rarely and incidentally fluted; the aperture does not ramify irregularly along the course of the fissures; there are no isolated pillars. Many of them have no drip of water from the surface; others are worn to a slope or a spout on one side by the entrance of a mountain stream. Near Settle there is a slight depression in the ground at a place called Robin Hood's Mill. Here a rumbling noise is continually heard which resembles the rush of water underground. I imagine that at this spot is situated the expanded part of some hidden water-course, which may be sooner or later converted into a shaft by yielding of the roof.

Swallow-holes of this second species frequently occur in a line sometimes in a ring round a hill-side. They are most abundant in the lower scar limestone, rarely occurring in the thinner limestones of the Yoredale series. The formation of the long caverns is favoured by the great horizontal partings which mark the scar limestone. In the regularity and great extent of these partings of the thick-beded Chalk beneath Norwich, which had been tapped by the deep-main sewers lately constructed, and which had proved almost insurmountable obstacles to the completion of the works. He also mentioned the case of a sudden sinking of land at Lexham, Norfolk, upon the farm of Henry Childs, Esq., leaving a deep circular depression in the field. A ploughman, plough, and pair of horses at work in the field were carried down with the land, but were providentially rescued, without harm, from a depth of twenty feet or more. Such pits, he remarked, were evidently the result of the falling in of the roof of one of these deep-flowing rivers in the Chalk beneath.

1 Prof. Phillips mentions a glen formed by a line of ancient subterranean caverns. The subsidence of the roof appears to have originally determined the direction of the watercourse. See paper on Formation of Valleys near Kirby Lonsdale, British Association Reports, 1864.
limestone, we have a suggestion of deep sea deposition, as well as an explanation of the constant association with the lower scar limestone of cavities of subsidence.

We are not without direct evidence to show the possibility of the sudden formation of a pit by the fall of ground which had been undermined by water. About a mile to the north of Ripon, near the river Ure, are a number of pits or hollows, fifty to a hundred feet in diameter, and in some cases as much as seventy feet deep. They are commonly of conical shape, some are perpendicular shafts. The majority are sunk through the New Red Sandstone, which here overlies beds of Red Marl, gypsum, and Magnesian limestone. In a paper read before the West Riding Geological Society, the Rev. J. S. Tute has placed upon record several accounts given by eye-witnesses of the sudden production of these pits. In 1860 the Rev. F. H. Dunwell observed the falling in of a pit 69 ft. deep and 22 ft. wide. Twenty years ago one fell in at Sharrow during the night. Forty years ago a stack upon which some men were working, near Bishop Monkton, disappeared, and its place was occupied by a hole which still remains. These pits are undoubtedly due to the yielding of the ground above a large hollow or cavern, but the difficulties of observation are so great as to prevent a full comprehension of the circumstances of excavation. Mr. Tute is of opinion that the subterranean waste has gone on in the Red Marl and gypsum beds. I should myself incline to believe that caverns in the Magnesian limestone have undermined the ground.

In many parts of Craven, particularly in Chapel-le-Dale and Ribblesdale, there are stories of chasms suddenly formed, but I have as yet been unable to authenticate any of these accounts by the testimony of eye-witnesses. If attention is once called to the point, well-attested cases will quickly accumulate. (See note ante p. 518.)

It is easy to understand that swallow-holes formed by subsidence may be much disguised by the superficial character of the ground. Some of the large conical depressions without an outlet, which occur in a calcareous district, may be due to the yielding of undermined rock beneath a thick mass of drift. I am inclined to adopt this explanation of many basins which occur in the Glacial drift of Craven, especially with regard to such as are pervious to water. Some of the most remarkable of these occur near Kirby Lonsdale, at the entrance to Underley Park. I do not know that Mountain limestone underlies them, though it is plentiful close at hand, for the thick superficial deposits and the large faults which disturb the district render it unsafe to infer that such is the case. But the supposition is not improbable,¹ and if it should be confirmed, we may find in the hypothesis of concealed swallow-holes a less adventurous explanation of these singular excavations than one which has gained currency, viz., that large blocks of ice have been heaped round with drift, and afterwards melted. Around Ingleborough, and

¹ In the subsequent discussion, Mr. T. McK. Hughes, of the Geological Survey, gave his opinion that the strata beneath these hollows were Devonian and non-calcareous. He also supported the ice theory mentioned in the paper.
also near Silverdale, are many conical and dry pits in Glacial drift, where the subjacent strata are undoubtedly calcareous and frequently pierced by swallow-holes.

It is worth while to separate the two sorts of excavations which have been described. They are locally known as "buttertubs" and "pots." If it be necessary to find terms more precise and dignified, they may be distinguished as "cavities of erosion" and "cavities of subsidence."

VI.—ALTERED CLAY-BED AND SECTIONS IN TIDESWELL DALE, DERBYSHIRE.\(^1\)

SIR,—The Geological Magazine for August, p. 394, contains a report of a paper communicated by the Rev. J. M. Mello to the Geological Society, on the 22nd June, 1870, on the above subject. On the 7th September, 1869, I had the honour to read a paper on the same subject to the Natural Science Section of the Nottingham Literary and Philosophical Society. Hence I beg to claim priority in publication on behalf of the above Society. Apart from this, I, of course, do not complain that Mr. Mello should happen to select a very interesting section like that in Tideswell Dale, no doubt being quite unaware that I had already published an account of the same. The sole, though rather dubious, deduction that the author is reported to have made, is "that the columnar clay-bed may perhaps be a local development of that which forms partings in the limestone near Litton Tunnel." In my paper (extracts of which I inclose) I endeavoured to account for the clay-bed, or rather mass, in another way, and was at some pains to prove, or to try to prove, that the bed in question was not a thickened clay parting, much less a series of partings. I do not know whether Mr. Mello's paper is correctly represented by the very brief account you give, but the Section was of opinion that my paper deserved a full report.

I was so much interested in what I saw in one day's trip that I determined to visit the district again and examine the igneous rocks of the Derbyshire Carboniferous Limestone more thoroughly. The opportunity has not again occurred. I can, however, conscientiously recommend the task to those of your readers who are conveniently situated for the purpose or who have time at their disposal.

EDWARD WILSON.

HALL STREET, SHERWOOD, NOTTS., 10 AUG., 1870.

"On the west side of the Dale (Tideswell), at the same level as, and almost directly opposite the marble quarry, I found a very curiously filled up cavity in the limestone, exposed in the cutting of the road along the hill-side. At the base limestone, highly fossiliferous beds, two to three feet thick, minor joints confined to single beds; above lies an apparently imperfectly laminated band of yellowish clay, which, at one or two places, dips down into, and fills up,

\(^1\) The publication of this communication has been unavoidably delayed from want of space.