ON THE NATURE, CORRELATION, AND MODE OF ACCUMULATION
OF THE DRIFT-DEPOSITS OF THE WEST RIDING OF YORK-
SHIRE ; WITH REMARKS ON THE ORIGIN OF ESCARPMENTS,
VALLEYS, AND OUTLET-GORGES, AND AN APPENDIX ON
THE CLIFFS OF PLUMPTON, BRIMHAM, GOREDALE, AND
MALHAM. BY D. MACKINTOSH, F.G.S., ETC., AUTHOR OF
"SCENERY OF ENGLAND AND WALES : ITS CHARACTER AND
ORIGIN," AND PAPERS ON DRIFTS IN THE "QUART. JOURN.
GEOL. SOC. OF LONDON."

[*For Plate and Explanation see Close of this Paper.*]

FOR the last six months I have been devoting almost undi-
vided attention to the classification and correlation of the
drifts of the West Riding, between York and Settle in one
direction, and between Ripon and Barnsley in another. I
started with the idea, which subsequent observations have
confirmed, that it is only by a comparison of the characteris-
tics of the drifts on plains with those in valleys and on hill
sides that we can arrive at correct notions of the mode of
their accumulation.

CLASSIFICATION AND DESCRIPTION OF THE DRIFTS OF THE
WEST RIDING.

1. *Greyish-blue and Variegated Boulder-Clay.*—So far as
I can ascertain, it is to the late Mr. Teale, of Leeds, that we
are indebted for the discovery of two lower boulder clays, the
blue and the yellow. He found patches of blue clay at New
Wortley, Nether Green, Woodhouse Moor, Adel, and Yeadon
Colliery, at various levels, and at Adwalton at a height of
about 600 feet above the sea. At nearly all these places he
found the blue clay overlain by the yellow clay. I have
traced the existence of blue clay up the valleys of the Aire
and Wharfe, and on the plain of Craven, where it is exten-
sively developed. At lower levels, to the south-east and north

of Leeds, it exists only in patches. In the north-west part of the West Riding, where it lies near to, or on the carboniferous limestone, the stones and boulders in the blue clay are principally limestone; south-eastwards, the limestone pebbles and boulders decrease in number. Everywhere, but especially in the upland valleys, the stones are generally much rounded, polished, and scratched.

2. *Yellowish-brown and Variegated Boulder-Clay.*—Though there are very few sufficiently-clear sections to warrant the conclusion, I believe that both the blue and yellow boulder-clays run under the extensive beds of dark laminated clay and sand and gravel which spread out over the vale of York. One (if not both) of the boulder-clays has been found under the laminated clay and sand and stratified gravel of the vale of York. From low levels, the yellow clay extends up the valleys, and up the sides of the hills, until as a loam it thins out on the summits of the gritstone table-lands. The stones it contains are almost exclusively grit and sandstone at high levels, with a few limestone pebbles and boulders lower down, until at the bottom of the valleys, and on the plains, the percentage of limestone is often considerable. On limestone rocks, the stones in the yellow clay are often nearly all limestone (as at Malham and Goredale), indicating a difference in the sources of supply for the clay and the stones. On and near the summits of the table-lands, the stones, with some striking exceptions, are angular or subangular; but they increase in bluntness and roundness downwards, until in many places they graduate into an unstratified boulder-gravel. The Rev. J. S. Tute, of Markington, informs me that the brown clay west of Ripon contains a few boulders of Shapfell granite.

3. *Boulder Sand and Stratified Gravel.*—It is often difficult to discover a line of separation between the unstratified and stratified gravel. The unstratified gravel, generally speaking,

does not run into sand, while the stratified gravel is more or less associated with deposits of sand. The sand, in most places, contains boulders, angular as well as rounded. The nearer to the mountains the smaller are the sand and stratified gravel deposits; the farther from the mountains, and especially in the vale of York, these deposits attain a great thickness, and spread out over wide areas.

4. *Upper Boulder-Clay and Loam.*—In various places I have found this deposit capping knolls of sand, or forming the upper part of terraces and platforms of gravel. In some places it is distinctly separated from, in others it graduates into, the underlying drift. Besides the above, there is a deposit to which the vague term *warp* may be applied. It looks like a re-deposition, not by ordinary river-action, but by tides, at a time when the land was only slightly submerged. According to the late Mr. Teale (who, I believe without sufficient grounds, regarded it as a lacustrine formation), it nowhere rises higher than 150 feet above the sea level. As I have not had much opportunity of examining it, I shall take no further notice of this warp.

Sections of Boulder-Clays and Gravels in the Plain of Craven.—In a drain, at a low level, a short distance south of Settle, I saw a good section of hard blue clay, full of stones, and a similar clay may be seen at intervals in the railway cuttings between Settle and Skipton.* South-west of Settle a knoll consists entirely, so far as can be seen, of hard clay, with numerous large boulders of limestone. In the new railway cutting the clay is reddish-brown, but it is probable that there is blue clay underneath. The thickness, as shown in the river bank, cannot be less than 70 feet. The boulders are polished and scratched all round. Further south, in the new

* Since writing the above I have traced the blue clay underlying the reddish or yellowish-brown clay on the watershed traversed by the railway to the west of Settle, and nearly as far as the valley of Lune.

railway cutting, on the slope of a hill, the reddish-brown clay is very compact, and full of angular, as well as rounded stones. Near to where this cutting joins the old line of railway the reddish-brown clay overlies the blue clay, with a very distinct line of demarcation between them. Between Long Preston and Skipton, the part of the plain of Craven traversed by the railway consists of a very remarkable series of knolls varying from a few yards to at least 200 feet in height. The outline of these knolls, which is very curvilinear, is owing to the extent to which they are made up of drift. The Yoredale strata of the plain of Craven rise up to nearly, if not quite the highest, parts of these knolls in some places, and in most of the knolls there is probably a rocky projection which acted as a protector to a leeward tail of drift which formed a nucleus for a larger accumulation. In many places the whole height of a knoll, through which the railway has been cut, consists of drift, and as the drift (as shewn here and there by brook-sections) extends to a considerable depth below the level of the railway, we cannot resist the conclusion that in the plain of Craven the drift often reaches a thickness of at least 150 feet. The greater part of it, in the sections, appears to consist of yellow or reddish-brown boulder-clay, but a considerable part of it is blue clay. The stones in both clays are in general well rounded—indeed, often as much so as on any sea-shore. Both clays, but especially the blue clay, graduate into an unwashed, and unstratified or imperfectly-stratified, gravel, which in railway cuttings often looks like washed gravel, owing to rain washing away the clay and leaving the stones. The drifts of the plain of Craven have no connection with any river. They are most typically developed on the watershed part of the plain which lies between the courses of the Ribble and the Aire. To the north, north-west, east, and south of Skipton, we find knolls of drift similar to those above described. The Eller Brook

exposes sections at least sixty feet in depth, consisting chiefly of clay, with boulders of limestone, indurated shale, and grit. Above the blue clay, and resting on a very uneven and eroded surface, there is a thin covering of yellow clay, with grit and other boulders. About three miles north of Skipton, one side of a ridge consists of rock, the other side of drift. The blue clay, in many places near Skipton, contains shale in various stages of decomposition; and east of the Grammar School, in a brick-pit, the highly-inclined limestone shale may be seen, exhibiting various gradations in the process of being worked up into blue clay. The stones and boulders, chiefly from the alternating limestone bands, may likewise be seen quite angular, subangular, rounded, polished, and scratched. In the cutting south of Skipton railway station, the blue clay comes nearly to the surface. In a quarry near to this cutting, one of the finest sections I have seen in Yorkshire has been exposed. The blue clay may be seen resting on the contorted beds of limestone—in one place on their edges, in another filling up a synclinal hollow. The limestone nowhere in this quarry shows any signs of glaciation. Between the blue clay and the yellowish or reddish-brown clay above there is a very distinct line of demarcation.

[Mr. Mackintosh then described about forty sections of drift he had examined near Keighley, Hainworth-Shaw, Marley, Rombald's Moor, Bingley, Baildon, Guiseley, Holbeck, Headingley, Arthington, Follifoot, Ripley, Ripon, Littlethorp, south and west of Bramham, Marston Moor, York, Royston, &c., &c. On the various phenomena presented by these sections he founded his explanations of the derivation and mode of accumulation of the drift-deposits.—For a number of the sections, see Plate, with accompanying explanations.]

DERIVATION AND MODE OF ACCUMULATION OF THE DRIFT
DEPOSITS OF THE WEST RIDING.

1. *The Greyish-blue Clay.*—The uniform character of this clay, and the fact that in the valleys traversed by the Aire, and in the plain of Craven (where the clay is principally developed), at least seven-eighths of the stones it contains are limestone, while the underlying rock and the rock forming the slopes and summits of the hills above it for great distances is often millstone grit,* renders it evident that this greyish-blue clay could not have been distributed either as *subglacial débris* moved forward by a great sheet of land ice, or the *supra-glacial* moraine of a valley glacier, for in both cases the local rocks as well as the rocks the ice must previously have passed over, would have been worked up into the clay and into the boulders. A rather shallow sea, as the land was gradually sinking, and a sea acting principally between about 300 and 600 feet above the present sea-level, would appear to have been the main cause of the distribution of the blue clay.† This sea could not have been much indebted to land-ice sliding down the hill sides or along the valleys, for such ice would have brought down a supply of materials different from those composing the blue clay. We are, therefore, driven to the conclusion that the ice which undoubtedly had a share in shaping the stones and boulders found in the blue clay was sea-ice, coast-ice, or ground-ice. Most of the stones found in this clay are much rounded, as if they had

* The occurrence of blue clay with a great preponderance of limestone boulders on millstone grit (as at Keighley) may be referred to an ice-laden current carrying materials, which, for great distances from the sources of supply, did not become much mixed up with local detritus.

† The shale and limestone which formed the principal sources of supply for the blue clay and its boulders do not rise higher than about 600 feet, and the surface of the sea which floated the boulder-laden ice could not have stood much higher.

been rolled, and not merely rubbed on one side. Ordinary wave-action on a sea beach would appear to have been a principal cause of their attrition. Comparatively few of them are uniformly striated. The scratches run *all round* the stones, and the small grooves cross each other at all angles. The striations, along with the polished surfaces exhibited by these stones, can be easily explained by the irregular and repeated action of coast ice. To coast-ice laden with boulders, stones, and *débris*, and floating on the surface of oceanic currents, we may likewise attribute the distribution of the coarser part of the deposit, which presents the appearance of having been dropped down on a sea bottom.* Above and around the more stony accumulations, we often find a considerable thickness of rudely-stratified clay with few or no stones, which may have been assorted by the ordinary action of the sea.† The blue-clay deposit is frequently made up of limestone and shale graduating from shale boulders down to fine clay. The greater part of it is evidently crushed or washed shale and broken limestone. At least seven-eighths of it would appear to have been manufactured out of what may be called the raw shale and limestone of the plain of Craven and ramifying valleys. It must have been principally derived from the lower Yoredale and upper limestone shales. The boulders would appear to have come chiefly from the low-lying limestones of the Craven district. I have principally examined the greyish-blue clay deposit in the valleys, valley-expansions, and plains between Leeds and Settle. Patches

* Not all at once, but in a successive manner, by different masses of floating ice, so as to prevent any general stratification resulting from the specific gravity of the materials.

† The facts presented by drift-phenomena, and not any prevailing theory, must approximately determine the degree of cold during any stage in the submergence or emergence of the land, and the nature of the accompanying glacial conditions, whether arising from astronomical or geographical causes, both acting in concert, or the one neutralizing the other.

of a dark clay, probably of the same age, with a greater or less per-centage of limestone boulders, may be found in the Wharfe valley; near Ripon; around Leeds; filling up abrupt hollows between Wakefield and Doncaster; in a railway cutting near Royston, &c.; but, instead of these patches being remnants of a much more extensive deposit nearly removed by denudation, their distance from the sources of supply, and their mode of occurrence, would, I think, render it more probable that they were never more than patches (though at one time probably larger), and that their deposition in abrupt hollows and protected situations was owing to the extreme activity of the currents sweeping over the areas where they are to be found; for we ought to remember that a force of current capable of denuding a deposit would be capable of preventing its deposition.*

2. *Yellowish-brown and Variegated Clay*.—It is not difficult to understand that, as the land subsided (either continuously or after a long interval) beneath the level which cut off the low-lying source of supply of the blue clay, the shales and sandstones of the upper Yoredale and millstone-grit formations composing the sides of the valleys and table-lands, would furnish materials for the yellowish-brown clay, with its boulders. This clay extends from the bottoms of the valleys

* In the area between Wakefield and Sheffield there is very little drift, if we except a very thin surface deposit with many angular, and occasionally a few rounded, stones, which are not the mere disintegration of the rocks underneath, and which may be looked upon as the gleanings left by the great scythe of denudation to which the ground owes its present configuration. There are, however, a few patches of what is usually called drift—one near Royston, already mentioned, and not far from it a considerable expanse of extra-rounded gravel, clay with rounded pebbles near Masborough station, a block of Shapfell granite, according to Mr. Green, F.G.S., in Royston, &c. These facts prove the sojourn of the sea in the area under consideration, and I think that the comparative absence of drift may be explained by supposing the area to have been a theatre of very active denudation, compared with the districts north and east, where deposition may have been in excess.

up to the highest summits of the moors. It contains very little limestone, generally speaking ; and that little, from the positions in which it is found, would appear to have been floated by ice. Nine-tenths of the yellow clay formation is local, and must have been principally washed out of the hill-sides where it is found, or carried downwards, or *transversely* to the direction of the valleys. At the bottoms of the valleys, as at Bingley, it graduates into well rounded boulder gravel. On the summits of the table-lands, up to the height of more than 1000 feet above the sea, it is as much a boulder-drift as in the valleys—with this difference, that the matrix of the boulders and pebbles is more sandy than at the lower levels. During the accumulation of this drift, the table-lands and moors must have been completely submerged. On Rombald's Moor, Harden Moor, and elsewhere, blocks and well-rounded pebbles of a fine light-coloured sandstone called *calliard stone*, may often be seen in abundance. I have particularly examined those on Harden Moor, where, on the very summit the calliards lie on the millstone grit. Unless their presence can be accounted for by supposing them to be the wrecks of a formerly-existing calliard bed *in situ* (which several considerations render very improbable), or to have been floated by ice from the outcrop of calliard beds at a higher level on neighbouring moors, it is difficult to conceive how they could have been transported. About 150 feet lower down than those found on Harden Moor, there is a bed of calliard *in situ*. Land ice could not possibly have pushed up fragments from this bed without mingling them with *débris* collected during the *preceding* part of its course. But to those who are acquainted with what is now going on in the Baltic the supposition will not appear unlikely that these calliards may have been progressively moved up the hill side by stormy wave-action, combined with the action of coast-ice and ground

ice, during the gradual subsidence of the land, and that the largest stones may often have been thrown up to the highest levels—as we, indeed, find on ordinary sea coasts. What would take place to a limited extent on a sea coast at a stationary level might take place to an indefinite extent on a sea coast progressively embracing a whole hill side. In the north-west part of Yorkshire, boulders may be found which must have come from a lower level. I have found them on the hill north-east of Settle; and other instances might be mentioned in which land ice would not afford a satisfactory explanation of the phenomena. I may here remark that the glaciated rock-surfaces I have seen in the millstone grit district are on or near the summits of moors (though they are probably not absent from lower levels), as on Harden Moor, near Keighley (where I believe they were first discovered by the geological surveyors), and on Rombald's Moor. On the highest platform of Harden Moor the rock is glacially planed, and on the summit of the north cliff-line of Rombald's Moor, west of the headland called *The Calf*, the rock (very lately exposed under a bed of typical brown boulder clay) is beautifully planed, polished, and striated in a direction due west and east at a height (about 900 feet above the sea) and in a position relatively to the surrounding ground which forbids the idea of its having ever been reached by a valley glacier. During the gradual rise of the land, the yellowish-brown boulder-clay may have received additions in some places, while in others it may have been washed down the hill sides. The stones and boulders would become more and more rounded towards the bottoms of the valleys, until they graduated into accumulations of boulder-gravel, such as those seen around Bingley.

3. *Derivation and Mode of Accumulation of the Stratified Sand and Washed Gravel.*—The blue clay appears to have undergone a certain amount of denudation before the yellow

clay was thrown down above it, as its surface is generally uneven, and apparently eroded. The yellow clay presents indications of its having been denuded before the deposition of the sand and gravel. A part of the sand may have been derived from the yellow clay, which is often more or less arenaceous, and a part from the direct denudation of the local carboniferous grits and sandstones. The sand seldom rises higher than about 350 or 400 feet above the present level of the sea. In the Aire valley, where I have principally examined it, it is evidently of the same age as the great sand formation of the vale of York, though in the vale of York the distinction between the sand and stratified gravel is generally better defined. About Keighley, Marley, Shipley, &c., the sand irregularly alternates with washed gravel. Both the sand and washed gravel contain boulders, as already stated, and from the position of these boulders it is evident that they must have been dropt in. The action of floating ice, therefore, could not have ceased during the deposition of the sand. In the vale of York, and likewise in the Aire valley, the sand contains perfectly *angular* boulders, as well as boulders more or less rounded. During the deposition of the sand there would appear to have been rapid currents in a shallow sea. The deflected and eddying action of these currents in peculiar situations would be likely to leave an undulating surface, varied by abrupt eminences. But the undulations left by deposition must have been modified by contemporaneous or subsequent denudation, for on a very uneven surface of sand (a surface unconformable to its stratification) an *upper boulder-clay* has been deposited. It may either have been derived from the denudation of the yellow boulder-clay, or from a direct denudation of shale and rock; and it is difficult to explain its position above the sand without supposing a slight reversion in the movement of the land, or a second partial subsidence.

4. *Final Denudation of the Drift-Deposits of the West Riding.*—I have hinted that the shape of the surface of drift deposits may have been partly left by deposition ; but the frequent cropping out of the laminæ on the side of a sand-hill, as if they had all been cut off, the capping of sand hills with boulder-clay, the existence of two or more drift-formations in one hill, irrespectively of the contour or shape of the hill, and other facts, would seem to show that the drifts collectively must have been subjected to a sweeping denudation, which, according to the form of the valleys, and the direction of the currents, must have left flat terraces or expanses of drift in certain positions, and gently undulating knolls or abrupt eminences in others. The only cause with the mode of operation of which we are acquainted which could have left the numerous undulations in the drift-deposits of the West Riding is the deflected and eddying action of oceanic currents. The boulder-clay and boulder-gravel knolls of the plain of Craven display an almost perfectly curvilinear outline, which here, and there graduates into hollows with no outlet for the surface-drainage. The knolls diversify a plain which could never have been subjected to the action of a valley-glacier, supposing a land glacial period to have succeeded to the deposition of the latest drifts of the West Riding. Atmospheric action could never possibly have given rise to the geometrical exactness of the outlines presented by these drift-hills. Atmospheric action is now making unsightly ruts down their smooth and continuous slopes. But it is difficult to resist the belief that the current-action which accomplished the last great denudation of the drift-deposits was much more powerful and sweeping than the ordinary action of tidal currents in existing estuaries and bays. Without, however, asserting that manifestations of marine agency capable of accounting for the final great denudation of drift-deposits may not yet be discovered in certain

parts of the world—in high, if not in low, latitudes—I would remark that many American geologists have lately found it difficult to explain all the phenomena presented by the enormous accumulations of boulder-drifts exposed by the railroads of British North America without coming back to the theory they now believe they too hastily rejected, namely, that, during the breaking up of the glacial conditions of the northern hemisphere, marine aqueous action acquired an intensity which, so far as we know, has not since been paralleled.

5. *Irregular Terraces in Drift.*—In the West Riding of Yorkshire, as well as in nearly every part of England and Wales, there are innumerable small terraces. The most striking I have seen are in the neighbourhood of Spofforth, Settle, and Malham (see plates). The last are the most worthy of consideration. They are chiefly in the yellowish-brown drift, but I have no doubt that in some places they are wrought into the solid rock. They may be seen on the east side of the Aire valley up to a great height above the river, both on steep slopes and on slopes at an angle of only two or three degrees. They are very seldom horizontal, but dip with the hollows and rise with the ridges. They generally present a rude parallelism, but are never perfectly regular. They conform to the longitudinal contour of the ground. To the north of Malham they are more ridges and furrows than terraces, and run not along, but *down* the face of the slope. Their mode of occurrence shows that they were only formed *along* the face of a slope when it happened to lie in the direction of the moving cause. In other cases they cross slopes in ascending and descending order. They thin out, reappear, swell, and diminish. They are very similar to the vast majority (not all) of the terraces of the chalk districts of the south of England; and in Yorkshire, as well as the south of England, in places where the terraces happened to approach regularity.

or to occur on a steep slope, they may have been taken advantage of, modified, or imitated by man for economical purposes. In the north of England, some of the geological surveyors, I believe, are disposed to regard them as the effects of land glacial action. For reasons which may be gathered from this paper, I am more inclined to look upon them as the marks left by currents laden with floating ice during the last great denudation of drift-deposits. The fact that there are terraces of artificial origin on hill sides in many parts of England, is no more a reason why we should regard the vast majority of drift-terraces as made-earth, than the existence of artificial mounds is a proof that all drift-knolls were piled up by man.

6. *Limits of River Action*.—Since the glacial submergence, rivers have been occupied in cutting well-defined channels in drift-deposits. In most parts of the valley of the Aire, they have not yet got down to the solid rock, and there is reason to believe that between Bingley and Skipton the drift in some places fills up hollows which at one time may have been lake-basins. The river deposits consist of small pebbles,* never spread out continuously for great distances, but, confined to patches or ridges, and of a nearly stoneless sand and loam, deposited over considerable areas. The rivers are not giving rise to boulder-deposits, or, with a few exceptions, to original drifts of any kind. A little investigation will show that where patches of pebbles are found in the river channels they have generally been washed out of boulder-drifts in the immediate neighbourhood. It may further be remarked that the stones and boulders of the valley drifts are often in positions where they could not have been left by river action, even supposing the rivers to have been formerly much larger

* These remarks are not intended to apply to mountain-torrents, or streams with considerable inclination of channel, which are capable of moving large stones during floods.

than at present—the abundance of limestone boulders and pebbles in the lower part of the course of the river Worth, for instance, where the river could only have brought down grit or sandstone. Dr. Milligan and Mr. Bottomley have satisfied me that at least one of three specimens of *Gryphæa*, found by them at Keighley, was obtained from the blue clay, and they believed that the other two had come out of the blue clay or overlying drift. If, as seems possible, these fossils were floated by ice from the north-east of Yorkshire, they must have come in a direction very different from that in which the river Aire flows, and from no point of the compass could they have been brought by that river. The so-called gravels of the West Riding valleys often rise more than 100 feet above the river channels (as at Bingley, where, from the surface downwards, they contain numerous boulders up to five feet in diameter, placed at all angles, and often striated), and there they are of the same nature as gravels found remote from rivers, at greater elevations, while at both high and low levels they graduate into the yellowish-brown boulder clay which rises to the summits of the moors. But an attentive examination of the sections will be sufficient, without any further remarks, to show that the gravels described in this paper are quite distinct from river gravels.

7. *Limestone Blocks resting on Millstone-grit.*—I have found small boulders of limestone in drift resting on millstone-grit up to about 900 feet above the sea, above Slippery Ford, near Keighley; and I have been informed that limestone boulders have been dug out of pits on the south and south-west side of Rombald's Moor at nearly the same height; but I have to thank Mr. Varley, C.E., of Skipton, for pointing out to me the existence of two large blocks, with smaller fragments of limestone, under a cliff, and resting on a platform of millstone-grit, at the south-west corner of Embsay Moor, at a height of about 1,100 feet above the present sea-

level, and Mr. Varley informed me that he found them on the other side of the moor, facing the Wharfe valley, at about the same height.

REMARKS ON THE ORIGIN OF ESCARPMENTS.—We do not stand in absolute need of the occurrence of erratic blocks as a proof that the moors of north-west Yorkshire were once under an ice-laden sea. The amount of decomposed shale and the number of stones and boulders entering into the composition of the drift-deposits can only be explained by supposing that a corresponding amount of denudation, as we have seen, must have mainly taken place on sea-coasts. The sea could not have abstracted the shales from the hill-sides without leaving indentations and undermining the overlying harder strata, so as to leave steep escarpments and cliffs. At a stationary level, the terraces would be rendered more or less horizontal, but as the land gradually moved up and down the sea would follow the outcrops of the shales so as to leave inclined or irregular terraces. The shales would often be left forming the platforms, or lower parts of the superjacent escarpments, but the sea would likewise, where its action was sufficiently persistent, wear out a terrace in the more solid rocks, and accordingly we often find terraces with both platforms and cliffs consisting of hard rock—for instance, on the south-west and west side of Embsay Moor, on the Rombald's Moor side of the valley between Skipton and Bolton, on the western side of Brimham Moor, &c., &c., (see plate). Many of the platforms of the terraces of the West Riding are covered with drift containing rounded among angular stones, generally local, but sometimes erratic (on the north side of Harden Moor, both sides of Rombald's Moor, and in innumerable other instances). This drift exactly corresponds with what one might suppose to have been deposited on a sea-beach, with a steep declivity below, under mixed glacial and marine condi-

tions. The cliffs and platforms of the Yorkshire moors could not have been formed by rain, because on hard rocks and on grass-covered shale rain cannot act in a state of dispersion so as to leave longitudinally-continuous indentations. When rain-water acquires denuding power by becoming concentrated into streams capable of washing down hill sides, it always tends to produce, not *horizontal* indentations or continuous terraces, but gulleys at considerable intervals *down*, and not along, the faces of the declivities. Where terraces already exist, rain-torrents tend to break up their longitudinal continuity.

At the base of, and insinuated into, the crevices and cavities of the cliffs, at Plumpton and elsewhere, we often find foreign pebbles, with or without clay, which show that something more than atmospheric agency has there been at work; and a detailed examination of all the phenomena connected with these rocks, with the Brimham rocks, the Wharneliffe rocks, and many other inland cliffs, would, I am convinced, lead to the conclusion that the sea has washed away the softer beds at a lower level; abstracted large blocks and removed them to positions where they could not have fallen; excavated narrow inlets up inclined planes; rounded many of the loose blocks, piled them on one another; and performed other feats entirely beyond the power, and incompatible with the mode of operation, of atmospheric agents.

Wind charged with sand, and its action concentrated by pre-existing indentations, has modified the shapes of many of the rocky pillars on Brimham Moor and elsewhere, but it could not have formed the cliffs, abstracted blocks so as to leave passages between pillars,* left uniformly ground-down

* The sides of these passages often consist of unweathered divisional planes, and where these planes have been acted on by rain, vertical small furrows have resulted.

prominences or ground-out hollows irrespectively of the structure of the rocks, or undermined pillars so as to leave the upper parts projecting. On Brimham Moor, many of the most striking pillars are close on, or near to, the verge of high cliff-lines, and they have undercut sides facing directions from which wind charged *with sand* could never have assailed them.*

ORIGIN OF VALLEYS AND OUTLET GORGES. — Professor Phillips long ago noticed the extent to which the contours of the valley-systems of Yorkshire were independent of the direction of the drainage, and no unbiassed observer can make a survey of the hilly districts of the West Riding without seeing that fresh-water drainage could never have excavated the principal valleys. In these districts there are innumerable valleys which cross watersheds, varying in depth from a few yards to more than a thousand feet. Though small streams flow down both ends of these passes, they may be called riverless valleys, and the amount of excavation in the middle, where no streams exist, has generally been greater than towards the two ends—that is to say, the sides of the passes rise highest in the middle. The passes between Skipton and Bolton, and between Skipton and Rilston, may be taken as average examples. It would be little else than a waste of words to endeavour to show that these valleys could never have been excavated by fresh-water streams. What are called river valleys are here and there connected by riverless valleys, and on examining one of these valleys—the valley of the Aire, for instance—we find that it consists of a number of valleys pointing in various directions. *Across* rather than *along* these valleys the rivers flow. The valleys have a contour independent of the channels

* Professor Ramsay's suggestions to Mr. Green, relative to the undercut mill-stone-grit pillars on the High Peak table-land, will not apply to the Brimham Rocks.

or courses of the rivers, and, were the connecting gorges through which the rivers escape to be blocked up, as they apparently once were, the valleys would be occupied by lakes. The rivers, in order to find their way to the sea, have repeatedly to change their course, and, were it not for the existence of outlet gorges, they would be unable to reach the sea at all. The rivers in pre-glacial times, as they flowed over the barriers of lakes, may have excavated some of these connecting gorges in hard rocks, as rivers in post-glacial times have forced their way out of lake-basins in drift by scooping out channels; but there are many instances in which the outlet gorges could not have been excavated by rivers, especially those where the levels of the lakes could not have reached, or nearly reached, the height of the barrier. This remark applies to the Don and the Went, which, after flowing along valley-expansions, make their escape through narrow gorges in the Permian Escarpment. There is reason to believe that the gorge at Went Bridge was first opened by one or more fractures or faults. This may have occurred under the sea, in which case currents may have cleared out and enlarged the gorge. But in whichever way the gorge of the Went was formed, it presents clear indications of having been subjected to the action of the sea during the last submergence of the land. These indications consist principally of a peculiar style of honeycombing which shows that the cavities must have been regularly ground out by a forcible agency, such as that of sea waves charged with sand or other solid abrading matter. We may see the difference between these pits and cavities and those now eaten out by atmospheric agency in an old quarry near the lower end of the gorge. The latter are invariably rough, and conform precisely to the unequal composition of the rock.

APPENDIX.

DETAILED NOTES ON THE PLUMPTON AND BRIMHAM ROCKS, WITH REMARKS ON GOREDALE AND MALHAM COVE.

THE PLUMPTON ROCKS.

1. Above the cliffs there is an extensive plateau on which the bare rock comes sometimes to the surface, but is in general covered with a sandy soil, or *débris*, containing rounded pebbles and small boulders. To the north of the cliffs there is a low ridge covered with rounded stones, and similar stones may be found in the valley under the cliffs. The stones are chiefly hard fine-grained sandstone and a kind of quartzite, and they must have been drifted from a greater or less distance—their parent rocks being found to the west or north-west,

2. Towards the north end of the range of cliffs I saw a curvilinear cavity containing rounded stones, most of them erratic, which extended into recesses where it is very unlikely they could have been thrown in by human hands. These stones may possibly have helped to grind out the cavity. In several other cavities I found similar stones. In some places the cavities contained a little loose grit, indicating the action of wind, or possibly of rabbits, though I afterwards saw reason to conclude that much of the loose grit in cavities must have been blown in from the gritty soil lying on the summit or at the base of the cliffs.

3. An insignificant stream, during heavy rains, may *flow* along the valley in front of the rocks (when I saw it the water seemed quite stagnant), but the few hundred yards in length of the water-collecting surface south-west of the watershed could never have rendered this stream sufficient to remove good-sized stones, or round them by attrition.

4. Arrived at a wide passage between stacks of rock, partly filled with powdered grit in a way showing that the grit could not have crumbled down from the sides of the cavity, but must have been *washed in horizontally*. At nearly right angles there is a narrow passage partly filled with grit, in addition to angular and rounded stones, some of them of considerable size.

5. Arrived at two small caves with flat bottoms—these caves evidently ground out, not weathered out. On the side of one of them, near the entrance, weathering seemed to have just commenced, and the *rough surface* resulting from it contrasts strongly with the smooth sides and roof of the cave.

6. In most places the fronts of the cliffs, or the parts of them facing the valley, present large *jointage-planes*, in places slightly roughened by the weather, in others lichen-covered.

7. Here, a joint half-a-foot wide has been crammed full of both

angular and rounded stones, which apparently did not fall in from above. A rather large stone has been jammed in under a number of other stones, some of them *erratic*. The sides of the joint, where exposed, exhibit no appearance of weathering. In the neighbourhood there is an unweathered joint from twelve to eighteen inches wide, which has been filled to a certain height with grit and stones; but here, as in other places, the infilling matter could not have been washed in by rain.

8. Another joint filled with grit and stones which could not have crumbled down (the sides of the fissure up to the top being unweathered) or fallen in. At the top of a neighbouring filled-up joint there is a good-sized cake-shaped stone crammed in, with its upper edge projecting. The form of the rock-surface here, as in many other places, shows that rain could not have filled up the joint.

9. In a large winding passage, the smooth and rounded rocky walls run deep down, *unaltered in form*, beneath the infilling of grit. In one part of this passage, six feet wide, the walls are evidently parallel jointage-planes, from between which masses of rock must have been abstracted, and that not by mere granular dissolution, as this process would not have uniformly stopped short at the remaining jointage-planes. To attribute the removal of the missing rocks to rain would be absurd, seeing that rain has left the jointage-planes intact. It is almost impossible to resist the impression that these passages must at one time have been traversed by waves capable of sweeping away fragments and blocks of rock.

10. In many parts of the ramifying passages near the artificial lakes, to which wind and rain have little or no access, a powerful agency, such as sea-waves, must have *ground* away the rocks so as to leave smooth and rounded projections and concavities. In front, or facing the lake, the rounded form of the cliffs is in many places the same above and beneath the talus of loose grit, showing that the talus must have been thrown up against the base of the cliffs, or washed down from the loose grit covering the top of the cliffs. The latter is not a disintegration *in situ*.

11. The cliffs above the lake have in many places been rounded on a large scale, irrespectively of the structure of the rock.

12. At this point rain has lately been washing down loose grit from the covering of the upper surface of the stack of rock. Much of the grit occupying certain positions at the bases of the cliffs, or in passages, has in this way been transferred from the summit, and not derived from the weathering of the cliffs.

13. A great deal of the undermining and rounding has taken place along the bases of cliffs rising from ground so flat, or so very slightly inclined, as to have prevented the washing away of the resultant detritus by rain.

14. The large fallen masses rising out of the lake in front of the cliffs occupy positions indicating a more powerful undermining cause than any form of fresh-water agency which could ever have existed in this small valley.

15. At the south-west end of the lake, the cliff-line has been deeply indented by an exceedingly picturesque winding creek, the greater part of which must have been scooped out by an agency capable of acting on level ground. This creek presents an intensely sea-coast aspect.

16. Between the lake and the Harrogate road, one may see a nearly square aperture, about four feet in diameter, and from fifteen to twenty feet long, the roof, floor, and sides of which show that it has not been left by weathering, but by the abstraction of fragments or blocks. Near it a rounded large stone may be seen in a joint. In this little-visited part of the Plumpton grounds, the *continuously perpendicular* cliffs rise above, and extend below the surface of the talus in a way demonstrating that the talus has not resulted from the decay of the cliffs, and that the cliffs must have existed before the talus began to accumulate. In this neighbourhood there is a cave with a rocky floor longitudinally level, so that rain could not have washed out detritus; and the rock composing its sides is too hard to be abraded by wind, supposing it to be accessible to wind, which is rather doubtful.

GENERAL REMARKS.

Among the Plumpton Rocks, but especially towards the south end, the impression cannot be resisted that, where the weather acts, it is on previously-existing cliffs which the weather could not have formed. The weather here is a modifier, or rather a destroyer—certainly not an originator.

As regards mere rain, it ought to be recollected that the most characteristic features of the Plumpton Rocks are to a great extent protected from its action, and that rain-drops, on *pervious* gritstone, sandstone, and sand, have very little abrading power. Where the summit-area of a rocky stack is adapted to collect rain-water and concentrate it into minute runlets—where these runlets become charged with a little loose surface-grit—where they fall over the brink of a cliff, and meet at some distance below, with projecting masses of rock, they wear out vertical furrows in these masses, as may be seen near the south end of the lake. But while there are a few instances of these vertical furrows among the Plumpton Rocks, they are evidently a super-imposed form of surface configuration quite distinct from the typical shape of the rock surfaces, which must therefore have been produced by a different cause.

The undercutting or undermining of the Plumpton Rocks has, on a small scale, often followed the structure of the rocks, and been directed

by the existence of comparatively soft matter. But the denudation of the cliffs on a larger scale has frequently crossed the false bedding and oblique lamination, and even the more massive stratification, in a way indicating a cause much more powerful than any subaërial agency.

In front of the cliffs, and more especially along the bottoms of the wider passages, where bare rock is accessible, it may often be seen that *the sites of the rocks which have been carried away consist of as hard grit as that composing the sides of the passages*—thus showing that the passages did not result from the washing out of softer matter, but from the abstraction of solid grit by an agency propelled in particular directions. In many instances this agency would appear to have *acted uphill along an inclined plane*, and to have abstracted the rocks now missing by a revulsive effort, as sea-waves now act in narrow inlets on coasts. The infilling of the passages with the existing grit and loose stones must have occurred subsequently to the excavation of the passages, and was probably brought about partly by the action of the sea, and partly by the more recent action of rain.

THE BRIMHAM ROCKS.

Near Brimham Hall, on the face of a slope, there are several very striking rocky projections consisting of laterally detached cliffs with tails graduating into the ground above (like skylight windows on the roof of a house), and perfectly detached and circumdenuded stacks. In most places the general slope comes up to the base of the rocks, but where weathering has taken place the fallen grit or sand forms a small underlying ridge. On the side and at the base of one rocky projection, there are rounded stones, including a large boulder imbedded in grit.

Near the base of the slope there are three stacks in close proximity. One of them about twenty-four feet, and another about fifteen feet high, are separated by a narrow passage with a hard rocky floor. On the west or overhanging fronts of both stacks a regular and apparently unweathered concavity looks as if it had been ground out by a powerful agency, probably ice wielded by water.

Nearly on a level with the valley at the base of the slope or escarpment, there is a striking stack of rock, about twenty-four feet high, with a concavity on its west side, and rounded as well as subangular stones beneath its undercut base. Some unknown cause seems to prevent the accumulation of fine grit or sand in such situations, and likewise the growth of grass. Some of the pebbles may have been gathered off the surrounding field and thrown in. They consist of a kind of quartzite, Permian limestone, and other rocks foreign to the spot, as well as grit. Under a smaller stack close by, pebbles of different rocks may be seen packed up in a recess. In some cases among these rocks, blown rain

has probably, by a revulsive action, bared their bases by washing back to a distance of two or three feet previously-deposited loose grit.

The slope under the parts of the above rocky stacks now undergoing decay, is too slight for rain to carry the decomposed grit or sand away. The rain sinks into the sand, and remains till it is evaporated. The bottom of the valley at the base of the slope, and within a few yards of the lower stacks, consists of clay, with rounded stones in its upper part at least. The absence of a section of the clay prevented my seeing whether it was argillaceous shale *in situ*, or a boulder drift (*see plate, fig. 14*). In either case, the bottom of the valley ought to be covered with sand according to the subaërial or "wash of rain" theory of the denudation of the rocky stacks. The rocks, now missing, by which these stacks were once joined together, would appear to have been swept clean away, with the exception of a little loose grit and sand. On the field around the unscathed rocks, rounded pebbles (as before stated), may here and there be found attesting the marine nature of the denudation by which the rocks were left.

In a quarry to the north of the above rocks, the line of demarcation between the hard gritstone and the coarse sand and detritus above, is so sharply defined as to show that the latter is not a disintegration *in situ*, but a local drift.

GOREDALE.

The entrance to Goredale is a large irregular cove bounded on each side by terraced slopes, and terminated behind by a wall of limestone rock, hollowed out into a smaller cove, which is breached at its inner end by a very narrow gorge. The reddish-brown clay of the plain of Craven, with a few sandstone mixed with numerous limestone boulders and pebbles (some of the latter scratched and striated all round), rises up on each side of the entrance to Goredale, covers the bottom of the valley, underlies the brook, and runs up as far at least as the mouth of the smaller or inner cove, where it is replaced by numerous angular blocks. The inner cove is bounded on three sides by a continuous wall of rock, except where the brook makes its entrance in the form of several cascades. A part of the cliff on the right-hand overhangs its base at an angle of at least 20 degrees from the perpendicular. Near its summit there is a noticeable pothole or smooth concavity. The inner and upper part of the rock on the left likewise overhangs. Its face is indented by a rough horizontal groove about half-way up, and a smooth groove near the top—both, I believe, the work of the sea. The height of the cliffs has been exaggerated. On the right-hand side the overhanging cliff rises above its base to a height of about 130 feet at one part, and 160 feet farther on. The cliff on the left is about 160 feet high, but the lower part, immediately above the stream, projects in the form of a

narrow terrace about 30 feet in height. The whole presents the appearance of being the effect of the conjoint action of the stream and the sea—the present cliffs bounding the outer and inner coves having been left by the undermining action of currents and waves about the time when the adjacent drift was deposited.

MALHAM COVE.

The South Craven Fault coincides with the slope or escarpment in which Goredale and Malham Cove have been worn back. The valley which terminates in Malham Cove strictly so-called is more or less covered with the reddish-brown drift already mentioned. Nearly as far as the inner termination of the cove many boulders may be seen in positions where they could not have fallen, and to which, therefore, they must have been carried. Not a few of the boulders are regularly lithomized—the holes (about two-thirds of an inch in average diameter, and often three inches in length) running at various angles from obliquely upwards to vertically downwards.

The cove is terminated by a wall of limestone rock in most places quite perpendicular, excepting where it overhangs. The average height of the vertically-continuous and perpendicular precipice cannot be less than 250 feet. The infant Aire rises from beneath the cliff-line on the left-hand side; and there is the appearance, in the shape of a shallow gully, of a stream having once, perhaps repeatedly, flowed over the brink of the cliff-line. But the face of the cliff-line runs along so continuously as to forbid the idea of a narrow stream, either above or below, having formed it by either an eroding or undermining process. It looks exactly like the work of the sea insinuating itself into a pre-existing deep ravine, and excavating it backwards so as to flatten its floor,* and leave a semicircular wall of rock. The various stages in the process of converting a ravine into a cliffed cove may be seen on many existing sea-coasts.

EXPLANATION OF PLATE.

FIG. 1. *Section in a Quarry South of Skipton.*—(A) Carboniferous Limestone; 1. Greyish-blue clay, with a few boulders; 2. Yellowish-brown clay, with many stones, running into stoneless sand and loam, (D); (B) Nearly stoneless layer of loam.

FIG. 2. *Sea-terrace carved out of Millstone-grit between Skipton and Addingham.*—It is traversed by the upper or old road.

FIG. 3. *Sea-terrace, with Limestone Boulders resting on Millstone-grit, S.W. corner of Embsay Moor, near Skipton.*

* There is, indeed, the appearance of the bottom of the cove having been once a shallow basin, the outer barrier of which has been breached so as to allow the present stream to escape in the direction of Malham village.

FIG. 4. *Section at Beach Mills, Worth Valley, Keighley (now built up).*

(A) Between six and eight feet of purplish-blue clay running into yellow clay and sand, with a few stones; (B) Slightly-laminated blue clay without stones; (C) Greyish-blue clay with many stones of all sizes up to 4 ft. in diameter—at least 80 per cent. limestone. Stones rounded and polished, and scratched and striated in various directions. Thickness not ascertained.

FIG. 5. *Section from Harden Moor to North Beck, Keighley.*—(A) Outcrop of calliard bed *in situ*; (B) Old sea-beach of yellowish-brown boulder clay; (C) Rounded calliard stones and boulders; 1. Greyish-blue boulder-clay reaching a thickness of from 40 to 50 feet; 2. Yellowish-brown boulder-clay; 3. Confusedly-laminated sand and gravel reaching 50 feet in thickness. In a direction at right angles to this section, or towards the west-south-west, the clay (2) rapidly thins out.

FIG. 6. *Section of a Sand-pit at Marley, near Keighley.*—3. Sand about 20 feet in thickness; 4. Loamy clay with boulders up to 2 ft. in diameter, lying at all angles, about 10 ft. in thickness. The sand shows clear traces of denudation before the deposition of the clay, and both clay and sand must have been afterwards denuded.

FIG. 7. *Section near a Farm-house North of the White Hart Inn, on the road between Aberford and Bramham.*—The knoll is nearly the highest part of the district (between 200 and 250 feet above the sea). (A) Permian limestone, overlain by patches of dark clay, and sand; 3. Gravel, consisting of well-rounded pebbles and boulders in a sandy matrix, about 10 feet in thickness; 4. Reddish clay, with rounded and subangular stones up to 2 ft. in diameter, consisting of sandstone, millstone-grit, carboniferous limestone, chert, local Permian *débris*, &c.

FIG. 8. *Section across the Aire Valley near Bingley.*—2. (N.E. side of the railway) Boulder-gravel running upwards into loamy clay. The boulders reach a size of 5 feet in average diameter, and consist principally of grit and sandstone. Some of them are decidedly striated. There are many small and extra-rounded pebbles, a large per centage of which are limestone. 2. (Between the railway and the river) appears to consist mainly of rounded stones up to 5 feet in diameter, in a matrix of clay or loam. I believe the blue clay might be found underneath, as a short distance to the North-west of the section I saw it in the river-channel under the yellowish-brown boulder-clay and loam. The bulk of the drift in the neighbourhood of Bingley consists of boulder-clay, and I have not been able to recognise the great expansions of so-called river-gravel mentioned by Mr. A. Tyler in his paper in the *Quart. Journ. of the Geol. Soc.*

FIG. 9. *Mode of occurrence of the Sand-hills on one side of the Aire Valley, near Esholt.*—The sand contains boulders of millstone-grit, limestone, &c., some of them nearly angular. Their positions show that they must have been dropt in. The laminae are crossed by nearly vertical streaks. The sand is covered by, or runs upwards into, loam and clay.

FIG. 10. *Section near Holbeck Station exposed by a cutting in the Leeds and Harrogate Railway.*—(A) Carboniferous sandstone; 2. Yellowish-brown loam and clay, with many rounded and subangular stones, and a few boulders, consisting of sandstone, millstone-grit, fragments of *Stigmaria*, quartz, &c., reaching 12 feet in thickness. It is difficult to say whether this plateau of drift was deposited before the valley of the Aire existed, or whether its deposition was continued in a northerly direction so as to fill up that valley, and afterwards removed as far as the south side of the canal by a process of re-excavation.

FIG. 11. *Section near the South and North entrance to the Arthington Railway Tunnel.*—Near the north entrance the yellowish-brown boulder-clay would appear to have been so violently driven against the rocky cliff as to make the one

graduate into the other. I believe the blue clay here underlies the yellow, as it does in other parts of the valley of the Wharfe, but the section is much obscured by talus.

FIG. 12. *Section exposed by Excavations in connection with the Headingley New Waterworks* (Feb. 1870).—(A) Purplish-blue clay with a few boulders, very compact, and fracturing like igneous rock, excepting where it frequently runs into sand. It reaches a thickness of at least 26 feet: (B) Metalliferous laminated sand, traversed by splashy seams of purple loam; (C) Yellowish-blue and variegated clay, with many boulders of sandstone, millstone-grit, &c., reaching an average diameter of at least 5 feet. I found twigs of plants where the boundary between the lower and upper clays was too indistinctly marked to warrant their being referred to the one or the other.

FIG. 13. *Section of Laminated Sand and Purplish-blue Clay in another part of the Headingley Excavation.*—The clay and sand partly represented in the above two sections is limited to a basin or trough less than half a mile in diameter. The slope rising from it on the eastern side is covered with sand, and farther on, in a quarry, reddish-brown boulder-clay is seen resting on rock.

FIG. 14. *Section exposed by the Railway Cutting between Pannal and Spofforth.*—(A) Carboniferous sandstone; (B) Boulder sand and loam with yellowish-brown and blue clay (order of succession not ascertained).

FIG. 15. *Section in a Quarry near Aldfield.*—(A) Permian marl slate; 1. Black clay; 2. Brown clay, both containing scratched and polished boulders. The brown is the usual surface clay of the district. It has a rough stratification, generally inclining to the east. (*Communicated by the Rev. J. Stanley Tute, of Markington.*)

FIG. 16. *Section close to Ripon Railway Station.*—(A) Dark laminated stoneless clay, evidently an outlier of the great expanses of laminated clay in the vale of York—horizon and relative age still unknown; (B) Light red sand; (C) Dark red sand, with a few pebbles, about 7 feet in thickness.

FIG. 17. *Roadside Section near Ripon Railway Station.*—(AA) Fine gravel; (B) Sand; (C) Sand with a few pebbles.

FIG. 18. *Section in a Brick-pit near Littlethorpe, Ripon.*—(A) Variegated boulder-clay and loam, called "carrion;" (B) Coarse sand with small pebbles, and fine red sand without pebbles; (C) Alternating yellow, blue, and brown beds of finely laminated clay without stones, about 12 feet in thickness.

FIG. 19. *Section in a Brick-pit a little farther north.*—(A) Red false-bedded sand; (B) Thin layer of stones; (C) Dark laminated stoneless clay.

FIG. 20. *Typical structure of the Cliffs on the north-west side of Brimham Moor, shewing the effects of a powerful undermining cause not assisted by the waste of softer rocks.*

FIG. 21. *Irregular Terraces and Ridges on the eastern slope of the valley of the Aire, south of Malham.*—They are merely a part or variation of the general configuration of the slope. Near Settle, many of the terraces are probably raised beaches or tidal ridges.

NOTE.—(*July, 1870.*)—One of the officers of the Geological Survey informs me that while in the neighbourhood of Leeds he heard of unfossilized sea-shells being obtained from the blue clay at an almost fabulous depth, near Seacroft, during boring operations. Information on this point will be thankfully received by Mr. Denny, Philosophical Hall, Leeds. The yellowish-brown boulder-clay covers a great part of the surface between Seacroft and Bramham, but I do not recollect having there seen any very decided section of the blue clay, though it probably underlies the yellow in some places. D. M.