cast down so as to form an intercepted drainage, giving rise to a swamp which engendered a peat growth; by the agency of which the portion of the forest so thrown down has been preserved from the destruction that by atmospheric or else human agency has overtaken the rest of it. Lastly, we have the introduction of the river over the previous land-surface and peat-swamp, bringing sediment which by its deposit has formed the marsh-clay of its former shallow bed, before that bed was reduced to its present narrow limits, and deepened by embankment.

In all this, save to the extent indicated in the *original* valley by the gravels ($x\ 1$, $x\ 2$, and $x\ 3$), we find nothing analogous to terrace-formation, or to the modification of an estuary by the successive elevation of the land and cutting down of its bed, until the estuary has become a river, as is described to us to be the case with the valleys of the Somme and the Seine.

(To be continued in our next.)

IV.—THE SEA AGAINST RAIN AND FROST; OR THE ORIGIN OF ESCARPMENTS.

By D. MACKINTOSH, F.G.S.

AS every part of the crust of the earth has at one time been the surface, it follows that all questions connected with the origin of the present "form of the ground" must be very important, and that on their issue the progress of Geology must in a great measure depend. But on this subject a very wide difference of opinion at present exists. According to one party, consisting of Professor Ramsay, Mr. Jukes, Mr. Geikie, Colonel Greenwood, Dr. Foster, and others, the more abrupt inequalities of the earth's surface have been produced by subaërial or atmospheric causes. According to the other school, embracing Sir Charles Lyell, Sir Roderick Murchison, Professors Sedgwick and Phillips, Mr. Edward Hull, etc., the sea has been the principal denuding or excavating agent.

The subaërialists start with the assumption that the sea tends to plane down the land, and that its newly-elevated bed presents a surface divested of abrupt heights or hollows. But this assumption is at variance with the generally-received principle of physical geography, that the bottom of the sea, at any given time, is as uneven as the dry land;¹ and it is equally opposed to the established geological fact that mountains have been islands and islands moun-

¹ There is a very extensive series of table-shaped mountains under the North Atlantic Ocean. Their comparatively level surface may be partly owing to their being covered with sand. Along their western and north-western edges the depth suddenly descends to 600 feet, and along the southern edge to 900 feet. The descent is nearly perpendicular. Besides these inequalities in the Atlantic there are deep furrows which run north and south (see article "Sea" in Penny Cyclopædia, and "Section of the Bed of the Atlantic" in Maury's Physical Geography of the Sea). The bed of the German Ocean, though very favourably situated for becoming a level surface, would likewise appear to be far from uniform in depth (see Lyell's Principles of Geology).

tains, while mountain-systems have been archipelagos and archipelagos mountain-systems. If we take a detailed chart of an archipelago, and compare the depths obtained by soundings, we shall find a striking correspondence between its inequalities and those of an elevated mountain-system.¹

The Sea not a levelling agent.—That the sea, regarded as a *denuding* agent, does not now tend to plane down the land, can, I think, be easily shown; for on coasts and among islands exposed to the action of currents and the fury of storms, it is continually forming coves, headlands, bays, creeks, straits, etc. Mr. Jukes admits that the sea can excavate gaps or passes on the crests of islands, and that marine denudation is effective about the sea-level;² but this distinguished geologist leaves out of consideration that the land has risen and fallen so as to enable marine denudation to be effective at *all* altitudes. The sea, by assailing coasts at different levels, may be said to have the land more completely at its mercy than any agency which oscillates with the land. But even at a stationary level the sea can bring cliffs several hundred feet high within its direct influence, while cliffs more than a thousand feet high are often subjected to its undermining sway.

The sea can form the most abrupt inequalities along its coasts during intervals between sudden elevations and depressions; and a succession of such lines or tiers of inequalities, each consisting of vertical cliffs,³ caves, coves, creeks, bays, promontories, and straits, would certainly not constitute a plane of marine denudation. I believe that most of the inequalities of Great Britain (so far as they are not the result of dislocation, elevation, depression, or subsequent glacial action) are unequally upheaved sea-coasts; and that while rivers have increased these inequalities, rain and frost have tended to reduce them.

Rain and Frost incapable of producing Cliffs.—The subaërialists would seem to contradict themselves in making frost and rain at one time a demolisher of the cliffs of river-gorges, and at another time a former of escarpments remote from rivers. Excepting in a case of an easily-eroded under stratum already exposed by marine denudation,

¹ Admitting that the inequalities of sinking archipelagos were partly formed by ancient subaërial causes, the sea would have an undoubted claim in the case of archipelagos which are gradually rising. But the advocates of atmospheric denudation cannot *consistently* appeal to submarine inequalities, as according to their theory the sea ought to reduce these inequalities previously to the area they occupy becoming dry land.

² Quart. Journ. Geol. Soc., vol. xviii., p. 391. Among the Shetland Islands the sea is now giving rise to a series of the most abrupt inequalities. The coasts even of the mainland are singularly irregular and broken, being indented with innumerable arms of the sea, called *voes*, which penetrate into and intersect the interior parts of the island in such a manner that, in traversing it, a traveller cannot find himself, at any one point, farther than three miles from one of these voes, or from the open sea (Penny Cyclopædia, "Shetland"). Among the Faroe Islands, the land close to the sea consists in general of perpendicular rocks, from 1200 to 1800 feet in height (*ibid.*, "Faroe").

³ Fac-similes of the highest and steepest inland precipices may be seen on our present sea-coasts.

it is difficult to conceive of rain or frost originating a cliff. But suppose these agents to have succeeded in originating a cliff, they could not cause it to recede to any extent, because, in time, the fall of *débris* would put a stop to their progress, by accumulating so as to protect the under bed from farther decay. In the absence of a river to remove the *talus*, the cliff would become a slope. If, as the subaërialists admit, rivers are incapable of maintaining the vertical walls of their channels without a continual removal of the *débris*, how can rain, frost, or even springs, wear back an escarpment in the absence of an agent of sufficient power to carry away the fallen fragments or blocks.

It is not true that rain and frost are possessed of a regular or systematic undermining power. Suppose a soft and yielding bed under a hard stratum of rock. By the time the former is worn backwards so as to cause the latter to project, it ceases to be accessible to rain (and, in the absence of springs, to frost), unless it be situated on the windward side of a declivity. With regard to frost, it seems to be forgotten that it would be less likely to influence clay or shale than the overlying jointed sandstone or limestone rock. The subaërialists would likewise appear to forget that there are many cliffs and escarpments the bases of which do not consist of comparatively yielding materials.¹

But one of the most striking proofs of the inadequacy of atmospheric action to originate or alter the configuration of cliffs is to be found in the fact that many lines of cliff in limestone districts present little or no *débris* along their bases. Some of them appear as if the agent by which they were formed had swept away nearly all the traces of its undermining action, while under other cliffs we find deposits consisting of matter which could not have been derived from the rock above. Among the limestone cliffs, which present few indications of atmospheric waste, may be mentioned the more compact and mural cliffs of the Mendip Hills, in Somersetshire; of Derbyshire, especially near Matlock; of the Eglwyseg range, especially the upper terraces, near Llangollen; of the neighbourhood of Abergele and Cefn, North Wales; and of many parts of Craven, in Yorkshire.

Marine Débris under Cliffs—I believe that in most instances an attentive examination would show that the majority of the blocks and fragments found scattered under cliffs have not fallen since the last emergence of the land. They either exist in too great numbers, at too great a distance from the parent cliff, heaped up, apparently thrown back, or arranged in such a manner as to point to the laterally-operating and revulsive action of the sea. At Wharnccliffe, near Sheffield, and other parts of the West-Riding of Yorkshire, we may see the neighbourhood of Millstone-grit escarpments strewn with blocks, both angular and rounded, some of them isolated and at a considerable distance from any cliff, while others are arranged in

¹ The chalk escarpments above the terraces of upper greensand, in West Sussex, Hampshire, etc., furnish striking examples of the effects of an *unconditional* undermining agent.

rows or ridges, which can only be explained by reference to similar accumulations now thrown up by the sea on the coasts of Caithness, or among the Shetland Islands.

Rain incapable of abrading hard Rocks.—Mere rain, before it has assumed the shape of running water over incoherent materials so as to furnish it with solid artillery, is possessed of very little abrasive power on hard rocks. Rain comes from the atmosphere quite unprovided with the means of abrasion. Mr. Geikie,¹ admits that *uncharged* water, even when it dashes with the force of the waves and currents of the sea, is unable to abrade rocks. This accounts for many inland rocky projections and pillars retaining the forms with which they rose above the sea. In an article on the Brimham Rocks,² and in a paper read before the British Association at Birmingham last year, I showed that the Millstone-grit rocks of Yorkshire have in many instances not been abraded by rain or weathered by any kind of subaërial agency since the last emergence of the land. It is true that the windward side of certain kinds of sandstone and other rocks frequently present the appearance of recent atmospheric decay. But a little experience will enable one to distinguish between a chemically-corroded, frost-eaten, or rain-worn surface of rock, and a rock abraded by the sea. The former is rough, pitted, exfoliated, or fretted (as may be seen in the walls of our New Red Sandstone churches), without any determinate shape being produced; the latter (with the exception of limestone rocks chemically acted on by the sea) comparatively smooth with more or less of a regular form or continuous outline. In most places the Millstone-grit of Yorkshire and Derbyshire presents few or no signs of pluvial abrasion. On the contrary, the joints and crevices are often filled up (as at the Black or Stonnis rocks, near Matlock) with a deposit distinct from powdered grit, and resembling the drift of the neighbouring valley. Mr. Hull has found that the Millstone-grit projections of the Peak District retain their wave-worn forms; and if, at an elevation of about 2,000 feet above the sea, rain and frost have not been able to lower the rocky surface many inches since the close of the last submergence, would it not be rash to assign to them a power equivalent to the denudation of the surrounding area?

But rain has not only been powerless among the rocks of the north of England. Among the granitic tors of Dartmoor, what is commonly called *weathering* would appear to be very limited in its effects. In many instances one side of a tor would appear to have been stripped bare by a very powerful laterally-operating cause, whilst the blocks and fragments were scattered on the other side.

¹ Scenery of Scotland in connection with its Physical Geology. The descriptive powers of this accomplished geologist render him as worthy to be an illustrator of Playfair, as Playfair was of Hutton.

² GEOL. MAG., vol. ii., No. 4. After the reading of the paper at Birmingham, the President of the Section, Sir R. I. Murchison, expressed his entire concurrence with the author's views in reference to the sea-shore origin of the Brimham Rocks, and the resistance they have offered to the atmosphere. He likewise referred to the preservation of glacial-markings on rocks as a proof of limited atmospheric denudation.

Not one out of a hundred of these blocks could have *fallen* into the places they now occupy, and they must therefore have been carried by a strong current of water, unless it can be shown that they were dispersed by glacial action. In the south and south-east of England the newer sandstones would appear to be able to resist atmospheric denudation, as may be inferred from the present form of the stones composing so-called Druidical Circles or temples, such as Stonehenge.¹

Limited Atmospheric Denudation proved by Glacial markings.—It is admitted by all geologists that ice-marks on rocks, and moraines in valleys, have resisted atmospheric denudation to such an extent that many parts of Wales and Cumberland retain the same general features which they presented at the close of the Glacial-period. It is not necessary to show that very delicate scratches have been preserved in exposed situations. The mere fact that the smoothed and rounded surfaces of rocks, many of them of considerable extent, have been perpetuated, is a clear proof that they have not been subjected to any process worthy of the name of *weathering*. But if these rocky areas have retained their ice-worn shape, have we not reason to believe that neighbouring areas, and indeed all areas equally unsusceptible to atmospheric action, have likewise retained their ancient surface-configuration? The same consideration applies to moraines, which in most valleys have only been visibly interfered with, and that to very limited extent, by the action of streams. The subaërialist's answer to all this will probably be in the sublime language of Playfair: "It affords no presumption against the reality of the progress of decay that, in respect of man, it is too slow to be immediately perceived. The utmost portion of it to which our experience can extend is evanescent in comparison with the whole." But the Post-glacial period is so very much longer than the period of human experience, that the subaërial geologists may be fairly called upon to establish a good claim in favour of rain and frost during that period before proceeding to speculate on what may previously have occurred. The last few thousand years furnish sufficient exemplifications of the denuding power of the sea, and of its capacity to produce inequalities which are fac-similes of those found in inland districts.

Denuding Power of the Sea.—It would be difficult to exaggerate the battering, disentangling, undermining, excavating, upthrowing, and transporting power of the sea; and it is worthy of remark that while it is *mainly* a laterally-operating and undermining agent, the atmosphere is *mainly* a vertically-operating and degrading agent. The sea, therefore, has the first claim to be considered the cause of all phenomena which on any considerable scale show traces of having been produced by undermining. The subaërialists ought to assign a reason why they make a distinction between a cliff now washed by the waves and a precisely similar cliff a few miles inland, or a fac-simile of both at a greater distance from the sea.

¹ Though I have not lately had an opportunity of visiting the spot, I have no doubt that the rocky projections (including the Toadstone) and cliffs, near Tunbridge Wells, could be shown to be the work of the sea.

But with the subaërialists resemblance has little weight. They virtually ignore one of the fundamental principles of inductive reasoning—similar effects must be referred to similar causes. The inductive geologist is not required to explain the absence on any particular spot of certain minor indications¹ of the former presence of the sea, which may never have existed, or which may have gradually disappeared, while he can point out not only the strictest resemblance between new and old sea-coast rocks, but a peculiarity about the latter which the sea only could have formed. Among the peculiar shapes communicated by the sea may be mentioned the arched buttress, which may be found projecting from many inland cliffs. There is one near Torquay, on the right-hand side of the lower road leading to Teignmouth; another behind Mrs. Weatherhead's house at Brimham, near Harrogate; a third near the base of the Cefn cliff, near Denbigh, and many others which might be mentioned.

Remarks on the Cotswold Escarpment.—Sir Roderick Murchison has not only added a new geological world to that previously known, but he has evoked from the grave of bygone time a sea rolling through the "Straits of Malvern," dashing against its south-eastern Oolitic barrier, and scooping out its shores into "combes and bays, beautifully rounded."² In the neighbourhood of Cheltenham and Gloucester, the escarpment has been quarried at various periods, and it is difficult to ascertain which parts have retained their natural forms. The same difficulty applies to the *débris* under and on the sides of the escarpment. In the neighbourhood of Crickley there are some rocks which present no trace of their having ever been quarried, and which look very much like sea-coast rocks. Certain parts have been worn into holes, and between them the rock has been smoothed and rounded. To the south of Mr. Odell's house, above Crickley, the smooth part runs along in the form of a groove, or nearly horizontal depression.³

¹ Rounded pebbles are not a necessary indication of the former presence of the sea. The degree of roundness, or angularity, will depend on the nature of the stones, the distance they have rolled, and the length of time the area they occupy remains at a stationary level. In the Midland Counties, drift composed of rounded pebbles, and drift composed of angular flints, graduate into each other on the same horizon. There, also, drift, interstratified with beds of sand containing sea-shells, may be seen on the same horizon with and graduating into drift in which no sea-shells have yet been discovered.

² Buckman's Straits of Malvern.

³ See Lyell's Elements of Geology. In the two lines of cliff (Inferior Oolite) which have been more or less quarried above and beyond Leckhampton, one may see a very striking illustration of the way in which atmospheric action tends gradually to obliterate a precipice. The weathering, so far as it affects the compact rocks, is chiefly limited to parts that overhang, which are gradually falling down, one block or fragment from under another, thus tending to convert an overhanging into a vertical cliff. The next stage of the process is not connected with the cliff itself, but consists of streams of oolitic fragments from the loose incoherent bed on its upper surface. These streams give rise to ridge-like buttresses in front of the cliff, the tendency being to conceal the cliff under a slope of *débris*. In this way, in all probability, a great part of the ancient sea-wall of the Cotswolds has been converted into a grass-covered slope, and quarrying operations have in some places been equivalent to

Limited Atmospheric Denudation in the Chalk Districts.—The influence of rain in the Chalk as well as Oolitic districts of England, must be very considerable. But it acts more as a solvent than transporting agent. The matter dissolved is re-deposited.¹ It becomes covered with grass, and not one-hundredth part of it ever finds its way beyond the nearest valley or depression. That rain has not altered the general contour of the Chalk districts since their rise above the sea, can be proved by the fact that thousands of raised beaches, many of them only a few feet in height, may be found in Wiltshire, Dorset, and other counties. These beaches generally conform in inclination to the surface of the neighbouring ground. In valleys they often descend very near to the bottom, thus proving that these valleys have not been excavated since the beaches were formed. One of the most remarkable assemblages of these terraces may be seen undulating along the side of a valley to the east of Mere. On the south-eastern escarpment of the vale of Blackmore they may be seen curving round headlands in successive tiers. *These terraces are so intimately associated with the valleys, combes, and escarpments, as to render it evident that all have had a common origin.*

On the Denudation of the Weald.—I think it cannot be doubted that the Weald district of Sussex and Kent has undergone some complicated revolutions since the escarpments acquired their general outline;² and to these revolutions we may partly attribute the obliteration of certain particular traces of the former action of the sea. But that the sea has been there, and that the escarpments are old sea-coasts, cannot be doubted by any one who does not ignore the validity of analogical induction. If we begin with what the sea is now doing at Beachy Head, and then follow the windings of the inland cliffs in a north-westerly direction, we cannot resist the conclusion that they have been shaped by the sea. Beachy Head, and its accompanying combe, may be regarded as a living monument of the denuding power of the waves—the headlands and combes, which stretch into the interior, as dead monuments; but though dead, they yet speak, in language that cannot be misunderstood by any mind not deaf to the voice of analogy. A great part of the escarpment of the South Downs (to which I shall at present confine attention) consists of a succession of headlands, bays, and combes. The latter point most unequivocally to the peculiar action of the sea. Towards the western boundary of the Weald district many of them have been *excavated in the chalk quite irrespectively of any relation between soft or*

laying bare the original sea-worn rocks. But in all this we see a tendency the reverse of that ascribed to the atmosphere by subaërialists; for, instead of rendering more abrupt the inequalities of the earth's surface, it operates in the contrary direction. Among the Cotswold valleys, springs have given rise to landslips (Mr. Witchell, *Quart. Journ. Geol. Soc.*, vol. xx., Nov., 1864); but these landslips can never tend to increase, and far less to originate, the continuous and smooth regularity of a line of escarpment.

¹ Sometimes the re-deposited Chalk-rubble becomes compact enough to be mistaken for Chalk itself. See Mr. W. Whitaker's paper in *Quart. Journ. Geol. Soc.*, vol. xxi., 1865.

² See Sir R. I. Murchison's elaborate paper, "On the Drifts of the South-East of England," in *Quart. Journ. Geol. Soc.*, vol. vii., 1851.

hard materials. A hollow excavated by rain-torrents would assume more or less of the V form, and would necessarily shallow out towards the summit of the escarpment. But in many of these combes the innermost part of the surrounding cliff is the steepest, showing that they must have been formed by an inwardly-directed cause. They frequently display a geometrical regularity, combined with other unmistakeable indications, that they were literally scooped out by a sweeping, undermining, and gyratory action. These semi-cup-shaped hollows are not confined to the escarpment. They exist, though in smaller numbers, on the south side of the Downs. About two miles, on the left-hand side of the road leading from Brighton to Lewes, a very deep and strikingcombe gradually opens to the view of the traveller, which is as much a sea-cove as if it were still washed by the spray. There is another called Kingley Bottom, in the neighbourhood of Chichester. In forming an opinion relative to the origin of combes, it is advisable to retire to some distance, so that their entire outline and connection with neighbouring phenomena may be embraced at one view.¹

In a future article I intend to consider the indications presented by river-channels and valleys, of the limited extent of *fluvial* denudation in England and Wales. From what has been already said I think it must follow that rain and frost can only be justly regarded as *supplementing* the denudation effected by the sea; that their capacity to lower the earth's surface is comparatively small, unless immediately assisted by streams of sufficient transporting power; that the sea, by its laterally-excavating agency, and by uniting in itself, at the same time and on the same spot, a power of detaching and removing, can alone prove equivalent to the production of such a series of escarpments, cliffs, mural precipices, rocky pillars, terraces, headlands, and combes, as those composing the more abrupt inequalities of the surface of the earth.

¹ I think it is difficult to conceive of an explanation more perfect, simple, harmonious, and convincing than Sir Charles Lyell's marine theory of the denudation of the Weald. That the same cannot be said of the atmospheric theory will, I think, appear from the following extracts:—"The rate at which the escarpment will be worn back will depend on the rate at which the *river* deepens its valley. . . . The *excavating power* of the stream in the longitudinal valley will depend on that of the transverse valley, and if the sea-level remains constant, the transverse stream will go on deepening its bed and lessening its excavating power, until at last it ceases to have any at all. A slight elevation of the land would once more give the transverse stream an excavating power, which in time would be communicated to the longitudinal streams. . . . It must not be inferred, however, that we consider escarpments to be *river-cliffs*. The longitudinal streams, though running parallel to these escarpments, do not run immediately below them, but often, as with the Medway itself, at a considerable distance. No *river-gravel* in this area is ever found on the face of the escarpment, nor can we discover thereon any traces whatever of river-action" (Foster and Topley, Quart. Journ. Geol. Soc., vol. xxi., No. 84, 1865, pp. 471, 473). I do not think that Dr. Foster and Mr. Topley have succeeded in showing that the gravel-terraces in the basin of the Medway (containing Tertiary pebbles and Greyweather fragments, and dipping lower than the inclination of the river) are of fluvial origin, or that a vertical extent of 300 feet has been scooped out by rain and rivers; but admitting a considerable amount of denudation along the courses of rivers, the bays and combes of the great Chalk escarpments would still form a distinct class of phenomena, and require a separate explanation.