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cluding the final excavations of the valleys and the translation of enormous masses of broken materials into the adjacent low countries of France.

In conclusion, it is suggested, that the dispersion of the far-travelle Alpine blocks is a very ancient phænomenon in reference to the historic æra, and must have been coeval with the spread of the northern or Scandinavian erratics, which it has been demonstrated was accomplished chiefly by floating ice, at a time when large portions of the Continent and of the British Isles were under the sea. Viewing it therefore as a subaqueous phænomenon, Sir Roderick is of opinion that the transport of the Alpine blocks to the Jura falls strictly within the dominion of the geologist who treats of far bygone events, and cannot be exclusively reasoned upon by the meteorologist, who invokes a long series of years of sunless and moist summers to account for the production of gigantic glaciers upon land under present terrestrial conditions. This last hypothesis is, it is shown, at variance even with the physical phænomena in and around the Alps, whilst it is in entire antagonism to the much grander and clearly established distribution of the erratics of the North during the glacial period. The effect in each case is commensurate with the cause. The Scandinavian chain, from whence the blocks of northern Europe radiated, is of many times larger area than the Alps, and hence its blocks have spread over a much greater space. All the chief difficulties of the problem vanish when it is admitted, that enormous changes of the level of the land in relation to the waters have taken place since the distribution of large erratics; the great northern glacial continent having subsided, and the bottom of the sea further south having been elevated into dry land, whilst the Alps and Jura, formerly at lower levels, have been considerably and irregularly raised.

JUNE 13, 1849.

The following communication was read :—

On the Valley of the ENGLISH CHANNEL.

By ROBERT A. C. AUSTEN, Esq., F.R.S., F.G.S.

THE valley of the English Channel presents two points of geological interest which may be considered as new—the one relating to the nature of its bed, as a guide to the conditions of origin of our older marine formations; the other to its age as an area of depression. For the former purpose the area may appear to be too limited; the extent of surface, however, from the Straits of Dover to the outward line of soundings, is more than equal to the whole of the South of England from the Land's End to the Wash, an area which comprises the whole series of English geological formations. Having had frequent opportunities of cruising about this Channel, I have been enabled, at one time or another, to visit nearly every portion of its shores on either side, and to examine its bed with the dredge and sounding-lead.

The English Channel occupies a valley bounded by two parallel systems of elevation. The line of $49^{\circ} 58'$, commencing from the east coast of France, near Dieppe, and which passes a little south of the Lizard Point, is as long a straight line as can be drawn within it. A physical area may have a general form and outline, which may not at all represent the direction of the forces by which it has been produced. The movements by which relief has been given to portions of the earth's crust are seldom continuously linear; the lines themselves, taken separately, are constantly seen to diminish in amount in opposite directions, and to be arranged *en échelon*. Such is the case along the South of England; the accidents of the strata run east and west; such is also the case in Lower Normandy and Brittany; this is their true direction as areas of elevation, of which the Channel is the intervening depression: a central line along this area would have a general direction from E.N.E. to W.S.W.; in this instance therefore the geological and geographical features are not parallel. Like instances may be traced wherever long lines of elevation have been produced. A central line from the Straits of Dover across the German and North Seas would equally mislead us there; the true physical features of that depression are the straight north and south line of coast along the departments of the Somme and the Pas de Calais, the rocky masses of the Varne and the Ridge rising with steep sides from deep water; the same line, if prolonged, will pass in front of the Goodwin Sand, along a trough having in places a depth of forty fathoms, and will define the coast of England from Orford Ness to Yarmouth. The direction of the troughs having thirty fathoms water are also parallel with this line.

A series of transverse sections from the coast of England to that of France, drawn north and south, will show that the Channel area is one of depression. In all such sections the sedimentary strata on either side have an inward dip. This position of all the secondary beds is familiar to most geologists, and hardly requires illustration. The east and west strike of the older strata to the west of the secondary formations is indicated on the map, and the like direction obtains throughout the palæozoic groups of Brittany and Lower Normandy. The lower valley of the Seine may probably be connected with the later disturbances of the Channel valley; the lines of deepest water are along its south side, and will be shown to correspond with its original greatest depression: it is a common character of linear undulations of the earth's crust, that they break into fractures or faults at their extremities. The general direction of the valley of the Seine from Havre to Rouen is due east and west. The remarkable cliffs which occur at places along this valley have been described by Sir C. Lyell; they can hardly have been produced by the present river, nor is there any accumulation of shingle along its course to account for its occupation by the sea. The features are difficult of explanation, but it suggested itself to me when I last saw them, that they were the result of a fault traversing a mass of elevated strata, by which portions had been let down; a depression of the strata on one side corresponding with the vertical wall of the cliff

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on the other, according to what is to be observed in every valley of fracture. Whether this supposition respecting the valley of the Seine be correct or not, we at least meet with features on our own coast which make it probable. Thus, for instance, the vertical cliffs of the Watcombe fault have certainly been produced since the district existed in its present condition of dry land: the direction of this break is east and west. Again, Torbay, which is a portion of an east and west depression, has its recent age defined by the marine beds resting on the lines of elevation which bound it.

So much has been written respecting the quantity of matter carried down annually to the sea by rivers, that many have been led to regard it as the main source of submarine sediment: the English Channel is perhaps as good an instance as could be taken of the fallacy of such a supposition. The Seine is the only river of any magnitude which discharges into it. Now rivers carry forward matter in two ways—by holding it in suspension, and by drifting it along their beds. The quantity of suspended matter in the estuary portion of such a river as the Seine is occasionally considerable; but it is an inconsiderable portion of this only which finds its way out to sea at each ebb; whilst the sands which are subject to the drifting process accumulate in well-defined forms about its mouth. If we take the whole extent of the dry land drained by the rivers running into the English Channel, together with its mean elevation, we shall see that the whole of this mass, if removed down to the sea level, would be insufficient to fill up that depression. We may feel assured that the joint action of all the Channel rivers contributes but very little towards its accumulations. On comparing some old charts of the mouth of the Thames with the most recent ones, the principal feature in which they seemed to differ, was the present outward extension of the shoals and banks.

Sir H. De la Beche has treated of the action of the sea along its coast-line in full detail; it is this line which furnishes the great mass of materials we find strewed over its beds. To show that it is an adequate source, we have only to bear in mind, that in the instance of the area of the English Channel, if we follow its irregularities, we have an outline of not less than 1200 to 1300 miles, together with a great vertical range of tide. The removal of solid materials from the cliffs is not, however, so constant as some persons might imagine, not even on parts of the coast with yielding strata. There are very few places on our own side of the Channel, or on that of France, at which the sea at high-water regularly reaches the bases of the cliffs, and where it does so, from the hardness of the rocks, the rate of destruction is the slowest. As a general rule, it is only with high tides, concurrently with gales of wind setting on a given line of coast, that we see any considerable masses undermined and thrown down. If this be the case in such a sea as the Channel, where the power of the breakers is exhibited on so vast a scale, it teaches us to require enormous lapses of time for the production of sedimentary strata of the thickness of some of those for which the geologist has to account.

But though the sea for months together, and in places even for

whole years, may not acquire any fresh spoil, yet there are very few hours when its waters are unemployed, in abrading and fashioning the materials already acquired. The zone of depth along which this process takes place is comparatively narrow; much of the gravel and shingle seems to travel up and down from the exposed beach to slight depths below; accumulation of sand may go on for a time, but a heavier sea soon disturbs this arrangement. The materials of long lines of beach may also be entirely swept away, and carried down into deeper water; in this way I have seen, at one time or another, nearly every portion of our south coast in the condition of bare rock without sand or shingle: the sea-bed has no permanent character over the first few fathoms of its depth. Bars, sand- and shingle-banks, belong to this zone, and these are likewise all subject to change of form and to removal, but they speedily collect again; and it is worthy of notice, as bearing on conditions to be observed at greater depths, that every part of this zone preserves its distinct character—the banks which form again after a sweeping of the marginal zone are always of the same description as were collected there before.

The materials composing shingle beaches clearly show that the ordinary action of the sea is at right angles to the coast-line, as they will I think invariably be found to have been derived from the contiguous cliffs. The line of flint shingle along the French coast, at the eastern end of the Channel, is exactly conterminous with the chalk cliffs, and like facts may be seen carried out in the minutest detail along our own western shores, at places where limestone, trap, or granitic rocks occur. In this case the action is simply that of the tide. With this, however, there is an occasional tendency for the shingle to travel onwards in a given direction. This movement has nothing whatever to do with the action of the tide; for as this in every channel makes in the offing before it does in-shore, its force, even if it was equal to such a process, is exerted at right angles, and not parallel with the coast. Along our own southern coasts the movement of the shingle is from west to east, and on the opposite coast of France it is the same. Wherever the direction of the wind coincides with the line of coast, an onward movement is imparted to the marginal line of water, and this moves the shingle along with it; thus the flint shingle from the chalk cliffs of the department of the Somme travels south, towards the mouth of the Seine, under the influence of north and north-east winds. The easterly movement of the shingle along our own coast may be easily observed; and in order to show that the assumed cause is a sufficient one, it is only necessary to establish the fact, that along the Channel there is prevalence of winds setting in the requisite direction. From the position of the Channel, any winds between north and south passing through the west, will act obliquely on the coast on one side or the other; and these up-channel winds are known greatly to preponderate over those which pass from north to south through the east. There is a peculiarity which has been observed with respect to the winds west of south, that they blow with most violence at the times of high tides, and particularly that they come in at the first of the

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flood. We have taken the line from Dieppe westward as the one which indicates the line of the Channel: it appears that at this place, according to a register kept by M. de Bréauté, extending over twelve years, that the direction of the wind was 135 days between south and west, and 94 days between west and north, or 229 days out of the 365 during which the materials along some part or other of the Channel might have an eastward movement. There are no observations to guide us as to the rate at which the marginal line of shingle is made to travel forwards in this manner, but the distance at which it occurs from its point of origin is occasionally very great. On the Chesil beach may be collected pebbles of limestone, greenstone, trap, and old red sandstone, derived from the older rocks of South Devon.

Much of the irregularity of the present outline of the Channel, where it is independent of other causes, is due to the nature of the beds which occur along it. Passing over minor examples, good illustrations of this are to be seen in the deep bay between Berryhead and Portland, an interval which corresponds with that of certain yielding sands and marls; as also in the recess along the coast of Calvados.

Fig. 1.

Good illustrations of the process of cutting back along the marginal sea zone, and of the depth to which this action is carried in the case of hard compact beds, can be seen about the Channel Islands. Sections of some of these groups of rocks show that they rise off platforms, which have an uniform depth from the surface, and that from their edges there is a rapid fall to the general sea-bed below. The platform to the north of Ortach and Burhou comes nearly to the surface, so that the projecting points are uncovered: when the wind is fresh, the sea breaks violently on this platform; the fall is immediate into 18 fathoms water. Time being allowed, such a group as that of the Caskets (fig. 1) would ultimately disappear, and be reduced to a submarine shoal. Some of the actual shoals of these seas have probably at some former time existed as small groups of rocks;—that of the Pomier, two miles north-east of the Caskets, is apparently a good instance of a mass of rock reduced to its utmost with relation to the present sea-level. This shoal is a table-rock rising abruptly out of 170 feet water to within 36 feet of the surface, covered at top with patches of coarse sand and shingle, and, as usual, with a vast growth of sea-weed. Viewed in this way, the Channel Islands group, taken collectively, will present instances of masses in every stage of abrasion; and judging from the soundings round the several shoals, rocks, and islands, the depths to which such masses may be reduced will range down to between 40 and 50 feet at the very utmost.

This process, by which masses of solid materials can be planed off parallel with the sea-level, is due to the action of wind or surface

waves, inasmuch as in calm weather, when I have had opportunities of passing over some of these platforms, I have felt convinced that the only other agent, namely the tidal streams, had not sufficient velocity to exercise any mechanical power whatever.

With the present tendencies of geological speculations, it is of some interest to ascertain, if possible, the depths at which the sea-bed is liable to disturbance : on the determination depends the knowledge we may some day acquire of the conditions of accumulation, which the older stratified deposits exhibit.

Whenever a stream of water flows over a rocky or uneven bed, the interruption which the lower stratum experiences is indicated by a wave-disturbance at the surface : of this every running stream is a ready illustration. In parts of our seas, surfaces of broken water, known as races and overfalls, are constantly met with, and may even be observed from the land. The race of Portland occurs over a ledge of rock which runs out from the south extremity of the Bill ; the east and west sides of this ledge are steep : the case of the St. Alban's race is precisely similar. The surface-disturbance at these places is to be observed in the calmest weather, and in drifting over them at such times, the passage from smooth into broken water is immediate. In like manner the race of Barfleur, more formidable than either of the preceding, occurs over a ledge of rocks, running out from the headland of that name. As in all cases, the greatest disturbance, apart from the action of the wind, takes place at new and full moon, when the tide-stream flows with a velocity of from eight to nine miles an hour ; showing that the races are due to the arrest of the tidal stream by these ledges. The Boulogne fishermen sink their nets athwart the deeps at the east end of the Channel ; should the weather become too rough to allow them to get them in, they are sure to recover them on the coast between Cape Gris Nez and Calais, whither the flood tide drifts them in. These and many like cases to be collected along the coast show that the tidal movement extends to the whole depth of water. These cases are to be observed along the marginal zone, and some persons have drawn a distinction between the movement of the tide in deep as compared with shallow water. A broken or rippled surface is met with at certain places in the open part of the Channel, as along the entrance from the Atlantic : these appearances are in every instance connected with uneven ground below. The ripples over Jones's Bank are very considerable ; the shoalest part of this bank has 40 fathoms, with a surrounding sea-bed at 70. A like surface disturbance is constant along the edge of the Nymph Bank, which has a minimum depth of 45 fathoms. The Little Sole Bank has like indications even in the calmest weather : over the summits of this group there is a depth of 60 fathoms, with 100 fathoms at short distances around. In all these instances the place and extent of the ripples depend on the direction and strength of the tide : the slopes of all these banks are steep ; the process is the same as with the shallower ledges, and shows, according to what theory requires, that the tidal stream movement extends to the whole depth of the Channel.

In the earliest accounts we have of the Channel and its dangers, we

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find notices of "races" as occurring at the very spots at which we now meet with them; tending to show, that whereas the action of breakers along the coast-line has, within comparatively short times, produced great changes, by the removal of thick masses of strata, yet that no corresponding abrasion has been effected over these ledges under depths of not more than 17 fathoms.

The difference of velocity between the upper and lower strata of water put in motion by the tidal stream, as in every current, is less over the bed than at the surface; but the surface velocity, even in parts of the Channel where it is greatest, cannot be estimated at more than from five to six miles an hour, so that its movement over the ground or as a mechanical agent is very trifling.

The two actions, first, that of wind-waves when they break in shallow water; and, secondly, that of the tidal stream, are alone engaged in fashioning and arranging the materials of the sea-bed*. The principal action of the wind-waves, as exercised on the land, is confined to a zone extending from one range of the tide to the other. In a zone below this, a certain amount of shifting, and consequent abrasion of the materials, may take place; the breadth of this zone will depend on the nature of the coast, whether shelving or otherwise; for with the deepening of the bed beyond the line of wave-undulation this direct littoral action ceases. It would be difficult to lay down the precise zone of depth along which the action of wind-waves may be considered to cease; but as in high waves of this order, at a depth equal to one-third of a wave-length, the range of oscillation of the particles is only one-thirtieth of that of the particles on the surface, the depth to which water can be affected in any part of the Channel cannot be very great. Where the action of the wind-waves ceases, the permanent influence of the tide-stream begins; and as this extends to every depth and portion of the Channel, it has for its limits, as an agent of accumulation, only the length of time during which particles of matter may remain in suspension: in short, in every sea the power of abrasion is confined to a marginal zone, and that of dispersion, though with a wider range, extends only to the minuter particles of matter.

I am aware that a very different view of the movement of the water of the Channel has recently been given, and that in support of it the areas of discoloured water over certain banks at great depths, as well

* It is only proper to state, that M. Emey, who has treated the subject of the movement of the waters of the sea in great detail, so far as bars, sand- and shingle-banks, and even erratic blocks are concerned, attributes them to the action of what he terms his ground wave (*flot de fond*); that is, to the motion of the water near the bottom towards the shore. (*Mouvement des Ondes*, p. 51.) M. Emey adduces, as practical tests of his theory, first, that when bathing in the sea, at a short distance from the shore, and with the body upright, we are lifted up by the surface-undulation, whilst at the same time the horizontal passage of the ground wave to the beach is felt by the legs. Again, if two pieces of cork, one weighted so as just to sink to the bottom, be thrown into the sea, the floating piece will keep its distance from the shore, and only follow the surface-undulation, whilst the weighted one will be rolled along the bed, and thrown up on the beach.

as rippled surfaces, have been used as proofs that to such depths the sea-bed may be disturbed by gales of wind. It may be asked, on the other hand, how is it, if the oscillation of wind-waves at certain places can reach down to the bottom so as to disturb the bed, they do not do so equally over those wide areas where the sea has an uniform depth of that amount? Against this too may be adduced the direct and important testimony of those persons who have worked from the diving-apparatus, that with a fresh breeze and considerable surface-movement no disturbance was ever to be experienced below.

Discoloration is at all times to be noticed over the banks in question, even when the sea is perfectly quiescent, as far as wind-waves are concerned: we know from soundings that these places are within the range of fine sedimentary deposits; and with respect to matter falling through water slowly, we know, that at the distance of these banks from any land, it will be principally in the lower strata of water that the suspended matter will occur. The tidal current which has carried a column of water of 500 feet over a considerable space, on meeting one of these banks, is suddenly reduced to 300 feet. The effect of this is to produce that peculiar form of disturbance which resembles a boiling-up and flowing-off of the surface, and which is so characteristic of shoal disturbance in perfectly calm weather. By this process lower strata of water are forced up, and bring with them the finer particles which had reached those depths. The change in the colour of the water at these places is however very slight, being from blue to a pale disturbed green, and the quantity of suspended solid matter by which it is produced is exceedingly small.

§ 1. *Distribution of Materials and Map of the Channel.*

As the coast-line is the only source whence the materials which compose the sea-bed are derived, and as the movement of the water, at inconsiderable depths even in advance of this line, is totally insufficient to produce the forms and conditions of the materials which occur there—the same also with respect to all subsequent outward zones of depth—the mass forming the sea-bed at every place must have travelled outwards. The coarser materials of several areas can be identified with the rocks on the coast from which they have been derived: thus granite and tin-stone shingle occur round the Land's End and Scilly Islands, whilst the syenites and allied rocks of the Channel Islands group take a wide range on that side of the Channel. In addition to such instances as these, we have also the evidence from the shell-sand beds, which constitute such extensive areas in our Channel, and apparently in all seas; few if any of the shells whose fragments are so abundant over these areas belong to them, or have lived there: sharp sands, and such as can drift, are especially poor in submarine life, nor do we meet with any weed. The great proportion of these shelly materials has come from a contiguous higher zone; but mixed with these, and in considerable abundance, are the pounded fragments of the commonest littoral species; thus the *Haliotis tuberculata*, one of the peculiarities of the Brittany and Channel

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Island coast fauna, and which lives just below ordinary low-water, has its fragments carried out fifty miles from the nearest coast; with it, and abundantly, is *Patella vulgata*.

The general character of the sea-bed of the Channel is, that its component materials become finer as the distance from the coast-line and the depth of water increase. This relation of sea-bed to depth was long since noticed. In Lord Anson's 'Voyage' (1740-47) he states that he has tried soundings more frequently, and in greater depths, and with more attention than had been done before, and from the remarks occasionally made on their value, and the occasions on which they were taken, he seems to have relied on them when navigating unknown seas, as a sure indication of his distance from some land. His observations give

80—60 fathoms fine sands, mud and ooze,

60—40 „ sands with broken shells,

40—12 „ coarse sands, pebbles and small stones,

and appear generally to have been taken along lines of open coast.

These numbers are not here produced as the rule or scale of depths regulating the distribution of materials by the sea. But if we take lines of soundings seaward, we shall invariably find a progressive change as we advance from deep water and open sea, from mud to mud with sand, next sands which increase in coarseness; small subangular pebbles; and across beds of water-worn materials, described as of the sizes of peas, coffee-berries, beans, almonds, pigeons' eggs, &c., till we finally reach the marginal banks of gravel and shingle; so that the term soundings is well made to designate both the depth of water and the nature of the sea-bed—the condition of the one being the result of the action of the other. The bearing of this relation of sea-bed to depth, to what forms the greater part of the detail of pure geology, is obvious: the vast series of sedimentary deposits, nearly the whole of our areas of dry land, are the aggregates of the soundings of ancient seas, presented to us in their progress through long periods of time*.

Among the more interesting points connected with the subject of the older sedimentary deposits, are those known in descriptive geology as—§ 1. Mineral character; § 2. Stratification; and § 3. Sequence of deposits.

§ 1. Mineral character is simply the result of the process of distribution by a body of water in constant motion—an operation, the precise counterpart of what is employed in various economical processes whereby mixed materials are separated, arranged and carried forward according to size and specific gravity. The divisions on the Map of

* I had long since entertained the notion that geological speculations might be greatly assisted by a careful study of any given area of sea-bed (Geol. Trans. vi. p. 454), and the notes from which this paper has been drawn up date back many years; but I am ashamed to confess that at the time it was communicated to the Society I had not read Mr. Darwin's Observations on South America: the whole work is a rich store of facts and correct inferences, and as bearing on the observations contained in this part of my paper, I would refer to Mr. Darwin's first three chapters, and more especially to the first.—December 1849.

the bed of the Channel are as distinct as any which we establish on geological maps between portions of formations which differ mineralogically,—as between the ~~argillaceous~~ and the oolitic sands which surmount them. The mud ~~forming~~ ^{forming} in ninety fathom water in the central trough of the Channel are geological marls and clays; the only difference they present from one place to another being dependent on the source whence the constituent particles have been derived. On the English and Irish side of this deep area, the sea-bed is a black impalpable mud, the shells of *Dentalium* apparently very abundant, an accumulation such as in former seas has produced beds of lias, gault, or London clay. On the French side of the basin are white and yellow marly beds of like tenacity, and at the same depths, being apparently the finer particles derived from the feldspathic rocks, which the rough seas of that angle of the Channel are unceasingly abrading. Under the deeper water of this central area we obtain soundings of a mixed mud and finest sand, the exact counterparts of beds we are familiar with in connexion with the argillaceous portions of every formation, and which here seem to serve as a connecting group between areas of totally distinct mineralogical characters.

An area which would contrast strongly with that of mud and ooze, could the bed of the Channel be raised into dry land, would be that of the clean siliceous sands, which would present a continuous extent of surface equal to two-thirds of the South of England. The formations with which such areas as these suggest comparisons, are that of Bagshot, or the lower greensands, considered in horizontal, not vertical extent.

Higher up the Channel are accumulations of sand with coarse sub-angular and rounded shingle, and largely mixed with this mass are the dead shells of the larger mollusca. There exist then, even in our own Channel, large areas over which materials of distinct mineralogical character are being separately accumulated; and in this respect there must have been a complete identity in the operations of former times.

Upon this point a difficulty has been felt by many geologists, who being well-aware of the additions constantly being made to the materials of the sea-bed, have thought it strange that soundings should present such remarkable constancy as to depth. M. Brongniart and others have gone so far, on this ground alone, as to draw a line between the operations of present as compared with former seas, and to deny to the present seas the power of producing deposits which can in any way be compared with those of geological periods. "Wherever," he says, "we have been able to ascertain the nature of the sea-bed of any of the actual seas at distant times, we find it to have been the same as it is now." Such is no doubt the case, though the illustrations cited by M. Brongniart are not altogether unexceptionable. It may safely be admitted that in our own seas there is no variation in the depth or quality of the sea-bed. The soundings now obtained agree with those laid down by Captain White; and the French surveyors of their western coasts confirm the same fact, in the direct observations taken for the verification of their charts. The places are very few where fishermen and pilots seem to think that any vertical

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accumulation or depression is taking place—any at least of a permanent character; and the reason of it is, that accumulation does not take place in this direction, but according to a process of outward distribution already alluded to. The materials of the sea-bed are in equilibrium with the moving power—the water at every place; the sediment of the ninety fathoms' depths could not remain between the mainland and Alderney for a single tide. Should any extraordinary action of the sea, such as that of a continued gale and high tides, produce along the submarginal zone a deeper disturbance than usual, the common effect is, that an accumulation of sea-bed is brought up from such deeper zone and thrown down on a shallower one: such a disturbance is not unusual, but the effect is not permanent; such materials being within the ordinary moving power of the sea in their new place, are soon carried away*. In the course of last summer I received some curious information respecting the formation of such temporary banks, from men engaged in the oyster fisheries on the French coasts. It seems that with a continued gale from the west, large areas of their dredging-grounds become at times completely covered up by beds of fine marly sand, such as occurs in the offing, and which becomes so compact and hard, that the dredge and sounding-lead make no impression on it: with the return of the sea to its usual condition, a few tides suffice to remove these accumulations.

§ 2. The large areas of uniform sea-bed, wherever there are long lines of uniform depth, are the obvious results of the laws which we have seen determine the quality and distribution of submarine materials. The termination of deposits of a well-defined character, such as the shell-gravel beds or those of clean sand, is often by slopes more or less steep; the two conditions taken together point clearly to the mode of accumulation. If we take the great sand plain, the particles brought down are drifted on over the horizontal surface, till they reach the edge of that quality of sea-bed or soundings; they then fall over the slope, and are beyond the reach of the combined action which has moved them along: it is only therefore in advance of each area of definite character that the materials belonging to it are ultimately deposited. It is this process which has produced that diagonal arrangement to be observed in so many deposits from the crag to old red sandstone. The red crag shows us instances of the coarse-ground sea-zone, the coralline crag of the region of shell-sand. A modification of this arrangement is presented by these two groups; in the red crag we meet with a structure which may be called torrential, by an application of M. Necker's term; with this we meet with constant instances of the partial removal of the upper portions of subordinate beds, subsequent to their accumulation: with the coral-

* The Schöle bank rises out of twenty to twenty-five fathoms water. In 1824, Captain M. White describes it as having steep sides and covered with only seven and a half feet of water. He surveyed it again in 1831, and found it much increased in size, with regular soundings about it. In 1833 the French surveyors found it much in the condition in which Captain White first described it. Such an instance as this indicates only rapid accumulation for a few years, followed by as rapid removal. There are many cases of like character, but they all belong to the submarginal zone at most, and to this very rocky part of the Channel sea-bed.

line crag there are seldom continuous beds of great extent, but a simple arrangement of diagonal laminae. Portions of the lower greensand present us with instances where the component strata are carried on for great distances, with their upper and lower planes strictly parallel, and with cross structure throughout in the same direction: in these cases the angle of laminae is uniformly higher than in the more confused and shorter bedding. The angle of rest for drifted sand will be high in proportion to the stillness of the water into which the sand-bed is extending itself; so that in these several well-known characters of deposits we seem to have a guide as to the condition of depth and directions of moving power over these old sea-beds.

In the torrential structure of river deposits the direction of the bedding is with the stream. In marine beds we constantly meet with it, as in the pleistocene drift and crag deposits, setting in opposite directions in consecutive beds, as contradistinguished from those setting constantly in a given direction. In the first case the materials are mostly mixed and coarse—laminated sands, between horizontal gravel beds; in the latter the materials are finer, and indicate the undisturbed process of constant outward accumulation. In the confused stratification alluded to, and in the thin layer of sand which is so constantly interposed between masses with opposite diagonal bedding, we have an arrangement which may be due to tidal influence. If we take a portion of the east end of the Channel, and where the tidal movement of the water is well known, we find that the flood at the syzygies runs 4^h 40', at the ebb 6^h 50'; that the minimum velocity, which depends on the height of the tide, is at most half of the maximum velocity, or that with high tides the flood is more rapid than the ebb. Making allowance for these different forces and directions, the confused arrangement to be observed in these deposits becomes intelligible.

In the deeper sea sand beds, which travel outwards by additions in front, the formation of a single stratum may be continued until the effect of its accumulation is such on the body of water entering such sea as to admit of a new bed being formed above it; so that the interval of time between one stratum and another in this zone may be very great. The dimensions of strata of this kind are greater than those presenting other arrangements. Diagonal beds of great thickness may be noticed in the crag deposits, and I have seen them upwards of twenty feet thick in the lower greensand, a thickness which would correspond with a sudden increase in soundings of from three to four fathoms.

A very common form of arrangement is where the lines of deposition are parallel with those of bedding; in this case we seem to have no guide as to zone of depth. We meet with it in the so-called raised beaches, which are marginal sea-beds, ranging down to 10–15 fathoms. The stratification of the beds at Branton is most distinct and regular. This mass is the shallow water accumulation of a sheltered bay; but we may trace the same arrangement in beds which were evidently deep and wide sea deposits, such as those of the white chalk, or where like masses have been altered into crystalline limestones.

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But even here, in proportion as one part of the formation affords indications of greater depth than the rest, as between the chalk marl and upper chalk, so stratification becomes less distinctly marked: the deep sea mud-beds, such as the old slate rocks in their original condition, the London and other great clay groups, are not stratified, but only laminated. Lines of stratification are obviously due to an interference from time to time in the process of horizontal deposition, but as to the cause in this particular case I am unable to offer any conjecture, nor can I meet with one.

In a sea where accumulation goes on by an outward distribution of materials, there will be an obvious tendency to form banks and terraces. The termination of the sands over the mud-bottoms are of this character, and such are also the accumulations of a higher zone which surround the deep pits between the coasts of France and those of the south-west of England.

In order to realize the geological bearings of such processes as we have here considered, we have only to imagine a long valley formed by subsidence or otherwise, to be so placed that the waters of an adjacent sea should flow in and occupy it to the depth of 100 fathoms. The nature of its action would be as follows: The products of wave destruction along the coast-line would be carried outwards and arranged in zones according to states of comminution and specific gravities; simultaneous accumulation of all these various conditions of detritus would take place, and if followed from the coast-line outwards would present a gradual change from one mineral character to another. By lapse of time and process of accumulation, the bed of such an area would be raised, the depth of water diminished; sands would then be carried out where silt and ooze had been deposited at first, and beds of coarse materials would occupy the zones of finer sands. The accumulations from either side might thus be brought up, till a large portion of the area would have the kind of sea-bed known as coarse-ground. When the higher portions of such channel no longer offered any places for the finer sediment, it would travel outwards, or towards the opening and lower portion of such depression; and the whole of such an area would bear the same relation to the wider ocean with which it communicated, that its own river estuaries bore to itself. Such is the actual relation of the English Channel to the Atlantic Ocean: it is the estuary of the rivers of a portion of Western Europe, in which are repeated on a wider scale all the phænomena of tidal action which minor estuaries exhibit.

In the case here imagined, we have assumed a given area or valley of depression, modified afterwards by the process of accumulation alone; the whole of the process would be conducted along a very narrow zone of breadth compared with the extent of the sea, whenever the sea was an open one, and for all geological purposes such lines of section will perhaps be safer guides than those taken in close seas. In our own Channel, as we shall see, the area of sedimentary deposits is bounded on the west by the barrier which separates it from the great valley of the Atlantic: the distance of the deep sea mud from Cape Clear south is about the same as that of the same deposit from the Scilly Isles,

and agrees with the distances given below, the results of a number of lines of soundings derived from charts. The inference we must derive from this is, that extended lines of deposits, having an uniform mineral character, must have had at their periods of deposition a certain parallelism with the coast-lines of their seas.

§ 3. The necessary and obvious result of a process of accumulation where the quality of the sea-bed is dependent on depth and distance, and where the progress of the several zones of materials is outwards, will be, that in process of time each distinct zone of mineral matter will overlap the one immediately in advance of it. A deep sea channel thus filled up would present, in the long vertical sections through its bed (which is the manner in which we look at ancient sea-beds), a gradual change in mineral character; the tenacious mud would pass into fine silt and ooze—the original deep water beds; after a certain amount of accumulation, these would be surmounted by the sands of the next zone of depth, a progressive increase in the coarseness of this arenaceous series would be observable; lastly, the coarse ground zone would be found running out and resting on that of clean sand: throughout the series, taken as a whole, there would be a regular order of superposition. If we imagine a sea-bed, *a b*, thus accumulated, to be subsequently raised to an uniform level, without any reference to the former depths of deposition, just as the deposits of the secondary and tertiary periods mostly are at present, and be made to exhibit a section at right angles to its coast-line, we should have, first, such a succession as represented fig. 2; and which if described in

Fig. 2.

the ordinary language of geology would be—a thick ascending series, commencing with clays and marls, or pure limestones, according to the preponderance of the remains of animal life (Zoophytes, Mollusks) over that of the mineral masses on the coast-line, passing up into and succeeded by a vast accumulation of sand, and finally surmounted by coarse beds of gravel and shingle: concurrently with this mineral change, there would be another as great in the suites of animal remains, if we confined ourselves to such as should indicate that they had lived at the places where they might occur.

With respect to the finer and more distant sedimentary beds, the change upwards in mineral character would be progressive; whilst in other cases, and nearer the coast-line, where an accumulation of sand or gravel might have travelled out with a diagonal arrangement over a previously formed sea-bed, the line of separation might be very defined, or as we should say geologically, the mineral character would change suddenly. All these appearances might be presented, and yet not warrant the supposition of any violent physical change; the sea-bed of this and of every past period must be considered as a syn-

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chronous series, of which every portion has been derived from one common source—the coast-line. At particular places, in sections taken through them, masses of one set of materials would be found resting on another, as sands upon marls, and gravels upon sands; and we might find these sands dipping away as a mass from the one, and passing at the distance of a few miles beneath the other, as in section fig. 2; yet the only inference will be that the marl beds, which, in a vertical line, are beneath a mass of sand, are before them in respect of time; not, as we now imagine, that any one group or portion of a series had priority as a whole.

The application of these several conditions of accumulation to the deposits which form our tertiary and secondary series of formation, forms the second part of this communication: and the only point I would now notice, connected with the bed of the Channel, is the remarkable irregularity it presents at its western boundary, but which it would have been premature to have noticed in the early observations on the Channel as a physical area.

The law of progressive change in the character of sea-bed requires that the most remote deposits of the Channel should be the finest, and that no coarse materials should occur at any considerable distance from the coast: this law holds good for a given extent round all the shores of the Channel, but beyond the area of mud and ooze, fine and coarse sands, shingle and bare rock are again met with. It will be seen by the map that the Channel bed slopes gradually west through 8° or 9° of longitude, but that instead of running on with such inclination into the valley of the Atlantic, after having attained a depth of 90 and 100 fathoms, it rises again to within 50 and 60 fathoms of the surface: it is on the sides of this rise that the coarse beds occur. The moving power of the sea at 60 fathoms (the highest level of these rises) is limited to fine sand; but the whole of these groups, whether the Sole Banks or Jones's, are separated from the zones of coarse materials depending on the coast-line, by a broad intervening area of the finest quality of sea-bed. We are precluded from supposing that the lines of coarse materials can have travelled over the mud zones, as their upper surface is soft and incoherent, into which the sounding-lead sinks some distance before the mass is tenacious enough to stop it, and in which the dredge buries: if therefore marginal or sub-marginal zone materials are found in places beyond well-defined areas of the low moving power of water, they become a clear indication that since their accumulation a great change in the position of such place, as to depth of water and distance from coast-line, has taken place.

If we take the contour-lines of the Channel valley as they are given on the accompanying map, beginning from the coast, it is very evident that they conform to the features of that coast-line, particularly where it is due to physical structure; a larger scale, and an intermediate 5-fathom line would show this in a very remarkable manner, in the case of one or two valleys of fracture: the features derived from the direction of given masses are continued through the submerged portion of the valley, and are merely modified by the quantity of modern seabed accumulated over them. Thus the Channel Islands are the west

extensions of the masses of crystalline rocks of the Cotentin, which occur in the cliffs of its coast at places due east; the submarine run of these masses is indicated by the rocks across the intervening sea: it is the unyielding granite ridge, which connects the granite of Alderney with that of Cape la Hague, that causes the race at that place, and so throughout the whole of that group (*vide* Map). On our side of the Channel the mineral character of the crystalline rocks is different from that of the Cotentin and Brittany; the granite of Scilly belongs to the west of England group, and due west again is Jones's Bank, a nucleus of solid rock invested with granite sand and shingle. This conformity of contour-lines to the coast becomes weaker as we proceed seawards, and at the distance of the 50–70-fathom line of soundings has only a general agreement with it; the deep sea-beds are spread out over this area: beyond these the configuration of the sea-bed begins to put on a new direction, and in its extension west we find that this depends on the form of the mass, which rises between 48° and 49° north lat. and $8^{\circ}30'$ to 10° west long.

The places along the opening into the Channel at which we meet with shingle and gravel are very numerous; some of these are indicated on the map, but the scale is too small for the admission of all; but with respect to them all, we must suppose, as in the case of the Little Sole Bank, that they are the indications of a marginal zone or coast-line.

It may be objected to this, that these distant sand, gravel and shingle beds may belong to any age, and not in any way be connected with the present seas. In tracing the remains of marine animals seawards, we may observe a like gradual comminution with that noticed with respect to mineral materials, long after the forms of shells have ceased to be recognizable. The sea-bed, particularly on the French side of the Channel, is mainly composed of shell-sand, or sand in which few particles of anything but such as show shell-structure occur. Areas of this character are laid down by the French surveyors, and occur in the interval between the Land's End of France, or Ushant, and the Little Sole Bank; yet on the sides of this bank, and more particularly on its western slopes, large, perfect, though decayed shells again occur, and what is more remarkable, *Patella vulgata*, *Turbo littoreus*, &c. Taking the two phenomena together, the occurrence of littoral shells and of marginal shingle, we may safely infer that we have at this place the indication of a coast-line of no very distant geological period, buried under a great depth of water, and removed to a great distance from the nearest present coast-line.

The duration of time, estimated in the ordinary measure, during which the sea must have worked at its present level, must have been very great, from the extent and uniformity which its zones of deposit have attained with relation to that level; and it may be argued, that if such be the case, these coarser beds and littoral shells would not now lie exposed on the sea-bed, but would long since have been covered up by the accumulations of fine deep-sea sedimentary matter. The obstruction the Little Sole Bank offers to the flow of the tidal stream into the Channel—the surface-disturbance resulting from it,

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which is always to be observed over the whole of the area—the suspended matter which the water here indicates—alike favour the supposition that the minute particles of matter which could alone find their way to such a distance, could not accumulate at such a place.

If on such evidence we assume that the whole of the Channel valley had at some former period a higher level than at present, many other anomalies become intelligible. The banks of the Channel, such as Jones's, have tabular summits, often of rock, whilst the sides are steep, and composed of coarse materials; they are just such masses as some of the groups of rocks (such as have been already noticed in the vicinity of the Channel Islands, and which have been cut down by the prolonged action of the sea at a given level) would be if let down into fifty fathom water. The summits of all the Channel banks keep nearly the same depth, and would seem to point to some former higher and common level, for their distance from the present surface is such that the sea cannot possibly affect them mechanically.

In the very coarse beds which form the floor or lowest levels of the Deeps in the upper part of the Channel, from the meridian of Cape la Hague eastward, and which have a depth of forty and fifty fathoms, we also seem to have the highest marginal zone of some former period, over which the drifting beds of the actual period are spreading; and on the other hand, such masses as Jones's bank are to be considered as protruding portions of an older sea-bed isolated amidst the ooze deposits of the present sea.

The data are as yet too few to enable us to determine whether indications of more than one former permanent level can be detected in the characters of these portions of the Channel bed; but there is enough to warrant the conclusion, that at certain places former depths must have been different, and apparently less than they are at present, and that one such marginal level existed about the line of fifty to sixty fathoms.

There is yet a point to be noticed connected with the physical history of the Channel valley, and that is the nature of the rise which takes place at its western extremity, and which serves as its boundary with respect to the Atlantic depression. The Little Sole Bank has depths on its eastern side of ninety fathoms; but this rise is very trifling compared with that which its western slopes present. I have attempted a representation of the outline of this portion of the Channel sea-bed, by the aid of the soundings which have been taken by the French and English surveyors; and in explanation of it, it may perhaps serve to give a better notion of the extent of inequality of surface here indicated, if I borrow an illustration from the physical features of a well-known district, than to attempt to represent it by sections*. Within a distance from the summits of the Little Sole Bank, not so great as from the top of Snowdon to the sea, soundings have been obtained of 529 fathoms; in other words, the Sole Bank rises from that level to a greater height, and more rapidly, than does

* Lengthened sections having an approach to a true scale accompanied the paper when read; these cannot be reduced, and to alter the scale of distances and depths would be to do away with their use.

the mass of Snowdon from the sea-level of the Caernarvon coast by the Menai Straits.

The character of the greater part of the Channel area, if laid bare, would be that of extensive plains of sand, surrounded by great zones of gravel and shingle, and presenting much such an admixture and arrangement of materials as we may observe at present over the Bagshot district of deposits; whilst along the opening of the Channel there is an obvious configuration of hill and valley, and an amount of inequality equal to that of the most mountainous part of Wales.

From the summit-levels of the Little Sole Bank to the 200-fathom line of soundings on the west, the slopes, though steep in places, are regular. If we deduct the fifty fathoms of water, the remainder will give 900 feet for the elevation of this ridge above the 200-fathom level; or a range of hills having just the same uniform tabular elevation above such line that the Haldon and Blackdown ranges have above the present sea; it is about the lower levels of this group that the coarse materials already noticed seem to occur.

Beyond the 200-fathom line the outline is irregular, and sinks rapidly to very great depths. This remarkable fact occurs not only at one particular spot, but is continued northwards, and in the contrary direction has been traced by Captain Vanhelle from Cape Finisterre to the parallel of the Lizard. The investigation of this line seems to have been the special service on which he was employed in 1828 and 1829. He states that immediately beyond the 200-fathom line they often failed to obtain soundings by running out as much as 400 fathoms; and also that the ridge of the Little Sole is placed on the east edge of that 200-fathom line. Of the true nature of such a sudden line of depression we can at present only form conjectures: it may represent lines of old escarpments; or should lines of sea-cliff have gone down rapidly into deep water, where no mechanical action could modify them, such features would be preserved: lines of faults and upheaval would also present such unequal soundings; but the outline is too irregular to represent the termination of the sedimentary mass of the present seas; besides which, we have constant indications of a surface of bare rock.

Sir H. De la Beche has represented the course of the 100-fathom line round the British islands*, with which that of 200 fathoms has a very close conformity, and he remarks on the agreement which this line presents with that of the strike of the older ranges of this country: such is undoubtedly the case with respect to a portion of this line; but if it be suggested by this, that the date of this submerged line be the same as that of M. E. de Beaumont's 'System of the North of England,' it must be remembered that this 200-fathom line, if viewed along its entire length, presents no such parallelism,—that it is continued along the coasts of countries whose ranges present

* Theoretical Researches, p. 190. In closing these observations on the condition of the bed of the Channel, I gladly acknowledge my obligations to this work; to it, and Sir C. Lyell's 'Principles,' I must trace the idea I have attempted to work out.

no accordance with that of the north of England,—and that it crosses at right angles, and cuts off ranges, which not only have been raised, but were deposited long after the ‘System of the North of England’ rise took place.

§ 2. *Age of the Channel Valley.*

The valley of the Channel being due to depression and not to excavation, the geological period of such depression is another obvious point of interest connected with it.

From the parallelism of the valley of the Channel with certain lines of elevation along the South of England, Sir Charles Lyell has suggested that the movement from which this configuration resulted might be referred to some portion of the eocene period: but with such an abrupt termination as the Bagshot series presents, and with the occurrence of the lower portions of the eocene deposits up to the very edge of the chalk escarpment of the Wealden denudation, we must suppose, as we do with respect to the secondary beds of the same district, that the whole of the eocene group, as it exists in the South-east of England, was originally carried continuously over the Wealden; and that the phenomena of denudation of this district are entirely referable to some post-eocene date: geological features, or rather physical ones, may present parallelism, but these will be found to have very little connexion with the question of geological age.

The only way by which to test the relative levels which portions of a country may have had at any distant time, is by the beds which occur over them. If of two areas, one presents a surface of eocene strata, and the other, like eocene deposits, surmounted by distinct and younger beds, of the existence of which the other area offers no indications whatever, we rightly infer that these two areas had in the interval assumed different relative levels. Such is the difference between the two valleys of the English and German Channel—the crag deposits occupy both the English and Belgian sides of the German, whilst they are altogether wanting in the English Channel valley. Between the uppermost freshwater deposits of Hampshire and the Isle of Wight, we have no indication whatever of marine beds containing intermediate forms between those of the eocene and present seas.

Marine beds containing existing species occur at intervals along the coast-line of the English Channel: they were never probably continuous, and all belong to the marginal zone. The movement of the materials of this zone, in the present state of the Channel, has been noticed in the former part of this paper, as taking place in a direction from west to east.

In a description I gave of raised beaches at the entrance into Torbay and at Slapton, I stated that chalk-flints, and other materials from rocks to the eastward, entered into their composition, and that these materials were not to be found in any of the beaches in the vicinity at present. I re-examined these beds in the course of last summer, and found the proportion of chalk-flint, in subangular fragments, far greater than from recollection I had supposed it to be. It must not be understood from this that chalk-flint pebbles are not to

be found with the shingle on any West of England beach at the present day ; a great mass of flint shingle occupies the middle portion of the Channel far beyond the range of the chalk strata on the coast : and these very raised beds must have continually supplied a portion : the difference consists in the amount of wear, and relative proportion—on the present beaches they are exceedingly scarce, and only in the condition of rounded shingle : the like holds good with respect to the raised marine beds with chalk-flints at every other place.

Sir H. De la Beche has noticed the presence of chalk-flints in the “raised beaches” he has described on the coast of Cornwall, and adds, “The occurrence of these flints, as at Coverach Cove and at other places in the Lizard district, while they are not found inland in the adjoining country, is not easy of explanation*.” On the other side of the Channel a like mixture of chalk-flints with other materials is described by Sir W. Trevelyan in the raised marine beds about the Channel Islands†. Such facts clearly indicate that the marginal movement of the materials, during the period of accumulation of these raised deposits, was from east to west along either side of the Channel, or the reverse of what takes place at present.

These accumulations have hitherto been noticed as proofs of recent changes ; but in my communication on the subject in 1834, I noticed the poverty of the marine fauna of the period to which they belonged, and suggested that the sea-waters were then less favourable to marine life than at present, owing to a lower temperature. If the observations of the several geologists who have described the pleistocene period and its beds‡ be kept in mind, when considering the raised beds of the West of England and coast of France, it will lead I think to the inference that they also belong to the pleistocene epoch. The raised marine beds of the coasts of Cardigan and Merioneth cannot be separated from the pleistocene beds of Wicklow and the opposite coast. The intervention of the area of the Bristol Channel is not sufficient to cause similar deposits on the north coasts of Somerset, Devon, and Cornwall, to be considered of a different age from those on the Welsh coast. From the Irish Channel to the western coasts of England, and to those of France and the Channel Islands, we have a continuous series of like phenomena ; and if one portion is of pleistocene age, so is the whole.

The bearing which this view of the age of these deposits has on the physical history of the English Channel is not without interest. A portion of the pleistocene littoral zone of sea-bed is preserved on the coast of Sussex, where it was first noticed and most accurately described by Dr. Mantell : these beds serve to connect the history of the east and west extremities of the Channel. The Brighton beds contain (as is well known from Dr. Mantell’s description, as also to all those who may have examined them) that admixture of foreign crystalline rocks which is so characteristic of the pleistocene accumulations of the

* Report on Devon and Cornwall, pp. 429–646.

† Proceedings of the Geological Society, vol. vii. p. 577.

‡ More particularly Mr. Morris on the valley of the Thames.

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Eastern counties. These rocks belong to the Northern ocean area, and must have passed from that into the area of the English Channel. We thus arrive at the precise date at which the English Channel became sufficiently depressed so as to be occupied by sea, as well as at the date of the subsidence of the chalk strata along the north and south line before indicated, and which produced the Dover Straits. The movement of the drift materials over the Northern and German ocean area during the pleistocene period was from north to south ; and when the Channel valley was opened to the waters of that period, the drift was continued with a like direction into that area : in like manner the chalk-flints of the eastern portions were made to travel west ; and in the meagre character of the marine fauna of the raised beds of the Channel, we see that it was influenced by arctic currents, and not southern ones as at present.

The levels of the portions of the littoral zone of the pleistocene period in the English Channel show the depression of that area to have been rather lower at that time than it is at present. There would also appear to have been an intermediate level, of which the shingle bed between Brighton and Rottingdean is a familiar illustration—a level which was of sufficient duration to allow of the formation of cliffs ; the Elephant bed, as it is named by Dr. Mantell, belonging to a vast series of deposits, to be noticed in the sequel, and of the age of the drift.

Fig. 3.

Fig. 4.

The drift beds are the uppermost portion of the pleistocene group ; and under the name of diluvium were long since traced down into the Thames valley, and fully described as to their characteristic admixture of northern materials by Dr. Buckland. On the south side of the Thames they may be seen extending over the surface of the tertiary district, in many instances overlapping it, and resting on older denuded strata. But as we approach the district where the physical features of the Wealden begin to show themselves, these accumulations diminish in thickness, till at length we reach an area over which no trace whatever of them is to be found. This termination of the pleistocene drift takes place by a well-defined marginal bed, of which clean sections have recently been exhibited in the cuttings of the Reading and Reigate Railway. The detail of about twenty miles of this coast-line, where it ranges across the county of Surrey, will be sufficient, as all that I wish is to connect the phænomena north of the Weald with those on the south. If we commence with this line at Farnham,

we find that the chalk range subsides for an interval, and gives way to a low tract covered superficially with gravel. This accumulation is spread out westward along the valley of the Wey, and abuts against the ridge of lower greensand which bounds the stream, and which evidently defined its limits. In other places the gravels thin out against the slopes of the higher ground, as underneath Crooksbury, where their sides are occupied by it : good instances and sections may be seen, first, in the cutting near the Mill, and on the road to Moor Park, as also in the Pine-wood beyond Waverley : the teeth and the tusks of elephants have been lately met with in these gravels, in extraordinary abundance. The character of the accumulation about Farnham is better conveyed by a woodcut illustration than by verbal description (fig. 3).

From Farnham the gravel beds pass outside the chalk range, and not the slightest trace of them is to be found in the valley between the escarpment of the chalk and the line of hills south of it. At Guildford the gravel passes through the break in the chalk, and is thence spread out over the area of the Peasemarsch (fig. 4), and ends off with an uniform level against the base of the hills which encircle this valley. The remains of elephants, as well as of other animals, are very abundant at this place. The railway-cutting from Guildford to Godalming (fig. 5), and from Shalford to Postford (fig. 6), has given

Fig. 5.

Fig. 6.

sections of these gravel beds ; which indicate clearly their marginal character, by the mixture of gravel and shingle with sands diagonally arranged. The boundary-line is here also well-defined.

The condition of this part of England antecedent to the accumulation of the pleistocene beds is well shown in the Peasemarsch : the remains of trees are found beneath the gravels with elephants' teeth and tusks ; in one instance so many bones occurred together, in the clay which underlies the gravel, as to warrant the conclusion that an entire skeleton was buried at that spot.

A north and south section from this marginal line of drift, as from Guildford or Farnham to between Brighton and Rottingdean, would show the pleistocene gravels, with characteristic animal remains, end-

ing off at nearly the same level against a central area, over which no trace whatever of such gravels is to be found, and thus insulating it in the pleistocene sea. At Dorking the geological phænomena of the Guildford valley are repeated.

A series of raised marine beds, as already described, surround the West of England on the south-west and west; and except at considerable heights, we find no traces whatever of any drift beds over this area. Here again the highest drift beds with elephants' remains are above the pleistocene beds with shells, as they are on the Sussex coast: such was the position of the Plymouth beds described by Dr. Moore*.

The whole of the South of England, from the Wealden area on the east, to the Land's End, does not appear to have been a continuous line of dry land during the pleistocene period. Between the two tracts here noticed we find a wide interval over which water-worn materials of distant origin occur abundantly. The whole of the valley of the Exe is filled with an accumulation of this sort, derived from the rocks of North Devon; these beds spread out over the country east and west of the actual course of the river, and have afforded elephants' remains from a variety of places and elevations. Dr. Buckland was the first to call attention to the curious fact of the occurrence of pebbles of milky quartz over the highest levels of the Blackdown range. I have described elsewhere the characters by which the bed which contains these pebbles is to be distinguished from all other accumulations of the district, as also the fact of its distinct superposition†; and in spite of the present elevation of the Blackdowns, I see no solution of the difficulty but by supposing that the whole of that area was submerged during the latest portion of the pleistocene period.

The western boundary of this interval of depression, or perhaps better the coast-line of this western island in the latest and highest range of the pleistocene sea, is well defined along the northern extremity of Great Haldon, by a clean outline of water-worn materials and immense blocks, which occur from that point by Whadden Barton, Chudleigh, round the Bovey valley, particularly at Pen Wood, Staple Hill, and thence to Newton. For the evidence that all this material has travelled south—that all the remarkable faults and fissures of the Chudleigh district were produced before the dispersion of this gravel; as well as that the difference of level which it occupies in the Bovey valley and on the summit of the Haldons, is due to changes of level which have taken place since their accumulation, I must refer to a former notice of the district‡. The strongest proof of all, that the highest levels of the Haldons and Blackdowns (900 to 1000 feet) must have occupied a low level with respect to the Dartmoor group, is, that the summit gravel contains pebbles of its schorly granite.

The two areas of the South of England which thus seem to have been insulated in the pleistocene sea, have certain physical features in common, the prominent one being the east and west axes of their mineral masses. The boundary-line of the pleistocene drift from the

* Report of Brit. Assoc. 1841, p. 62.

† Geological Transactions, vol. v.

‡ Ibid.

coast of Belgium runs parallel with the east and west range of the Netherlands ; and such also, according to the line traced by M. Berg-haus, is its direction across the continent of Europe. South Wales presents a like east and west arrangement, and does not seem to have been submerged. In the South of Ireland again, we have a district where all the physical features are dependent on an east and west direction ; and here again the drift beds, which are so widely spread over the rest of Ireland to the northwards, are altogether wanting.

The geographical aspect of the north-west part of Europe at the period of the furthest range of the pleistocene sea would, according to these views, be somewhat such as represented in the map*. The northerly areas of insulation are taken from Prof. E. Forbes, and are in perfect accordance with the pure geological evidence of the greatest amount of depression which the north of this island presents.

In this view I have considered all stratified wide-spread gravels containing elephants' remains to be of the same period with the uppermost pleistocene drift, whether the deposits contained marine shells or not. The elephant remains, so abundant even in the highest pleistocene bed, are commonly treated as those of the animals of that period. These remains occur in the neighbourhood of the Wealden island, and indeed everywhere, under two very different conditions.

1. In the beds of ancient lakes, ponds, or river-beds, where, as at Petteridge, Peasemars, Valley of Arun, &c., great quantities of bones and entire skeletons occur.

2. In the sands and gravels of the drift : in these beds the remains consist of the harder portions only, and are mostly water-worn.

A recent examination of the Crag deposits of Suffolk, in company with Mr. Prestwich, Mr. Morris and Mr. Tyler, has satisfied me that the change from pliocene to pleistocene conditions took place by gradual subsidence, and consequent decrease of the area of dry land of England which was contiguous to the pliocene sea ; that this was attended by a diminishing temperature ; and that the marine conditions, so far as animal life was concerned, had assumed their arctic character long before the whole of Northern Europe had reached its greatest amount of depression. The remains of the land animals have, in the case of the drift beds, been derived from the sweeping of the surface of the area of dry land over which the pleistocene waters spread, and over which surface such remains might have been accumulating for countless ages. These, and the remains in the bone-caves, represent the fauna of the whole period during which the principal part of this island was in the condition of dry land.

The period at which we have clear evidence of the area of the Channel having been occupied by sea, is separated from the eocene formations by such a long lapse of geological time, that a glance at its condition during the interval forms a necessary part of its physical history. I endeavoured to show, in a former paper on part of South Devon†, that along every valley through which a river

* Exhibited when the paper was read, but not included in the illustrations.

† Geological Transactions, vol. v.

takes its course, alluvia are to be found at elevations such as the existing streams never attain. At that time I was disposed to refer these former broad river-courses to the period of the so-called raised beaches. I have recently had an opportunity of re-examining some of these valleys, and of looking at like phænomena in other places, and I now feel satisfied that the two classes of accumulation are perfectly distinct as to time.

The volume of the rivers of a district depends directly on the amount of moisture precipitated over it, and this depends on its elevation above the sea; so that to depress any given area will not tend to increase its rivers. There are other objections apart from this general one; if we take any river-course opening out into the English Channel, such as that of the Dart, and suppose a depression of the land to take place of 100 feet, we should obtain a great extension of the estuary portion of such river, which portion would be permanently characterized by its cliffs and accumulations. This new water-level, though it might account for estuary beds and shells at a higher level than before, would have no influence on the upper portions of the streams flowing down into such estuary, so as to augment their volume. In the valley of the Dart, however (as well as in all the others), there is no indication whatever of any estuary beds at higher levels than the present ones; but the ancient alluvia, which conform to the dimensions of the valley, and are distinguishable from the recent by their coarse torrential character, as well as breadth, can be traced by Holne Bridge and Staverton, till they pass down beneath the accumulations of the present estuary. These observations apply to every river of the West of England; none of them show estuary beds above the present water-level, but their upper portions show alluvia which are.

The conditions which alone will account for these appearances are obvious—the country, instead of having been placed at a lower level at the period of these broad alluvia, had a much greater elevation above the sea, and when the sea did not reach such portions of these valleys as it does now. This condition is not local, but is applicable to every considerable river-course in the island, along every one of which we can find indications of the larger dimensions of the former rivers. The Thames and the Severn are striking examples.

That the whole area of the English Channel had at one time a higher level, is directly proved by the numerous instances along its shores where old forest ground passes beneath the present sea-bed: these are marked on the map. It seems to be constantly assumed that the original position of these wooded tracts was close to the coast-line, or at the sea-level; but for such a supposition there seem to be no grounds whatever. Proximity to the sea is generally unfavourable to the growth of timber. If we take the whole line of the coasts of the Channel on either side, we shall not find any wooded tracts coming down to it, or even single trees of any magnitude; yet in many instances the trees of these submerged lands had attained a very great size. Again, the trees which have been identified from these submerged woods, such as the elm, oak, chestnut, hazel, are none of them such as have their usual habitats along the sea-board. But per-

haps the strongest argument is from the presence of the *Pinus sylvestris*: its natural zone of growth, requisite condition of soil, great susceptibility of the influence of sea-air, alike point to the improbability of its having grown in masses, or attained any size, in the vicinity of the sea.

The conclusion we may safely arrive at is, that the area of the present English Channel was in the condition of dry land previous to its occupation by the waters of the pleistocene sea, or during the period of the pliocene (crag) accumulations of the German basin, and that, together with a large area beyond, it served to connect the British Islands with France on the south, and Ireland on the west, into a tract which had a far greater amount of elevation than any portion of it has at present.

The geologist will require that many conditions resulting from such a state of things should have left their evidences. At many places along the shores of the Channel, thick accumulations of earthy materials come down to the sea-level. The western coast affords the best opportunities for studying these beds. The bold coast-line from the Start Point westwards presents a yellow band rising from the line of high-water, and which might at first sight be taken for a line of raised marine beds: from the Start to the Prawle this bed expands in thickness, and forms a low cliff of loose uncemented materials upwards, of twenty feet thick. The whole of this accumulation is the result of the disintegration of the rocks of the district: throughout the whole thickness of the mass, but without any defined arrangement, occur fragments and angular blocks of all sizes, some containing several cubic feet. The accumulation is strictly local; along the whole of this line of section the angular fragments have evidently been detached from the chlorite slate precipices which overhang it, nor does it afford a single pebble which would indicate attrition by water.

Following these beds to the mouth of the Erme, they are found on either side of the entrance, above the high-water level, whilst inland it is clearly seen that the area of the present estuary has been excavated out of this accumulation.

In every one of the Channel Islands group a like accumulation comes down to the sea-level, and from the more rapid disintegration of the crystalline rocks, its thickness is often very great. Here again we meet with repeated illustrations of the local character of the accumulation, that the angular blocks have merely fallen from masses of rock immediately above, without the slightest indication of horizontal movement.

These accumulations are due to *subaërial conditions*, continued through a vast lapse of time, and dating back to periods long anterior to the present relative position of land and sea. The thickness of these beds increases westwards, and as atmospheric agency is greater as the elevation of the land on which it is exercised increases, it adds one more argument to many others in favour of the view, that at the period of greater elevation that of the west of England was most considerable.

In the foregoing considerations, which the study of the area of the

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English Channel suggests, I have endeavoured to confine myself to those which belong to pure geology. I might however have borrowed great aid from a branch of inquiry first imagined by Prof. E. Forbes—that of the relation which an existing flora may bear to past geological changes*. I would suggest whether it may not be sufficient to reduce the existing fauna and flora of this country to two periods of origin; one which has come in since the period of the glacial drift, the other that which forms the local character of several districts, which we have shown were insulated in the pleistocene ocean, and which flora has outlived all subsequent changes. In this way the characteristic plants of the south of England and Ireland† will be the residual portion of that of the pliocene period, which corresponds with that of the greatest amount of area and elevation. The Scandinavian character of the floras of part of Wales, the Lake district‡, and more particularly the north of Scotland, will, under this supposition, be the remains of the alpine regions of the same period.

The condition of surface prior to the overlap of marine pleistocene accumulations is indicated by the remains of vegetation so constantly found beneath the drift with elephants' remains; but traces of this vegetation are also met with (as over the Wealden) in tracts which the pleistocene waters never reached. Of the remains of this antecedent vegetation, the *Pinus sylvestris* is perhaps the most characteristic. Undoubted trees of this species, and of great size, occur over the surface of the Wealden denudation, buried in old peat bogs, and are remarkable for the great thickness of their bark—a character which becomes marked in proportion as the tree advances to a colder region.

The period of the terrestrial conditions of greatest cold over the area of Great Britain would therefore be, when it was part of an area of much greater extent, and at a much greater elevation. With this extended area, and absence of internal seas, there would be, as compared both with the pleistocene and present condition, an excessive or continental climate. The character of the flora of such a geographical condition would be at the same time more southern and more northern. Much of what now constitutes upland sandy tracts devoid of vegetation, from insufficient moisture, would then have been included in the regions of pines and forests, of which the buried Scotch and spruce firs are the remains.

In like manner the period of the marine conditions, with a meagre fauna, would be that of the greatest amount of depression and expanse of sea. From what has gone before we may infer that the process of submergence during the pleistocene period was gradual and progressive from north to south, the marine fauna being such as waters coming in such a direction would bring with them: the terrestrial and marine periods of minimum temperature do not therefore correspond in geological time.

Even at the period of greatest depression, the *Pinus sylvestris* might continue to live on over the northern insulated part of the

* Memoirs of the Geol. Survey, vol. i.

† Floras i. ii. and iii.

‡ Flora iv.

island, which region, although at 2000 feet lower level than at present*, would still have presented a wide area, and ranges of some thousand feet of elevation. It is diminished area and elevation which at present unfit the West of England to produce that growth of oak and gigantic fir which before the period of the drift seems to have clothed every portion of the region of Dartmoor, and which would still more be unfitted for it when at its lower pleistocene level: on such low districts, however, and in a climate modified by a surrounding sea, some portion of a previous flora might have been enabled to live on.

An examination of those portions of the several formations which occur within short distances of the coast-line of the Channel valley on either side, tends strongly to establish the supposition of a recurrence of like conditions along the same area at several distinct geological epochs.

The thick beds of shingle at certain places in South Devon (Ugbrook, Connor, &c.) indicate the proximity of the littoral zone of the carboniferous deposits; these beds occur upon a group of strata, which again indicate a series of antecedent local elevations, attended with the diffusion of trappean matter, over which zoophytes constructed the Devonian coral reefs: on the other side of the Channel the limestone masses of the Cotentin were evidently formed under like conditions, and at the same time: lower than these in the same series occurs the coarse shingle of the French and Jersey slate rocks.

At the subsequent period of the new red sandstone, the lower beds constantly suggest conditions of marginal accumulation: the movement which attended the accumulation was one of gradual subsidence, but the sheet of porphyritic matter which contributed so much material to the new red conglomerate must have been for a considerable period at the water-level, as high in the series, and after an enormous amount of accumulation, large blocks of porphyry have been thrown down over beds which from their composition must have been deeper-water deposits than such as occur beneath them. The condition of the materials along the edge of the new red sandstone group in Calvados and La Manche is often that of true shingle, of great thickness, composed of the quartzose rocks of the district. The older strata of this part of France run east and west, and this elevation was acquired before the new red sandstone period; so that we seem to have the direction of an area of dry land east and west, and that of a line of coast shingle conforming to it. From this coast-line the new red sandstone sea stretched away north and east with an increasing depth, except where, as in South Devon and Somerset, islands presenting coast-masses of limestone or porphyry rose to the surface, from the spoil of which the coarse conglomerates were formed. The great blocks of porphyry of the middle beds of the new red series in the West of England, included in sands and marls, indica-

* Nicol "On Recent Formations near Edinburgh," *Quart. Journ. Geol. Soc.* vol. v. p. 23.

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ting no great moving power, seem to require some such agent as that of floating ice to account for their position.

Terrestrial conditions of great geographical extent, and of long duration, intervened between the oolitic and cretaceous periods: the Wealden strata of Sussex, Isle of Wight and Dorset indicate clearly, by the interchange of marine and freshwater conditions, that the Wealden area was at the sea level, or at the lowest portion of the area of dry land to which it was subordinate. It is not necessary to consider the direction of the dry land of the period; it is sufficient that no beds of the Wealden age underlie the Neocomian deposits from Trouville to Cape la Heve: the slight and even questionable traces of the Wealden in the Boulonnais show that it had its limit in that direction. The palæozoic series of the Boulonnais had received, long prior to this, the features of elevation and folding which it now presents; the line of this disturbance extends eastwards: if prolonged west it would pass along the English Channel, which, being occupied by the lower oolitic groups, whilst the Boulonnais presents only the middle and upper, prove it to have been relatively an area of depression.

Coarse rounded shingle formed of local materials, such as of the siliceous bands of the carboniferous deposits, occurs abundantly at the base of the greensand beds west of the Haldon Hills. The equivalent beds in the Cotentin are also a shallow-water accumulation.

Terrestrial conditions again obtained during the course of the eocene accumulations; but the freshwater deposits of Hampshire and the Isle of Wight, and which are entirely included in the area of the present Channel, indicate, by the alternation of marine, brackish, and freshwater conditions, a like position with respect to the area of eocene dry land, which the Wealden lake had presented before at the same place.

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of the
ENGLISH CHANNEL.
By Robert A. C. Austen Esq.