in the upper beds only; while the Skiddaw series, in which no dendroid graptolites are known to occur, seems to be more nearly related to the upper than to the lower Ramsey Island beds. The Dendroidea are, however, probably represented in the Upper Arenig rocks at St. David's, though not yet found, for this group is known to extend up to the Llandeilo beds in this area; but from the great abundance of these dendroid forms in the Lower Arenig rocks, it seems extremely improbable that these beds were deposited contemporaneously with the Skiddaw slates; while the presence in the higher beds of Skiddaw slate species only (so far as yet known) indicates a much more probable equivalency, and seems to show that the Skiddaw slates, which have hitherto been considered our oldest graptolite-bearing rocks, are of more recent age than the lowest graptoliferous rocks of St. David's.

TIDAL ACTION AS A GEOLOGICAL CAUSE.

By T. Mellard Reade, C.E., F.G.S.

The more we attempt to unravel geological mysteries, the plainer does it become that one of the first essentials to success is a full and accurate knowledge of the various phenomena of Nature now taking place around us. The history of the earth is the history of vast changes; but the principles of Nature—her *modus operandi*—though various, remain, if not absolutely fixed and immutable, yet, so far as the geological eye can penetrate, the same now as in the earliest ages to which we can trace a sedimentary deposit.

The subject of my paper is one which a close study of the Drift—the marine Boulder-clays and sands of the

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N. of England—has naturally forced upon me. The denuding and transporting effects of tides have been well discussed and understood so far as our coast lines are concerned, and it is to horizontal changes of currents—created in some cases by the actual deposit of the current itself, which has again caused deflection, and like the channels of the Mersey in the Liverpool Bay, taken them through a cycle of change of greater or less duration—that the alternate attacks at special points of a coast-line are due. Prevailing winds also have their effect, and the character of the materials or rocks, hard at one point and soft at another, becomes in turn a governing cause. It is only in some few places like the West Bay of the Isle of Portland that uniformity of action and effect has prevailed for ages past; the result being the formation of that wonderful work of Nature—so imitative of art—the Chesil shingle bank.

These are phenomena well known, and which have been fully treated of by Austin, Lyell and many other observers; but my object now is of rather a different nature, which I will presently explain.

It has been well observed by Mr. Godwin Austin, in his admirable essay "On the Valley of the English Channel," that at the depth at which the action of the wind-wave ceases "the permanent influence of the tidal stream begins." It is to this permanent influence, divested of the complications produced by superficial oscillation or suface currents, that I intend addressing myself this evening. To make my reasoning understood, I must first explain, as succinctly as I can, the difference between the wind and tide-wave.

When a cork or any light body is floating in deep water, disturbed by the ordinary surface waves of equal intervals and heights, it revolves—as do also the surface

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particles of water—either in a vertical circle or an ellipse not very different from one, having the longer axis vertical. These waves are classed as waves of the second order, and are purely oscillatory. In the tide-wave—the wave originally produced by the action of the sun and moon—called the Free tide-wave, which is a wave of the first order, the movements of each particle of water, on the contrary, may be regarded as that of an excessively elongated ellipse, the shorter axis of which is vertical. Sir John Herschell explains very clearly that this difference in the motion of the particles of the tide-wave and the surface wave arises from the vast breadth of the tide-wave from crest to crest (usually called the length of the wave) compared to its height. He says:—

> "The breadth of the tide-wave from crest to crest, supposing all the earth to be covered, would be half the earth's circumference, or 12,500 miles, in comparison of which the depth of the sea is insignificant; and the slightest consideration suffices to show that as all the water which goes to form the elevated portion must be brought from the depressed, this can only take place by a *lateral approach of the vertical sections of the sea when the water is rising, and their recess from each other when falling—i.e.*, over a quadrant of the globe in either case, which is only another way of expressing an alternating forward and backward current at any given place."*

It also differs from the wind wave in the force producing it (called in the lunar theory the *tangential* element of the disturbing force), affecting every particle equally, down to the most profound depths of the ocean, while the wind forces creating the former, act only on the surface, and even in the most violent storms agitate the sea but to a trifling depth.†

Without going into more minute description, it is thus seen that the alternate advance and recess in the bottom of the ocean is the same as at the surface, if we

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* "Physical Geography," p. 63.

† Ten fathoms would appear to be the limit in the seas about the British Isles.

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leave friction on the bottom out of our calculation. In the free ocean, however, the total height of the tidal-wave between high and low water is but small; and Sir John Herschell observes that "a tide-wave of four feet in total height, advancing over a sea 30,000 feet deep, implies only an advance and recess of 2,800 feet, which, being spread over six hours, is nowhere very rapid."

In shallow seas it may seem strange at first sight, that the tide-wave rises higher and the horizontal current is more rapid in the inverse ratio of the depth of the water; but when we consider that the tide-wave is first generated and propagated in the open ocean, we can readily conceive that as the momentum of this vast body of water must expand itself somewhere, when the sectional area of the stream diminishes, the water must of necessity be propelled at a greater speed, and a derivative wave be created.*

Being desirous of ascertaining by calculation, the abraiding power due to Tidal action at various depths, I communicated with Sir G. B. Airy, the astronomer Royal, the greatest living authority on the theory of tides and waves, and he sent me the following lucid exposition, which I should only spoil by putting into any other language than his own:—

"The proportion of velocity of wave current at the top and at the bottom of the water, depends in a most

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* "The principle of concentration of forces, on which these phenomena depend, as pointed out by the late Professor Fleming, can be easily demonstrated experimentally, by placing in water an inverted funnel with its upper orifice closed—when this orifice is suddenly opened, the water will spring up in a jet higher than the level of the fluid in which it is placed. This principle is also well exemplified in a circumstance mentioned by Mr. T. Stevenson, C.E. ("Harbours," p. 48.):—"In November 1837, during a ground swell without wind, the water rose to the gilded ball on the top of the Bell Rock lantern, which is 117 feet above the rock, or 106 feet above the sea level at the time."

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remarkable degree on the proportion of the interval between two waves to the depth of the water. When the interval between the waves is not greater than the depth of the water, the bottom movement is insensible; when the interval between two waves is 100 times as great as the depth, the velocity at the bottom is sensibly as great as at the top. This supposes there is no friction between the water and the bottom.

"But there is in sea channels such as we find them, much friction between moving water and the earth with which it is in contact; and this friction retards the speed of the bottom water, and that degree of retardation is a measure of the friction, or a measure of the rub of the water upon the ground, or a measure of the effort which the water is making to tear up the ground, and this I believe is all that could be said."

As the length of a tide-wave such as that of the Irish Sea, which is derivative, is so enormous compared to the depth of water it travels in, the theoretical movement of bottom water must be nearly equal to that at the surface. My object being to attempt a practical application of the principle enunciated, it struck me that, given the actual rate of the surface current, Beardmore's formula for surface bottom and middle velocities in streams, rivers, and tidal estuaries would apply. I wrote again to Sir G. B. Airy, to that effect. He replied as follows:—"I dare say that the formula which you give from Beardmore will do very well. There is probably some difference depending on the smoothness of the bottom, (as affected by the quality of the bottom.) When I looked on the water flowing along the exposed iron troughs of the Loch Katrine—Glasgow waterworks, I was much struck with the appearance of perfect uniformity of flow in all parts, as well as the eye could see."

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Having now obtained a principle to work upon, by which a rough approximation could be made, the next thing was its application. I carefully consulted the sailing directions of the St. George's and English Channels, and those of the West and South-West Coasts of Ireland, with a view of extracting all the information I could, relative to the tides and the physical peculiarities and nature of the bottom. The Maps of the Irish and English Channels, prepared by Captain Beechy, and published in a reduced form in Beardmore's excellent Manual of Hydrology, and also the Charts of the British Islands, compiled from the latest Admiralty Surveys, have supplied me with much information.

On the Chart exhibited, I have marked in red lines, taken from Capt. Beechy's original paper, in the Philosophical Transactions, the set and rate of the flood stream in the Irish Channel, also the direction of the tidal currents in the English Channel, at the same instants of time as the outgoing tide in the Irish sea; and the maximum velocities at various stations in the map, all from the same source. Capt. Beechy says:—

"An inspection of this map shows, that the tide enters the Irish Sea by two Channels, of which Carnsore Point and Pembroke are the limits of the Southern one, and Rathlin and the Mull of Kintire the boundaries of the Northern."

The stream in the Southern Channel has been ascertained to move simultaneously in one vast current throughout, running 6 hours nearly each way, at an average rate of from two to three knots per hour at the height of springs, increasing to four knots and upwards near the banks, and at the pitch of the headlands; its times of slack water corresponding sufficiently near for all practical purposes with the times of high and low water at Morecombe Bay, or more correctly at Fleetwood, which is twelve minutes earlier than Liverpool. The tidal stream is of course affected by the headlands, and the eastern portion passing Linney Head, rushes with great rapidity between the Smalls, Grasholm, and Milford Haven, towards the Bishops, which it passes at the rate of between four and five knots. After making the circuit of Cardigan and Carnarvon Bays, it rounds the South Stack at Holyhead, and sets towards the Skerries at a rate of upwards of four knots.

In the North Channel, the stream enters between the Mull of Kintire and Rathlin simultaneously with that passing the Tuskar into the Southern Channel, but flows in a contrary direction. It runs at the rate of three knots at springs, increasing to five knots near the Mull, and to four near Torr Head on the opposite side of the Channel. Near the Mull of Galloway the stream increases in velocity to five knots.

The meeting of the Southern and Northern tidal streams is in Morecombe Bay on the East, and off St. John's on the West.

Before commenting on the observed action of the tide on the sea bottom, let us see what would be its calculated effect in abrasion and movement of materials.

An inspection of the chart of the Irish Sea shows that the minimum velocity is actually zero off St. John's Point, and the maximum velocity opposite Kintire 505·7 feet. per minute. Centrally between the northern point of the Isle of Man and Wigtonshire the velocity is 384·3 feet; while in the southern entrance of the Irish Sea the velocity varies in the mid portions from 230 feet to 323 feet per minute. It will also be seen that all intermediate velocities are met with at various points.

Let us begin with the smallest velocity marked on the map—101·2 feet. Turning to Beardmore's Table of Surface, Middle, and Bottom Velocities, calculated from the formula $b = (\sqrt{s} - 1)^2$, where the velocity at the surface in the middle is s and that at the bottom b, we find that the bottom velocity will be 61 feet per minute. This rate of motion will disturb fine gravel. No doubt the effect will only be feeble. It will be seen that even so low a velocity is capable of carrying about and re-arranging the finer materials. For 230 feet the bottom velocity is 167·2 feet. 120 feet is put down by Beardmore as capable of disturbing rounded pebbles, and 180 feet angular stones. These data are given for the guidance of the engineer in limiting the velocities in artificial cuts to the permanent stability of the materials, and may perhaps on that account be, if anything, over-stated. For 323

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feet the bottom velocity is 247 feet; and for 505 feet 409 feet, per minute.

The most complete set of experiments on the practical effect of running water were made by Mr. T. E. Blackwell, C.E., for the Government Referees on the Metropolitan Drainage plans, with the object of ascertaining what velocities are applicable to the movement of materials likely to be collected in sewers. Consulting this table, we find that a velocity of from 120 to 135 feet per minute started a piece of broken granite weighing 6·50 oz. and having a specific gravity of 2·66; while a velocity of from 180 to 195 feet carried it along, at the rate of 60 feet per minute. A boulder weighing 11·87 oz. started with a velocity of from 105 to 125 feet; and with a current of only from 165 feet to 180 feet, it was carried along at the rate of 90 feet per minute.

These experiments were made in a trough composed of elm, 60 feet long, 4 feet wide and 3 feet deep, set horizontally, and fed by a pond at 2 feet higher level, with sluices so placed as to direct a current uniformly down the trough. It is not stated, but I presume the velocities given are the average ones; which will, of course, exceed the bottom velocities, and so tell in our favour.

I think I have now given you sufficient information to show that the tidal stream is capable of effecting very considerable work on the sea bed, both in the carrying and piling up of materials, and also in abrading power. I have also shown that the stream varies in velocity at different points, being governed by the nature, depth, and width of the channel and the form of its bottom, and by the flux and reflux from neighbouring channels, if they exist. We may safely assume that wherever the sectional area of the stream is contracted, whether horizontally, by headlands, or vertically, by shoals or rock

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shelves, there the velocity is sure to increase. It has been shown by Mr. Godwin Austin that a shoal shows itself by ripples on the surface. Thus, "the rippling over Jones' Bank is very considerable; the shoalest part of the bank has 40 fathoms, with a surrounding sea-bed of 70." "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." This is also a proof of the bottom movement of the water, and Mr. Austin also observes: "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 Griz Nez and Calais, whither the flood-tide drifts them."

Mr. Godwin Austin has also attempted to show, in the paper before referred to, that the coarser materials are found inshore, and the further out we go into the offing, the finer the materials composing the sea bed become. I do not, however, think that this statement can be supported as a wide generalisation, and he himself has to struggle against many exceptions. It appears as if though stating correctly the tidal theory, he insufficiently appreciated the mechanical force of the tides. Applied to a lake, or to an almost tideless sea, like the Mediterranean, the theory he propounds is, no doubt, consonant with facts.

NATURE OF THE BOTTOMS OF THE IRISH SEA AND ENGLISH CHANNEL.

The late Capt. White, R.N., gives the following general sailing directions in approaching the south-west coast of Ireland and the Bristol Channel from the Atlantic:—

> "When running in from the Atlantic Ocean for the purpose of rounding Cape Clear, the quality of the ground is of much greater con-

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sequence than the depth; for so long as the ingredients brought up by the lead remain free from oozy matter, you cannot be nearer than 6 leagues (9 geographical miles) from any part of the Irish coast between the Skelligs and Browhead, let the depth be what it may, but may be considerably farther from it. On the other hand, if oozy ground be obtained, in any depth of water between 62 and 92 fathoms, you may be sure you are within that distance, and consequently northward of the latitude 51° 10′; for were you southward of that parallel, the ground between those limited depths would be totally free from ooze until you had advanced as far eastward as the meridian of Cape Clear."*

Between the 100 fathom line west of the Little Sole Bank and a line drawn between Ushant and the Land's End, the soundings are nearly all sand or sand and shells. This is practically the entrance of the English Channel. Between the Great Sole Bank and latitude 51° 10″ it is the same. But the great central area from the Great Sole Bank to the Bristol Channel and between the Land's End and the south coast of Ireland is occupied by mud and ooze. In the Irish Sea, between St. David's Head and Bardsey Island in Carnarvon Bay the bottom is mostly sand, or mud, sand, and shells, with or without stones. Off Holyhead there is mud, sand, and shingle; from thence round to the Liverpool Bay it is sand and shells, and in the estuaries of the Dee and Mersey ooze and silt. Midway between the Isle of Man and the Great Orme's Head, and from thence to Morecambe Bay, is mud and sand; while in the area of no-current between the Isle of Man and Ireland is a deposit of fine blue mud. The patches of blue on the chart represent shingle or stones, as do also the spots marked with a blue ring. Comprehensively speaking, it is difficult to draw a distinction between the character of the bottom of the Irish Sea in the course of the stream tide from the entrance between Tuscar and St. David's Head. Sand alternates

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* "Sailing Directions for the West and South-West Coasts of Ireland," p. 80.

with mud, shells, sand, and gravel; mud, sand, and stones; mud, sand, and shells; and mud, sand, shells and stones; and these changes seem to occur without much reference to depth. On the east coast of Ireland, between Tuskar and the Codling Banks, sand and shells, with or without stones, seem to preponderate; while the bottom of Cardigan Bay seems to retain the general character of the main channel. At the head of the stream there is a preponderance of mud and ooze, and this applies generally to the bottom off the Lancashire coast. Skirting the stream on the west, between Lambay Island and the Calf of Man, the mud preponderates, gradually developing into pure mud as the central area of "*no-stream*" is approached. Between this area and Ardglas Bay, sand, sand and shells, and mud, sand, and shells, are found.

In the North Channel, from a line drawn between Cathair Point, in Islay, and a point a little south of the Mull of Kintire, the bottom is nearly all sand, shells, and gravel, the whole way across to the North of Ireland. The Firth of Clyde is mostly mud; the North stream tide, for the remainder of its distance until it meets the Southern stream, seems to have the same character of bottom as that which I have described the Southern stream as travelling over. This character of bottom seems to occur without reference to depth. Off St. Bee's Head there is mud and ooze. The Solway Firth is nearly all mud and sand.

Such is the character of the Irish sea bottom. If, on the other hand, we turn to the English Channel, we find it is of a much clearer description, being nearly all sand, fine gravel, and shingle, with or without shells.

Before investigating the relation, if any, which the depths bear to the tidal currents, as modified and governed by the original form of the bottom before sub-

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mergence, can we from the few facts I have mentioned draw any legitimate inferences? I think we may. I have shown, theoretically, that the stream tide is capable of moving even shingle; and, if the force acted constantly only in one direction, its effects would be most destructive; but this it does not do. The stream travels backwards and forwards, oscillating like a great pendulum; and it cannot deal with any matter excepting what is brought into it by rivers, what it erodes from the coast, or what it finds on the bottom itself. I have no doubt that the mud of the Irish Sea is principally re-distributed and re-composed Drift matter. The whole of the land on either side, comprising drainage areas of great extent, all delivering into the Irish Sea, is wrapped over with the clays and sands of the Glacial period, and doubtless the Irish Sea bottom was also thus covered, and has since been re-covered by Post-glacial Deposits of the period, represented by the Formby and Leasowe Marine Beds.* The rivers and the sea have, comparatively speaking, little to act upon except this Drift. If, again, we turn to the Frith of Clyde, we see the bottom is nearly all mud. The cause, again, is obvious: it is derived from those classic beds of silt and laminated clay which have made the Clyde geologically famous.

In the Sound of Islay the same phenomena occurs; and it is only when we get outside into the Atlantic that we get free from mud. The tides, and the winds assisting them, coming in from the pure ocean uncharged with mud, push up the sands, shells, and gravels resting upon the submerged plateau between the 100-fathom line and the land as far as and beyond the Mull of Kintire.

In the English Channel, on the other hand, the rivers

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* See my "Post-glacial Geology of Lancashire and Cheshire."—*Proceedings of Liverpool Geological Society*, Session 1871–72.

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draining into it are of little moment, and the land is not of the nature to produce so much mud. South of a line between Bristol and London, there is no Drift of any consequence to be met with. It is true there are the clays of the Lias, a patch of Red marl in Dorsetshire, the Kimmeridge clays and the chalk cliffs, to yield materials for mud-making; but these cannot compare in extent or capacity with the Northern Drift. Again, those who have seen the coast of Dorsetshire and the Chesil Bank will appreciate the sand-making capacities of the tides and winds acting upon the coast from the Land's End to the Bill of Portland, where a mass of silicious shingle is ever travelling backwards and forwards, but mostly Eastwards, and getting ground down into the finest gravel and coarse sand. It is to these causes, I am convinced, we must look for the difference in the nature of the bottoms of the two channels.

We have now seen that the materials of the bottoms may be grouped in classes, and that within these large groups the sea sorts and arranges its materials as it does on the beach, into sand, mud, shells, gravel, shingle, &c.; and, though to determine in detail why sand is here or gravel there, would be too complicated a mechanical problem to enter upon, yet, broadly speaking, we must recognise that the materials of the bottom are in exact equilibrium with the moving forces. The tidal movement is oscillatory, and varies in intensity and direction both in the ebb and flood. If we could imagine a tide of equal intensity and of equal time as to ebb and flood acting in parallel lines—a practical impossibility—the materials of the sea bottom (assuming the particles to be of the same size, form, and specific gravity, and the bottom a perfect plane) would also arrange themselves in parallel lines. The moment, however, we introduce

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the slightest deviation from these conditions, variations in the resistances at different points are caused. These, again, by the piling up of materials, in certain localities cause deflections of the current, which again react on other portions of the bottom; and so on, *ad infinitum*. If to these causes of variation we add originally unequal bottom, irregular coast line, headlands, and river estuaries, and the different rates as well as direction of the tidal stream caused by them, we may easily conceive why the sea sorts its materials in the way it does. We must not, however, lose sight of the great fact that, though the ebb and flood are not quite of equal duration in the Irish Sea, yet the materials travel backwards and forwards over the same area. Though this is the case, it is easy to see that if either the ebb or flood preponderates constantly by ever so small an increment, the tendency will be to push the materials in one direction. Again, if the bottom of the channel rises in a regular gradient, say to the head of the tide, the materials of that channel must tend to work downwards by gravitation, even if the forces of ebb and flood be exactly balanced. The rivers pouring their quota of water into the sea making the ebb preponderate, be it to ever so small an extent, must also act in the same direction; while the prevailing winds, by producing an additional head of tide, must also have their effect. It is a well-known fact, also, that shells are strewed over the sea bottom which have come from the littoral zone;* and unless a *progressive* motion were imparted to them, in addition to the oscillatory one, this could not happen. Therefore, in my opinion, the tides perform the great function of distributing the materials that come within their grasp over great areas of the ocean floor. On

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* Mr. Godwin Austin mentions the *Haliotis tuberculata* as occurring 50 miles away from any spot where it could have lived.

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any other supposition it is impossible to account for the sand and shells, and also gravel and stones, found at great depths off the 100-fathom line on the west coast of Ireland; for, even assuming them to have been in the same position since submergence — a supposition for which there are no grounds — the mud with which the ocean is to a certain extent charged, as shown by extensive deposits over portions of the Atlantic, must be prevented by currents of some kind from deposition, or else they would get covered over. Thus in the line of the French Cable in Latitude 47° N., the soundings showed sand, mud, and small shells, pretty nearly the whole way across the Atlantic, and at depths reaching to 2,460 fathoms. If there were no currents capable of moving sand, the whole would be evidently covered up with fine mud, and if there were no currents capable of moving mud, there would be nothing but pure carbonate of lime extracted from the water, by *Foraminifera* and other organisms.

FORM OF THE BOTTOM IN RELATION TO TIDAL CURRENTS.

Areas of Erosion.—I have shewn in my "Post-glacial Geology of Lancashire and Cheshire," that within the depths of from 6 to 8 fathoms in the Liverpool Bay, and also on the littoral zone, there are areas of denudation and areas of deposition, and that these areas are not constant, but inter-changeable, so that, what was once an area of deposition may by change of currents become an area of denudation, and *vice versa.* In the Mersey estuary, excepting on the littoral zone, I know of only one locality, situated in the Crosby Channel, where the actual clay of the Drift is bare, so that practically at the Mouth of the Mersey, and as is the case in all similar estuaries, the principal work done by the tides, is the pushing

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about and re-arranging of the recent sands and silt. It is now my purpose to extend the observations to greater depths, and the following are some of the examples upon which I rely:—

Mr. Thomas Jamieson, F.R.S., in his excellent paper on the "Last Changes in Scotland,*" says, that Mr. Robert Dawson, of Cruden, who has explored the Malacology of the Aberdeenshire Coast with great success, tells him that when dredging, he finds a great many semi-fossil Arctic Shells, belonging to a species which he never meets with alive. These he supposes to be derived from Glacial beds passing underneath the sea, and extending for a considerable distance out from the Coast. In Mr. Dawson's own words—

> "All the fossils included in the list were dredged by me off the Coast of Cruden and Stains, at a distance of from three to eight miles from land, and at a depth of from thirty to forty-five fathoms. As however, some of them (*Trophon Scalariformis* and *Gunneri*, *Pecten Islandicus*, &c.,) have been brought up by the fishermen's lines at the distance of thirty miles from land, I believe the fossil-deposit, whatever it may be, extends to a greater distance seawards. The reason why they are not found nearer the land appears evidently to be, that the sea-bottom for at least three miles from shore, consists of fine sand, covering probably the fossil-deposit beneath. None of these species have been found by me *alive*; and from the appearance of all the specimens, I believe that none of them are alive in the district."

Dr. W. King says, in *The Geologist*, vol. vi., p. 169, "When dredging in 50 fathoms on the West-side of the Dogger Bank, off the Coast of Durham, the Dredge brought up a large quantity of dead specimens of *Mya truncata* in a chalky condition," and infers the bed to be a Glacial or a Post-glacial, and not a recent deposit.

Again, the Sailing directions for the North Coast of Ireland says p. 81, the Channel between Irishtraull Island and Garvan Island, "has from 20 to 40 fathoms in it, with the streams of tide setting directly

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* "Quarterly Journal of Geological Society," 1865, p. 200.

through." "*The velocity of the tides has swept away all the loose soil, and left an irregular bottom at the above depths.*"

A reference to the Chart of the West Coast of Ireland shews, Leck rock off Dursey Head bare at 40 fathoms, and Edye rock, situated further South, bare at 43 fathoms. These rocks appear to be surrounded with water of from 50 to 70 fathoms.

Between Dunmore Head and Loop Head, in a space extending a degree West of the coast, are no less than nine soundings, showing rock at the bottom in depths ranging, from 40 to 77 fathoms.

Kerry Head Shoal from fourteen to twenty fathoms is an uneven rocky bottom.

Between Loop Head and Skird rocks off Galway Bay, there are seven soundings, showing rock at depths of from 38 to 53 fathoms.

Outside of the one hundred fathom contour, and North-west of Broadhaven Bay, there is a sounding, showing rock at 146 fathoms, and North of this again, rock and shells at 115 fathoms.

From Broadhaven Bay round the North Coast to Malin Head there are no less than sixteen soundings given as rock, at depths ranging from 36 to 64 fathoms.

These are some of the examples we have before us to reason upon, and if similar observations were made in other seas and on other coasts, no doubt they could be considerably extended. We are I believe justified in drawing the following conclusions:—

First—That in all probability many of these spots have been originally covered with drift or other deposits, which have been swept away; but as we know there have been oscillations of level, it is impossible to say when or at what depths this has occurred. We must bear in mind

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that, with the exception of Leck and Edye rocks, the rocky soundings given are not projecting prominences, but are surrounded by water of the same, or about the same, depths. It must not be forgotten that these soundings are the records of very careful observations, made for the guidance of mariners, who, in thick weather, when for days they may have to navigate without the possibility of astronomical observation, are dependent on the nature of the bottom, taken together with the depth, for the power of groping their way, figuratively speaking, in the dark. Granting also that there may possibly be some difficulty in distinguishing a hard bottom of any kind, by soundings, from actual rock, it is quite sufficient for my purpose that it is a hard bottom; for in that case, except in very exceptional instances, it is not a recent deposit. There is this circumstance also to be considered—that, were there only little bottom movement, a deposit of mud would surely take place; and if we turn to a tideless sea, such as the Mediterranean, we find it distinguished by a fine muddy bottom, which peculiarity, Dr. Carpenter says, accounts for the barren result of his dredging in that sea, the fine impalpable mud being unfavourable to animal life; and I think we might add, the want of that interchange of water which daily takes place, even in the open ocean, from tidal causes. We know that in the area of "no-tide-stream" in the Irish Sea there is nothing but fine mud, we know also that in the Irish Sea we find mud here, sand there; in one place stones, in another shells. We know also that this sea is receiving daily contributions of mud from the many rivers flowing through countries covered with drift-clay, and we see that these materials are assorted and distributed in a certain orderly way over the sea bottom. If, then, we have a right to infer a peculiar set of currents, or combination of currents, which accounts

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for this *non*-deposition of material in certain areas, may we not also legitimately infer that in some of these areas the tidal currents being a little stronger, may even erode the bottom in the open ocean—as, for instance, off the west coast of Ireland, or off Cornwall, in the English Channel, where in a place quite near enough to receive mud deposits from the Irish Sea, there is rocky bottom at 40 fathoms. It is also evident that in the German Ocean, full of moving sands and other deposits of a recent character, the beds of drift are, in places, bare and eroded. These observations are none the less, but rather more valuable, inasmuch as they were not made for the purpose of supporting any theory, but are a body of facts carefully collected by practical men for practical purposes only. When we find by theory—the result of calculation from observed facts—that the tidal stream at very great depths should be able to move considerable masses of material, and when, on consulting practical observations made for other purposes, we find that such materials must have been moved, and when we know that the disturbance due to wind-waves reaches down but to inconsiderable depths, there is (unless we take refuge in the absurdity that the bottom of the sea is in just the same condition as when it first subsided) no other explanation left us than that the cause, primarily, of the arrangement of materials composing the sea bottom, except in the profoundest depths, is tidal action. I have quoted from practical mariners to show that the tidal currents in certain places have swept away the loose material of the bottom. It is also extremely probable that, from the nature of the coasts, channels, and set of the stream, that confluent streams unite and produce a bottom velocity greater than that at the surface. It is also probable that, as the stream tide is in some places not constant in direction, and that the

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ebb either does not traverse the same area or crosses it at a different angle, erosion in one place and deposition in another is the result. It is also a well-known fact that in some places the ebb tide lasts greatly longer than the flood. In making for the English Channel, vessels coming from the southward, in consequence of the tide running nine hours to the northward and only three to the southward, frequently fall into the Bristol Channel. This is caused by the flood tide exceeding the ebb; but flood and ebb are only relative terms, for what is ebb in one place makes flood in another. This unequal stream begins about 14 leagues west from Scilly. It first runs N.N. W., and continues to alter till it comes to the E.N.E.; the flood tide then ceases to run.

Time tells me I must bring my remarks to a close, or I could have given many more examples. There is, however, a remarkable phenomenon which I have reserved for the last. Capt. Beechy says:—Speaking of the tide entering the North Channel. "The *main body* sweeps to S. by E., taking nearly the general direction of the channel, but pressing more heavily on the Wigtonshire Coast; *off which it has scooped out a remarkable ditch, upwards of* 20 *miles long by about a mile only in width, in which the depth is from* 400 *to* 600 *feet greater than that of the general level of the bottom about it.*" This be it understood, has taken place at a maximum depth of 146 fathoms or 876 feet, a convincing proof, of what in special circumstances the tide is capable of effecting.

Again, in the English Channel there is a similar excavation on a smaller scale as regards depth, called Hurd's deep. It extends E.N.E. and E.S. eastwards, 10 leagues or 30 miles, and then takes a turn rather suddenly to the N.N.E. more than 2 leagues, and is more than 2 miles wide, being of a serpentine shape. The greatest

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depths are 95, 92, and 72 fathoms, coarse gravel, and 62, 54, and at its extremity 50 fathoms all coarse gravel. The surrounding bottom being from 30 to 40 fathoms. This deep is an excellent guide to mariners groping for their whereabouts. To the South-westward of this is the west deep about 11 leagues in extent E. and W., and from 2 to 3 leagues in breadth, having from 37 to 45 fathoms.

Further up the Channel is the North deep, extending from abreast Christ Church Head to above Brighton, at a distance of from 5 to 6 leagues from the coast. It is of various breadths, from 2 to 5 leagues, and has throughout coarse gravel, with from 4 to 10 fathoms greater depth than will be found between it and the land.

The bottom of the North Channel Gulley before referred to, is composed of mud and shells, sand, and sand and shells, and is in fact similar in nature to the bottom surrounding it. The bottom of the English Channel is of a coarser nature than that of the Irish Sea, particularly off the coast of France. This is only another proof, that the sea deals only with the materials placed immediately within its grasp. If we imagine a valley the width of our Mersey at Egremont, and seven times deeper than it is at the deepest part, measuring from the level of the Pier Head to the bottom, we shall get a good idea of the North Sea Gulley. We cannot of course positively affirm, that the whole of this has been excavated by the tide; but it is a remarkable fact, that its longer axis corresponds precisely with the lines of stream tide given by Capt. Beechy, and if not entirely excavated, it certainly must be kept open by the current. The Hurd Deep also corresponds with the direction of the English Channel, though its Western end, is crossed by the tide from the Gulf of St. Malo—The West Deep also follows the same rule—The North Deep is much shallower

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and more irregular, being near the head of the tide in the English Channel. Roughly speaking the bottom contours of the Irish Sea also follow the direction of stream tide, so that without being able to affirm how many feet of material the tide has eroded here, or deposited there, is it not pretty evident a full consideration of all these facts collected from such diverse sources, shews that Tidal Action has a good deal to do with shaping the bottom of the sea?

Shoals and Banks.—If material is planed away from one place, it must be deposited somewhere else; hence the origin of banks and shoals. I have only time now to briefly allude to these; but if we cast our eye on the chart we shall see that those dangerous banks on the east coast of Ireland follow the same rule, and the Blackwater, Arklow, and Kish Banks take, in their longer axes, the direction of the stream tide. The shoals in the Straits of Dover also take the direction of the channel, as shown in the Vergoyer, Bassurelle, Ridge, and Varne Banks. Over these shoals the tide flows very fast, showing that the current brings the material by a combination of causes to these spots; and, by heaping them in its course, actually quickens the flow at certain times of the tide. Some shoals are doubtless only the original form of the land; and Mr. Godwin Austen gives very good reasons for inferring this to be the case with the Little Sole and some other banks. In the sea bottom there are also doubtless wide areas of deposition keeping a tolerably uniform level, and it is also not to be forgotten that in the area of "no stream" in the Irish Sea there is deep water, showing pretty clearly that the thickness of a deposit must necessarily increase but slowly where only very fine particles are transferred from other areas to it.

I must now conclude, with apologies for the imperfection of my sketch. The subject is, so far as my know-

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ledge of what has been written on Physical Geology, a new one. It has, however, I am convinced, very wide and important bearings, and supplies us with a means of accounting for the very curious stratification, cross laminations, and bedding to be found in most sections of the marine Boulder-clay of the neighbourhood. I confess they were a puzzle to me (and I have drawn many sections of them, which at a future time I hope to have the pleasure of showing you) until a combination of evidences, all pointing in one direction, caused me to follow out the investigations which you have patiently listened to this evening.

MARCH 10TH, 1874.

THE PRESIDENT, ISAAC ROBERTS, F.G.S.,

in the Chair.

Mr. T. MELLARD READE, C.E., F.G.S., described an Ice-marked surface on the Keuper Sandstone, in a field opposite the Police Station, Crosby. The direction of the Striæ 40° W. of N.

The following communications were read:—

THE METAMORPHIC ROCKS OF THE MALVERN RANGE, AND THE STRATA DERIVED FROM THEM.

BY CHARLES RICKETTS, M.D., F.G.S.

The first portion of this communication was chiefly directed to the consideration of evidences of stratification in the metamorphic rocks, which constitute the Malvern range of hills, and was illustrated by sketches and rock-specimens. (Reference is directed to a paper "On the

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