CHAPTER XVII.

Reproductive effects of Tides and Currents—Silting up of Estuaries does not compensate the loss of land on the borders of the ocean—Bed of the German Ocean—Composition and extent of its sand-banks—Strata formed by currents on the southern and eastern shores of the Mediterranean—Transportation by currents of the sediment of the Amazon, Orinoco, and Mississippi—Stratification—Concluding remarks.

FROM the facts enumerated in the last chapter, it will appear that, on the borders of the ocean, currents co-operating with tides are most powerful instruments in the destruction and transportation of rocks; and as numerous tributaries discharge their alluvial burden into the channel of one great river, so we find that many great rivers often deliver their earthy contents to one marine current, to be borne by it to a distance, and deposited in some deep receptacles of the ocean. The current not only receives this tribute of sedimentary matter from streams draining the land, but acts also itself on the coast, as does a river on the cliffs which bound a valley. The course of currents on the British shores is ascertained to be as tortuous as that of ordinary rivers. Sometimes they run between sand-banks which consist of matter thrown down at certain points where the velocity of the stream had been retarded; but it very frequently happens, that as in a river one bank is made of alluvial gravel, while the other is composed of some hard rock constantly undermined, so the current, in its bends, strikes here and there upon a coast which then forms one bank, while a shoal under water forms the other. If the coast be composed of solid materials, it yields slowly, or if of great height, it does not lose ground rapidly, since a large quantity of matter must then be removed before the sea can penetrate to any distance. But the openings where rivers enter are generally the points of least resistance, and it is here, therefore, that the ocean makes the widest and longest breaches.

But a current alone cannot shape out and keep open an

estuary, because it holds in suspension, like the river, during certain seasons of the year, a large quantity of sediment; and when their waters, flowing in opposite directions, meet, this matter subsides. For this reason, in inland seas, and even on the borders of the ocean, where the rise of the tide happens to be slight, it is scarcely possible to prevent a harbour from silting up; and it is often expedient to carry out a jetty to beyond the point where the marine current and the river neutralise each other's force, for beyond this point a free channel is maintained by the superior force of the current. The formation and keeping open of large estuaries are due to the *combined influence* of tides and currents; for when the tide rises, a large body of water suddenly enters the mouth of the river, where, becoming confined within narrower bounds, while its momentum is not destroyed, it is urged on, and, having to pass through a contracted channel, rises and runs with increased velocity, just as a swollen river, when it reaches the arch of a bridge scarcely large enough to give passage to its waters, is precipitated in a cataract, while rushing through the arch. During the ascent of the tide, a stream of fresh-water is flowing down from the higher country, and is arrested for several hours; and thus a large lake of brackish water is accumulated, which, as soon as the ebb causes the sea to fall, is let loose, as on the removal of an artificial sluice or dam. By the force of this retiring body of water, the alluvial sediment, both of the river and of the sea, is swept away, and transported to such a distance from the mouth of the estuary, that a small part only can return with the next tide. In many estuaries, as in the Thames, for example, the tide requires about five hours to flow up, and about seven to flow down; so that the preponderating force is always in the direction which tends to keep open a deep and broad passage. But as it is evident that both the river and the tidal current are ready to part with their sediment whenever their velocity is checked, there is naturally a tendency in all estuaries to silt up partially, since the causes of retardation are very numerous, and constantly change their position.

The new lands acquired within the mouth of an estuary are only a few feet above the mean level of the sea, whereas cliffs of great height are consumed every year. If, therefore, the

area of land annually abandoned by the sea were equal to that invaded by it, there would still be no compensation *in kind.*

Many writers have declared that the gain on our eastern coast, since the earliest periods of history, has more than counterbalanced the loss; but they have been at no pains to calculate the amount of the latter, and have often forgotten that, while the new acquisitions are manifest, there are rarely any natural monuments to attest the former existence of what is now no more. They have also taken into their account those tracts, artificially recovered, which are often of great agricultural importance, and may remain secure, perhaps, for thousands of years, but which are nevertheless exposed to be overflowed again by a small proportion of the force required to remove the high lands of our shores. It will seem, at first sight, somewhat paradoxical, but it is nevertheless true, that the greater number of estuaries, although peculiarly exposed to the invasion of the sea, are usually contracting in size, even where the whole line of coast is giving way. But the fact is, that the inroads made by the ocean upon estuaries, although extremely great, are completed during periods of comparatively short duration; and in the intervals between these visitations, the mouths of rivers, like other parts of the coast, usually enjoy a more or less perfect respite. All the estuaries, taken together, constitute but a small part of a great line of coast; it is, therefore, most probable, that if our observations extend to a few centuries only, we shall not see any, and very rarely all, of this small part exposed to the fury of the ocean. The coast of Holland and Friesland, if studied for several consecutive centuries since the Roman era, would generally have led to the conclusion that the land was encroaching fast upon the sea, and that the aggrandizement within the estuaries far more than compensated the losses on the open coast. But when our retrospect embraces the whole period, an opposite inference is drawn; and we find that the Zuyder Zee, the Bies Bosch, Dollart, and Yahde, are modern gulfs and bays, and that these points have been the principal theatres of the retreat, instead of the advance, of the land. If we possessed records of the changes on our coast for several thousand years, they would probably present us with similar results; and although we have hitherto seen our estuaries, for the most part, become partially converted into dry land, and

portions of bold cliffs intervening between the mouths of rivers consumed by the sea, this has merely arisen from the accidental set of the currents and tides during a brief period.

The current which flows from the north-west and bears against our eastern coast, transports, as we have seen, materials of various kinds. It undermines and sweeps away the granite, gneiss, trap rocks, and sandstone of Shetland, and removes the gravel and loam of the cliffs of Holderness, Norfolk, and Suffolk, which are between fifty and two hundred feet in height, and which waste at the rate of from one to six yards annually. It bears away the strata of London-clay on the coast of Essex and Sheppey—consumes the chalk with its flints for many miles continuously on the shores of Kent and Sussex—commits annual ravages on the fresh-water beds, capped by a thick covering of chalk flints, in Hampshire, and continually saps the foundations of the Portland limestone. It receives, besides, during the rainy months, large supplies of pebbles, sand and mud, which numerous streams from the Grampians, Cheviots and other chains, send down to the sea. To what regions, then, is all this matter consigned? It is not retained in mechanical suspension by the waters of the sea, nor does it mix with them in a state of chemical solution,—it is deposited *somewhere*, yet certainly not in the immediate neighbourhood of our shores; for, in that case, there would soon be a cessation of the encroachment of the sea, and large tracts of low land, like Romney Marsh, would everywhere encircle our island. As there is now a depth of water, exceeding thirty feet, in some spots where cities flourished but a few centuries ago, it is clear that the current not only carries far away the materials of the wasted cliffs, but tears up besides many of the regular strata at the bottom of the sea.

The German Ocean is deepest on the Norwegian side, where the soundings give one hundred and ninety fathoms; but the mean depth of the whole basin may be stated at only about thirty-one fathoms*. The bed of this sea is encumbered in an extraordinary degree with accumulations of debris, especially in the middle or central parts. One of the great central banks trends from the Frith of Forth, in a north-

* Stevenson, on the Bed of the German Ocean, or North Sea.—Ed. Phil. Journ., No. V., p. 44; 1820.

easterly direction, to a distance of one hundred and ten miles; others run from Denmark and Jutland upwards of one hundred and five miles to the north-west; while the greatest of all, the Dogger Bank, extends for upwards of three hundred and fifty-four miles from north to south. The whole superficies of these enormous shoals is equal to about one-fifth of the whole area of the German Ocean, or to about one-third of the whole extent of England and Scotland*. The average height of the banks measures, according to Mr. Stevenson, about seventy-eight feet; and, assuming that the mass is uniformly composed to this depth of the same drift matter, the debris would cover the whole of Great Britain to the depth of twenty-eight feet, supposing the surface of the island to be a level plain. A great portion of these banks consists of fine and coarse siliceous sand, mixed with fragments of corals and shells ground down, the proportion of these calcareous matters being extremely great†. As we know not to what distance our continents formerly extended, we cannot conjecture, from any data at present obtained, how much of the space occupied by these sands was formerly covered with strata, subsequently removed by the encroachments of the sea, or whether certain tracts were originally of great depth, and have since been converted into shoals by matter drifted by currents. But as the sea is moved to and fro with every tide, portions of these loose sands must, from time to time, be carried into those deep parts of the North Sea where they are beyond the reach of waves or currents.

So great is the quantity of matter held in suspension by the tidal current on our shores, that the waters are in some places artificially introduced into certain lands below the level of the sea; and by repeating this operation, which is called "warping," for two or three years, considerable tracts have been raised, in the estuary of the Humber, to the height of about six feet. Large quantities of coarse sand and pebbles are also drifted along at the bottom: and when such a current meets with any deep depression in the bed of the ocean, it must necessarily fill it up; just as a river, when it meets with a lake in its course, fills it gradually with sediment. But in the one

* Stevenson, on the Bed of the German Ocean, or North Sea.—Ed. Phil. Journ., No. V., p. 47; 1820. † Ibid.

case, the sheet of water is converted into land, whereas, in the other, a shoal only will be raised, overflowed at high water, or at least by spring-tides. The only records which we at present possess of the gradual shallowing of seas are confined, as might be expected, to estuaries, havens, and certain channels of no great depth; and to some inland seas, as the Baltic, Adriatic, and Arabian Gulf. It is only of late years that accurate surveys and soundings have afforded data of comparison in very deep seas, of which future geologists will avail themselves.

It appears extraordinary that in some tracts of the sea, adjoining our coast, where we know that currents are not only sweeping along rocky masses, thrown down, from time to time, from the high cliffs, but scouring out also deep channels in the regular strata, there should exist fragile shells and tender zoophytes in abundance, which live uninjured by these violent movements. The ocean, however, is in this respect a counterpart of the land; and as, on our continents, rivers may undermine their banks, uproot trees, and roll along sand and gravel, while their waters are inhabited by testacea and fish, and their alluvial plains are adorned with rich vegetation and forests, so the sea may be traversed by rapid currents, and its bed may suffer great local derangement, without any interruption of the general order and tranquillity.

One important character in the formations produced by currents, is the immense extent over which they are the means of diffusing homogeneous mixtures; for these are often coextensive with a great line of coast, and, by comparison with their deposits, the deltas of rivers must shrink into insignificance. In the Mediterranean the same current which is rapidly destroying many parts of the African coast, between the Straits of Gibraltar and the Nile, preys also upon the Nilotic delta, and drifts the sediment of that great river to the eastward. To this source the rapid accretions of land on parts of the Syrian shores where rivers do not enter, may be attributed. The ruins of ancient Tyre are now far inland, and those of ancient Sidon are two miles distant from the coast, the modern town having been removed towards the sea*. But the south coast of Asia Minor affords far more striking examples of advances of the land upon the

* Hoff, vol. i., p. 253

sea, where small streams co-operate with the current before mentioned. Captain Beaufort, in his Survey of that coast, has pointed out the great alterations effected on these shores since the time of Strabo, where havens are filled up, islands joined to the main land, and where the whole continent has increased many miles in extent. Strabo himself, on comparing the outline of the coast in his time with its ancient state, was convinced, like our countryman, that it had gained very considerably upon the sea. The new-formed strata of Asia Minor consist *of stone*, not of loose, incoherent materials. Almost all the streamlets and rivers, like many of those in Tuscany and the south of Italy, hold abundance of carbonate of lime in solution, and precipitate travertin, or sometimes bind together the sand and gravel into solid sandstones and conglomerates: every delta and sand-bar thus acquires solidity, which often prevents streams from forcing their way through them, so that their mouths are constantly changing their position *.

Among the greatest deposits now in progress, and of which the distribution is chiefly determined by currents, we may class those between the mouths of the Amazon and the southern coast of North America. It is well known that a great current is formed along the coast of Africa, by the water impelled by the Trade Winds blowing from the south. When this current reaches the head of the Gulf of Guinea, it is opposed by the waters brought to the same spot by the Guinea current, and it then streams off in a westerly direction, and pursues its rapid course quite across the Atlantic to the continent of South America. Here one portion proceeds along the northern coast of Brazil to the Caribbean Sea and the Gulf of Mexico. Captain Sabine found that this current was running with the astonishing rapidity of four miles an hour where it crosses the stream of the Amazon, which river preserves part of its original impulse, and its waters not wholly mingled with those of the ocean at the distance of three hundred miles from its mouth †. The sediment of the Amazon is thus constantly carried to the north-west as far as to the mouths of the Ori-

* Karamania, or a brief Description of the Coast of Asia Minor, &c. London, 1817.

† Experiments to determine the Figure of the Earth, &c., p. 415.

noco, and an immense tract of swamp is formed along the coast of Guiana, with a long range of muddy shoals bordering the marshes and becoming converted into land *. The sediment of the Orinoco is partly detained, and settles near its mouth, causing the shores of Trinidad to extend rapidly, and is partly swept away into the Caribbean Sea by the equatorial current. According to Humboldt, much sediment is carried again out of the Caribbean Sea into the Gulf of Mexico. The rivers, also, which descend from the high plateau of Mexico, between the mouths of the Norte and Tampico, when they arrive at the edge of the plateau, swollen by tropical rains, bear down an enormous quantity of rock and mud to the sea; but the current, setting across their mouths, prevents the growth of deltas, and preserves an almost uniform curve in that line of coast †. It must, therefore, exert a great transporting power, and it cannot fail to sweep away part of the matter which is discharged from the mouths of the Norte and the Mississippi. It follows from these observations, that, in certain parts of the globe, continuous formations are now accumulated over immense spaces along the bottom of the ocean. The materials undoubtedly must vary in different regions, yet for thousands of miles they may often retain some common characters, and be simultaneously in progress throughout a space stretching 30° of latitude from south-east to north-west, from the mouths of the Amazon for example, to those of the Mississippi—as far as from the Straits of Gibraltar to Iceland. At the same time, great coral reefs are growing around the West Indian islands; and in some parts, streams of lava are occasionally flowing into the sea, which become covered again, in the intervals between eruptions, with other beds of corals. The various rocks, therefore, stratified and unstratified, now forming in this part of the globe, may occupy, perhaps, far greater areas than any group of our ancient secondary series which has yet been traced through Europe.

In regard to the internal arrangement of "pelagian" formations deposited by currents far from the land, we may infer that in them, as in deltas, there is usually a division into strata;

* Lochead's Observations on the Nat. Hist. of Guiana. Edin. Trans., vol. iv.

† This coast has been recently examined by Captain Vetch.—See also Bauza's new chart of the Gulf of Mexico.

for, in both cases, the accumulations are successive, and, for the most part, interrupted. The waste of cliffs on the British coast is almost entirely confined to the winter months; so that running waters in the sea, like those on the land, are periodically charged with sediment, and again become pure. It will happen, in many cases, that the melting of snow will yield an annual tribute of fluviatile sediment in spring or summer, while violent gales of wind will cause the principal dilapidations on the shores to occur in autumn and winter; so that distinct materials may be arranged in alternate strata in deep depressions of the bed of the ocean.

Those geologists who are not averse to presume that the course of Nature has been uniform from the earliest ages, and that causes now in action have produced the former changes of the earth's surface, will consult the ancient strata for instruction in regard to the reproductive effects of tides and currents. It will be enough for them to perceive clearly that great effects now annually result from the operations of these agents, in the inaccessible depths of lakes, seas, and the ocean; and they will then search the ancient lacustrine and marine strata for manifestations of analogous effects in times past. Nor will it be necessary for them to resort to very ancient monuments; for in certain regions where there are active volcanos, and where violent earthquakes prevail, we may examine submarine formations many thousand feet in thickness, belonging to our own era, or, at least, to the era of contemporary races of organic beings.