

35. *The ESTUARIES of the SEVERN and its TRIBUTARIES; an INQUIRY into the NATURE and ORIGIN of their TIDAL SEDIMENT and ALLUVIAL FLATS.* By Professor W. J. SOLLAS, M.A., F.R.S.E., F.G.S., Fellow of St. John's College, Cambridge. (Read June 6, 1883.)

THE tidal channel of the Severn is notorious for its mud. At high tide it is filled with a sea of turbid water, thick and opaque with tawny-coloured sediment; as the tide ebbs a broad expanse of shining mud flats is revealed fringing the coast; but so like is the water to the mud that, seen from a distance, it is often hard to tell where the sea ends and the shore begins. It is the same with its tributaries, the Wye, the Usk, Ely, and Rhymney on the Welsh side, the Avon, Yeo, Parrot, and others on the English coast.

The source of this mud has been made a subject of much dispute.

That it is chiefly supplied by the rivers themselves to their respective estuaries might sound to geologists like an obvious truth; but such is certainly not the opinion of those who have most closely inquired into the matter. Engineers like Mr. C. Richardson and Mr. Howard have long been of opinion that the sediment of the tidal Avon is furnished to it by the Severn; the like is asserted of the Parrot, and I do not think one stands in any fear of contradiction when stating as a general truth that all the estuaries opening into the Severn derive their mud at least immediately from the main channel. This being so, whence then has the Severn obtained it? The answers given to this inquiry by engineers are various: some attribute it to the sea, meaning, it is to be supposed, the mouth of the Bristol Channel; some to the mud shoals of the estuary; some to its bordering cliffs; and others to the fresh water of its tributary rivers.

There is, no doubt, truth in all these opinions, and the only mistake lies in regarding them as mutually exclusive, or in assigning to any one source a larger share than its due.

With regard to the fluctuating mud-banks in the channel, they have been deposited by the tidal water, and will in time be washed away again, and redeposited, and so on again and again. However obviously a source of mud, they are certainly a long way from being an ultimate source, and nothing is to be gained from their further consideration.

With regard to the relative share contributed by the remaining agents, the view which geologists would take on general grounds is no doubt correct; the rivers which discharge into the Severn estuary, draining, as they do, a catchment basin of 9193 square miles, are the chief sources of supply; but that much is produced by the waves which wash the shores of the estuary, assisted, as they are, by sub-aerial agents, is also clear, and to this the cliffs of Penarth, Aust, and Portishead bear striking testimony. That the distant sea has contributed anything at all is not an idea likely at first sight to find much

favour ; yet I shall hope to show that it is one, at all events, supported by evidence of considerable weight.

When, however, all these sources have been admitted as genuine, there still remains one difficulty which has much exercised the minds of many painstaking observers. The Severn and its tributaries are not, except when flooded, very muddy rivers ; the wash of the cliffs is not, as a rule, excessive ; the sea, if it furnishes anything, certainly cannot furnish much ; and yet the vast body of estuarine water which extends from Weston to Portishead is never otherwise than a sea of more or less diluted mud\*.

The explanation of this lies in the fact that the water in the tidal portion of the Severn channel flows up and down twice daily at the rate of from 6 to 12 miles an hour, a velocity much greater than that required to move along large boulders of rocks. Water moving at this rate is far more likely to denude than to deposit material ; and indeed in certain parts of the Severn it is, by scouring along great masses of boulders, deepening the channel ; and to its past action in this way the deep water known as the "shoots" is attributed by Mr. Richardson.

In this rapidly moving body of water, the direction of which is reversed twice daily, the mud discharged by the rivers and washed from the beach accumulates, and from it sediment is supplied to all the tributary estuaries during flood tide ; a sufficient diminution in the velocity of the current will of course be marked by the subsidence of sediment, and when the velocity sinks to zero sedimentation is copious. Such a cessation of movement appears to take place in the Avon during ebb tide, as Mr. W. R. Browne has well shown by a series of experiments made with an ingenious current-meter devised by my colleague Prof. H. S. Shaw. I give Mr. Browne's results in his own words † :—" In ordinary tidal channels, such as the Avon below Bristol, the course of events during an ebb seems to be as follows. At first the slope of the surface is exceedingly small (in the Avon it was about  $1\frac{1}{2}$  foot in  $7\frac{1}{4}$  miles), and, while the velocity at the surface is considerable, it diminishes rapidly from thence downwards, and at some distance from the bottom becomes *nil*. This continues for about two thirds of the ebb, the surface-velocity increasing up to a certain point, and then becoming nearly constant. During all this time not only is no scour going on at the bottom, but, if the waters be muddy, an actual deposition of silt is taking place. At this time, after about two thirds of the ebb, the water has fallen about three quarters of its total height, the slope of the surface has considerably increased, and the conditions approximate to those of an ordinary river. The bottom layers of the water then spring suddenly into motion, the surface-velocity diminishes steadily as the tidal waters disappear, until it assumes the normal rate of the low-water flow.

\* This expression is doubtless somewhat too strong. Actual experiments made in 1837, showed the presence of  $\frac{1}{26\frac{1}{2}}$  part, by weight, of sediment in the tidal water opposite Avonmouth, and  $\frac{1}{3\frac{1}{2}}$  part on the opposite coast (B. A. Rep. Trans. of Sections, p. 76). Fresh determinations are doubtless needed.

† Proc. Inst. Civil Engineers, vol. lxvii. p. 1. To this valuable paper is appended the report of a no less valuable discussion.

During this period a scour of the bottom is of course going on ; but, as this velocity is not much higher than in the subsequent period of low-water flow, the rate of scour will not be much greater ; and the actual scour will be insufficient to compensate for the amount of deposit from the tidal waters which has taken place, not only during the period of high water, but also during the first two thirds of the ebb. It must follow therefore that the scouring effect of the tide is little or nothing, and the observed incapacity of tidal flows to sweep away the silt they have deposited is amply and satisfactorily explained."

Though some of the silt in the tidal water may, as thus explained, stay behind in the estuaries themselves, yet the greater portion is carried seaward ; for, in addition to the oscillating movement of the tidal water, there is of course a discharge into the sea of as much water as the rivers bring down into the estuary, and this is probably accompanied by a transference to the sea of a corresponding quantity of suspended mud, so that the final resting-place of the sediment of the Severn is situated some distance out to sea. But between this quiet spot and the margin where the Severn meets the tide the sediment is carried up and down, far and frequently, and it is not till many journeys are accomplished that it comes permanently to rest.

Thus in the waters of the Severn estuary there is a storage of suspended sediment, the accumulation of as many days, or weeks, or months as are occupied in its wanderings to and fro. The accumulation is always being diminished by withdrawals seaward, and as constantly renewed by fresh accessions provided by the denudation of the land.

This is the whole explanation of the remarkable turbidity of the estuarine Severn.

*Microscopical Examination of the Tidal Mud.*—With a view to throwing some additional light on the sources of the Severn silt, I have examined under the microscope specimens from a large number of localities on both sides of the Severn, including its tributaries ; thus Weston-super-mare, Penarth, Portishead, Avonmouth, and Gloucester are sufficiently far apart for the sampling of the Severn itself ; Bridgewater served for the Parrot, Rhymney Bridge (near Cardiff) for the Rhymney, Newport, Mon., for the Usk, Chepstow for the Wye, and Rowenham Ferry, near Bristol, for the Avon.

The character of the mud from all these places is so similar that a description of one would serve for all the rest.

The ingredients may be classed as mineral and organic ; the former consist of :—a variable quantity of fine argillaceous granules, small angular fragments of colourless transparent quartz containing numerous minute included cavities, a few similar fragments of flint, siliceous fragments of a glauconitic green colour, minute crystals of quartz of the ordinary form, minute prisms of tourmaline, highly dichroic and similar in form to macroscopic prisms of schorl, and minute rhombohedra of calcite.

The organic constituents are siliceous and calcareous, the latter include :—coccoliths and rarely coccospheres, both of the ordinary

cyatholith type so common in adjacent seas and in the Atlantic ooze; Foraminifera of various species, such as *Miliola*, which are usually small and scarcely if at all distinguishable from the young of *Miliola obesa* figured by Max Schultze (Org. der Polythalamien, plate ii.), *Textularia*, probably *T. variabilis*, but more than one species is present, *Nonionina crassula*, *Polystomella umbilicata*, *Rotalia*, sp., *Spirillina*, sp., and others, including some finely arenaceous forms; spicules of Alcyonaria rarely; fragments of Echinoderm skeletons and minute spines; and triradiate spicules of Calcisponges, probably derived from *Sycandra ciliata* and *S. compressa*. Most of the Foraminifera are quite empty, glassy and transparent; but some contain a brownish soft granular material; and in one instance a small Rotaline form was observed partially replaced by pyrites.

The siliceous constituents are chiefly sponge-spicules, very rarely Radiolaria, and a variable quantity of Diatoms. The sponge-spicules are of very various forms and sizes. They include:—simple acerates, some smooth like those of *Amorphina panicea*, others entirely microspined, like those of *Hymedesmia inflata*; simple acuates; acuates with a pin-like head, some of which may have been derived from *Cliona*, and others from *Suberitis ficus* and other Suberites; small acuates entirely microspined, similar to the echinating spicules of some species of *Dictyocylindrus*, and others similar to the smaller acuates of *Microciona armata*; large pin-headed acuates with the head only spined, similar to the large spicules of *Microciona armata*; large trifid spicules with simple projecting rays, probably derived from a Geodine sponge; and others with expanded bifid rays somewhat similar to those of *Eccionema ponderosa*; Geodine globates and stellates of *Tethya lyncurium*; in one instance a bihamate, such as might have come from *Hulichondria inornatus*. Though many of the spicules are entire, the majority are mere fragments, little rod-like cylinders of very various lengths and thickness, perforated by an enlarged axial canal.

From the inorganic constituents but little is to be learned, least of all from the mud; the fragments of quartz are more interesting, since precisely similar fragments abound in the tributary rivers of the estuary, viz., the Severn, Stratford Avon, and Bristol Avon; similar quartz grains, however, are common in the cliffs of Aust.

By far the most remarkable constituents are the remains of organisms: for these are all marine, and yet occur on the banks of rivers at a great distance from a truly marine area.

Past experience has shown me that rivers sometimes bear to the sea considerable quantities of undissolved calcareous matter derived from the formations through which they flow; thus coccoliths and Foraminifera derived from the denudation of the chalk are always to be found floating in the water of the river Cam near Cambridge, and have in past times been deposited along with other sediment in its gravels, as, for instance, near Barnwell, a fact which has led me to suggest\* that the cornstones of the Old Red Sandstone have

\* Quart. Journ. Geol. Soc. vol. xxxv. p. 492.

probably been formed from mechanical sediments derived from the denudation of Cambrian limestones, such as those of Bala and Hirnant.

Hence in discussing the source of these constituents of the Severn ooze, three possibilities present themselves for investigation. The marine organisms may have been derived (i) from the older formations through which the Severn and its tributaries flow; or (ii) from the alluvial flats of its estuary; or finally (iii) from the coast of the Bristol Channel, where under true marine conditions organisms which could furnish such structures as we have described are known to flourish abundantly.

To commence with the first suggestion. Although it may seem improbable that the older formations should have furnished any considerable portion of the organic remains, yet to set the matter at rest, I visited the Severn and two of its tributaries, the Bristol and Stratford Avons (which seemed most likely sources, since they flow through Secondary formations), and obtained from them samples of mud at points above the limit of tidal influence. The locality selected on the Severn was about two miles above Worcester; on the Stratford Avon at Defford; and on the Bristol Avon, at Saltford and Keynsham. In every sample sponge-spicules occurred pretty freely, but a close examination proved to a certainty that these were all fluviatile, and not marine; they not only agreed in size and shape with spicules of *Spongilla fluviatilis*, but were sometimes associated with the characteristic spicules of the statoblasts, or even with the entire statoblast itself. This observation was interesting, as showing not only the entire absence of marine forms, but also a wider distribution of freshwater sponge-spicules than I had previously supposed. Not only were marine spicules absent, but there were also no traces of Foraminifera, coccoliths, or any other marine remains, such as are present in the tidal silt. Thus the rivers, as a possible source of these remains, are eliminated.

The chief constituents of the silt at Worcester are fragments of quartz with some little flint; at Defford similar fragments, together with rhombohedra of calcite, both separate and aggregated into masses like sugar candy, as well as Diatoms and spicules of *Spongilla fluviatilis*; at Saltford also fragments of quartz containing minute cavities, minute crystals of quartz, some flint, occasional flakes of mica, many spicules of *Spongilla fluviatilis*, and Diatoms.

We have next to inquire into the second possibility, *i. e.*, the chance of derivation from the ancient alluvium of the Severn; this is not so readily dismissed. The blue silt of the Severn alluvium is strikingly similar in all its characters to the modern ooze; it consists of a similar admixture of mud and angular siliceous fragments; while marine sponge-spicules, Foraminifera, coccoliths, and other marine remains similar to those of the modern silt, are universally disseminated throughout its mass. They occur in its upper portion where it forms the shore of the estuary, and on the surface of fields where it is tilled; and they are just as plentiful deeper down, 15 or 20 feet below the surface, as in the new cutting for the railway to the Severn tunnel,

Fig. 11.—*Sketch-map of the Alluvial Deposits of the Estuary of the Severn.* (Scale about 25 miles to 1 inch.)

or even over 30 feet below, as in the new docks at Cardiff. Distant from the sea, as at Locking, 3 miles inland, they are not less abundant than on its shores; and it is a point worth passing mention that the alluvium on which a part of the city of Bristol stands contains them equally with the rest.

Thus, if the alluvium undergoes any considerable denudation, and so supplies sediment to the tidal waters, it cannot fail to furnish them at the same time with sponge-spicules and those other organic remains already described.

It is important then to inquire (i) whether the alluvium is undergoing extensive denudation, and (ii) whether the organic débris in the recent silt has all those characters which it should possess if it is thence derived.

The alluvium is certainly being denuded, and that partly by the numerous small "renes" and "pills" which flow through it, and partly by the waves which fall along the coast. It has also been suggested that the scour of tidal waters must act powerfully on any alluvial tracts which may possibly form a part of the floor of the estuary. Whether these exist or not I do not know, and have no evidence for or against them. The denudation effected by the waves must be very inconsiderable, since a stone sea-wall extends along the greater part of the margin of the alluvium, and where it is absent, denudation does not as a rule take place; if it did, a stone wall would have been built for protection. To this rule there is, however, at least one exception known to me. This is along the tract just north of Avonmouth: here the alluvial flat is cut into a line of low cliffs, which, owing to the tenacious homogeneous character of the deposit, present a curved profile of remarkable regularity; a gentle slope at the base curves upwards till it attains verticality just above middle height, and there bends outwards to end beneath a projecting cornice of grassy turf.

The streams or "pills" certainly have some effect, first undermining their banks, and then washing the mud resulting away out to the tide-way.

We may then conclude that a not inconsiderable, but undetermined, quantity of sediment containing minute fossils is contributed by the alluvial deposits to the estuarine water. It by no means follows, however, that the whole, or even the majority, of the organic structures found in the estuary owe their origin to this source. To the discussion of this point we next pass.

In the first place, considering that the modern mud of the estuary is furnished chiefly by the river Severn and its tributaries, and only to a small extent by the banks of the estuary itself, one would expect, were these the sole source of the organic remains, to find a much smaller quantity of them, relatively to the mineral constituents, in the modern than in the ancient silt. This, however, is the reverse of being the case; the organic remains are as plentiful in the one as in the other. Since the dilution, if one may so speak, of the ancient by the modern mud has no effect in reducing the relative quantity of organic remains present in the latter, one must conclude that a cer-



tain addition of these constituents is now being made from some other source, in order to maintain the proportion unchanged.

In the next place, it is well known that siliceous sponge-spicules when left to the action of sea-water \* slowly dissolve, the first signs of solution to make their appearance being usually an enlargement of the excessively fine canals which perforate them axially. The calcareous spicules of the *Calcispongiae* are, as one might expect, but to a far greater extent than one would expect, more soluble than siliceous ones, and thus their preservation is exceedingly rare.

The spicules which occur in the alluvium of the Severn, particularly the broken ones, generally give marked evidence of this solution; the canals of whole spicules are frequently, and of fragments always, obviously enlarged. An interesting difference in this respect is to be noticed between the spicules of the superficial alluvium at Avonmouth and that deeper seated, say at about 12 feet from the surface, as in the cutting for the Severn tunnel; those from the latter, having been exposed to solvent action for a much longer time than the former, are traversed by canals from  $\frac{1}{8}$  to  $\frac{1}{2}$  of their diameter, sometimes more, so as to present us with mere shells or husks, though sometimes less; but the canals of those found near the surface are seldom as much as  $\frac{1}{4}$  of the diameter of the spicule, and often less. As, however, it is the superficial alluvium which is now in course of erosion by streams and waves, we may in considering the source of the spicules found in the tidal waters confine our attention exclusively to it †. With respect to the spicules now found in the tidal waters, one may as well state at once that they also show marked signs of solution, not quite to the same extent perhaps as the fragments found in the alluvium, although the difference is very slight. Entire uninjured spicules, untouched by solution, are, on the whole, slightly commoner in the former.

Admitting that there is very little difference in the average size of the canals of the spicules found in the superficial alluvium and those floating about in the estuary, one might still argue that had the latter been derived from the former, they should, making allowance for their additional soaking in the water, present us with larger canals. But this is certainly not the case, the difference, if any, being the other way: and thus one might conclude that the floating spicules have not been washed out of the alluvium. Considering, however, the important conclusions which would follow such an admission, I shall not lay any stress on evidence of such a superfine nature, but prefer to adduce two sets of facts, which have the appearance of bringing the matter to a demonstration. The

\* Salt water is not necessary to this solution, as is shown by the fact that the spicules of *Spongilla* found in river-mud frequently exhibit greatly enlarged canals.

† If, however, tracts of alluvium form part of the bed of the estuary, the tide must by this time have denuded down to the lower deposits, and the spicules derived from them would be those which have undergone extreme solution; and as the spicules of the recent mud do not possess greatly enlarged canals, this source is excluded.



first is that calcareous spicules, which, being more amenable to solution, furnish a much more delicate test, do not occur in the alluvium, or, if so, very rarely, and then as broken and corroded fragments \*; in the recent ooze, on the other hand, as on the mud-banks at Rownham Ferry, they are far from uncommon, frequently entire, even to the points, and always colourless, transparent, and glassy, as though only just shed from a decaying sponge. The next fact is, that at Portishead some spicules very similar to those of *Isodictya cinerea* were found in the sample of mud I had from that place, still closely associated, being entangled together in some kind of organic matter; a fact easily explained if they had only recently been washed away from a dead sponge, but well-nigh impossible of belief if we imagine them to have been washed out of the alluvium, where all animal matter must, one would think, have long since lost its coherence, and certainly its power of holding spicules together during a rough voyage.

After a close examination of the recent silt and the ancient alluvium, and by reason of the facts just adduced, I feel convinced that the majority of the organic remains in the tidal waters have been brought from a different source from that offered by the alluvium. This is a conclusion to which, on general grounds, one would naturally incline; for the alluvium has, according to all evidence, been formed under just such conditions as prevail in the estuary at the present day, making some allowance for slight differences in level; and the presence of spicules and other organic débris in it cannot be accounted for in a different manner from that adopted for the more recent deposits.

Having estimated the influence of the alluvium, we next turn to the third possible, and the chief, sources of the organisms in the modern silt; this in all probability will likewise have been the source of the fossils in the alluvium.

So far as can be determined from a careful examination of the coast, sponges do not grow anywhere so near Bristol on this side of the Channel as Portishead and Weston; Lynton, which is about 60 miles away, is the nearest possible locality; while Ilfracombe, about 15 miles further west, is well known as a rich collecting-ground for both siliceous and calcareous sponges and a host of other marine forms, including Sea Urchins and Starfish, which might well furnish the Echinoderm network and spines so frequent in the ooze. On the other side of the Channel one would need to go to Bridgend before meeting with much in the way of shore life, and I doubt, after a hasty visit to that locality, whether much would be found there; a good deal farther west is Tenby, and no naturalist needs to be informed of the luxuriant growth of all kinds of marine animals, including sponges, to be met with there.

\* The strength of this argument is impaired by the fact that since writing the paragraph, I have found in the superficial alluvium near Weston-super-Mare, one or two triradiate calcareous spicules scarcely touched by solution. The question of the solubility of calcareous spicules evidently requires further investigation.

Hence it seems probable that the organisms which furnish the sponge-spicules, tests of Foraminifera, spines and other skeletal fragments of Echinodermata, and the rest, have their home along the coast of the Bristol Channel, from Ilfracombe to Lynmouth on the one side, and from Tenby for an unknown distance eastwards on the other; thence they or their débris, as they perish and decay, are swept away by the tidal current, which rushes up the Severn at the rate of from 6 to 12 miles an hour, and are so distributed both along its shores, even as far north as Gloucester, and to every tributary estuary which opens into it. On these shores, so remote from their source, some of these organic fragments find a permanent resting-place, and thus far inland we discover along a river-bank deposits containing marine remains. But those which stay are few compared to those which are washed away again and carried out to sea, there to be deposited in marine mud-banks, probably not far from their original home.

As now, so in the past, the same process was in progress; but deposition inland took place on a larger scale, for the estuary of the Severn has for so long a time maintained unchanged its present elevation relatively to the sea-level that deposition along its banks is now exceptional and rare. Its alluvial flats are already built up, and are seldom added to; but in its main outlines the process by which they were formed is that which we witness at the present day.

*The Alluvial Flats.*—The great difference in conditions which obtained during the formation of the alluvial flats was a difference in level relatively to the sea. I here present a series of sections, some new, some borrowed from older sources, which will serve to illustrate the general structure of these plains (figs. 1–10, p. 611).

No. 1, Porlock, is constructed from Mr. Godwin-Austen's well-known paper (Quart. Journ. Geol. Soc. vol. xxii. p. 3). The lower bed of peat marks an old forest-growth; the upper peat-bed contains remains of the yellow Iris, a plant which appears to be common in all the peat-beds of the alluvium which I have had an opportunity of examining.

No. 2, Bridgewater levels, is from Buckland and Conybeare (Trans. Geol. Soc. 2nd ser. vol. i. p. 310).

No. 3, Huntworth, Bridgewater, is by W. Baker (Trans. Somerset Archæol. & Nat. Hist. Soc. vol. i. p. 126).

In the gravel-bed near the base remains of pottery are said to have been found; the peat is in two layers, a point worth noticing, since the upper part in No. 7 (New Passage) also exhibits in places a division into two layers, thus suggesting the occurrence of some general change affecting the whole margin of the estuary, probably a double cessation of depression.

No. 4, Huntsworth, Bridgewater, is by Mr. Poole (Quart. Journ. Geol. Soc. vol. xx. p. 118).

The bed of gravel, nearly 8 feet from the surface, is interesting, as it appears to emphasize a change which affected the estuary generally, but is elsewhere not so well marked.

No. 5 is a section of a well now being sunk by the Psychical Society, close to the village of Locking, Weston-super-Mare.

The uppermost half of the 14 feet of blue clay above the peat contains less argillaceous matter, and a larger proportion of angular siliceous fragments, than that below, which is also characterized by containing a good deal of decaying vegetable matter. The peat consists of various plant-remains, including leaves and roots of yellow flags and spores and mycelia of fungi, while its upper surface is strewn with trunks and branches of trees, oak, fir, and birch being the chief. The fir still retains its bark, and the heartwood, when cut, is often found to have preserved its original colour. Some of the wood has been bored by some kind of beetle. The peat is remarkably free from intermixture with mineral sediment, a grain or two of angular sand, a sponge-spicule, and a Foraminifer here and there being all that I could find in a specimen appropriately prepared for microscopic examination. In one of my slides the leg of some species of insect is displayed. The clay immediately beneath the peat is much more argillaceous than that above, and of a darker blue colour, attributable probably to the influence of decaying vegetable matter. Sponge-spicules and Foraminifera, however, are common in the sandy, sediment that remains after washing away the argillaceous matter of the clay. At 20 feet from the surface the clay becomes far more sandy and, as a loose blackish sandy clay, extends down to 23 feet, where it rests on a surface of red clay. This red clay closely resembles that of the Trias. It is, however, penetrated by thin fibres of vegetable matter, apparently root-lets, as far down as it has been followed, *i. e.* to 29 feet; if these fibres are those of small plants, as the absence of stumps of trees would suggest, it would seem to follow that the clay cannot be Triassic, and hence one feels a certain amount of doubt as to the age of the red clay in the other sections, where we have regarded it as Triassic.

No. 6, Lower Clevedon, is after Mackintosh (Quart. Journ. Geol. Soc. vol. xxiv. p. 283). This is interesting as showing peat at the same depth below the surface as the upper peat in No. 7.

No. 7. This is a section of a shaft sunk preparatory to beginning the cutting for the new railway, which is to run through the Severn Tunnel; I am indebted for it to the kindness of the Engineer of the Tunnel, Mr. C. Richardson. A similar section, not quite so detailed, appears in a valuable paper by my friend and former pupil Mr. Evan D. Jones, Assistant Engineer of the Tunnel (Proc. Geol. Assoc. vol. vii. no. 6, fig. 4, section 6).

The upper six feet of the blue clay above the peat are (like the upper part of this clay at Locking) fuller of angular siliceous fragments than the rest below; and the lower three feet are not only more argillaceous, but charged with fragments of black and decaying vegetable matter. In association with this vegetable matter we find, and not only here, but also at Cardiff and Locking, abundant spherules, separate and aggregated, of iron pyrites. These

spherules are precisely similar to those occurring in ancient sediments, particularly limestones; they are described in my paper on the Silurian district near Cardiff (Quart. Journ. Geol. Soc. vol. xxxv. p. 504). The direct connexion of the pyrites with the vegetable matter is beautifully shown by their frequent occurrence within the cells of vegetable tissue, where they may be seen occupying the place of the departed protoplasm, and surrounded on all sides by the persistent cellulose cell-wall.

The clay below the first peat is not yet clearly exposed in this cutting. I have so far been able to examine it sufficiently to state that it contains organic remains like those of the upper clay.

The sand, six feet in thickness, is of a greenish blue colour and consists of fragments of colourless quartz, with included cavities and microliths, green grains, and numerous shelly fragments which give it a white-speckled appearance. The most noticeable organic constituents are abundant fragments of some species of Polyzoa; besides these are many chips of Lamellibranch shells, amongst which I noticed a small broken *Avicula*, Foraminifera, spines of Echinoderms, and sponge-spicules.

The lower bed of peat is not yet exposed in the cutting.

The lowest gravel consists of rolled pebbles, angular and subangular blocks of Millstone Grit, vein-quartz, Mountain Limestone, and it may be of other material. Some of the blocks are more than a cubic foot in size, and one subangular fragment of Mountain Limestone was found well smoothed and striated as if by ice.

No. 8 is taken from a paper read by Mr. W. C. Lucy, before the Cotteswold Club, March 6th, 1873. The blue clay is stated to have yielded, at from four to six feet from the surface, nests of *Tellina solidula*, a shell which abounds on some parts of the shores of the estuary at the present day. The peat contained many trunks of trees, chiefly oak, alder, beech, and hazel; some of the oaks were of great size.

No. 9 is a section obtained in excavating the New Docks at Cardiff. I have to express my best thanks for it to my friend Mr. John Storrie, Curator of the Cardiff Museum, who has not only generously sent me full information concerning it, but specimens for examination.

Below 4½ feet of made ground is blue clay, twelve feet thick, the upper five feet full of Foraminifera, the lower seven feet charged with disseminated vegetable matter, but still containing marine organisms. Next below is peat, from six to eighteen inches thick; of this I trust that Mr. Storrie, with his extensive botanical knowledge, will furnish us with fuller information at some future time. It is remarkably uncontaminated by mineral sediment, if I may judge from the specimen in my possession; only a few grains of angular sand, and some sponge-spicules and Foraminifera occur in it.

Below the peat is 22 feet more of blue clay, in its upper part containing fewer Foraminifera than that above the peat, and many of these are pyritized; in its lower part are still fewer Foraminifera, but many examples of *Scrobicularia piperata*. It is interesting to

find here a *Scrobicularia*-clay, occurring at the same depth as in the shaft at Caldicot, near Portskewet, which is about nineteen miles further north. The clay rests on gravel consisting of Millstone-grit pebbles.

No. 10 is taken from Mr. Evan D. Jones's paper (*loc. cit.*); it was obtained in sinking a shaft through Caldicot Marsh near Portskewet. In Mr. Jones's paper the section has slipped too near the datum-line in the figure; it should be raised till the surface of the clay is on the same level as that of no. 6, fig. 4. The *Scrobicularia*-marl which occurred in this section is of yellowish-grey colour, and is characterized by an admixture of freshwater and brackish-water shells such as *Limnæa*, *Planorbis*, *Scrobicularia piperata*, and *Cardium edule*. Diatoms are common in it, and also remains of *Chara*. It presents a striking contrast in colour and composition to the rest of the alluvium.

The foregoing material enables us to classify the alluvial deposits in the following manner:—

- |                        |  |
|------------------------|--|
| Zone 1. Upper clay.    | { a. More sandy zone, 5 to 7 feet.<br>b. More argillaceous zone, with disseminated vegetable matter. |
| Upper peat.            |  |
| Zone 2. Lower clay     |  |
| Lower peat.            |  |
| Zone 3. Sands and mud. |  |
| Gravel.                |  |

With the gravel we have not now to do; the presence in it of glaciated stones is very suggestive; but, as further information with regard to it will be forthcoming as the works of the Severn Tunnel progress, we may defer for the present the question of its formation. The sand is evidently a marine or tidal deposit, like the blue clay, from which it differs chiefly in containing no argillaceous sediment or scarcely any. It is not a constant deposit, and may possibly be explained by local current-action, though the gradual succession from coarse through fine gravel to this sand in ascending order seems to require some more general explanation. The fact that it is entirely absent at Caldicot on the opposite side of the river, but is represented there by ordinary blue silt, is in favour of merely local action. The mud below this gravel in Section 3 is on this horizon; its upper part, on which the gravel reposes, is penetrated by rootlets, indicating a land surface.

There is a difficulty, when only one layer of peat is present in a section, in determining whether it is upper or lower; we may safely regard the lower bed at Porlock, and at New Passage, and the single bed at Lydney as lower peat; the remaining peat-beds are probably upper.

The lower peat must evidently have accumulated at a time when the relative level of land and sea was different from that of the present day. At New Passage, for instance, it lies at half-tide level, and would have been, under existing conditions, always submerged for one half the day. An elevation of twenty feet, however, is all that is

required to bring the layer of peat up to the same level as that of the existing surface of the ground ; and more than this cannot, I think, well be allowed, for the tidal deposits lying conformably above and below both beds of peat seem to point to a simple movement of depression interrupted by occasional pauses. The tidal mud beneath the peat proves that during its formation the margin of the land was below water, just as surely as the layer of peat proves that during its formation it was above. We can account for the silt on the theory that it was a case of "deposition during depression ;" and we can also account for the peat by supposing that the downward movement ceased for an interval ; during which deposition continued and led to the silting-up of the creeks and bays of the estuary to above the high-water level of ordinary spring tides : extraordinary spring tides would raise the level somewhat above "high-water spring" mark ; and a marsh-growth would raise it somewhat higher still. The cleansing of muddy water on passing through the reedy margin of a marsh has been alluded to by Sir Charles Lyell, and may be invoked here to account for the general purity of the peat, which, nevertheless, does contain some sponge-spicules, Foraminifera, and sand-grains, though few.

After a long pause, during which the lower peat, with its associated remains of forests, was formed, subsidence set in again, and the lower blue clay gradually accumulated over the layer of vegetable matter.

Another interval of rest succeeded, during which a new alluvial surface rose above the tide, and the upper bed of peat was produced ; again the movement of depression was renewed, and apparently not uniformly, since the lower part of the upper clay contains scattered fragments of plants which were probably derived from some exposed portion of the peat, which the waves ploughed to pieces and distributed far and wide. During the continuance of the depression the upper gravel bed at Bridgewater was laid down, probably through local current-action due to the change in the configuration of the estuary consequent on its depression. Finally, the upper part of the blue clay was deposited ; and this is more arenaceous than the lower part of the same deposit, because the continued depression had brought the sea nearer the area of deposition. The tidal waters, as the land sunk, extended further and further up the estuary and its tributaries ; and, meeting the upland waters further inland, sooner received their supplies of sediment. But it was from these muddy tidal waters that the silt of the alluvial flats was supplied, and thus, the source of sediment being shifted nearer the area of deposition, we have, according to a well-understood rule, coarser succeeding to finer sediments.

Thus then we explain the origin of the alluvial tracts of the Severn. Save for differences of level, they have been formed in the same way as tidal deposits are accumulating at the present day ; in the past as in the present the tidal waters rose and fell in the estuary, transporting with them sediment of a double origin, the joint product of the land and sea.

*The Sewage Question.*—The important bearing of these observations on the conclusions of modern engineers as to the fate of sewage poured into tidal waters need scarcely be pointed out. It is certain that the fæcal residues which destroy the purity of our streams, and serve as breeding-matter for disease-germs, do not obtain at once a safe burial in the sea, but linger with us for days or weeks, or may be for months, wandering with the ceaseless oscillation of the tides; while a part never reaches the sea at all, but is strewn with impartial hand at the foot of every town which the tidal current reaches and defiles.

In conclusion, I desire to offer my best thanks to my friends Messrs. T. J. Ranson of Weston-super-Mare, T. Jones, F.G.S., of Newport, Mon., F. G. Evans and J. Storrie of Cardiff, for their kindness in sending me specimens for examination.

*Note.*—Since writing this paper I have received from my brother Mr. Edgar W. Sollas of London, specimens of mud taken from the banks of the Thames near London Bridge. On examination I find in them characteristic sponge-spicules, Suberitic and others, indicative of marine origin.

#### DISCUSSION.

Prof. BOYD DAWKINS said that he congratulated the author upon the way in which he had dealt with the phenomena which he had brought before the Society. The bearing of his remarks upon the sewage question was very important. The physical change implied by the submarine forest in the area examined by the author, and which Prof. Dawkins had studied for many years, was to be observed all round our coasts where the shore was a shelving one. The forests of oak, yew, and Scotch fir occupy a belt stretching from about Ordnance datum to below low-water mark, and he had identified the short-horned ox, goat, sheep, and hog among the animals discovered in them at various points. Between Porlock and Minehead he and the Rev. W. H. Winwood had found numerous flint chips and flakes. The forests, therefore, were flourishing in the age of the domestic animals, or the Prehistoric period, most probably in the Neolithic stage of that period, and formed a belt extending from our shores to an unknown distance seawards. With regard to the section at Porlock Weir, he could not agree with the author that there was a second bed of peat. It was, as Mr. Godwin-Austen describes it, merely a surface-growth of *Iris*.

Dr. HICKS said that he could quite confirm, from personal observation, the views of the author in regard to the extension westward of the old forests. That the mud went landward instead of seaward was a point with important physical bearings. He remarked upon the distribution of the materials according to their weight and volume.

Mr. WHITAKER said that the paper had an interest from the analogies of the Severn deposits with others of a like kind. He had recently been working near the Wash, the low land bordering which



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was formed of material deposited by the up-tide, so that the materials were derived from the Yorkshire coast. The sections of the Severn alluvial flats corresponded with those of the Fenland. He thought it would be better to say that submerged forests occur at the junction of a river with the sea, rather than on a low shelving shore, as stated by Prof. Boyd Dawkins. "Submerged forests" and "peat-beds" were substantially the same phenomenon. It was, however, important to remember that the subsidence need only be slight. He had lately heard some facts with reference to the action of the tide in the Thames:—experiments had been made with floats, and in some cases the floats were found after a fortnight or more to have travelled up the stream; others, however, had slowly descended. It was therefore evident that much remained to be learned about the tides.

Prof. SOLLAS was glad to find that the results of his study of this particular estuary were sufficiently in harmony with Prof. Dawkins's generalizations. He differed, however, in two particulars: the first was with reference to the deposits immediately beneath the peat, which he regarded as not fluvatile, but tidal or marine; and the second as to the extent of the submergence which had taken place subsequent to the formation of the peat; he thought the land need not have stood more than 20 feet higher than at present for the growth of the first peat-bed, and 10 feet for the second.