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LVII. *On the Boulder Formation, or drift and associated Freshwater Deposits composing the Mud-cliffs of Eastern Norfolk.* By CHARLES LYELL, *Esq.*, *V.P.G.S*, *F.R.S.*, *&c.**

THE cliffs extending from Happisburgh or Hasborough light-house to near Weybourne, north-west of Cromer, in Norfolk, comprising a distance of about 20 miles, are designated in some maps as "the mud-cliffs." They are for the most part composed of deposits of two kinds, first, stratified and unstratified drift, called by some "diluvium;" secondly, freshwater strata. Both of these rest on chalk, which is usually concealed below the level of the sea. Occasionally between the chalk and drift or the chalk and freshwater beds, a thin layer is found of marine crag, agreeing in its fossils with that of Norwich, but occurring only in patches of small extent, except near Weybourne, where it is more continuous.

The drift, which sometimes attains a thickness of more than 300 feet, consists principally of clay, loam, and sand, in some places stratified, in others wholly devoid of stratification. Pebbles, and in some places large boulders of granite, porphyry, greenstone, lias, chalk, and other transported rocks are interspersed, especially in the unstratified portion. Pure and unmixed white chalk rubble, and even huge fragments of solid chalk, are also associated in some localities. No fossils have been detected in this drift which can positively be referred to the æra of its accumulation; but besides the organic remains derived from secondary strata, it contains almost everywhere broken fragments of shells which agree in species with those of the Norwich crag, from which there is good reason to believe them to have been washed out.

* Communicated by the Author.

The freshwater strata associated with the boulder formation above mentioned occur for the most part in patches at the bottom of the drift, and immediately above the subjacent chalk and crag, where the latter is present, as may be seen at a variety of places between Happisburgh and Runton near Cromer. The two spots where it is most largely developed are at Mundesley and Runton. At the latter place it underlies the drift and rests immediately on chalk, with the occasional intervention of marine crag; while at Mundesley it occupies for a certain space the whole cliff, taking the place as it were of the drift, and appearing in part to be of contemporaneous origin, and in part of subsequent date and superimposed. Everywhere it contains the same species of shells, and as these are almost without exception identical with well-known British species, it is evident that the entire formation of the mud-cliffs, whether freshwater or drift, belongs to the latest part of the tertiary period, the only doubt being whether it should not rather be considered as post-tertiary or referable to a class of deposits which contain exclusively shells of recent species.

I mention at once this conclusion, because the recent origin of the drift adds a peculiar interest to the great derangement and change of position which it has undergone since its deposition. In no other parts of our island, or perhaps of Europe, are there evidences of local disturbance on so great a scale and of an equally modern date, for there are proofs of the movement both downward and upward of strata several hundred feet thick for an extent of many miles; together with most complicated bendings and foldings of the beds and the intercalation of huge masses of chalk, and what is no less perplexing and difficult of explanation, the superposition of contorted upon horizontal and undisturbed strata.

The line of coast in which the formations above alluded to are displayed was well described in Mr. R. C. Taylor's Geology of East Norfolk, published in 1827, and afterwards in Mr. Woodward's Outline of the Geology of Norfolk, 1833. Both these papers are the result of a careful survey of the coast, and contain original observations of great merit. In both are given coloured sections of the cliffs, from which a good general idea of their structure and composition may be derived. A memoir was also read to the Geological Society in January 1837, by the Rev. W. B. Clarke, in which among other remarks he insists on the necessity of separating the diluvium of Norfolk from the crag *.

My own observations on the coast of East Norfolk were made first in the year 1829, and afterwards in 1839; and as

* Geological Transactions, 2nd series, vol. v. part ii. p. 363.

the sea has been continually encroaching on the cliffs, I found after an interval of ten years that a different section of the same beds was exhibited, and some difficulties cleared up which I had been unable to explain on my first visit. Nevertheless a high beach precluded me at both periods from obtaining a view of the lowest beds, which are sometimes exposed in winter at low water, and after storms. During my last visit in particular (1839) the prevalence of easterly gales prevented my seeing in some places no less than 12 feet in vertical height of the section which was visible in the summer of 1829.

The principal deposit which constitutes the mud cliffs of Eastern Norfolk is strictly analogous in character to that which has been called the "boulder formation" in Denmark and Sweden, and which, from the numerous erratics included in it, forms so remarkable a feature in the superficial geology of Scandinavia, and all the countries surrounding the Baltic, as well as northern Russia. It may be said to extend uninterruptedly from Sweden through the Danish islands, Holstein, and the countries of Hamburgh, Bremen, and Osnabruck, to the borders of Holland, and then to appear again with the same characters in Norfolk and Suffolk. Throughout this tract, however, the average number and dimensions of the included erratic blocks, especially those of granite, porphyry, gneiss, and other crystalline rocks, diminishes sensibly on proceeding from north to south.

As I am of opinion that the boulder formation in all these countries has been accumulated almost exclusively on ground permanently submerged beneath the waters, and that it does not consist of materials transported either by one or many transient rushes of water over land which had previously emerged, I shall dispense as far as possible with the term "diluvium," substituting that of "drift" for such portions of the deposit which cannot be proved to be fresh-water. Part of this drift consists of clay and loam wholly devoid of stratification, to which the name of "till" may be applied, a provincial term widely used in Scotland for similar masses of unstratified matter, which there also contain most commonly included boulders. The entire want of a stratified arrangement in the *till*, whether in Scandinavia, Scotland, or Norfolk, implies some peculiarity in its mode of origin; yet in all these countries some of the till has accumulated contemporaneously, and apparently in the same body of water, as much of the accompanying stratified gravel, sand, and clay. Moreover the stratified drifts are often identical in composition with the *till*, the distinction consisting merely in the mode of arrangement.

I have seen no kind of deposit now in progress precisely similar in character to the till, except one, namely, the terminal moraines of glaciers. These, as Charpentier has justly remarked, are entirely devoid of stratification, because the accumulation has taken place without the influence of any currents of water by which the materials would be sorted and arranged according to their relative weight and size. Year after year the ice, as it melts at the extremity of a glacier, adds fresh mud, together with fine and coarse sand, gravel, and huge blocks, to the moraine, all being carried to the same distance*, without the least reference to the volume or specific gravity of the component particles or masses.

There can be no doubt that similar accumulations must take place in those parts of every sea, where drift ice, into which mud, sand, and blocks have been frozen, melts in still water, and allows the denser matter to fall tranquilly to the bottom. The occasional intercalation of a layer of stratified matter in the till, or the superposition or juxtaposition of the same, may be explained by the existence or non-existence of currents, during the melting of the ice, whether successively in the same place or simultaneously in different places.

It is, I believe, a common error of those who are not unwilling to admit the agency of ice in reference to the larger fragments of transported rock, to forget that what carries heavier masses from place to place must unavoidably convey a much larger volume of lighter and finer materials.

Having offered these preliminary remarks, I shall proceed to describe in detail some of the appearances which present themselves to one who travels along the coast from Hasborough to Weybourne. The section of the mud cliffs begins at the more southern of the two lighthouses about a mile and a half south of Hasborough. The cliffs here, which are between sixteen and twenty feet in height, are composed generally of a mass of blue clay covered with yellow sand, the clay and sand being both stratified in some places with great regularity, but in others the clay or mud is quite unstratified. Included in this *till* I found pieces of unrounded white chalk, angular chalk flints, fragments of argillaceous limestone (lias ?), blocks of dark greenstone, and other rocks. There are also interspersed pieces of shells, apparently belonging to *Cyprina*, *Cardium*, *Mactra*, and *Tellina*, such as might have been derived from the denudation of the Norwich crag. At some points where stratified clay reposes on the till, the surface of the latter is very uneven, and was evidently so when the superior deposit was thrown down upon it. Examples of intercalation of

* *Ann. des Mines*, tom. viii.

till between laminated beds of clay and loam are not unfrequent. In 1839, I saw at a spot between the two lighthouses, till resting on stratified clay and covered by stratified gravel and white chalk rubble, which latter formed the top of the cliff.

Owing to the continual dilapidation of the cliffs the details of the sections seen by me in 1829 and 1839 were very different. During my last visit the beach at Hasborough was too high to allow me to see the fundamental bed of lignite which exists there, which in June 1829 was exposed at low water, the descending section being then as follows: 1st, sand and loam, 13 feet; 2ndly, unstratified mud or till varying from 8 to 16 feet; 3rdly, laminated sand and clay, one foot and a half, part of the clay being bituminous and inclosing compressed branches and leaves of trees. The clays, which were blackish, greenish or brown, contained occasional layers of small pebbles, rounded and angular, mostly of chalk flint. The entire height of the cliff was about 35 feet.

This locality has been mentioned by various authors as the principal site of the submarine forest of East Norfolk, which has been described as occurring about the level of low water; and Mr. R. C. Taylor observes of this deposit generally,—

"That it consists of forest peat, containing fir cones and fragments of bones; in others of woody clay; and elsewhere of large stools of trees standing thickly together, the stems appearing to have been broken off about 18 inches from their base. They are evidently rooted in the clay or sandy bed in which they originally grew, and their stems, branches, and leaves lie around them, flattened by the pressure of from 30 to 300 feet of diluvial deposits. It is not possible to say how far inland this subterranean forest extends; but that it is not a mere external belt is obvious from the constant exposure and removal of new portions, at the base of the cliffs *."

A letter of the Rev. James Layton is thus cited by Mr. Fairholme:—

"One remarkable feature in this compact blue clay is a stratum of wood, exhibiting the appearance of a wood overthrown or crushed *in situ*. At Paling the stumps of trees seem now to be really standing, the roots are strong, spread abroad, and intermingling with each other; were a torrent to sweep away the mould from the surface of a thick wood, leaving the roots bare in the ground, the appearances would be exactly the same. This phænomenon occurs again at Hasborough: the line of crushed wood, leaves, grass, &c., frequently forming a bed of peat, extends just above low-water mark. About this stratum are found numerous remains of mammalia, the horns and bones of at least four kinds of deer, the ox, the horse, hippopotamus, rhinoceros, and elephant. These fossil remains are found at Hasborough and its neighbourhood on the denuded clay shore: at Mundesley they are found in the cliff. The great mine, however, is in the sea, some miles from land, where there is an oyster bed on a stratum of gravel about six fathoms deep. How far this bed of fossils extends, I cannot pretend to say, but in 1826 some fishermen while dredging for soles

* Geology of E. Norfolk, p. 21.

on 'the knowl,' a bank 20 miles off shore, brought up an entire tusk of an elephant nine feet six inches long. The elephants must have been abundant; I have at least 70 grinders, and the oyster dredgers reported that they had fished up immense quantities and thrown them into deep water, as they greatly obstructed their nets *."

Mr. Woodward had previously spoken of the same oyster bed, which was discovered off Hasborough in the year 1820, and says that during the first twelve months, many hundred specimens of the molar teeth of the elephant were dredged up by the fishermen, and that the remains of upwards of 500 animals must have been found there †.

I was not so fortunate either here or elsewhere on this coast as to see the stools of trees erect in this stratum, but so many independent eye-witnesses have lately described them to me with such minuteness as to leave in my mind no doubt of the fact. Besides the accounts of several fishermen, Mr. Simeon Simons of Cromer states, that at Cromer he saw ten or more trees in the space of half an acre exposed below the cliffs eastward of that town, the stumps being a few inches, or all less than a foot in vertical height, some of them no less than 9 or 10 feet in girth, the roots spreading from them on all sides throughout a space twenty feet in diameter. Many others were seen by him laid open on the beach opposite Sidestrand, about three miles further to the eastward, evidently belonging also to a submerged forest. All these roots were in a laminated blue clay, with associated blue sand, the whole, six or seven feet thick, resting on chalk. In one place a thin layer of Norwich crag intervenes between the chalk and the bed of blue clay with lignite. Shells had been found immediately below the roots, but I have been unable to obtain them.

I ascertained that at Woolcot Gap, between Hasborough and Bacton, the bed of lignite, containing the bones of elephants, pieces of wood, and the roots of trees *in situ*, had been exposed at the base of the cliff in the preceding winter of 1838–39. A mass of incumbent drift about 30 feet thick must have been removed by the waves and currents, in order to lay open this lignite on the spot alluded to, and the great extent of the submerged forest is proved not only by the numerous points between Paling and Runton, which are about 18 miles apart, reckoning by the sea-coast, and nearly as far in a direct line, but also by the proofs afforded of its extension inland in proportion as the overlying beds are swept away by denudation.

It follows then from the facts above stated that the chalk in this region had been overspread with layers of sand and

* Rev. James Layton, cited in Fairholme's Geology, p. 281.

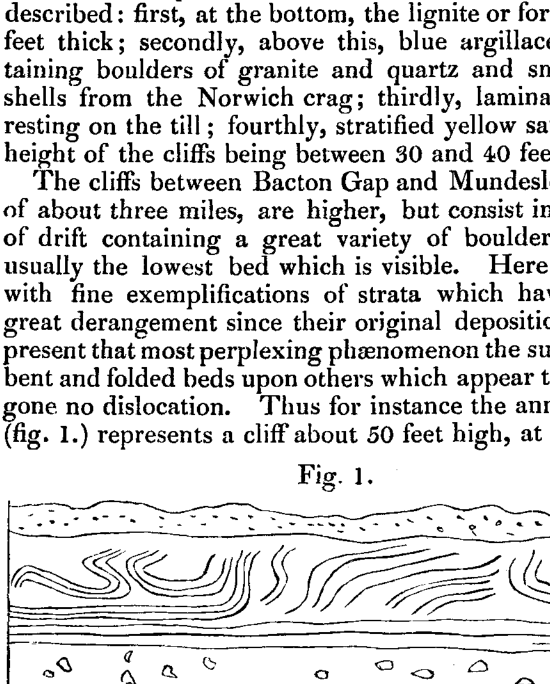
† Geol. of Norfolk, pp. 7 and 23.

clay, and converted into dry land, on which forest trees lived; these were afterwards submerged, broken off short near their roots, and buried with their branches and leaves. The subsidence implied by the submergence of the forest continued afterwards, so as to allow of the superposition of a considerable thickness of stratified and unstratified drift.

The general character of the cliffs between Hasborough and Bacton Gap, a distance of about three miles, may be thus described: first, at the bottom, the lignite or forest bed, a few feet thick; secondly, above this, blue argillaceous till, containing boulders of granite and quartz and small pieces of shells from the Norwich crag; thirdly, laminated blue clay resting on the till; fourthly, stratified yellow sand, the entire height of the cliffs being between 30 and 40 feet.

The cliffs between Bacton Gap and Mundesley, a distance of about three miles, are higher, but consist in like manner of drift containing a great variety of boulders, this being usually the lowest bed which is visible. Here we first meet with fine exemplifications of strata which have undergone great derangement since their original deposition, and which present that most perplexing phænomenon the superposition of bent and folded beds upon others which appear to have undergone no dislocation. Thus for instance the annexed section (fig. 1.) represents a cliff about 50 feet high, at the bottom of

Fig. 1.



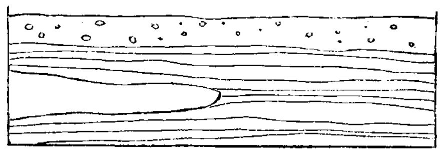
Cliff 50 *feet high between Bacton Gap and Mundesley.*

which is *till* containing boulders, having an even horizontal surface on which repose beds of laminated clay and sand about 5 feet thick, which in their turn are succeeded by vertical, bent, and contorted beds of sand and loam 20 feet thick, the whole being covered by flint gravel. Now the curves of the various coloured beds of loose sand, loam, and gravel are so complicated, that not only may we sometimes find portions of them which maintain their verticality to a height of 10 or 15 feet, but the replication is often such that a continuous seam of fine loose sand between two layers of gravel or loam might be pierced three times in one perpendicular boring. As it is clear that some of the underlying horizontal beds, and apparently the till also, of which the surface is so even, have not participated in these movements even in the smallest degree, we are compelled to suppose that some lateral force has been exerted against the upper masses of drift which has not been applied to the lower ones. Yielding beds having a thickness of at least 15 or 20 feet must in some cases have been subjected to this sideway pressure and moved bodily; and it is impossible to conceive that any original irregularity in the mode of deposition, nor any shrinking or settling of the materials, nor anything in short but mechanical violence, could have produced such complicated folds. Commonly we are in the habit of attributing such movements to a subterranean force acting from below, but it is difficult to imagine how such agency could have disturbed the overlying beds without affecting the subjacent. I shall defer to the sequel the consideration of the various hypotheses which may be suggested to account for such appearances, first describing other irregularities and apparent anomalies which present themselves in this same line of cliffs.

At one spot between Bacton and Mundesley, where the cliff is 50 feet high, I observed at a depth of 30 feet from the top, a small pit or furrow as it were cut into strata of blue clay, and filled with fragmentary white chalk and chalk flint, regular strata of sand and loam being superimposed. This indentation was four feet deep and six wide, and precisely resembles those irregularities which we see in superficial gravel; and they may all be explained if we suppose, that during the subsidence which is indicated by the buried forest, the drift of the mud cliffs was formed in very shallow water, so as to be exposed to the denudation of small streams or currents, by which narrow grooves and hollows were excavated, then filled with drift, and then, after the sinking of the whole, overspread with regular strata.

Freshwater Strata at Mundesley. — Both to the north and south of Mundesley, the cliffs, varying in general from 40 to 70 feet in height, consist in their lower part of blue clay or till, covered with stratified yellow sand and loam; but at the town of Mundesley itself the cliff lowers to a height of between 20 and 30 feet, and for several hundred yards is occupied by a freshwater deposit, covered with about 10 feet of flint gravel. The freshwater beds consist of brown, black, and grey sand and loam, mixed with vegetable matter, sometimes almost passing into a kind of peaty earth containing much pyrites. A few layers also of gravel occur composed of rounded flint pebbles. These beds are often irregular and rarely continuous for great distances. The bottom of the deposit is unseen, but is probably not much below the level of the sea, as Mr. Simons of Cromer tells me that he has seen chalk *in situ* at Mundesley at low water. In 1829 I observed a mass of the till prolonged in such a way into the freshwater formation at the southern junction of the latter with the drift as to imply the contemporaneous origin of the lower part at least of both formations. (See diagram, fig. 2.)

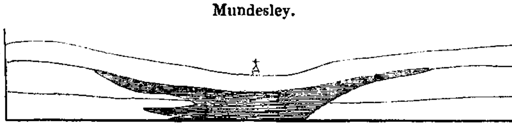
Fig. 2.



Interstratification of drift and freshwater at Mundesley.

Yet I inclined then to the conclusion that the Mundesley formation, which I traced for nearly 300 yards along the coast, might, as a whole, be considered as the deposit of a lake or hollow excavated in the drift. In 1839, when a new section had been laid open by the sea, it appeared to me rather that these strata of Mundesley were simply a large development of those observable at the base of the cliff at Hasborough and other places, and that their position relatively to the drift might be represented by the diagram, fig. 3.

Fig. 3.



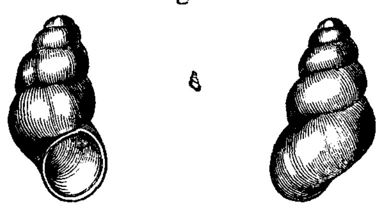
Position of the freshwater beds at Mundesley.

We may imagine that while the coast was sinking gradually, a small river may have entered here bringing down drift wood, freshwater shells, mud, and sand, and the flow of the stream may have partially counteracted those causes by the influence of which the boulder formation was accumulating in the spaces immediately contiguous. The following is a list of the shells which I obtained from the Mundesley beds, including some which Mr. Fitch of Norwich, and others which Mr. J. B. Wigham have kindly communicated to me: 1. *Paludina impura*; 2. *P. minuta*, Strickland, (see fig. 4); 3. *Valvata cristata*; 4. *V. piscinalis*; 5. *Limnea glutinosa*; 6. *L. peregra*; 7. *Planorbis albus*, var. (less flat, and aperture less oblique than the common form); 8. *P. vortex*; 9. *P. lævis*, Alder, Newcastle Trans.; 10. *Cyclas pusilla*; 11. *C. cornea.*

Specimens of *Unio* or *Anodon* occur, but too imperfect to be determined; one however resembles *A. cygneus.*

Of the eleven shells above enumerated, the only one which is unknown as a living species is the *Paludina minuta*, found by Mr. Strickland in a freshwater deposit at Crophorn, in Worcestershire, and also by Mr. Wood at Stutton on the Stour in Suffolk. Mr. George Sowerby, who has examined this species for me, finds that among recent species it agrees most nearly with the *Turbo thermalis*, Lin., as its volutions are exactly *four*: its apex is more obtuse and its volutions are more ventricose than in other recent species, and it is constantly smaller. (See fig. 4.)

Fig. 4.



Paludina minuta, from the freshwater beds at Mundesley; the middle figure is of the natural size.

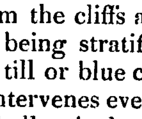
Insects.—The elytra of beetles are not uncommon in the clay of Mundesley, especially those of the genus Donacia, a tribe which frequents marshy grounds. The beautiful green and gold colours of these wing cases are almost as bright when first the clay is removed as in the living insect, but they soon lose a great part of their lustre on exposure to the light. Mr. Curtis, to whom I am indebted for an examination of these fossils, says that there appear to be two species of Donacia, (one of them *D. linearis*?) both probably identical with recent British insects; and among the other remains he found the thorax of an Elater, and the elytron of one of the Harpalidæ (*H. ophonus* or *H. argutor*). He also refers with confidence another elytron to *Copris lunaris*, a British beetle.

Fish.—I found many scales of fish, together with one large tooth, at Mundesley, and Mr. J. B. Wigham sent me similar remains, together with a smaller tooth, and some vertebræ and ribs of fish. These I submitted to the Rev. Leonard Jenyns and Mr. Yarrell, who referred them to the genera Perch, Carp, Pike, and Trout. The pike appears both by the teeth and scales to be the common *Esox lucius*. Of the salmo there were several small and one large scale, in which the concentric striæ of growth were extremely minute; the species was not determined. The scales of the perch were very numerous, but they did not agree in a satisfactory manner with those of the common British *Perca fluviatilis* which we were able to procure. The cilia of the free edges were proportionally smaller and blunter in the fossil, and the divisions in the fan at the basal extremity were longer and more numerous. But a more extensive comparison might perhaps have enabled us to identify these fossil scales with those of the living European perch. Most of the vertebræ and ribs may probably belong to this same fish.

Mammalia.—I was informed at Mundesley, that many years ago, when a zigzag road was cut down to the beach, the horns of the Irish elk were found in the cliffs, but I know not where they are preserved and by what naturalist they were seen, nor whether they were found in the freshwater deposit, as is most probable, or the overlying gravel.

Plants.—Among the vegetable fossils the most common and best preserved are the seed-vessels of an aquatic plant which Mr. R. Brown refers to *Ceratophyllum demersum*, English Botany, 947; (see fig. 5.) and I learn from Mr. J. B. Wigham, that his father considers the remains of the accompanying trees and shrubs to be those of the oak, alder, fir, and bramble; but more specimens will be required before a perfect reliance can be placed on these last determinations.

Fig. 5.



Seed vessel of *Ceratophyllum demersum*; Mundesley.

Between Mundesley and Trimmingham the cliffs are composed as usual of drift, the upper part being stratified and more sandy, the lower part consisting of till or blue clay with pieces of white chalk. Whether there intervenes everywhere between this drift and the fundamental chalk a bed of lignite like that of Hasborough or Mundesley, I was prevented from ascertaining by the height of the beach, but I found a substratum of this kind with numerous flattened leaves and branches at the base of a cliff 70 feet high about a mile northwest of Mundesley.

Protuberances of chalk near Trimmingham.—We have now followed the mud cliffs for a distance of about eight miles without finding any chalk *in situ* above the mean level of the sea, but near Trimmingham are three remarkable protuberances of chalk which rise up and form a part of lofty cliffs, the remainder of which consists entirely of drift. These detached masses or outliers of chalk were noticed in Mr. Greenough's map of England, and are described by Mr.

R. C. Taylor, who had opportunities of observing them at low tide as being continuous with the solid bed of chalk extending under the sea for nearly a mile from Trimmingham to Sidestrand, constituting everywhere under water a level platform. He also says that the chalk of this platform contains throughout parallel strata of flint, is harder than that of Cromer or Norwich, is characterized by several peculiar fossils, and occupies, he thinks, a higher place in the series than the chalk at Norwich *.

Now the platform here alluded to is evidently what the sea has left after sweeping away by gradual denudation all that once rose above low water, and it is therefore impossible for us now to conjecture to what height the chalk thus removed may once have risen. The most southern of the three protuberances before mentioned occurs near the Beacon hill, about half way between Mundesley and Trimmingham, and it is in contact with stratified drift the beds of which are highly inclined. The mass of chalk is about 20 feet in height, its extent along the beach about 100 feet, and its thickness from the beach inland a few yards only. It stands up like a narrow wall, which will ultimately be destroyed, and then the whole face of the cliff will consist of clay sand and gravel.

The surface of this wall of chalk, where in contact with the drift, dips inland at an angle of about 45°, and the beds of the newer deposit conform to this slope. As the chalk offers more resistance to the waves than the drift, a small promontory is produced at this point, which projects about 40 feet beyond the general coast line, and by aid of this promontory we are able to see the junction of the chalk and newer beds, both on the north and south side, so that the relative position of the two formations is very clearly ascertained (see fig. 6.)

When I visited this spot in 1829, I found the cliff nearly in the same state as it remained in 1839, and the description which I gave of it in the Principles of Geology would still be appropriate †.

But when last there I was able to examine the entire structure of this cliff more thoroughly, and I was more fully confirmed in my opinion that both the chalk and incumbent formation, for the thickness of several hundred feet, must have been subject to some common movement, whether sudden or gradual, by which the strata of both have been tilted.

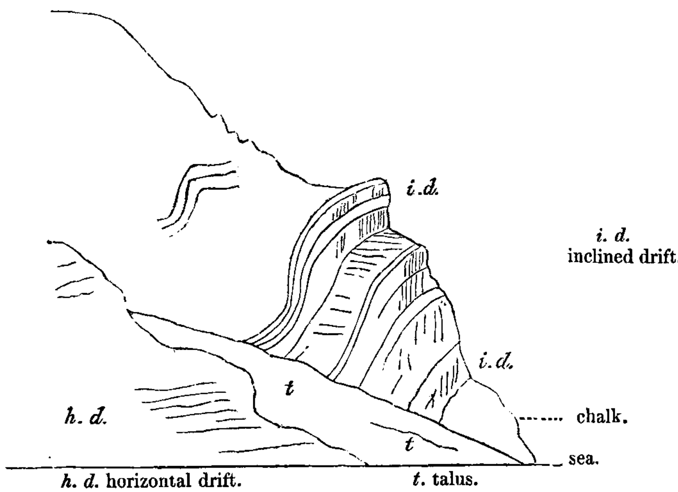
The annexed view of the promontory (fig. 6.) was taken from a point on the sloping cliff a few hundred yards to the south, where the beds have already recovered their hori-

* Geol. Trans., vol. i. 2nd series, p. 376.

† Vol. iii. 1st edit. p. 179, or 5th edit. vol. iv. p. 85.

zontality, although they seem to correspond to the beds of

Fig. 6.



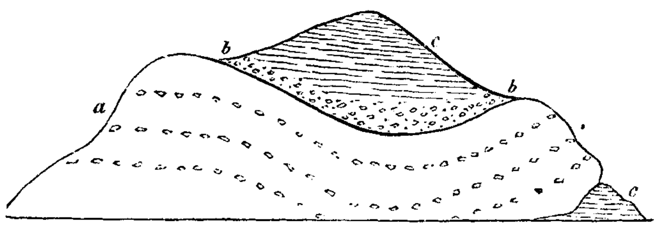
Southernmost protuberance of chalk, Trimmingham.

sand and clay which are so highly inclined near their point of contact with the chalk. In the diagram it will be seen that from the projecting point of chalk the cliff retires in a series of ledges and small precipices in which inclined beds of drift, *i, d,* are exposed for an aggregate thickness of several hundred feet. At the top of the cliff, which I conjecture to be about 400 feet above the sea, the beds of sand seemed to be horizontal, but these it should be observed are not immediately over the inclined beds. Respecting the tilted beds which are in contact with the chalk, it will be sufficient to say that they consist of gravel, sand, clay and loam like the stratified drift before described, that the clays are occasionally finely laminated, and that broken fragments of Norwich crag shells are dispersed through some of the strata; but there are no signs here of the freshwater or lignite beds.

The second or middle protuberance of chalk is near that last described: its front along the shore measured in 1839, 65 yards. Its height was between 15 and 20 feet.

The third and most considerable mass extends along the beach for a distance of 106 yards, (see fig. 7.) and its position deserves particular notice, for it forms like the southernmost mass a projecting promontory about thirty yards beyond the general line of cliff. On both sides of this promontory it is seen that the beds of gravel, clay and sand which abut against the wall of chalk are vertical, (see diagram, fig. 8.) yet the beds of the same formation have but a moderate inclination

Fig. 7.



Northern protuberance of chalk, Trimmingham.

a. Chalk with flints.
b. Gravel of broken and half-rounded flints.
c. Laminated blue clay.

in the lofty cliff behind. A layer of chalk flints *in situ* shows that the stratification of the chalk itself is nearly vertical at least in one place, although the beds seen in a large cave facing the sea show a slight curvature only. Where the chalk joins the drift on the southern or Mundesley side of the promontory, I observed in 1839, at the junction, 1st, a portion of the chalk itself decomposed, then a vertical bed of gravel, (*g*, fig. 8) 30 feet high and several feet thick, then dark blue clay with white chalk pebbles, then sandy, and then other beds of ordinary drift. Some of these disturbed beds contain fragments

Fig. 8.

t. talus. *Side view of the same.*

of marine crag shells, as *Cyprina*, *Cardium*, *Tellina*, &c. I have stated in the Principles* that this mass of chalk at its northern edge, or towards Trimmingham, actually overlies some beds of blue clay or drift as at the right hand extremity of fig. 7. Now this remarkable superposition was still evident in June 1839, notwithstanding the unusual height of the sea

* Vol. iii. p. 180, 1st edit., and vol. iv. p. 86, 5th edit.

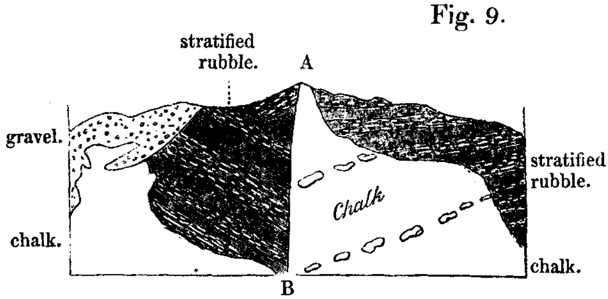
beach, the clay, containing broken chalk flints, being traceable for seven feet under the chalk. It is known to have extended formerly much further in a seaward direction. It appeared to me impossible that any landslips or movements of the present cliffs could have given rise to this inverted position of the chalk and newer formation. Some persons employed in the Preventive Service assured me that the cliffs immediately above and behind this chalk are upwards of 400 feet high, but they appeared to me less elevated. They also said that in digging a well at Trimmingham at the top of the cliff they reached chalk at a depth of 120 feet from the surface. Without insisting on the precise accuracy of their measurements, I think it by no means improbable that the three protuberances of chalk may belong to a much larger mass, which still forms the nucleus of, the hill called Trimmingham Beacon, and I have no doubt, that as the sea encroaches, the chalk will eventually occupy more of the cliffs between Trimmingham and Cromer.

In like manner it may be observed that in other localities further to the north these masses of chalk are included in drift, or where strata of white chalk rubble enter largely into the composition of the cliffs we always find the chalk cropping out in the interior at a short distance from the shore.

In speculating on the time when, and the manner in which, the protuberances of chalk near Trimmingham have been brought into their present position, we may safely assume that the event happened after the deposition of the greater part of the drift, which has been subjected to precisely the same movements, and abuts in some places in vertical beds against the wall of displaced chalk. As the submerged forest before mentioned occurs both to the north and south of Trimmingham at about the level of low water, we must suppose that the Trimmingham cliffs have participated in the subsidence of 300 or 400 feet, and in the subsequent upheaval to an equal amount which the buried forest has undergone. If we imagine the drift to have accumulated gradually while the first or downward movement was going on, we must conclude that the disturbance of the beds did not take place till nearly the whole of this movement was completed; for had it occurred sooner, the upper beds in the Trimmingham cliffs would have been unconformable to the lower ones, whereas they are seen to be conformable throughout a thickness of at least two or three hundred feet of the beds above the chalk. I conceive therefore that the deranged position of the chalk and newer formation was more probably effected during or after the upheaval of the mass, and must in that case have been a very modern event. Although there is an obvious connexion between the amount of derangement of the newer strata and their proximity to the outliers of chalk, I saw nevertheless no signs of the masses of solid chalk having pierced the newer beds, as if forced through them; on the contrary, it appeared to me in every case, that the lowest bed of the drift, whether inclined at a high angle or vertical, conformed everywhere to the surface of the chalk, as if the same bed might have been originally in contact with it when horizontal. The chalk itself appears to have been in a flexible state, and therefore its beds of flint are variously bent.

Proceeding northwards from Trimmingham, we find the cliffs near Overstrand, about a mile S.E. of Cromer, entirely composed of clay and sand; but this drift does not continue far inland, and if the sea should advance for a few hundred yards, we might expect to see the whole cliff composed of chalk; for at the surface at Overstrand, a chalk pit is worked in which the very disturbed and shattered state of the chalk deserves notice.

Fig. 9.



Disturbed chalk in a pit at Overstrand, near Cromer.

In one part of the quarry we find what appears to be a fault, the line A B (fig. 9.) representing 18 feet in vertical height, where the solid chalk with flints, inclined at about an angle of 40°, comes abruptly in contact with alternating beds of white chalk rubble and gravel having an opposite dip, also at an angle of about 40°. After removing part of the chalk rubble I ascertained that the plane of the fault was continuous inwards at right angles to the line of section represented in the annexed diagram. The inclined chalk is covered by beds of stratified rubble resembling those before mentioned.

I stated that there were no signs of the submerged forest or freshwater deposit at the junction of the drift and chalk at Trimmingham, but this forest has been seen by Mr. Simons, about a mile and a half north-west of Trimmingham, at a place called Sidestrand, where the cliff, composed of drift, is 120 feet high. When I was there the base of the cliff was concealed by a high beach; but when this is removed, beds of laminated blue clay and sand, 6 or 7 feet thick, make their appearance, in which are some trunks of trees 3 feet in diameter, broken off to within a few inches of the roots, which spread for a distance of several feet on all sides. At one point near the bottom of this cliff a stratum of clay has been seen, in which freshwater shells of the genus *Unio*, apparently *U. ovalis*, abound.

At the town of Cromer itself, Mr. Simons has observed beneath the drift, several feet below low-water mark, a bed of lignite, in which were found the seeds of plants, and the wing-case of a beetle.

Norwich crag at Cromer.—At a still lower level than the freshwater beds last mentioned, and only exposed at very low water, is a thin bed of Norwich crag *in situ*, about one foot thick, resting immediately on the chalk. It was barely visible at low tide on the west side of the jetty when I visited Cromer, but with the assistance of Mr. Simons, I obtained many fragments in which pebbles, sand, and shells were aggregated together by a ferruginous cement. The most abundant shells were the *Purpura crispata*, Min. Con., *Tellina solidula*, and *Littorina littorea*, both the common form and the variety called *L. squalida*; I found also a *Fusus contrarius* and *F. striatus*, and *Cyprina islandica*, but I could detect no small or delicate shells, and the deposit had the appearance of having been formed in a shallow sea, and not in still water.

Although the deposit at Cromer varies slightly at each new spot where we examine it, it appears from repeated observations of Mr. Simons that the following section would give a fair representation of the whole: first, chalk, with horizontal surface; 2ndly, Norwich crag, with marine shells, from 1 to 2 feet thick; 3rdly, laminated blue clay, with pyrites, and the bones of mammalia, 8 feet. The upper part of this clay is at about high-water mark, and it forms the beach; 4thly, above high-water mark, layers of pure sand alternating with blue clay, with occasionally patches of gravel. In these beds the bones of mammalia occur and lignite abounds, thickness 10 feet. To these horizontal strata succeed the curved beds of drift, partly argillaceous and partly white and yellow sand, with imbedded masses of chalk and chalk rubble, the whole 60 feet thick.

Among the mammalian remains found on the beach and chiefly *in situ* in the blue clay, No. 3, Mr. Owen has recognized the following: 1. Teeth of *Elephas primigenius*; 2.

tooth of rhinoceros; 3. teeth of horse, the largest which Mr. Owen has ever seen fossil; its longest transverse diameter is 1 inch 4-10ths, which, however, does not exceed that of large living individuals; 4. bones of the ox; 5. horns and bones of a deer of the size of the red deer, and the base of a shed horn of the same; 6. a smaller species of deer; 7. lower jaw left ramus of the beaver, a species larger than the living one and apparently distinct. Among other characters the anterior molar of the lower jaw has a much greater proportional breadth.

The wood collected from the lignite bed, No. 4, is coniferous, and a cone which Mr. Simons procured from the same bed is certainly not the Scotch fir. Mr. R. Brown, who has examined it, has little doubt that it belongs to *Pinus abies*, or the spruce fir, a northern species not indigenous to Britain.

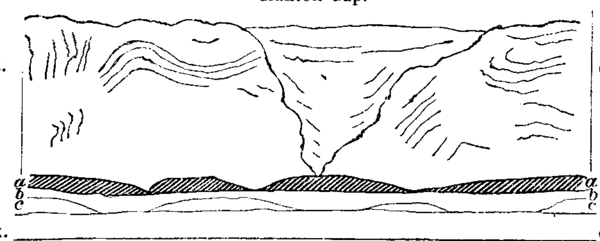
Cromer is the most south-eastern point on this coast at which I observed yellow ferruginous crag; but a blue sand containing the same marine shells has been traced for more than a mile further in that direction by Mr. Simons; and I have lately learnt from Mr. J. B. Wigham, that at Bacton Gap before mentioned, about 8½ miles distant in a straight line from Cromer, the hard ferruginous crag has been found immediately on the chalk. At that place, besides some of the usual shells, teeth of a small rodent (*arvicola*?) have been found, as at Norwich. About a mile *westward* of Cromer the crag re-appears, and again at Runton, as will be presently mentioned.

Freshwater strata of Runton between Cromer and Weybourne.—I shall mention here the only locality in which the freshwater deposit has been seen beyond Cromer, namely, at about 2½ miles N.E. of that town, on both sides of West Runton gap. Here it contains many shells as at Mundesley, and its position is unequivocally at the bottom of the drift, and immediately over the fundamental chalk, which is covered with patches of crag as at Cromer.

Thesection seen here on both sides of the gap consists, first, of drift, having its usual characters and irregularly curved stratification, and including small dispersed fragments of crag shells, its thickness being 60 feet and upwards. At the bottom of this the freshwater deposit occurs in patches of black earth from 3 to 5 feet thick, under which is a bed of reddish sand about 3 feet thick with freshwater shells in its upper part, and below this the crag in a discontinuous stratum less than a foot in thickness. The fundamental chalk contains large flints or paramoudræ. The lower part of the section beneath the black earth was covered up in June last, but exposed to view in March, and examined by Mr. Simons.

Fig. 10.

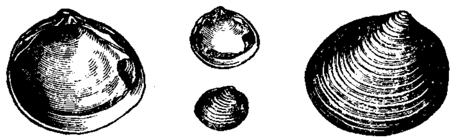
Runton Gap.



a. Black earth with shells } freshwater.
b. Reddish sand }
c. Norwich crag in patches.

I shall now describe, first the freshwater beds and their fossils, and then the fossils of the subjacent layer of crag. The black earth is heavy and turns greenish when dried. It is sometimes divisible into layers, on the surface of which shells are seen in a compressed state; but this is not always the case, the shells being often uninjured and irregularly dispersed. Although the colour of this earth is doubtless due to vegetable matter, I have not found seeds in it, but occasionally small pieces of wood. The most shelly portions which I have seen were sent to me before my last visit to Norfolk, through the kindness of Robert Fitch, Esq., of Norwich. The red sand below resembles the crag in colour and contains the same shells, of which the following is a list, all of which have been examined by Mr. G. Sowerby: 1. *Paludina vivipara.* 2. *P. impura.* 3. *Valvata piscinalis.* 4. *Limnea palustris.* 5. *L. stagnalis.* 6. *Planorbis imbricatus.* 7. *P. albus.* 8. *P. marginatus.* 9. *Ancylus lacustris.* 10. *Cyclas cornea.* 11. *C. appendiculata.* 12. *C. amnica*, var.? Besides these is a small shell allied to *Turbo ulvæ*, but apparently different, of which I only procured one individual; also fragments of Anodon. Among these twelve species the only one which could not be identified with well-known British living species is the *Cyclas*, resembling *C. amnica.* It belongs to the sub-genus *Pisidium*, and is remarkable, says Mr. G. Sowerby, "for its great proportional altitude, in which respect it differs not only from the recent *P. amnicum*, but also from the fossil variety of *P. amnicum*, found at Grays in Essex. The concentric ridges on the outside of each valve are much more prominent than in the recent *P. amnicum*, particularly near the beaks, and in this circumstance they resemble the Grays fossil var. of *amnicum*. The shell appears to be rather thicker than the recent *P. amnicum*, and the teeth stronger: see fig. 11.

Fig. 11.



Cyclas (*Pisidium*) *amnica*, var.?

From the freshwater beds at Runton. The two middle figures are of the natural size.

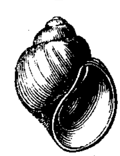
Neither here nor at Mundesley was I able to find *Cyrena trigonula*, which however we might have expected to discover in these beds, as it accompanies a similar assemblage of shells from various localities in Suffolk and Essex.

I found no remains of insects in the black earth, but the Hon. and Rev. R. Wilson, of Ashwell Thorpe, showed me in his collection, in 1838, the elytra of beetles of the genus *Donacia*, preserving their colours, which he had found several years before at Runton. I observed the scales of perch and of other fish resembling those of Mundesley in the black earth. Mr. Simons has also found fragments of the scapula and horns of a deer in the black earth.

In general it is most difficult to speak with certainty respecting the position of fossil bones of quadrupeds derived from the mud cliffs, because they have been picked up at the base of the cliff after portions of it had been washed away by the sea. It is the opinion, however, of collectors that they are chiefly derived from strata, in which the lignite and submerged trees occur. The remains are those of the elephant, rhinoceros, hippopotamus, horse, ox, pig, beaver, deer, &c. At Cromer and Weybourne some mammalian bones occur in the crag, but they are commonly more rolled and worn than those derived from the lignite deposits. Unfortunately no freshwater shells have yet been obtained from precisely the same bed as that in which the bones of the elephant and other extinct quadrupeds are met with, nor from the stratum in which the stools of buried trees are enveloped. The freshwater shells of Mundesley and Runton, although they may probably belong to the same formation, are not yet proved to be strictly coeval with the extinct quadrupeds. The present state, therefore, of our knowledge would not enable us to enter into minute details in regard to the order of superposition of the beds between the chalk and drift in the mud cliffs, but it would appear that the principal site of the bones of extinct mammalia as well as of the buried forest and lignite is between the marine crag and those beds from which freshwater shells have been procured.

Crag at Runton.—In the patches of marine crag below the freshwater at Runton, the following shells have been found and presented to me by Mr. Simons: 1. *Fusus striatus.* 2. *Scalaria grænlandica.* 3. *Littorina littorea.* 4. *Natica helicoides*, Johnston, (see fig. 12.). 5. *Tellina obliqua.* 6. *T. solidula.* 7. *Cardium edule*, and a fragment of a *Helix*.

Fig. 12.



Natica helicoides, Johnston; from the crag at Runton, near Cromer.

The shell which I have called *N. helicoides* is identical with No. 58. in my list of Norwich crag shells published in the Mag. Nat. Hist., vol. iii. new series, 1839, p. 313. I have given it there as a new and extinct species, stating, that it resembled in shape *Paludina solida*, Say. I afterwards learnt from Mr. Edward Forbes that it had been found recent on our east coast in Berwick Bay, and published by Dr. Johnston in the Berwick Transactions, 1835, under the name of *N. helicoides.* That gentleman has since sent me the recent shell, which is quite identical with the fossil figured above. The species is remarkable for departing from the normal form of the genus *Natica*. It seems to have been much more abundant in the sea of the Norwich crag than in our own sea at present.

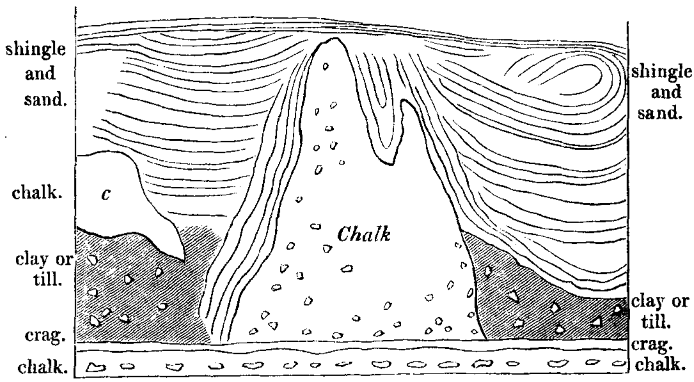
Cliffs between Cromer and Sherringham. — The drift near Cromer and to the north of it includes a much larger quantity of chalk rubble than to the southward, and huge fragments of chalk itself are sometimes intercalated in a manner which is very difficult of explanation. It is often no easy matter to decide whether the largest of the chalky masses associated with drift have been regenerated or not, in other words whether they have been brought piecemeal or in mass into their present position; but there are some clear and unequivocal exemplifications of both of these modes of transport. Some of the enormous fragments of chalk which are interstratified with drift have not only layers of undisturbed flints, but also sandpipes in the middle of them, or cylindrical cavities filled with sand and gravel, such as are found penetrating the chalk at various depths from the surface in the interior of Norfolk. These pipes seem to me to imply that such masses of chalk were once at or near the surface of emerged land, but a hasty observer seeing such patches of sand or pebbles in the middle of the chalk might suppose the whole mass to have been broken up and then redeposited, whereas in fact it has been brought bodily into its present position. The intercalated masses of unregenerated chalk are sometimes horizontal, sometimes vertical. Of the former I observed an example near West or Upper Runton, where a mass of chalk marl 15 feet thick, which I could not distinguish from undisturbed chalk, reposed on stratified blue clay 20 feet thick, and was again covered by stratified loam 30 feet thick.

The most remarkable example which I saw of a mass of chalk protruding in the midst of the drift adjoins to Old Hythe Gap about three quarters of a mile west of Sherringham: it is represented on a small scale by Mr. R. C. Taylor in his coast section, though nowhere described as far as I am aware. I found the shape of this mass considerably altered between the years 1829 and 1839, and by a comparison of its appearance at these two periods, I was able to form a more correct idea of its relative position to the chalk and drift than I could possibly have done during a single visit. In order to understand the peculiar position of this great outlier, the reader must be informed, that the fundamental chalk, which at Cromer does not rise above low water, begins, immediately west of Sherringham, to rise and form a ledge a few feet above high-water mark, being usually covered by a hard breccia of crag, commonly called *the pan*, nearly 1 foot thick. The waves at high tides and during storms wash over this ledge, and sweep away the more destructible clay, sand, and gravel of the overlying drift, which is thus made to recede four or five feet inward from the beach or seaward termination of the ledge of chalk. The chalk thus clearly exposed is seen by its horizontal layers of flint to be undisturbed.

The drift sometimes reposes in horizontal and sometimes in curved beds on the pan or ferruginous breccia of crag. At Old Hythe point above mentioned, the beds of drift suddenly become vertical for a height of nearly 70 feet, and flank an enormous pinnacle of chalk between 70 and 80 feet in height, (see fig. 13), which is enveloped in drift.

In this figure the fundamental chalk is seen at the bottom with its horizontal flints, and immediately upon the chalk the pan or layer of consolidated crag, continuous in this spot and varying in thickness from 6 to 12 inches. It contains large chalk flints and fragments of shells cemented by oxide of iron. The broken shells are abundant at some spots. Among them were observed *Cyprina islandica*, *Tellina solidula*, *Mya arenaria ? Cardium* ——, *Littorina littorea*, *Fusus striatus*, *Balanus* ——. Next above the crag is the huge pinnacle or needle of chalk, distinctly separated from the fundamental chalk by "the pan." Chalk flints are scattered somewhat irregularly through the outlier of chalk, which is distinctly forked in its upper extremity. It will be seen that the pinna-

Fig. 13.



*Included pinnacle of chalk at Old Hythe point, west of Sherringham**.

cle is flanked on both sides by drift: that on the east, or Sherringham side (left of the diagram), consists of alternate layers of loam, clay, and white chalk rubble several feet thick, which must have been deposited horizontally although now vertical. These are traceable from within a few yards of the pan to near the summit of the chalk, for a height of 60 feet or more. Between the two prongs of the fork, near the top of the cliff, are curved beds of drift. On the western or right side of the pinnacle the beds of drift are not the same as those on the left. They consist first, and nearest to the chalk, of strata of flinty gravel; secondly, layers of sand with round flint pebbles; thirdly, loose yellow sand, alternating with loam. These join on to curved beds of drift, which are represented near the top of the cliff on the right of the diagram—innumerable layers of sand and shingle, some of them bent round upon themselves and containing seams of carbonaceous matter, or in other places small white pieces of broken shells. Near the bottom of the section argillaceous till rests immediately on the crag, and on one side comes in contact with the chalk pinnacle near its base. Through this till small pieces of chalk and flint are interspersed. Another included fragment of chalk (*c*) occurs nearly half-way up the cliff, enveloped in drift to the westward of the pinnacle.

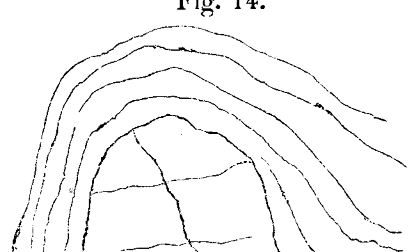
* This sketch is taken principally from my own drawing, but corrected from a view by Mr. Simons taken in March 1840, when the waves during a storm had reached about 8 feet above the level of the pan or crag, removing the talus which previously masked the junction.

The most singular and important circumstance connected with the great outlier of chalk at Old Hythe is the fact of its being perfectly disunited from the subjacent horizontal chalk. I could not myself positively determine this point either in 1829 or 1839, because there was a talus at the base of the vertical cliff resting on the projecting ledge of chalk and concealing the junction; but when the whole was cleared away by the waves in March 1840, after a storm, Mr. Simons visited the spot, and ascertained the continuity and infra-position of the crag which I had before inferred. My inference, previously announced to the Geological Society, was drawn from a comparison of the state of the cliff in 1839, with my sketches and memoranda made ten years before. At both periods I was able to trace the horizontal crag to within 5 feet of the base of the precipice, composed of vertical beds of drift enveloping the chalk; and as the sea had advanced greatly in the interval of ten years, the pan, had it not been continuous, must have been entirely removed before my last visit, in which case nothing could have been visible but chalk on the ledge immediately opposite the pinnacle.

From the summit of Old Hythe point the land slopes down to Old Hythe gap with a rapid descent. It also slopes, though at a less angle, directly inland, so that as the sea advances the cliff at this point will become less elevated. In 1829 the two masses of chalk appeared much more equal in size, and wrapped round as it were both on their sides and at the top with strata of shingle and drift.

Another included mass of pure chalk was also observable in 1839 between Cromer and Lower Runton near the bottom of the cliff. It was traversed by several rents, and alternating beds of laminated clay and sand were bent round it, as in the annexed diagram (fig. 14), which represents a perpendicular section 25 feet in height.

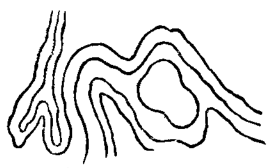
Fig. 14.



Section 25 feet high, west of Cromer.

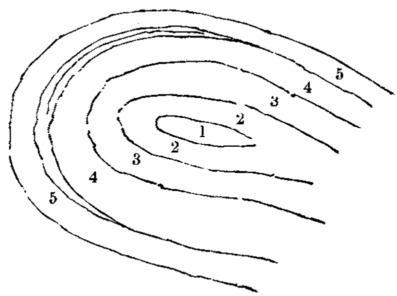
This mass, although on a smaller scale, may be compared to that of Old Hythe point (fig. 13.). It will sometimes happen, however, that the enveloping beds of drift appear to be folded completely round a nucleus of chalk or sand, or any other material found in the mud cliffs as in the annexed cut (fig. 15.) or in fig. 16, which represents a perpendicular cliff 20 feet high,

Fig. 15.



Folding of the strata between East and West Runton.

Fig. 16.



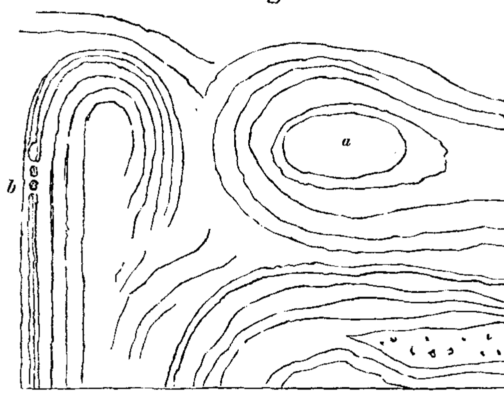
Section of concentric beds west of Cromer.

in which the beds are: 1. blue clay; 2. white sand in thin layers; 3. yellow sand; 4. striped loam and clay; 5. laminated blue clay; and I saw curves not far from this place which extended for a vertical height of 50 feet, in which 30 distinct strata, without counting the subordinate laminæ, in all 24 feet thick, presented the same concentric arrangement. The beds consisted alternately of blue clay and white sand, the bed of sand exposed in the centre being blackened by bituminous matter.

I have mentioned some of these cases of the apparent folding of the beds round a central nucleus in the Principles of Geology, especially one which occurs in the cliffs east of Sherringham, where a heap of partially rounded flints about five feet in diameter appears nearly enveloped by finely laminated strata of sand and loam, in the midst of which again is a nucleus of loam. After a more scrupulous examination of many of these cases, I have now ascertained that they are all, without exception, examples of the intersection of a series of strata which have been bent into a convex form, the apparent nucleus being in fact the innermost bed of the series, which has become partially visible by the entire removal of the protuberant part of the outer layers.

I observed a portion of a cliff 8 feet in vertical height between Beaston Hill and East Runton, in which a nucleus of very loose sand 18 inches in diameter (*a*) was surrounded by layers of clay and loam as represented in fig. 17. The vertical beds on the left side of the cut consisted of similar incoherent materials, some of the seams of sand being characterized by broken crag shells, and in one place some flint pebbles, *b*, occupying the space of several layers of loam.

Fig. 17.



Section 8 feet high of vertical and curved drift in the cliff near Runton.

Between the Runtons and Sherringham, and at a short distance from the latter place, are seen strata of vertical drift, on the one side of which are horizontal, and on the other curved and folded beds. The change in these cases from the horizontal set to the vertical is very abrupt.

Crag near Weybourne.—It is not until we arrive within less than two miles of Weybourne, that the Norwich crag appears in considerable force *in situ* above the level of the sea, in a cliff about 30 feet high, between Old Hythe Gap and Weybourne. At two different points I observed the chalk in contact with several feet of shelly sand and clay containing pebbles and the fossils of the Norwich crag without any intervening breccia or "pan." This crag was covered with clay and loam without shells.

About half a mile from Cliffend, Weybourne, the following section appeared, in a vertical cliff about 40 feet high, where I saw the greatest thickness of crag abounding in shells: 1st, horizontal chalk with flints, 8 feet; 2ndly, sand and flint pebbles with crag shells, 1 foot; 3rdly, fine sand with perfect crag shells, 10 feet; 4thly, sand and pebbles without shells, 3 feet; 5thly, unstratified clay or till with flints, 10 feet.

The following is a list of the shells obtained from this crag: *Fusus striatus*, *Littorina littorea*, *L. squalida* (var. of preceding?), *Purpura crispata*, perhaps var. of *P. lapillus*, *Cyprina islandica*, *Cardium edule*, *Cardium echinatum?* *Tellina obliqua*, *T. solidula*, *Nucula Cobboldiæ*, *Mya arenaria?* *Mactra*, *Astarte*.

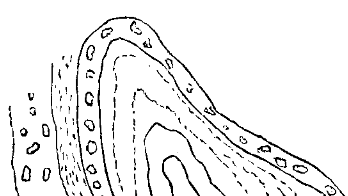
Among the above, the *Fusus striatus* and *Nucula Cobboldiæ* were very rare.

I have remarked, that westward of Sherringham, where the fundamental chalk rises a few feet above high-water mark, its surface, whether covered by the ferruginous breccia or not, is for the most part very level, a singular fact when the contortions of the overlying strata are considered. A slight exception occurs at one place near Cliffend, Weybourne, where the surface of the chalk undulates; so that in the distance of a few paces the chalk sometimes rises 12 feet above the level of the sea, then sinks to 1 foot, and then rises again to 8 feet above that level, being covered everywhere with a similarly undulating breccia made up of slightly rolled chalk flints and crag shells more or less broken.

Finally, near Weybourne, at the extreme end of the cliff, where it is 10 feet in height, the section given in the annexed diagram (fig. 18.) is seen. We here see the shelly crag subjected to the same violent movement so common elsewhere in the drift. The vertical gravel beds *a c* are separated by loose sand. Other loose sand occurs in the arch at *c c*. The crag shells in the gravel, consisting chiefly of *Cardium* and *Cyprina*, are in fragments, and the denudation of such beds may well have supplied those smaller and worn pieces of these shells which are so widely dispersed through the mud cliffs of Eastern Norfolk.

Fig. 18.

Arched beds of shelly crag at Cliffend, Weybourne; height of section 10 feet.



a, *c*. flint gravel with crag shells.
b. loose sand.

THEORETICAL CONSIDERATIONS.

Age of the deposits composing the mud cliffs.—It has been shown in the above account of the cliffs between Hasborough and Weybourne, that the chalk is everywhere the fundamental rock, lying southward of Cromer at about the level of low water, and rising on the north of that town to the height of a few yards above that level. Its surface between Cromer and Weybourne is covered with occasional patches of

Norwich crag, which is rarely more than one or two feet thick, except near Weybourne. Upon the crag, and where this is wanting immediately upon the chalk, rests here and there a lignite and freshwater formation, which varies in thickness from five to ten feet and upwards. It is seen at intervals throughout the whole line of cliff from Hasborough to Runton. In some places it resembles a bed of lignite, in others a black earth like that found in connexion with peat, while occasionally it consists of gravel, sand, clay, and marl, such as may be met with in any lacustrine deposit. In certain localities it contains the stools of trees, which remain in the position in which they originally grew, and which could only have been buried under the strata now incumbent on them by the submergence of what was once dry land. At Mundesley the freshwater formation is about 40 feet thick and occupies the whole cliff.

As both the crag and freshwater formations are extremely discontinuous in the mud cliffs, we sometimes find the one and sometimes the other in immediate contact with the chalk, while in many places both are wanting, and then the chalk is covered exclusively by drift, of which the great mass of the mud cliffs is composed. A cursory observer, indeed, might see nothing but drift from Hasborough to Cromer, except at Trimmingham, where the protuberances of chalk occur; and the section north of Cromer would seem to present little more than the same drift, with a slight exposure of chalk on the sea beach. The thin stratum of freshwater origin and the subjacent marine crag are most commonly hidden by the beach, or by the sea, except at low water.

Age of the crag.—As to the age of the crag, it agrees with that of Norwich in the species of marine shells which it contains, and the occasional presence of land shells and the rolled bones of mammalia. From the various localities above enumerated, I obtained the following eleven species of shells: *Purpura crispata*, *Fusus striatus* and *contrarius*, *Littorina littorea* and *squalida*, *Scalaria grœnlandica*, *Natica helicoides*, *Nucula Cobboldiæ*, *Cardium edule*, *Cyprina islandica*, *Tellina obliqua*, *T. solidula*, and *Mya arenaria?* All of these are known as recent except three, *Fusus striatus*, *Tellina obliqua*, and *Nucula Cobboldiæ*. It would be rash however to pretend to determine the per centage of recent species from so small a number, and the late discovery of *Natica helicoides*, one of the eleven, in a living state, should make us careful not to assume, when reasoning on these more modern deposits, that we have acquired a perfect acquaintance with the present Fauna of our seas.

Age of the freshwater deposit.—Next, as to the age of the freshwater beds, we know as yet too little of the species of mammalia, fish, insects, and plants, which are imbedded in them in considerable abundance, to entitle us to lay much stress on their evidence alone. But we have from Mundesley and Runton, at least nineteen species of shells in an excellent state of preservation, namely, *Paludina vivipara*, *P. impura*, *P. minuta*, *Valvata piscinalis*, *V. cristata*, *Limnea palustris*, *L. stagnalis*, *L. glutinosa*, *L. peregra*, *Planorbis vortex*, *P. imbricatus*, *P. albus*, *P. marginatus*, *P. lævis*, Alder, *Ancylus lacustris*, *Cyclas cornea*, *C. appendiculata*, *C. amnica*, var.? and *C. pusilla*.

Of these all but two are certainly identical with species now living in Great Britain. One of these two, *Cyclas*, fig. 11, p. 364, may possibly be a variety of our living *C. amnica*, while the other, *Paludina minuta*, fig. 4, p. 354, is unknown. I have not included in the list the shell allied to *Turbo ulvæ*, because it would be unsafe to decide on a species from a single individual; nor have I enumerated among the recent species *Anodon cygneus* and *Unio ovalis*, although there is little doubt that the freshwater mussels of Mundesley and Sidestrand belong to these species.

Upon the whole we may conclude that this freshwater deposit must agree very nearly in age with those of Stutton in Suffolk, Grays in Essex, Cropthorn in Worcestershire, and others, which contain nearly the same species, with fossil bones of extinct quadrupeds. It is still a question in all these cases, whether all the species are not living, although some few may not be British shells, or whether there is really a very slight per centage of lost species, to which opinion I incline. It will be seen that the freshwater stratum in the mud cliffs everywhere overlies the crag when in contact. Many, however, of the same species of fluviatile or lacustrine shells are found intermixed with the marine crag itself near Norwich, in which latter the same Cyclas figured above (p. 364) is met with.

Age and origin of the drift.—As to the age of the drift, it is proved by direct superposition to be newernot only than the Norwich crag, but also than the freshwater beds at Runton and Sidestrand. At the same time the section at Mundesley (fig. 2, p. 353) seems to prove, that in some places the deposition of the drift was going on contemporaneously with the accumulation of freshwater beds. To frame a satisfactory theory respecting the origin of the drift is difficult. The fluvio-marine contents of the Norwich crag imply the former existence of an estuary on the present site of parts of Norfolk and Suffolk, including the eastern coast of Norfolk. Into this estuary or bay one or many rivers entered, and in the strata then formed were imbedded the remains of animals and shells of the land, river, and sea. Certain parts of this area seem at length to have been changed from sea into low marshy land, either because the sea was filled up with sediment, or because its bottom was upheaved, or by the influence of both these causes. Two consequences followed: first, trees grew on some spaces gained from the sea; secondly, in other spots freshwater deposits were formed in ponds or lakes, and in the channels of sluggish rivers, or grounds occasionally overflowed by streams. Next succeeded a period of gradual subsidence, by which some of the lands supporting the forests were submerged, the trees broken down, and their roots and stumps buried under new strata. At the same time, the freshwater beds, whether resting on crag or immediately on chalk, became covered with drift, except in certain places, such as Mundesley, where for a small space the accumulation of drift seems to have been entirely prevented, perhaps by the continued flow of a small body of freshwater.

I have met with no fossils so imbedded in the drift as to entitle me to form any positive opinion whether it be of freshwater or marine origin. The regularly stratified arrangement of a large part of it, and the different materials of the alternating strata, clearly demonstrate that it was formed gradually, and not by any single or sudden flood. The boulders which it contains, some of large size, seem to imply, that while a great proportion of the mass may have been derived from neighbouring regions, part at least has come from a great distance. Mr. R. C. Taylor observes, that the shore to the west of Cromer exhibits a singular accumulation of travelled fragments of rocks, whence it would not be difficult to collect a tolerably illustrative series. They consist chiefly of rounded blocks of granite, basalt, porphyry, trap, micaceous schist, sandstones of various kinds, chert, breccia, besides limestone and claystone; also fragments derived from the chalk, plastic clay, London clay, green sand, Kelloway's rock, the oolites, lias, and marlstone; in fact almost every formation above the coal-measures. These, he says, are of all intermediate magnitudes up to four tons weight, large bouldered masses appearing in the sea at low water, lying mixed with flints upon the chalk. One block of granite is stated to be near six feet in diameter, and another mass, standing six or eight feet high, has for some years been known to the fishermen under the name of Black Meg. This collection extends about two miles, chiefly opposite to Beeston Hill*.

The author just cited truly remarks, that this singular assemblage of boulders must have been dislodged from the wasting cliffs, of which the softer and finer materials have been removed by currents, for similar boulders are occasionally observed in the midst of the clay or till of the cliffs.

In different parts of the interior of Norfolk, boulders weighing several tons have been found in blue clay or till†.

I stated in the first edition of my Principles of Geology that I was unable in 1829 to draw a line of demarcation between the crag and the drift or diluvium. The Rev. W. B. Clarke afterwards insisted on the distinctness of the two formations‡, in which opinion I now concur, although I am still unable, in many spots, as, for example, near Weybourne, and between Southwold and Yarmouth, to say where the crag ends and the stratified drift begins. But this difficulty arises from the absence of fossils in the crag as well as the drift, and from the fact that the strata in the latter are often as regular and continuous for considerable distances as those of the crag.

Professor Sedgwick informs me, that in the unstratified brown clay or till of certain parts of Cambridgeshire, large angular blocks of lower green sand and chalk, with fossils of the Oxford clay and lias, occur. The till alluded to attains at some points a thickness of 300 feet: it resembles that in the Norfolk mud cliffs, and has been traced over many of the adjoining counties. Its extent therefore in area and depth render its history of high importance in the geology of the east of England.

I mentioned in the beginning of this paper, that I recognized the strongest resemblance between the boulder formation which I have seen in Sweden, Denmark, Holstein, and other countries, and the drift of Norfolk; and as I believe coast-ice and icebergs to have been instrumental in transporting much of the large and small detritus in Scandinavia, so I presume that at the same period the effects of the same agency was extended to the British seas, although on a smaller scale. But while some of the Norfolk erratics may be of northern origin, other portions of the associated drift may have been brought from neighbouring regions, and perhaps in an opposite direction, just as we now observe that

* Geology of East Norfolk, p. 24, 1827.

† C. B. Rose, Geology of West Norfolk, Lond. and Edin. Phil. Mag., January 1836, p. 195.

‡ Geol. Trans., 2nd Series, vol. v., part 2, p. 363.

some granitic boulders are floated in ice from the distant shores of Labrador into the Gulf of St. Lawrence, while other large fragments of rock, together with much gravel and sand, are firmly frozen into ice and carried down every winter by various rivers into the same gulf. As the part of Canada where this drift is now forming corresponds in latitude to that of Norfolk, the adoption of this theory of ice-drift does not of necessity require us to assume the former existence of a colder climate than that now prevailing in North America.

Dr. Mitchell, in a paper on the Drift of Norfolk, Suffolk, &c., (Geol. Proc., vol. iii., p. 5) has suggested that the materials have been in great part derived from the destruction of strata which once occupied the site of the German Ocean. This conjecture is, I think, by no means improbable, and we are often too prone, when speculating on the original site of travelled boulders, to refer them exclusively to the places where similar substances happen now to be exposed above water, whereas they may often have come from a neighbouring region now submerged. The island of Heligoland for example, about forty miles off the mouth of the Elbe, has been wasting away for centuries, and in time will probably disappear. Its cliffs, from 100 to near 200 feet high, composed of marl and marlstone of the new red sandstone formation, might supply stony fragments and red mud, which if stranded by ice or other agency on the adjacent coasts of Holstein, Bremen, or Friesland, would differ entirely from the rocks occurring there *in situ*, or from any rocks met with nearer than parts of Hanover, situated 100 or 150 miles in an opposite or eastern direction. We ought always, therefore, to bear in mind, that fragments of chalk, green sand, oolite, and lias, imbedded in the drift of Norfolk and other counties, may not have come from the westward where those formations now crop out, but possibly from the N.N.E., like the erratic blocks, if some of these be really of Scandinavian origin.

The association of stratified drift with unstratified materials or till, a general character of this formation in Sweden and Scotland, as in Norfolk, has been already attributed to the possible cooperation of ice and currents of water (see p. 348).

DISTURBED POSITION OF THE STRATA.

The chalk and overlying formations seen in the cliffs between Hasborough and Weybourne may have been brought into their present contorted and dislocated position by three distinct kinds of mechanical movement; first, by ordinary upheaval and subsidence, to which geologists are accustomed to attribute the bendings, inclination, and dislocation of strata; secondly, by landslips or the sliding down of sea-cliffs, or the falling in of undermined banks of rivers or of submarine sand banks; thirdly, by the stranding of islands and bergs of ice. It is possible that all these three causes of disturbance may have co-operated to produce the complicated movements which we now behold in the cliffs under consideration.

By ordinary subterranean movement.—First, in regard to ordinary subterranean movements, a general subsidence must, I conceive, have taken place over a considerable area, in order to explain the submergence and burial of the trees of which the stools are found *in situ*; and this forest bed could not have been brought up again, together with the incumbent drift, to the level of low water, without a subsequent upheaval nearly equal in amount to the previous subsidence. But such a depression and re-elevation of a large tract may have taken place slowly and insensibly, and without any derangement of the stratification. A question would still remain, whether such protuberances of chalk as those at Trimmingham (p. 357), and the inclination or verticality of the associated drift, should be attributed to a local and violent movement from below, fracturing the chalk and thrusting up portions of it above the ordinary level of that formation. It is scarcely profitable to speculate on a subject which could only be set at rest if the section were prolonged downwards into the subjacent chalk. I have described in the Geol. Trans., vol. v., part 1, p. 243, masses of drift entangled in chalk at the top of the cliffs of Möen in Denmark; but in those lofty cliffs the section extends downwards for a depth of more than 400 feet into the underlying chalk with flints. The verticality of some of the layers of flint, the curvature of others, and numerous faults, bear testimony to such repeated convulsions, that I did not hesitate to refer the entanglement of the upper chalk and incumbent drift of Möen to subterranean movements. During those convulsions, fissures and chasms may have opened in the chalk, and masses of the superimposed boulder formation may have been engulfed.

There are many sections, such as that represented in fig. 14, p. 368, where the first hypothesis which suggests itself is the protrusion upwards of a boss of chalk, which has forced the yielding and incumbent beds to fold round it, so that the beds become perfectly vertical on the flanks of the protuberant chalk. But it frequently happens that these masses repose on chalk and crag so horizontal and undisturbed, that we are entirely precluded from the supposition of a movement from below upwards.

By landslips and slides.—The last remark leads naturally to the consideration of every combination of causes which can give rise to great disturbance in the overlying beds, while the stratification of those below remains even and unchanged. For striking examples of this phænomenon the reader is referred to figures 1 and 13, in which the superposition of vertical to horizontal drift, and of huge fragments and needles of chalk to horizontal chalk and crag, are clearly exhibited. In order to explain these sections, we may imagine that banks of mud and sand existed beneath the sea in which channels were occasionally excavated by currents. In banks of this kind off Great Yarmouth, a broad channel sixty-five feet deep was found in 1836, where there had been only a depth of four feet in 1822*. If the cliffs of loam or sand bounding this new channel give way, large masses may descend bodily and assume a vertical or curved position. They may easily escape subsequent denudation, because the direction of the currents are constantly shifting. Thus strata which have assumed a vertical position may be forced laterally against the opposite sides of the channels, where the beds have remained horizontal. Both the juxtaposition of vertical and horizontal beds, and the superposition of disturbed to undisturbed strata, may be caused in this manner. The constant descent of strips of land into river beds in the deltas of the Indus, Ganges, and Mississippi, on the subsiding of the annual inundations, are well known, and may give rise to analogous effects.

During the late landslip near Axmouth on the 24th of December 1839, a lateral movement took place, by which masses of chalk and green sand, which had been undermined, were forced more than forty feet in a seaward direction, and thrown into great confusion, while the subjacent lias was not disturbed†. The pressure moreover of the descending rocks urged the neighbouring strata extending beneath the shingle of the shore, by their state of unnatural condensation, to burst upwards in a line parallel to the coast, by which means an elevated ridge more than a mile in length, and rising more than forty feet, has been made to form an extended reef in front of the present range of cliffs. This ridge when it first rose was covered by a confused assemblage of broken strata and immense blocks of rock, invested with sea-weed and corallines, and scattered over with shells, star-fish, and other productions of the deep.

* See Elements of Geol. p. 307.

† I have been indebted to the kindness of the Rev. W.D. Conybeare for a description and section of this landslip, which I have published in the 6th edition of the Princ. of Geol. vol. ii. p. 78.

We may imagine in like manner masses of chalk and overlying drift to have fallen from cliffs, and to have been forced sideways over a floor of horizontal chalk; but it appears to me impossible, even if we adopt this hypothesis, to explain how the Old Hythe pinnacle of chalk (see p. 367) became enveloped by drift, and this drift in great part vertical and resting on horizontal crag and chalk. It seems necessary first to suppose that a needle of chalk was thrown down on horizontal drift, and then that the whole was forced by lateral pressure into a vertical position, the fundamental rocks remaining unmoved.

It cannot be objected to explanations of this kind that ancient cliffs and adjoining needles of chalk are no longer visible, because they may have existed when the country was subsiding, and they may have been removed by denudation, when brought down within the action of the waves.

By pressure of drift ice.—There is still another cause, hitherto, I believe, overlooked, by which great foldings and contortions may be produced in the upper portions of banks of sand and gravel, while the lower remain undisturbed; I mean the stranding of icebergs and large masses of packed ice. In different parts of Scotland, Sweden, Norway, and probably everywhere in Europe where drift is found containing erratic blocks, between the latitudes 50° and 70° north, coiled and folded beds of loam, gravel, and sand are frequent, and I have often seen them in Scotland resting on and covered by strata which remain horizontal.

In the account given by Messrs. Dease and Simpson of their recent arctic discoveries, we learn that in lat. about 71° N. long. 156° W. they found "a long low spit named Point Barrow, composed of gravel and coarse sand, in some parts more than a quarter of a mile broad, which the pressure of the ice had forced up into numerous mounds, that viewed from a distance assumed the appearance of huge boulder rocks*." So many facts indeed have come to my knowledge of the manner in which masses of ice, even of moderate size, in the Baltic, and still more in the Gulf of St. Lawrence, push before them large heaps of boulders, that I can scarcely doubt that lateral pressure, exerted under favourable circumstances by drift ice on banks of stratified and incoherent sand, gravel, and mud, is an adequate cause for producing considerable flexure and dislocation. The banks on which icebergs run aground occasionally between Baffin's Bay and Newfoundland are many hundred feet under water, and the force

* Journ. of Roy. Geograph. Soc., vol. viii. p. 221.

with which they are struck will depend not so much on the velocity as the momentum of the large floating islands. The same berg is often carried away by a change of the wind and then driven back again upon the same bank, or in other cases it is made to rise and fall by the waves of the ocean, and may thus alternately strike the bottom with its whole weight, and then be lifted up again until it has deranged the superficial beds over a wide area. On these beds new and undisturbed strata may be afterwards thrown down. In other cases, when banks of mud and sand forming the top of a shoal have been made to assume various shapes by the lateral pressure of icebergs, the bed of the sea may subside, and then the disturbed beds may be overspread by horizontal strata, which may never afterwards be deranged by similar mechanical violence.

LVIII. *On the Method of performing the simple Experiment of Interferences with two Mirrors slightly inclined, so as to afford an* experimentum crucis *as to the nature of Light. By* R. Potter, *Esq.**

FRESNEL'S genius devised the experiment which is the most direct test of the reality of the interference of light, and which proves that property in the most unequivocal manner. This experiment is performed by causing the light diverging from a luminous point to be reflected by two plane mirrors, placed side by side, whose surfaces are *nearly* in the same plane, but which contain an angle a little less than 180°, and then examining the light by means of an eye-lens. Each mirror gives an image of the luminous point, and we have the reflected light proceeding as if it diverged from these two images and also from its having originally constituted only one pencil, the two reflected pencils are in the same state, so that they interfere where they cross each other's direction, producing in ordinary light coloured bands parallel to the line of intersection of the planes of the two mirrors, with dark intervals between them. These bands are seen in the air in the focus of the eye-lens when looking towards the images of the luminous point.

Without examining the experiment more minutely than just to ascertain that both the pencils are necessary to the production of the bands, it must be admitted that it is conclusive in establishing the theory of interferences.

The theory of interferences was brought forward by Dr. Young as a consequence of the undulatory or wave theory of

* Communicated by the Author.