THE
LONDON AND EDINBURGH
PHILOSOPHICAL MAGAZINE
AND
JOURNAL OF SCIENCE.

[THIRD SERIES.]

OCTOBER 1839.

XXXV. *On the tubular Cavities filled with Gravel and Sand called "Sand-pipes," in the Chalk near Norwich.* By CHARLES LYELL, *Esq., F.R.S., V.P. G.S., &c.**

THE white chalk with flints in the neighbourhood of Norwich, is covered with a mass of variable thickness of irony sand and gravel, with some intermixture of red clay, the sand passing occasionally into a ferruginous sandstone. The surface of the chalk when the gravel is removed is extremely uneven, presenting sharp ridges, deep furrows, and pits, and some protuberances which are larger at the summit than the base. In a word, it is impossible to conceive that so soft a rock as chalk could have acquired such an outline simply by ordinary denudation, or could have retained it if once acquired during the accumulation of the mechanical deposit now superimposed. It is equally difficult to refer to any known mode of denudation those deep and narrow hollows, filled with sand and gravel, which are the same as those called in France "puits naturels," and which will form the subject of the present communication.

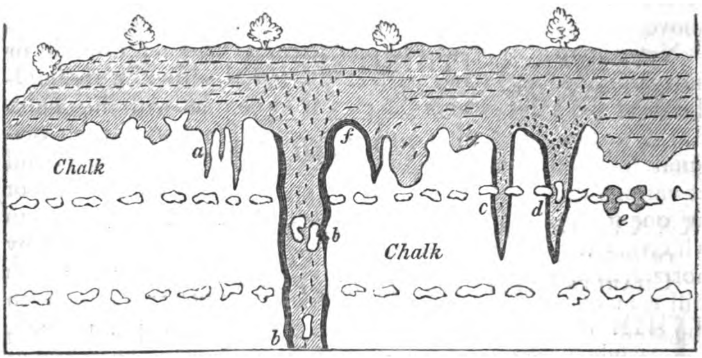
Form of the Sand-pipes at Eaton.—I was indebted to Mr. Ewing for first calling my attention to some fine examples of these phænomena which he had accurately observed on his property at Eaton, about two miles west of Norwich, where the chalk has been extensively excavated for the manufacture of lime. Cylindrical hollows filled with loose materials, evidently derived from the overlying tertiary formation, are here called "Sand-pipes" by the workmen. They resemble those which occur in many other districts in England, where the chalk is covered by sand and gravel.

* Communicated by the Author.

Digitized by Google

These deep and narrow pipes are very symmetrical at Eaton, having the form of inverted cones, which at their upper extremity vary in width from a few inches to more than four yards, while at their lower they taper down to a fine point: see fig. 1. The smaller ones, which are usually about a foot

Fig. 1.



Sand-pipes in the Chalk at Eaton near Norwich.

in diameter, seldom penetrate to the depth of more than twelve feet, while the larger are sometimes more than sixty feet deep. They are for the most part perpendicular in their direction, and nearly circular in shape, although they often appear of an oval form when cut through in the precipices surrounding the Eaton quarries, because the plane of intersection is there in reality oblique, and inclined at an angle of about 80° with the horizon. Several sand-pipes often approach very near to each other without any tendency to unite. In proof of this general fact, Mr. Ewing pointed out to me three pipes close to each other, which we explored from top to bottom by digging. The depth of one proved to be twelve feet, that of another nine feet, and that of the pipe placed between the other two six feet. Although they all came within three or four inches of each other, the parting wall of white soft chalk was in no instance broken through; see *a*; fig. 1.

Contents of the Sand-pipes.—The materials filling the sand-pipes are of three kinds: 1st, sand and pebbles; 2ndly, loose unrounded chalk flints; 3rdly, fine ochreous sandy clay, not impervious to water. The rounded pebbles in the first consist chiefly of black flint, while a small number are of white quartz. With these are sometimes seen unrounded fragments of sandstone, with a cement of oxide of iron; the whole agreeing with the contents of the deposit incumbent on the chalk, which at

Digitized by Google

Eaton is about twenty feet thick. The clay is also similar to the finer portion of that found in the gravel above. As a general rule, admitting of few exceptions, the sand and pebbles occupy the central parts of the pipe, while the sides and bottom are lined with clay. In the clay, at the bottom of one small pipe, which was only six inches wide at the top and a yard deep, I found some black carbonaceous matter, probably derived from the roots of trees which had penetrated from above.

Not a particle of calcareons matter, whether organic or inorganic, occurs in any part of the pipes, either in the middle or at the sides, where the clay is in contact with the chalk. Large unrounded nodules of flint, still preserving their original form and white coating, (*b b*) are dispersed singly, and at various depths, in those larger pipes which exceed one foot or one foot and a half in diameter. The smaller pipes, in which these loose flints never occur, are frequently crossed by horizontal layers of siliceous nodules, as at *c*, *d*, *e*, fig. 1, which still remain *in situ*, not having been removed together with the chalk in which they must have been originally imbedded. Single flints, forming part of these continuous layers, sometimes appear in the middle of a small pipe, as at *d*, fig. 1, surrounded and supported by sand, so that at first sight it is not easy to imagine how it can have retained its position during the substitution of the sand and gravel for the original chalk. But it should be remembered that these flints in the chalk near Norwich, are usually of a large size and irregular shape, and may be still supported at one extremity by the chalky matrix. Neither a loose nodule of flint nor a heap of nodules has ever been observed at the bottom of a sand-pipe at Eaton.

In general there is no order in the arrangement of the materials of the pipes except that the coarse sand and gravel occupies the middle of each and the clay the outside and bottom. There are some exceptions to this rule; but even where coarse sand and gravel come into immediate contact with the chalk they are usually imbedded in a paste of sandy clay, which is wanting in the centre of the pipe. This parting layer of clay, an inch or more in thickness, which lines the walls and attains some thickness at the bottom, may sometimes be traced upwards until it bends round, and continues to intervene between the chalk and overlying gravel, so that the same layer which is perfectly vertical within the pipe becomes horizontal over the chalk, as at *f*, fig. 1. The fine yellow clay at the bottom of some of the pipes has been found by Mr. Colkett, of Norwich, to make a good oil paint of a colour between raw sienna and Roman ochre.

Digitized by Google

For the distance of several inches, or even in some places four or five feet from its junction with the sand-pipe, the chalk at Eaton is moist and softened, and becomes friable when dried, and is discoloured by containing a slight mixture of fine sand, clay, and iron, the same chalk being quite pure, and perfectly soluble in acids at points more remote from the pipes. In some cracks and interstices of the chalk, even at a distance from the sand-pipes, are found thin leaf-like layers of reddish and greenish clay, which may have been introduced from above through numerous joints which traverse the rock, in a nearly vertical direction, and by which the flints also are sometimes divided. The surface of the flints thus naturally split is discoloured and iron-stained, and distinguishable from that obtained by fresh fracture. At Eaton the joints do not appear to be connected with the sand-pipes, except here and there accidentally. They have in general a more oblique direction than the pipes.

The course of a sand-pipe is usually traceable above the level of the chalk for some distance upwards through the incumbent gravel and sand by the obliteration of all signs of stratification. In some instances however I observed at the mouth or upper extremity of the pipe, as in the pipe *d*, fig. 1, beds of gravel and sand bending downwards, so as to attain a perfectly vertical position within the pipe, precisely as would have happened if horizontal beds had subsided, in consequence of a failure of support from below.

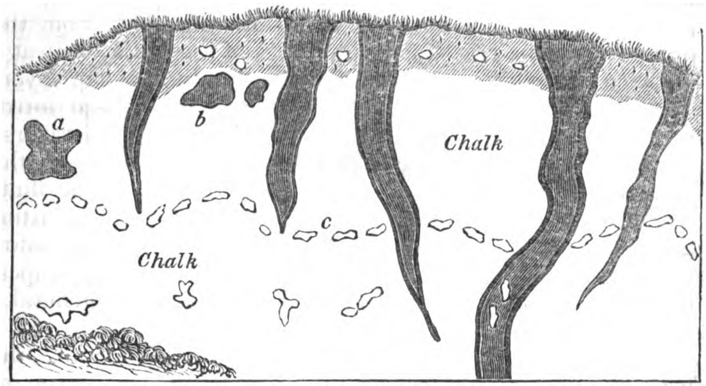
Age of the Gravel.—As to the age of the gravel and sand overlying the chalk at Eaton, there can be no doubt that it belongs to the Norwich crag, as there are not only casts of marine testacea characteristic of that formation in the ferruginous sandstone at Eaton, but also, as I learn from Mr. J. B. Wigham, some shells of the genera Mya, Mactra, Cardium, and Mytilus, in which the calcareous matter is still preserved.

I am also indebted to Mr. Wigham for the following observations. " At Heigham, in the suburbs of Norwich, are sand-pipes resembling those at Eaton, except that they descend in a slanting and often winding course. In the pit represented in fig. 2, which is 30 feet deep, the chalk is barely covered by vegetable soil. Its upper portion to the depth of 4 feet is intermixed with sand and gravel. In the undisturbed chalk below are some irregular cavities, *a*, *b*, from 10 inches to 2 feet in diameter, which have no communication with the surface, and which on examination are found to terminate after penetrating horizontally about 2 feet, the chalk in contact being everywhere solid. They are evi-

Digitized by Google

dently elbows of tortuous sand-pipes, the other parts of which had been removed during the excavation of the pit. The

Fig. 2.



Tortuous Sand-pipes in the Chalk at Heigham, near Norwich, from a drawing by J. B. Wigham, Esq.

layer of chalk flints, *c*, is far from being horizontal, as will be seen by the sketch, and seem to imply that the chalk has been disturbed.

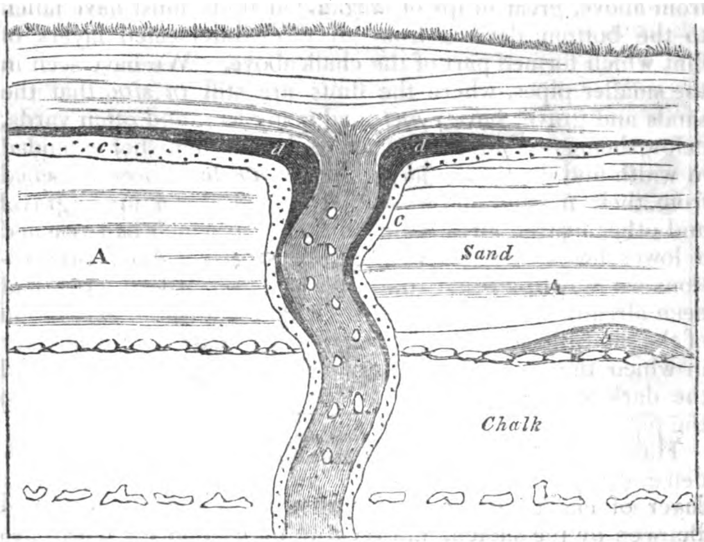
"At Hellesden, about 3 miles N.W. of Norwich, where similar appearances are exhibited in a chalk pit 20 feet deep, the upper extremity of one pipe, 5 feet in diameter, is covered by undisturbed layers of chalky rubble resembling chalk, alternating with fine clay for a thickness of four feet. One of the pipes in the same pit measures no less than 23 feet across, its depth being unknown.

"At Thorpe is a sand-pipe (see fig. 3.) which is 20 feet in diameter where it enters the chalk. It is filled with gravel, sand, clay, stones, and chalk-flints. It penetrates through 35 feet of chalk, tapering downwards very gradually. It is remarkable for the regularity with which it continues its course through 10 feet of sandy strata, A A, which overlie the chalk, some beds of which, as at *b*, are rich in the shells of the Norwich crag. A layer of light-coloured sandy clay, *c*, fig. 3. (indicated by dots) lines the sides of the pipe for many yards, both where it passes through the chalk and through the overlying arenaceous beds A; this same clay also continuing its course horizontally beyond the opening or upper end of the pipe. The dark bed, *d*, fig. 3. which is in contact with this clay, is an indurated layer of sand coloured by oxide of iron, which contains casts of marine shells, not only where horizontal, but in that part also

Digitized by Google

which descends into the pipe as far down as where it enters the chalk.

Fig. 3.



Upper Portion of a Sand-pipe at Thorpe, near Norwich, from a drawing by J. B. Wigham, Esq.

"At the junction of the chalk and overlying sand," observes Mr. Wigham, "there occurs at Thorpe, (see fig. 3.) a layer of large flints which have suffered slightly from attrition."

Origin of the Sand-pipes.—We have now to consider in what manner these cylindrical hollows have been first formed and then filled with gravel and sand. If no pipes but those of the smallest size had occurred, we might have imagined that the tap roots of large trees had first pierced the chalk, and then after growing to their full size and decaying had left a vacant space into which loam and gravel fell. But when we reflect on the dimensions of some of the pipes, we at once perceive that more powerful causes must be appealed to.

On consideration of all the facts above described, we can scarcely hesitate to admit the following conclusions: 1st, That the chalk has been removed by the corroding action of water charged with acid, in which the siliceous nodules being insoluble, were left *in situ* in the smaller pipes after the calcareous matrix had been dissolved. 2ndly, It is clear, from the manner in which the large detached flints are dispersed through the contents of the widest sand-pipes, that the excavation and filling of the pipe were gradual and contemporaneous pro-

Digitized by Google

cesses. For had the tubes, some of which are from 50 to 60 feet deep, and seven yards or more wide, been hollowed out of the chalk before the introduction of any foreign matter from above, great heaps of unrounded flints must have fallen to the bottom, derived from all those intersected layers of flint which formed part of the chalk above. We have seen in the smaller pipes, where the flints are still *in situ*, that the sands and gravel have penetrated many feet, and often yards, below them; so that if these cavities had been further extended in width and depth, the large flints would have been loosened from their matrix, and would have sunk down upon gravel and other matter already introduced, and which had reached a lower level. 3rdly. As a corollary of the above propositions we must hold that the strata of the Norwich crag had been already deposited upon the chalk before the excavation of the sand-pipes, and this is further confirmed by the manner in which the layers of loose gravel of the pipe *d*, fig. 1, and the dark sand with casts of shells, *e*, fig. 3, have sunk into the pipe.

Having then adopted these opinions, and rejected all sudden and violent agency, whether for the erosion or filling of the cavities, it only remains for us to inquire how waters charged with acid may most naturally be conceived to have produced such hollows. If some of the largest pipes of which the bottom has not been yet reached, be prolonged indefinitely downwards and connected with deep fissures, we may suppose that springs charged with carbonic acid rose up at some former period through the chalk and crag while these were still submerged, as we know that in many parts of the bed of the sea such springs do break forth. In proportion as the chalk was corroded, the incumbent substances would subside into the hollow thus formed, and the water would freely percolate the matter thus intruding itself, dissolving any calcareous ingredients which may be associated with it, and still continuing to widen the tube by corroding its walls.

But this hypothesis will not account for the form of the greater number of the sand-pipes, as some, even of those which exceed fifty feet in depth, have been found to diminish gradually downwards to a point. It is therefore more probable that such pipes are due to rain-water, which becoming impregnated with carbonic acid derived from the atmosphere and vegetable soil, has descended into pits or furrows which may have existed on the surface of the chalk. Such water, after dissolving a portion of the chalk, may readily have passed out of the cavities which it gradually eroded, and penetrating downwards might break out again in other places in the form

Digitized by Google

of springs charged with carbonate of lime, such as are commonly seen to issue from chalk. This hypothesis of the adequacy of pluvial waters was first pointed out to me by Mr. Blackadder of Glammiss, and Mr. De la Beche separately expressed to me the same opinion. But it struck me as an objection to this view, that rain-water would in that case be now in the act of shaping out cylindrical hollows everywhere, both where chalk comes to the surface and where it is overspread by gravel.

But Mr. Strickland, in reply to this objection, has communicated to me in a letter, dated August 31, 1839, the following very interesting remarks. "During a residence of about seven years in the neighbourhood of Henley-on-Thames, I frequently observed subsidences to take place in the gravel above the chalk. They occurred on the top of a chalk hill between 200 and 300 feet above the Thames, and far removed from the action of any running water which might be supposed to have undermined the gravel. The latter formed a stratum from 10 to 20 feet thick above the chalk, and the subsidences appeared to take place quite suddenly, leaving a nearly circular cavity with upright sides from 3 to 6 feet wide, and from 2 to 4 feet deep. As no mechanical action of running water could possibly operate in these situations, it appears to me that the true explanation of the phænomenon must be the corrosive action of acidulated water acting on the surface of the chalk at the particular points to which it may percolate through the incumbent mass of clay and gravel. We have a further evidence of this in the fact, that these subsidences never occur, as far as I am aware, in those places where the chalk is exposed to the day, the rain being there absorbed equally over the whole surface, instead of being conducted to particular points, as is the case where the clay and gravel covers the chalk. If this view be correct, we may infer that many, if not all, of those gravel-filled cavities so common in the chalk, may have resulted from atmospheric agency."

According then to the theory above-stated, we may attribute the larger size of the upper extremity of each sand-pipe to the longer time during which the rain-water has there acted; as the corroding operation proceeded from above downwards, and the percolation for ages of acidulous waters will account for the absence of shells, except as casts, in the contents of the tubes.

In those cases where the tube penetrates the overlying sand and gravel for a certain distance, and then ends abruptly, and is capped by perfectly undisturbed strata, which occasionally consist of chalk rubble, we have only to suppose that the upper portion of the deposit traversed by the tube has been

Digitized by Google

cut away by denudation, and other beds afterwards superimposed.

As to the sandy clay found at the bottom and round the exterior of the pipes, there can be little doubt, whatever hypothesis we adopt, that this is due to rain-water which in its passage through the gravel and loam has become charged with fine particles of mud and iron, and has parted with these particles at the point where it was absorbed by the surrounding chalk. A very minute quantity of the same mud enfiltered into the contiguous chalk itself, has discoloured the rock and rendered it impure as before described. The moistened state of the chalk for a distance of several feet from each pipe, also shows that this cause is still in operation. The layer of ochreous clay extending upwards beyond the pipe, and intervening between the chalk and overlying gravel or sand, may in like manner be ascribed to the absorption of muddy water by the porous chalk, a vacant space being gradually prepared for the deposition of the mud by the corrosion of the limestone by the acidulous water.

It is scarcely necessary to state that the gradual undermining of the pipes and the successive subsidence of small masses, is an hypothesis which accords well with the fact before alluded to, p. 259, and *f*, fig. 1, that beds of loose gravel and sand once horizontal, now bend into the orifice of some tubes in a vertical direction. Had the entire pipe been filled at once, this arrangement would have been destroyed, and accordingly no such stratification remains in those materials which have descended by repeated movements to considerable depths in large pipes. The grains of the sandstone containing casts of shells which at Thorpe form the dark-coloured bed *d*, fig. 3, which enters the pipe on both sides for many yards, must have been loose and incoherent when they first assumed their present position, and must have been afterwards consolidated within the pipe.

Assuming then that the sand-pipes of Norfolk are due to atmospheric waters, it follows that chalk covered by crag had emerged from the sea before the formation of the pipes. How then shall we explain those cases where chalk not covered by gravel or crag is traversed by large and deep sand-pipes? as at Heigham, fig. 2, and other neighbouring localities. We may answer that aqueous denudation has removed large portions of a deposit once overlying the chalk, and which supplied, in the manner already described, the contents of the sand-pipes. We may also suppose that this same denudation has obliterated all traces of superficial pits and hollows like those above noticed as having been recently formed at Henley.

Digitized by Google

But if all this be granted, those geologists who have examined Norfolk will admit that the denudation here alluded to must be that which gave to this district its actual valleys, and many of the leading features of its present geographical configuration. We are thus brought round to the conclusion that land in this country must have emerged from the sea after the deposition of the Norwich crag, and yet at a period anterior to that of the denudation just alluded to. But as we know of no denuding agency capable of excavating great valleys in a flat country like Norfolk, except the power of the ocean, operating either at the time of the submergence of land or that of its emergence from the waters, we must infer from all the facts and reasonings above set forth, that land, consisting of chalk covered by crag, was first laid dry before the origin of the sand-pipes, and then submerged again before it was finally raised and brought into its present situation.

For my own part I readily adopt the hypothesis of these oscillations of level, because I have found them indispensable to explain other geological appearances on the coast of Norfolk, not many leagues distant from Norwich, where there is independent evidence of the land having been first laid dry, after the deposition of the crag, so as to support a forest; then submerged again, so as to subside to the depth of 400 feet or more, the signs of the forest being buried under strata several hundred feet thick; and, lastly, of the same tract having been re-elevated, so as to bring the monuments of this remarkable succession of events into view. On this subject I shall shortly enlarge, when treating of the age and origin of "the Mud Cliffs" of Eastern Norfolk.

XXXVI. *On the Use of a Secondary Wire as a Measure of the Relative Tension of Electric Currents. By* JOHN W. DRAPER, *M.D., Professor of Chemistry in the University of New York; late Prof. of Physical Science in Hampden Sydney College, Virginia*.*

[With Figures: Plate I.]

IT is the object of this memoir to establish the following propositions:—

1st. That by means of a secondary wire, we may always determine the relative tension of electric currents.

2nd. That there is reason to doubt whether the processes usually supposed to affect the condition of an *electric current*,

* Communicated by the Author.

Digitized by Google